

# CONFERENCE PROCEEDINGS

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2019

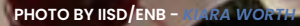
AFRICAN CLIMATE  
RISKS CONFERENCE 2019

Dismantling barriers to urgent climate adaptation action



ADDIS ABABA, ETHIOPIA  
7 – 9 OCTOBER 2019





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## ACKNOWLEDGEMENTS

The African Climate Risks Conference (ACRC) Secretariat would like to extend thanks to the development partners and the Scientific Steering Committee for making the event possible. The event received a formal endorsement from the Intergovernmental Panel on Climate Change (IPCC). The Coordination, Capacity Development And Knowledge Exchange (CCKE) unit for the Future Climate for Africa (FCFA) programme housed within SouthSouthNorth (SSN) organized the event with support from the Scientific Steering Committee that worked devotedly to realize this conference. Dr. Christopher Jack of Climate Services Analysis Group, University of Cape Town, chaired the Scientific Steering Committee. Partner organizations represented in the Committee are: the World Meteorological Organization (WMO), the Intergovernmental Panel on Climate Change (IPCC), Global Framework for Climate Services (GFCS), World Climate Research Programme (WCRP), UNECA-African Climate Policy Centre (ACPC), West African Science Service Center on Climate Change and Adapted Land Use (WASCAL), African Academy of Sciences (AAS), University of Addis Ababa and FCFA programme partners.

The ACRC Secretariat would like to extend their appreciation to the UK Department for International Development (DFID) and Natural Environment Research Council (NERC) whose support made this event possible. The support from our donors assisted the participation of 140 participants, through either full or partial participation grants. Of these sponsored participants priority was given to early career researchers, 97% were African, and 36% were female.

Many thanks to the Government of the Federal Democratic Republic of Ethiopia, through the Environment, Forestry and Climate Change Commission (EFCCC) and Ethiopian National Meteorological Agency who provided valuable support to the organizing committee.

## PARTNERS





## ABOUT THE ORGANISERS

### Future Climate for Africa.

*Future Climate for Africa (FCFA)* is an international research programme jointly funded by the UK's Department for International Development (DFID) and the Natural Environment Research Council (NERC). FCFA aims to generate fundamentally new climate science focused on Africa, and to ensure that this science has an impact on human development across the continent. FCFA consists of five research consortia, *AMMA-2050*, *FRACTAL*, *UMFULA*, *HyCRISTAL*, and *IMPALA* who's collective focus is on advancing scientific knowledge, understanding and prediction of African climate variability and change on 5 to 40 year timescales, together with support for better integration of science into longer-term decision making.

The African Climate Risks Conference was organized by the Coordination, Capacity Development And Knowledge Exchange (CCKE) unit of FCFA housed within SouthSouthNorth.

### SouthSouthNorth

*SouthSouthNorth (SSN)* supports national and regional responses to climate change through policy and knowledge interventions, partnerships and deep collaboration. We do this by connecting people and information, enhancing capability and mobilising resources to respond innovatively to the challenges and opportunities that climate change presents. Being positioned in the Global South affords SSN a deeper understanding of, and connection to, the climate and development challenges facing the region.

- We enhance developing countries' access to climate information by brokering climate knowledge through formalised exchanges among various stakeholders.
- We assist decision makers in delivering climate compatible development by informing policy formulation and implementation.
- We bring good governance to management of donor funds, technical assistance and project management.



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## CONFERENCE OVERVIEW



PHOTO BY IISD/ENB - KIARA WORTH

The Africa Climate Risk Conference (ACRC) was an open platform for sharing the latest research on African climate among researchers, and with policy makers, Regional Climate Centres (RCCs), National Meteorological and Hydrological Services (NMHS), and development partners. ACRC's goal was to ensure greater impact and legacy of completed and ongoing research programs by promoting the uptake of new data, tools and knowledge; brokering new research collaborations; and coordinating targeted donor support.

## Background

Climate projections for Africa show that the continent may be the second hardest hit by climate change impacts, immediately following polar zones (IPCC, 2007). About 90%<sup>1</sup> of all disasters caused by natural phenomena in sub-Saharan Africa are weather and climate related and their extremes can negatively impact a country's GDP by 10–20% in the year of a disaster<sup>2</sup>, reverse economic gains and slow down socio-economic growth and development. Adapting to climate variability and change is therefore key to achieving Africa's development targets.

However, according to the World Bank, many NMHSs in sub-Saharan Africa are unable to meet current needs for weather and climate services across different sectors. Furthermore, government agencies, private sector businesses, and the general public are unable to either access relevant, local weather or climate information, or use the information (where it is accessible) for better-informed decisions.

Persistent challenges include inadequate research infrastructure; gaps in Africa's weather and climate observation systems; gaps in scientific understanding of past and current states of the climate and how these will evolve in the future; communication gaps between stakeholder groups; limited involvement of development practitioners to co-produce knowledge; limited sharing of good practices; and lack of a critical mass of weather and climate scientists.

Addressing these challenges and building smart adaptation mechanisms require engagement with a broad group of actors including academia, community-based organizations (CBOs), relevant line ministries and departments in government, non-governmental organizations (NGOs), as well as the private sector.

In response to the above challenges, several initiatives have been launched over the past few years to progress the necessary scientific research as well as support the rollout of operational climate information services (CIS) at continental, regional, national, sub-national and community scales across diverse Africa locations. While the ultimate intended results of these initiatives align with enhanced adaptation to climate risks and protecting the livelihoods of vulnerable communities, there has been limited coordination and alignment of the initiatives resulting in isolated interventions and a lack of scalable solutions.

## Objectives of the Conference

1. To disseminate results and share insights from new and ongoing climate science and adaptation research in Africa;
2. To provide a forum to identify common priorities in the African climate research for development agenda through African-led collective discussions;
3. To contribute to efforts addressing barriers to effective use of climate information by promoting the uptake of new data, tools and knowledge within planning and decision-making processes; and
4. To link researchers to a diverse network of other actors necessary for moving research into policy and practice: decision-makers, national meteorological agencies, knowledge brokers, donors, and NGOs.

<sup>1</sup> UNISDR, (2015) The Human Cost of Weather related disasters 1995 –2005. ([http://www.unisdr.org/2015/docs/climatechange/COP21WeatherDisastersReport\\_2015\\_FINAL.pdf](http://www.unisdr.org/2015/docs/climatechange/COP21WeatherDisastersReport_2015_FINAL.pdf))

<sup>2</sup>African Hydromet Forum Communiqué, 23, September 2017.

## Event Structure

The majority of the agenda for the 3-day conference supported a marketplace for interdisciplinary exchanges between climate scientists, impact scientists and adaptation scientist. The event featured a variety of sessions structured around eight themes, and consisted of 132 oral presentations, 60 poster presentations and 19 support sessions.

The conference commenced on day one with a high-level opening session which framed the urgency for climate action in Africa, which was followed by key findings from the Future Climate For Africa (FCFA) programme on the latest climate & climate change research in Africa. The rest of the day consisted of three thematic parallel sessions under the themes: Latest research on climate science of Africa, Evidence for action – Climate change risk analysis, Coproduction of knowledge between science, business, policy, practice and local communities and Information distillation and communication. Day one's programme also featured six support sessions, which included workshops, panel discussions, seminars and journalist training.

On day two the programme opened with a plenary entitled State of climate research for development in Africa– challenges and opportunities, and was followed by the second FCFA session focusing on Linking new science to application: piloting new ways of supporting climate relevant decisions. These sessions were proceeded again by three thematic parallel sessions under the themes: Latest research on the science and projections of future climate change in Africa, Delivering resilience in the face of climate change uncertainty, and Cross-cutting Issues: water-energy-food-health nexus. A further seven support sessions ran in conjunction with the thematic sessions consisting of panel discussions, workshops and seminars.

Day three of the conference started with a plenary session on the State of Climate Information Services for development support in Africa. Day three's programme also features key symposiums entitled: Mobilizing investment in climate services and Climate Services Initiatives in Africa. Along with six support sessions, day three also consisted of side meetings, including a dedicated Donor Roundtable to bring together development partners to progress coordinated support for African-led climate research and service priorities. The conference concluded with a closing ceremony which highlighted the challenges and opportunities to dismantling barriers to urgent climate action in Africa.

For more details of the content of the conference please see the [Book of Abstracts](#).

For a more in-depth partial coverage please see [IISD's report of the event](#).

## Outcomes

1. New data, tools and knowledge shared with wider research and user networks to support uptake and effective use of climate information.
2. Lessons, success stories, good practices and challenges shared between climate research and adaptation projects in Africa, and with users, practitioners, private sector, policy makers and development partners.
3. Recommendations on progress and challenges that should inform updating of African climate research agenda in terms of emerging themes, persisting and new challenges; opportunities; and initiatives to break down barriers and facilitate integrated climate risk analysis in Africa.
4. Proposals on bridging the gap between research, operational services and policy; sustaining existing research efforts; and scaling up the use of climate services."

## Convening Partners

The conference was convened under the auspices of key global, regional and national institutions. The following organizations supported to the event: the [WMO-GFCS](#), [WMO-AMCOMET](#), [WCRP](#), [UNECA-ACPC](#), [CR4D](#), [WASCAL](#), [SSN](#) and [FCFA](#) partner organizations. The conference received formal endorsement from IPCC.

## Conference Participants

The Africa Climate Risks Conference was attended by more than 370 participants from across 53 countries world-wide. Participants came from a variety of sectors and backgrounds. Through the support of our funders ACRC was able to support the attendance of approximately 150 participants through either full or partial participation grants.



Nationality of participants of the African Climate Risks Conference 2019



## EXTENDED ABSTRACTS



## CONFERENCE THEMES

01

### Latest Research on climate science of Africa:

This theme focuses on the analysis of observations, re-analysis and modelling of African climate with strong focus on variability across multiple timescales (from days to decades, including weather) and the frequency of extreme events. It includes new results from global and regional high resolution climate model simulations and evaluations of climate processes in models across different scales throughout Africa with a focus on key global, regional and sub-regional climate processes.

02

### Latest research on the science and projections of future climate change in Africa:

This theme covers modelling of future African climate with global and regional (high resolution/convection permitting) climate models across multiple timescales (including the future 5 to 40 year period). Other topics include:

- understanding the uncertainty in projections of the African water cycle and other variables
- understanding how well climate models simulate processes of climate change
- use of climate model projections in driving impact models
- using the latest science to identify areas of confidence and uncertainty about future climate projections

03

### Evidence for action: climate change risk analysis (data on climate related risks and potential impacts):

This theme focuses on gathering and using evidence on the impacts and risks of climate change and the need for adaptation. It covers compilation of data on climate impacts and vulnerability; assessing climate risks to society; and exploring the best way to use this knowledge to protect the public and inform policymakers, including addressing the needs of specific sectors and stakeholders.

04

### Delivering resilience in the face of climate change uncertainty:

This theme covers the way in which we can address management of risks and uncertainties of climate change by building societies, ecosystems and long-lived infrastructure that are resilient to environmental and socio-economic change. It includes risk and uncertainty assessment; scenario development and planning participatory modelling; and developing transformative adaptation pathways that can cope with a wide range of future conditions. Sector Specific options for improving resilience are also covered within the theme on cross-cutting issues. This will present tools and guidance that support climate-risk management from pilot studies and real-life applications.

05

**Co-production of knowledge between science, business, policy, practice and local communities:**

This theme explores collaborative processes for developing climate services and aims to encourage interactions between the policy, practice and research communities, including the private sector and local community groups. It showcases different approaches that demonstrate how these groups can work together to co-produce knowledge around climate change information and adaptation options. Included here are approaches to achieve a cohesive ethical framework to govern development and application of climate services (quality assurance and ethics).

06

**Information distillation and communication:**

Information distillation relates to the process of constructing climate information within a broader co-production context. In contrast to the co-production theme, this theme focuses directly on how science engages with the broader context and process. Particular issues that fall under distillation are: determining the underlying problem and question framing and how this impacts choices around data, models, methods, and communication; identifying and determining assumptions and their consequences for the resultant information, communication, and uptake; dealing with contradictions and disagreements within disciplines (e.g. datasets, models, method), between disciplines, and between disciplines and practice/experience; involving other disciplines and practitioners in the distillation process; and transparency of the process and resultant communication methods.

07

**Mobilising investment in climate and weather services:**

This theme reflects on the importance of increasing investment to enhance the development and delivery of weather and climate services in Africa, by the private sector, alongside the state and voluntary sectors. It also focuses on demonstrating the value of weather and climate services to donors and investors. These entail sharing weather/climate services business models for private sector, research, academia and practitioners to learn and innovate together and create scalable services. This theme covers risks, opportunities, financing and business solutions, as well as exhibition of successful creative solutions to share experiences; and methods for valuing weather and climate services to determine the socio-economic benefits such as development opportunities, avoided losses, reduced disaster risks, and enhanced productivity of economic sectors.

08

**Cross-cutting issues: water-energy-food-health nexus:**

This theme considers climate change adaptation actions in various sectors (water, energy, food security, health, DRR) in terms of practical methods and policy guidelines that enhance resilience, taking into account the interconnections and interdependence among the sectors. It includes potential synergies, trade-offs, and a broader framework for making adaptation responses and decisions more effective at multiple scales (including approaches to decisionmaking).

under uncertainty). Research, policy and practice that attempt to take this wide view across multiple sectors or scales will be covered. Sectors under this theme includes, but not limited to:

***Agriculture and Rural Livelihoods*** – Will focus on the use of weather and climate information in decision-making to enhance adaptive capacity of local communities through increased resilience of agriculture, including linkages with food security and livelihoods.

***Urban Planning, Energy and infrastructure*** – Includes the design, implementation and assessment of options to increase resilience to climate change impacts on energy and urban infrastructure (including water supply and sanitation); energy supply and demand management; transport; as well as planning for disaster risk reduction in these sectors.

***Surface and groundwater resources*** – Will consider how adaptation to changes in extremes (floods and droughts) and longer-term water availability can be delivered through improved risk assessment methods, catchment management, behavioral change (e.g. demand management), technological solutions (e.g. storage or improved water treatment), and improved groundwater and surface water quantity and quality assessment (including scenario planning).

***Health*** – Provides a venue for work that focuses on the way in which adaptation can address climate impacts on human health and wellbeing, with a view to increasing resilience to disasters, and advancing our understanding of temperature-related health impacts, air quality impacts, impacts of extreme events on human (and animal) health, vector-borne diseases, water-related illnesses, nutrition, mental health and populations of concern.



## THEMATIC AREA 1

### Latest Research on climate science of African

This theme focuses on the analysis of observations, re-analysis and modelling of African climate with strong focus on variability across multiple timescales (from days to decades, including weather) and the frequency of extreme events. It includes new results from global and regional high-resolution climate model simulations and evaluations of climate processes in models across different scales throughout Africa with focus on key global, regional and sub-regional climate processes.



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## LIST OF PRESENTERS AND TITLES OF PRESENTATIONS

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**Martin Addi**

The role of large-scale climate indices in drought variability in Coastal Ghana

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**Arragaw Alemayehu**

Local Spatiotemporal Variability and Trends in Rainfall and Temperature in the Central Highlands of Ethiopia

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**Fabien Desbiolles**

Role of the Ocean Mesoscale in Shaping the Angola-Low Pressure System and the Southern Africa Rainfall

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**Jennifer Fletcher**

Nowcasting storms in tropical Africa with satellite observations

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Heatwaves in the Sahel: a comparison of thermal indices and physical processes

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**Mary Kilavi**

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**Gretta Muhimpundu**

Assessment of Orographic Effects on an Extreme Rainfall Event in Rwanda Using the Weather Research Forecasting (WRF) Model

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**Ritah Nakanjako**

The Effect of the Indian Ocean Dipole (IOD) on the Seasonal Rainfall Patterns in the Lake Victoria Basin, Uganda

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**Victor Ongoma**

Projected changes in rainfall and temperature extremes over East Africa

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**Michael Vellinga**

Predicting variability of the East African Long Rains

**Beth Woodhams**

Aircraft observations of the lake – land breeze circulation over Lake Victoria from the HyVic pilot flight campaign

**Sinclair Zebaze**

Synoptic variability of precipitation over Congo basin during northern spring

**The role of large-scale climate indices in drought variability in Coastal Ghana**Martin Addi\*, Kofi Asare<sup>1</sup>, Samuel Fosuhene<sup>1</sup>, Kenneth Aidoo<sup>1</sup>, Comfort G. Botchway<sup>1</sup><sup>1</sup>Ghana Space Science and Technology Institute, GAEC, Accra

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Drought is a naturally occurring hazard which threatens lives and livelihoods. In Coastal Ghana, meteorological droughts are prevalent in August during the boreal summer. Drought adversely affects rain-fed agriculture production and the livelihood of farmers. To address this challenge, rainfall data from meteorological stations were analyzed to characterize drought using standardized precipitation index (SPI). The association of drought variability to global climate indices was investigated using grid point correlation and predictive model for August drought SPI was developed using multiple linear regression and stepwise regression. SPI results confirmed that meteorological droughts were prevalent in August with interannual mode of variability. There was a positive relationship between drought SPI and the Tropical South Atlantic (TSA) index. Predictive models were developed with TSA and other significant indices as predictors and August drought SPI as predictant. The model's Root Mean Square Error ranges from 0.43 to 0.79 and R-square of 0.11 to 0.35. The result suggested that TSA is a prominent oceanic index modulating meteorological drought over coastal Ghana.

KEY WORDS: Meteorological drought, climate indices, Prediction

**Introduction**

Drought is a naturally occurring climate extreme over land characterized by below-normal precipitation on different timescale. It affects agriculture, hydroelectric production, water production for domestic and industrial use. Several local and remote factors can cause meteorological drought on different spatio-temporal timescales [3]. Drought can be triggered by remote ocean-atmosphere teleconnections. In Coastal Ghana, there are two rainy seasons; the major and minor seasons. The major rainfall season over Coastal Ghana starts from April-May-June-July (AMJJ) whereas the minor rainy season starts in September - October (SO) [4]. In August, the region is characterized by meteorological drought. Rainfall over Ghana is influenced largely by the latitudinal movement of the Intertropical Convergence Zone (ITCZ). Predictions and characterization of drought is important to develop an early warning system to mitigate the impact of climate on socio-economic developments.

The study seeks to understand the role of large-scale oceanic climate indices on incidences of meteorological drought in Coastal Ghana and develop a predictive model for climate risk reduction, enhance informed decision making and proper planning by relevant stakeholders.

## Data and Methods

### The Data

The datasets used for the study were rainfall from six coastal stations of Ghana Meteorological Agency (GMet). The stations are Axim (Lat. 4.87, Lon. -2.23), Takoradi (Lat 4.88, Lon. -1.77), Saltpond (Lat. 5.2, Lon. -1.07), Accra (Lat. 5.6, Lon. -0.17), Tema (Lat. 5.62, Lon. 0) and Ada (Lat. 5.78, Lon. 0.63). Extended Reconstructed Sea Surface Temperature (ERSST), Atlantic Meridional Mode (AMM), Atlantic Multidecadal Oscillation (AMO), Southern Oscillation Index (SOI), Tropical North Atlantic (TNA) and Tropical South Atlantic (TSA) indices from National Oceanic and Atmospheric Administration's (NOAA) Earth Systems Research Laboratory (ESRL). The duration of datasets used is 1980 to 2014.

### Methods

The study was investigated using standardized precipitation index (SPI) [2], grid point correlation, Multiple Linear Regression (MLR) and Stepwise regression analysis. Three months SPI was computed to characterize drought over Coastal Ghana. The grid point correlation between drought SPI and global ocean SST was done to identify the oceanic indices linked to drought variability over coastal Ghana. The identified climate indices were further analyzed using both MLR and stepwise regression to isolate the significant climate indices modulating the drought SPI. The lagged indices were used as predictors in the stepwise regression to screen for final predictive model.

## Results and Discussion

The SPI revealed the seasonal cycle of rainfall and drought periods over coastal Ghana (See Figure 1). Two phases of the rainfall season, AMJJ and SO were shown for all meteorological stations. Likewise, the drought months of December-January-February (DJF) and August was indicated by the SPI. During boreal summer, rainfall peaks in the month of June and falls (drought) in August. The short drought in August affects crop growth and other agricultural activities. From Figure 1 Axim experiences moderate to severe drought whereas Accra, Saltpond, Tema, Ada and Takoradi have moderate drought in August.

The August SPI was extracted for further analysis to understand variability and trends. In general, drought over Coastal Ghana exhibit interannual variability with stable trends (e.g. Figure 2) except Ada which show decadal patterns, suggesting drought trends over the years have not changed significantly in the phase of global climate change.



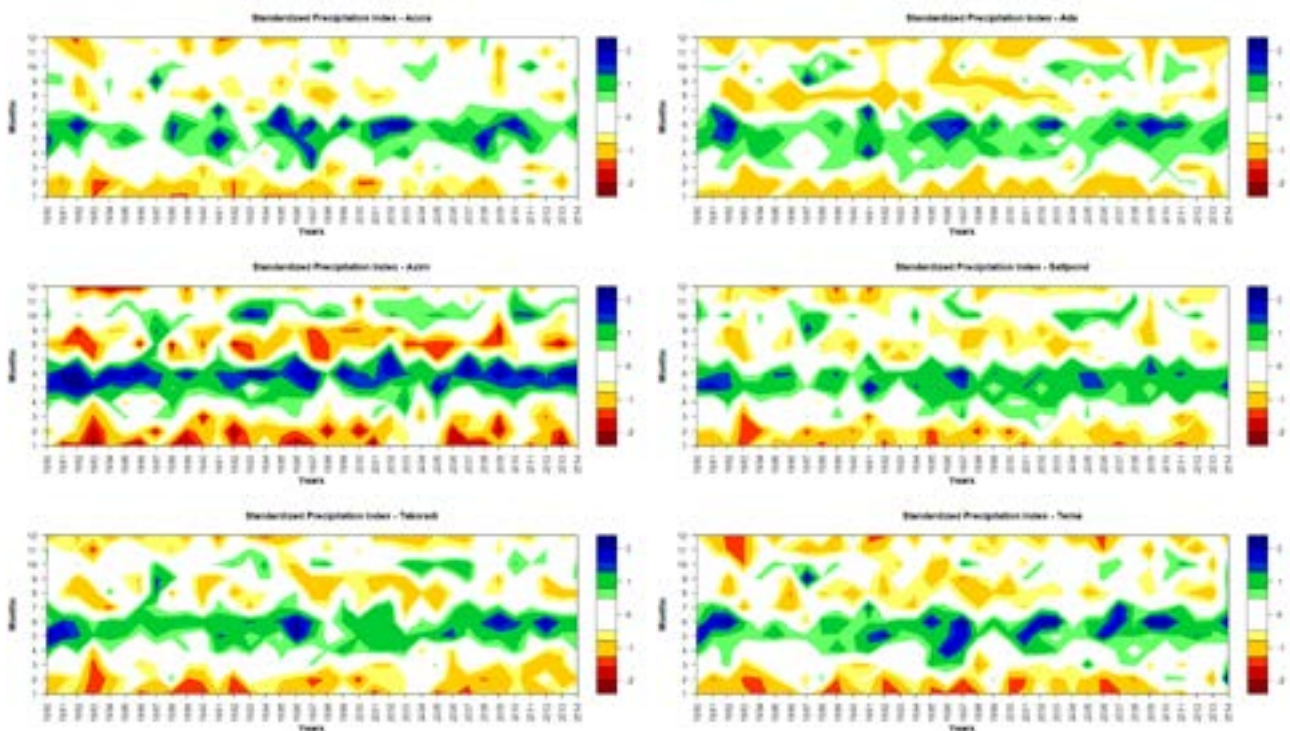


Figure 1. SPI for the six synoptic Coastal Meteorological Stations in Ghana.

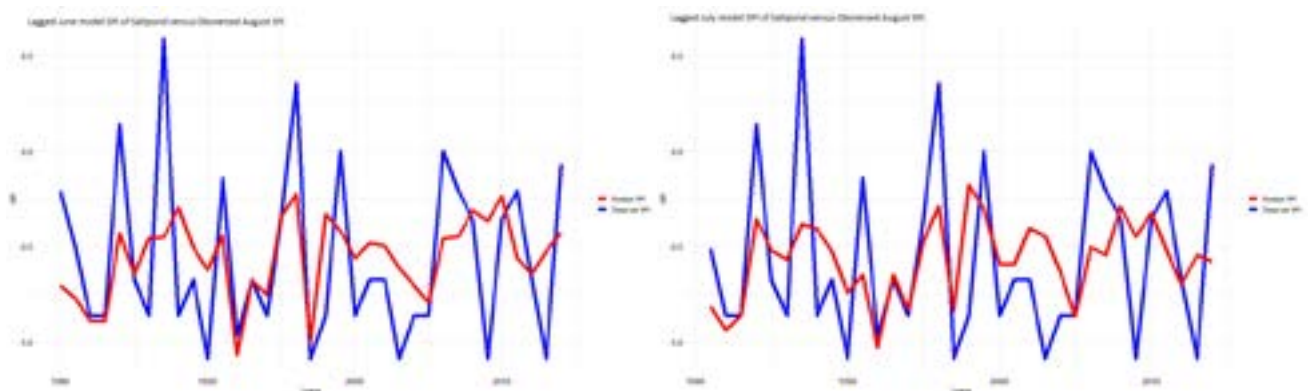


Figure 2. Comparison between modeled SPI and Observed SPI for Saltpond

The lagged time scale grid point correlation of June and July SST with August SPI showed Pacific ocean's Southern Oscillation Index (SOI), Atlantic Meridional Mode (AMM), Atlantic Multidecadal Oscillation (AMO), Tropical North Atlantic (TNA) and Tropical South Atlantic (TSA) indices were linked to the August drought SPI of coastal Ghana. The MLR determined the significant level and contribution of each climate index on the August SPI. The criteria set for the stepwise regression was 95% confidence level. All indices that satisfy this criterion were retained. The prominent oceanic index were statistically significant in modulating the August drought for all stations along the Coast except Ada was TSA. TNA was the significant index linked to Ada. TSA had positive relationship with August SPI, suggesting that when SST is at a low (high) phase the region is drier (wetter). In general, July and August has low SSTs over the tropical south Atlantic; suppresses convective activities which results in a decline in rainfall along the Coast in August. Similar findings were made over the West African Coast precipitation[1]. The predictive model showed the trend of the SPI with a root mean square error between 0.43 to 0.79 and R-square of 0.11 to 0.35.

## Conclusion

Meteorological drought over Coastal Ghana, trend and connections with global oceanic indices was investigated. Meteorological drought was prominent in August and DJF. August drought in coastal Ghana can be classified as moderate to severe. They exhibit interannual variability with stable trend over the years. TNA, TSA, SOI, AMO and AMM indices were linked to August drought, the stepwise regression suggested TSA was the most prominent statistically significant oceanic index with positive association modulating drought in Coastal Ghana. The fitted regression model predicted the trend of the drought but did not explain much of the variability. The outcome of the study was useful for developing a robust predictive tool for drought in Ghana.

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## Local Spatiotemporal Variability and Trends in Rainfall and Temperature in the Central Highlands of Ethiopia

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This study evaluates recent spatiotemporal variability and trends in rainfall and temperature in the central highlands of Ethiopia by using monthly rainfall and temperature records. The monthly rainfall data are for 132 points of 10×10 km grids reconstructed from weather stations and meteorological satellite observations, which cover the period between 1983 and 2013. The monthly maximum and minimum temperatures are for the same points and grids, but cover the period 1981 to 2011. Linear regression is used to each of the 132 grid points to detect changes or trends in rainfall, maximum and minimum temperatures and the statistical significance of the trends is determined by the F-distribution test. These points were reclassified into the three districts studied having different agroecologies by extraction techniques with ArcGIS 10.1 and converted into raster to generate surface data using the simple krigging interpolation technique. Annual and June–September (Kiremt) rainfall exhibit statistically insignificant increasing trends in most of the grid points while March–May (Belg) rainfall shows significant decreasing trends. Significant spatiotemporal variability in the maximum and minimum temperatures is observed across the study area. The warming trends in the maximum and minimum temperatures for Basona Werana and Efratana Gidim, respectively, are statistically significant at  $p = 0.05$  and  $p = 0.01$  levels. It is concluded that trends of rainfall and temperature vary considerably within the study area. This indicates the need for local level analysis, and context-specific planning and implementation of climate change adaptation interventions.

**KEY WORDS:** climate variability, rainfall and temperature trends, Ethiopia

## Introduction

There are many studies on temperature and rainfall variability and trends in Ethiopia covering different temporal and spatial scales [1-3][5-7][9-10]. Studies on temperature are generally consistent with each other in reporting warming trends in the minimum and maximum temperatures with the minimum temperature more often increasing faster than the maximum temperature. Local increase and variability in temperature affect soil moisture and evapotranspiration. This in turn has implications to determine suitable crop types and cropping calendars in the area [8]. Studies on rainfall do not show clear trends for the country as a whole; the patterns of change are mixed.

The aim of this study is to contribute to the existing literature on local scale variability and trends of rainfall and temperature in the central highlands of Ethiopia where a detailed previous study does not exist. The study of trends in rainfall and temperature is critical not only for adaptation to future climate change and variability but also for development planning as natural rainfall variability has always been a significant burden to the Ethiopian economy. The study area in particular is frequently affected by droughts and floods. In the following section, we present a brief description of materials and methods of the study, and this is followed by the results and discussion section.

## Data and Methods

### The Data

The study is based on gridded monthly rainfall and maximum and minimum temperature data series at a resolution of 10x10 km. The gridded data are a reconstructed data series based on records of weather stations and meteorological satellite observations, which was done by the National Meteorological Agency (NMA) of Ethiopia and the International Research Institute for Climate and Society of Columbia University, USA. The purpose of the reanalysis was to generate homogeneous and improved time series climate data for the country. Reading University, UK, conducted calibration and validation of the gridded dataset, and reported a strong correlation ( $r = 0.8$ ) coefficient, indicating that the reconstructed gridded data are of good quality to investigate climate variability and trends in the country [4].

The gridded dataset are very useful in view of the fact that weather stations are limited in number, unevenly distributed and located only in towns, leaving the vast rural areas of the country underserved. On the other hand, meteorological satellite observations suffer from heterogeneous time series, short period of observation, and poor accuracy particularly at higher temporal and spatial resolutions.

The monthly rainfall data used for this study are for 132 points (each representing areas of 10x10 km) for the period between 1983 and 2013. The monthly maximum and minimum temperatures are for the same points and grids, but cover the period from 1981 to 2011. All were collected from the National Meteorological Agency of Ethiopia.

### Analysis

Standardized rainfall anomaly (SRA), precipitation concentration index (PCI) and coefficient of variation are used to examine inter-annual and intra-annual variability of rainfall. Linear regression was used to each of the 132 grid points to detect changes or trends in rainfall and minimum and maximum temperatures. The gridded monthly rainfall and temperature data were input into Geographic Information Systems (GIS) as point data, and this was converted into raster to generate surface data using simple kriging interpolation technique. Simple kriging interpolation techniques were used to prepare surface maps for rainfall and maximum and minimum temperatures with ArcGIS 10.1.

## Results and Discussion

### Rainfall Variability and Trends

The main rainy season (*Kiremt* rainfall) contributes largest to the annual rainfall totals in all the three districts. The inter-annual rainfall variability is shown by coefficients of variations; it can be seen that rainfall in the area shows moderate inter-annual variability. On the basis of the PCI values, rainfall shows high concentration in few months of the year in all the three districts. The highest monthly rainfall, which is also a measure of rainfall concentration shows that it accounts about 42% in Basona Werana and 47% in Menz Gera Meder. Annual rainfall shows statistically significant decreasing trend in Basona Werana at  $p = 0.01$  level, but no significant trend in Efratana Gidim and Menz Gera Meder. Belg rainfall shows significant decreasing trend in all the three sites at  $p = 0.05$  level. The proportion of negative anomalies ranges from 37% (Efratana Gidim) to 71% (Basona Werana) of the grid points. For annual and Kiremt rainfall, the 1980s and 2000s were drier than 1990s while Belg rainfall peaked in the 1980s which was the driest decade in most parts of the country.

### Temperature trends

The highest levels of maximum and minimum temperatures in the study area are May–June and November–December, respectively. The mean annual maximum and minimum temperature show warming trend in all the three districts for the period 1981–2013. In both maximum and minimum temperatures, warming trends are observed in most of the grid points, most of which are statistically significant. Seasonal anomalies in the maximum and minimum temperatures have almost similar patterns to mean annual maximum and minimum temperatures.

## Conclusions

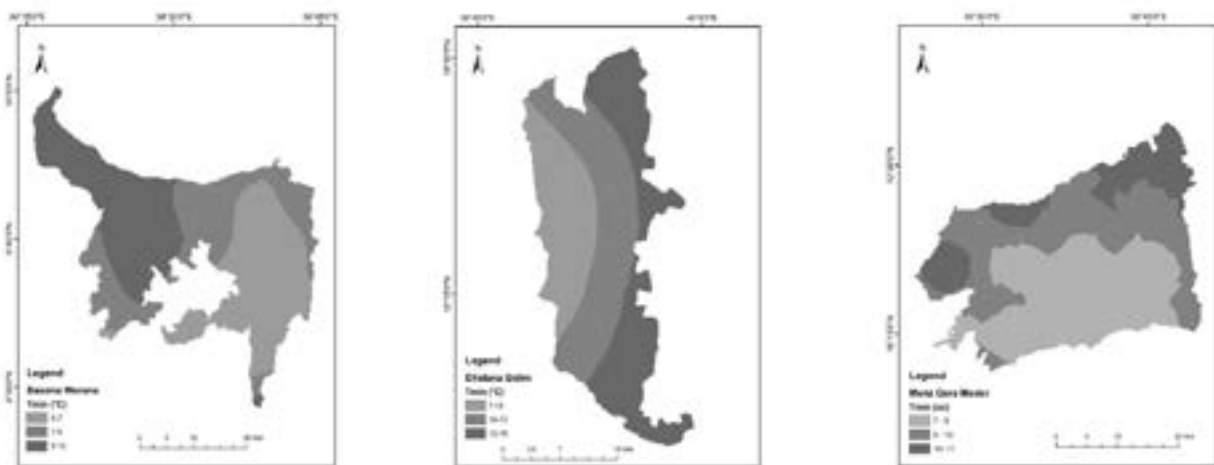
This study presents the analysis of recent spatiotemporal variability and trends in rainfall and temperature in the central highlands of Ethiopia. The year-to-year variability in annual and seasonal rainfall totals, as well as mean annual maximum and minimum temperatures suggest that climate dependent sectors such as agriculture (both crop and livestock) and water resource developments are already highly exposed to current climate related risks, and future climate change will be a significant added burden. Therefore, a sustainable climate risk management approach is recommended to adapt to the ongoing impacts of climate variability and climate change in the study area.







(b)



(c)

**Figure 3.** (a) The spatial distribution of annual rainfall. (b) The spatial distribution of maximum temperature. (c) The spatial distribution of minimum temperature.

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## Role of the Ocean Mesoscale in Shaping the Angola-Low Pressure System and the Southern Africa Rainfall

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Southern Africa's climate is under the influence of both tropical and subtropical systems which result in a complex area where important interactions co-exist over a large spectrum of spatiotemporal scales. The Angola Low (AL), situated on boundary between tropical and subtropical southern Africa, has been diagnosed as a key modulator of moisture distribution in the region on daily to seasonal time scales. It has been demonstrated that the AL pressure system is sensitive to the dynamics of neighbouring oceans, but to date no study has considered simulation resolution of air-sea interactions required to simulated this sensitivity. Using regional atmospheric model sensitivity experiments which differ only in the mesoscale SST forcing characteristics (either the full spectrum of SST variability or only its large-scale components are included), we first quantify the importance of SST gradients on the Angola-Low strength and variability. The specific role of the Angola-Benguela Frontal Zone (ABFZ) is then discussed and results suggest that the mesoscale variability of the front favors a late-summer AL activity. Synoptic-scale tropical lows, which form the AL, are automatically detected, and results suggest more extreme events when the model is forced by mesoscale SSTs (everywhere and in ABFZ only). Associated rainfall of those events suggests that tropical-low episodes are associated with nearly 15% of the total rain in Angola and Namibia. The link between AL dynamics and wet spells is also discussed and the former show a differentiate spatial pattern as well as frequency when the ocean is fully resolved. The topography control of the AL is discussed.

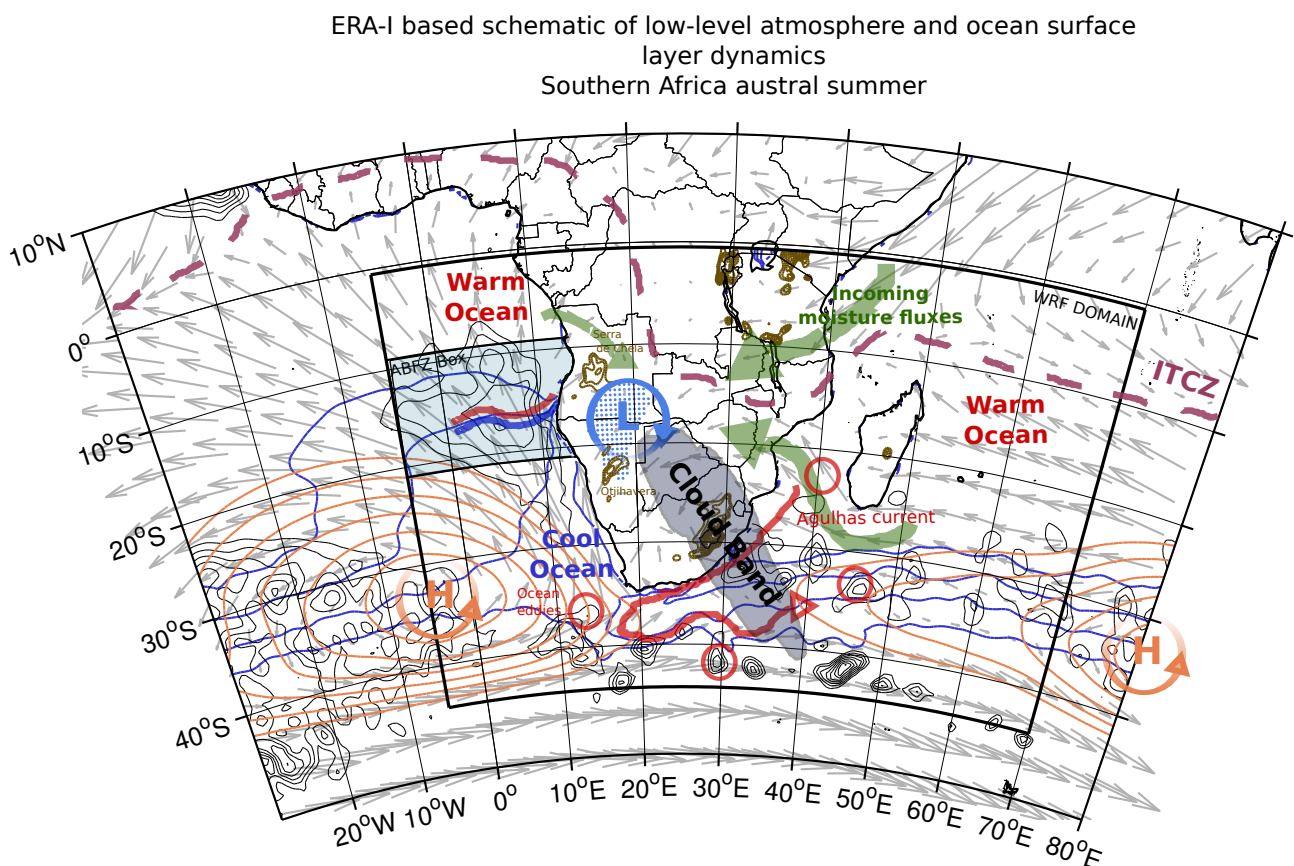
### Introduction

One of the larger challenges facing the climate modeling community in southern Africa is that climate models appear to poorly represent some of the key regional circulation processes, and as a result struggle to produce reasonable simulations of regional rainfall patterns [10]. The difficulty is partly due to the regional climate of southern Africa being complex and strongly modulated by processes operating on the global scale down to regional and local scales. Furthermore, due to its geographic position being in the subtropics (south of 10°S), the region straddles the zones dominated by both mid-latitude and tropical weather systems. The narrow, peninsula-like geography of the southern African landmass allows regional ocean phenomena (e.g., the highly variable and dynamic great Agulhas Current system) to exert a strong influence on rainfall. These challenges highlight the need for further work on understanding the regional climate dynamics of southern Africa.

### The atmospheric and ocean circulations important for Southern Africa

Figure 1 introduces some of the key features of the atmospheric and oceanic circulation features important for southern Africa during the austral summer. Low-level atmospheric synoptic circulation is dominated by semi-permanent subtropical high-pressure cells (orange contours

on Figure 1) over both the South Atlantic (Saint Helena High; SAHP) and southwestern Indian Ocean (Mascarene High; SIOHP). The latter plays a vital role in regional climate through moisture transport into the continent from the subtropical South Indian Ocean whereas subsidence and alongshore winds associated with the SAHP lead to strong upwelling and cool SST along the west coast, keeping western southern Africa dry in summer.



**Figure 1.** ERA-Interim based schematic showing the important low-level atmospheric and oceanic features of southern Africa during austral summer (DJF). The mean vertically-integrated moisture flux (surface to 850hPa) is represented by grey arrows, while the green arrows summarize the important directions of the key low-level moisture fluxes. The mean position of the ITCZ is represented by the thick dotted purple line. The Angola Low is denoted by the letter L, which is shown through the geopotential height at 850 hPa that is higher than 1490m being marked with blue dots. The orange contours represent the subtropical highs over the Atlantic and Indian Oceans. Cool and warm ocean areas are shown through the 18°, 20°, 22° and 24°C contours of SST (shaded blue) and the black contours its standard deviation. Also illustrated is the location of the influential Agulhas Current and its retroflection (red line), and the ABFZ (represented by a blue-red line) separating the so-called warm and cool oceans in the southeast Atlantic (the delimitation follows here the 22°C SST contour at about 16°S). Locations of considerable topography are contoured in brown. The cloud symbols refer to the tropical-extratropical cloud bands that typically extend from the AL over subtropical southern Africa.

Running poleward along eastern South Africa is the warm Agulhas Current (red arrow in Figure 1), which, globally, is one of the most important western boundary currents in terms of its dynamics and variability. Strong air-sea interactions have been identified in the southern Agulhas region, acting on both oceanic and low-level atmospheric dynamics [13] and intensifying storms. In Desbiolles et al. (2018), it was shown that the Agulhas eddies and meanders can influence the vertical air column up through the troposphere. These results provide further support for earlier studies that highlight the key role that the Agulhas Current plays in the weather and climate of southern Africa. Further north in the Indian Ocean, there is a strong inflow of moisture towards eastern Africa resulting from the North East Monsoon.

Over the southeastern Atlantic, the resulting alongshore wind associated with the SAHP leads to the divergence of the seaward Ekman current and causes cooling in the upper ocean forming the

basis of the well-known Benguela Upwelling System (BUS, denoted as “Cool Ocean” in Figure 1). It has been shown that various spatial scales of the alongshore winds play crucial role in shaping the spatial sea surface temperature (SST) pattern along the south-western African coast, from synoptic to small-scale perturbations induced by topography [1]. The underlying dynamics of the upwelling develops a cold oceanic coastal jet moving northward up to the convergence with the Angola Current. This confluence produces the Angola-Benguela Frontal Zone (hereafter ABFZ) where the largest standard deviation in SST in the South Atlantic Ocean is observed (thin black lines in Figure 1; see also [5]). This variability occurs across a range of time scales, at least from decadal (Benguela-Niño, e.g. [4]) down to substantial interannual and intraseasonal variability [8]. Seasonally, the SST front varies in term of both width and strength. Although the mid-position is relatively stable (around 16.4°S), SST gradients are steepest in austral summer and persist over a wider zonal area [16]. The meridional displacement during the course of the year (about 2° of latitude) is important and can also be highlighted by the standard deviation of the SST (Figure 1). Numerical experiments have shown that the strength and position of the ABFZ are sensitive to the SAHP as well as exhibit their own internal variability [2].

The warm tropical Atlantic basin and its dynamics significantly contributes to regional climate through westerly inflow of moisture into the Angola Low (marked ‘L’ in Figure 1, and AL hereafter) and helps to facilitate deep convection in this region [12]. Shifts in the position or strength of the ABFZ can drive rainfall variability over the adjacent continent [12].

Rainfall in southern Africa during the summer is produced by a wide array of convective systems, with tropical-extratropical cloud bands typically accounting for the most widespread rainfall across the subcontinent [6]. These cloud bands, locally known as tropical-temperate troughs (TTT), often extend diagonally over the subcontinent from southern Angola (near the ‘L’ region in Fig. 1) to the east coast of South Africa and out into the southwest Indian Ocean [14]. They have been found to contribute substantially to the seasonal rainfall variability over most countries within southern Africa, including parts of Angola, Botswana, Zambia, Namibia, Zimbabwe, Mozambique and South Africa [7]. Although the importance of TTTs for regional rainfall has been addressed in the literature, there still remains uncertainty regarding the processes that play a role in their formation, frequency and distribution.

One key diagnostic of rainfall variability in southern Africa is the presence and strength of the AL which appears to play a crucial role in the distribution of moisture across southern Africa, especially into the semi-arid parts. The AL is a semi-permanent cyclonic feature occurring during the austral summer, with a peak of activity during the core summer (December-January-February; DJF hereafter), and positioned over the Angola/Namibia border near 17°S. It is still not clear what constrains the AL to this particular geographic location during the summer period, but it is hypothesized that topographic features inland of Angola and Namibia (Serra del Chela and Otjijavera mountain ranges, north and south, respectively; see Figure 1), act as a dynamical barrier for the confluence zone of low-level moisture fluxes. The AL is characterized here by the minimum of the 850 hPa geopotential height during the austral summer [10] (blue dots in Figure 1) and is associated with the confluence zone of low-level moisture fluxes originating from tropical and sub-tropical western Indian and tropical Atlantic Oceans (green arrows in Figure 1). Thus, the AL dynamics, along with the two high pressure systems located over the adjacent oceans, are viewed as integral in modulating the moisture transport over the southern Africa continent. A stronger (weaker) AL has often been linked to an increase (decrease) in rainfall across the region (e.g., [10]). New evidence suggests the phase of the AL (i.e. dry heat low versus moist tropical low) also impacts regional rainfall [9]. The tropical low phase of the Angola Low is the aggregation of a series of moist-convecting transient cyclonic low pressure systems that form in Angola and Zambia and propagate around central and southern Angola. It is therefore paramount to understand and evaluate the mechanisms that influence the formation and evolution of the AL and the associated rainfall events.

The main processes which affect the strength and position of the AL and its moisture supply are still poorly understood and are part of ongoing research. Earlier studies have indicated that the aforementioned SST patterns in the neighbouring South Atlantic and Indian Oceans influence southern African climate and rainfall variability [17]. In particular and closely located to the AL, the ABFZ, exhibiting strong sub-seasonal variability and important mesoscale SST structures, has been identified as a key source region for southern African climate variability. Despite the vast literature on the influence of oceanic large-scale variability on southern African summer rainfall [11][12], the influences of mesoscale SST properties on local weather and climate remain elusive. This presentation builds on the contribution of Desbiolles et al. (2018) by focusing on the specific role the ocean mesoscale plays in shaping the AL system [3]. Through the use of a regional climate model and a suite of sensitivity experiments, we aim to disentangle the effect of the ABFZ variability from the different important mesoscale dynamics of the surrounding oceans.

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## Nowcasting storms in tropical Africa with satellite observations

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Severe storms threaten the lives and livelihoods of people throughout tropical Africa, but the lack of weather radars and the poor performance of NWP in the region makes them difficult to monitor and predict on near real-time scales. The EUMETSAT's NWCSAF product is designed to use geostationary satellite observations to provide real-time monitoring of storms and prediction of their growth and propagation in the upcoming hours (nowcasting). The extensive NWCSAF products are rarely used by African meteorologists, and many of the assumptions built into their code were developed using observations in Europe. In April 2019, the GCRF African SWIFT project held a two week, 24-hour forecasting testbed in Nairobi, with partners from Kenya, Nigeria, Ghana, Senegal, Uganda, Tanzania, and the UK participating. The testbed included nowcasting over East and West Africa with the NWC SAF products, a world-first for Africa.

In this talk, I will demonstrate the use of NWCSAF nowcasting tools to monitor and predict severe storms during the Testbed period. I will show examples illustrating how thresholds used in the NWCSAF products might not be appropriate for tropical Africa. Finally, I will describe current work within SWIFT to support African partners obtaining NWCSAF for their operational centres and researchers, and the input that SWIFT partners are giving to NWCSAF developers in order to improve its applicability to African conditions. Through this work, the SWIFT project is utilising EUMETSAT's existing satellite observation technology to enable African forecasters to issue more accurate storm warnings.

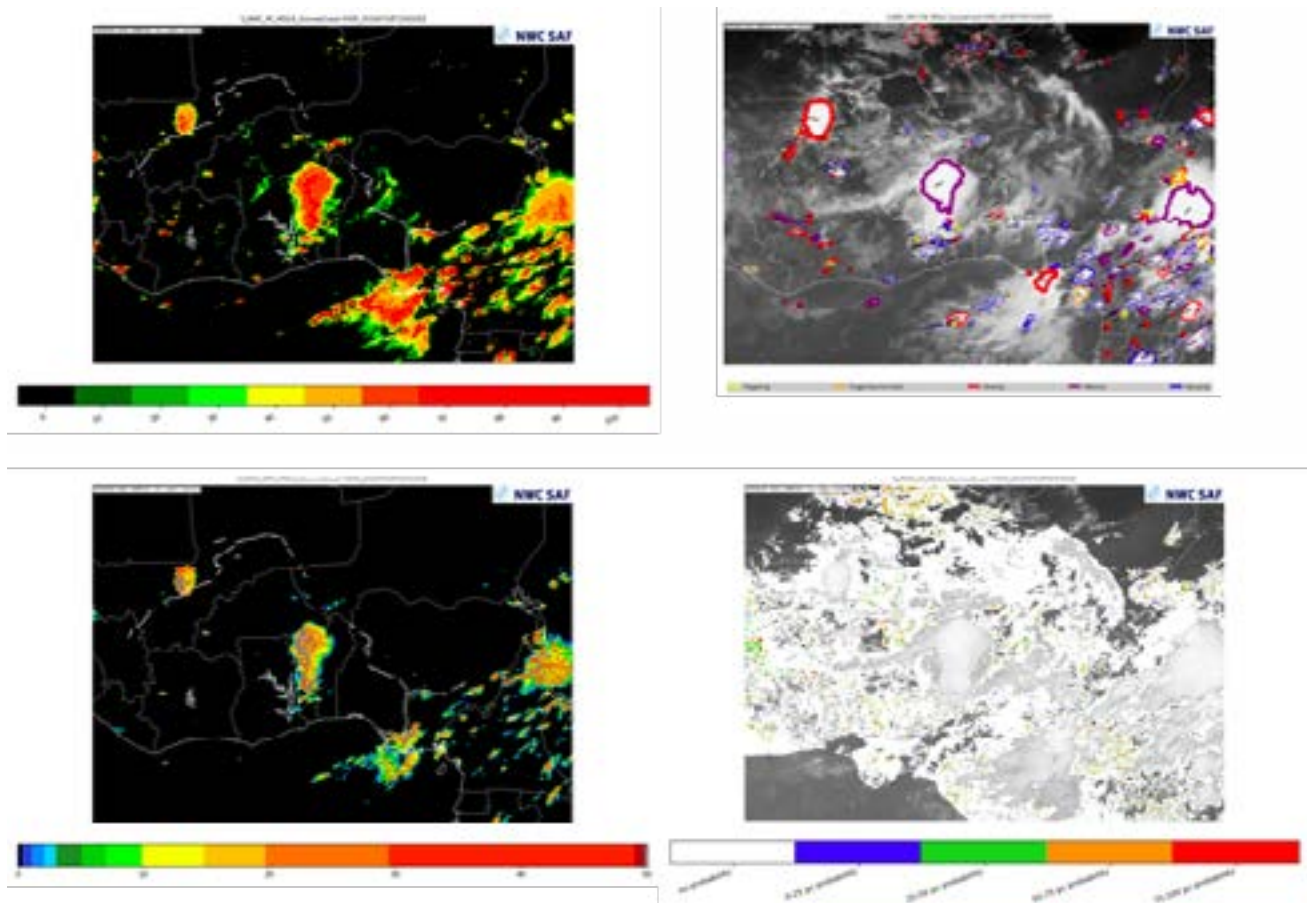
### Introduction

Near term prediction of severe storms in tropical Africa has the potential to save many lives. Lack of data is a major barrier to this near term prediction on 0–6 hour time scales, also known as nowcasting. This lack of data is partially due to a dearth of observations. Weather radars are the best tool for nowcasting, but few if any run routinely in tropical Africa. Additionally, numerical weather prediction performance in the tropics has far lower skill than in the midlatitudes, so it is not possible for forecasters to rely on NWP as an alternative to radars. However, there are existing tools — namely, those based on geostationary satellite observations — available that have the potential to greatly improve nowcasting in tropical Africa. Operational centres often use infrared brightness temperature from Meteosat, but far better tools exist to monitor and predict convective storms, and these tools would greatly enhance the capacity of African nowcasting. One of these tools is the EUMETSAT suite of products called NWCSAF. These products use SEVIRI images from many channels as well as short term forecasts from the Global Forecast System (GFS) to produce analysis of many quantities of interest to nowcasters, including various convective indices. One significant product is their rapidly developing thunderstorm product which identifies convective cells whose brightness temperature is rapidly falling.

In 2017 the UK Global Challenge Research Fund (GCRF) African Science of Weather Information and Forecasting Techniques (SWIFT) project began. SWIFT is a joint project of met services and universities from five countries: Senegal, Ghana, Nigeria, Kenya, and the UK, with additional involvement from the pan-African organisation ACMAD. The African SWIFT programme aims to foster the improvement of weather forecasts on a range of time scales, both through contributing to infrastructure and through capacity building of African forecasters. One of the major efforts of SWIFT is to build capability in nowcasting. This capacity-building is being accomplished through (1) training for forecasters and researchers to install, run, and interpret the output of NWC-SAF software locally; (2) the provision of satellite receiving dishes for SWIFT partner universities in Africa to access the Meteosat and other data used by the NWC-SAF software.

## SWIFT Testbed 1B

African SWIFT includes three forecasting testbeds. The first one (Testbed 1) was held in two stages, with Testbed 1B held from 23 April–6 May 2019 being the main event. Testbed 1B had researchers and forecasters producing and evaluating forecasts from the nowcasting to the synoptic scale in a quasi-operational environment, running 24 hours per day. It was, to our knowledge, the first of its kind in tropical Africa.



**Figure 1.** NWCSAF products used during Testbed 1B. Clockwise from upper left: chance of precipitation (PC), rapidly developing thunderstorms (RDT), chance of convective rainfall (CRR), and chance of convective initiation (CI).

In advance of Testbed 1B we set up a satellite receiving dish at the UK Chilbolton Observatory and installed the NWCSAF software, as well as a python plotting suite, to produce near real time images of NWCSAF products for use by nowcasters in the testbed. These images are available at <https://sci.ncas.ac.uk/swift/>. Nowcasters in Testbed 1B made particular use of the following products: Rapidly developing thunderstorms (RDT), chance of precipitation (CP), convective rainfall rate (CRR), and chance of convective initiation (CI). An illustration of these products is shown in Figure 1. This figure illustrates that some of the NWCSAF products have been tuned for midlatitude conditions, with little chance of convective initiation predicted in most of West Africa at a time when several large convective systems existed. During Testbed 1B nowcasters took note of strengths and weaknesses of various NWCSAF products for nowcasting in tropical Africa.

## Conclusions

Although radars are extremely difficult to install and maintain, there is a promise for using satellite imagery for nowcasting in tropical Africa. Given the longevity of storms in the region, as well as its position directly below the Meteosat satellite, tropical Africa is well positioned to make

use of satellites to predict storm initiation, growth, and propagation on very short time scales. One such satellite product already exists: the EUMETSAT's nowcasting system called NWCSAF. The GCRF African SWIFT project is building the capability of African partner institutions to implement the NWC SAF products at their institutions and use them both for nowcasting and research. This has the potential to save lives with improved nowcasting as soon as it is put in place.

## Heatwaves in the Sahel: a comparison of thermal indices and physical processes

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### Introduction

The Sahel, in West Africa, is a semi-arid region experiencing high temperatures all over the year with two peaks in the spring and autumn seasons [8]. The few researches on temperature extremes evidenced an upward trend [7][13] with increasing frequency and intensity of heatwaves [6][2][1]. This urges to take actions in order to mitigate their impact on Sahelian populations. An effective early warning system however requires to first ensure of the relevance of the heat measure. Thermal indices have been designed to account for the actual feeling that results from the combination of temperature with other environmental variables such as moisture, wind and/or solar radiation [11][18][15]. Another condition to setting up an efficient heatwave early warning system is the skilful prediction of these hazards [12]. This starts with a good understanding of the physical mechanisms underpinning them.

The present research has therefore two main objectives: (i) to characterise heatwaves over the Sahel using different thermal indices and (ii) to describe their underlying physical processes. For each of the objectives, a comparative analysis is carried out between results from the different thermal indices in a bid to assess their variability.

### Data and Methods

The Sahel is defined hereafter as the continental domain located between 20°W–30°E and 10°–20°N. This study focuses on the February to June seasons over 1979–2017, and uses the ERA-Interim reanalysis dataset [4] at 1° x 1° resolution. Five distinct thermal indices (see table 1) are chosen to simulate as many exposure scenarios as possible while keeping them at a reasonable number for the comparison. For each of them, a nighttime (daytime) component is obtained by combining the daily minimum (maximum) temperature with the daily averages of the other variables. The Environmental Stress Index does not have a nighttime component since it is designed to account for the effects of solar radiation.

Heatwaves are defined in this study as periods of at least three consecutive days where the 90-day highpass filtered anomaly of an index at a given gridpoint exceeds two local intensity thresholds: (i) the 75th percentile of the total distribution and (ii) the 90th percentile of the calendar day distribution. To assess the synchronicity of heatwave binary time series, the Jaccard coefficient of similarity [9] is used.

An additional spatial constraint of 600,000km<sup>2</sup> is included to retain only large scale heatwaves that are used for the physical process investigation[1]. The latter is based on the analysis of composite means surface energy budget and the 925 hPa level heat budgets.

**Table 1.** Description of thermal indices used in this paper

Index name (abbreviation)	References	Formula	Variables	Environmental characteristics
1-Temperature (T)	(Fischer and Schär (2010))	T	T: temperature	Classic heat measure; shielded indoor conditions
2-Heat Index (HI)	Steadman (1979)	$HI = -42.37 + 2.04T + 10.14RH - 0.22T \cdot RH - 6.83 \times 10^{-3}T^2 - 5.48 \times 10^{-2}RH^2 + 1.22 \times 10^{-3}T^2 \cdot RH + 8.52 \times 10^{-4}T \cdot RH^2 - 1.99 \times 10^{-6}T^2 \cdot RH$	(i) T: temperature (ii) RH: relative humidity	Shielded indoor conditions integrating moisture effect
3-Apparent temperature (AT)	Steadman (1994)	$AT = T + 0.33e - 0.7V - 4$	(i) T: temperature (ii) e: water vapour pressure (iii) u: wind speed	Shielded outdoor conditions
4-Net Effective Temperature (NET)	Li and Chan (2000)	$NET = 37 - \frac{37 - T}{0.68 - 0.0014RH + \frac{1}{1.76 + 1.4V^{0.75}}} - \frac{0.29T}{1 - 0.001RH}$	(i) T: temperature (ii) RH: relative humidity (iii) v: wind speed	Shielded Outdoor Conditions accounting for human physiology
5-Environmental Stress Index (ESI)	Moran et al. (2001)	$ESI = 0.62T - 0.007RH + 0.02SR + 0.043T \cdot RH - \frac{0.078}{0.1 + SR}$	(i) T: temperature (ii) RH: relative humidity (iii) SR: solar radiation	Exposed outdoor conditions

## Results

### Heatwave characterisation

Based on an analysis across all thermal indices, heatwaves over the Sahel can be said to be short-lasting as compared to other regions across the globe [3]. The average number of days making up an event barely exceeds the minimum duration constraint of three days with maxima of five days. They also have a relatively low frequency with most places recording less than two events a year. Daytime heatwaves are slightly more frequent and longer lasting than their nighttime counterparts. Sahelian heatwaves show standardised intensity in general in excess of 2.5 with more intense events nighttime than daytime. Regarding the spatial distribution of these characteristics, the Eastern Sahel hosts the longest lasting, most frequent and most intense events.

A strong consistency is found in terms of basic statistics and characteristics across thermal indices when considered over the same-day period. Yet, surprisingly they do not sample the same events. Figure 1 indeed shows that the average Jaccard coefficient of similarity between an index and the four (three) other indices for daytime (nighttime) is below 0.4 (0.6) over most gridpoints. Worst, the similarity between the daytime versus nighttime components of each index is typically below 0.1. This suggests that nighttime and daytime heatwaves do not occur synchronously. Barbier et al. (2017) drew a similar conclusion[1].



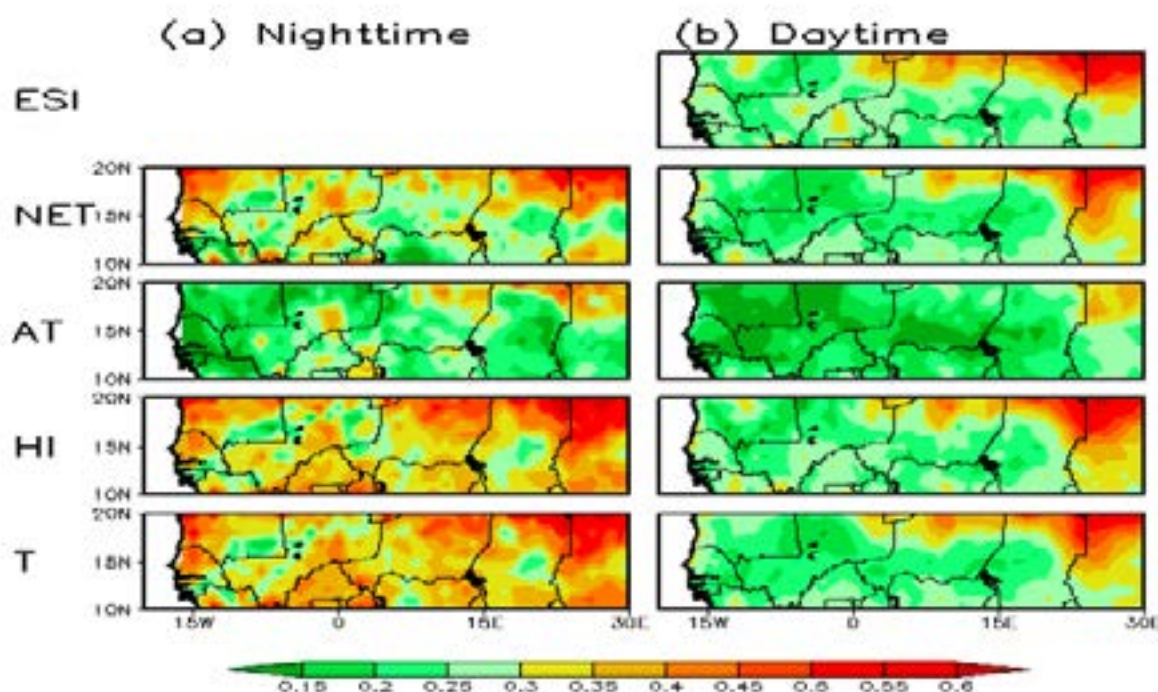


Figure 1. Average Jaccard coefficients of similarity for each thermal index versus the others for (a) nighttime and (b) daytime.

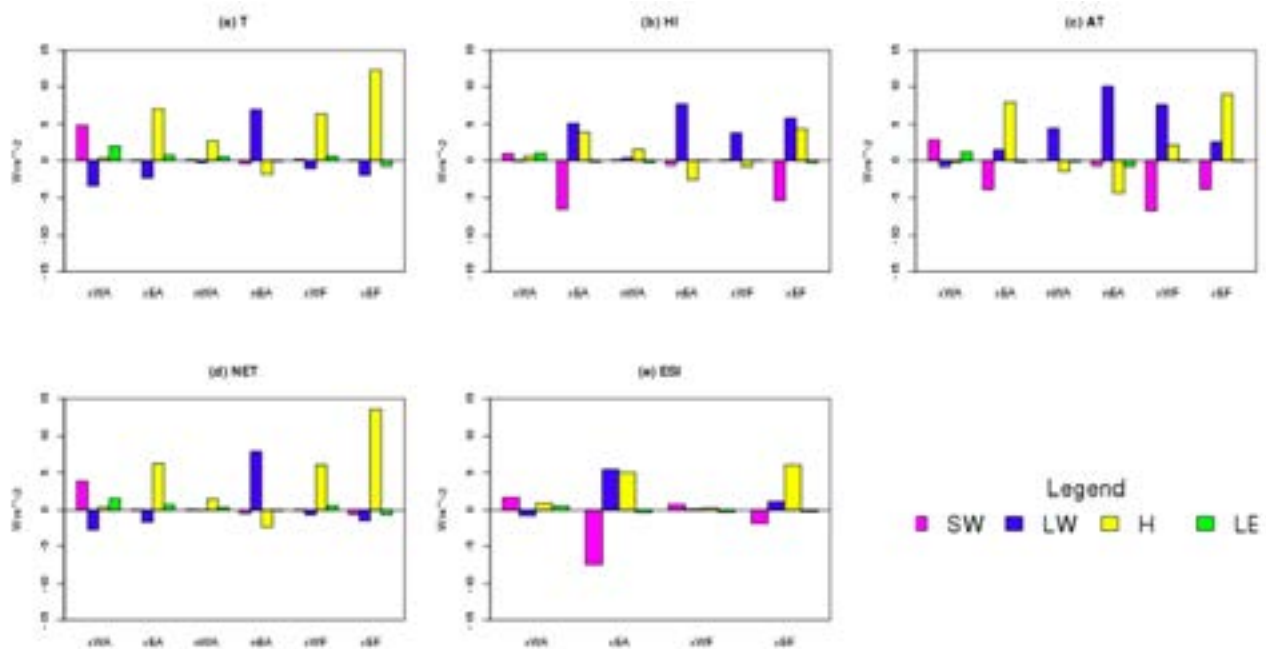
### Physical processes

To examine the physics underlying major heatwave events, the February to June time period is split into two seasons namely late winter (February–March) and pre-monsoon (April to June) consistently with Moron et al. (2018), with day and night events taken separately [14]. The leading EOF mode of each thermal index during such events, insensitive to moderate changes to the spatial domain, consists of a zonal dipole, opposing the east to the west of the Sahel. Consequently, six distinct heatwave types are identified based on these spatial structures, the two seasons and the diurnal cycle, with no major heatwaves at nighttime during the late winter season.

A large complexity characterises the physical processes shaping heatwaves. For a given thermal index, the underlying physical causes vary from one heatwave type to another. Sahelian heatwaves generally result from a combination of various processes. The most important in terms of both magnitude and consistency across heatwave types include temperature advection in the boundary layer, sensible heat flux and longwave warming at the surface. The latter process is caused primarily by water vapour and in a lesser extent by clouds.

Furthermore, as expected from the low Jaccard coefficients of similarity, the physical processes are sensitive to the choice of the thermal index, each one of them having its preferred driving process(es). Figure 2 illustrates this sensitivity based on the surface energy budget terms. It is apparent therefrom that (i) the HI index predominantly points to longwave radiation as leading process across most heatwave types, (ii) T and NET indices show very close processes with sensible heat flux contributing positively to most heatwave types, (iii) AT-based heatwaves result from both sensible heat and longwave forcing and (iv) the ESI index is characterised by small amplitude processes. Ultimately these differences from an index to another spring up from the various physical variables and mathematical formulations used to combine them.





**Figure 2.** Area averaged anomalies of surface energy budget terms for each thermal index. Acronyms: SW: Shortwave radiation, LW: Longwave radiation, H: sensible heat flux, LE: Latent heat flux. xWA: daytime heatwaves over Western Sahel in AMJ, xEA: daytime heatwaves over Eastern Sahel in AMJ, nWA: nighttime heatwaves over Western Sahel in AMJ, nEA: nighttime heatwaves over Eastern Sahel in AMJ, xWF: daytime heatwaves over Western Sahel in FM, xEF: daytime heatwaves over Eastern Sahel in FM.

## Conclusions

All the five thermal indices used in this study present the potential to depict the threat caused by hot weather to human health. The differences in their respective heatwave samples mean that each of them features a different hazard from the others. Therefore, in heatwave early warning plans, care should be given to the choice of either index to ensure targeting the correct exposed population group with the right index. Furthermore, as the physical processes differ from an index to another, their predictability might also differ. Further research is thus needed in that area to help on choosing the indices for heatwave monitoring in the Sahel.

## Acknowledgement

This research is funded through the Peter Carpenter African Climate Scholarship.

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## How predictable was the extreme rainfall over Central Kenya during the Long-Rains 2018 and what is the potential for early warning and action?

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The Long-Rains wet season of March–May (MAM) over Kenya in 2018 was one of the wettest on record with major impacts from flooding on lives, livelihoods, agriculture, transport and infrastructure. Here we assess the causes, predictability and potential for improved early warning. The exceptionally high MAM rainfall resulted from several multi-day heavy rainfall episodes. These events appear to be associated with the combined effects of active Madden–Julian Oscillation (MJO) events in MJO phases 2–4, and at shorter timescales, tropical cyclone events over the southwest Indian Ocean. Predictability of such events was assessed over a range of forecast lead times. Consistent with low skill of long-lead seasonal forecast products for MAM over Kenya there was little indication of extreme wet conditions in the MAM 2018 seasonal forecasts. However, at shorter lead times of a few weeks, the seasonal and extended-range forecasts provided a clear signal of extreme rainfall, which is likely associated with skill in MJO prediction (see paper by MacLeod et al). Short lead weather forecasts from multiple models also highlighted enhanced risk. Analysis of sub-seasonal hind casts suggests potentially useful skill for such rainfall events. Implications: (i) Potential exists for the integration of sub-seasonal and short-term weather prediction for flood risk management in Kenya. During MAM such lead times are favored given low skill in seasonal forecasting. In contrast, greater seasonal predictability of the Short-Rains in the October–December season means greater potential for early warning and preparedness over longer lead times.

### Introduction

East Africa is prone to climate and weather extremes with a highly variable climate, and has relatively high levels of population exposure and vulnerability. In the past few years, the region has experienced both significant drought and flood events. The most recent flood event occurred during the March–May (MAM) season mainly over Kenya. This paper aims to explain and quantify the nature, impacts, and large-scale climate drivers of the extreme rainfall over Kenya during March and April 2018, which led to widespread flooding across Kenya. We then use this event as a case study to assess the potential for forecasting extreme rainfall over a range of lead times, in order to support early preparedness actions.

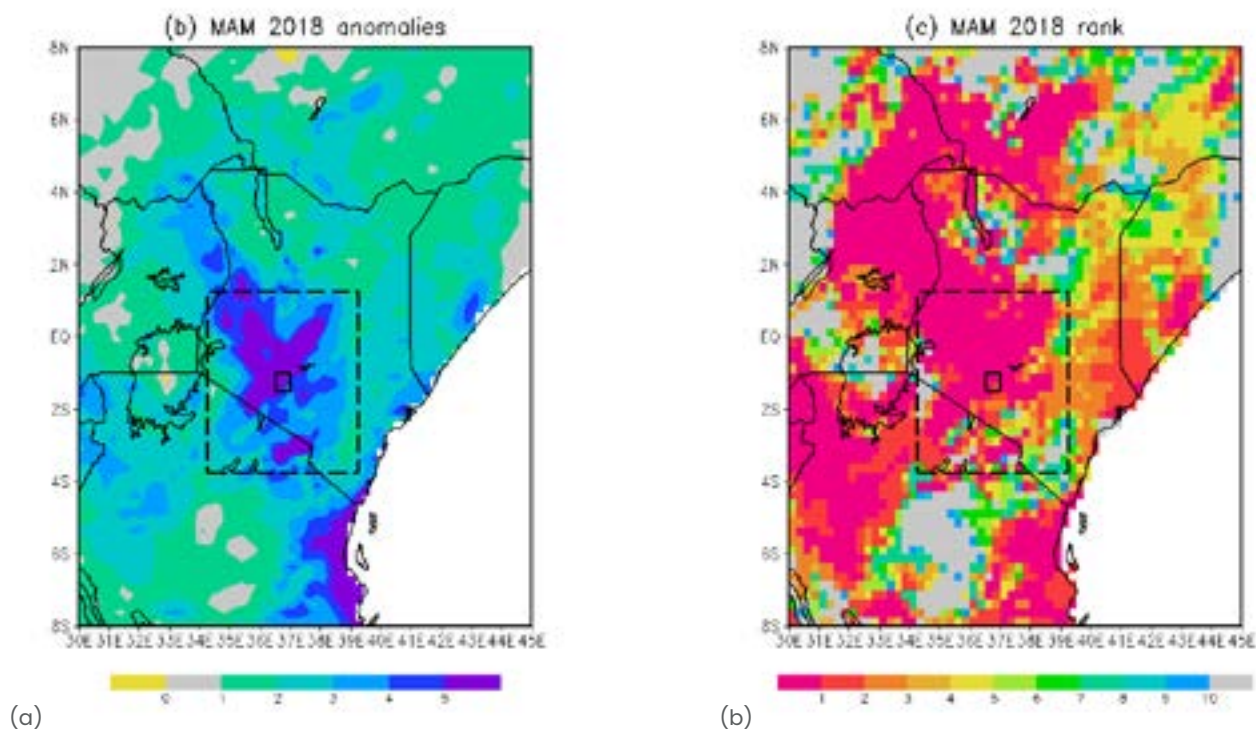
## Methodology

The spatial and temporal structure of the extreme rainfall events during the period was examined over the East African region across spatial scales. The large-scale atmospheric circulation, the MJO activities and the Tropical cyclones which were active in the southwest Indian Ocean during March–April 2018 are diagnosed from ERA-Interim reanalysis data and the S2S project hindcast database. Forecast products for March and April 2018 are examined over a range of lead times, from multiple sources, including the GPCs (WMO LC-LRFMME, the European Centre For Medium-Range Weather Forecasts (ECMWF) seasonal forecast system (SEAS5)) and the Met Office Global Seasonal Prediction System 5 (GloSea5) as well as the regional and national forecasting centres, IGAD Climate Prediction and Applications Centre (ICPAC) and KMD, respectively.

## Results

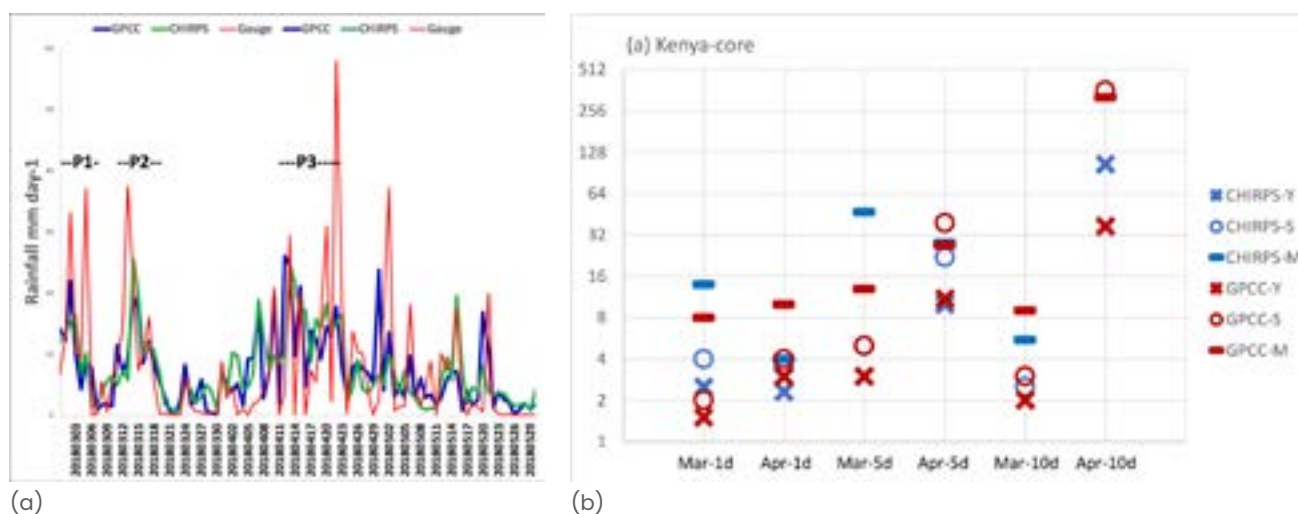
Most of East Africa experienced anomalous high rainfall during MAM 2018 (Figure 1). Anomalies were strongest over central and southern Kenya, including the Nairobi region. Much of Kenya experienced at least twice the normal rainfall for this wet season period and locally up to three times. Over much of Kenya, 2018 saw the wettest MAM season over the 119-year record of the Global Precipitation Climatology Centre (GPCC) data, and the 118 years of CenTrends data (Figure 1b).

Within the March–April period, the anomalous rainfall occurred primarily during three main periods of the intra-seasonal time scale that we define as 28th February–6 March (P1), 12–19 March (P2), and 13–23 April (P3), as shown in Figure 2a. The major intra-seasonal events P1–P3 are far more extreme than the daily rainfall events (figure 2b).



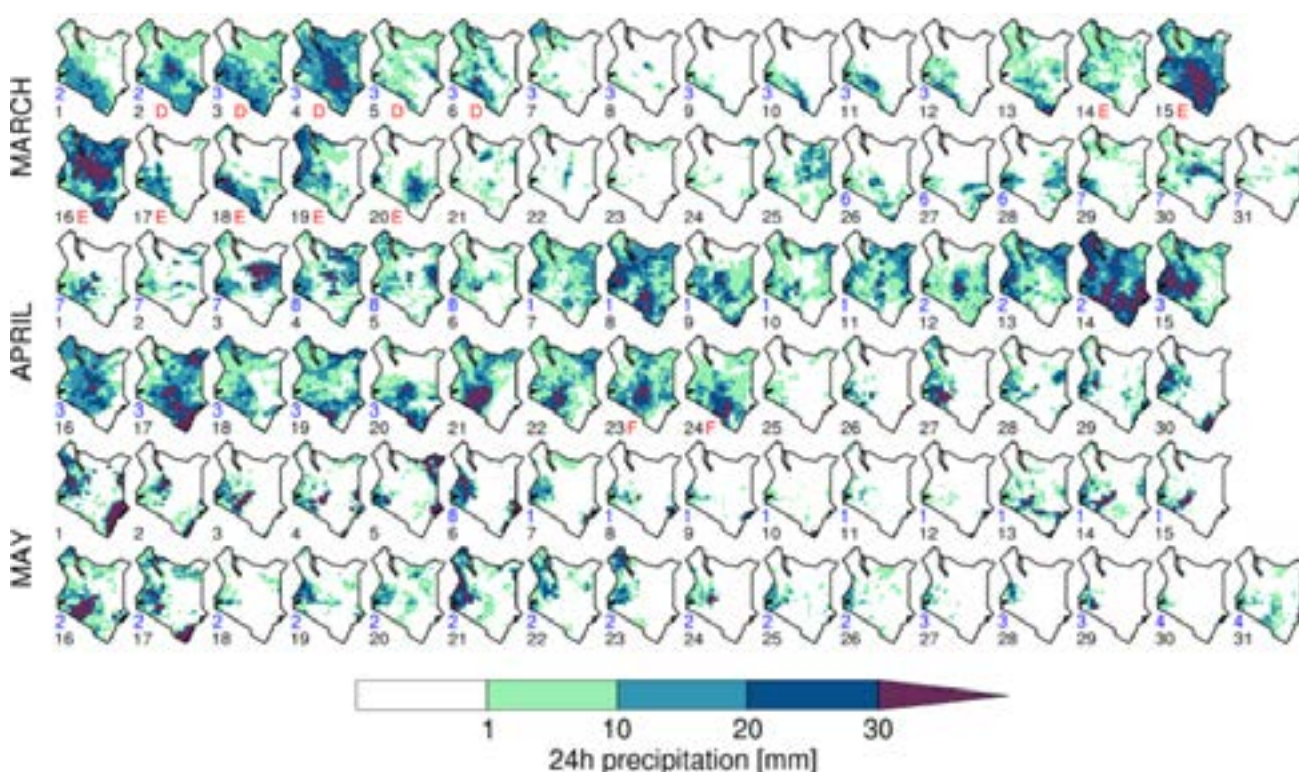
**Figure 1.** Rainfall over East Africa during March, April, and May (MAM) 2018 from Climate Hazards Infrared Precipitation with Station Data (CHIRPS) data (a) Absolute anomalies (mm day<sup>-1</sup>). (b) The rank of the MAM 2018 season within the 117-year CenTrends data. The large black dashed, and smaller solid squares, indicate the Kenya-core and Nairobi regions, respectively, which are used for areal averaging.



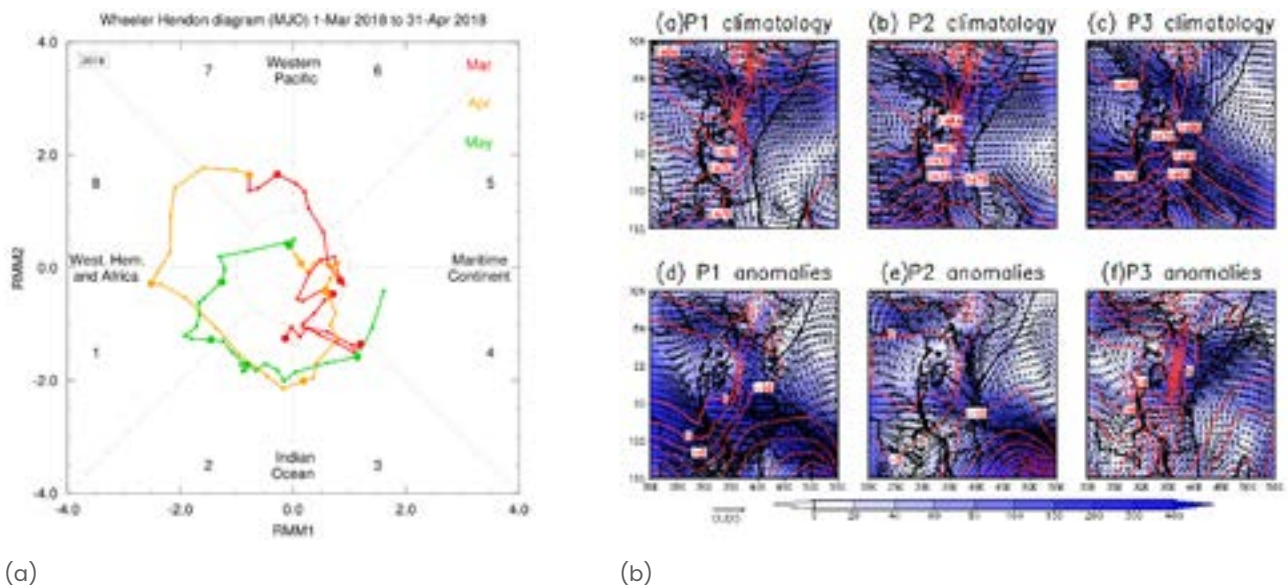


**Figure 2.** (a) Time series of daily rainfall from CHIRPS (green) and GPCC (blue) averaged over the Kenya-core region and from the area averaged Nairobi gauges (red). The periods of intra-seasonal enhanced rainfall P1-P3 are indicated. (b) Estimated return periods for the Kenya core region within a year, season (MAM), and month (March or April), respectively

Broadly, the periods of enhanced and suppressed rainfall over Kenya corresponds with the MJO phasing and activity in March and April 2018 and also with and tropical cyclones/storms activities in the southwest Indian Ocean (figure 3 below).

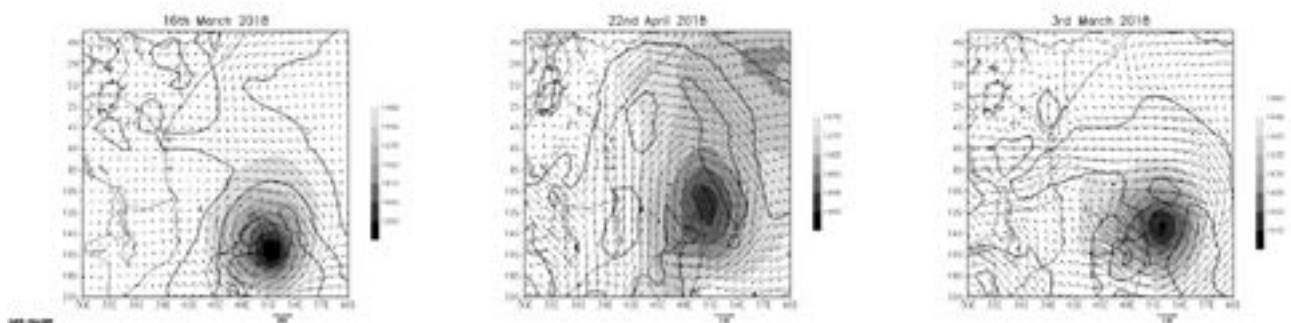


**Figure 3.** CHIRPS daily rainfall over Kenya during MAM 2018. The lower number in the bottom left of each panel indicates the date, and the upper number indicates the concurrent phase of the MJO (only 'active' days with MJO index greater than one are shown). The letters D, E, and F indicate days when tropical cyclones/storms Dumazile, Eliakim, and Fakir were active near Madagascar



**Figure 4.** (a) MJO activity during MAM 2018 plotted on a Wheeler–Hendon diagram. MJO data are from <http://www.bom.gov.au/climate/mjo/>. (b) Climatological (top) and anomalous (bottom) circulation during wet periods P1–P3. 850 hPa moisture flux anomalies (vectors), scalar q-flux (shaded), and 850 geopotential height (red contours).

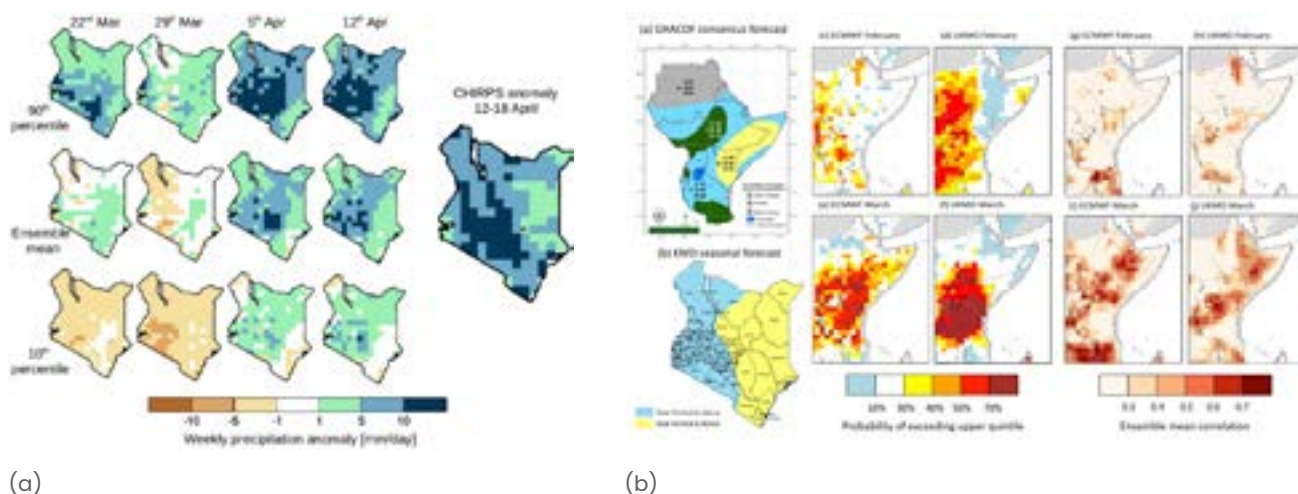
All three wet periods P1–P3 are associated with strong westerly or north westerly anomalous low-level circulation which is broadly consistent with the circulation anomalies during active periods of MJO in phases 2–3 [4]. It is also an indication of a strong influence of tropical cyclones/storms in the southwest Indian Ocean in periods P1, P2, and P3 when tropical cyclone Dumazile and tropical storms Eliakim and Fakir, respectively tracked southward close to the east coast of Madagascar (figure 5).



**Figure 5.** Circulation during tropical cyclone/storm events (a–c) Dumazile, Eliakim, and Fakir showing low-level (850 hPa) geopotential height, wind vectors, and speed (contours five, 10, and 15 ms<sup>-1</sup>)

The seasonal forecasts issued in February 2018 gave no indication of wetter than normal conditions for the MAM season over Kenya or indeed anywhere in East Africa (figure 6a). However, those forecasts issued at the start of March indicated strong wet rainfall anomalies. At sub-seasonal time scale, all the rainfall episodes were captured reasonably well by the ECMWF (figure 6b) and GloSea5 systems which have the high skill for MJO prediction with a lead time of about two weeks.





**Figure 6.** (a) Comparison of seasonal rainfall forecasts for MAM 2018 (b) Forecast of weekly averaged precipitation anomaly (top to bottom: the ensemble 90th percentile, mean, and 10th percentile) from the ECWMF extended-range system, for forecasts of the week 12–18 April, issued one to four weeks ahead (columns left to right). The observed CHIRPS rainfall anomaly is shown the right.

Much of the country suffered from surface flooding, with 40 out of 47 counties affected. In total, there were an estimated 186 flood-related deaths and approximately 800,000 people affected in some way. The Floods damaged or rendered critical infrastructure and services inaccessible

## Conclusions

The March 2018 case is consistent with the understanding that a long lead time indication of anomalous rains over Kenya for MAM does not have a strong basis, given the lack of slowly evolving drivers and subsequent low seasonal forecast skill. However, the analysis indicates that skill exists for a 'late view of MAM' and at sub-seasonal timescales. This implies that for the MAM season, the national meteorological services should lay more emphasis on the sub-seasonal to short term lead times forecasts which are much more skilful. This underscores the need for the met services to have access to the WMO S2S data. The relatively short windows for anticipatory action during MAM requires well-developed and functional forecast-based action systems for heavy rain and flood risk management

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## Does convection-permitting climate simulation improve the replication of rainfall distribution and extreme over Guinean coast and surroundings?

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Please see original version:

Kouadio K, Bastin S, Konare A, Ajayi VO (2018): Does convection-permitting simulate better rainfall distribution and extreme over Guinean coast and surroundings? *Clim Dyn*. doi: 10.1007/s00382-018-4308-y

This study assesses the sensitivities of Weather Research and Forecasting (WRF) Model to the changes in horizontal resolution (convection permitting versus parameterized) on the replication of West African monsoon for year 2014. Sensitivity tests were done for response of rainfall to changes in microphysics (MP) and planetary boundary layer (PBL) schemes. Generally, the result shows that WRF fairly replicates rainfall distribution with an adequate replication of the dynamical features of the West African monsoon system. The high-resolution (wrf-4km) shows driest bias along the coast of the Gulf of Guinea. However, it, generally, outperforms the wrf-24km run especially in the simulation of the extreme rainfall. Both runs at 24km and 4km pain to reproduce the typical diurnal cycle of rainfall. The sensitivity of WRF to MP (only sophisticated MP were tested) and PBL highlighted stronger impact of PBL than MP on rainfall distribution and the most significant added value over the Guinean coast and surroundings area was provided by the configurations using non-local PBL scheme (as ACM2). The changes in MP and PBL schemes in general seem to have limited effect on the explicit runs (wrf-4km) in the replication of the rainfall over the Gulf of Guinea and the surroundings seaboard.

**KEY WORDS:** high resolution, WRF, West Africa monsoon, Parameterization, Rainfall, convection permitting.

### Introduction

Irrespective to constant progress of models to permit adequate representation of the West African Monsoon (WAM), at the present day, models still have many difficulties to simulate the West African climate features. Several reasons are proposed to explain these underperformances. The reasons are varying from the physics of the models, scale interactions, lack of reliable and dense observation data suited to the resolution of the models. For example, Chang (2011) proposed that the limitation of climate models to reproduce the diurnal, seasonal and annual cycles of rainfall over West Africa is related to a limited capacity of meteorological services in getting observations data set and human and informatics resources[1]. Moreover, Intergovernmental Panel on Climate Change (IPCC) acknowledged on its Third Assessment Report (TAR) that a model run at coarse resolution does not allow detailed extreme rainfall evaluation [4].

Some earlier studies [8][9][5] showed an improvement of their simulations using high resolution simulation. Marsham et al. (2013) investigated the role of the moist convection over West Africa throughout a comparative study based on a horizontal resolution's cascade simulations using the UK Met Office Unified Model (UM)[8]. Their result underlines the importance of the interaction between monsoon and convection. In addition to the explicitly resolving of deep convection, convection-permitting run also allows a better representation of fine-scale orography and variations of surface fields.

However, the high-resolution simulation across West Africa remains largely low due to its cost that requires high computational resources, innumerable computing time, and processors to

high storage capacity. Thus, the analysis of the WAM at very high resolution remains an important concern. In addition, the prevention of events with high social, economic and environmental impacts remains a constant challenge over the region. There is a need for identification of accurate models with optimal parameterizations for better understanding of the processes which allow a better prediction of West African rainfall variability and extreme and then provide the best way of using of regional dynamical model as a forecast tool and overcoming the difficulties of explaining the detailed rainfall and intense rainfall process over the West African region and particularly along the Guinean Coast and surrounding.

The present study evaluates the added-value of performing a convective permitting simulation in a climate mode, covering a longer period than a case study (several months) for the representation of rainfall distribution over Guinean coast, with a focus on heavy rainfall. Several combinations of parameterization schemes are compared in this explicit convective climate mode and the best combinations for replication of high rainfall events over Guinean Coast and surroundings are proposed.

## Method

Two set of runs are conducted using the WRF Model to first assess the capability of High-Resolution Regional simulation (convective-permitting) of West African Climate.

first set of simulations uses two nested domains over the West African region from March to September 2014. The coarser domain extends from 25°W to 30°E and from 10°S to 40°N with 24km horizontal resolution. The inner domain is one-way nested from 17°W to 10°E and from 4°N to 20°N run at 4km horizontal resolution. The outer domain is forced by the Centre for Medium-Range Weather Forecasts (ECMWF) reanalyses ERA-interim (Dee et al. 2011) data sets and feeds the inner domain.

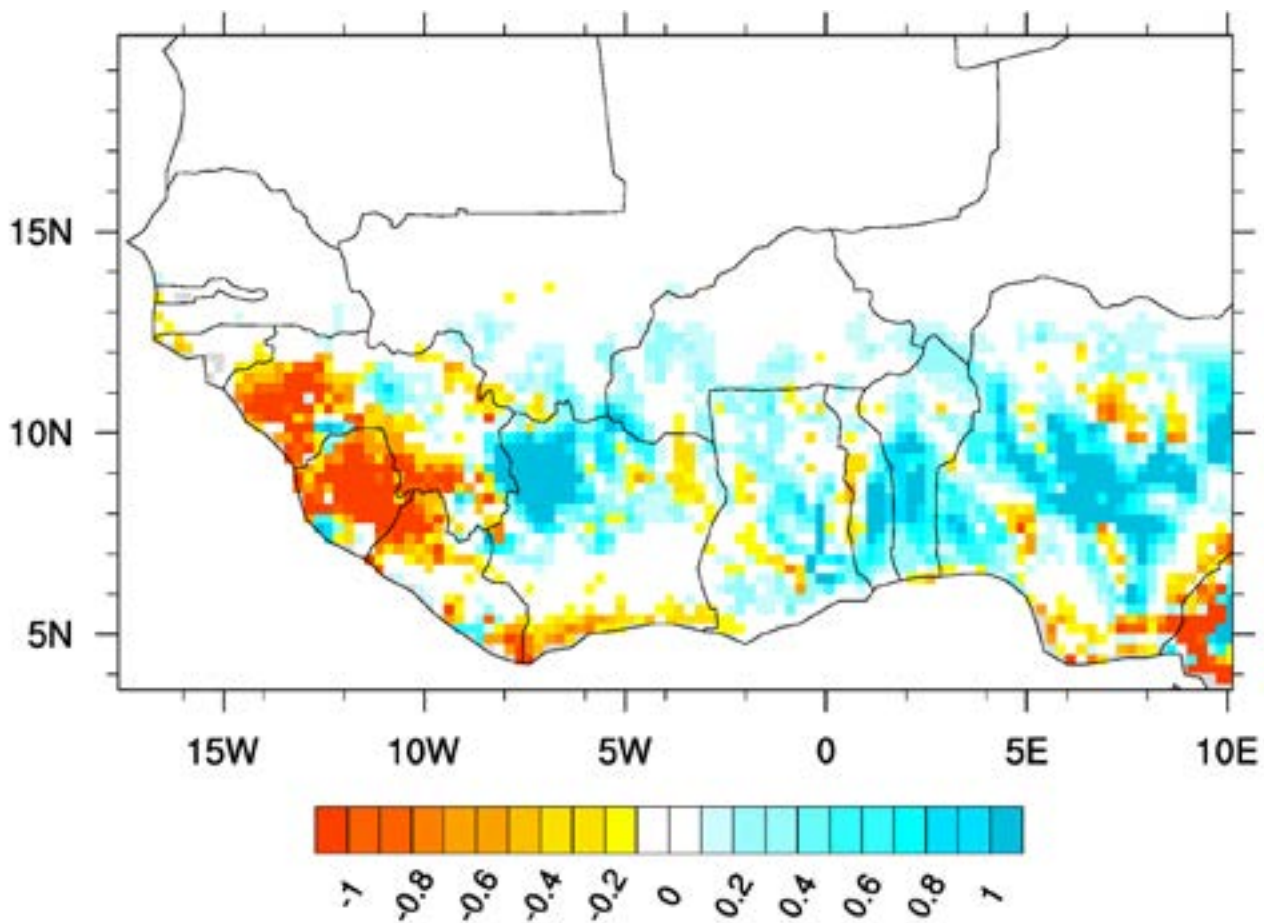
The second set of runs is performed to focus on the physical processes of rainfall over the Guinean Coast, particularly on the influence of MP and PBL processes on the simulation of intense precipitation. These experiments consist of an ensemble of runs combining three different boundary layer and three microphysics schemes

## Result

At seasonal scale, in comparison to the Tropical Rainfall Measuring Mission (TRMM) and the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) datasets, WRF shows good performance in the replication of rainfall distribution over the region mostly near-Sahel and Sahel (north of 8°N). There is, however, an underestimation of the rain amount over the coastal area of the Gulf of Guinea and mainly over the sea during the pre-onset period and at the end of the rainy season. This leads to strong dry bias from the sea to about 6°N (beyond the coast) during the Sahelian rainy season. This dry bias could be related to a more and early inland penetration of the rain by WRF.

From the dynamics, the differences between the two sets of run of WRF, which share the same physics but not convection, are mainly reduced to the low-level circulation, which has a stronger zonal component in WRF-24km than in WRF-4km. It affects the intensity of moisture convergence between 5 and 10°N.

Generally, the run at high resolution, outperforms the 24-km resolution one over the Guinean band and southern Sahel, i.e. presents an upscaled added-value. There is, however, some area where the high-resolution run seems to degrade the information instead of improving the simulation, especially over Ivorian coast, south-west of Guinea and Sierra Leone (Fig.1).



**Figure 1.** (a) Comparison of seasonal rainfall forecasts for MAM 2018 (b) Forecast of weekly averaged precipitation anomaly (top to bottom: the ensemble 90th percentile, mean, and 10th percentile) from the ECWMF extended-range system, for forecasts of the week 12–18 April, issued one to four weeks ahead (columns left to right). The observed CHIRPS rainfall anomaly is shown the right.

At diurnal scale, TRMM shows the main light rain events from midnight to 12 UTC and the diurnal cycle of medium rain events have less variation however a peak is observed at 15 UTC. Wrf-4km outperforms wrf-24km in the replication of these features especially the timing, and the number of events. The intense rainfall events are shown to occur anytime with nearly the same probability but none of the simulations is able to reproduce this. The parametrized convection run situated the peak of occurrence of intense rain events in the afternoon at 15 UTC. This is mainly due to the fact that convection is generally high when net radiative energy is at its maximum, near 15 UTC for these regions while the explicit run shows the intense rain occurrence mostly from the evening to early morning with a maximum around mid-night.

## Conclusion

This present study assesses the sensitivity of the WRF Model to horizontal resolution and physics schemes in the simulation of West African precipitation for the year 2014. Several runs were performed using parameterization or explicit convection.

The high-resolution which uses the explicit convection exhibits driest bias along the coast of the Gulf of Guinea but generally outperforms the 24km run especially in the replication of the extreme rainfall distribution.

The results also highlighted an appropriate reproduction of the dynamics of West African monsoon system with a less subsequent added value of permitting convection in the replication of low levels atmospheric circulation.

The impact of microphysics is not as much as that of PBL schemes in either explicit or parametrized convection modes. The convection-permitting simulations thus seem well relevant for the study of extreme events (i.e. heavy precipitation). However, the simulations can be affected by the limitation of the domain size, the absence of two-way interactions between the inner domain and the rest of the globe, and the lateral boundary condition issues.

Finally, this work focuses only consider a single year because of the cost of such experiment. It is then worth to mention the importance of extending the run over several years to allow more significant analysis of physical processes and statistical analyses. Such work needs subsequent cluster resources and is beyond the scope of this paper. The use of only three MP and PBL and one convective parameterization scheme may be a limitation of the methodology.

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## Assessment of Orographic Effects on an Extreme Rainfall Event in Rwanda Using the Weather Research Forecasting (WRF) Model

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Extreme rainfall events have negative impacts on both social and economic aspects. In Rwanda, high altitude regions are classified as flood prone areas associated with extreme rainfall events. An understanding of orographic precipitation mechanisms over areas with complex topography is very complicated due to poor availability of ground-based meteorological observations. In this study, a past extreme rainfall event, was simulated using NCEP FNL data in a high resolution (3 x 3 km). Two sensitivity tests were performed to choose the best among five convective parameterization schemes (CPSs) leading to the smallest verification errors in terms of precipitation. Another sensitivity test was performed by forcing the model with reduced topography and it was found that reducing the terrain height not only affected spatial



rainfall distribution but also affected the wind field and convergence areas which resulted in rainfall decrease in some areas and rainfall increase in other areas. In addition, according to the simulated vertical velocity, cloud water and rain water mixing ratios, mechanisms by which mountains affected rainfall in Rwanda during this particular extreme rainfall event were mainly the seeder-feeder mechanisms, the blocking effects and overturning flows which were connected to both local and regional motion systems.

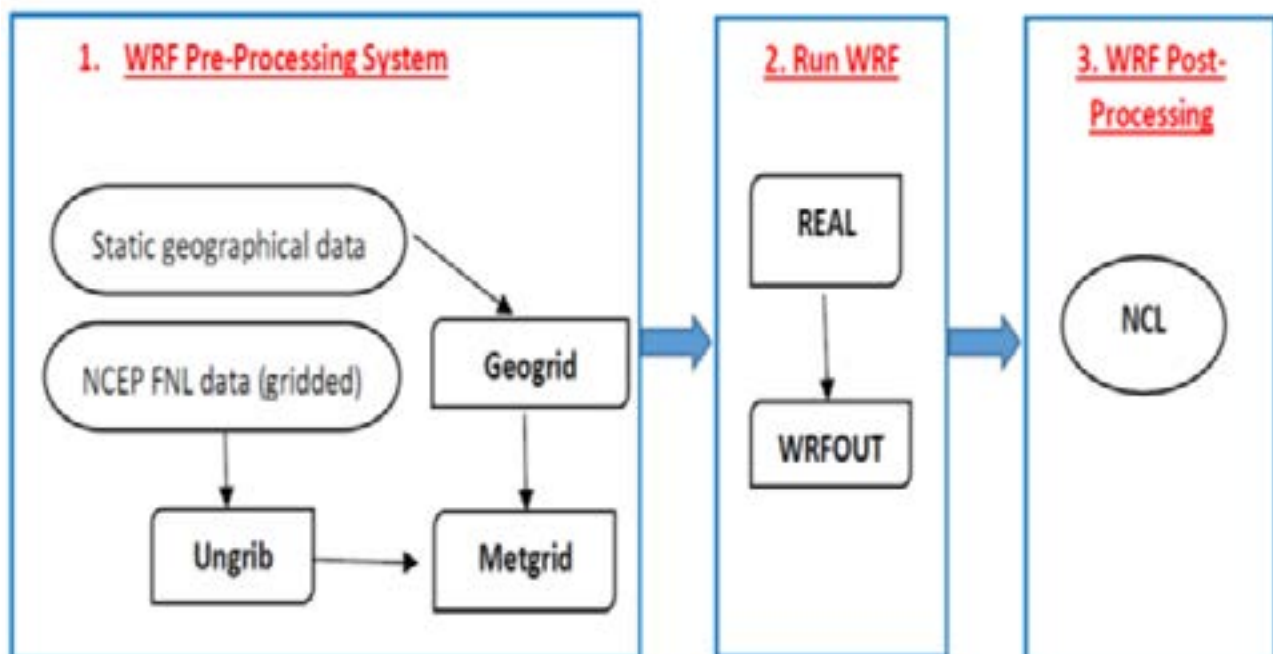
## Introduction

In Rwanda, heavy rainfall, in combination with natural factors like topography, is having great impact in some areas of the country such as the North and Western Provinces. The main objective of this research was to “assess basic mechanisms by which high mountains affected an extreme rainfall event during a short rainy season in Rwanda using one of the most commonly used numerical weather prediction (NWP) models such as WRF”.

## Methodology

This study used the WRF version 3.7 to simulate the 30th November 2011 event using NCEP data as input. Threat score, Bias score, Root Mean Square Error and Mean Absolute Error were used for model skillfulness verification comparing WRF output with observation data from stations

## WRF Modeling system flow chart



For verification: Threat score, Bias score, Root Mean Square Error and Mean Absolute Error were used

Figure 1. Flowchart of the methodology used to pre and post process WRF model

## Results

### A. Sensitivity of WRF to different Convective Parameterization Schemes (CPS)

Five CPSs were used for this study in order to test the best CPS close to the observation and therefore leading to the smallest verification errors in terms of precipitation. Among the five CPSs, the one which gave the best simulation of the observed event statistically was used for further simulations with reduced topography.

The results show that among the five CPSs tested, for this specific rainfall event case, the Betts Miller Janjic (BMJ) scheme performs better than the other schemes, as verified using statistical assessment (Figure 3). The verification results showed RMSE and MAE around 15 mm and 10 mm (on average), respectively. Nevertheless the model showed quite good performance in terms of Threat Score (TS) and Bias Score (BS) for the threshold rainfalls between 5 and 20 mm.

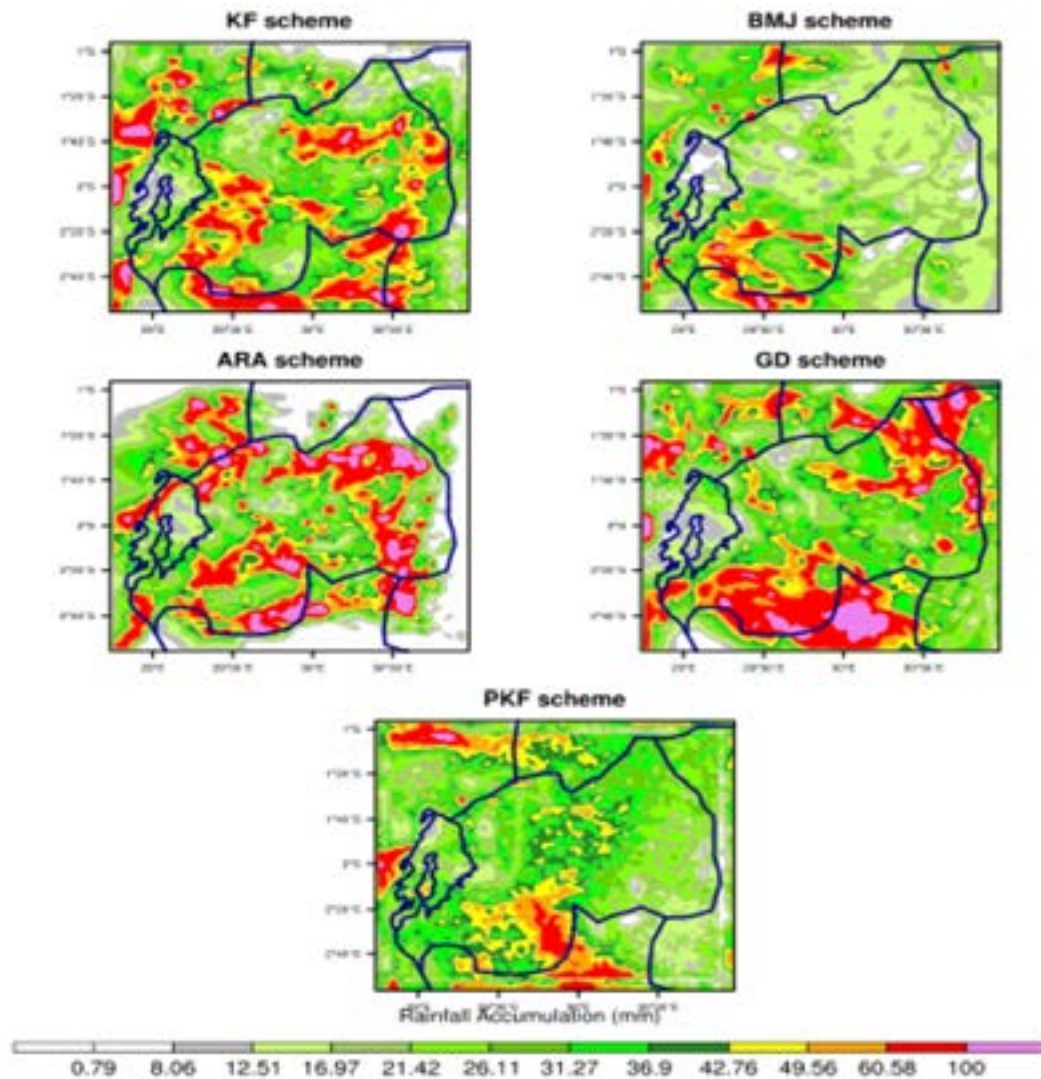
### B. Sensitivity test with modified topography

To assess the influence of topography on rainfall amount and spatial distribution over the country using the WRF model, the Model is forced with reduced topography. The 24-hr accumulated rainfalls results shows a slight decrease of rainfall in some locations and increase largely at other locations (Figure 4 in the left) especially around Lake Kivu. This showed that, reduced topography simulations affected the spatial rainfall distribution.

The areas where the rainfall decreased on one hand and increased on the other hand, are shown clearly with the calculations of differences between the WRF output with reduced topography (RT) and WRF output with actual topography (AT). The 24-hr accumulated rainfalls (Figure 4 in the right) generally show larger increases compared with the 15-hr accumulated rainfall.

## Conclusion

In this study, we investigated the mechanisms related to an extreme rainfall event which occurred on 30 November 2011 in Rwanda using a fully-compressible and high-resolution numerical model, the Weather Research and Forecasting (WRF) model. Our results show that among the five CPSs tested, for this specific rainfall event case, the Betts Miller Janjic (BMJ) scheme performs better than the other schemes. In addition, the cross section analyses revealed that the orographic rainfall in Rwanda, at least for this specific case, is mainly affected by the seeder-feeder mechanism, the overturning flow and the blocking effects (see Figure 5) which are connected to both the local and regional circulation systems.



**Figure 2.** The simulated total accumulated rainfall (in mm) from 0000 UTC 30 November to 0000 UTC 1 December with 5 different CPSs

As recommendation, further studies on topography influence on orographic effects on rainfall distribution should be done by considering other parameterization schemes, such as explicit microphysics, planetary boundary, land surface and radiation processes in order to find a good combination which can give a more accurate and optimal spatial rainfall distribution. A sensitivity test of land use on the rainfall distribution is also encouraged.

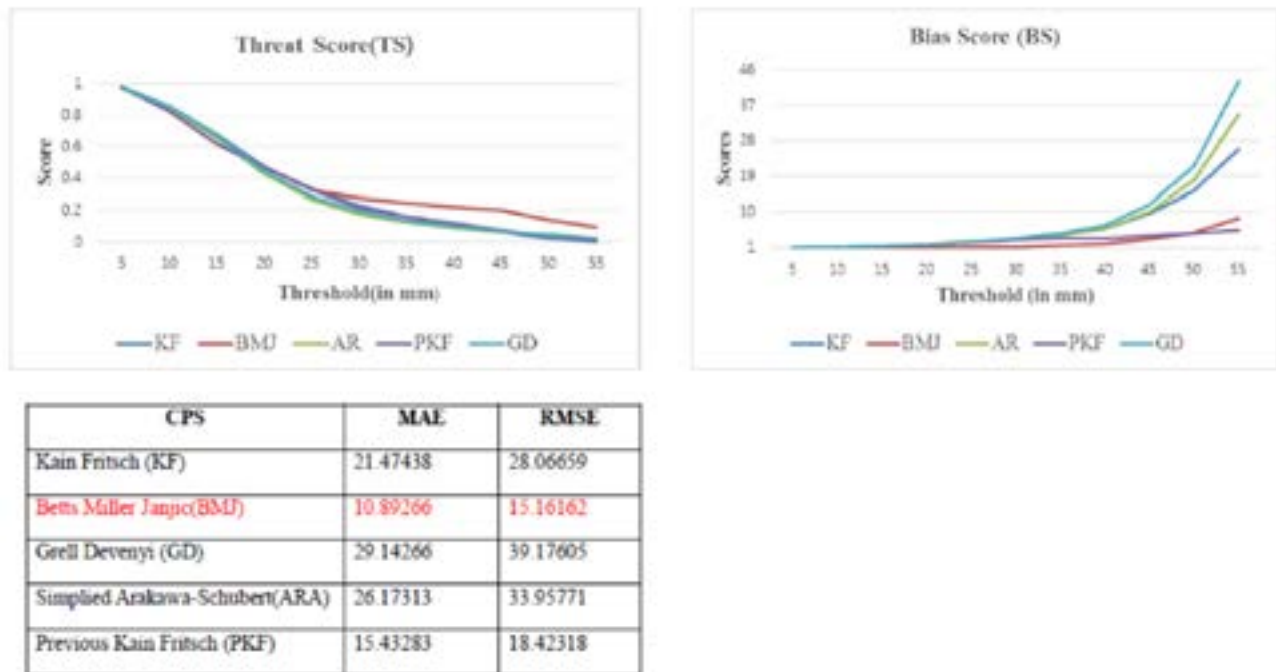


Figure 3. Model Skillfulness verification

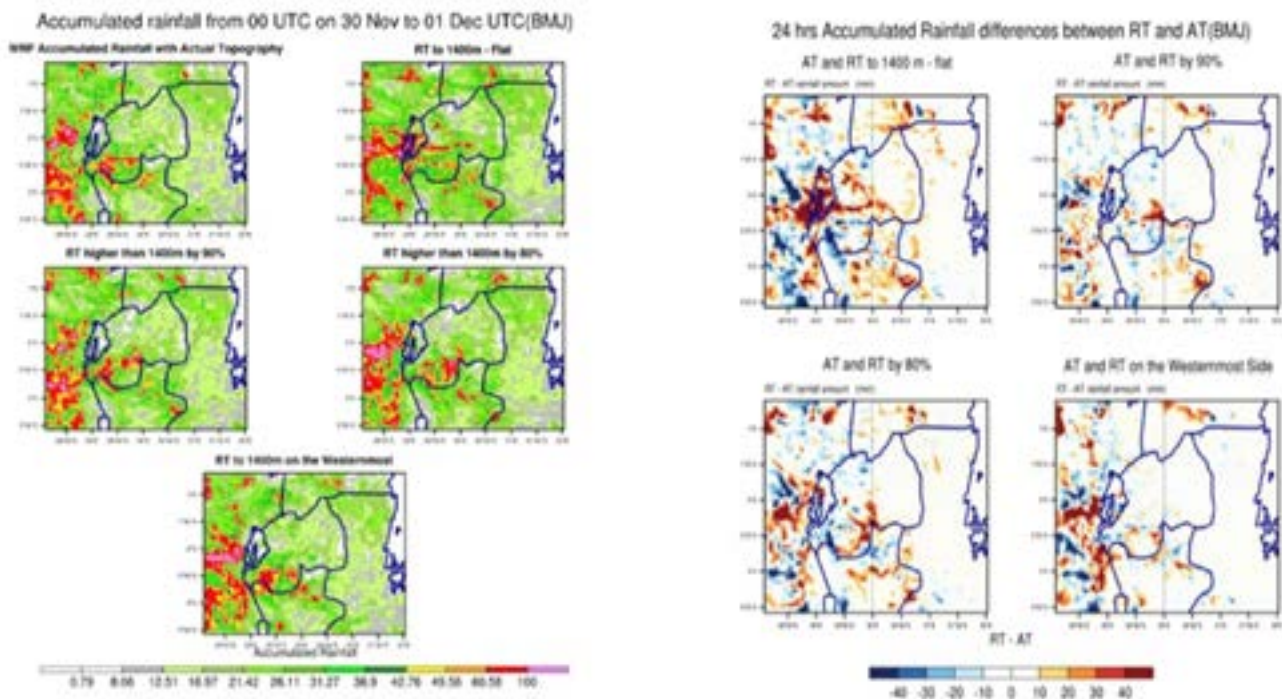


Figure 4. Simulated 24-hr accumulated rainfall (in mm) using the Betts-Miller-Janjic (left) and differences between the WRF output with reduced topography (RT) and WRF output with actual topography (AT); that is, RT - AT (right)



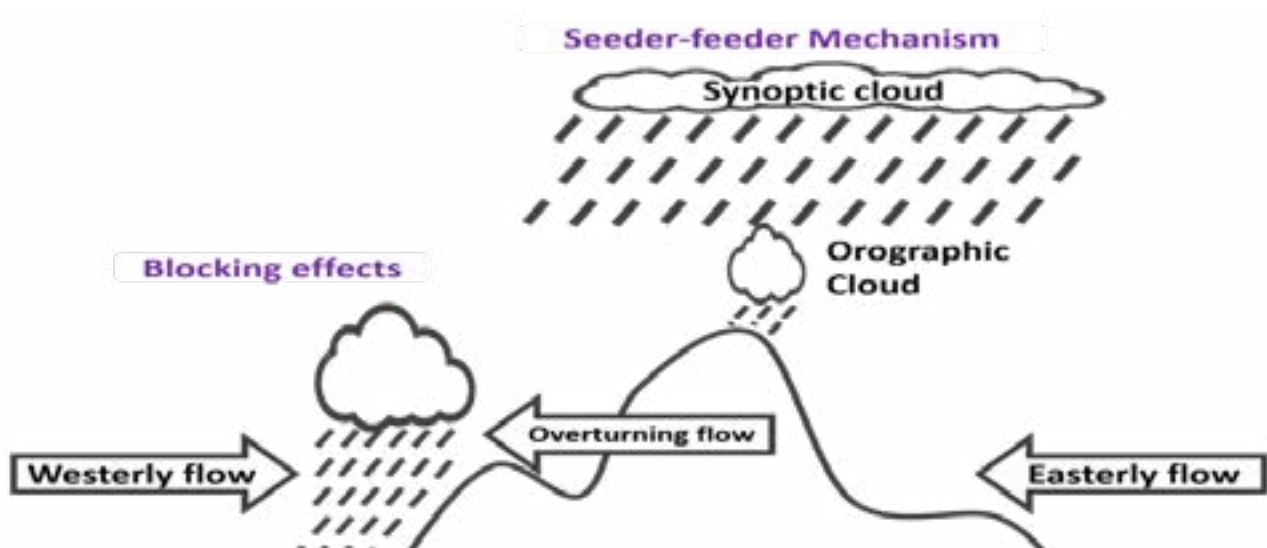


Figure 5. A conceptual schematic diagram of representing the orographic effects on the 30 November 2011 extreme rainfall event in Rwanda.

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## The Effect of the Indian Ocean Dipole (IOD) on the Seasonal Rainfall Patterns in the Lake Victoria Basin, Uganda

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In Uganda, a number of factors influence the variability of rainfall. This study aimed at determining the effect of the Indian Ocean Dipole (IOD) on the seasonal rainfall patterns over the Lake Victoria Basin (LVB). Use was made of gridded rainfall data from the Global Precipitation Climatology Centre (GPCC) and IOD in terms of the Dipole Mode Index from National Oceanic and Atmospheric Administration from 1982 to 2012. A Mann-Kendall's test was used to test the seasonal trends of the different stations. Both seasons indicated a decreasing trend in the rainfall patterns. The spatial analytical tool in the Python software indicated rainfall increasing eastwards of the basin for the first 20 years (from 1982 to 2002) and later decreased during the March – May (MAM) season. The September – November (SON) season showed a decrease in the spatial patterns throughout the entire period of the study. The Pearson Product Moment Coefficient indicated no significant correlation for all stations ( $P > 0.05$ ) for the MAM season. However,



correlating the IOD with the SON season, two of the stations (Entebbe and Kampala) indicated a positive significant correlation ( $R=0.5$ ,  $P<0.05$ ).

**KEY WORDS:** IOD, Seasonal rainfall, GPCC, Dipole Mode Index, Uganda.

## Introduction

The distribution of rainfall over Uganda shows a high degree of spatial and temporal variability. This has been attributed to the varied topography (presence of lakes and mountains), synoptic weather systems and teleconnection patterns (El Nino Southern Oscillation (ENSO) & Indian Ocean Dipole (IOD)) [3]. IOD is a coupled ocean-atmosphere mode [4] characterized with a negative and positive phase [1] with cool and warm Sea Surface Temperatures (SST) over the Eastern and Western Indian Ocean respectively. Studies (e.g. [2]) have shown that IOD enhances the rainfall over East Africa during the positive Dipole Mode Index (DMI), which suggests that there is a significant relationship between the DMI and East African rainfall. It's on this basis that the study sought to focus on the effect of IOD on the seasonal rainfall patterns over the LVB. This study was guided by two questions; (1: What are the temporal and spatial seasonal rainfall patterns over the Lake Victoria Basin? And (2: what is the effect of the IOD on the seasonal rainfall patterns of the Lake Victoria Basin.

## Methodology and Results.

Monthly gridded rainfall totals extracted for the four stations; Entebbe, Kampala, Kabale and Mbarara distributed over the LVB was obtained from the Global Precipitation Climatology Centre (GPCC) available on a spatial resolution of  $0.50 \times 0.50$  from National Oceanic and Atmospheric Administration NOAA website. In addition, the IOD (DMI) data was obtained from NOAA at a temporal resolution of 30 years, which was freely downloaded from the NOAA website.

## Temporal and Spatial analysis of the data.

The seasonal temporal patterns were revealed using graphical displays (Figures 1&2) and were statistically quantified using the non-parametric test, Mann Kendall (Table 1), based on the hypothesis that there were no significant trends in the seasonal rainfall over the LVB. In addition, the seasonal spatial rainfall patterns over LVB were plotted on a decadal time scale (Figure 3).

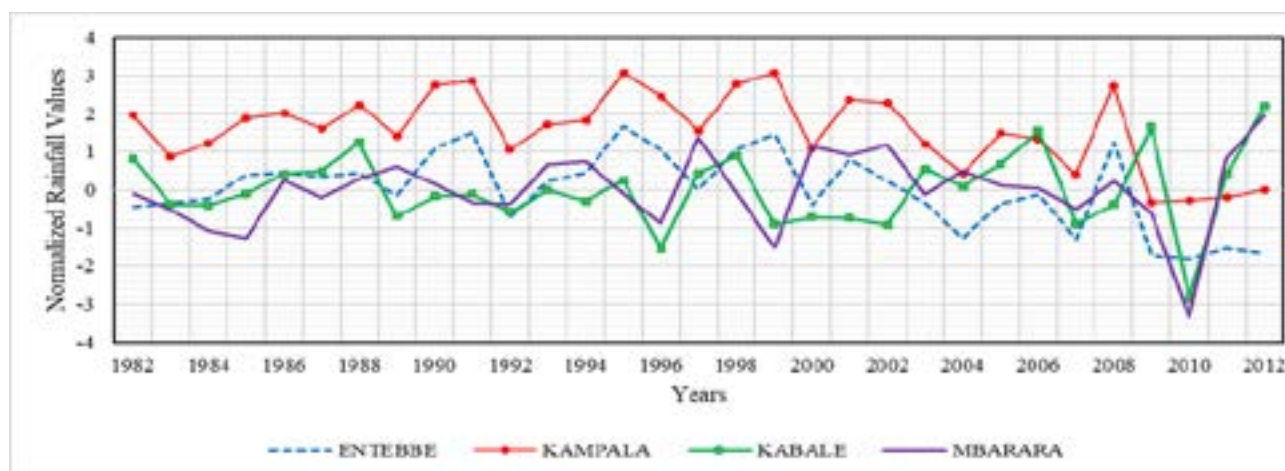


Figure 1. MAM season temporal rainfall variability over LVB.

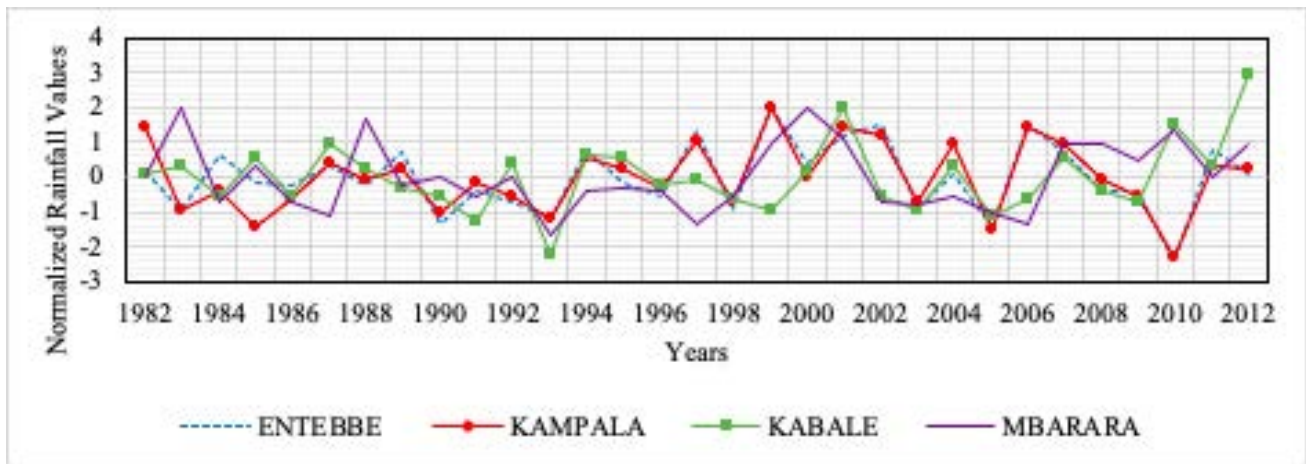


Figure 2. SON season temporal rainfall variability over LVB

Table 1. Mann Kendall trend results of MAM and SON over the LVB from 1982–2012 (Confidence level of 95% ( $\alpha = 0.05$ )).

SEASON	STATION	$\tau$	P value	Comment
MAM	ENTEBBE	-0.322	0.00022	Reject H0
	KAMPALA	-0.323	0.00022	Reject H0
	KABALE	-0.254	0.00355	Reject H0
	MBARARA	-0.2227	0.00933	Reject H0
SON	ENTEBBE	-0.252	0.0038	Reject H0
	KAMPALA	-0.237	0.0065	Reject H0
	KABALE	-0.26	0.0029	Reject H0
	MBARARA	-0.25	0.0041	Reject H0

## Results from spatial rainfall patterns.

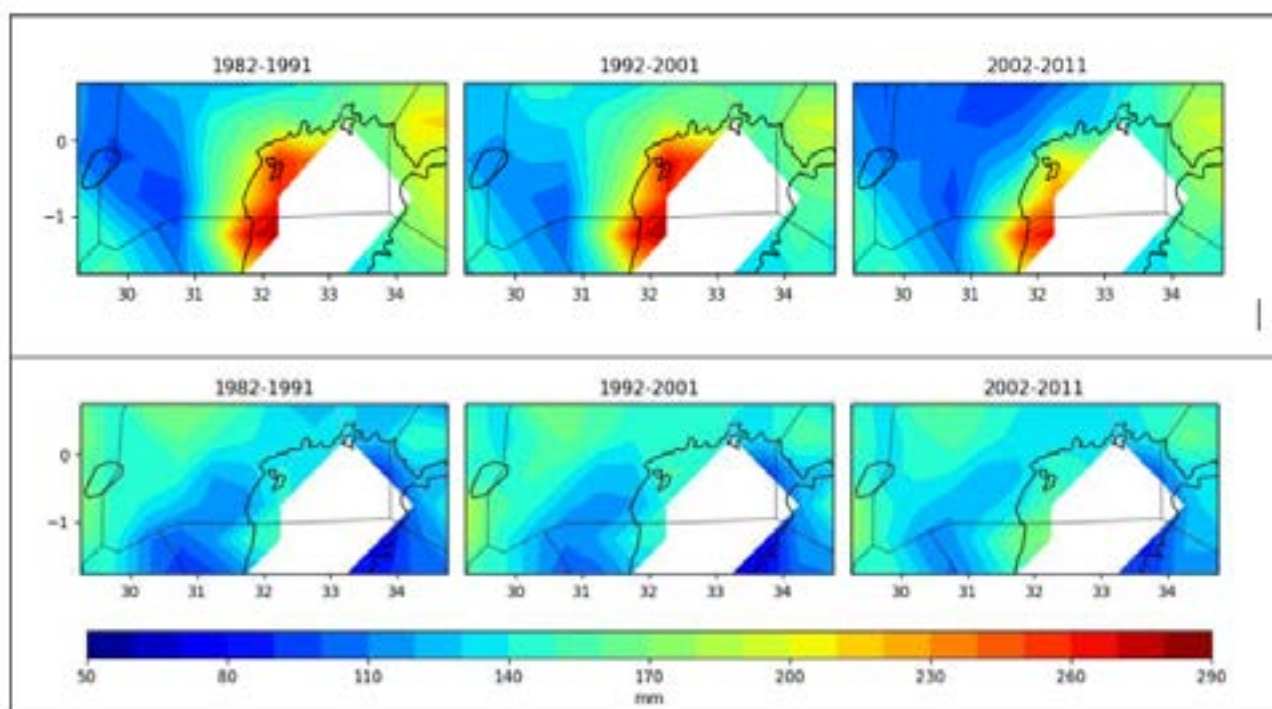


Figure 3. MAM (above) and SON (below) spatial variations for 10 year averages; 1982-1991 (left), 1992-2001 (middle) and 2002-2011 (right).

## Investigation the effect of the IOD on the seasonal rainfall patterns of the LVB.

The seasonal rainfall totals and the DMI data were subjected to a correlation analysis in order to determine the relationship between the two variables (Table 2).

## Conclusion

The overall objective of the study was to determine the effect of the IOD on the seasonal rainfall patterns over the LVB. Results from the temporal analysis showed a high temporal variability during the SON season than the MAM season. However, during the 2007 and 2010 years of the MAM season showed very low rainfall totals for almost all stations which was attributed to the strong La Nina events during those two years. In addition, during the SON season, the outstanding peak of rainfall in almost all stations in 1997 was attributed to the strong El Nino event that occurred that year. In general, the results showed a decreasing trend in both seasons for the 30-year period.

**Table 2.** Pearson correlation results of MAM and SON seasons with the IOD over the LVB from 1982–2012 (Confidence level of 95% (Alpha =0.05)).

SEASON	STATION	R Value	T-TEST	F Value	COMMENT
<b>MAM</b>	ENTEBBE	-0.100	-0.543	0.592	Accept H0
	KAMPALA	-0.120	-0.649	0.522	Accept H0
	KABALE	-0.075	-0.404	0.689	Accept H0
	MBARARA	-0.077	-0.415	0.681	Accept H0
<b>SON</b>	ENTEBBE	0.536	3.417	0.002	Accept H0
	KAMPALA	0.546	3.509	0.001	Accept H0
	KABALE	0.078	0.424	0.675	Accept H0
	MBARARA	-0.224 -	-1.238	0.226	Accept H0

The seasonal spatial distribution showed a general increase of rainfall eastwards of the LVB than the westwards during the MAM seasonal distribution and decreasing eastward during the SON season. However, in both seasons, the area of Mbarara showed no significant change of distribution, which indicated low rainfall throughout the 30 years. This could be because of the area lying in the cattle corridor, which is a dry land area.

From the correlation analysis, all stations show no significant correlation between the MAM season and the IOD. However, the SON season correlation analysis showed a positive significant correlation with the IOD with two stations; Entebbe and Kampala with an R-value of 0.5 and a significance of 0.001.

The results of the study revealed a decreasing trend in the seasonal rainfall patterns and a positive significant correlation between the IOD and the SON rainfall season as revealed by two stations. This indicated that the IOD has a significant effect on the SON season by 0.5 correlation coefficient and 0.001 significance.

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## Projected changes in rainfall and temperature extremes over East Africa

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East Africa is prone and vulnerable to effects of climate change. The ongoing decrease in rainfall and increase in rainfall and temperature extremes is causing huge losses especially in the agricultural sector. This work looks into the projected variability of extreme rainfall and temperature events. The study uses extreme climate indices computed from daily rainfall (temperature) simulations of 18 (24)-member Couple Model Intercomparison Project (CMIP5) multimodel ensemble (MME) mean. Two radiative forcing pathways (RCPs 4.5 and 8.5) are considered. Extreme indices used were proposed by the WMO's Experts Team on Climate Change Detection Indices (ETCCDI). Extreme in equal 30-year time periods, mid (2021–2050) and end (2071–2100) of the 21st century are compared to the baseline period (1961–1990). Trend analysis is explored using Mann–Kendall test statistic and Sen's slope estimator. Temperature exhibits significant increase with an increase in radiative forcing. The end of the 21st century is likely not to record any cool days and cold nights. There will be an increase Very wet and extremely very wet days, mainly over Western Kenya, and entire of Uganda. The change in maximum 1-day precipitation and maximum 5-day precipitation amount shows a remarkable increase in variance towards the end of the twenty-first century. In as much as these results are derived from relatively low resolution data, they present the possible conditions that can be factored in long-term planning. The finds as well forms a good basis for advanced studies.

**KEY WORDS:** Climate extremes, Temperature, Rainfall, ETCCDI, CMIP5

### Introduction

Rainfall is the most important weather variable in East Africa (EA) region given its role in supporting agriculture. Thus, the population is vulnerable to changes in rainfall variability and change [3]. The common and most devastating rainfall related extremes in the region are drought and floods [4]. Temperature on the other hand has influence in the distribution of crops since some crops only do well in cool and wet areas. Other than agriculture, there is growing concern following the increase in temperature in the region which favors the survival of malaria spreading mosquitoes [5].

Studies have shown that rainfall is decreasing in the main rainfall season; March–May (MAM 'long rains') over EA [6]. Occurrence of severe and widespread droughts is a major concern too. Thus, there is need of understanding how extreme events are likely to change in future over the region so as to help policy makers to come up with informed decisions on adaptation measures that will ensure food security in the area.

### Data and Methodology

East Africa (EA) is made up of three countries: Kenya, Uganda and Tanzania. In this study, Rwanda and Burundi are treated as part of Tanzania. The data and methodology used in this study is adopted from Ongoma et al. (2018a)[8]. The study uses data from 18 (24)-member Couple Model Intercomparison Project (CMIP5) multimodel ensemble (MME) mean, for rainfall (temperature). The analysis of moderate extreme events is based on daily data under radiative forcing pathways RCPs 4.5 and RCP8.5. The study employed extreme indices used defined by the WMO's Experts Team on Climate



Change Detection Indices (ETCCDI). Climate extreme in 30-year time periods, mid (2021–2050) and end (2071–2100) of the 21st century are considered against the events in the baseline period (1961–1990). Anomaly is used to investigate change in extreme events. Mann–Kendall test statistic and Sen’s slope estimator are used to investigate trend.

## Results and Discussion

There is growing concern of ongoing decrease in the ‘long rains’ over EA. Fig. 1 shows decadal rainfall anomaly in which the recent decades are getting drier. This is a paradox given that models project increase in rainfall over the region throughout the 21st century.

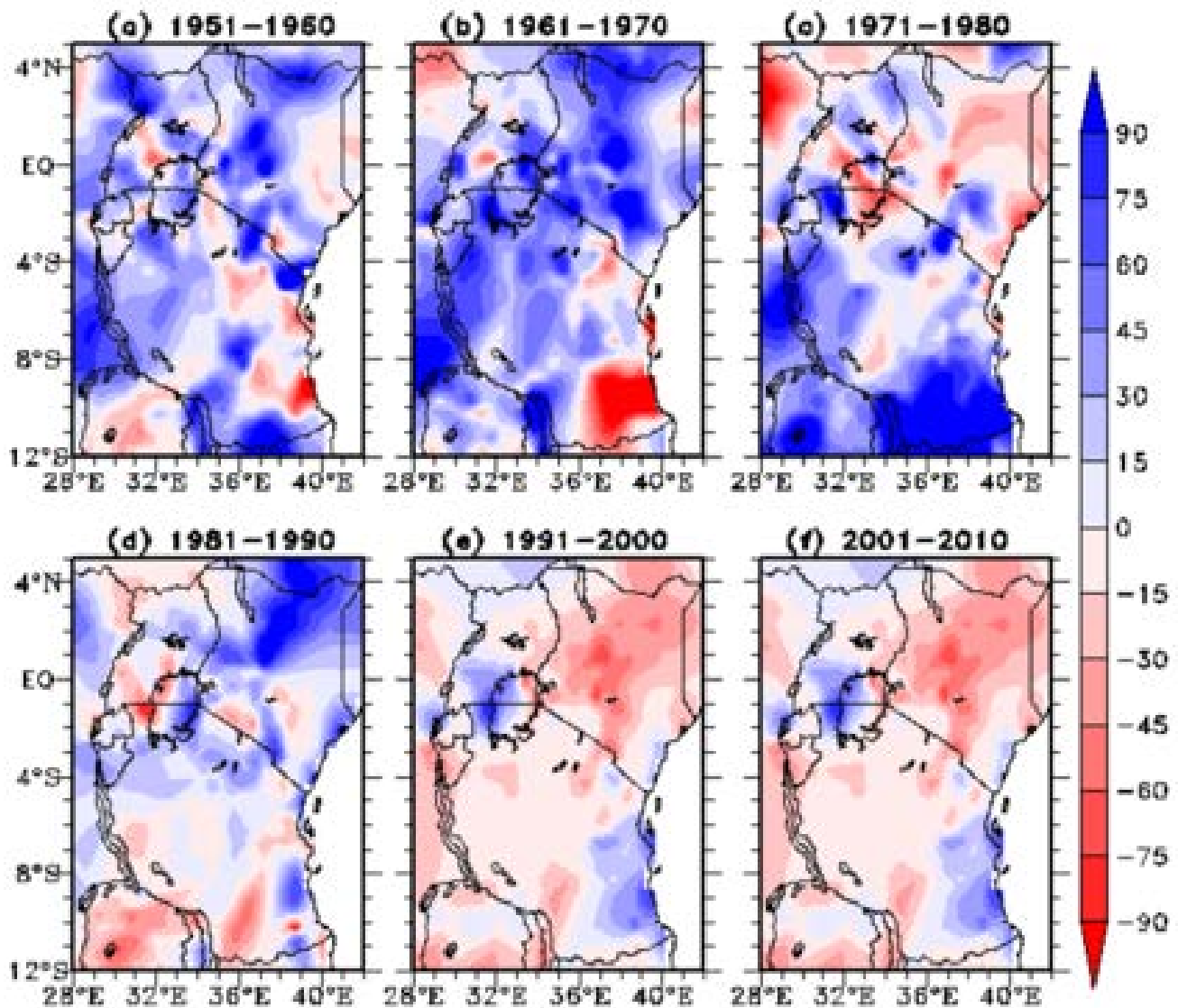


Figure 1. Decadal long rain anomalies over East Africa, 1950s – 2000s, relative to baseline period, 1960–1990 based on Climate Research Unit data.

According to the findings in Fig. 2, it is evident that there is a high likelihood of increase in both very and extreme wet days in both scenarios. The increase is likely to be high in the western side of the study area i.e. mainly over Uganda.

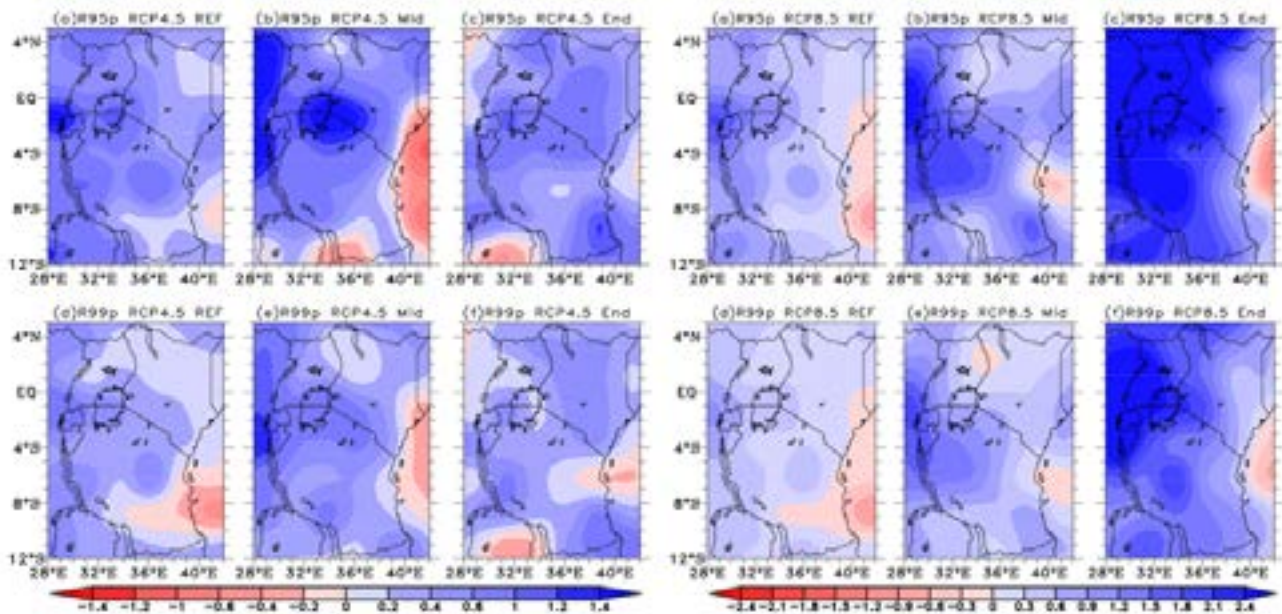


Figure 2. Trends (mm/year) for annual series of Very Wet days (R95p [top]) and Extremely Wet days (R99p [bottom])

The projected change in cold and warm nights is given in Fig. 2. In both scenarios, it is evident that there will almost be no cold nights by the end of 21st century. In the opposite, warm nights are on an increase, with the change increasing with increase in radiative forcing.

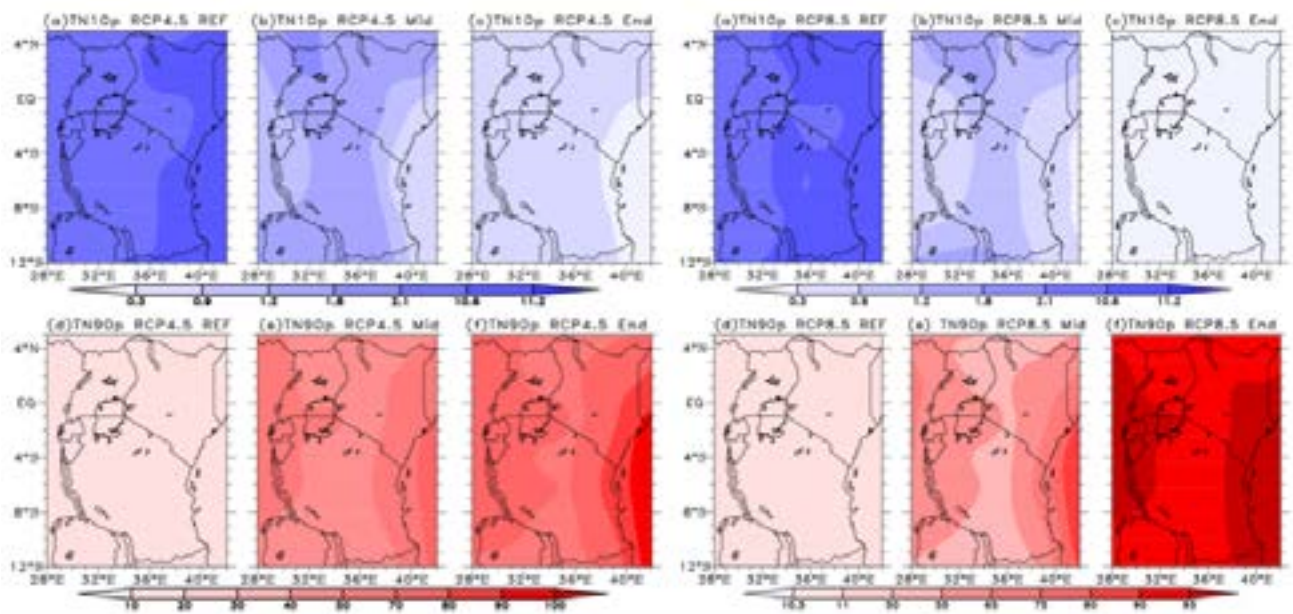


Figure 3. A annual frequency of percentile indices, cold nights (top [TN10p]) and warm nights (bottom [TN90p]). REF is the baseline period.

In Table 1, it is clear that the yearly maximum and minimum for the recorded daily minimum (maximum) temperature will increase. The change increase with time and radiative forcing. As expected the magnitude of change reduces towards the end of 21st century under RCP4.5.

**Table 1.** Sen's slope estimator for the yearly maximum (minimum) value of the daily minimum (maximum) temperature [TNx (TXn)], at 95% confidence level

	<b>RCP</b>	<b>1961–1990</b>	<b>2021–2050</b>	<b>2071–2100</b>
<b>TNx</b>	<b>8.5</b>	<b>0.017</b>	<b>0.044</b>	<b>0.06</b>
	<b>4.5</b>	<b>0.015</b>	<b>0.027</b>	<b>0.006</b>
<b>TXn</b>	<b>8.5</b>	<b>0.014</b>	<b>0.027</b>	<b>0.043</b>
	<b>4.5</b>	<b>0.013</b>	<b>0.021</b>	<b>0.003</b>

Probability density function (not shown) shows a positive shift in the amount of maximum 1-day and 5-day precipitation amount under both scenarios. This is in agreement with the projected increase in mean rainfall [7]. It is worth noting that the projected changes are likely to be lower than what will be observed given that there is a tendency of GCMs to underestimate precipitation magnitudes [2].

## Conclusion and Recommendations

The projected increase in rainfall if realized then it will be a relief to the at risk agricultural sector. However, on the other hand, the increase in extremes such as 1-day and 5-day precipitation is likely to cause havoc if not well planned for. An increase in warm temperature extremes and a reduction in cold temperature is a worrying trend given the associated health effects, and the reduction in human labor capacity[1].

Although the findings are based on course resolution datasets, they give an indication of the likely change in temperature and rainfall extremes that can form a basis of long term planning in the absence of better datasets. There remains a need for improvement of the performance of GCMs in simulating rainfall over EA.

## Acknowledgements

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## Predicting variability of the East African Long Rains

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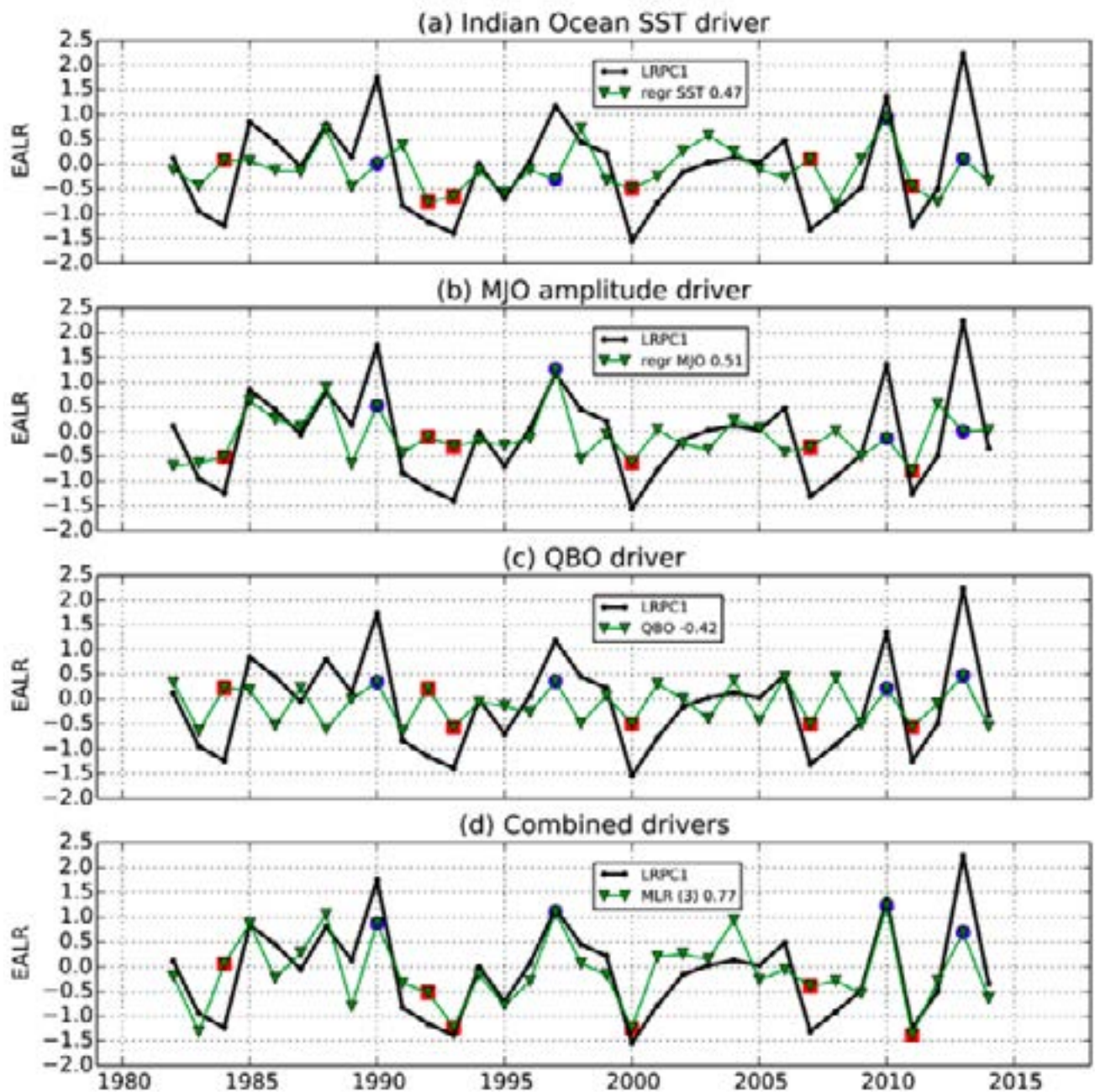
We have used various reanalysis datasets and instrumental observations to understand how remote forcing can influence rainfall variability during the East African Long Rains season. Remote forcing by three processes explains about 50–60% of the regional-mean rainfall variability. We have developed a statistical prediction technique for the Long Rains, based on our understanding of the remote forcing. This statistical prediction scheme can be used to supplement predictions by dynamical seasonal forecast models. The dynamical models do not capture teleconnections to the season very well and only have limited skill.

Rainfall in East Africa occurs mostly during two main seasons: the Long Rains (March–May) and Short Rains (October–December). Dynamical seasonal forecast models have limited skill for predicting precipitation during the Long Rains. This is in sharp contrast with the good forecast skill for precipitation during the Short Rains, which derives mostly from predictability of El Niño/Southern Oscillation (ENSO) and Indian Ocean Dipole (IOD). During the Long Rains forcing by ENSO and IOD is not very important for interannual variability.

We use a combination of reanalyses and instrumental observations to identify and understand alternative sources of remote forcing of the Long Rains during March and April. We find three processes that, together, explain about 50–60% of the regional-mean rainfall variability. The three most important forcing processes are: activity of the Madden–Julian Oscillation during February–March, as measured by the RMM1,2-amplitude (Wheeler and Hendon 2004); SST in the northwestern Indian Ocean during March–April; and the quasi-biennial oscillation (QBO) during September–November of the preceding year. Because the importance of these drivers is seen in various reanalysis datasets and instrumental observations we believe them to be robust. A detailed analysis of the mechanisms is presented in Vellinga and Milton (2018).

Based on our understanding of the remote forcing of the Long Rains we developed a statistical prediction scheme for year-to-year precipitation variability during this season. This scheme is developed for regional-mean rainfall variability and is not suitable for sub-regional rainfall variability. We show that this statistical prediction scheme has better skill than dynamical forecast models. It is able to successfully predict the record wet 2018 Long Rains season. We propose that this prediction scheme presents a useful source of information and can offer support for the seasonal outlook for the region.





**Figure 1.** East African Long Rains time series (black curve, 'EALR') and its relation to three drivers (1982–2014). In (a–c) each driver timeseries is regressed individually onto EALR. The 'predicted' timeseries obtained from this regression is shown by thin green line, its correlation with the actual EALR (black curve) is shown in the panel legends. (a) March–April mean Indian Ocean SST averaged over 5–20°N, 55–80°E (b) Feb–Mar mean (RMM1,RMM2)–MJO amplitude (c) QBO during SON of the preceding year. (d) Multiple linear regression of three drivers from (a–c) onto EALR. Blue circles (red squares) denote the six wettest (driest) EALR years in the period used (1982–2014). Data shown here is for MERRA2 reanalyses. For details see Vellinga and Milton 2018.

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## Aircraft observations of the lake–land breeze circulation over Lake Victoria from the HyVic pilot flight campaign

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An exciting new dataset of aircraft observations of the lake–land breeze circulation over Lake Victoria in tropical East Africa is presented. These observations were collected during the HyVic pilot flight campaign in January 2019, which consisted of an evening flight and subsequent morning flight to observe the lake and land breezes respectively. Properties of the lake–breeze front during the evening and boundary layer over the lake and land during both the evening and morning flights are presented and compared to high-resolution convection-permitting MetUM simulations.

### Introduction

The Lake Victoria region in East Africa is a hotspot for severe convective storms that are responsible for the deaths of thousands of fisherman each year [3][2]. However, the processes responsible for the initiation, development and propagation of these storms are poorly understood and forecast skill is limited [6]. Whilst it has been shown that the lake–land breeze circulation plays an important role in the formation and propagation of storms in the region, the circulation has not previously been observed in detail [4][1][6].

### Methods

In January 2019, the HyVic pilot flight campaign collected unprecedented observations of the lake–land breeze circulation using the FAAM (Facility for Airborne Atmospheric Measurements) research aircraft. Two flights were performed to observe the lake breeze (evening) and land breeze (morning) across a transect from Entebbe to the eastern shore of the lake and into Tanzania. Moisture, temperature and wind observations by instruments on-board the aircraft, as well as sondes dropped along the transect, are presented alongside high-resolution (300 m, 1.5 km and 4.4 km) convection-permitting (CP) Met Office Unified Model (MetUM) simulations driven by boundary conditions from the ECMWF IFS model.

### Results

Observations of the lake breeze during the evening flight show that the leading edge of the lake breeze (measured at 150 m a.g.l.) exhibited a sharp front ~50 km inland at 1300 UTC, across which specific humidity reduced by more than 10 g kg<sup>-1</sup> and the wind reversed direction in the space of a few kilometres. The location of this front was generally simulated correctly by all model resolutions, although the gradient in moisture and wind across the front decreased with coarser resolution, at least in part due to the representation of orography at different horizontal grid-spacings. The nose of the lake breeze was also observed, with an approximate horizontal extent of 50 km at 150 m a.g.l..

Observations in the lake boundary layer taken during the morning flight confirmed the existence of a bulge of moisture over the lake, formed by convergence of opposing land breezes, previously only predicted by simulations in Woodhams et al. (2019)[6]. Specific humidity in this bulge exceeded 17 g kg<sup>-1</sup> over large regions. It is anticipated that the properties of this bulge could be important in determining whether a storm initiates over the lake.

Although the model runs generally captured the observed features of the lake–land breeze circulation – especially at 300 m horizontal grid-spacing – the simulated boundary layer and

lake and land breeze density currents were too deep compared to observations from the dropsondes and low-level flying.

## Conclusions

Unique aircraft observations of the lake–land breeze circulation over Lake Victoria are presented for the first time. These observations were collected during the HyVic pilot flight campaign during January 2019, using the FAAM aircraft. These detailed measurements have been used to improve understanding of the properties of the lake and land breezes and the boundary layer over the lake and surrounding land.

Whilst a CP model with 300 m horizontal grid-spacing is able to capture many of the features of the observed lake–land breeze circulations, the boundary layer and lake/land breezes are too deep in the simulation. In addition, a horizontal grid-spacing of 300 m is not currently suitable for an operational model. Given the importance of the lake–land breeze circulation in the formation of storms, improved representation of these processes in models could greatly improve forecasting skill.

The unique observations from this campaign will continue to be used to improve the forecasting of storms over the Lake Victoria region, both through an improved understanding of the lake–land breeze circulation and through the evaluation of high-resolution CP models in the region.

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## Synoptic variability of precipitation over Congo basin during northern spring

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This study examines the synoptic variability of precipitation over the Congo basin during March–June rainy season based on analysis of Global Precipitation Climatology Project (GPCP), outgoing longwave radiation (OLR) and National Centers for Environmental Prediction (NCEP)–National Center for Atmospheric Research (NCAR) Reanalysis data. To examine the spatial structure of synoptic variability in the precipitation during the northern spring, we use strong deviations of

the 2–10-day bandpass-filtered regional precipitation time series to define events. Composite analysis of these modes shows that synoptic precipitation anomalies grow and decay with convection, and have maximum amplitude near the Gulf of Guinea and in the Atlantic ITCZ. Precipitation anomalies and convection associated with 2–10-day variability progress eastward with deseasonalised precipitation events. This study also shows that precipitation increases with enhanced phase of Kelvin waves and decreases few days after. The contribution of the synoptic scale to the total variability is assessed to be about 58% over the western sector of Central Africa.

## Introduction

West and Central Africa have been identified by the United Nations as one of the nine “hot spots” of the world for environmental changes. It is also the region in the world which has experienced the largest decrease in rainfall over the past sixty years, despite a partial return to normal since 1990 [7]. It is a region where economic development and people’s lives are strongly influenced by climatic fluctuations and in particular the progress of the different seasons (rainy and dry season) associated with the African monsoon. Synoptic variability is important for the overall agricultural efforts over Congo basin. It has been shown that westward propagating African easterly waves are not the only synoptic system, but that eastward propagating CCEK (Convectively coupled equatorial Kelvin) waves are also present (between 4 and 6-days), less frequently than easterly waves, but with a similar impact on convection and rainfall modulation when they occur [8][6][3][12]. Todd and Washington (2004) have shown that positive rainfall anomalies over Central Equatorial Africa (CEA) is related to anomalous westerly mid-tropospheric zonal winds over the CEA/Atlantic region and that large-scale circulation structure associated with CEA rainfall variability is similar at both inter-annual and multi-annual time scales[9].

The objective of this study is: first (i) to describe the spatial structure of the synoptic perturbations of the precipitation in the northern spring (March–June: MAMJ) over Congo basin and (ii) to focus on the synoptic scale variability through the detection and analysis of the main associated disturbances, their characteristics, and links with convection and Kelvin waves variability.

## Data and Methods

### The Data

Datasets used are based on the daily OLR with a resolution of 2.5° latitude–longitude (Grueber and Krueger 1974). The daily-interpolated OLR dataset were produced by the Climate Diagnostic Center [5]. The GPCP One Degree-Daily (1DD) combination has been also used [1]. Atmospheric fields were drawn from the NCEP/CAR reanalysis [2]. These data are available at 2.5° x 2.5° latitude–longitude resolution. The period of record used here is from 1997 to 2008.

### Method

The analysis involved temporal bandpass – filtering, based on the Lanczos filter described in Duchon (1979). To examine the spatial structure of synoptic variability in the precipitation over the Congo basin region during the northern spring, we use strong deviations of the 2–10-day bandpass-filtered regional precipitation time series to define events. Strong MAMJ extrema of the precipitation time series with magnitude greater (lower) than 1 (–1) STD (standard deviation) are selected, for a total of 183 (142) positive (negative) precipitation events are obtained. The results represent the regional wet (dry) conditions. Composites are generated by averaging precipitation, wind fields and other variables across all positive events. To extract Kelvin waves, wavenumber–frequency filtering was applied on the daily OLR dataset as same as methodology done by Wheeler and Kiladis (1999)[11]. Filtering for the Kelvin wave box was performed with a period of 2.5–10 days, with eastward wave numbers 1–14 and equivalent depths of 8–90 m.

## Results

Figure 1 shows the precipitation mean climatology (contour) and variance (shaded) for the 1997–2008 northern spring season. The largest precipitation values, above 5 mm/day, are collocated with the MAMJ mean position of the inter-tropical convergence zone (ITCZ), near 5°S– 5°N over the Gulf of Guinea, but the precipitation pattern is more discontinuous, partly because of the topography, the largest precipitation values are located by the Atlantic ocean near 2°– 8°N. The maximum variance is strike along the Gulf of Guinea. The 2.5–10-day bandpass filter of rainfall index are created, then averaging over the Congo basin. We would then compared this regional time series to Synoptic kelvin waves index. We correlate regional 2.5–10 day rainfall from GPCP with synoptic Kelvin waves. Maximum and minimum correlation between both data and Synoptic Kelvin waves are identified. Composites show Positive (negative) events characterized by a significant enhancement (suppression) of precipitation between 2–10°N from 0–15°E. The synoptic regime is also shown in figure 2.

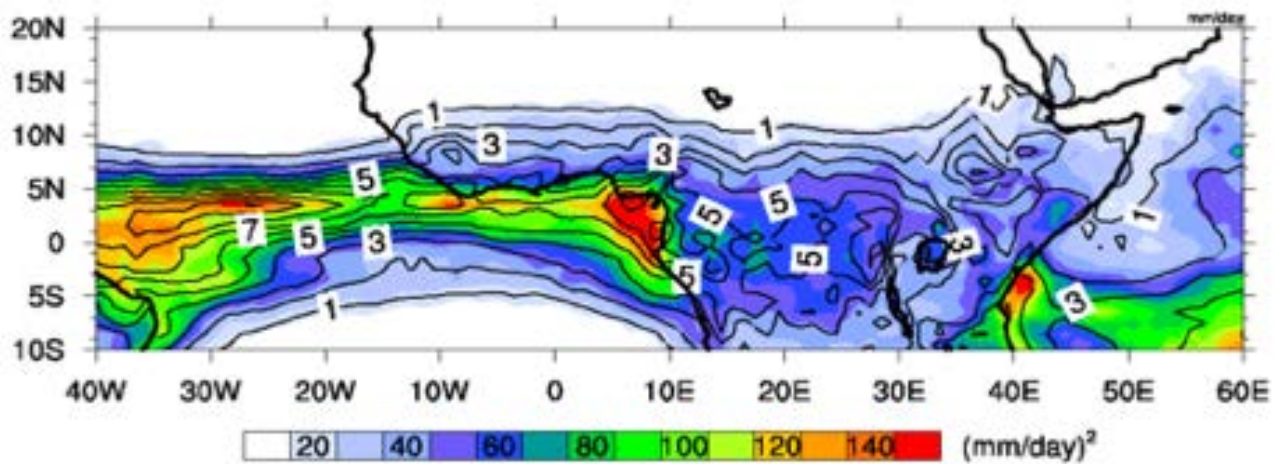
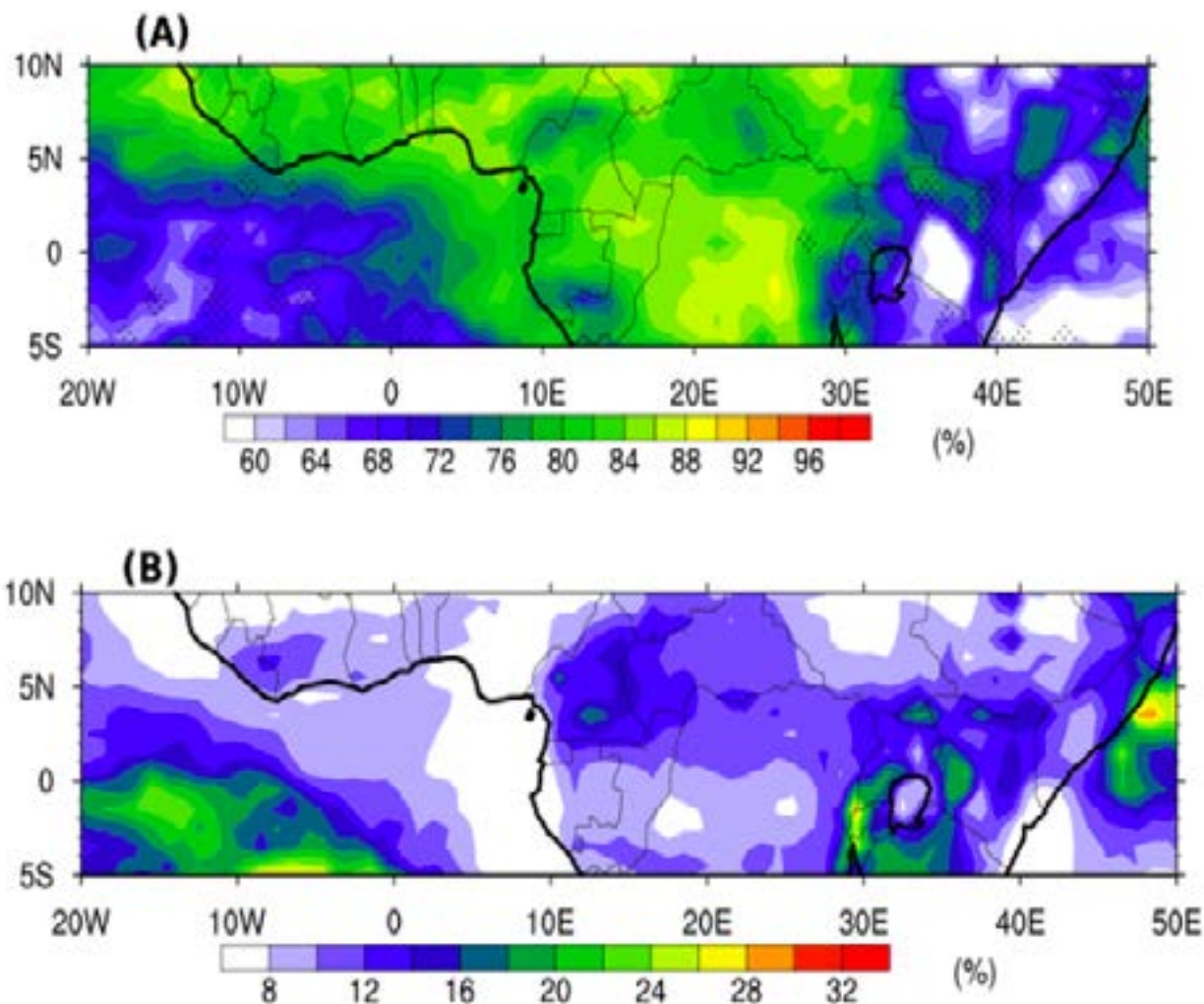


Figure 1. March–June of unfiltered GPCP precipitation mean (mm/day, contours) and variance (mm<sup>2</sup>/day<sup>2</sup>, shaded) during 1997–2008



**Figure 2.** (A) The ratio of synoptic scale variance to total variance from GPCP. (B) The ratio of Kelvin filtered variance to total variance from GPCP 1997–2008. Kelvin-filtered is based on GPCP filtered for the Kelvin waves signal over the period range 2.5–17 days, wave numbers 1–14 and equivalent depth ranging from 8 to 90 m.

## Conclusions

This study proposes an overview of the main synoptic modes of precipitation in the northern spring (March–June) of 1997–2008 over Congo basin and to understand their atmospheric dynamics. Based on analysis of the 2–10-day band pass-filtered precipitation, it has been shown that the main mode of rainfall variability is located along the Guinean coast with an extension over Central Africa. Corresponding composite deseasonalised atmospheric fields highlight an eastward propagation of patterns consistent with convectively coupled equatorial Kelvin wave dynamics. A spectral analysis indicates that synoptic precipitation variability is dominated by two distinct time scales with significant spectral peaks centered near periods of 3 days and 5 days. Strong CCEK is commonly observed over the Congo basin during Northern spring. The contribution of the synoptic scale to the total variability is assessed to be about 58% over the western sector of Central Africa. This study thus provides a focus on the Congo basin synoptic variability. Such synoptic suppressed and enhanced precipitation events are frequent during MAMJ season and robust. Thus the monitoring and forecasting of precipitation at short time-scale can provide useful information for early precipitating systems.



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## THEMATIC AREA 2

### Latest research on the science and projections of future climate change in Africa

This theme covers modelling of future African climate with global and regional (high resolution/ convection permitting) climate models across multiple timescales (including the future 5 to 40 year period). Other topics include:

- understanding the uncertainty in projections of the African water cycle and other variables
- understanding how well climate models simulate processes of climate change
- use of climate model projections in driving impact models
- using the latest science to identify areas of confidence and uncertainty about future climate projections



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## LIST OF PRESENTERS AND TITLES OF PRESENTATIONS

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### **Tesfay Gidey Bezabeh**

Using the Yield-SAFE model to assess the impacts of climate change on yield of coffee (*Coffea arabica* L.) under agroforestry and monoculture systems

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### **Declan Finney**

Future mean and extreme rainfall over Eastern Africa in a convection-permitting model

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### **Elizabeth J. Kendon**

Enhanced future changes in wet and dry extremes over Africa at convection-permitting scale

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### **Naomi Kumi**

Potential Impacts of 1.5°C and 2°C Global Warming on Rainfall Onset, Cessation and Length of Rainy Season in West Africa

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### **Siny Ndoye**

SCUS-2050: Exploring the future of the Southern Canary Upwelling System

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### **Alex Nimusiima**

Evaluation of Past and Future Extreme Rainfall Characteristics over Eastern Uganda

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### **Ponnambalam Rameshwaran**

How might river flows in West Africa change in the future?

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### **Denis Sonkoué**

Evaluation and projected changes in daily rainfall characteristics over Central Africa based on a multi-model ensemble mean of CMIP5 simulations

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## Modeling the impact of climate change on haricot bean (*phaseolus vulagris* l.) production and identify adaptation option in Melkassa area, semi-arid Central Rift Valley of Ethiopia

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\* Corresponding author email: Letaabrehm@gmail.com

This study was conducted to characterize local climate, assess its impact on haricot bean production and identify management options as an adaptation strategy of future climate changes in Melkassa area SA-CRV of Ethiopia. From 36 years (1977–2013) of daily climate data, Past and present extreme climate event was assessed using daily climate data from the past 36 years (1977–2013). For future projection, climate change scenarios for rainfall, minimum and maximum temperatures were developed for the period 2010–2069 by using the ensemble GCM Model under RCP 4.5 and RCP 8.5 Special Report on Emission Scenarios. Decision Support System for Agro-technology Transfer (DSSAT), crop model used to simulate future changes in haricot bean yield and to determine best adaptation measures in Melkassa area under modified environment. Annual rainfall amount was found to increase with significance for 36 years period with the values varying between 1110 mm/year 1977 and 548 mm/yr at 2002. The future projection analysis showed an increasing trend of annual rainfall and increasing trend for temperatures during the period from 2010–2069. The crop model simulation indicated a contrasting impact on two haricot bean varieties– Nasir and Awashmelka. The positive impact observed on the Nasir cultivar was all time slices except in RCP8.5 2050; yield will increase between 3.28 to 10.33 % in projection period. Whereas the negative impact observed on the Awashmelka cultivar was all time slices decrease between 8.17 to 14.13% in projection period. Therefore, growing haricot bean under future climate condition with improved management options could ensure high yields during rainy season.

### Study area and data

This research was carried out at Melkassa Agricultural Research Center, hereafter referred as the study site, Central Rift Valley of Ethiopia. The past and present climate of the study area was examined using ground observation data as recorded at MARC (1977–2013) meteorological station. Some missing and the outlier data was filled with gridded data (Dinku et al, 2007). Data was collected related on agronomic management including: date of planting, date of emergence, plant distribution, plant population, planting density, row spacing and fertilizer application (rate, time and used) and phenological data.

### Methodology

Arranging monthly precipitation data into deciles is another drought-monitoring technique. The decile method was selected as the meteorological measurement of drought within the Australian Drought Watch System. The technique they developed divided the distribution of occurrences over a long-term precipitation record into tenths of the distribution. They called each of these categories a decile.

The start of the rainy season (SOS) can be defined as the first at least 20 mm occurrence of total rainfall received over three following days without consecutive dry spell followed by greater than 10 days of length within 30 days from planting (Mamo 2005). The end of the season (EOS) is the end of rainy season plus the time required to evapotranspire 100 mm of stored soil (Vertisols) water (Feyera, 2013; Stern et. al, 2006; Girma, 2005).

The projected climate data of study area/station produce by using R application software.

Crop simulation model, (DSSAT) version 4.6 was used for the prediction of Haricot bean yield at different management scenarios in this study.

## Output

Figures 1 and 4 present sample outputs. Figure 1 the temperatures in the study area follow increasing in variability, observed trend during the period of 1977-2013. In other way, the rainfall anomalies at Melkassa can be examined using Standardized.

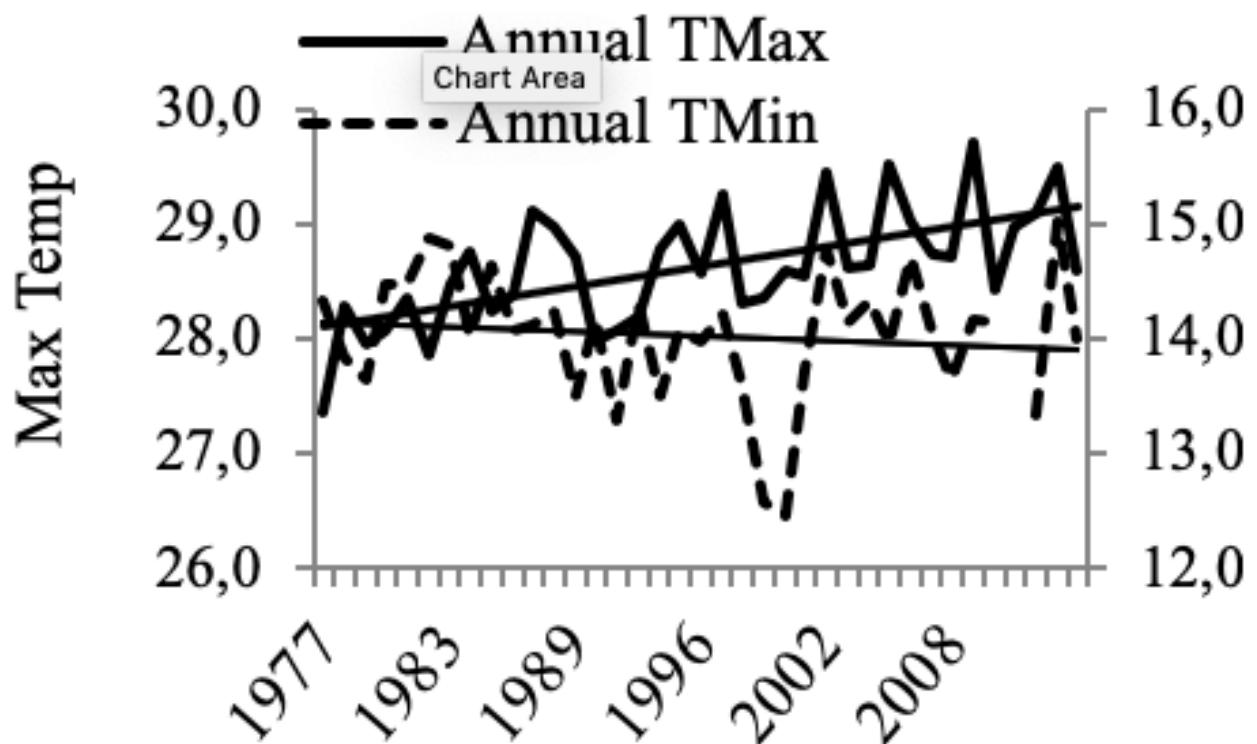


Figure 1. Time series of Melkassa maximum and minimum temperature (1977-2013).

Precipitation Index approach (Figure 2). Estimation of changes in the last three decades was increasing from time to time over the past thirty-six years pattern in seasonal rainfall amount during kiremt (JJAS).



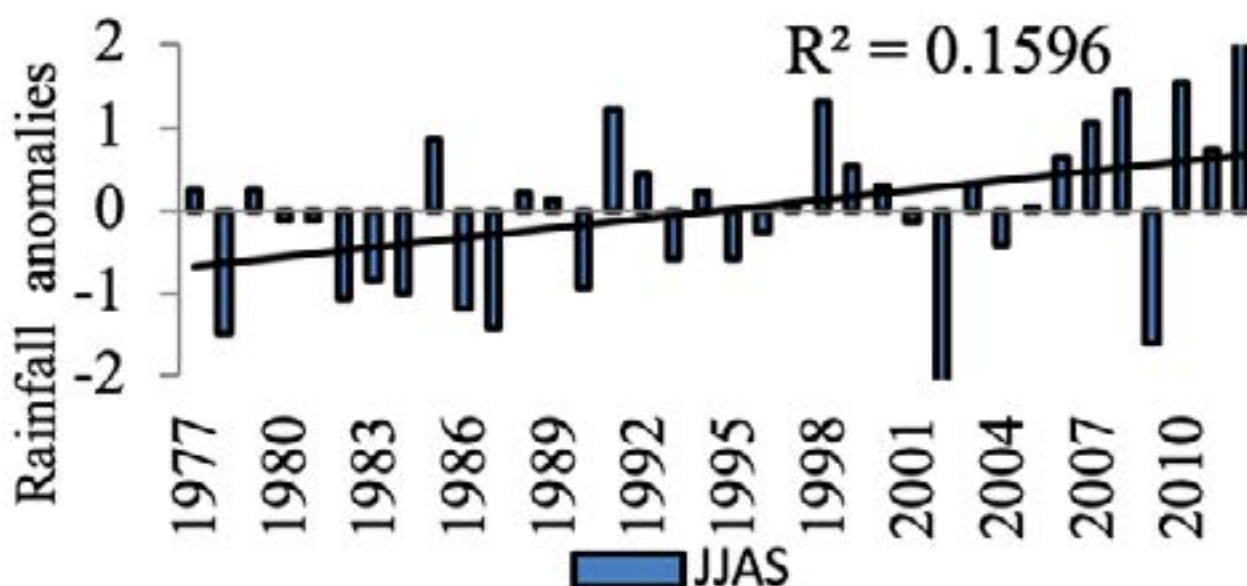


Figure 2. Time series showing rainfall anomalies and trend of Kiremt season at Melkassa.

Dependable rainfall starts over the region from 150 (DOY) to on forward with an increase probability, exceeding 50% and less risk to miss chances to get rains (Figure 3).

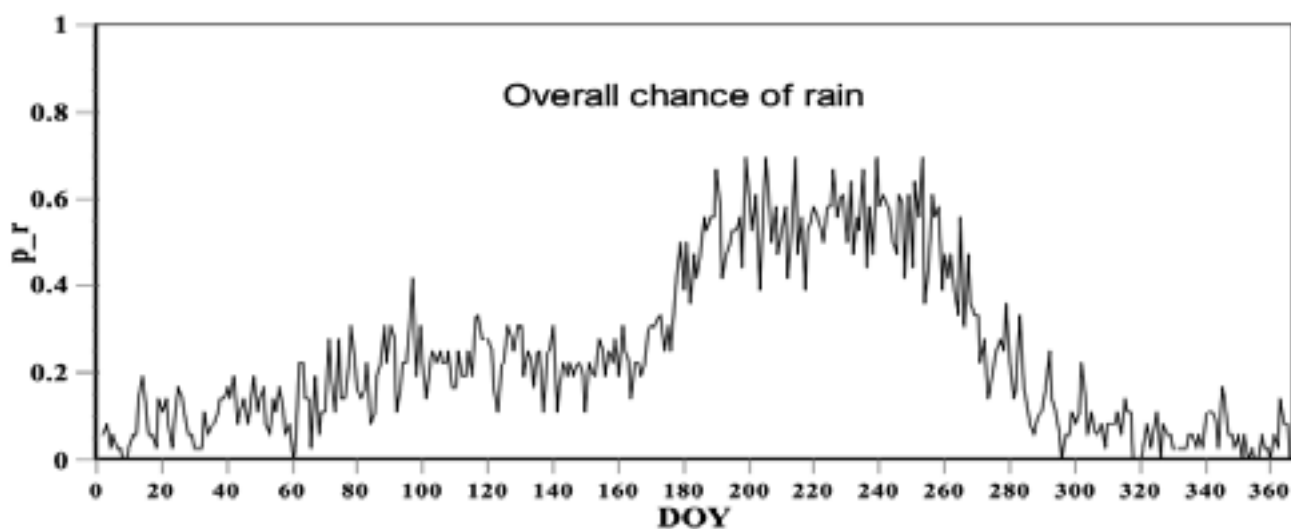


Figure 3. Possibility of getting measurable rainfall amount at the study site

In the study area, planting earlier than 05 May (126 DOY) is possible only once in every four years' time, whereas it is possible earlier than 25 Jun (177 DOY) in three out of four years' time. For the end date, the respective lower and upper quartiles fall between Sep 26 (269 DOY) and 12 Oct (286 DOY) (17 days) (Figure 4). Therefore the results also confirmed that haricot bean varieties that require an LGP of 68 to 180 days can be produced with no risk in and around Melkassa areas.

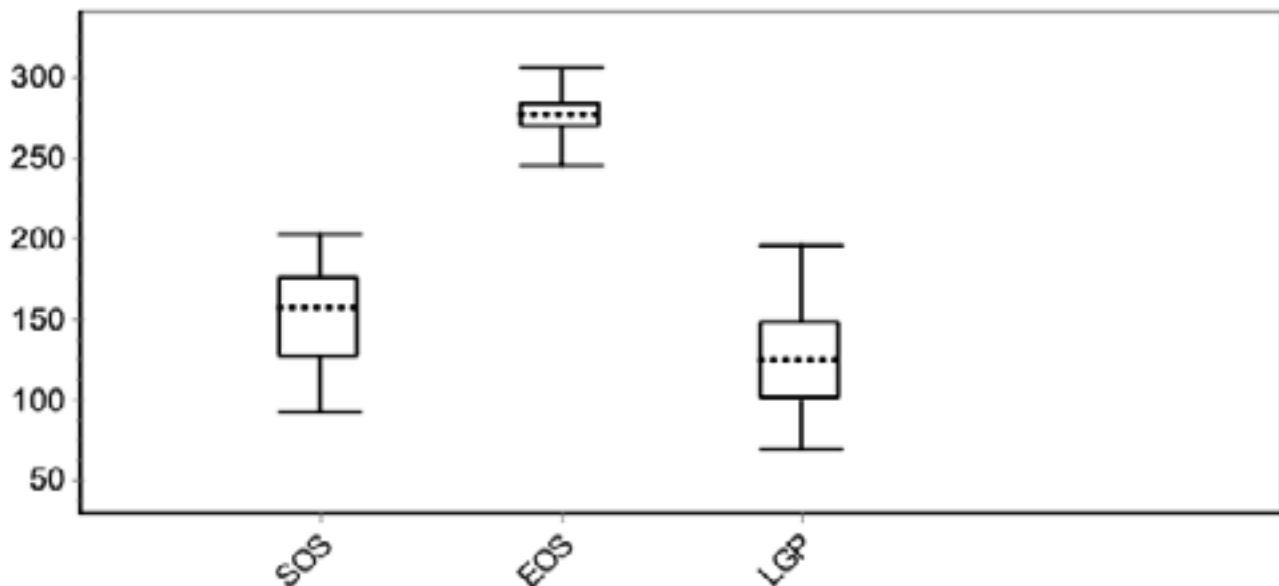


Figure 4. Possibility of getting measurable rainfall amount at the study site

### Impact of projected climate change

The projected future climate change for 2030 and 2050 has a positive impact on Nasir grain yield in the study area in both scenarios with the exception of 2050 RCP8.5 scenario. Comparing both scenarios, the results revealed that the RCP 8.5 has resulted in reducing yield than the RCP 4.5 scenario (Figure 5).

### Evaluation

As mentioned above, the response of simulated grain yield of haricot bean to future climate change indicates the impact of increasing temperature on haricot bean yield. This study, positive impact of climate change on yield has observed for Nasir in both RCP 4.5 and RCP 8.5 scenarios except RCP8.5/2050 negative impact on Nasir.

The evaluations of specified adaptation responses to identify preferred measures and take actions in response to changes in local and regional climatic conditions are very crucial. From predicted historical climate data were also used to simulate grain yield and accordingly evaluate the impact of climate change on yield of each sowing dates.

### Summary

The impact of climate change on haricot bean production, analysis of future adaptation measures was carried out to address part of the global problem. Finally, adaptation measures that can serve to reduce the damages were proposed. This study further investigated how haricot bean production is affected by future climate change and what adaptation measures could be used as options for mitigation.

The study proposed future adaptation measures such as choice of cultivar and arrangements of planting date in addition to other options at different level of crop management such as planting date, planting density and fertilizer application rate resulting in yield difference. On the other hand, in the near future, haricot bean yield will be very sensitive to sowing time, which is either early or late sowing dates according to projections.

## Using the Yield-SAFE model to assess the impacts of climate change on yield of coffee (*Coffea arabica* L.) under agroforestry and monoculture systems

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Ethiopia's economy depends strongly on *Coffea arabica* production. Coffee, like many other crops, is sensitive to climate change and recent studies have suggested that future changes in climate will have a negative impact on its yield and quality. An urgent development and application of strategies against negative impacts of climate change on coffee production is important. Agroforestry-based system is one of the strategies that may ensure sustainable coffee production amidst likelihood future impacts of climate change. This system involves the combination of trees in buffer extremes thereby modifying microclimate conditions. This paper assessed coffee production under: 1) coffee monoculture and 2) coffee grown using agroforestry system, under: a) current climate and b) two different future climate change scenarios. The study focused on two representative coffee growing regions of Ethiopia under different soil, climate and elevation conditions. A process-based growth model (Yield-SAFE) was used to simulate coffee production for a time horizon of 40 years. Climate change scenarios considered were: Representative Concentration Pathways (RCP) 4.5 and 8.5. The results revealed that in monoculture systems, the current coffee yields are between 1200–1250 kg ha<sup>-1</sup> yr<sup>-1</sup>, with expected decrease between 4–38% and 20–60% in scenarios RCP 4.5 and 8.5, respectively. However, in agroforestry systems, the current yields are between 1600–2200 kg ha<sup>-1</sup> yr<sup>-1</sup>, the decrease was lower, ranging between 4–13% and 16–25% in RCP 4.5 and 8.5 scenarios, respectively. From the results, it can be concluded that coffee production under agroforestry systems has a higher level of resilience when facing future climate change and reinforces the idea of using this type of management in the near future for adapting climate change negative impacts on coffee production.

**KEY WORDS:** *Albizia gummifera*, CORDEX, Ethiopia, HADCM3 model, process-based model

### Introduction

Coffee, which is grown in about 70 countries, is one of the most important tree crops in the world and covers an area of about 11 million ha. In 2015, coffee generated over US\$ 39.3 billion export revenues for many developing countries [8]. In the same year, Ethiopia was the fifth exporter of coffee in the world, contributing to about 4.5% for the world's total coffee production [6][8]. Coffee is an important export commodity for Ethiopian economy, being responsible in 2015 for about 25–30% of total exports [7] and 10% of the country's GDP [6].

The Intergovernmental Panel on Climate Change (IPCC) set different climate change scenarios depending on world future population growth and economic development [19]. On its fifth assessment report, the latest Representative Concentration Pathways (RCPs) scenarios were developed for its use as input data for climate models. These new scenarios projected by 2050 to increase mean temperature between 1.1–3.1 °C whereas to decrease precipitation between 5–10% during the rainy season (June–August) in Ethiopia. Some studies have assessed how these new conditions would affect coffee production in Ethiopia: Davis et al (2012) suggest that the land suitability is expected to decrease by 65–100% in 2080 [5]; while the prolonged drought and higher temperatures would have an effect on coffee flowering and fruiting resulting in a decline of productivity and quality [7].

The presence of trees with coffee in agroforestry systems allows to buffer extreme temperatures, reduce soil evaporation and coffee transpiration [10][4][16][9]. In addition, other environmental benefits have been associated to agroforestry-based coffee production, such as the reduction on the severity and occurrence of coffee pests [1] and the improvement of soil nutrient and moisture retention [10][4]. Due to these positive effects, agroforestry-based coffee production has been considered as a potential practice for tackling climate change negative impacts [10][4].

Ecological models are developed for a wide range of purposes, including projecting impacts of climate change on crop yields or tree growth [18][11]. Modelling results can help decision makers on the selection of adaptation strategies against impacts of climate change [11]. Up to date, just a few process-based models have been developed to project impacts of climate change on agroforestry systems [18][11]. The Yield-SAFE model [18] is one of these few models and is able to predict impacts of climate, soil and management on yields of crop monoculture, agroforestry systems or forestry plantations [17].

In Ethiopia, there is a limited study on long-term impacts of climate change on coffee productivity at a hectare basis using a process-based model [13][7]. The objective of this study was then to fill this gap of knowledge by assessing long-term impacts of climate change on coffee productivity under monoculture and agroforestry systems using a process-based model (Yield-SAFE), under different climate change scenarios, in two coffee growing regions of Ethiopia (south-eastern and south-western) that can be representative coffee production systems of Ethiopia under different soil, climate and elevation conditions [3][4][9].

## Materials and Methods

### Study sites

South-eastern and south-western regions of Ethiopia are major contributors for Ethiopian total coffee production and exportation, with estimation of 92 and 88%, respectively [12]. The regions also represent all types of coffee production systems in Ethiopia including agroforestry and monoculture systems under different soil, climate and elevation conditions [3][7]. One representative site (the Wonago site from the south-eastern and the Limu Kosa site from south-western parts of Ethiopia) were then considered for this study to be a nation assessment on impacts of future climate change on coffee production.

Different data sources were used for validation the Yield-SAFE model. In each study site, 20 plots (each 20 m x 20 m) were established inside of the coffee farms (agroforestry-based and monoculture) with an interval of 500 m along elevation gradient following the procedures developed by Negash and Kanninen (2015) for the sites [14]. For agroforestry-based coffee production, the peacock flower tree (*Albizia gummifera*), a native multipurpose leguminous tree was selected as being the most common shade tree for coffee in the sites [3][6]. From each plot, density of coffee and the tree was counted and the tree's diameter at breast height (DBH) at 1.30 m and height (m) were measured. The observed DBH of the tree was found in the ranges of 20–40 cm at age of 20 years with average height of 13 and 15 m in Wonago and Limu Kosa, respectively. Age of the tree plantations was considered to be 20 years in the sites [20]. Tree biomass was then estimated using allometric equation developed by Binkley and Ryan (1998) using the observed DBH and height, valuing between 95–215 kg tree<sup>-1</sup> for Wonago and 105–225 kg tree<sup>-1</sup> for Limu Kosa [2]. Furthermore, the tree's leaf area was considered in between 75 and 105 m<sup>2</sup> tree<sup>-1</sup> at age of 20 years [20].

In addition, for validating coffee yield, its seven years' average yield was taken from previous studies instead of taking from the sample plots as it is fluctuated due to seasonal weather [4][15] and for practical reasons. Yields in monoculture and agroforestry systems were then considered



to be 1000–1200 and 1400–1520 kg ha<sup>-1</sup> yr<sup>-1</sup>, respectively for Wonago [15] and 1100–2100 and 1400–2100 kg ha<sup>-1</sup> yr<sup>-1</sup>, respectively for Limu Kosa [4].

### Model inputs

For simulating coffee yield under monoculture and agroforestry systems, Yield-SAFE model needs different inputs from each study site, including soil (texture and depth), tree and/or crop managements and parameters, daily climate. The model requires tree and/or crop management inputs, including planting density, pruning and thinning to simulate yields under monoculture and agroforestry systems. For the simulation of agroforestry-based coffee production, 60 trees of *Albizia gummifera* and 2500 coffee plants ha<sup>-1</sup> were considered from our field count. However, for coffee monoculture plantations the planting density was higher (3000 plants ha<sup>-1</sup>).

To predict the impacts of 40 years climate variability on coffee yield under monoculture and agroforestry systems, historical daily climate data (current) and two future climate scenarios of the sites were also needed as inputs for the model. For this study, the scenarios RCP 4.5 and 8.5 were selected. These scenarios represent an increase of the radiative force values of 4.5 and 8.5 W m<sup>-2</sup>, respectively, that would represent an increase of 2.4 OC or 4.9 OC by 2100 in the world [19].

As no historical climate data is available for the study sites [13], simulated historical climate data was retrieved from the CORDEX data base (Coordinated Regional climate Downscaling Experiment <http://www.cordex.org> – for Africa). For this study, the datasets developed by the Hadley Centre for Climate Prediction and Research's General Circulation Model (HadCM3) were used as they have offered decent results in previous studies in Ethiopia [5][13]. Forty years of daily temperature, precipitation, radiation and relative humidity of historical (1966–2005) and for the two future climate scenarios (2006–2045) were downloaded from the platform. A program in Python programming language ([www.python.org](http://www.python.org)) was developed to retrieve data time series for the latitude and longitude of the study sites, and the data then formatted to be used as Yield-SAFE model inputs.

At the study sites, in future climate scenarios, the monthly average temperature will increase, whereas precipitation is expected to decrease. These values differ for both sites: in the Wonago, the 40 years average monthly temperature (20 oC) is expected to increase by 0.6 in the RCP 4.5 and 0.8 oC in the RCP 8.5. However, the average monthly precipitation is expected to decrease from its current average of 94 mm by 3 and 6 mm for both scenarios. Similarly, for the Limu Kosa, it is projected that the average monthly temperature under current scenario (19.5 oC) is to increase by 0.5 and 0.7 oC while the average monthly precipitation (96 mm) is to decrease by 2 and 3 mm in RCP 4.5 and 8.5 scenarios, respectively.

### Model calibration and validation

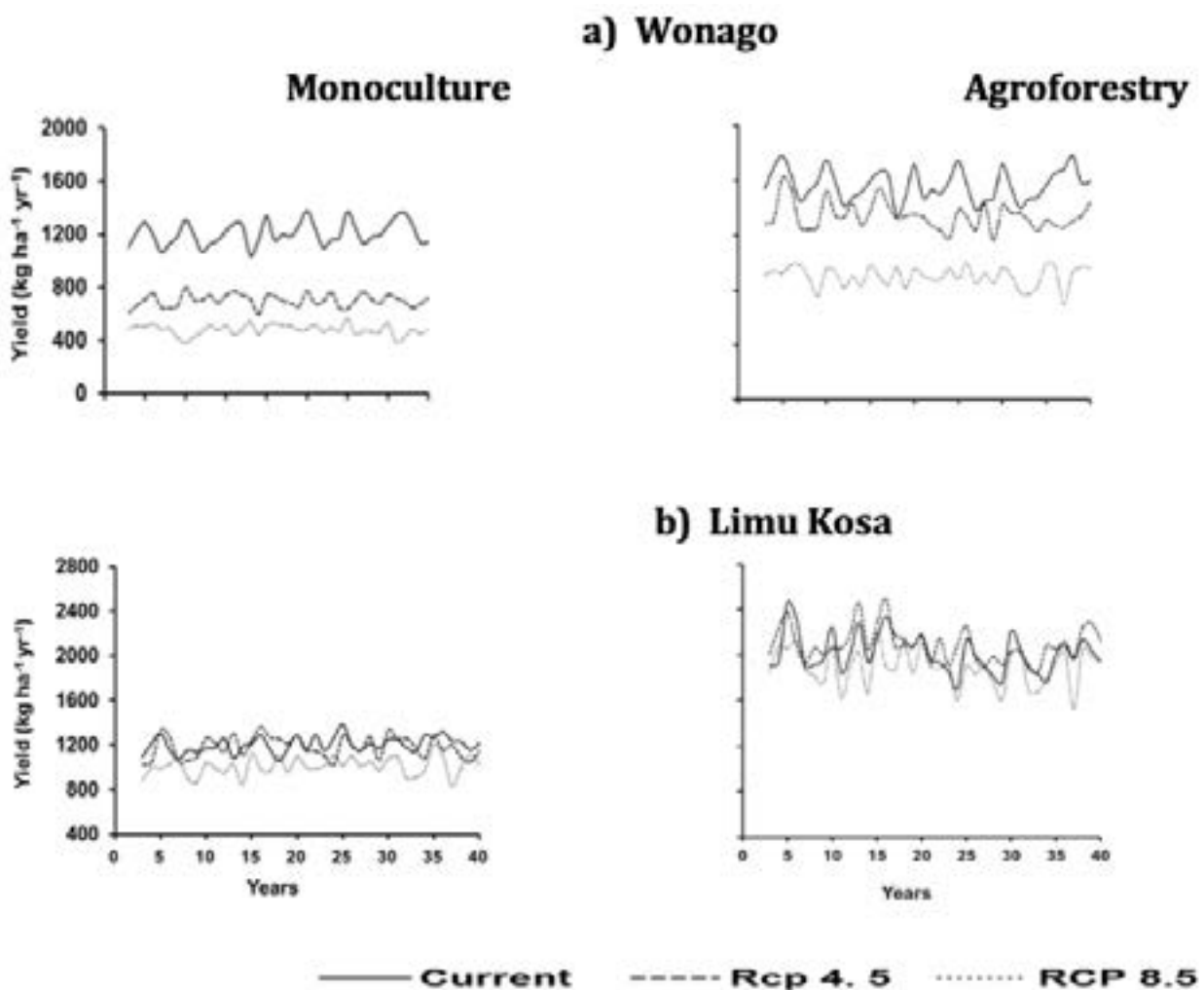
For each study site, DBH, tree biomass and leaf area of *Albizia gummifera* grown in monoculture were first simulated by the Yield-SAFE model using the tree parameters and historical climate data. The parameters related to these were then adjusted in order to match within the range of “reference” (observed) values. Similarly, coffee yield in monoculture system was simulated in the model using the crop parameters, soil inputs and daily historical climate data. The average simulated yield was then calibrated to fit the reference values between 1000 and 1200 kg ha<sup>-1</sup> yr<sup>-1</sup> in the Wonago and between 1100–2100 kg ha<sup>-1</sup> yr<sup>-1</sup> in the Limu Kosa. After the model calibration for the tree and coffee plantations grown as monoculture systems, we used the same parameter set to simulate coffee yield under agroforestry systems, where both species are combined and competing for light and water. The reference coffee yields used were between 1400 and 1520 kg ha<sup>-1</sup> yr<sup>-1</sup> for Wonago and between 1400 and 2100 kg ha<sup>-1</sup> yr<sup>-1</sup>, for Limu Kosa. The parameter set defined during the validation process was then used for simulating coffee yield under

monoculture and agroforestry systems for a simulation period of 40 years comparing historical climate data and two future climate change scenarios (RCP 4.5 and RCP 8.5).

## Results

### Impacts of climate change on coffee productivity

For the Wonago site, under current climate scenario, Yield-SAFE model simulated an average coffee yield in monoculture system around 1200 kg ha<sup>-1</sup> yr<sup>-1</sup>. Simulated yields with climate change scenarios show this average yield to decrease by 38 and 60% in RCP 4.5 and 8.5 scenarios, respectively (Fig.1a). However, the average yield under agroforestry system in current climate was 1600 kg ha<sup>-1</sup> yr<sup>-1</sup> and the expected decrease was lower (13% in RCP 4.5 and 25% in 8.5 scenarios) (Fig.1a). For the Limu Kosa site, the average yield in monoculture system under current scenario was simulated to be 1250 kg ha<sup>-1</sup> yr<sup>-1</sup>. With climate change scenarios this average yield was expected to decrease by 4 and 20% in RCP 4.5 and 8.5 scenarios, respectively (Fig.1b). But, the average yield under agroforestry systems in current climate was 2200 kg ha<sup>-1</sup> yr<sup>-1</sup> and the expected decrease due to climate change is 4 and 16% in RCP 4.5 and 8.5 scenarios, respectively (Fig.1b).



**Figure 1.** Coffee yields under monoculture and agroforestry systems in current and future climate change scenarios at: a) Wonago b) Limu Kosa sites

It was projected that the average coffee yields reduction under monoculture systems in the study sites to be between 4–38% in RCP 4.5 and 20–60% in RCP 8.5. However, the yield reduction under agroforestry system was lower (4–13% in RCP 4.5 and 16–25% in RCP 8.5 scenarios) (Fig.1). For a lower yield reduction under agroforestry systems, the Yield-SAFE model suggests that the tree presence with coffee plants is effective in reducing soil evaporation and total evapotranspiration, both from the soil and the coffee, especially under future climate scenarios. In the Wonago site, the effects of climate change on coffee yield were expected to be higher (Fig.1a) due to the positive effects of the tree presence with coffee on microclimate, loss of water from soil in the form of evaporation was found to be lower by 61 and 74% in RCP 4.5 and 8.5 climate scenarios, respectively, as compared to monoculture coffee. Total evapotranspiration from the soil and the coffee crop was also predicted to be lower under agroforestry compared to monoculture by 16 and 26% in RCP 4.5 and 8.5, respectively.

## Conclusion

This was the first time that the process-based Yield-SAFE model was calibrated and validated for coffee arabica, showing an interesting performance when used for predicting impacts of future climate scenarios on coffee productivity under monoculture and agroforestry systems in Ethiopia. Findings of the present study evidence that future climate change is expected to decrease coffee productivity between 4–25% in agroforestry systems and up to 20–60% in monoculture systems, depending on the climate scenarios. The lower yield reduction of coffee produced in agroforestry system seems to be due to the presence of shade trees that help to reduce soil evaporation and coffee respiration through a decrease in radiation exposure, wind speed and vapour pressure. Therefore, this study offers evidence of the agroforestry systems as a practice to be included in the adaptation strategy for mitigating the negative impacts of future climate change on coffee production.

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## Future mean and extreme rainfall over Eastern Africa in a convection-permitting model

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Eastern Africa's fast-growing population is vulnerable to changing rainfall and extremes. Using the first pan-African climate change simulations that explicitly model the rainfall-generating convection, we investigate both the climate change response of key mesoscale drivers of Eastern African rainfall, such as sea and lake breezes, and the spatial heterogeneity of rainfall responses. The explicit model shows widespread increases at end-of-century in mean and extreme rain rates, whereas the sign of changes in rainfall frequency have large spatial heterogeneity. In comparison, an equivalent parametrised simulation has greater moisture convergence and total rainfall increase over the eastern Congo and less over Eastern Africa. The parametrised model also does not capture: (1) the large heterogeneity of changes in rain frequency, (2) the widespread and large increases in extreme rainfall, and (3) the response of rainfall to the changing sea-breeze, even though the sea-breeze change is captured. Consequently, previous rainfall projections are likely inadequate for informing many climate-sensitive decisions, e.g. for infrastructure in coastal cities.

### Introduction

Robust and well-understood predictions of changes in extreme weather events, particularly rainfall, are urgently needed by impact scientists, engineers, non-governmental organisations and governments worldwide to prepare for future climate change. Eastern Africa is no exception, with several recent high-profile floods and droughts in the region, highlighting vulnerabilities in current climate [4].

Many studies of Eastern African climate change have already been undertaken [9][7][8][11][5][6]. Whilst these are vital in helping populations prepare, the climate models used are limited due to their representation of convection. A number of studies have shown that the use of convection-permitting (CP) models, i.e. representing convection explicitly instead of through approximations ("convective parametrisations"), can improve the modelled rainfall and its coupling with convergence [1][2]. However, until recently CP models have not been applied for continental-scale, tropical climate change simulations.

A new dataset simulating current [10] and future [3] climate over Africa with a CP model at 4.5km grid spacing (CP4), and a parametrised convection model at ~25km grid spacing (P25), has



shown that for Africa as a whole, explicit convection increases the change in extreme rainfall [3]. This new dataset allows us to address critical unanswered questions for Eastern Africa, a region already shown to have a different climate change response to much of Africa [3].

## Data

Two regional climate models based on the Met Office Unified Model have been independently applied over an African domain [10]. Each simulation has of 10 years of data. Both regional models are 1-way nested within an un-nudged N512L85 global atmospheric model using the Global Atmosphere/Land 7.0 (GA7/GL7) configuration – the latest science configuration of the Unified Model. All models are driven by sea-surface temperature (SST) analyses.

The convection-permitting regional model (CP4) has no convection parametrisation, instead convection occurs explicitly based on the atmospheric equations of motion. Convection is possible without parametrisation due to the high resolution used (4.5km grid spacing at the equator). The parametrised convection regional model (P25) is a regional simulation with parametrised convection and is used to compare against the convection-permitting simulation.

The CP4 and P25 models have also been run for a future climate scenario [3]. The global driving model has also been run for a future climate using the Representative Concentration Pathway 8.5 for greenhouse gas concentrations for a decade at end-of-century. A temperature change for SSTs is calculated on a grid cell and monthly basis as the climatological change in SST between end-of-century and present-day from HadGEM2-ES global climate model simulations. Ozone and aerosol climatologies are not changed from the current climate simulation.

## Results

### Change in rainfall metrics

Both models show the largest increases in annual rainfall occur in the driest parts of East Africa (northern Kenya, Somalia, eastern Ethiopia, and the Awash valley). There are smaller increases and decreases in the south of the region over Tanzania and along the Kenya coastline. Percentage changes are larger in CP4. Both models also show a similar pattern of changes in the frequency of rainfall, with clear decreases in frequency in the south of the domain. However, the P25 model has much smaller percentage changes in frequency compared to CP4. This is because it has very high, unrealistic frequency of rainfall in current climate and therefore has less scope for large percentage changes in future. Instead the P25 spatial pattern of annual rainfall changes are largely dominated by the changes in intensity of rainfall. Meanwhile, the CP4 model intensity changes are much more homogenous across the region (~40% increase). Similarly, CP4 has a reasonably homogenous ~50% increase in the 99th percentile of wet 3-hour periods.

### Change in Victoria nocturnal rainfall and land breeze

Rainfall over Lake Victoria falls at night-time as a result of the converging land breeze on the lake. Because the land warms faster than the lake under climate change (lake surface temperatures prescribed here), the land-lake temperature contrast at night weakens, as does the land breeze. As such, this acts to reduce convergence over the lake and against the increase of atmospheric humidity. In these simulations the humidity increase wins out, and both models show increased rainfall over Lake Victoria in the future climate. However, around parts of the lake where land breeze convergence reduces most, there are smaller increases in rainfall.

## Change in coastal rainfall and sea breeze

Along the coastline of East Africa there is an afternoon sea breeze that propagates inland over the course of the evening, with rainfall forming along the line of convergence. Under climate change the land warms more than the ocean, thereby increasing the temperature contrast and the sea breeze convergence. The convergence begins further inland as well. Both models simulate similar changes in the sea breeze convergence. However, only CP4 shows rainfall to be strongly associated with the sea breeze in current climate (as in observations), and only CP4 shows a clear response of rainfall to the changing sea breeze convergence in the future climate.

## Conclusions

We highlight two main conclusions:

1. For changes in rain frequency and rain rates, the parametrised model is limited: it fails to capture the widespread increases in extremes seen in the explicit model instead only simulating larger changes where mesoscale forcings are strong.
2. Inadequate interaction between parametrised convection and circulations induced by land-sea temperature contrasts can limit the reliability of parametrised model's day-time response to climate change in key locations. Though at night the parametrised scheme performs better. These small-scale features are critical drivers of Eastern African rainfall, especially around some of the major population centres.

The approach used here allows novel determination of uncertainty from the way in which convection is parametrised, but not from the global uncertainties, which must instead be obtained from global ensembles [5][6]. Our results provide new detailed user-relevant information on important possible changes to Eastern African climate, and clearly show that parametrised models should not be the sole source of climate change information for long-lived decisions.

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## Enhanced future changes in wet and dry extremes over Africa at convection-permitting scale

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Rapid growth of African economies and populations, combined with their vulnerability to climate change, generates the urgent need for understanding future climate change in this region if we do not curb emissions of greenhouse gases. This study presents future climate projections across Africa using, for the first time, a very high resolution (4.5km grid) climate model that covers the whole region (CP4A). The high resolution enables the model to better represent convection and therefore improves its ability to simulate short-duration (sub-daily) rainfall. CP4A shows greater future increases in extreme 3-hourly precipitation compared to a coarser resolution 25km model. It also projects a lengthening of dry spells during the wet season over western and central Africa, which is either weaker or not found in the 25km model. These differences relate to the more realistic representation of convection in CP4A. We conclude that future changes in both wet and dry extremes over Africa may be more severe than we previously thought.

### Introduction

Until now future climate projections across Africa have been provided by relatively coarse resolution climate models that are unable to accurately simulate convective processes and as a consequence African weather extremes. This makes it difficult to predict the impacts of climate change and develop adaptation strategies.

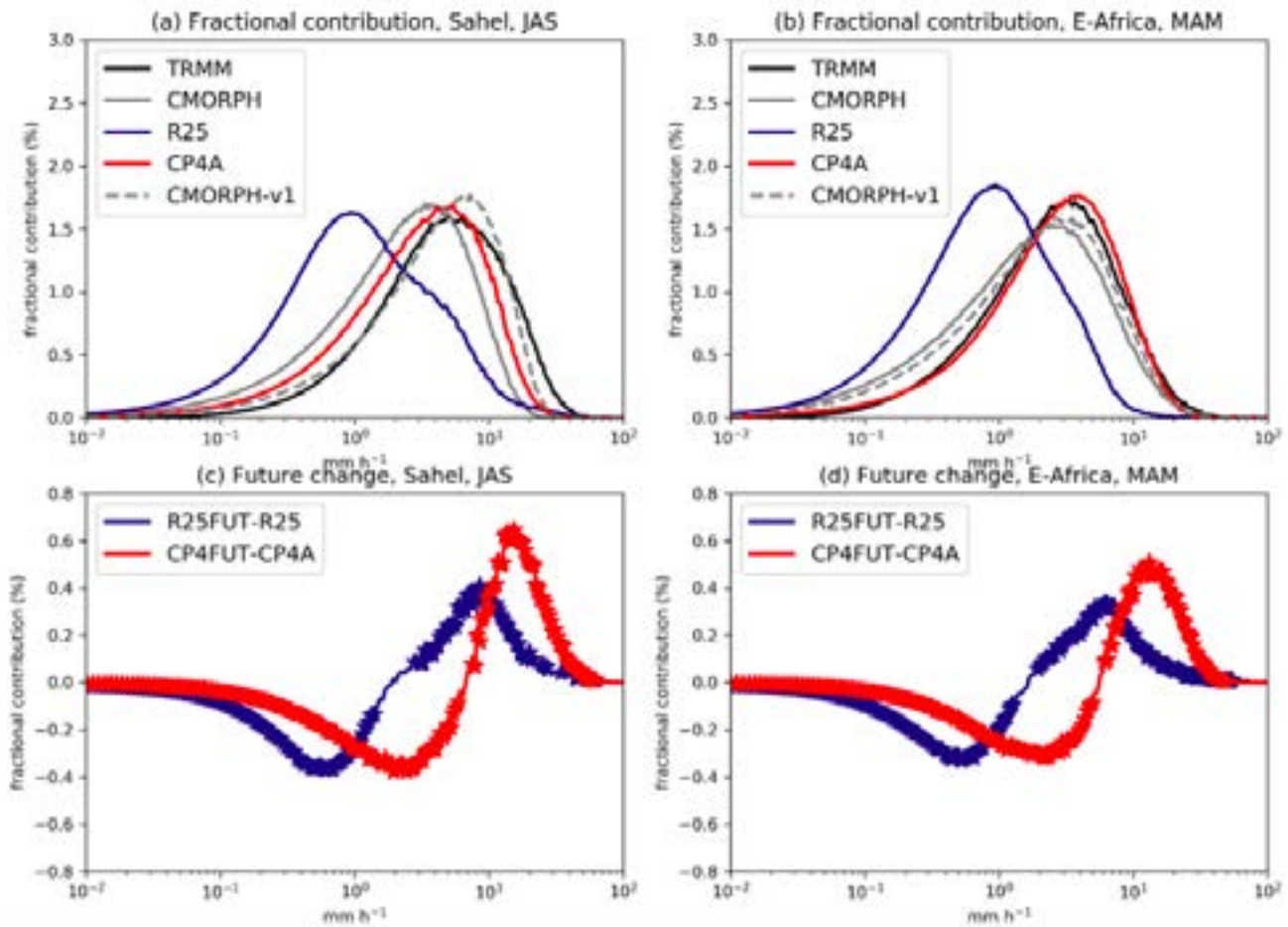
The climate model used here provides a step change in our understanding of how African climate may change in the future. The model uses very high resolution (4.5km grid), which is more typically used for weather forecasting. This provides very detailed projections and also new information on changes in extremes, due to its better representation of the physical processes. In particular, the model is termed 'convection-permitting' because larger storms are represented explicitly without the need for parameterisation.

### Models

Results from the 4.5km model, CP4A, are compared with a coarser resolution 25km regional model (R25). Both models are configurations of the Met Office Unified Model. They have been run for 10-year present-day (1997–2007) and 10-year future (~2100) periods using a high greenhouse gas emission scenario (RCP8.5). R25 has similar model physics to CP4A, except that convection is parameterised and it uses a different cloud and boundary layer scheme. Details of the models are provided in Kendon et al (2019)[1].

### Conclusions

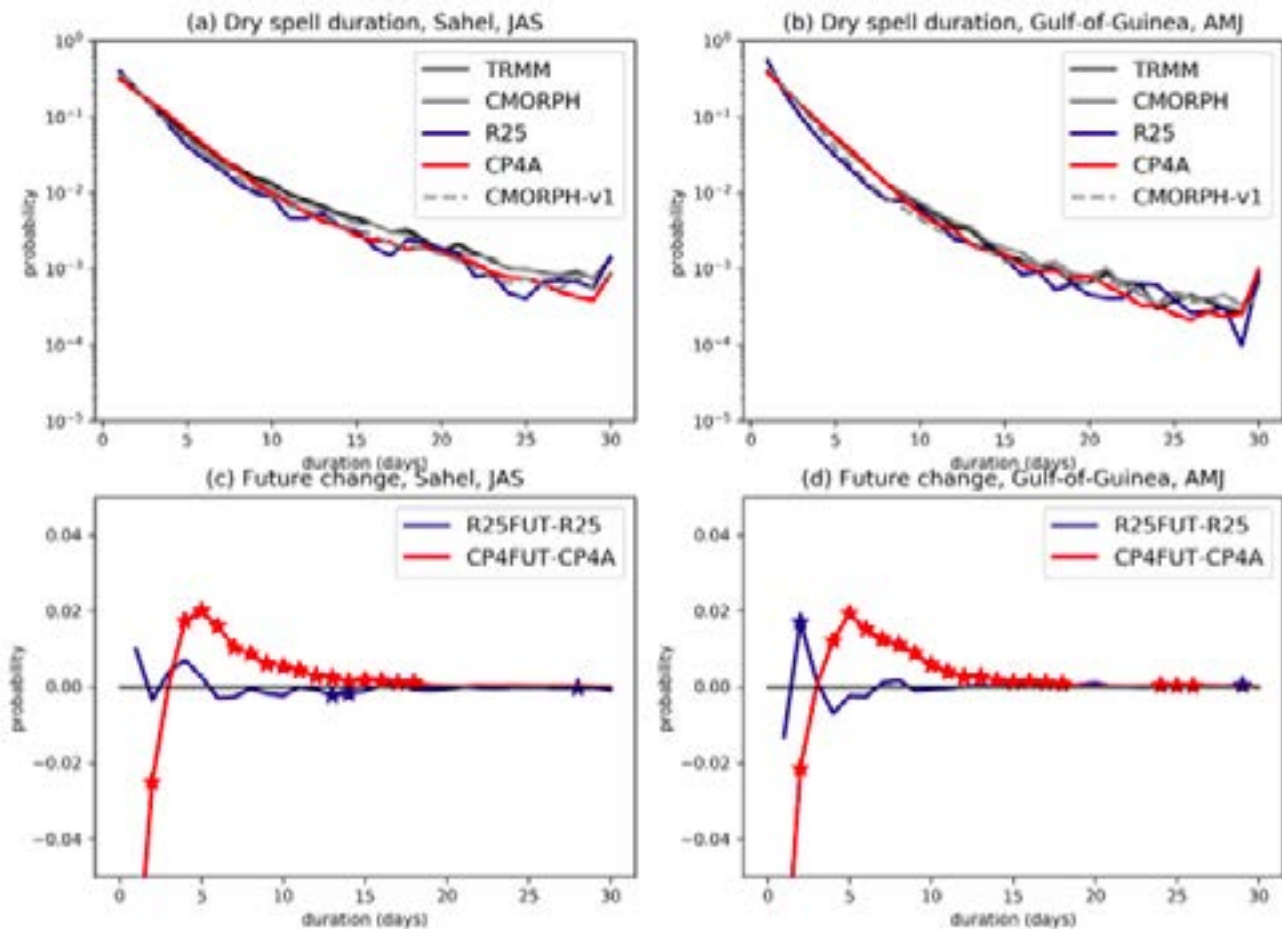
For the first time we have analysed multi-year climate-change projections for an African wide domain at convection-permitting (4.5km) resolution (CP4A). We find that CP4A shows greater future increases in extreme 3-hourly precipitation compared with a 25km model R25 (Figure 1). Exceeding 60 mm in 3h, at the 25km scale, is found to be 7–8 times more frequent in the future, compared to the present-day, for the Sahel and East Africa. So an event which occurs typically once every 30 years becomes once every 3–4 years in the future. Such high rainfall amounts may lead to local flash flooding.



**Figure 1.** Fractional contribution of 3-hourly precipitation intensity bins to the total precipitation, for Sahel (July–August–September) and E Africa (March–April–May). (a,b) Fractional contribution (%) for present-day for TRMM and CMORPH observations and R25 and CP4A models. (c,d) Difference in fractional contribution between 2100 and present-day for R25 and CP4A. Stars indicate where future changes are significant at 1% level. See Kendon et al (2019) for more detail.

In terms of changes in dry extremes, CP4A projects a lengthening of dry spells during the wet season over western and central Africa (Figure 2). In particular, dry spells exceeding 10 days in length are almost twice as frequent in the future compared to the present-day. Such changes are either weaker or not found in the 25km model. It is dry spells during the wet season, when crops are growing, that have the greatest impact on farmers.





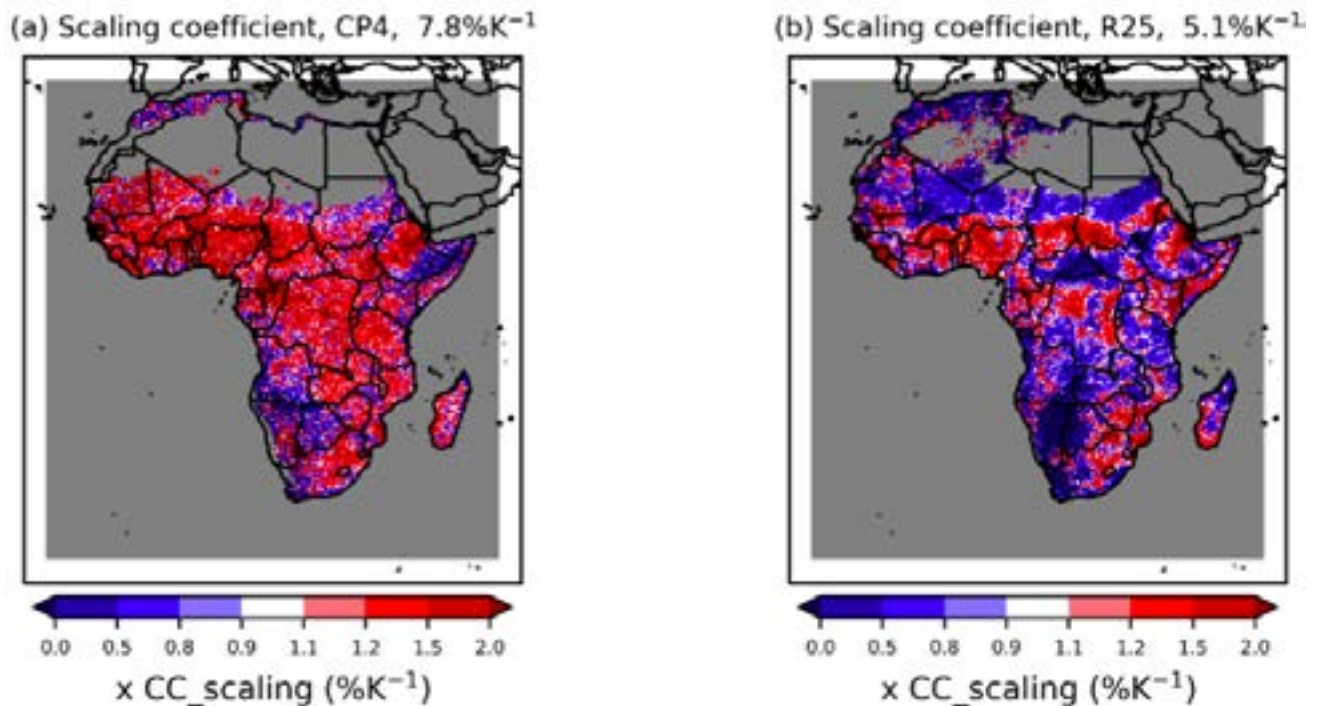
**Figure 2.** Probability distribution of dry spell duration, for Sahel (July–August–September) and Gulf-of-Guinea (April–May–June). (a,b) Present-day duration of dry spells for TRMM and CMORPH observations and R25 and CP4A models. (c,d) Difference in dry spell distribution between 2100 and present-day for R25 and CP4A. Dry spells are defined as continuous days with <1mm of rainfall. Stars indicate where future changes are significant at 1% level. See Kendon et al (2019) for more detail.

The findings indicate the importance of the representation of local convective processes for predicting future changes in rainfall extremes over Africa. The scaling of extreme rainfall changes with increased atmospheric moisture is higher in the convection-permitting model (Figure 3), which may be explained by local dynamical feedbacks within storms amplifying increases. Dry spell changes also appear to be related to the more realistic triggering and propagation of convection in CP4A, and their response to future increases in stability. We conclude that changes in extreme rainfall and dry spells may be underestimated in all models where convection is parameterised.

The work in this study provides key foundations for other regions to use convective-permitting climate simulations and acts as an important benchmark comparison for other modelling studies. One drawback is that the results are from only one climate model so it is not possible to estimate model uncertainty and future studies should utilise more convection permitting models in order to better account for this.

The results are of major concern, as Africa is one of the world's most vulnerable regions to climate change. Millions of people rely on rainfall-fed agriculture, floods can devastate lives, homes and infrastructure, and widespread poverty leaves little capacity for adaptation.

This work is led by the UK Met Office, with contribution from Leeds University. It is funded by DFID and NERC via the Future Climate for Africa (FCFA) IMPALA (Improving Model Processes for African Climate) project. More details can be found in Kendon et al (2019).



**Figure 3.** Scaling between future changes in extreme 3-hourly precipitation intensity and dew point temperature, for the wet season across Africa, for (a) CP4A and (b) R25. Shown is the scaling ( $\%/K$ ) divided by the Clausius-Clapeyron (CC) relationship of  $6.2\%/K$ , such that a value of 1 corresponds to CC scaling. Extreme precipitation intensity is the 95th percentile of wet values ( $>0.1\text{mm/h}$ ) for daily maximum 3-hourly precipitation. See Kendon et al (2019) for more detail.

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## Potential Impacts of 1.5°C and 2°C Global Warming on Rainfall Onset, Cessation and Length of Rainy Season in West Africa

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This study examines the potential impacts of 1.5°C and 2°C global warming (GWL15 and GWL20) on rainfall onset dates (RODs), rainfall cessation dates (RCDs), and length of the rainy season (LRS) in West Africa under RCP4.5 and RCP8.5 scenarios. Nineteen multi-model multi-ensemble simulation datasets from eight regional climate models (RCMs) that participated in the Coordinated Regional Climate Downscaling Experiment (CORDEX) were used for the study. The ability of the model ensemble mean to reproduce the characteristics of RODs, RCDs and LRS for past climate were evaluated using two observed datasets. The impacts of GWL15 and GWL20 on each parameter were quantified and compared. The models reproduced the characteristics of RODs, RCDs, and LRS as observed in the historical climate over West Africa although with few biases. The models projected the western and eastern Sahel as hot-spots for a delayed ROD and reduced LRS in the 1.5°C and 2°C warmer climate under RCP4.5 and RCP8.5 scenarios. A delayed

RCD and longer LRS are projected over the western part of the Guinea coast. The uncertainties associated with the projections are high for RCD but lower for ROD and LRS. While an increase in global warming from 1.5°C to 2°C enhances late ROD over the entire West Africa under the RCP4.5, it fosters early ROD over the Sahel zone under the RCP8.5. It also encourages a decrease in the LRS over the Sahel zone and an increase in LRS over the Guinea zone but produces opposite results under RCP8.5. The results of the study have application in reducing the impacts of global warming over West Africa.

**KEY WORDS:** Multi-model. Multi-ensemble. Regional Climate Model. Projected. Scenario.

## Introduction

Understanding the characteristics of onset, cessation and length of the rainy season in West Africa is crucial. Many socio-economic activities of the people depend on rain-fed agriculture and most agricultural planning (e.g., land clearing, crop selection, seed planting and crop harvesting) require the knowledge of rainfall onset and cessation. For instance, the rainfall onset controls the best planting dates (when the soil moisture is sufficient to sustain the crop from seed germination to maturity), while the cessation and length of rainy season determine the type of seed to plant. However, rainfall onset and cessation exhibit a large variability over West Africa due to the complexity of the West African monsoon system, which is driven by the temperature gradient between the sub-continent and the Atlantic Ocean. There are indications that the ongoing global warming may alter the temperature gradient because several studies have shown that the warming is more rapid over land than the oceans. This suggests that global warming may enhance the variability of rainfall onset and cessation dates over the region. Despite the numerous studies on future impacts of climate change in West Africa, there is a dearth of information on how climate change could affect the onset, length of the rainy season and cessation of rainfall over West Africa. The present study provides more information in this area.

Hence, the aim of this study is to examine and compare the future impacts of 1.5°C and 2°C global warming on rainfall onset, cessation and length of the rainy season in West Africa under two future climate forcing scenarios (RCP4.5 and RCP8.5).

## Data and methodology

### Data

The observation datasets are the African Rainfall Climatology version 2 (ARC2) and the Climate Hazard Group Infrared Precipitation with Stations (CHIRPS). ARC2 consists of daily precipitation estimation data over Africa at 0.1° x 0.1° horizontal grid resolution for a period of 30 years (1983–2012), while CHIRPS consists of daily precipitation data over Africa at 0.05° x 0.05° horizontal grid resolution for a period of 35 years (1981–2015). The observed datasets were used to evaluate the simulated rainfall datasets. For easy comparison, 30 years data were extracted from the observation datasets (ARC2: 1983–2012; CHIRPS: 1983–2012) and re-gridded to the resolution of the simulation datasets (0.44° x 0.44°). The simulated rainfall datasets are from the CORDEX-Africa project. They are 19 multi-model simulation datasets produced by eight CORDEX RCMs (ALADIN, RCA, CCLM, RACMO-VI, HIRHAM, REMO, RACMO-V2, and WRF). The RCMs and the GCMs they downscaled are given in Table (1).

**Table 1.** The 30-year periods of 1.5°C and 2°C global warming levels (GWL15 and GWL20) in RCP4.5 and RCP8.5 simulations used in the study. The method for calculating the periods are described in Déqué et al. (2017).

RCMs	GCMs	RCP4.5		RCP8.5	
		GWL15 Period	GWL20 Period	GWL15 Period	GWL20 Period
RCA	CCCMA	2002 – 2031	2017 – 2046	1999 – 2028	2012 – 2041
	CNRM	2021 – 2050	2042 – 2071	2015 – 2044	2029 – 2058
	CSIRO	2020 – 2049	2033 – 2062	2018 – 2047	2030 – 2059
	ICHEC-r12	2010 – 2039	2031 – 2060	2005 – 2034	2021 – 2050
	HADGEM	2016 – 2045	2032 – 2061	2010 – 2039	2023 – 2052
	IPSL-MR	2002 – 2031	2020 – 2049	2002 – 2031	2016 – 2045
	MIROC	2026 – 2055	2059 – 2088	2019 – 2048	2034 – 2063
	MPI-LR	2006 – 2035	2029 – 2058	2004 – 2033	2021 – 2050
	NCCN	2027 – 2056	2062 – 2091	2019 – 2048	2034 – 2063
CCLM	CNRM	2021 – 2050	2042 – 2071	2015 – 2044	2029 – 2058
	ICHEC-r12	2010 – 2039	2031 – 2060	2005 – 2034	2021 – 2050
	HADGEM	2016 – 2045	2032 – 2061	2010 – 2039	2023 – 2052
	MPI-LR	2006 – 2035	2029 – 2058	2004 – 2033	2021 – 2050
ALADIN	CNRM	2021 – 2050	2042 – 2071	2015 – 2044	2029 – 2058
HIRHAM	ICHEC-r3	2009 – 2038	2030 – 2059	2006 – 2035	2023 – 2052
REMO	MPI-LR	2006 – 2035	2029 – 2058	2004 – 2033	2021 – 2050
RACMO-V1	ICHEC-r1	2006 – 2035	2028 – 2057	2003 – 2032	2021 – 2050
RACMO-V2	HADGEM	2016 – 2045	2032 – 2061	2010 – 2039	2023 – 2052
WRF	NCCN	2027 – 2056	2062 – 2091	2019 – 2048	2034 – 2063

## Methodology

The ROD and RCD definitions that were used in this study (Table 2) have been shown to give reliable RODs and RCDs over West Africa. Here, we applied them on each dataset (observation and simulation) to obtain RODs and RCDs for past and future climates over each grid point in our study domain (West Africa; Fig 1) and used the difference between the ROD and RCD (i.e. RCD minus ROD) as the LRS over the grid. To quantify the impacts of a warming level on the parameters, we obtained the difference between the projected future values (for the warming level) and the historical values (i.e. Future minus Historical). The difference in impacts of the two global warming levels was also quantified under the RCP4.5 and RCP8.5 scenarios.



Table 2. Definition of ROD, Cessation and Length of Rainfall dates over West Africa

Parameter	Definition	Reference
Rainfall Onset Date (ROD)	The total of at least 20 mm of rainfall within 5 days. The starting day and at least two other days in this 5-day period must be wet (at least 0.1-mm rainfall recorded), followed by a no dry period of seven (7) or more consecutive days occurring in the following 30 days.	Stern et al. (1981)
Rainfall Cessation Date (RCD)	Any day from 1 <sup>st</sup> September after which there are 21 or more consecutive days of rainfall less than 50% of the crop-water requirement.	Omotosho et al. (2000)
Length of Rainy Season (LRS)	The period between rainfall onset and cessation dates (i.e. RCD minus ROD)	Omotosho et.al. (2000) and Mugalavai et.al. (2008)

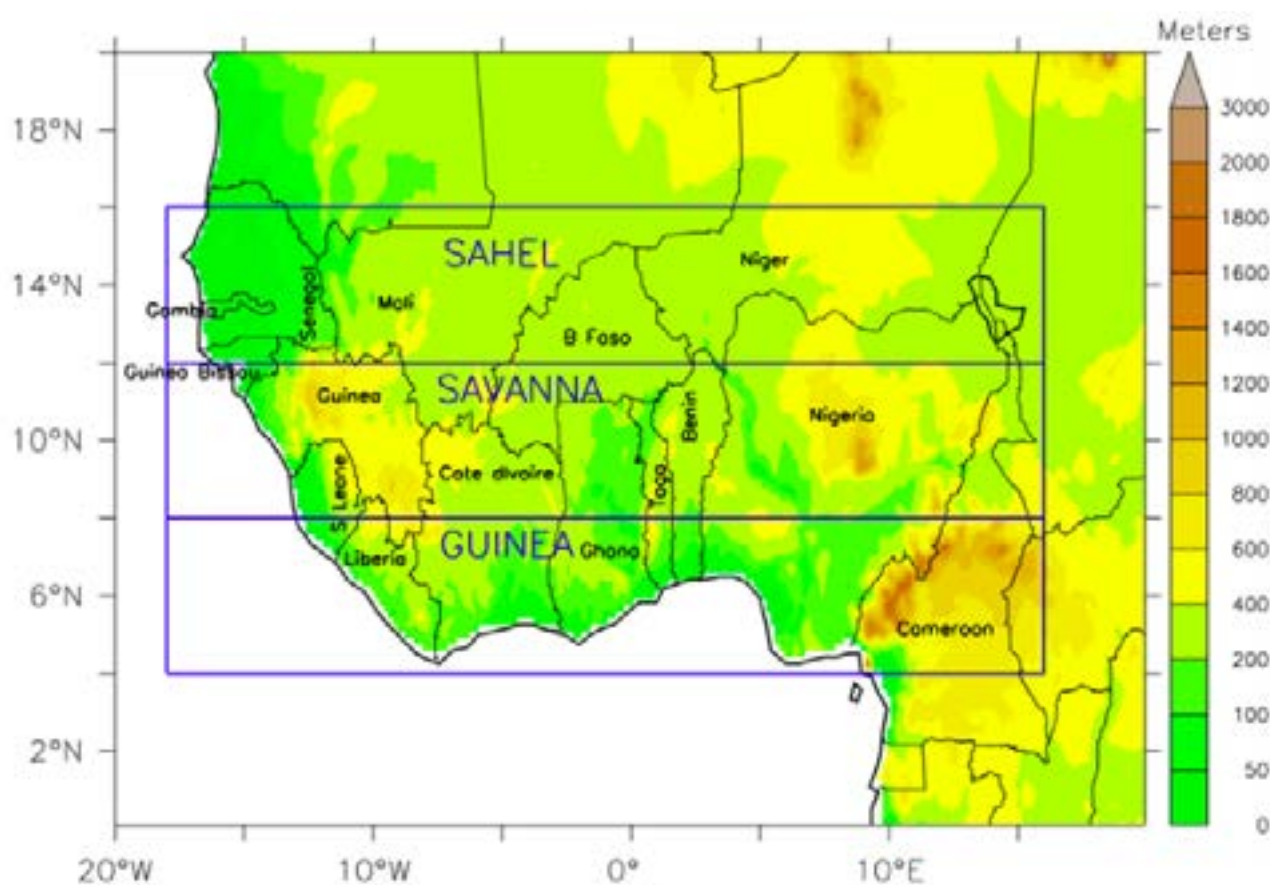


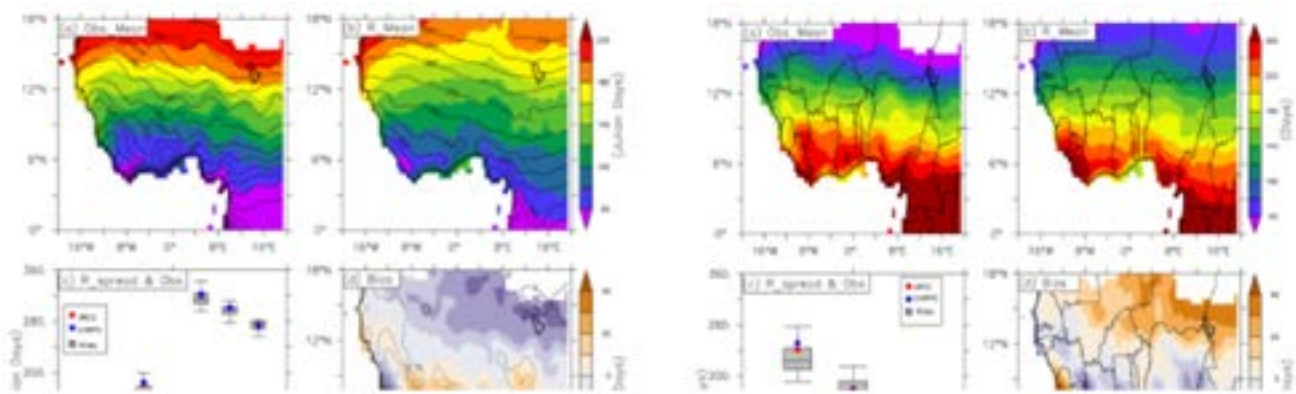
Figure 1. West African domain showing the topography (meters) and regions designated as Guinea, Savanna and Sahel zones.



## Results and discussion

### Model Evaluation

The RCM ensemble realistically reproduced the spatial distribution of RODs over West Africa. The correlation between the simulated and the observed values was high ( $r_o = 0.97$ ), and all the essential features in the observed pattern were well reproduced by the models (Fig.2, left panel). The models also gave a credible simulation of RCDs over West Africa, where the simulated RCD pattern strongly correlated with the observed pattern. The simulations agreed with the observations on the zonal distribution and southward increase of the RCDs ( $r_c = 0.94$ ; Fig.2, left panel, contours). The good performance of the models in reproducing ROD and RCD was reflected in the simulated LRS (Fig.2, right panel). The level of agreement between the observed and the simulated LRS was also high ( $r_l = 0.97$ ).



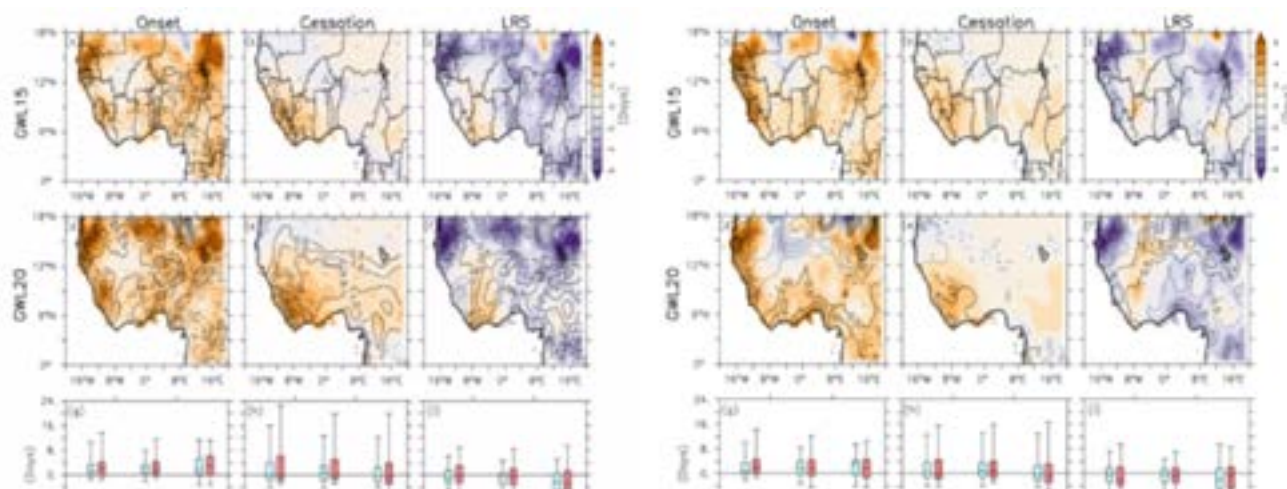
**Figure 2.** The climatology of RODs and RCDs (shaded and contour, respectively; left panel), and LRS (right panel). Panel (d) shows the simulation bias and the correlation, and panel (c) shows the box plot.

### Future projections of ROD, RCD and LRS under RCP4.5 5 and RCP8.5 scenarios

The RCM ensemble mean projected a delay in future RODs under RCP4.5 (Fig.3, left panel). Although the horizontal distribution of the projected delay was similar under both GWLs (GWL15 and GWL20), the period of the delay was generally higher under GWL20 than GWL15 (Fig.3a and d, left panel). The impact of global warming on RCDs was weaker than it was with regard to RODs (Fig.3b and e, left panel). As projected changes in the ROD were stronger than those in the RCD, the pattern of changes in the LRS mirrored that of the ROD (Fig.3c and f, left panel). The RCP8.5 projection suggested that the increase in GWL (from GWL15 to GWL20) enhanced the ROD delay only over the Guinea zone, while fostering early ROD over the Sahel zone (Fig.3b and e, right panel). Again, the RCP8.5 projected a delay in RCD only in the south-western part of the Guinea zone. Hence, with RCP8.5, the additional warming (i.e., from GWL15 to GWL20) generally encouraged a decrease in the LRS over the Guinea zone and an increase in the LRS over the Sahel zone, but, with RCP4.5, the reverse was true.

## Conclusion

The RCM ensemble gives a realistic simulation of RODs, RCDs and LRS in the historical climate and captures all the essential features in the observed field. Over each climatic zone, the RCM spread encloses the observed values. For both GWL15 and GWL20 under the two scenarios (RCP4.5 and RCP8.5) the RCM ensemble projects a delayed ROD and shorter LRS over the western and eastern Sahel, and a shorter LRS over the western part of the Guinea coast. There are uncertainties in the projections over each climatic zone, but the uncertainty associated with ROD and LRS is lower than that of RCD. In general, the level of uncertainties is comparable across the zones, GWLs and climate forcing scenarios.



**Figure 3.** The future projection of RODs (panel a, d), RCDs (panel b, e) and LRS (panel c, f) over West Africa (shaded) for GWL15 and GWL20 (top and middle panels) under RCP4.5 (left) and RCP8.5 (right) scenarios. The future projections over each climatic zone over West Africa (i.e. Guinea, Savanna, and Sahel) are shown in panels (g, h, and i, respectively).

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## SCUS-2050: Exploring the future of the Southern Canary Upwelling System

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Located off Mauritania, Senegal and Guinea, the Southern Canary Upwelling System (SCUS) is among the most productive oceanic areas in the world. The SCUS and its ecosystems are under rising pressure, due to economic development, demography, and also presumably the effect of climate change. The SCUS project investigated the coastal consequences of projected regional-scale long-term changes for the Southern Canary Upwelling System. The aim is to gain understanding on SCUS climate variability and change, and hence to explore SCUS vulnerability at the end of the 21st century. The main objective of the Work Package (WP) 4 is to downscale the trends obtained for the Northeastern tropical Atlantic over the West Africa coastal Ocean. Downscaling will be dynamical and involve realistic ROMS / CROCO high resolution modeling ( $\Delta x \approx 2$  km) forced by CMIP5 models. We explore how the large scale climatic variability (atmospheric and oceanic) modify the typical hydrological and flow patterns in the SCUS including pathways and characteristics of upwelled water masses. The main results of the SCUS project are 1) the meridional wind stress is also projected to decrease ( $\sim 10\%$ ) during the twenty-first century when averaged over the whole southern SMUS ( $12^\circ\text{N}$ – $20^\circ\text{N}$ ) due to northward shift of the Açores anticyclone. 2) These changes do not result in a significant reduction of upwelling even when oceanic stratification changes are also accounted for. 3) remote forcing of coastal Kelvin waves by winds in the Guinea Gulf is an important determinant of present-day climate along WA. For input from and feedbacks to end-users

community, two stakeholders meetings were organized to inform and build robust links between researchers and stakeholders concerned with the impacts of climate change on Senegal's marine (ocean and coastal) environment.

## Introduction

The Southern Canary Upwelling System (SCUS) encompassing southern Mauritania, Senegal, and the Gambia is one of the most productive areas of the world's oceans due to coastal upwelling processes which bring nutrient-rich waters from the deep ocean to the surface. It supports large populations of commercially important fish. The SCUS and its ecosystems are under rising pressure, due to economic development, demography, and environmental stresses due to climate change [3]. Our understanding of climate change impacts on marine ecosystems is largely limited to the open ocean. Global climate models generally have a rather coarse spatial resolution ( $\sim 2-3^\circ$  in the atmosphere,  $\sim 1-2^\circ$  in the ocean), which does not permit an adequate representation of regional dynamical processes, and particularly those impacting coastal upwelling ecosystems [1]. The SCUS-project aims to gain understanding on SCUS climate variability and change, and hence to explore SCUS vulnerability at the horizon 2100. We investigated the regional atmospheric conditions leading to synoptic episodes of trade wind intensification, the related upwelling response and the evolution of their frequency at the end of the 21st century. The project is organized in 3 strongly connected Work Packages (WP) and one WP ensuring a close link with stakeholders (WP1). The aim of WP2 was to identify the processes responsible for the southern Canary Upwelling system (SCUS) climatological features and their modulation by climate variability and change. The WP3 analyzed the seasonal cycle of the senegalo-mauritanian upwelling (SMUS) and its response to climate change in the database of the Coupled Models Inter comparison Project Phase 5 (CMIP5). The WP4 propose to explore how the large scale climatic variability (atmospheric and oceanic) modify the typical hydrological and flow patterns in the SCUS including pathways and characteristics of upwelled water masses. Our objective on this WP4 is to downscale the trends obtained for the Northeastern tropical Atlantic over the West africa coastal Ocean.

## Materials and methods

Several methods and tools have been utilized in this project. In WP2 Kounta et al, used an eddy permitting NEMO model simulation (NEMO3.6; Madec, 2014; TROP025) to investigate origin of waters masses feeding WA coastal upwelling[2]. Sylla et al in WP3 using the CMIP5 data base, have defined five dynamical and thermodynamic indices that could be compared among the CMIP5 simulations[8]. These indices were then applied to simulations of climate change (RCP85). The WP 4 are focused on the SCUS downscaling experiments. The downscaling approach is used to represent the regional and local processes that can modulate, amplify, dampen the expression of global climate change in a given ocean sector [1]. Dynamical downscaling is developed to better predict the regional impact of global changes in the framework of scenarios RCP8.5. The ocean circulation model ROMS/ CROCO (<https://www.croco-ocean.org>) has been used. Configuration realism and resolution ( $\Delta x \approx 2$  km) are sufficient to reproduce the fronts that separate different water masses over the shelf [7]. High resolution sensitivity experiments have been carried out to idealized Climate Change perturbations and downscaling of perturbations from CMIP ensemble mean. We have first diagnosed the vertical stratification (0-200 m) in the CMIP models to identify the best models to be used for initial and ocean boundary conditions. Nine models, reproduced well the stratification over the Senegal area (compared to the World Ocean Atlas datasets), have been selected for the downscaling experiments.

## Summary and Conclusions

The SCUS project investigated the coastal consequences of projected regional-scale long-term changes for the Southern Canary Upwelling System. In WP2 Kounta et al, (2018) were focus on the origin of the water masses feeding the west african (WA) coastal upwelling and the dominant modes of atmospheric variability that affect the WA upwelling dynamics on intraseasonal to interannual time scales[2]. They showed that these waters masses come from a current called WABC for West African poleward Boundary Current, located along the continental slope. The WABC is composed of a poleward undercurrent (PUC) and of a surface-intensified current also toward the pole and frequently referred to as Mauritania Current (MC). The investigation of the seasonal cycle of the WABC showed that it exhibits two peaks of transport: a first one in April-May and a second one in October-November. This seasonal cycle results from coastal trapped wave activity generated by fluctuations of the wind forcing. The first peak is explained by local wind changes (i.e along the west african seaboard) while the second peak is mainly due to a remote forcing (wind fluctuations in the Gulf of Guinea).

This work tends to substantiate old assertions about the connection between the boundary current flowing offshore of Senegal and Mauritania as well as poleward flow in the Gulf of Guinea, during part of the year. More details can be found on this link <https://www.ocean-sci.net/14/971/2018/os-14-971-2018.html>.

In WP3 Sylla et al, have first highlighted the ability of the climate models to reproduce the system, as well as their biases[8]. The CMIP5 simulations suggest that the intensity of the SMUS winter/spring upwelling will moderately decrease in the future, primarily because of a reduction of the wind forcing linked to a northward shift of Azores anticyclone and a more regional modulation of the low pressures found over Northwest Africa [8]. The implications of such an upwelling reduction on the ecosystems and local communities exploiting them remains very uncertain.

In WP4, the relevant local processes identified in WP2 and WP3 have be imposed at the domain boundaries as anomalies with respect to present-day conditions. The present state has been documented using various in-situ observations and carrying out several simulations (<https://academicjournals.org/journal/AJEST/article-full-text-pdf/197B0F959403>). Ndoye et al, 2017, 2018 using a numerical model for varying forcing fields during the upwelling season (November-May) showed that the vertical velocity patterns suggest that upwelling predominantly occurs in the northern part of the domain where the coldest SSTs are found[5][6]. Downscaling experiments suggest upwelling intensity will moderately decrease in the northern part (around the Hann Bight) and increase in the southern part of the SSUS domain. The projected changes of wind conditions along the West Africa for 2090 (~10%) do not result in a significant reduction of upwelling even when oceanic stratification changes are also accounted for. Upper ocean stratification conditions will change mainly due to temperature changes ( 2-3° C in RCP8.5). These changes are detrimental to upwelling and reinforce the wind reduction effect in the southern sector (12-16°N). [Ndoyeet al, 2019, to be submitted]. This increase in stratification may or may not translate into a change in nutrient input into the euphotic zone. Likewise, changes in the dissolved oxygen concentration of the subsurface waters that are upwelled onto the WA continental shelves may or may not be affected. Analyses of the CMIP5 Earth System models with biogeochemical modelling will be needed to investigate this question. According Wiafe et al, (2008), the most significant impacts on the resource could come from these changes in temperature because the main species of zooplankton (*Calanoides Carinatus*) present in Senegal's upwelling is sensitive to temperatures above 23 °C and these temperatures will be frequently exceeded in 2090[9].



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## Evaluation of Past and Future Extreme Rainfall Characteristics over Eastern Uganda

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### Introduction

Weather and climate are very important as they influence various aspects of daily life including water resources, food security, transport, tourism and health [7][3][12]. Like other agrarian countries, Uganda's economy is heavily regulated by weather and climatic conditions. Therefore, a better understanding of climate variability and anomalies will help stakeholders to devise strategies and policies for sustainable and climate resilient economy [1][5].

Consequently, there is an increasing concern regarding increasing frequency, intensity and duration of weather extremes as a consequence of anthropogenic activities [4][6]. These anomalies affecting the climate may increase the potential to trigger disasters especially in vulnerable regions [8]. In Uganda, the frequent incidences of extreme rainfall events have led to widespread damage to livelihoods. For instance, the 1961/62, 97/98 and 2007 floods resulted into infrastructure damage, displacement and destruction of livelihood assets. Similarly, in September 2010, floods hit the Teso sub-region in eastern Uganda, leading to rotting cassava, sweet potato tubers and groundnuts worth UGX8 billion which consequently led to food insecurity [10]. Information on characteristics of extreme climatic events is therefore vital for effective disaster preparedness and mitigation planning.

Africa is one of the most vulnerable continents to climate change and climate variability [14]. According to [15], extreme precipitation changes over eastern Africa such as droughts and heavy rainfall have been experienced more frequently in the last 30–60 years. Rainfall trends in eastern



Africa however vary greatly over time and space. Some assessments suggest that wet seasons will be more intense and droughts less severe over eastern Africa by the end of the century, which indicates a reversal of the observed increase in droughts and heavy rainfall during the past 30 to 60 years [15][16].

In Uganda, climate change and increased climate variability has been observed and it is manifested in the increasing frequency and intensity of weather extremes including high temperatures and precipitation leading to prolonged drought and erratic rainfall patterns [9]. Moreover, the frequency and intensity of extreme climatic events has generally been on the increase in the last century [9]. Agricultural products are the major economic resource in Uganda where over 80% of the population's livelihoods are based on rain-fed agriculture [17] and therefore the heavy reliance of the rural and agriculturally dependent population may severely harm them because of its high sensitivity to impacts of adverse effects of climate change.

Previous studies on rainfall variability and trends over Uganda and the region [13][17][11] mainly focused on seasonal or annual totals and also the assessments of climate change that have been done are often limited to mean rainfall. It's on this basis that detailed studies on rainfall extremes are carried out especially over Eastern Uganda that has frequently experienced extreme events (such as floods). Nevertheless, there's a need to understand how these extremes are changing because of their profound effects on agriculture which is the backbone of the economy. This study therefore aimed at assessing the trends and variability of the observed and future rainfall extremes in Eastern Uganda.

## Methods

The study utilized both observed and modeled daily rainfall data to study both historical and projected precipitation indices. The observed station gauged data for Soroti weather station (1.72°N, 33.62°E, see figure 1) was obtained from the Uganda National Meteorological Authority (UNMA) for the period 1981–2016. We analysed downscaled daily rainfall from the Rossby Center Swedish Meteorological and Hydrological Institute (SMHI) regional climate model (RCA4) within the Coordinated Downscaling Experiments (CORDEX) framework that was used to downscale a set of GCMs from the Coupled Model Inter-comparison Project Phase 5 (CMIP5) global climate projections. All simulations were performed at a grid resolution of 0.44°×0.44°.

RCP 4.5 and 8.5 were chosen as they represent the intermediate and upper range respectively of the radiative forcings and are considered more realistic in comparison to RCP2.6. RCP4.5 represents a mitigation scenario, which stabilizes radiative forcing at 4.5 W/m<sup>2</sup> at 2100. while RCP8.5 represents a rising scenario with very high greenhouse gas emissions and radiative forcing of 8.5 W/m<sup>2</sup> at 2100.

The future daily precipitation time series were collected from CMIP5 global circulation model (GCM); Norwegian Earth System Model 1- medium resolution (NorESM1-M), under two Intergovernmental Panel on Climate Change (IPCC) Representative Concentration Pathways (RCP) 4.5 and 8.5 for the period of 2021–2050 which was downscaled by Regional climate model (RCM) SMHI-RCA4 of the Swedish Meteorological and Hydrological institute (SMHI) under CORDEX Africa downscaling initiative. The RCM data was obtained from the Africa Coordinated Downscaling Experiment (CORDEX) website.

## Extreme precipitation indices

This study used four indices from the Expert Team on Climate Change Detection and Indices (ETCCDI) that are based on daily precipitation and have also been widely used in climate extreme studies. The details of the indices are shown in Table 1, and a full descriptive list of the indices can be found on the ETCCDI website: [http://etccdi.pacificclimate.org/list\\_27\\_indices.shtml](http://etccdi.pacificclimate.org/list_27_indices.shtml).

Table 1. Selected indices for the analysis of rainfall extremes

Index	Indicator name	Definition	Units
R20	Number of very heavy precipitation days	Annual count of days when precipitation $\geq 20\text{mm}$	Days
R50	Number of severe precipitation days	Annual count of days when precipitation $\geq 50\text{mm}$	Days
R95p	Very wet days	Annual total precipitation from daily rainfall $> 95^{\text{th}}$ percentile	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days in the year	mm/day

## Conclusion

The rainfall extremes over Eastern Uganda were investigated through four rainfall indices calculation for both the past (1981–2010) and future (2021–2050) periods using RClimDex. The results revealed that for all the indices both for the past and future periods revealed no significant trends. However the mean shifts in the indices showed significant changes in two out of the four indices. Baseline findings indicated decreasing trends in all the indices showing a reduction extreme rainfall in Eastern Uganda. Future projections however showed increasing trends for all the indices for both scenarios except the SDII which is projected to decrease under RCP4.5. All indices are projected to have a positive shift in future except the precipitation per day (SDII) which will continue to decrease slightly. These results indicate that rainfall extremes will continue in the future and are likely to impact natural ecosystems as well as agricultural and societal infrastructure. It therefore calls for decision makers to design appropriate preparedness and mitigation strategies in Eastern Uganda

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## How might river flows in West Africa change in the future?

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West Africa has a history of extreme climate variability especially in its semi-arid Sahelian region. With rising air temperatures, there are growing indications that the long-term climate across West Africa is changing [3], affecting ecosystems and environments and potentially impacting on hydrological extremes such as severe floods and droughts. There is still considerable uncertainty as to how climate change will affect rainfall patterns but the direction of change and current impacts are largely known. However, the impact on river flows is less well understood. In the work presented here, we aim to address this gap in our understanding. Regional scale grid-based hydrological simulations for West Africa are used to support an analysis of change in peak river flows under a range of projected future climate scenarios (CMIP5) up to the end of the century. A physically-based hydrological model has been configured and assessed to simulate flows continuously across the whole of West Africa on a 10km grid. The model (Hydrological Modelling Framework – HMF) includes estimates of water use, current and future population growth, and wetland inundation to achieve spatially-consistent simulations of river

flows at across the whole region. Model simulated river flows for an ensemble of future climate simulations are analysed in order to quantify projected changes in the frequency, severity, timing and scale of extreme events across West Africa. The results are highly spatially variable across the region, highlight vulnerable regions and countries, and provide valuable information for planners of development and infrastructure.

## Introduction

In recent decades, West Africa has experienced some of the most extreme rainfall variability anywhere in the world and has a history of prolonged and severe droughts, most notably in its semi-arid Sahelian region. There is an increasing indication that the long-term climate across West Africa is changing, which can lead to extreme hydrological situations (floods as well as droughts). AMMA-2050 investigated how the West African monsoon will change in future decades, and examined the causes of High Impact Weather (HIW) and how they might change in the future. We used this information to increase the understanding of FUTURE changes in peak river flows. We carried out simulations of regional scale hydrological modelling under a range of climate scenarios using present-day and future climate data and a gridded hydrological model – the Hydrological Modelling Framework (HMF).

## Hydrological Modelling

The HMF model is a grid-based, spatially distributed hydrological model similar to the G2G [1]. It uses surface and sub-surface runoff-production and kinematic-wave routing of flows along river channels. It has been set up for rivers across West Africa with the aim of estimating projected future impacts of climate change through scenario development. The model includes estimates of water use, current and future population growth, endorheic regions and wetland inundation to achieve a spatially-consistent models of river flows at across the whole region (Figure 1).

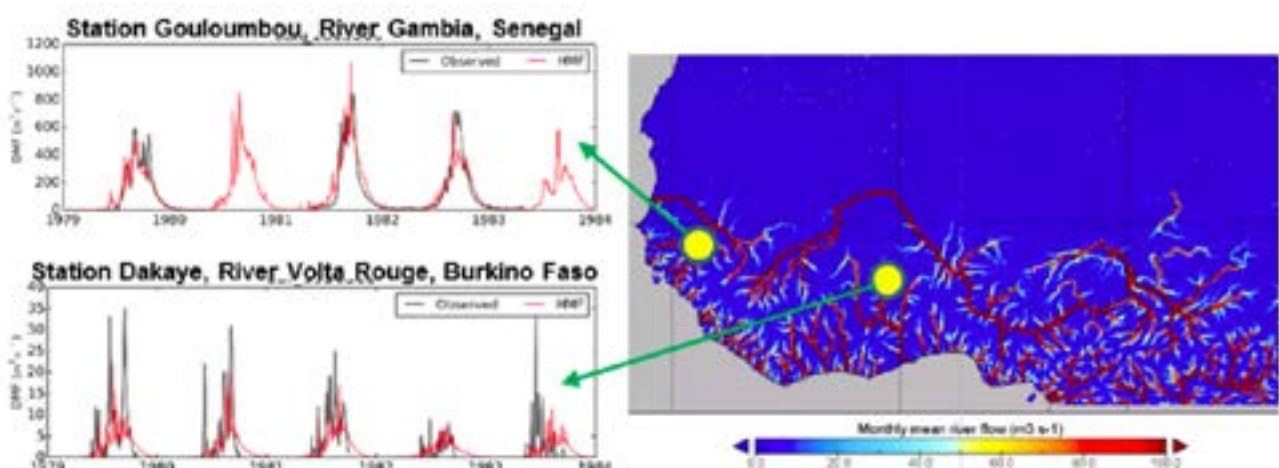
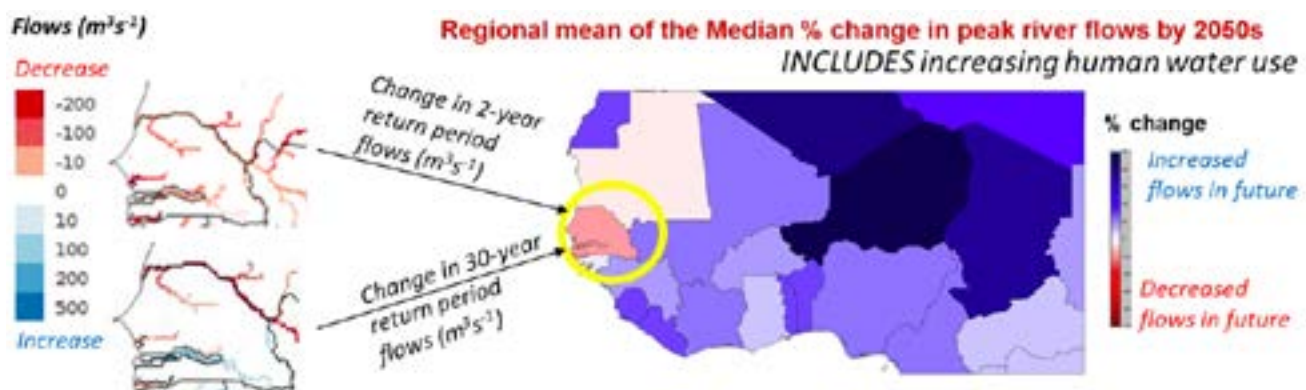


Figure 1. Modelling historical river flows across West Africa with HMF

Using CMIP5 climate model projections up to the end of the century [2] we conducted regional-scale climate-impact simulation to quantify projected changes in the peak flow events across West Africa and highlight vulnerable countries (Figure 2).



**Figure 2.** Change in peak river flows by 2050s. This is the median change in flows between present (1976 – 2005) and future (2030 – 2059) across 29 RCP8.5 CMIP5 models.

## Conclusions

Across West Africa most hydrological simulations using CMIP5 projected climate data agree that peak river flows will increase in future except in Senegal and neighbouring rivers, where a majority of models agree on future decrease in peak flows.

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## Evaluation and projected changes in daily rainfall characteristics over Central Africa based on a multi-model ensemble mean of CMIP5 simulations

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This study uses daily rainfall data from CMIP5 project and eight rainfall indices defined by the ETCCDI, to investigate the changes in extreme weather conditions over Central Africa (CA) under the RCP8.5. The performance of the multi-model ensemble (MME) mean which in fact refers to the best performing models selected through the Taylor diagram analysis was evaluated by observed datasets during the historical period (1998–2005). Results show that although some uncertainties may exist between observation datasets (TRMM and GPCP), MME consistently outperform individual models and reasonably reproduced the observed pattern rainfall indices over the region. The assessment of the climate change signal in those indices was done for the late twenty-first century, relative to the baseline historical time period (1976–2005). We found a significant increase in PRCPTOT over southern (northern) CA from December to February (from September to November). This is mainly due to the increase of high intense rainfall events rather than their frequency. The results also reveal that the increase in PRCPTOT was coupled with



increase in RX5DAY, in R95PTOT, with more robust patterns of change at the late twenty-first century. The increase in extreme rainfall events is likely to increase flood risks. Also, the decrease in CWD and PRCPTOT coupled with the increase in CDD observed could worsen drought risk and significantly disrupt priority socio-economic sectors for development. For that, decision-makers are invited to seriously consider adaptation and mitigation measures, in order to limit the risks of natural disasters that peoples may suffer in the future.

## Introduction

Changes in future extreme rainfall events at the end of the twenty-first century are projected to have negative effects on the vulnerable biodiversity of the African countries. The Fifth Assessment Reports (AR5) of the Intergovernmental Panel on Climate Change (IPCC), shows the evidence of climate change as challenge nowadays. This, because of natural disasters such as severe droughts and flooding linked to extreme weather events that may cause stress in water resource availability [4]. The increase of greenhouse gas (GHG) concentrations in the atmosphere and oceans, mainly due to human activities, is considered by the scientific community as the main driver causing these changes.

Few studies are devoted to the extreme weather conditions in Central Africa today [1][5][9][6]. Mostly of these studies, analysis focus only either on a single data source or a large ensemble of all available models. Also, the method used to select the best performing models is sometimes only based on average rainfall and therefore can be subject to the uncertainties brought by different interpretations. This, depending on the choice of the data source or the type of the ensemble used. Therefore, it would be interesting to first select the models that simulate the different studied rainfall indices in a realistic way and then use their ensemble mean to assess the climate change signal of extreme weather events over the region.

We propose in this study, to use eight rainfall indices to firstly evaluate the capability of an ensemble mean of best performing CMIP5 simulations in representing past (1998–2005) daily rainfall characteristics and, secondly present their projected changes over Central Africa.

## Methodology

During the historical period, the agreement between the simulated and observed daily rainfall indices is evaluated through the Taylor diagram [21], which provides a concise statistical summary of the degree of correlation (PCC; pattern correlations coefficient), root mean square error (RMSE), and standard deviation (SD). The similarity between simulations and observations is therefore quantified in terms of their correlation and the amplitude of the variability. The highly performing models are selected according to the following two criteria: (a) The PCC should be greater than 0.6; and (b) The SD should be within the range of  $1.00 \pm 0.25$ .

During the future period, the significance and robustness of the climate change signal is defined according to the methodologies used in previous studies, in order to measure the model agreement and thus the reduction of uncertainty in the projected changes [7][8]. So the climate change signal is robust if the following two criteria are fulfilled: (a) More than 80% of GCMs simulations agree on the sign of the change and (b) The signal-to-noise ratio (SNR; i.e., the ratio of the mean and the standard deviation of the ensemble of climate change signals is  $> 1$ ).

## Results and discussion

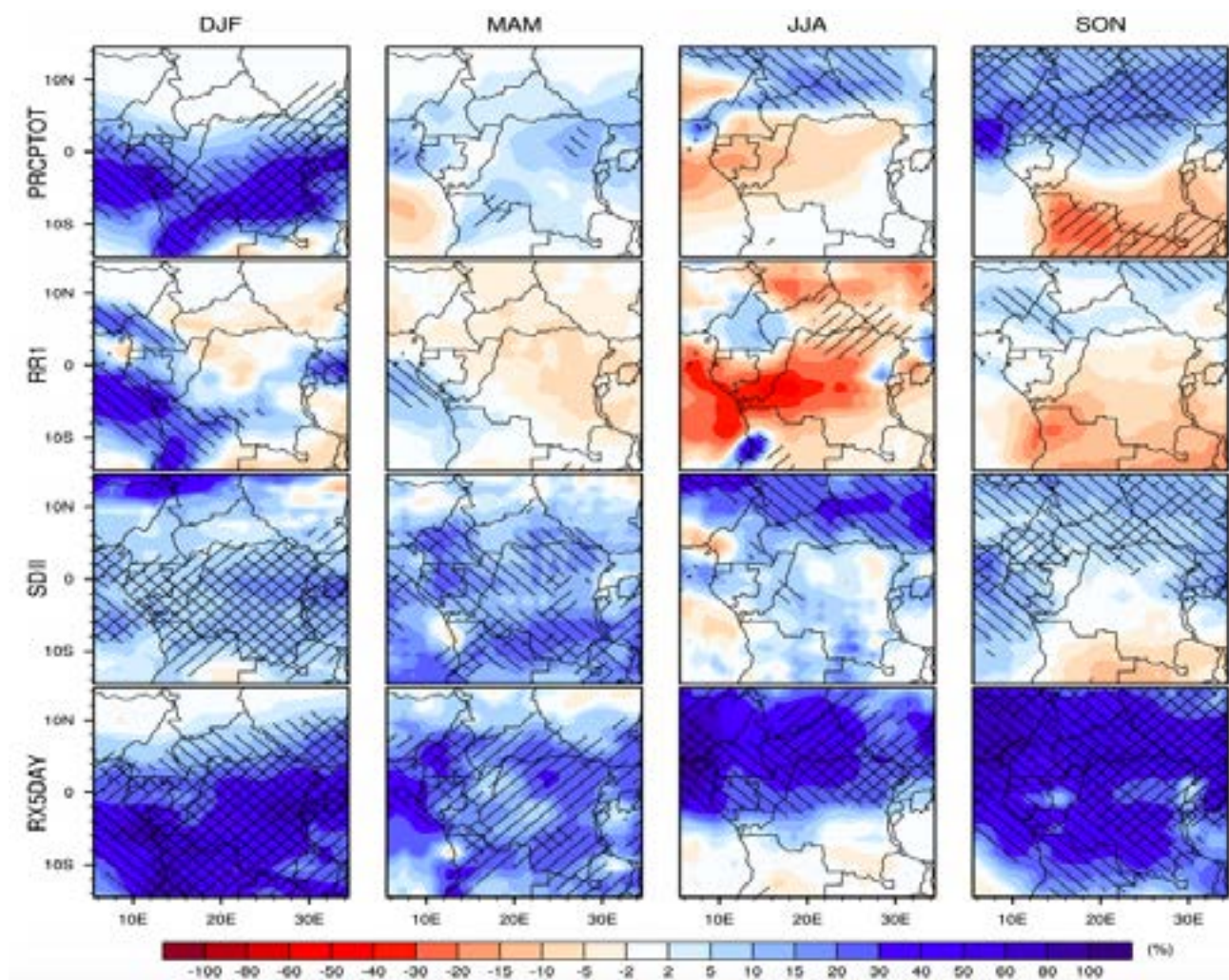
### Evaluation of daily rainfall indices

Figure 1 presents the seasonal Taylor diagram of different rainfall indices used, averaged over the study domain (land grid only), computed for TRMM, each of the 20 CMIP5 simulations and

The spatial distribution of MME seasonal changing signal (in %) is shown in Figure 2 for four distinct indices. The MME projects a significant decrease in PRCPTOT over southern Central Africa in SON with maximum value found around Angola. Recently, Tamoffo et al. (2018) show that decrease in rainfall and moisture divergence was very correlated across the region, and likely caused by substantial increase of zonal moisture divergence fluxes in upper atmospheric layers[10]. On the other hand, PRCPTOT tends to increase over southern (northern) Central Africa during DJF (SON), with more consistent patterns of change at the late twenty-first century (Fig. 2; first row). However, there are almost no significant changes during March to August and regions where SNR is  $> 1$  are very small. This indicates that there is a small signal and/or large spread across the GCMs simulations during this period of the year. For RR1, the MME projects an



decrease which is significant only over certain parts of the study domain during the late twenty-first century. The MME for SDII and RX5DAY generally project a consistent increase over the whole Central Africa for both periods, with area of consistent agreement and magnitude larger during late twenty-first century (Fig. 2; third and fourth rows). A higher SDII means that rainy days become wetter, resulting in more intense rainfall events, even if RRI decreases. Similar results showing an increase in rainfall intensity through an ensemble of RCMs were also reported over Africa [3][8]. It is possible that the decrease found in PRCPTOT is associated with the decrease in RRI, while its increase is linked to the increase in SDII. This implies that during different seasons, Central Africa will experience strong increase in natural disaster such as flooding mainly due to high intense events, which are more pronounced during the late twenty-first century.



**Figure 2.** Spatial distribution of MME seasonal changing signal (in%) between late twenty-first century (2066–2095) and historical periods (1976–2005). For total wet day rainfall amount (PRCPTOT, first row), wet day frequency (RRI, second row), wet day intensity (SDII, third row), and maximum consecutive 5-day rainfall amount (RX5DAY, fourth row). Areas where the changing signal is significant are where at least 80% of simulations agree on the sign of the change and are highlighted by this hatching symbol ('/') and ('\\') indicate the robust change areas where the SNR is >1

## Conclusions

In summary, the results obtained through the MME projections indicate that most of Central African countries will experience a general increase/decrease of extreme rainfall indices more pronounced during late twenty-first century. The tendency towards increase of extreme rainfall events found is consistent with the main findings in the literature done based on climate models.

## Acknowledgement

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## THEMATIC AREA 3

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### **Evidence for action: climate change risk analysis (data on climate related risks and potential impacts)**

This focuses on gathering and using evidence on the impacts and risks of climate change and the need for adaptation. It covers compilation of data on climate impacts and vulnerability; assessing climate risks to society; and exploring the best way to use this knowledge to protect the public and inform policymakers, including addressing the needs of specific sectors and stakeholders.





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## LIST OF PRESENTERS AND TITLES OF PRESENTATIONS

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### SALE ABOU

Main Climate Hazards And Water Risks Faced By Sorghum Farmers And Adaptation Constraints In The Semi-Arid Zone Of Cameroon

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### Haftu Abrha

Monitoring forest fire risk under climate change in Desa'a forest, Ethiopia

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### Ifeoma Quinette Anugwa

Farmers' Adaptation Strategies to the Impacts of Climate Change on Rice Production in Anambra State, Nigeria

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### Desalegn Yayeh Ayal

Psychological Dimensions of Climate Change: Vulnerability, Perceptions, Collective Efficacy and Responses in Berehet District, North Shoa, Ethiopia

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### Sylvia Diamond Dorbor

Attribution-Based Parametric Insurance: Towards Affordable Premiums

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### Dube Kaitano

Increasing rising Sea Surface Temperature and its implications on coastal areas in South Eastern Coastal Areas of Africa.

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### Rofida G. Abd El-Wahab

Implications of land use /land cover changes on vulnerability of coastal regions to Sea Level Rise

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### Zied Haj-Amor

Development of a risk assessment methodology for evaluating climate change effects on soil physicochemical properties in African regions

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### Meryl Jagarnath

Integrating urban land change and climate change data to inform spatial planning decisions: A case study of Durban, South Africa

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### Joyce Kimutai

Probabilistic Attribution of 2018, 2016 and 2012 March–April–May (MAM) Extreme Rainfall in Kenya

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**Dereck Mamiwa**

Climate Change Narratives for Blantyre city, Malawi

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**Dereck Mamiwa**

Determinants of Development Decisions in an African City: Evidence-based decision processes for Blantyre

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**Rudo Mamombe**

Climate change risks, vulnerabilities and decision making for the water sector in the city of Harare, Zimbabwe; lessons for African cities

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**Yèkambèssoun N'Tcha M'Po**

Mid-Century Daily discharge scenarios based on climate and land use change in Ouémé river basin at Bétérou

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**Steve Noutchie**

Evidence of drought events over Congo basin since 1970

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**Musonda Ng'onga**

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**Guillaume Rohat**

Future human exposure to dangerous heat in African cities

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**Brent M. Simpson**

Development and Use of Agronomic Weather Indices in Assessing Intra-Seasonal Climate Change Risks to Rainfed Cropping Systems.

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Estimation of Flood damage for housing in flood-prone areas in ouagadougou (Burkina FASO)

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**Christopher Ewaechabo Tiyo**

Understanding Small-Scale Farmers' Perception and Adaption Strategies to Climate Change Impacts: Evidence from Two Agro-Ecological Zones Bordering National Parks of Uganda

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## Main Climate Hazards And Water Risks Faced By Sorghum Farmers And Adaptation Constraints In The Semi-Arid Zone Of Cameroon

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This article deals with the problem of sorghum farmers' adaptation to climate hazards and water risks engendered by climate variability in the semi-arid zone of Cameroon. The overall objective is to analyze the perceived main climate hazards, water risks and their consequences, then to evaluate the adaptation strategies used and their adoption constraints in order to propose ways for improving farmers' resilience. The stratified random sampling method was used to select the sites, which consist of twenty (20) villages, and the sample, which consists of six hundred (600) farm household heads. After conducting focus-groups in ten villages and interviews with resource persons, the primary data were collected using a semi-open survey questionnaire. SPSS's descriptive and inferential analysis tools were used to analyze the data. This study shows that the poor rainfall spatiotemporal distribution and the drought are respectively the main climate hazard and water risk faced by sorghum farmers with severe environmental, social and socioeconomic consequences; It also comes out that these sorghum farmers are simply coping with the climate variability, but they do not really adapt to it; then, the lack of access to information and training about adaptation strategies, and the poverty, constitute the main constraints to the adoption of recognized efficient adaptation strategies. In this case, improving the resilience of these sorghum farmers to climate variability must absolutely go through improving their access to agricultural innovations (especially agro-meteorological forecasting) and to training, and their socio-economic (poverty), environmental, and infrastructural conditions.

### Introduction

Almost all of the scientific work on adaptation to climate variability impacts in Africa have shown that farmers have adopted adaptation strategies. Moreover, while it has been shown that some farmers truly adapt to this climate variability with visible and measurable impacts on the ground [5][6], others simply cope with it. But, contrary to most of the research works which have been limited to a critical analysis of the farmers' adaptation strategies, we have analyzed these adaptation strategies in a linear relationship between the main climate hazards, the main water-induced risks, and the adaptation strategies adopted by sorghum producers; in addition, this study sought to identify the real reasons for not adopting the scientifically recognized efficient adaptation strategies.

### Methodology

The stratified random sampling method was used to select the sites, which consist of twenty (20) villages (figure 1), and the sample, which consists of six hundred (600) farm household heads. After conducting focus-groups in ten villages and interviews with resource persons, the primary data were collected using a semi-open survey questionnaire. SPSS's descriptive and inferential analysis tools were used to analyze the data.

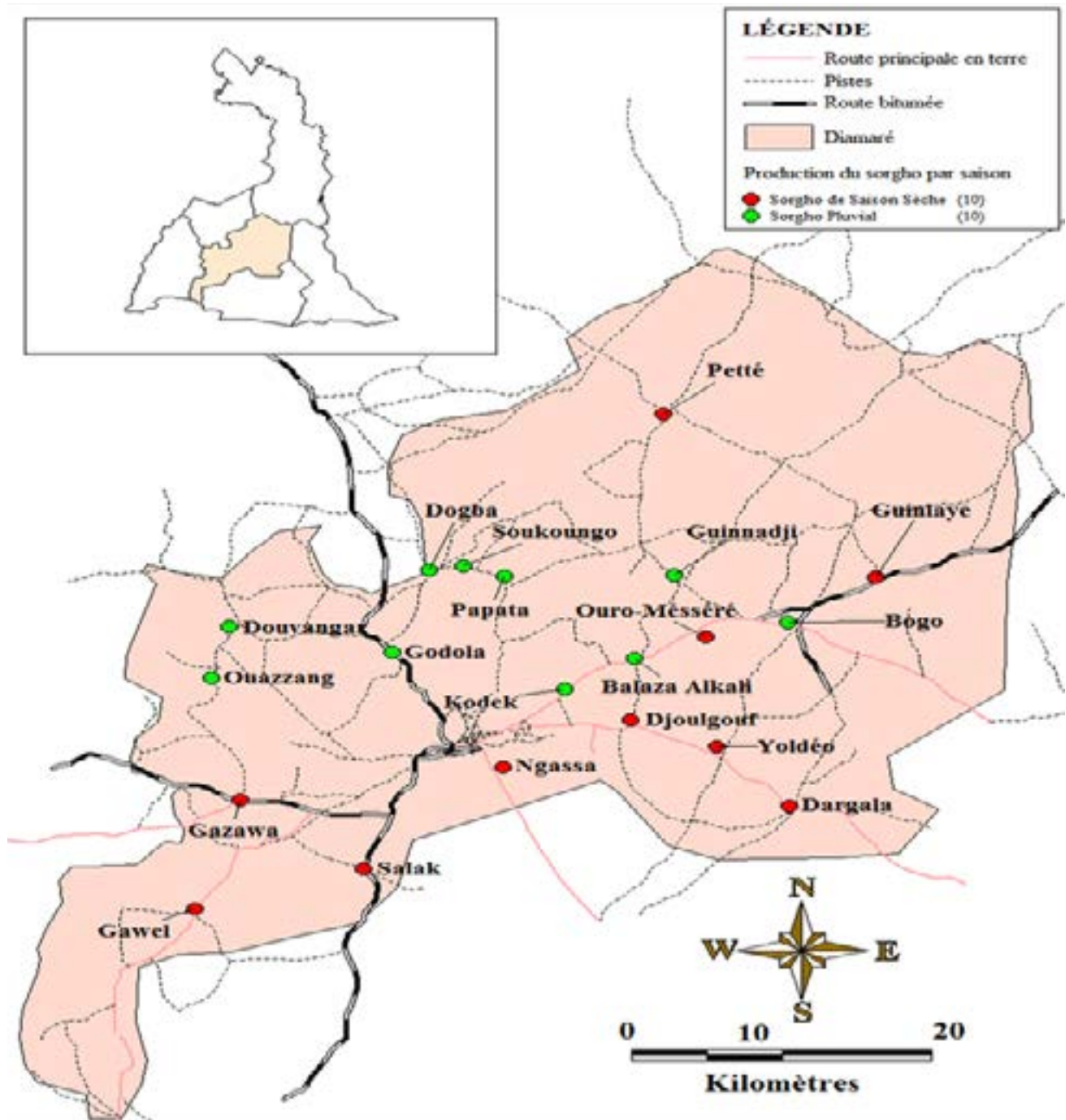


Figure 1. Study area and dry season sorghum (Red) and rainfed sorghum (Green) selected sites.

## Results

### Climate hazards dominated by the poor spatiotemporal distribution of rains

The main climate hazards identified by rainfed and dry season sorghum farmers are summarized in Table 1 below.

Table 1. Main climate hazards identified by sorghum farmers

Climate hazards	Rainfed sorghum		Dry season sorghum	
	Number	%	Number	%
Late or early onset of rains	235	78,33	109	36,33
Early or late cessation of rains	207	69	293	97,67
Poor spatial distribution of rainfall	178	59,33	212	70,67
Longer and frequent dry spells	255	85	220	73,33
Heavy rains (torrential rains)	102	34	253	84,33
Stormy rains	98	32,67	27	09
Overall decrease in the total amount of rainfall	240	80	296	98,67
High temperatures (rapid drying up of ponds and other water sources, rapid drying up and induration of soils)	-	-	295	98,33
Hot and dry winds (rapid drying of ponds and other water sources, rapid drying and induration of soils)	-	-	265	88,33
Light rains at the beginning of the rainy season	-	-	284	94,67
Absence of heavy rains at the end of the rainy season	-	-	278	92,67
Absence of haze during the dry and cool season	-	-	106	35,33

Overall, Table 1 shows that the farmers' perception of the main climate hazards, it appears that:

- the nature of the climate hazards listed by the sorghum farmers indicates that they are essentially related to rains (rainfall hazards);
- the analysis of the rainfall hazards' dynamics (the most numerous) according to their three known modes of action (absence or decline, excess, poor spatiotemporal distribution), indicates that in terms of numbers, those linked to the poor spatiotemporal distribution of the rains are the most numerous;
- the analysis of the whole climate hazards according to their frequencies and percentages of perception by sorghum farmers, indicates that the most perceived by both rainfed and dry season sorghum farmers are those related to the poor spatiotemporal distribution of the rains;



- on the basis of all these results, we could conclude that the sorghum farmers of the Diamaré division perceive that “the poor spatiotemporal distribution of the rains” constitutes the main climate hazard they are facing.

### Water risks dominated by drought, mostly of natural origin and of meteorological nature

The search for water risks induced by the different climate hazards listed by the sorghum farmers gave the results mentioned in the following table 2.

Table 2. Consequences of climate variability perceived by sorghum farmers

Climate hazards	Corresponding water risks
Late or early onset of rains	Drought
Early or late cessation of rains	Drought
Poor spatial distribution of rainfall	Drought /Floods
More frequent and longer dry spells	Drought
Heavy rains (torrential rains)	Floods
Stormy rains	Floods
Overall decrease in the total amount of rainfall	Drought
High temperatures	Drought
Hot and dry winds	Drought
Light rains at the beginning of the rainy season	Drought
Absence of heavy rains at the end of the rainy season	Drought
Absence of haze during the cool season	Drought

The analysis of the “immediate impacts” induced by the set of climate hazards listed by the sorghum farmers indicates that they lead either to water deficits that are synonymous with drought or to water excesses that are synonymous with floods. That means the main water risks that are facing these sorghum farmers are mainly droughts and floods.

### Perceived consequences of climate variability are social, socio-economic and environmental

An analysis of the climate variability consequences enumerated implicitly by sorghum farmers during the identification of the climate variability indicators gave the results mentioned in the following table 3.

Table 3. Consequences of climate variability perceived by sorghum farmers

Consequences	Frequency	%
Frequent failures of agricultural campaigns	425	70,83
Gradual extinction of old crops and crop varieties for the benefit of new ones	234	39,00
Proliferation of crop pests	354	59,00
Frequent attacks and destruction of crops by pests	329	54,83
Degradation of agricultural lands	456	76,00
Declining of agricultural yields and production	524	87,33
Decrease in the multiplication of the livestock	257	42,83
Increased frequency of famine episodes	185	30,83
Migration of farmers to other cities or villages	358	59,67

### Sorghum farmers cope with climate variability but do not really adapt to it

The summary of adaptation strategies used by sorghum farmers to combat climate hazards and water risks, indicates that they are constituted by those indicated in the following Table 4.

Table 4. Nature and frequency (percentage) of adaptation strategies' adoption by sorghum farmers

Adaptation strategies	Rainfed sorghum		Dry season sorghum	
	Frequency	%	Frequency	%
Sowing of early maturing ecotypes or varieties	131	43,67	175	58,33
Early sowing or transplanting	178	59,33	139	46,33
Sowing of drought resistant ecotypes or varieties	178	59,33	194	64,67
Diversification of crops' varieties	94	31,33	182	60,67
Diversification of crops	268	89,33	272	90,67
Changing of crops or crops' varieties	105	35	25	08,33
Plowing plots and / or ridging of plants	234	78	96	32
Temporary or permanent relocation of crops	170	56,67	30	10
Making of lockers or bunds	103	34,33	203	67,67
Use of soils and water conservation techniques (agroforestry, organic manure, mineral fertilization, stone bunds, crops' associations, crops' rotations, mulching)	271	90,33	82	27,33
Multiplication of weeding	123	41	20	06,67
Re-sowing /transplanting of melted or dried seedlings	166	55,33	05	01,67
Diversification of income-generating activities	195	65	141	47
Late transplanting	-	-	125	41,67
Variation of pile depth according to soil moisture	-	-	129	43
Nursery staggering	-	-	203	67,67
Organic or mineral fertilization of nurseries	-	-	107	35,67
Cleaning out of water sources (ponds, rivers)	-	-	131	43,67
Finding water over great distances	-	-	95	31,67

The search for the real reasons for the non-adoption by the sorghum producers of the adaptation strategies scientifically recognized as efficient, gave the results mentioned in the following table 5.

Table 5. Order of importance of the reasons for the non-adoption of efficient adaptation strategies by sorghum farmers

Reasons for not adopting adaptation strategies	Rainfed sorghum		Dry season sorghum	
	Average Rank	Rank	Average Rank	Rank
Strategies not adapted to the area	2,18	1	2,41	1
Stratégies contraignantes	3,73	2	3,56	3
Expensive strategies	4,01	3	2,96	2
High manpower demanding strategies	4,14	4	5,11	6
Unprofitable or inefficient strategies	4,37	5	4,08	4
Strategies with damaging consequences	4,58	6	5,24	7
Unknown strategies	5,00	7	4,65	5
	N	300	N	300
	W of Kendalla	,213	W of Kendall <sup>a</sup>	,306
	Khi-square	384,007	Khi-square	550,354
	Ddl	6	Ddl	6
	Sig.	,000	Sig.	,000

## Conclusion

In the rest of the Sahel, the poor spatiotemporal rainfall distribution and the drought constitute respectively the main climate hazard and the main water risk sorghum farmers are facing. But, they are simply coping, but they do not really adapt to them. A significant improvement of their resilience depends mostly on their regular access to agro-meteorological forecasting, the improvement of their access to agricultural innovations and training, the diffusion of these innovations through ICTs and interpersonal communication channels based both on innovation systems and on a pluralistic and demand-driven extension, the integrated management of socio-economic activities and natural resources; the integration of farmers agricultural innovations and formal agricultural innovations, and the improvement of their socio-economic (especially poverty), environmental and infrastructural conditions.

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## Monitoring forest fire risk under climate change in Desa'a forest, Ethiopia

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Climate change influences the spread and occurrence of forest fire. Forest fire modeling is one of the most important tasks to fight forest fires. Current climate data (1980–2010) was projected to near term (2010–2039), mid term (2040–2069) and end-term (2070–2099) using Representative Concentration Pathway (RCP4.5 and 8.5) of an ensemble of twenty General Circulation Models using R-software. Current and projected climate data were used to determine the impact of climate change on current and future forest fire using Keetch-Byram Drought Index. Current and future forest fire-vulnerable areas were mapped and weighed using Inverse Distance Weighting. The result indicates that, while no forest fire occurrence in the current, there might be a high forest fire risk in near-term. It might be become very high in mid and end-term. The size of forest fire-vulnerable areas might be increased to 12.85, 18.8, 17.1 and 46.26% in Mid-RCP4.5, Mid-RCP8.5, End-RCP4.5 and End-term-RCP8.5 respectively. Fire may occurred in winter and spring seasons. The risk might move to higher elevation of the forest. This directs increase of forest fire occurrence and spread due to climate change. The study recommends that forest fire management should be applied before fires happen to sustain the forest and its products.

**KEY WORDS:** Wildfire; Forest; Drought; Risk; KBDIS

## Introduction

Forest fire is a disaster that destroys forests and wildlife [8][2]. Climate, weather conditions and topography influence the fire regime by determining the fuel distribution and the occurrence of fire. Climatic factors such as wind, temperature and drought influences incidence and spread of forest fires [10][13] and there is strong linkage between drought and forest fire [3]. Prolonged drought and strong wind speed [6] with high temperature and low rainfall creates natural forest fire.

Direct measurements of forest biomass moisture and fuel are slow, time consuming and expensive. Modeling forest fire vulnerability based on meteorological data is more significant [7] [12]. The Keetch-Byram Drought Index (KBDI) is a fire potential index which is widely used in the United States where it is a part of the National Fire Danger Rating System. It is used to estimate forest fire based on meteorological data [9][11]. The main purpose of this paper is to investigate the impact of climate change on the spatio-temporal forest fire occurrence using Keetch-Byram Drought Index (KBDI) and Arc GIS in Desa'a forest.



## Methodology

### Study area

Desa'a protected forest lies between 130 20' and 140 10' North and 390 32' and 390 55' East. It is positioned at a strategic site in northeastern Tigray and northwestern Afar, well placed for joint regional planning and its tributaries flow towards the Afar plains.

## Methods

### Climate input datasets

Climatic variables namely; maximum temperature and rainfall were used for this study. Maximum temperature was obtained from ENACTS satellite while gauge blended data and rainfall were obtained from CHRIPS daily rainfall data which are produced by interpolation of meteorological and satellite data. The data were obtained from 1981 to 2016. The obtained data were projected to near (2010–2039), mid (2040–2069) and end term (2070–2099) using R-software using ensemble of twenty General Circulation Models (GCMs) in two Representative Concentration Pathways (RCP) 4.5 and 8.5 which describes both medium and high emission scenarios.

### Keetch–Byram Drought Index (KBDI)

The KBDI was developed by the United States Department of Agriculture's Forest Service for forested and wild land areas of the south-eastern United States. Over the years it has also been applied to many other regions of the world [4]. The climate data used to estimate forest fire were taken from the lowland (Berahle district) and highland (Astibi district) part of the forest. KBDI of the two elevation classes were calculated and categorized according to Table 1. Calculated forest fire risk area of the two points was interpolated to the whole forest area using Inverse Distance Weighting (IDW).

Table 1. KBDI fire risk levels

KBDI (inches)	Risk Levels	Description
< 99	Very Low	Upper soil and surface litter are wet and fire potential is very low
100-199	Low	Upper soil and surface litter are moist and do not contribute to fire
200-299	Moderate	Upper soil and surface litter are moderately dry and may contribute to fire
300-399	High	Upper soil and surface litter are dry and contribute to fire intensity
400-599	Very High	Upper soil and surface litter are very dry and fire suppression is a significant
600 +	Extreme	Upper soil and surface litter are extremely dry and increase wildlife occurrence

## Result

### Forest fire risk period

The intensity of current and future forest fire using KBDI in Desa'a forest is 145, 383, 367, 425, 437, 433 and 476 in current, near term RCP 4.5, near term RCP 8.5, midterm RCP 4.5, midterm RCP 8.5, end term RCP 4.5 and end term RCP 8.5, respectively. This means, in present time frames there is low forest fire occurrence. In the near term there may be a high probability of forest fire occurrence. However, in the medium and high emission scenarios of mid and end term, there

may be a very high forest fire occurrence. In addition, the risk is higher in winter and spring (Figure 1, 2).

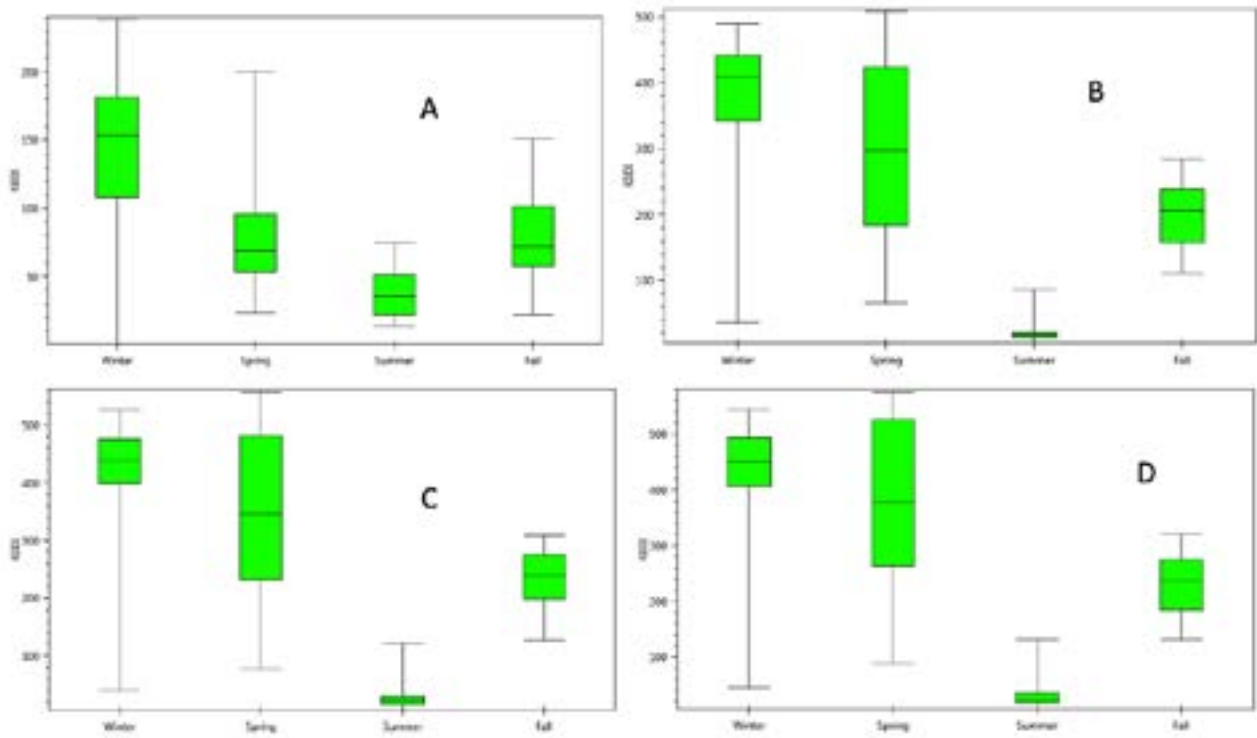


Figure 1. Forest fire risk seasons in medium emission scenario A) current B) near term C) midterm D) end term

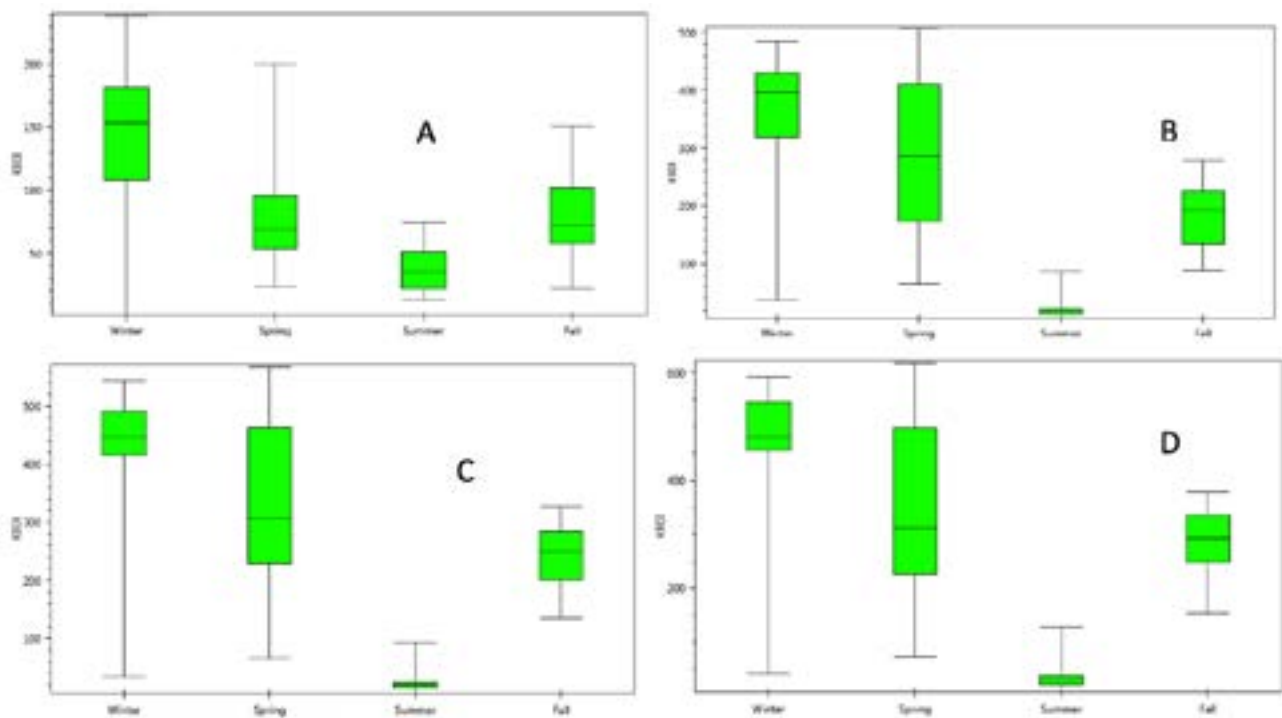
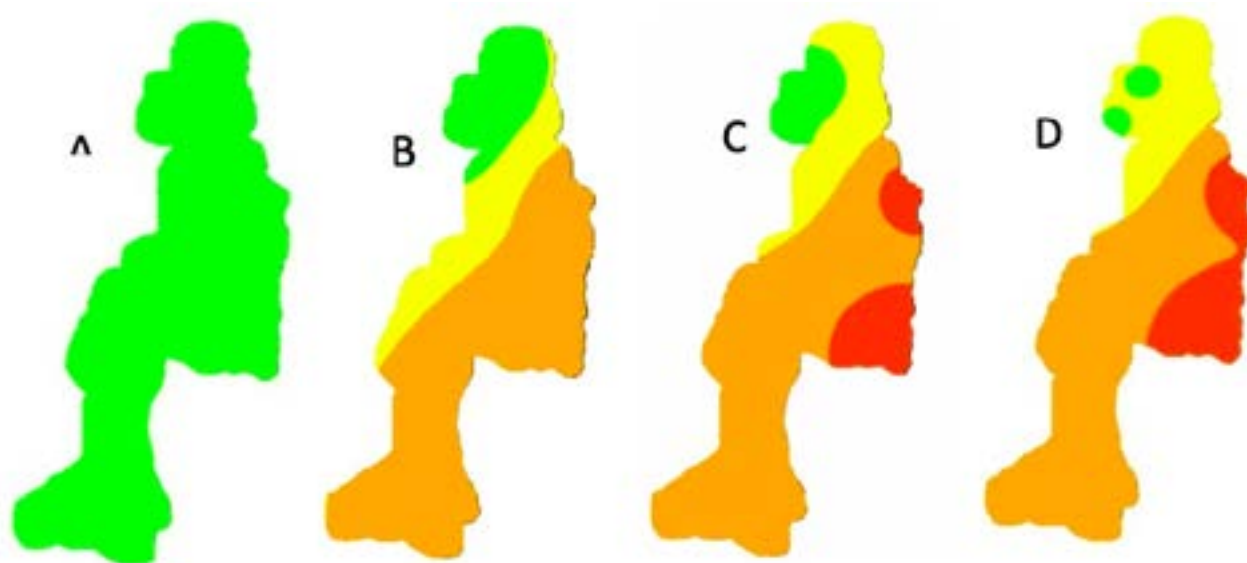


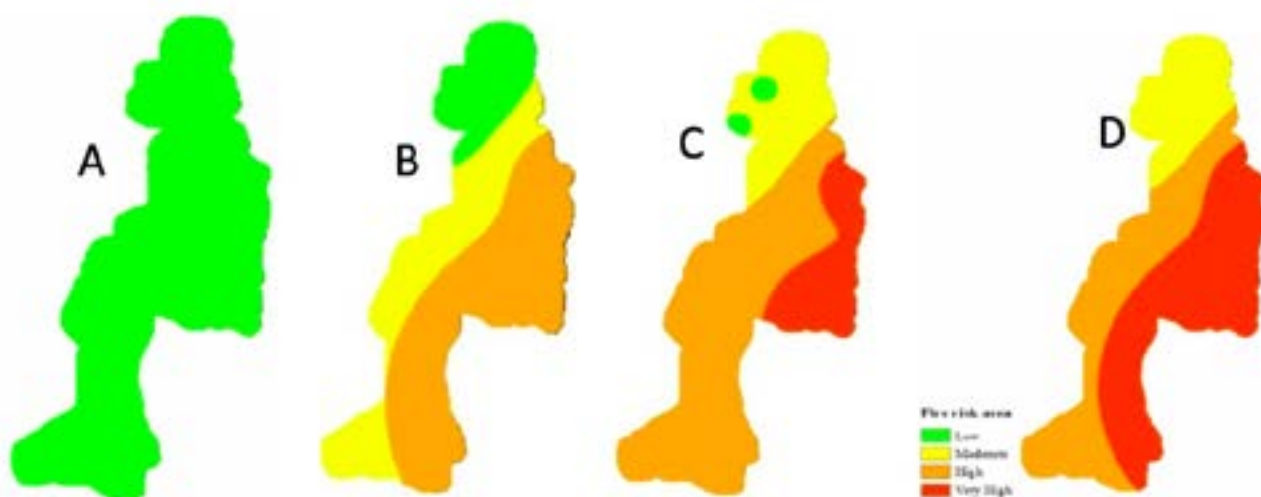
Figure 2. Forest fire risk seasons in high emission scenario A) current B) near term C) midterm D) end term

### Forest fire risk area

Currently, there is no wildfire risk areas in the forest. However, there might be high wildfire vulnerable area in the near term of RCP 4.5 and 8.5. In the current and near term scenarios there is low to high fire vulnerability areas. However, there might be very high forest fire vulnerable areas in the mid and end terms of the century. High and very high forest fire vulnerable areas may increase from zero to 12.85, 18.8, 17.1 and 46.26% in Mid RCP 4.5, Mid RCP 8.5, End RCP 4.5 and End term-RCP 8.5 of the century, respectively (Figure 3, 4).



**Figure 3.** Forest fire risk area in medium emission scenario A) current B) Near C) Mid D) End term (green, yellow, gold and red color shows low, moderate, high and very high forest fire risk respectively).



**Figure 4.** Forest fire risk area in high emission scenario A) current B) Near C) Mid D) End term

There might be low to medium forest fire occurrence in the highland parts of the Desa'a forest, whereas in lowland parts of the forest there might be source of ignition to wildfire. Additionally, there might not be a very high severity of fire in current and near term scenarios, however it might occur in the mid and end term, and shifts to high elevation due to climate change (Table 2).

Table 2. Attitudinal shift of forest fire occurrence

Time Slices	High (m.a.s.l)	Very high (m.a.s.l)
Mid RCP 4.5	965-2676	965-2155
Mid RCP 8.5	1193-2676	965-2268
Mid RCP 4.5	1080-2676	965-2239
Mid RCP 8.5	1227-2635	965-2676

Similar studies [5][1] indicate that the world's forests will be vulnerable to wildfires due to climate change. Flannigan et al. (2009) study further validates that in circumboreal forest wildfire is projected to increase by 18% and 50% in the near and end term of the century respectively[5].

## Conclusion

This study finds out that there is a potential wildfire occurrence due to impacts of climate change. The study further demonstrates that forest fire risks might reach the maximum level during winter and spring seasons. Notably the lowland part of the forest is more vulnerable to wildfire ignition than other parts located at higher altitudes. Hence, the study recommends that sustainable forest fire management practices such as firebreak construction should be applied to control the fire.

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## Farmers' Adaptation Strategies to the Impacts of Climate Change on Rice Production in Anambra State, Nigeria

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The study investigated farmers' adaptation strategies to the impact of climate change on rice production in Anambra State, Nigeria. Purposive sampling procedure was used in selecting ninety-six rice farmers across eight rice-producing communities in Anambra State. Key informant interviews, personal observations and surveys were used in collecting both qualitative and quantitative data from the respondents. All the respondents indicated that climate change had a devastating impact on rice production in the areas of low yield as a result of reduced grain quality and increased rice chaff content (95.8%), low income arising from low yield (97.9%), among others. A greater proportion (59.4%) of the respondents sourced for climate change related information on rice production mainly from fellow farmers. The adaptation strategies mostly adopted by farmers were drainage management (99.0%), furrow-irrigated raised bed planting (99.0%), minimum tillage (99.0%), integrated nutrient management (81.3%) and crop diversification (72.9%), among others. Major constraints perceived by the farmers to their use of the adaptation measures were poor government assistance in the provision of funds for adopting adaptation measures, high cost of applying rice production technologies, poor credit access, poor profit margin realized from rice production as a result of applying adaptation measures, and flooding, among others. The government should provide an enabling environment for the application of adaptation measures by rice farmers through the provision of credit facilities.

### Introduction

Climate change has posed a significant threat to sustainable agricultural production in Nigeria since agriculture is mostly rain-fed. In Southeast Nigeria, the evidence of climate change is glaring – droughts have been relatively less persistent, rainfall is observed to be increasing, while temperature increases and decreases moderately over the years. Anambra State, located in the Southeastern part of the country, is a riverine area always prone to excessive rainfall and flood and these extreme weather conditions have increased over the years due to climate change. These fluctuations in climatic conditions can exert pressure on the crop agriculture sector adversely, especially in rice production [6], which is one of the most important staple food crops in Nigeria.

In Nigeria, there has been a steady increase in rice production over the years, from 600,000 metric tonnes in 1980 to 3.7 million tonnes in 2017 [3][5]. This large improvement in rice production has been due to the intervention of the federal government in the local rice industry and as well as increased acreage of land placed into production [3]. However, it is uncertain whether it will be possible to sustain increasing rice production into the future, due to its susceptibility to climate change. Rice is sensitive to the climate and as such unfavourable changes in climatic factors (such as temperature, precipitation and relative humidity) is expected to affect rice yield and yield stability adversely [2][7].

In order to sustain and promote rice productivity in the face of climate change, rural farmers' use of adaptation strategies is imperative. According to the Intergovernmental Panel on Climate Change (IPCC), adaptation practices are adjustments made to enhance resilience or reduce vulnerability to observed or expected changes in climate [4]. Adaptation strategies can reduce farmers' vulnerability to extreme climatic events such as droughts and floods [2] and help them cope with both current climate variability and future climate change [1].



In response to the adverse effects of climate change on rice production, farmers have adopted various adaptation strategies in many rice-producing countries including Nigeria. However, it is important to note that the magnitude of climate change in a given location determines the response of the particular crop and specific adaptation strategies used by the farmers, which is based on the local context [3]. Furthermore, farmers may face certain location-specific constraints to using climate change adaptation strategies and this could decline rice productivity. Therefore, the study was borne out of the need to investigate the location-specific adaptation strategies to climate change impacts on rice production and constraints to the use of adaptation strategies in flood-prone areas of Anambra State.

## Methodology

The study was conducted in flood-prone areas of Anambra State. The population for the study comprised all farmers who were actively engaged in rice production (they spend at least 75% of their farming time in rice production) in the state. Multistage and purposive sampling procedures were employed in selecting respondents for the study. In the first stage, two (2) senatorial zones (Anambra and Aguata) were purposively selected due to the prevalence of adverse climate change effects on rice production activities. In the second stage, two local government areas were randomly selected from each of the senatorial zones to give a total of four local government areas. The selected LGAs were Orumba South, Orumba North, Anambra East and Ayamelu. In the third stage, two town communities were selected purposively in each LGA due to their intensity in rice production making it a total of eight town communities. The town communities selected were Ifite-Ogwari, Umumbo, Nando, Aguleri, Ogboji, Ezira, Omogho and Ufuma. In the fourth stage, a list of rice farmers were collected from the community leader in each community, out of which twelve farmers were randomly selected. Thus, the total sample size for the study was ninety-six (96) farmers. Key informant interviews, personal observations and surveys were used in collecting both qualitative and quantitative data from the respondents.

Farmers were asked to indicate the perceived impacts of climate change on rice production as well as the adaptation strategies used in cushioning the impacts of climate change. Perceived constraints to farmers use of climate change adaptation strategies was measured on a five-point Likert type scale of very serious, serious, a little serious, not serious and not at all, with response options 4, 3, 2, 1 and 0, respectively. The mean cut-off score was 2. Descriptive statistics such as percentages and mean scores were used in analyzing the data.

## Methodology

All (100.0%) of the respondents indicated that there had been changes in their farming environment over the past ten years and attributed it to climate change. The respondents indicated the following as evidence of climate change; late onset of rainfall (82.3%), high sun intensity (72.6%), flooding (44.8%), drought (27.1%) and early onset of rain (5.0%). Furthermore, all (100.0%) of the respondents indicated that climate change had a devastating impact on rice production in the areas of low yield as a result of reduced grain quality and increased rice chaff content (95.8%), low income arising from low yield (97.9%) and increased pest and disease attack (86.5%). A greater proportion (59.4%) of the respondents sourced for climate change related information on rice production mainly from fellow farmers (44.8%). However, only 16.7% of them sought climate change information from extension agents. In response to the perceived impact of climate change on rice production, the adaptation strategies mostly adopted by the farmers were drainage management (99.0%), furrow-irrigated raised bed planting (99.0%), minimum tillage (99.0%), direct seeded rice (99.0%), integrated nutrient management (81.3%), crop diversification (72.9%), use of improved rice variety that is tolerant to flooding (44.8%) and adjusting planting date (41.7%). The farmers gave reasons for making use of the adaptation strategies. For example, they affirmed that furrow-irrigated raised bed planting helped to retain

water in the soil; drainage management aided in the removal of excess water by opening a part of the bond and allowing water to run off; directed seeded rice required less water compared to traditional transplanting and; zero/ minimum tillage held nutrients and water more in the soil. Major constraints perceived by the farmers to their use of adaptation measures were; poor government assistance in the provision of funds for adopting adaptation measures ( $M = 3.78$ ), high cost of applying rice production technologies ( $M = 3.56$ ), flooding ( $M = 3.35$ ), poor profit margin realized from rice production as a result of applying adaptation measures ( $M = 3.33$ ), poor credit access ( $M = 3.02$ ), high cost of labour ( $M = 2.93$ ), pest and disease attack ( $M = 2.68$ ), poor knowledge of innovative adaptation strategies ( $M = 2.68$ ) and poor extension services ( $M = 2.50$ ), among others .

## Conclusion

The location-specific adaptation strategies identified would serve as a useful guide in assisting policy makers in designing appropriate policies aimed at mitigating the adverse impacts of climate change on vulnerable communities in Anambra State. The study reveals that climate change has had a devastating impact on rice production. Since the study area is flood-prone, farmers mainly used age-long adaptation strategies involving water management and strategies to enhance soil fertility. This enabled them to adjust to the adverse impacts of climate change to some extent. However, it was observed that innovative adaptation measures such as weather based crop agro-advisories and contingent crop planting were not mostly used by the farmers probably because of lack of/inadequate awareness about these strategies. There is a critical need to strengthen agricultural research and support services to enhance information availability, accessibility and training on climate change adaptation measures to rice farmers by the government. The perceived constraints to farmers' use of adaptation strategies were mainly in the areas of inadequate government support in terms of financial assistance and inadequate institution support. The government should provide an enabling environment for the application of adaptation measures by rice farmers through the provision of credit facilities.

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## Psychological Dimensions of Climate Change: Vulnerability, Perceptions, Collective Efficacy and Responses in Berehet District, North Shoa, Ethiopia

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### Introduction

Human behavior has caused the earth's temperature to rise rapidly, and has disturbed the rainfall distribution behavior in the past centuries. Its impacts are far-reaching and, to varying degrees, potentially very damaging to all sectors and communities [4][5]. Impacts of climate variability are particularly harmful in Ethiopia, where rainfed agriculture is widely practiced. Frequent and severe drought, especially in the northeast, south and southeast lowlands and northern highlands of Ethiopia causes extensive damage to livestock and crop production [1][2]. Climate variability has been also important constraint for regions like the Amhara where the majority of people depend primarily on subsistence rainfed agriculture [9][6].

High population pressure, intensive and traditional farming systems, lack of appropriate land use policy, poverty and massive deforestation collectively have been playing tremendous roles in accentuating impacts of climate variability in Ethiopia. However, beyond the physical and socio-economic factors, the psychological factors are also central in dealing with the shocks caused by climate variability [3][8]. Understanding human responses to climate variability necessitates an integrative social sciences perspective, in terms of disciplinary, theoretical, and methodological approaches. It is, therefore, from this underlying fact that the researchers were gravely interested to uncover the major psychological dimensions of climate variability among people of Berehet district, North Shoa Zone, Amhara Region, Ethiopia.

### Methodology and Findings

This research was conducted to assess farmers' vulnerability and their collective and individual response mechanism to climate variability and extremes. Sequential mixed research design was applied. A total of 22 key informants and 32 FGD participants were purposely selected for the qualitative data. Quantitative data was secured from 124 randomly selected farmers through questionnaire. Three decades of temperature and rainfall data was also collected from National Meteorological Agency. Appropriate qualitative and quantitative data analysis techniques were employed.

### Results

Accordingly, the study revealed that the district has been experiencing a declining rainfall and increase in temperature. Persistent drought, low potential of surface and underground water, recurrent crop pests and animal diseases are adversely affecting farmers' productivity. Farmers attributing rainfall shortages and variability to the "annoyance of God" is decreasing. However, farmers' collective efficacy level of reversing the drought situation was found to be low. As a result, farmers are vulnerable to serious dependency syndrome. Social loan services, borrowing crops from relatives, working through Jegie have been major indigenous responses while planting drought resistant crop varieties, rainwater harvesting, destocking, cut and carry livestock feeding and soil and water conservation measures were major planned adaptation responses to the adverse impacts of climate variability.

**KEY WORDS:** climate variability, psychology, vulnerability, farmers' responses, collective efficacy

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## Attribution-Based Parametric Insurance: Towards Affordable Premiums

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To deal with the adverse impacts of climate change, index-based or parametric insurance has been recognized as an adaptation technique to compensate farmers for economic losses from extreme weather events. The insurance can be either private or sovereign. African Risk Capacity Insurance (ARC Ltd) offers the latter to African countries against drought events through contingency planning, risk pooling and transfers. While the insurance initiative seems promising, the current pricing policy does not consider the change in risk from anthropogenic climate change. As the frequency of extreme weather events rises, the price of insurance premiums is likely to rise. Representing a cutting-edge science from weather to impact attribution, this study links both attribution modelling with parametric insurance modelling to quantify how the probability of drought events has changed due to human influence on the climate system and translates the impacts into actual costs. To quantify this change, global climate models consisting of both factual and counterfactual world (without greenhouse gas emissions) experiments were post-processed and used as rainfall inputs into the insurance modelling software, Africa RiskView. Estimated response costs needed for drought assistance in a world with and without climate change were calculated in Malawi for the last 30 years. The empirical cumulative distribution function (ecdf) plots show that the distributions of models that represent the counterfactual natural world estimate lesser drought-affected population and lesser response costs for assistance than those of the factual world distributions. Although the results are preliminary, they suggest that climate change is likely to increase the price of insurance premiums in Malawi.

## Introduction

Anthropogenic climate change provides a key challenge for mankind and affects many sectors including the agricultural sector, which is a critical pillar for sustainable economic development [4][10]. This is particularly challenging in regions of Africa, where agriculture is highly dependent on rainfall [5][10].

To help farmers cope with extreme events impacts, index-based or parametric insurance has been recognized as an adaptation technique to compensate farmers for economic losses from extreme events. Index-based insurance schemes bring along a proactive lens, which represents a major shift from the reactive nature of traditional agricultural insurance [3]. This form of insurance uses rainfall levels, crops yield or a vegetation index as objective parameters which trigger payments when a specified threshold is exceeded [8]. The insurance can either be private, where private losses are insured or on a sovereign level, where countries insure against national scale damage [8][12].

While parametric insurance seems to be a promising initiative, the current policy does not consider the change in risks of extreme events due to human influence on the climate system. As the risk of extreme weather events increases, so will the cost of insurance, and this has both business and ethical implications. If insurance premiums get too high, vulnerable developing countries may not afford to take up insurance. The challenge thus lies in finding a way to make parametric weather insurance attractive to insurers, farmers and policymakers. By using the lens of attribution science [11], this study seeks to address both the business and ethical implications of climate change on parametric weather insurance. A novel idea, with scientific and developmental objectives, is explored by merging attribution science modelling with parametric insurance modelling to answer the following research question:

“Can attribution science be used to apportion the cost of insurance premiums between the background risk and the added risk from climate change?”

To answer the above research question, the probability of rainfall levels used in the insurance risk models is assessed to ascertain if the risks of drought event have changed due to human influence on the present-day climate, and if so, how the changed probability translates into the expected damage, and hence the cost of insurance products offered.

### **African Risk Capacity Insurance Company Limited**

African Risk Capacity Insurance (ARC Ltd), under the auspices of the African Union (AU), offers sovereign level insurance to African countries against extreme weather events (drought in this case) through contingency planning, risk pooling and transfer facilities to interested and affected African countries [1].

### **Africa Risk View**

To estimate risk, ARC uses the Africa Risk View (ARV) model. The number of people affected in a given area, as well as the response costs needed for assistance during a drought event, are estimated using ARV. The model uses dekadal (10-daily) rainfall data to calculate cumulative rainfall in an area and defines a rainfall threshold for a growing season. The rainfall estimates, along with other static inputs such as potential evapotranspiration and soil water holding capacity, are translated into spatial drought index using the Water Requirements Satisfaction Index (WRSI) model, originally developed by the Food and Agriculture Organization (FAO). The WRSI is in turn used to determine how a shortage in soil moisture may impact crop yields and pasture. The WRSI model monitors water deficit throughout a growing season and accounts for the amount, distribution and timing of rainfall on rain-fed crops. Thereafter, the drought index is overlaid on social indicators such as population vulnerability information to estimate the population affected by drought. The response costs are then estimated by multiplying a fixed cost (usually \$USD 100 for bimodal & \$USD 50 for unimodal rainy seasons) per person. The national modelled drought response costs underlie the basis of parametric insurance products and premiums that are negotiated with governments and insurance partners. [2].



## Methodology

This project was undertaken in two phases: post-processing of Global Climate Model (GCM) data into formats appropriate for use into ARV and the use of ARV to estimate response costs due to water stress in a given growing season.

### Data Post-Processing

Daily rainfall data from 15 GCMs, representing both the factual (historical simulations natural and human forcing) and counterfactual (natural forcing only) were extracted from the Coupled Model Intercomparison Project phase 5 (CMIP5) (see GCMs in Figure 1 legend). The factual world models' experiments consist of historical rainfall data up to 2005 and were extended with Representative Concentration Pathways (RCP8.5) up to 2018. The counterfactual models' experiments consist of historical rainfall data, for the last available 30 years. The observational dataset used is the African Rainfall Climatology version 2 (ARC2), one of the three satellite-based datasets used in the ARV software.

### Model Evaluation and Bias-Correction

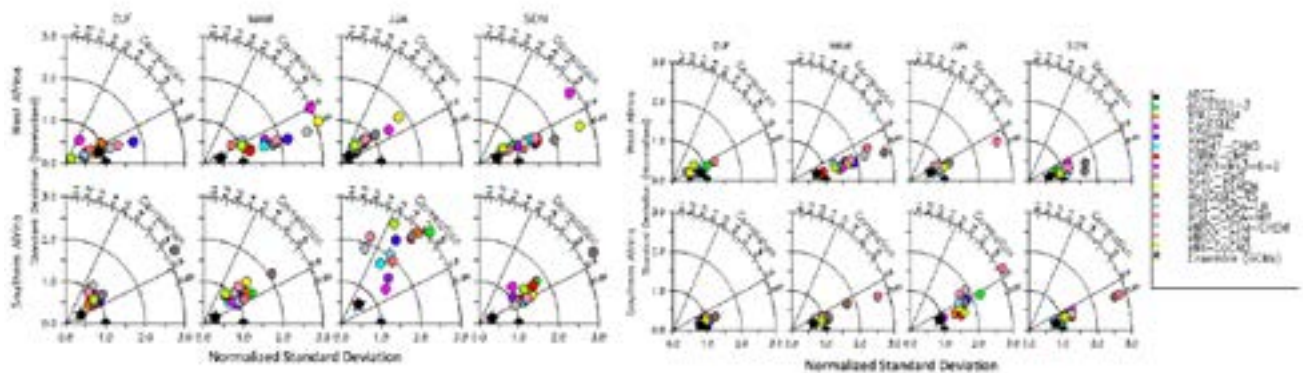
The models were re-gridded, and bias-corrected, against the observation resolution (0.1o) to cover the Africa-wide domain (-40o:40o lat, -20o:55o lon). Since ARV takes dekadal rainfall datasets, both models and observations were converted from daily to 10-daily rainfall, resulting into three dekads per month. The evaluation of the models was completed in two stages: evaluation before and after bias-correction on a seasonal, monthly and dekadal basis. The bias-correction was done using a quantile-quantile mapping of values [7]. For the historical factual world, the quantiles were calculated matching values at given percentiles on the distributions of the models and observation. For the counterfactual natural world, the models were matched against the factual models before being bias-corrected against the observation to preserve their differences.

### Use of ARV

The bias-corrected GCMs were converted into Image Display and Analysis (IDA) format (the format ARV uses with a maximum rainfall of 253 mm) and used as inputs into the insurance software model to calculate estimated response costs for a recent insurance estimation in Malawi previously undertaken by ARC. All other parameters in the model were held constant and rainfall was the only variable changed.

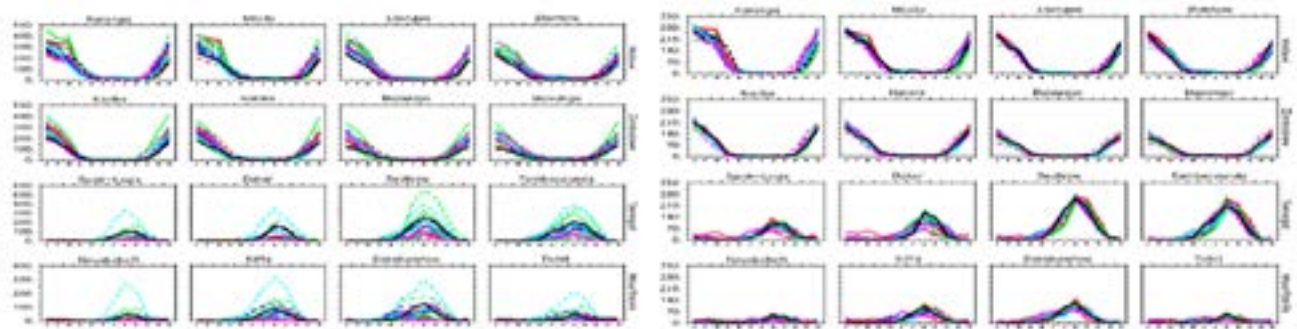
## Results

The Taylor Diagrams below show the correlation coefficients and normalized standard deviation of the seasonal mean precipitation of both models and observations before and after bias-correction (Figure 1). None of the models was negatively correlated to the reference observation over all seasons and all of the models evaluated showed improvement after bias-correction.



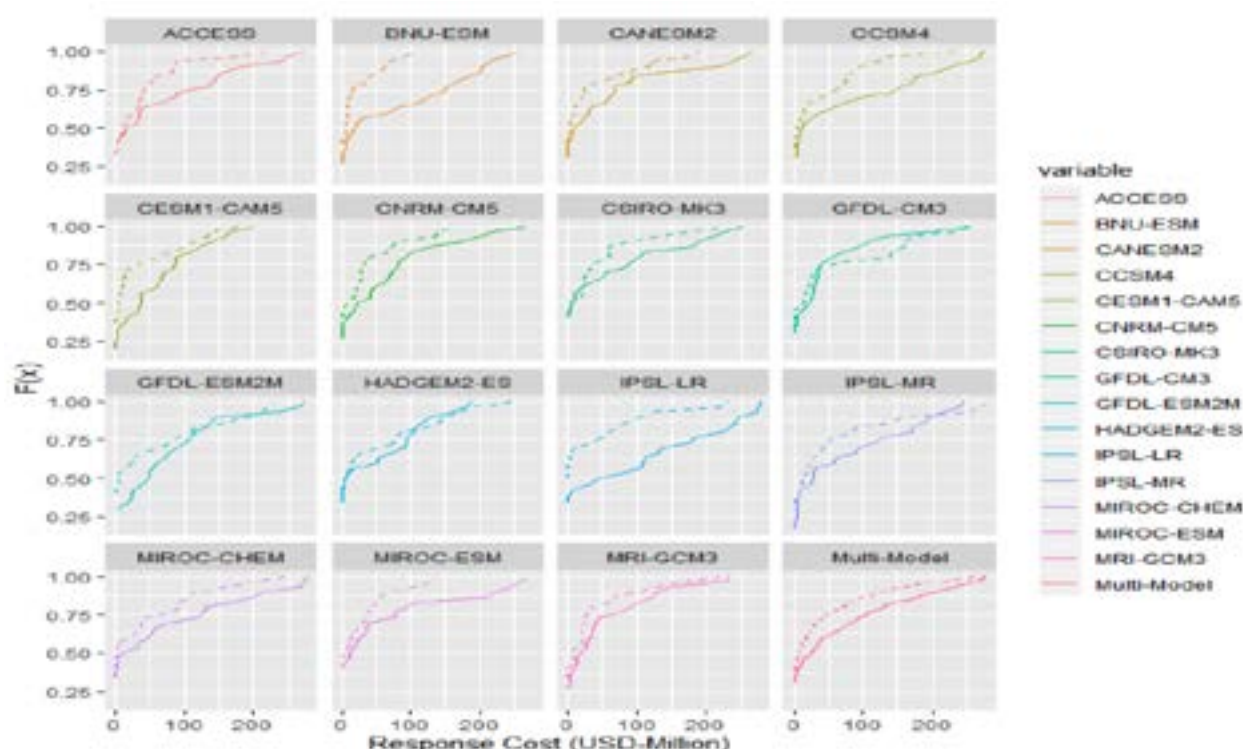
**Figure 1.** Taylor Diagrams showing seasonal mean precipitation for four seasons over West and Southern Africa from 1989–2018 for 15 models and a reference observation, left (uncorrected); right (biased-corrected)

The annual cycles show the mean monthly total precipitation in four cities in Malawi, Zimbabwe, Senegal and Mauritania respectively (Figure 2). The models captured the seasonality of rainfall in the respective regions before and after bias-correction and models performance improved after bias-correction, most especially in the Southern African countries.



**Figure 2.** Annual cycles showing monthly total mean precipitation for all months over four cities in Malawi, Zimbabwe, Senegal and Mauritania respectively from 1989–2018 for 15 models and a reference observation. Left (uncorrected); Right(biased-corrected)

The individual empirical CDFs plotted for estimated response costs in Malawi (Figure 3) show that the cost of responding to drought, as estimated in ARV, is lower for the counterfactual natural world than in the world we live in with climate change. Using the multi-model ensemble (which represents all models) as a reference, 75% (0.75 on the y-axis) of the response costs in the counterfactual natural world is less than USD 50 million, while 75 % of the response costs in the factual world is less than USD 100 million.



**Figure 3.** Empirical CDFs of the estimated drought response costs for 15 individual GCMs and a GCM ensemble consisting of the historical world (solid line) and the natural world (dash lines) over 1989–2018. The same response is evident for the estimated population affected (not shown), as the response cost for Malawi is a simple multiplier (\$USD 42) of population affected 1.1 million people in the counterfactual world and 2.4 million people in the factual world.

## Discussion and Conclusion

According to Gewirtzman et al. (2018), insurance schemes have been identified by the Warsaw International Mechanism (WIM) as a market-based instrument for addressing loss and damage [6], but it may not be reliable over time as it is subsidized by voluntary contributions and burdens vulnerable countries. As seen in this case, the results indicate that the estimated number of people affected by a drought event in a given year and the response costs required to assist those people are higher in the real world than a world without human-induced climate change. This suggests that human-induced climate change is affecting the cost of parametric weather insurance and will continue to do so, at an even higher rate, if business continues as usual.

Furthermore, the Intergovernmental Panel on Climate Change (IPCC) report states that the continent of Africa accounts for the least amount of greenhouse gas emissions but will be the most vulnerable to climate change [9]. It has also been ruled out in the Paris Agreement and WIM of the United Nations Framework Convention on Climate Change (UNFCCC) that direct compensation be given to vulnerable countries to address the socio-economic losses from climate change [12]. Using this case study as a scientific evidence, it can be practically argued that there should be a blend of international climate funds such as the Green Climate Fund (GCF) or other multilateral climate funds to account for the cost of the added risk from climate change, to make insurance premiums more affordable for vulnerable countries. Under such an approach, developing countries will have the responsibility of catering for natural variabilities in the climate or weather system, while any added costs brought on by climate change will be catered for by those responsible for the high level of damage.

To conclude, although the results are preliminary and the study is still ongoing in other countries, the initial results have already hinted that climate change is likely to increase the cost of

parametric weather insurance premiums. However, it should be noted that the results shown here are case-specific for Malawi and different results are likely in other countries.

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## Increasing rising Sea Surface Temperature and its implications on coastal areas in South Eastern Coastal Areas of Africa.

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The IPCC Special Report on the impacts of global warming of 1.5 °C above pre-industrial levels in 2018 warned that human beings had caused global temperature to increase by about 1°C and was on course to reach the tipping point of 1.5°C by 2030 if greenhouse gas emissions are not drastically cut. World Meteorological Organisation shows that the past five years or so have witnessed record high temperatures as greenhouse gas continue to spike raising fears of increased global warming. Anthropogenic warming has resulted in a drastic increase in sea surface temperature, which has recorded unusually high temperatures in recent past. Given the centrality of oceans in controlling global climate and weather, changes in sea surface conditions are feared to alter global climate and weather further worsening global climate vulnerability particularly that of developing countries which have poor resilience and adaptation capacity. In a case study that uses both primary and secondary data, this study seeks to show that increased surface temperature has been the leading factor in driving wave of increased cyclonic activities of historical magnitude in the Indian Ocean with devastating impact on island states and coastal areas in Southern East Africa. The research recommends serious investments into climate adaptation and resilient measures, and also disaster preparedness and management to reduce the impact and cost of extreme cyclones in the region to ensure sustainability going forward.

**KEY WORDS:** Tropical Cyclone Idai, Kenneth, flooding, sea surface temperature

## Background and Introduction

There is increasing consciousness and awareness on the pace of increase in the occurrence of extreme weather events across the world primarily attributed to climate change. The growth in anthropogenic greenhouse gas (GHG) emissions has been a subject of great concern in as much as this increase has been matched by the rise in average global temperature and the frequency, severity and losses from extreme weather events across the world. Global warming has been noted to be the key driver of climate change-related extreme weather events [2]. There is a growing concern over the impact of global warming on global oceans as the driving force for global climate disturbances. Increased global warming has a consequence of increasing sea surface temperatures, rising sea levels, intensification of harmful algal blooms [3].

Increasing sea surface temperature in the Southern eastern parts of Africa has been reported to be the leading driver of Tropical Cyclones and storms in the Mozambique channel which normally occur mid to late summer with devastating impacts on countries and areas near the coastal regions, which suffer the brutality of hurricanes and cyclones. According to Ash and Matyas (2012) and Mavume et al. (2009), tropical orogenesis in the Mozambique channel is a factor of vertical wind shear and high sea surface temperatures (SST) of above 28°C [1][5]. Jury et al. (1991), had observed the central role played by Cross-equatorial trade-wind flow as a crucial component for moisture advection into the Mozambique channel, and also the centrality of the Intertropical Convergence Zone aiding and abetting cyclonic vorticity at low levels and divergent anticyclonic outflow aloft to aid tropical cyclone formation [4].

This paper seeks to investigate the trend of SST and draw relationship with Tropical Cyclone trends in South East Africa coastal area. The study seeks to investigate the impact of rising sea temperature on South East Africa resultant weather patterns on communities resident in the region.

## Research Methodology

The study made use of archival data from various databases such as Wunderground Tropical Cyclone. The Wunderground archive is populated by data from NOAA with regards to past records of global tropical storms and cyclones. Subsequently, NOAA data from the National Centers for Environmental Information archive and Copernicus archived monthly data was used to determine Sea Surface Temperature Anomalies. Data on sea levels was obtained from NOAA/NESDIS/STAR laboratory for satellite Altimetry/ Rising Sea Level Data for sea surface temperature anomalies was obtained from for weather and climate, secondary data obtained from Topex and Jason 1-3 Space missions. Data from United Nation Agencies and other authoritative sources to draw conclusions and results.

## Results and discussion

The study found that on a global scale the sea surface temperature for the first three months of the year 2019 namely January, February and March in the Southern Hemisphere recorded 3-Month Running Means of SST Anomalies above average coming only second to the year 2016. This follows the pattern that have been observed over the past couple of years where global and sea surface temperatures are on an upward trend (see Figure 1).



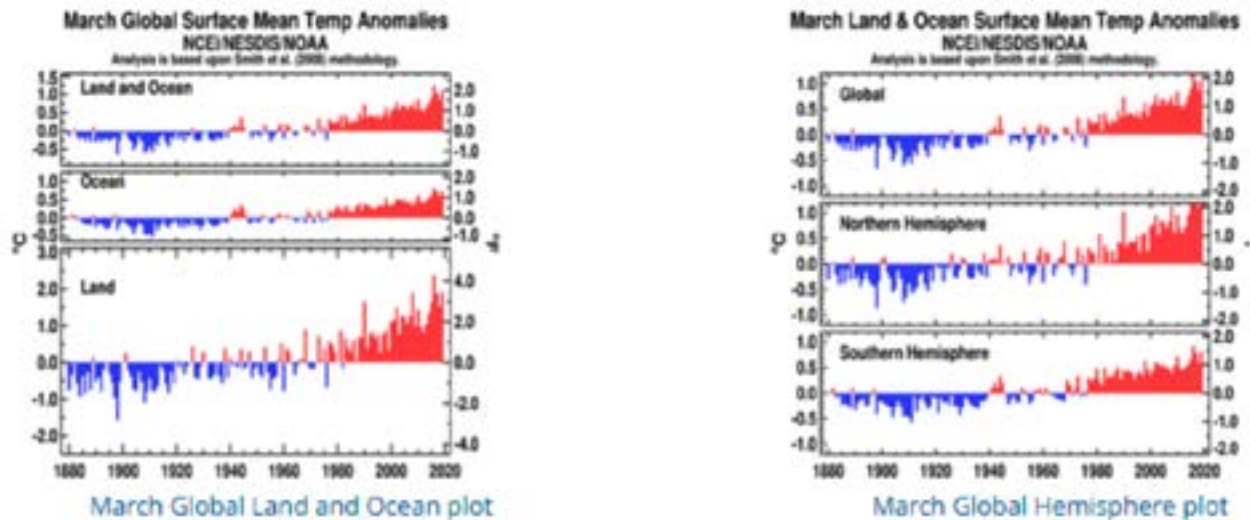


Figure 1. Global Surface Temperature Anomalies

According to records from NOAA sea surface temperature globally was  $0.90^{\circ}\text{C}$  above the 20th century average. This temperature represents the third-highest sea surface temperature recorded between January and March since the beginning of records on Sea Surface Temperature (SST) which started in 1880. In the Southern Hemisphere, SST for the same period was  $0.67^{\circ}\text{C}$  which made it also the second warmest period after 2016 and making a tie with 2017. April temperatures in the Indian Ocean were equally warmer rising to be the third-warmest month on record. Copernicus data confirmed that March was the second warmest month global with a temperature anomaly of  $0.67^{\circ}\text{C}$ . Data from Copernicus also shows that April was the second-highest warmest on record as it was  $0.6^{\circ}\text{C}$  warmer than the average February from 1981–2010 thereby continuing the temperature upward trend something that can be attributed to weather extremes during that month.

The Ocean Heat Content which causes rising sea level and used in global modelling of global climate. The study found that the period January to March 2019 recorded the highest global ocean heat content. The Pacific recorded had the highest heat content on record, while the Atlantic basin had the second highest heat content and the Indian basin had the 9th highest heat content (See Table 1) with consequences for global climate and sea level across the globe. Accordingly, Global ocean heat content (OHC) was on record highest first quarter of the year. This level of warming started in October 2018. As a consequent Jason-3 space mission recorded a continued increase in sea levels in 2019 along the Indian Ocean coastline, which has been increasing at an average of  $0.4\text{mm/year}$ .

**Table 1.** January–March 2019 Ocean Heat Content (1022 joules)

BASIN	0-700 METERS   RANK (1955-2019)					
	ENTIRE BASIN		NORTHERN HEMISPHERE		SOUTHERN HEMISPHERE	
Atlantic	7.414	2nd	4.075	2nd	3.339	2nd
Indian	2.852	9th	0.404	10th	2.448	9th
Pacific	7.773	1st	3.691	1st	4.082	1st
World	18.065	1st	8.196	2nd	9.869	1st

Meteorologist and climatologist generally agree that the increase in SST is partly responsible for the wild weather extreme events which manifest in the form of extreme rainfall events such as intense rainfall activity and tropical cyclones. The increase in SST in the Indian Ocean is blamed for the increase in intense tropical cyclones that have affected the coastal line of Southern Africa of late. Analysis of climate archival data from the Wunderground Tropical Cyclone and hurricane archives reveals that as SST increases in the Indian Ocean in the Southern Hemisphere that temperature increase was matched by a decline in the number of tropical storms particularly between 1979 and 2019 with the number of Tropical storms declining from about 25 per annum to about 9 currently. The number of hurricanes also declined from an average of about 8 to about 4 per year. The study, however, found that there was an increase in the intensity of tropical storms with several Cat 3 and 4 now being predominant. The year 2019 was particularly unique in South-Eastern African coastal areas as two high impact Tropical Cyclones happening less than a month and for the first time, a Category 5 Tropical Cyclone was witnessed.

Due to the combined effect of rising level and the storm surge that resulted from tropical cyclone Idai on Mozambique's Beira Coast the month of March witnessed one of the most costly tropical cyclones in the region as the tropical cyclone was accompanied by a 4m storm surge which worsened flooding leading to inundation of 90% of Beira and the nearest areas. The direct and indirect impact of the flooding stretched all the way to eastern Zimbabwe and Southern parts of Malawi. The flooding led to deaths, displacement, property damage, hunger, poverty and malnutrition in the affected states as livelihood security was adversely impacted by the two Tropical Cyclones Idai and Kenneth. United Nations agencies put the cost of Idai alone to be about US\$1 billion. According to a government report Zimbabwe would require close to US\$800 million [7] as a recovery package after cyclone Idai while Mozambique would require close to US\$500 million to cater for various relief needs according to a report by [6].

## Conclusions and Recommendations

The study found that there is an increase in global sea surface temperature, which is matched by a steady rise in sea levels and high-intensity Tropical Cyclones. Given the combination of rising sea levels and high-intensity tropical cyclones South Eastern African countries, are finding it difficult to cope with the impact of such extreme hydrometeorological events as they come at a considerable cost to countries that haven't built enough resilience and climate adaptation. Increased global and sea surface temperatures requires a proper land use planning and budgeting by the affected countries to be able to better deal with these extremes. There is a need to closely monitor and investigate the impact of an increase in sea surface temperature going forward to better understand the implications for future storm and cyclone trends, which is currently poorly understood, especially in Africa. The development of an early warning system

in such a scenario is a must for the region. The global and civic community has a crucial role in this through financing adaptation and providing relief where this is needed to ensure sustainable development.

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## Implications of land use /land cover changes on vulnerability of coastal regions to Sea Level Rise

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Vulnerability of coastal areas to future risks such as sea level rise (SLR) is largely determined by land use/land cover (LULC) patterns as different patterns of LULC imply different levels of sensitivity, and consequently varied vulnerability levels. Investigating implications of LULC changes on physical vulnerability requires the construction of LULC models, projections for future LULC, and conducting comparative analysis between the current and potential vulnerability.

Predicted LULC, in the case of western side of the Nile Delta coastal zone, revealed that continued expansion of human settlements, a noticeable decrease in undeveloped land and an overall decrease in cultivated land. Such expected changes mean increased potential vulnerability of human settlements to inundation compared to current vulnerability, which threatens more people and assets. Changes in potential vulnerability of cultivated land, on the other hand, are expected to be marginal compared to current vulnerability.

This means that the dynamics of LULC patterns are expected to have significant impacts on vulnerability to SLR. In such a case, planned and guided forms of LULC changes may play a crucial role in decreasing vulnerability to SLR impacts. For this purpose, projecting future LULC and assessing potential vulnerability compared to current one is essential.

## Introduction

Vulnerability of coastal areas to sea level rise (SLR) and its associated impacts is controlled by a wide range of factors, particularly land use/land cover (LULC) patterns that determine the sensitivity of these areas [4]. Existing patterns of LULC are usually dynamic and experience

continued changes that are driven by socio-economic and physical variables [8]. Assessing potential vulnerability to SLR impacts as a future risk, should be based on predicted patterns of LULC rather than current ones. This emphasized the needs for investigating implications of changes in LULC pattern on vulnerability to SLR impacts.

The coastal zone of the Nile Delta is considered to be one of the most vulnerable areas to SLR, due to its low-lying subsiding land. The vulnerability of Nile Delta to SLR impacts has been repeatedly assessed. Mostly, these previous studies were based on hypothetical SLR scenarios, and focused on assessing current vulnerability assuming that SLR is an immediate risk.

The paper is intended to assess the impacts of LULC change on vulnerability of the western region of the Nile Delta coastal areas to SLR impacts under different scenarios up to the year 2050. The western region of the Nile Delta extends from 29° 42' to 30° 31' E and from 31° 01' to 31° 28' N, covering a total area of 1818 Km<sup>2</sup>. It includes the eastern parts of Alexandria governorate and northwestern parts of Behaira governorate, with 4 major urban centers inhabited by total population of 7.7 million and host a variety of economic activity [5].

## Methodology

To attain the above-mentioned objective, current LULC patterns were delineated from three satellite images dated 1984, 2000 and 2016. The three images were classified and three thematic maps were produced representing different classes of LULC; water bodies, cultivated land, built-up area and undeveloped land in these years. The two thematic maps of 1984 and 2000 were employed to analyze and model LULC changes based on a number of driving variables. Accordingly, suitability images were created and integrated with Markov matrix for predicting LULC in 2016. The thematic maps of LULC of 2016 were employed to validate the developed model. Once the model was validated, it could be employed to predict LULC patterns in 2032 and 2050, using suitability images with conjunction of calibrated Markov matrix.

This is followed by conducting a comparative analysis between current and potential vulnerability under two different SLR scenarios up to the year 2050. For this purpose, a systematic vulnerability assessment was developed. Generally, vulnerability assessment of the Nile Delta to SLR should consider a variety of factors including: land elevation, land subsidence, expected SLR and spatial relationship with low-lying land and coastline. Firstly, a Digital Elevation Model (DEM) for the study area was depicted by interpolation of contour lines and spot heights derived from topographic maps scale 1:50000 and 1:25000 and a raster surface reflecting the land elevation of the study area in 2018 was generated. Thereafter, the DEM<sub>2018</sub> was updated by subtracting total land subsidence ( $T_{LS}$ ) from DEM<sub>2018</sub>. Thus, providing DEM<sub>2050</sub> for 2050.

$$DEM_{2050} = DEM_{2018} - T_{LS}$$

In order to identify low-lying areas in the study area that may be susceptible to SLR, the DEM<sub>2050</sub> was compared to SLR under RCP 2.6 scenario. According to RCP 2.6 scenario, SLR is expected to be 0.24 m by 2065. Other estimates suggested that downscaled SLR under RCP 2.6 scenario alongside the Nile delta coastline to be about 0.12 m on average by 2050 [11]. An area can be considered as a low-lying land if its elevation is less than SLR.

$$L = f(DEM_{2050} - SLR) \rightarrow 1$$

$$f(L) = \begin{cases} 1, & DEM_{2050} < SLR \\ 0, & DEM_{2050} \geq SLR \end{cases}$$

Where:

$L$  → Low-lying land or naturally protected land  
 $DEM_{2050}$  → Updated Digital Elevation Model in 2050  
 $SLR$  → Average SLR

Upon identifying low-lying land, areas vulnerable to inundation by SLR were delineated through examining the spatial relationship between low-lying land and coastline, where only low-lying lands with direct contact to the sea are expected to be vulnerable to inundation by SLR.

Such a systematic assessment was performed twice to current and predicted LULC patterns to investigate the impacts of LULC change on vulnerability of coastal areas to SLR comparative analysis was on current and potential vulnerability this was done in terms of total area and LULC.

## Results and discussion

The overall accuracy of the developed suitability that interprets changes in LULC between 1984–2000 on the basis of considered driving variables was found to be about 80%. Also, overall Kappa statistics for predicted image of 2016 was found to be 95.28%. Thus, the developed model was found to be valid and accurate to be used for predicting LULC for 2050 (Figure 1).

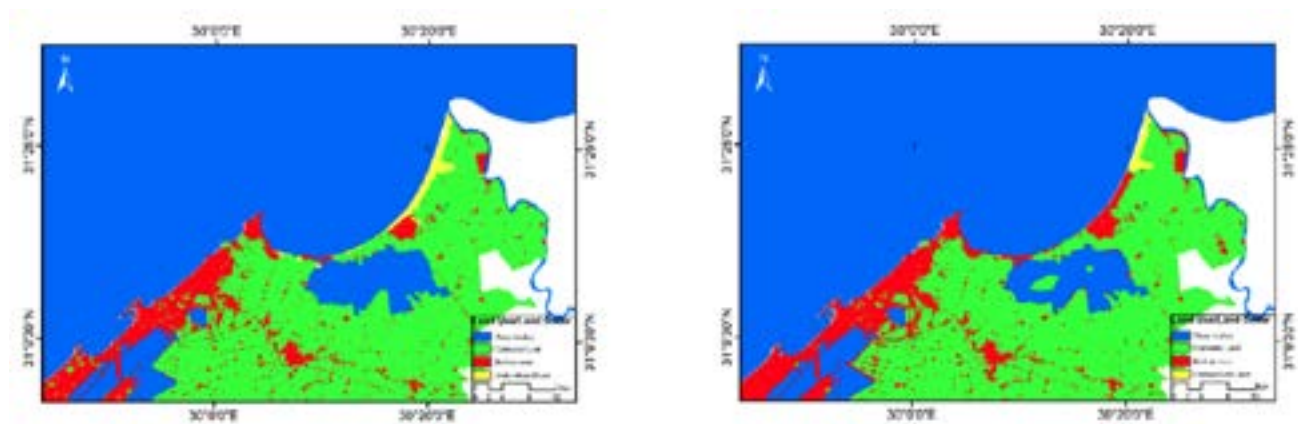


Figure 1. Land Use/Land Cover for 2016 (left) and projected Land use/land cover projected for 2050 (right)

## Historical and future changes in LULC

During the period 1984–2000, several transitions occurred to each LULC. Only built-up area has experienced continuing increase without transitioning to any other LULC with total increase of about 47.5 Km<sup>2</sup>. Cultivated land on the other hand, while extended noticeably (54.1 Km<sup>2</sup>), also experienced considerable decrease (20.5 Km<sup>2</sup>) as a result of built-up encroachment. Transformations from undeveloped land to other LULC is the largest change occurred in the study area with a total decrease of about 74.3 Km<sup>2</sup>.

The predicted LULC pattern reveals that built-up areas in the western side of the Nile Delta are expected to expand considerably up to 2050, particularly in the peripheries of main urban centers (table 1). In this respect, the total built-up area is expected to expand about 35.39 Km<sup>2</sup>, which represents about 14.1% of current built-up area. Mostly such an expected expansion of built-up area is expected to be on the account of cultivated land and undeveloped land. Meanwhile, cultivated lands are expected to experience both increase and decrease with overall decrease of about 7 Km<sup>2</sup>, due to the encroachment of human settlements on cultivated land.

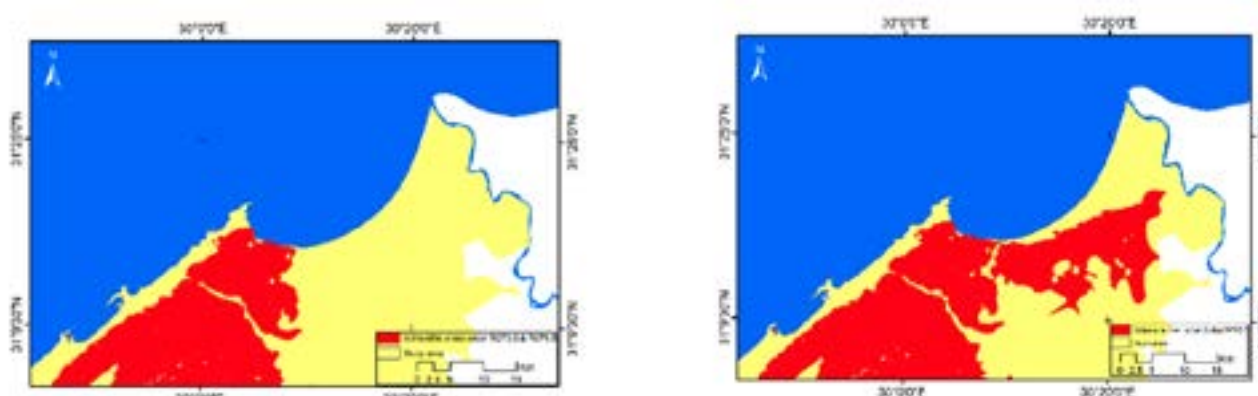


**Table 1.** Predicted LULC changes between 2016 – 2050

LULC classes	Area Km <sup>2</sup>		Change %
	LULC 2016	LULC 2050	
Water bodies	226.37	214.45	-5.3
Cultivated land	1315.83	1308.55	-0.6
Built-up area	249.61	284.76	14.1
Undeveloped	27.096	11.21	-58.6

### Implication of land use change on vulnerability

The total area vulnerable to inundation is estimated to be about 662 and 888 Km<sup>2</sup> under downscaled and global RCP 2.6 scenarios, respectively (Figures 3 and 4).

**Figure 2.** Areas vulnerable to sea level rise under downscaled RCP2.6 projects (left) and global RCP 2.6 projections(right).

As a result of LULC dynamics and subsequent changes up to 2050, it is expected that potential vulnerability of human settlements to SLR impacts in the western side of the Nile Delta is expected to be higher than current vulnerability by about 13.3 and 14.8% under downscaled and global RCP 2.6 scenarios, respectively. Compared to current vulnerability, potential vulnerability of undeveloped land to SLR impacts is expected to decrease considerably (-91.7 and -94.4% under the two scenarios, respectively) as most of undeveloped lands are expected to be developed and transformed to other LULC classes.

At the same time, changes between potential and current vulnerability of cultivated land due to LULC dynamics are expected to be insignificant as the vulnerable areas are potentially expected to decrease by 1.8 and 0.2% under the two considered SLR scenarios. However, relatively less vulnerability of cultivated land compared to current one can be attributed mainly to the reduced area of cultivated land predicted by 2050.

This means that the dynamics of LULC patterns have significant impacts on vulnerability of human settlements to inundation by SLR impacts. For example, while physical vulnerability in terms of total area vulnerable to SLR is the same, vulnerability of human settlements has increased, which may lead to more damage and loss as more people and assets are at risk. Consequently, current development trends of LULC pattern may increase the vulnerability of human settlements in the Nile Delta coastal zone to SLR impact.

**Table 2.** Current and potential vulnerability under global and downscaled SLR scenarios

SLR Scenarios	LULC	Vulnerable area (Km <sup>2</sup> )		Change %
		Current (2016)	Potential (2050)	
Downscaled RCP2.6	Water bodies	99.28	97.95	-1.3
	Cultivated land	473.57	464.84	-1.8
	Built-up area	85.02	96.33	13.3
	Undeveloped land	1.33	0.11	-91.7
	<b>Total</b>	<b>659.2</b>	<b>659.2</b>	
Global RCP2.6	Water bodies	207.88	197.24	-5.1
	Cultivated land	587.57	586.61	-0.2
	Built-up area	91.29	104.82	14.8
	Undeveloped land	1.99	0.11	-94.5
	<b>Total</b>	<b>888.79</b>	<b>888.79</b>	

## Conclusion

Dynamics of LULC patterns has a significant influence on the vulnerability of coastal areas to SLR by potentially placing more sensitive land uses in more exposed locations. It was revealed that the vulnerability of human settlements in the future is expected to increase as a result of LULC dynamics and associated continued expansion of the built-up area of these settlements. In contrast, the vulnerability of undeveloped land in the future is expected to decrease due to continuous development of these areas to meet the increasing demands for land.

To avoid and minimize vulnerability of the western side of the Nile Delta to SLR impacts, current urbanization patterns must be controlled to slow down the pace of urban expansion. Also, there is a need to guide the development efforts, apart from potential vulnerable sites and remaining undeveloped lands without development as a form of low-regret option in the case of the Nile delta. Such guidance can be achieved by employing command and control or market-based instruments.

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## Development of a risk assessment methodology for evaluating climate change effects on soil physicochemical properties in African regions

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Soil physicochemical properties are so important to soil fertility and plant growth. The purpose of this study was to develop a risk assessment methodology that should be kept in mind when assessing climate change effects on soil physicochemical properties. The methodology was developed based on three steps: (1) identification of key soil physicochemical properties; (2) modelling of climate change impacts on these key soil properties using a combination of the EPIC model and a geographical information system; (3) development of a soil management strategy for minimizing soil degradation. The developed methodology was tested in an arid African oasis (Chenini Oasis, Tunisia) and was highlighted three main findings: First, compared to the no climate change scenario, soil physical properties (bulk density, wilting point and field capacity) are predicted not to change significantly by 2050. However, a serious impact on the soil chemical properties (organic carbon content, pH and macro-nutrients) is predicted. Second, the most critical impact was recorded for soil organic carbon content which is predicted to decrease by 38% by 2050. Our results suggest that future climate change may seriously affect some key soil physicochemical properties. The developed methodology could be an effective guide to improve soil management in African regions with respect to climate change.

**KEY WORDS:** Climate change; Soil; Physicochemical properties; African regions

### Introduction

The responses of soil physicochemical properties to climate changes have been seriously investigated worldwide [3][1]. The results of these debates helped the global decision-makers to address the climate change threat perfectly through a good future management of soil resources [2]. Despite the positive outcomes of these studies, it appears that the approaches applied for evaluating the impacts of climate changes on soil characteristics needs further improvement and clarification for a better soil management. Against this lack, the overall objective of the present study is to improve a conceptual approach that should be kept in mind when assessing climate change impacts on soil physicochemical properties. A Tunisian coastal region was selected as a study area to achieve this objective.

## Materials and methods

### Study area

Field experiments were conducted in Chenini Oasis located in the southeastern coast of Tunisia.

### Study area

Field experiments were conducted in Chenini Oasis located in the southeastern coast of Tunisia.

### Pre-investigations:

Before the initiation of the project, some pre-investigations were conducted in the studied oasis to these data (1) Climate data; (2) plant data; (3) water management data; (4) Soil data.

### Assessment methodology

In this study, the risk assessment methodology was developed based on the following three steps: 1. First of all, selection and measurement of key soil physicochemical properties; 2. Then, modelling of climate changes effects on key soil physicochemical properties; and 3. Finally, development of a management strategy (option) for enhancing soil properties (Figure 1).

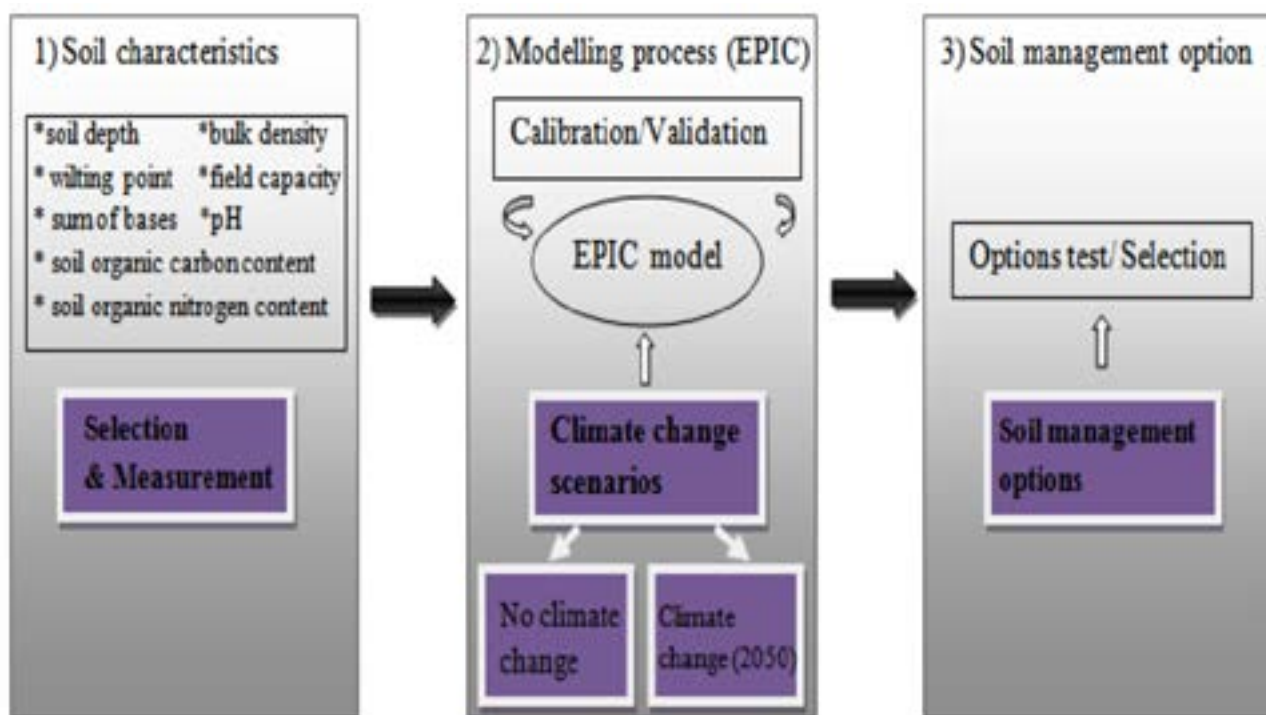


Figure 1. Design of the study methodology

## Results

The developed methodology was tested in an arid African oasis (Chenini Oasis, Tunisia) and highlighted the following main finding: climate change impacts on soil physicochemical characteristics: climate changes are expected to have serious impacts on soil physicochemical characteristics that define soil quality and consequently its sustainability to agricultural productivity. Hence, future changes in soil characteristics due to climate changes should be considered with great importance for conserving the sustainability of agricultural soil in the studied area. The methodology tested these changes by 2050 under two climate scenarios: no

climate change (baseline scenario) and climate change scenario. Overall, it was observed that compared to no climate change scenario, future climate change scenario will allowed to a minor change in soil physical characteristics (bulk density, wilting point and field capacity), however, a serious impact on soil chemical characteristics (organic carbon content, pH and macro-nutrients) is noted.

## Conclusion

This study develops a risk assessment methodology for evaluating climate change effects on soil physicochemical properties in African regions. Soil properties were assessed with regard to future climate changes (by 2050) based on a simulation approach (EPIC model). This model evaluated effects of some climate changes scenarios on temporal change in soil properties. Under future climate changes (by 2050), the simulation results showed significant degradation of the investigated soil properties in 2050. This is the first scientific contribution toward a reliable understanding of the potential impacts of climate changes on properties. The focus was on the development of a methodological approach useful to predict soil properties under a changed climate at the investigated oasis. Further improvement of the developed methodology could be achieved by the consideration of some factors such as agronomic factors that would allow performing a better soil properties assessment in African regions.

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## Integrating urban land change and climate change data to inform spatial planning decisions: A case study of Durban, South Africa

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In recent years, the spatial planning of cities has been recognized as a key integrated approach in managing climate change. However, various urban spatial change futures will have different implications for climate change planning. This research explores this issue, by simulating and evaluating the implications of projected land use change scenarios, based on local development plans, and downscaled projected climate change impacts for the coming decades using the Durban metropolitan area as a case study. The study is the first attempt at investigating the potential impact of future land use change in the context of future climate change for Durban. Projected climate change and land use change hotspots are identified in the short, medium, and long term under projected maximum and minimum temperature and rainfall increases. The study further highlights the need for flexible approaches and strategies in response to the shifting extent of climate change impacts and land use change over time.



## Introduction

There is increased evidence and awareness that many climate change policies are best implemented at the local scale [1]. Many of the efforts to integrate climate change in spatial planning focuses on already existing land use and urban developments and little research has been undertaken for cities in the global South [9]. Various urban spatial change futures will have different implications for climate change planning and assessing the impact of multiple shifting climate impacts, such as their range and extent, need to be included in spatial planning [2]. This study responds to this gap and is the first attempt at investigating the potential impact of future land use change in the context of future climate change for a sub-Saharan African city. Land use change scenarios, which focused on pathways to compact city development based on the municipality development plans, are simulated and evaluated for the case study area of the Durban (eThekweni) metropolitan area. In 2014, the Durban Climate Change Strategy (DCCS) [4] defined a city-wide approach to climate change adaptation and mitigation with land use planning and management considered as key to promote protection from climate change impacts and minimize GHG emissions. The findings from this case study aims to help inform the appropriate response for city governments to consider the future city with projected land use change, in the context of future projected climate change hazards.

## Methods

### Future land change and climate change 'hotspot' mapping

For this study, land change and climate change hotspots are identified referring to places needing urgent climate change actions, relating to emissions, risks and vulnerability. The approach for hotspot identification is based on spatial overlays of maps of projected land use change and climate change impacts and the intersecting areas are the hotspots of land use change and climate change.

### Land use change projections

Three scenarios were defined for the Durban metropolitan encompassing local spatial, sustainable, and climate change planning and details on the development and modelling of these scenarios are presented in Jagarnath *et al.* (2019)[7]. The scenarios are defined as Business as Usual (BAU), green space protection (GSP), and Integrated Rapid Public Transport Network (IRPTN). It is noted that these scenarios should not be not be interpreted as future forecasts, but rather as possible spatial development patterns. The scenarios were projected in Land Change Modeler (LCM) in Idrisi software [8], to understand past change patterns and processes, in this case from 1994 to 2016, based on medium-resolution Landsat satellite imagery using a supervised post-classification change detection approach [7]. LCM identified the historical trends and drivers of land use change from these maps, which was then used to model future scenarios through a suite of integrated spatial regression and spatial development incentives and constraints tools with the software. The three land use change scenarios were projected in twenty-year intervals up to the year 2076 from the 2016 baseline land use change map, per model requirements and for consistency.

### Climate change projections

The downscaled climate change projections used in this study were from the conformal-cubic atmospheric model (CCAM) from the Council for Scientific and Industrial Research (CSIR) [3], at a horizontal resolution of 1km [4]. This study uses the hotspots of increased maximum temperature (Tmax), minimum temperature (Tmin) and maximum rainfall under RCP 8.5 to demonstrate the 'worst case scenario' for climate change [10].

The various land use change and climate change impact maps for temperature and rainfall were given equal weightings as they are all considered of equal importance and severity. It is important to note that the land use change modelling and climate change modelling were both done independent of each other. Ideally, the climate model would be linked to the different land use change scenarios, however this is computationally and time intensive.

## Results and discussion

The potential spatial area impacted by projected maximum temperature and rainfall increase over time, under various land use change scenarios. For  $T_{max}$  increase, the projected hotspots show changes in area over time, as they may impact on 19.75% (49847.80 ha) of the total metro area in 2030 to 34.91% (88141.17 ha) in 2065. For  $T_{min}$  increase, the expected area affected may be up to 19.25% (48584.45 ha) in 2030 to 26.02% (65689.20 ha) in 2065. The hotspots of projected rainfall may impact on 27.96% (70575.40 ha) in 2030 to 29.16% (73615.24 ha) in 2065. The potential impact of climate change and land use change will be further elaborated using the increase in  $T_{min}$  as an example indicative of the changes to the expected.

Figure 1 shows the projected spatial patterns for the scenarios in the  $T_{min}$  hotspots. In the short term under, a similar spatial arrangement of land uses is expected for all development scenarios. In the medium term, BAU and GSP share the similar spatial pattern of residential traditional areas impacted in the northern coast. This contrasts with IRPTN which shows more residential formal and vegetation along the northern coast. In the long term, BAU and IRPTN share similar spatial arrangement, with residential formal areas impacted in the central core and along the northern and southern coast. GSP shows more vegetation and residential traditional land use affected along the northern and southern coasts. The most urban intensification is expected in the medium term for all three scenarios as the Pinetown industrial area is also affected by the hotspot, as well as the appearance of residential informal areas affected.

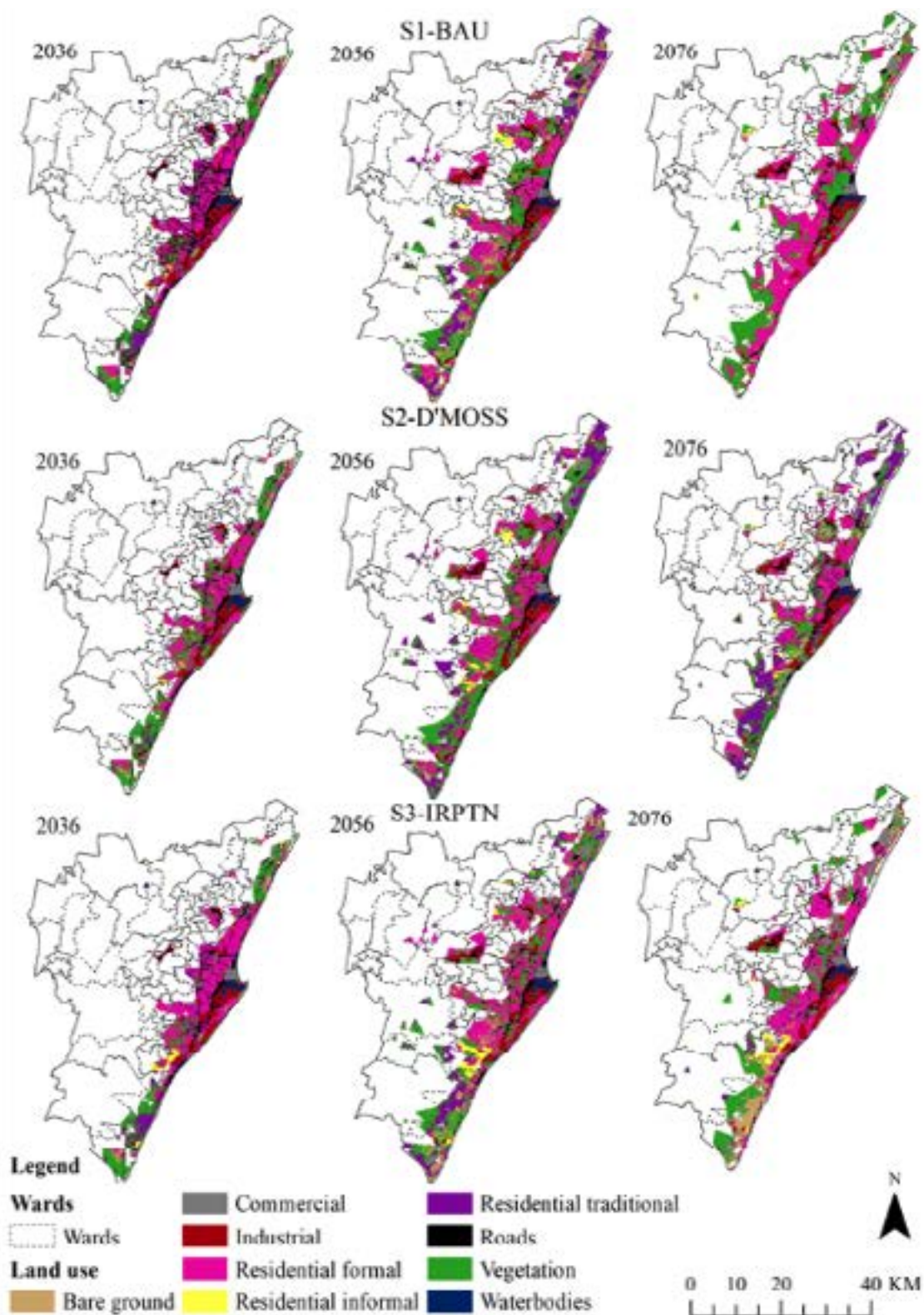


Figure 1. Spatial distribution of land use classes in increased minimum temperature hotspot areas under various scenarios.

The implications of projected land use and climate change are discussed with references to the two main development challenges of the Durban metropolitan municipality, thus a dual strategy is recommended to focus on (i) traditional authority areas and the (ii) formal, urban core areas, and industrial areas to reduce risk and vulnerability. For adaptation, the traditional authority areas are projected to be the most at-risk due to the projected temperature and rainfall increases over the short to long-term and their under-developed status [4]. From a mitigation perspective, the traditional authority areas are the lowest contributors to Durban's total carbon emissions [6]. These areas also lack land use management and as such there are many settlements that are unplanned and thus located on environmentally sensitive land. This is a key challenge as the major land use change transitions in these areas are from vegetation to residential traditional and from residential traditional to vegetation [7].

For the central business district (CBD), the  $T_{min}$  increase in the urban core and industrialized areas in the west, and along the coastline, shows the UHI extent. The land use classes in these areas are mainly residential formal, industrial, commercial and roads and are more populated, and are the highest contributors to GHG emission in Durban [6]. These areas are key from a mitigation perspective because in response to projected increased temperature, people would use more air cooling to achieve indoor thermal comfort which causes an increase in outdoor temperature at a local scale [5]. Increased temperatures may also cause people to move to the greener areas on outskirts, such as environmentally-sensitive land, and may increase the rate of land change and the conversion to built-up land classes, contributing to surface and anthropogenic heat due to increased built up mass and population, and potentially increasing the spatial extent of the UHI.

## Conclusion

This spatial assessment of projected climate change impacts and land use change scenarios highlights the need for flexible approaches and strategies in response to the shifting impact of climate change over time. This information from the spatial analysis of urban land use change and climate science information can be used in integrated development and spatial plans to update development thresholds, zoning, and safe urban spaces and standards for planning towards a low carbon climate resilient city.

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## Probabilistic Attribution of 2018, 2016 and 2012 March–April–May (MAM) Extreme Rainfall in Kenya

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Eastern Africa climate is characterized by high seasonal variability. The region has experienced a sequence of extreme weather and seasonal climate events in the past two decades. While drought has predominantly prevailed, the period has been punctuated by extreme flood events that have had devastating impacts, particularly on agricultural and hydrological systems. Precipitation extremes are expected to respond to changes in global mean surface temperature. The changing likelihoods of extreme climate/weather events, in terms of frequency, intensity, spatial extent, duration, and timing is one of the most noticeable and damaging manifestations of anthropogenic climate change. In this study, we aim to understand whether anthropogenic influence on climate altered March–April–May (MAM) 2018, 2016 and 2012 rainfall anomalies in Kenya. This paper covers the first step of attribution analysis; event definition. Results show that MAM 2018 seasonal totals had the highest return time in the central highlands (including Nairobi area) and parts of the western highlands (including Lake Victoria region). For 2016, the western highlands and the north western part of the country had the highest return times in the total seasonal rainfall while central highlands and south eastern parts had the highest in 2012. Future work will make use of attribution experiments of weather@home and Climate of the 20th Century Plus Detection and Attribution project C20+D&A to assess changes in return times and probability of occurrence of three events

### Introduction

The aim of extreme event attribution is to estimate whether and to what extent the probability of an extreme climate/weather event has changed due to human influence on climate. Eastern Africa region experiences a bimodal rainfall regime; March–April–May (MAM) ‘long rains’ and October–November–December (OND) ‘short rains’. For MAM 2018, all the meteorological stations in the country recorded above-normal rainfall (above 100 percent of the long term means (LTMs)). Some stations recorded the highest on record; Narok station (highest since 1950), Eldoret (highest since 1972), Kitale (highest since 1979), Kericho (highest since 1974), Laikipia (highest since 1957), Makindu (highest since 1950), Kakamega (highest since 1958), Nakuru (highest since 1964), Embu (highest since 1976) and Nyeri (highest since 1968). For MAM 2016, much of the rainfall was recorded during the second half of April through the month of May. Most stations located on the western highlands (including Lake Victoria region) and the north west parts of the country recorded between 75 and 125 percent of their LTMs. For MAM 2012, several rainfall storms were recorded during the season. The heaviest storm of 105 mm was recorded at Embu station on 16 May and 104.5 mm on 15 May 2012 at Malindi station. Other stations that recorded above 80 mm include Kakamega and Kericho in western Kenya, Moi Airbase and Wilson Airport in Nairobi, Nyeri in the central highlands, Machakos in southeastern Kenya and Msabaha along the Coastal strip. Kericho station recorded the highest seasonal rainfall amount of 892.4 mm (132% of its LTM).

This paper discusses event definition, a first step in probabilistic attribution of MAM 2018, 2016 and 2012 extreme rainfall events in Kenya. We aim to assess the spatial and temporal characteristics of the rainfall anomalies to inform the attribution analysis.



## Methodology

The study uses a Probabilistic Event Attribution (PEA) methodology which compares two climate worlds; a factual world which represents the current climate/weather conditions in which the event occurred and a counterfactual world in which anthropogenic forcings on the climate system are removed[1-4]. The methodology entails event definition, model evaluation and attribution analysis. This paper presents findings of the first methodological step; event definition. This is the assessment of both spatial and temporal definitions; region domain, variable(s) to be investigated, the length and quality of the observational datasets and extremity/rarity of the event. Here we use station data from Kenya Meteorological Department and CHIRPS[1] gridded datasets for the period (1981-2018) to define the event. Return time periods were estimated to understand the rarity and extremity of the event. The area with the highest rainfall anomalies, reported impacts and return times was chosen as the study region.

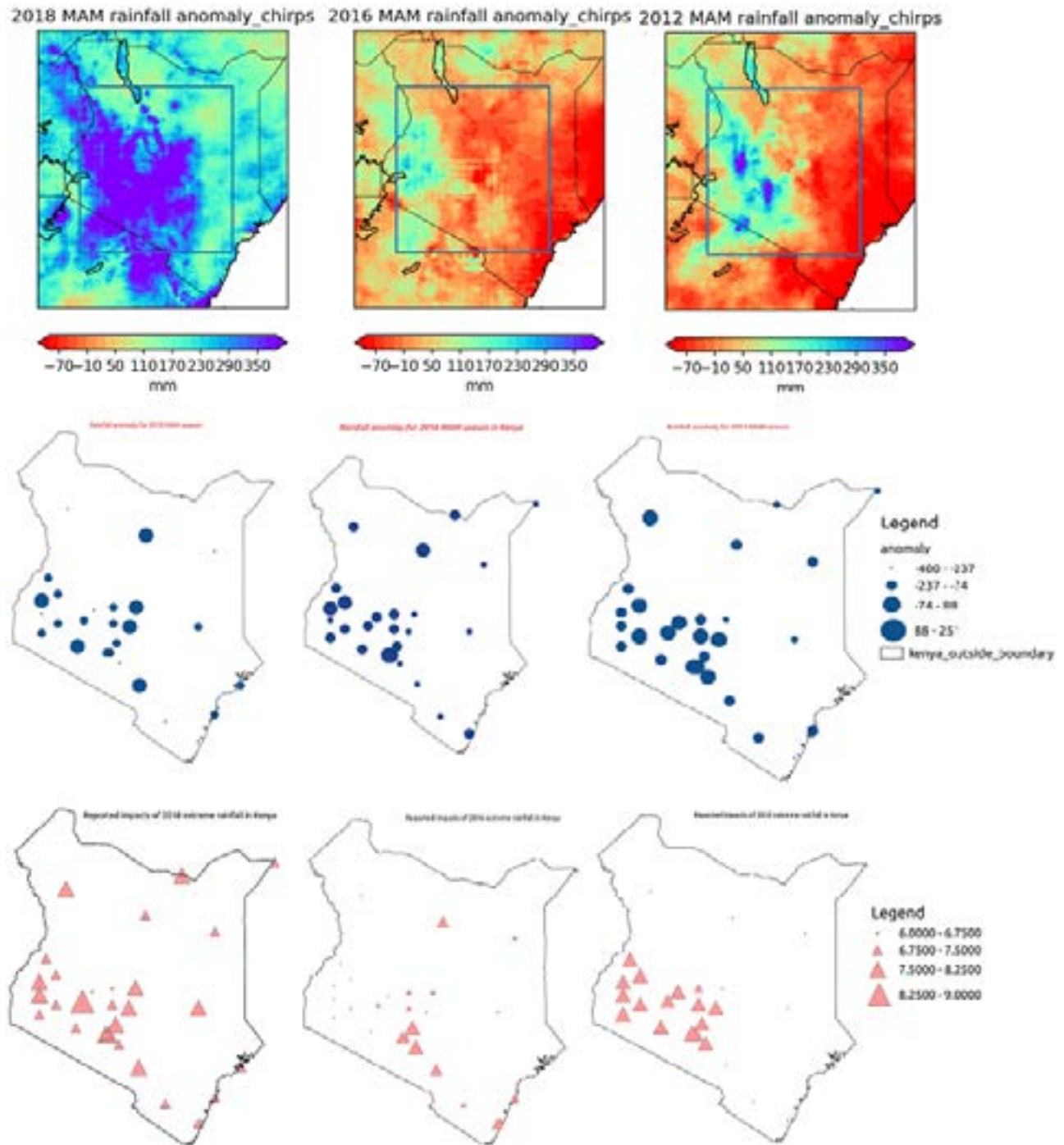
## Results

Figure 1 presents a spatial distribution of seasonal anomalies and reported flood impacts. Seasonal rainfall anomalies for MAM 2018, 2016 and 2012 were calculated using CHIRPS and station data with respect to 1980-2016 climatological period. Quality controlled data from 22 weather were used. MAM 2018 was more anomalous with an even spatial distribution compared to 2012 and 2016. The reported impacts were obtained from Kenya National Disaster Management Centre website and Kenya Red Cross Society seasonal hazard reports. Estimation of impacts is based on 3 to 10 rating score where 10 represents the most severe impacts and 3 minimal impacts. Reported deaths, landslides and river/dam burst are considered severe with a rating of 7- 10 while submerged farmlands and impassable roads are considered minimal with a rating of 3-6.9.

Figure 2 presents a cumulative distribution of rainfall for the three MAM seasons for the study area and selected stations within the study region. The temporal distribution and accumulation of rainfall within the three seasons is uneven. MAM 2018 experienced an early onset compared to 2016 and 2012 which had onsets in the second and the third week of the April respectively. It is evident that MAM 2018 was one of the wettest years in record while 2016 and 2012 were among the wettest years in some stations.

Figure 3 presents return time plots for seasonal totals of the study area and selected stations within the study region. An average recurrence interval for MAM 2018 is 38 years, 4 years for 2016 and 5 years for 2012.

Grid box 34.5°E, 40° E 3°S 3°N, a common region which experienced the most anomalous rainfall and had highest return times was chosen as study area.



**Figure 1.** Seasonal rainfall anomalies in Kenya using both station and gridded datasets for MAM 2018, 2016 and 2012 and the reported impacts of the floods. The box region marked in the first panel row indicate the study region.

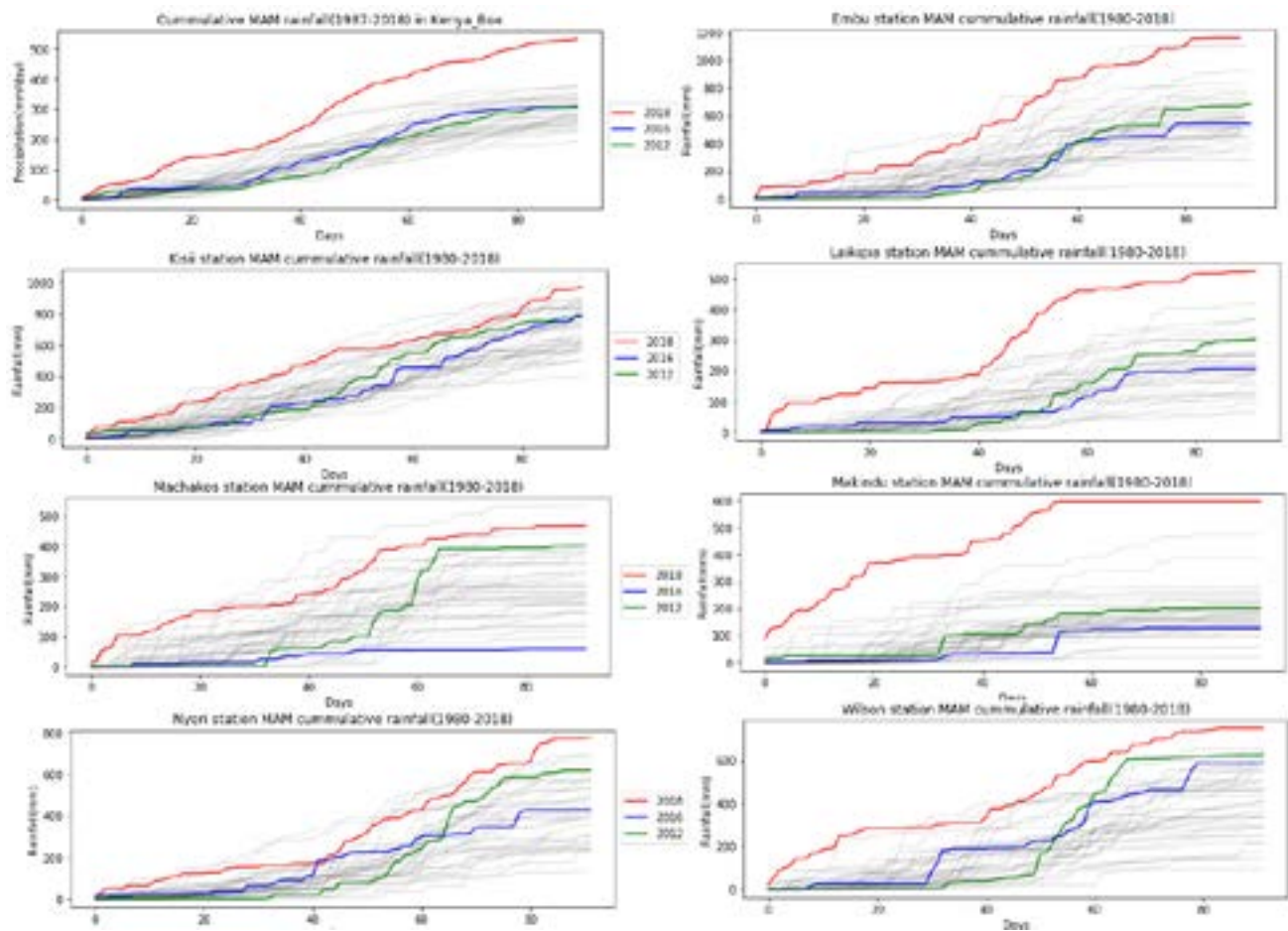


Figure 2. Seasonal cumulative rainfall for the study region using CHIRPS and selected stations within the domain of study using station data

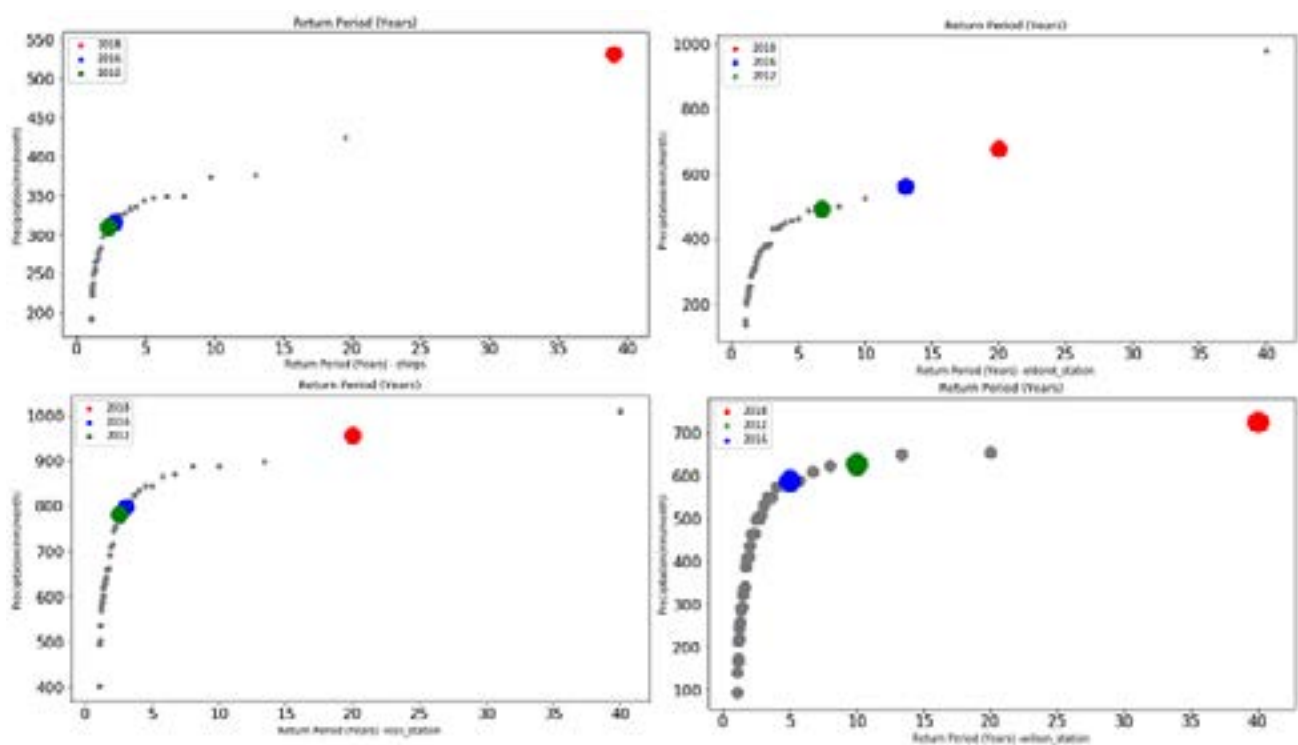


Figure 3. Return-time plots of total seasonal rainfall over the study region and for selected stations within the region.

## Conclusion

Results show that MAM 2018 seasonal totals had the highest return time in the central highlands (including Nairobi area) and parts of the western highlands (including Lake Victoria region). For 2016, the western highlands and the north Western part of the country had the highest return times in the total seasonal rainfall while central highlands and south eastern parts had the highest in 2012. Return times for intra-seasonal characteristics (10day and 20day max) were also evaluated (not shown). Future work will make use of attribution experiments of weather@home and Climate of the 20th Century Plus Detection and Attribution project (C20+D&A) to assess changes in return times and probability of occurrence of the three rainfall events.

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## Climate Change Narratives for Blantyre city, Malawi

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Blantyre city is the main industrial and commercial hub of Malawi. Research to develop climate change narratives for Blantyre city was carried out with the purpose of generating knowledge that informs climate sensitive decisions for the city. A multi-disciplined research team in climate change, urban planning, engineering and land economy was assembled. Literature review and brainstorming sessions with stakeholders were conducted in the generation of the narratives. A validation workshop was held with experts and stakeholders to scrutinize and refine draft narratives. The narratives are based on climate change predictions for Blantyre city by the year 2040 for three climate change scenarios and accompanying assumptions. The scenarios are: Hotter, slightly drier and fewer rain-days; Hotter, no change in total annual rainfall, heavier rainfall events and fewer rain-days; and Warmer, slightly wetter, heavier rainfall events and fewer rain-days. The energy and water supply sectors were chosen as a priority area for the narratives. In 2040, Shire river, the main source of energy and water for Blantyre, remains vulnerable to the impacts of climate change and variability. The position of the city as a commercial hub is threatened due to heavy water and electricity rationing affecting all social and economic sectors. Unless the city authorities, the government and other stakeholders invest in less-climate-sensitive alternative water and electricity sources, the future remains bleak.

**KEY WORDS:** urban settlement, year 2040, scenarios, vulnerability, Shire river

## Introduction

Blantyre city, the main industrial and commercial hub in Malawi, is one of the oldest urban settlements in the southern Africa region. It was established by Scottish Missionaries in the 1870s and was named after the town of Blantyre in Scotland, birth place of the famous missionary and explorer, Dr. David Livingstone. The city covers an area of over 220 square kilometres (sq. km). Population of Blantyre is projected to be 2.1 million people in 2040 from 1.5 million in 2030. It has a very high population density, with 4600 people per sq. km against the national average of 200 people per sq km.

Blantyre is one of the Tier 2 cities participating in the FRACTAL Project. The write-up presents climate change narratives for Blantyre city, which was one of the sub-projects of FRACTAL. The purpose of the narratives was to co-develop knowledge that will inform climate sensitive decision in cities in the region. The narratives have been developed based on climate change predictions for Blantyre city by the year 2040 for three climate change scenarios and their accompanying assumptions. The scenarios are: Hotter slightly drier and fewer rain-days; Hotter, no change in total annual rainfall, heavier rainfall events and fewer rain-days; and Warmer, slightly wetter, heavier rainfall events and fewer rain-days. Although the city of Blantyre is affected by a number of climate sensitive sectors such as energy and water supply, land and population, food security, health and flooding, priority for coverage in the narratives was on the energy and water supply sector.

## Methodology

A multi-disciplined research team in climate change, urban planning, engineering and land economy was assembled. Literature and expert knowledge reviews alongside brainstorming sessions were conducted in the generation of the narratives. Drafting of the narratives firstly involved coming up with climate sensitivities for Blantyre city. The energy and water supply sector was identified to be the most climate sensitive sector for the city. The climate change narratives around the energy and water supply were then drafted. The process was guided by the assumption of business as usual and their corresponding Blantyre city climate scenarios of plausible future (in 2040). The draft narratives were then subjected to critiquing by research team members. The draft narratives were later on introduced to Blantyre City Council officials and experts from FRACTAL in Cape Town for their input. The final draft narratives were then developed, incorporating their comments. The final draft narratives then underwent stakeholder validation.

## Climate Change, energy and water supply for Blantyre City

Lake Malawi and Shire River are critical to the energy-water nexus for the city of Blantyre. Lake levels affect the flow of Shire River. Walkers Ferry in-take on the Shire is the main source of water in the city of Blantyre. In addition, the city has Mudi reservoir which supplements water supply from the Walkers Ferry. This reservoir supplied less than 1% of city's water demand in 2015 [4]. The Shire River is also the source of water for 98% of hydroelectric generation capacity for the country.

## Scenario 1: Hotter slightly drier and fewer rain-days

It is 2040, and Blantyre is supplied with electricity by Electricity Supply Corporation of Malawi (ESCOM). Power is mostly sourced from hydropower stations that are cascaded along the Shire River. Water level in the lake is very much sensitive to climate change. Of late, the water level in the lake is decreasing. This is due to decreasing trend in total annual rainfall in the catchment area and increase in ambient temperature leading to increased evaporation. Reduced Shire River flow is directly limiting power production, and Blantyre and the rest of Malawi suffer from power shortages. This affects social, commercial and industrial activities.



The city population now grows at around 3% per year. Urbanization has increased at an average of 5 % per year since 2020 in combination with increased temperature that translate into increased energy demand for household purposes [7]. Demand for alternative energy sources has increased. There is no charcoal supplied to the city from the surrounding districts as most of the trees have been removed already. Charcoal and firewood demand increases. Urban poor rely on agricultural waste/residues as cooking energy. Malnutrition among urban poor increases, partly resulting from shortage of energy for preparing food. Well-to-do residents rely on gas, which is now expensive, while those in peri-urban resort to illegal cutting down of trees for cooking energy. The mountains parks and catchment areas of reservoirs are now bare. The city has fewer rain-days of high intensity, which are characterized by high run-off as a result of reduced groundcover. The Mudi reservoir is greatly silted. The reservoir is drying due to reduced volume of water received in the catchment area coupled with increased evaporation rates of the reservoir.

The position of Blantyre as the commercial city of Malawi is under threat. Companies are not able to produce goods and services at optimum capacity. The city suffers economically now as most of the industries have closed and manufactured goods come from elsewhere. The multiplier effect of the city is negated. Further, small-scale businesses suffer because of unavailability of electricity. This impacts heavily on employment of city residents, on revenue generation, as well as increased cost to the country for import. Poverty levels have increased above 65%, resulting in crime and illegal activities like burglary and prostitution. Prostitution worsens the spread of sexually transmitted diseases such as HIV/AIDS.

Blantyre city still receives most of its potable water from Walkers Ferry reservoir on Shire River. Water shortage is aggravated by siltation of Walkers Ferry intake. A significant proportion of city residents now depend on alternative sources of unprotected water supply such as shallow wells and rivers. The city registers increased cases of outbreaks of diarrheal diseases like cholera and dysentery, especially in the slums.

## **Scenario 2: Hotter, no change in total annual rainfall, heavier rainfall events and fewer rain-days**

It is 2040, and Blantyre is supplied power by ESCOM. This power is mostly sourced from hydropower stations that are cascaded along the Shire River. Small amount of power is supplied from diesel generators and solar PV systems. Flow in the Shire River, the only outlet from Lake Malawi, depends on water level in the lake which is very much sensitive to climate change. Since total annual rainfall is the same, the water level in the Lake is reduced due to increased evaporation due to hot condition. However, the heavy rainfall events cause floods that destroy hydropower generation equipment and power supply infrastructure as it happened in 2001, 2003 [5] and in 2009 [6]. Blantyre as well as the rest of Malawi is suffering from power shortages. This power shortage is not only affecting social activities, but also commercial and industrial ones.

The population of the city now grows at around 3% per year. High urbanization at an average of 5 % per year since 2020 in combination with increased temperature translate into increased energy demand. This creates a situation the same as that of Scenario 1 above.

## **Scenario 3: Warmer, slightly wetter, heavier rainfall events and fewer rain-days**

It is 2040, and Blantyre is supplied power by Electricity Supply Corporation of Malawi (ESCOM). This power is mostly sourced from hydropower stations that are cascaded along the Shire River. Small amount of power is supplied from diesel generators and solar PV systems. Flow in the Shire River, the only outlet from Lake Malawi, depends on water level in the lake which is very much sensitive to climate change. Although the heavier rainfall would have resulted in increase in lake level, the lake level is unlikely to change significantly due to increase in evaporation. However, the

heavy rainfall events cause floods that destroy hydropower generation equipment and power supply infrastructure. Blantyre as well as the rest of Malawi is suffering from power shortages. This power shortage is not only affecting social activities, but also commercial and industrial ones.

The rise in population growth and increase in urbanization that has increased at an average of 5 % per year since 2020 in combination with increased temperature translate into increased energy demand for household purposes. The situation that follows is the same as that of Scenarios 1 and 2 above.

## Conclusion

In 2040, Shire River, the main source of energy and water for the city of Blantyre, remain vulnerable to the impacts of climate change and climate variability. The position of the city as the commercial hub of Malawi is threatened due to heavy water and electricity rationing that is affecting all social and economic sectors. Unless the city authorities, the government and other stakeholders invest in less-climate-sensitive alternative water and electricity sources, the future remains bleak.

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## Determinants of Development Decisions in an African City: Evidence-based decision processes for Blantyre

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Prioritising development projects in an African city can be challenging considering varied stakeholder interests. Research in Blantyre, Malawi, on 'Perspectives and values underpinning decision to expand power infrastructure through generation of sustainable energy from solid wastes' demonstrated that priorities are mandate and responsibility driven. This implies that a democratic and inclusive decision process for development in the city will be challenging. Data was collected through key informant interviews, focus group discussions and a think-tank workshop. Main decision determinants are policy actors and their networks and the local context in which the decisions are made. Information gathered from stakeholders revealed that evidence

and knowledge available on the policy issue are not prioritised. However, a review of literature shows that knowledge and evidence from well analysed data contributes positively to decision making processes. Local authorities need to focus on policy actors and their networks and the local context in which the decisions are made. Policy makers need to deliberately identify and include evidence or knowledge available on a policy issue when deciding on the direction of development.

**KEY WORDS:** economy, governance, projects, perspectives, policy, values

## **Introduction**

### **Deciding on Municipal Development Priorities**

Priority setting for development projects of a city in a developing economy is challenging considering the multiple needs that may exist. This is further compounded by varied interests among stakeholders emanating from their different areas of authority, mandates or business ventures. When politics weigh in, the complexity on the platform for decision is even worse. The local governance structure, often contained in the city council, requires to seek a balance within diverse definitions of 'development', perspectives and values. In managing urban transformations, the government plays a strategic role in forging stakeholder partnerships [5]. Further to this there are policy and contextual factors requiring attention. Some valuable project ideas in African cities have never been implemented because of diverse priorities among stakeholders and inability of local authorities to strike a balance among such diversity within existing policy framework, context and evidence or knowledge available on the policy issue. It is for this reason that identifying the key determinants becomes essential in the decision process for development. A case study on 'Perspectives and values underpinning decision to expand power infrastructure through generation of sustainable energy from solid wastes' is hereby employed to characterize the main determinants of development decisions in an African city. Policy actors and their networks include government officials, funding agencies, civil society, program implementers, and others, as illustrated in Figure 1 below. The local context in which decisions are made may be political, socio-economic and cultural.

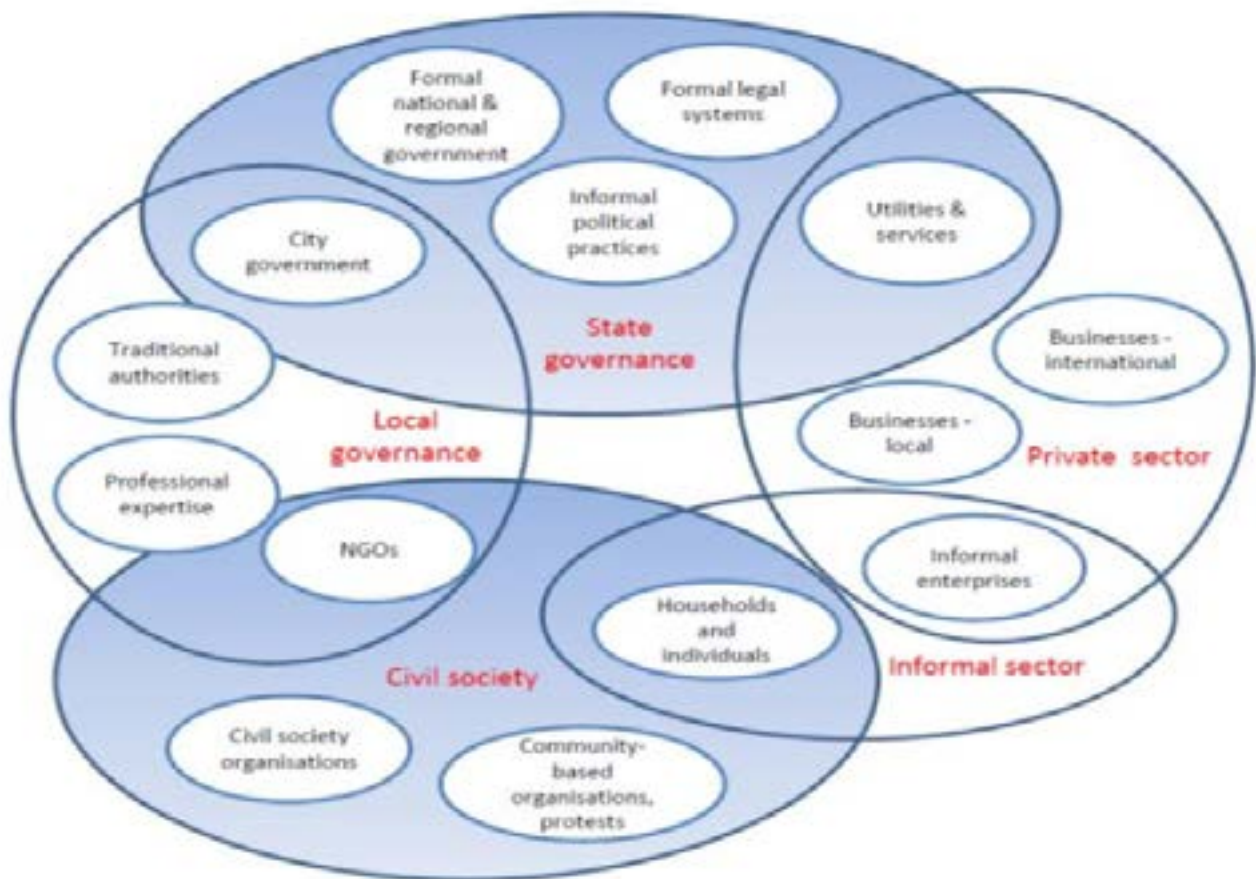


Figure 1. Actors & institutions in urban governance{1}

Local participation is critical in decision making for urban governance. Fouché & Brent cemented on the benefits of public participation as an agent for social learning, trust building, knowledge sharing, building a common understanding, changing perceptions and kick-starting ongoing collaboration[2]. These benefits of public participation in decision making are the ones that would help in development of sustainable energy in Malawi.

Decision making for city development is an urban governance process. Slack & Cote stipulate that urban governance shapes the physical and social character of urban regions; influences the quantity and quality of local services and efficiency of delivery; determines the sharing of costs and distribution of resources among different groups; and affects residents' ability to access local government and engage in decision-making, influencing local government accountability and responsiveness to citizen demands[4]. Parliament of Malawi highlights three main factors that influence decision –making: policy actors and their networks: local and international contexts within which policy decisions are being made; and evidence or knowledge available on the policy issue, and the prevailing framing of the issue in development discourses locally and internationally [3].

### Research Question

The key research question was “What are the perspectives and values that underpin the decision to expand the power infrastructure through generation of sustainable energy from solid wastes in the City of Blantyre?”

## Methods

The study was mainly qualitative. Key informant interviews were carried out with city development stakeholders. In addition, a think tank discussion was held which included breakaway focus group discussions to obtain level of variation in responses to the questions with respect to participants' institutions and mandates. Desk review complemented primary data. Sampling was purposive. The qualitative data was analysed using manual coding and identification of recurrent themes and trends.

## Analysis and findings

Thematic priorities that emanated from the group discussions were infrastructure for utilities and social services, industry and commerce, and, waste management. The priorities apparently emanated from institutional mandates and responsibilities.

This informs that decisions are mandate and responsibility driven. Having a mix of different mandates and responsibilities among stakeholders implies that a democratic and inclusive decision process for development in the City will be slow and difficult. Each policy actor appeared to direct priorities towards their area of responsibility and mandate. This demonstrates that policy actors and their networks are a significant determinant of development decisions. The City authorities need to balance between democracy and inclusiveness, and progress. This will require understanding biased priorities of stakeholders and national development agenda, so that stakeholder inputs may translate into positive and holistic development outcomes.

Evidence or knowledge available on waste to energy value chain was not identified by the stakeholders as an opportunity. Therefore this seems not to be relevant in driving the direction of decision for development of Blantyre city. However, a review in a number of literature shows that knowledge and evidenced from well analysed data contributes positively to decision making processes, and this is applicable to city development.

Figure 2 below summarises this Section.

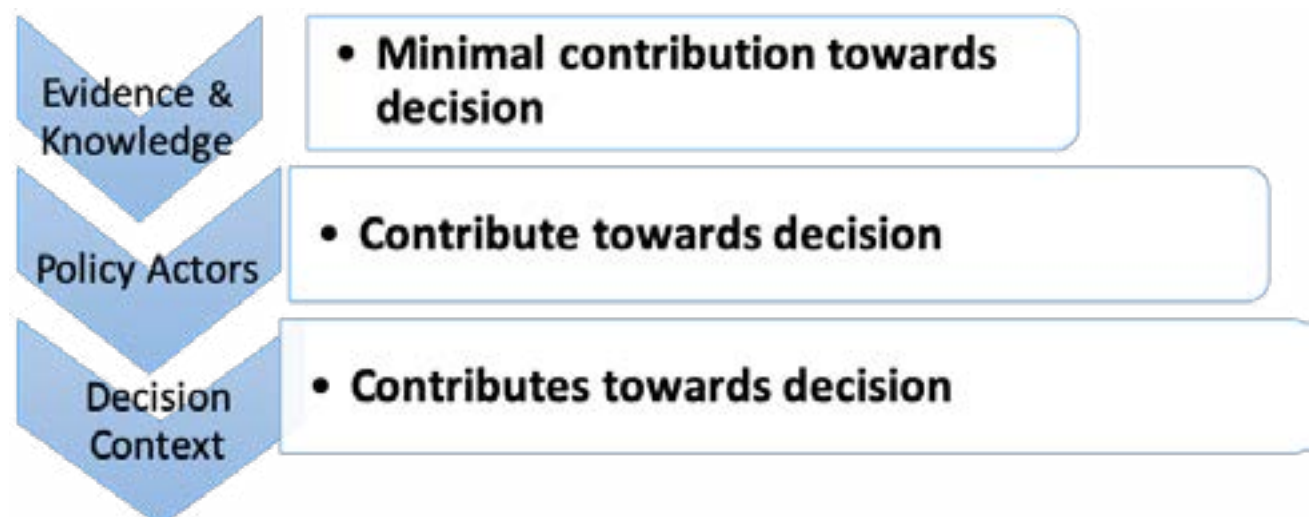


Figure 2. Determinants of development decisions in an African city

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Figure 2 below summarises this Section.

## Climate change risks, vulnerabilities and decision making for the water sector in the city of Harare, Zimbabwe; lessons for African cities

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Climate plays a significant role in the health and integrity of water resources. This study sought to determine climate change and variability risks and to understand decision making processes for the water sector in Harare. A mixed method approach was employed to collect data. Temperature and rainfall (quantitative) data were used to determine historical climate trends. Qualitative data was obtained from household questionnaires and key informant interviews. Perceptions on climate were compared with actual climate trends as well as risks and vulnerabilities on water resources. Household respondents and key informants' perceptions which included significant increases in temperatures and high rainfall variability matched actual climate trends. Climatic risks identified included exposure to high temperatures, droughts and floods while non climatic but related risks included outbreak of diseases, population expansion and less productivity within households among others. Barriers to effective decision making included reactive decision making, financial issues, overlap of stakeholder roles, lack of accountability and out-dated infrastructure. Results provide lessons on the importance of decision making for building and developing climate resilience in cities.

**KEY WORDS:** climate change, variability, risks, vulnerability, decision making, Harare

### Introduction

Urban areas contribute towards climate change through greenhouse gas emissions but are also are vulnerable to its impacts [8]. Impacts of climate change are being felt in Africa as evidence points to warming trends [2]. There has been an increase in the frequency and intensity of extreme weather events such as droughts and floods and prolonged intra season dry spells, rainfall variability, frequency of storms and hailstorms and poor rainfall distribution within rainy seasons in the past century in Zimbabwe [5][7].

Emerging evidence shows that climate change will affect freshwater resources through reduced renewable surface water and groundwater in most dry subtropical regions. The IPCC recently developed the Global Research and Action Agenda on Cities and Climate Change Science whose

main purpose was to explore the climate change risks, vulnerabilities in cities and the mitigation measures mainly underlined by the co-benefit concept, a research gap exposed in the IPCC (2014) report. Given that African cities are challenged by multiple stressors such as urbanization, obsolete infrastructure and governance challenges, climate change is, therefore, coming in as an additional stressor.

Understanding pre-existing risks and vulnerabilities is therefore fundamental to deal with the challenges brought about by climate change. Addressing climate change risks and vulnerabilities will also indirectly address sustainable development challenges and help cities and regions attain their SDGs. Furthermore, decision making plays a fundamental role in all these efforts. Given the similarities in challenges that cities face, the city of Harare provides lessons for similar African cities that experience challenges in decision making which are linked to already existing risks and vulnerabilities. This is expected to contribute towards building resilience in cities through sharing of lessons.

## Method

The study was carried out in Harare, the capital city of Zimbabwe. A mixed-method approach that employed both quantitative and qualitative methods was used. Quantitative climate data (temperature and rainfall) was obtained from the Zimbabwe Meteorological Services Department for the period of (1984–2014). Qualitative data was obtained from key informant interviews ( $n=18$ ) with stakeholders in the water sector of Harare and household questionnaires ( $n=120$ ) within six sampled suburbs. These represented three categories that are high, medium and low density based on the age of suburbs and population density. The idea was to assess the differences in vulnerabilities across a typology of suburbs in Harare. Perceptions on climate change and variability, risks, were compared to actual historical climate trends.

Historical temperature and rainfall trends for a period of thirty years were determined using a linear regression analysis and Temporal Trend Analysis Graphical Interface in R respectively. Seasonal rainfall anomalies were used to classify rainfall seasons into normal, wet, dry, extremely wet and extremely dry years and the drought severity index was used to classify droughts as moderate, severe and extreme [1]. The coefficient of variation was used to analyze the variability of rainfall [4]. Descriptive statistics and a multinomial logistic regression in SPSS were used to determine the extent of exposure to risks and vulnerabilities among the suburbs. Chi square tests were performed in order to test for association between location, levels of education and income and the various responses from household respondents.

## Results

A linear regression analysis indicated a warming trend in temperatures as depicted by the slope of the regression line (Figure 1). However, the correlation between temperature and time is weak [ $R^2 = 0.15$  (0.1495)]. Annual trend analysis using Temporal Trend Analysis (TTA) shows that there has been a statistically significant increase ( $P < 0.05$ , Sen Slope  $> 0.05$ ) in average temperatures in Harare ( $P = 0.032$ ;  $N = 30$ ). Minimum temperatures also show statistically significant (TTA;  $P = 0.05$ ;  $N = 30$ ) increases (Sen slope = 0.15) whereas maximum temperatures depict a statistically non-significant ( $P = 0.07$ ;  $N = 30$ ) but increasing trend (Sen slope = 0.02) over time.

Key informants reported that there has been a noticeable increase in temperatures over the years and this has resulted in frequent heat waves which matched historical temperature trends. According to key informants, increases in temperatures contribute to an increase in evaporation within water bodies resulting in the water bodies drying up thereby affecting water availability in the city. Residents' perceptions on temperature were similar across all the locations, Old High Density (Old HD), New High Density (New HD), New Medium Density (New MD), Old Medium Density

(Old MD), Old Low Density (Old LD) and New Low Density (New LD) (Figure 4.5). More than 50% percent of the respondents across all the locations reported that they observed increases in temperature over the years.

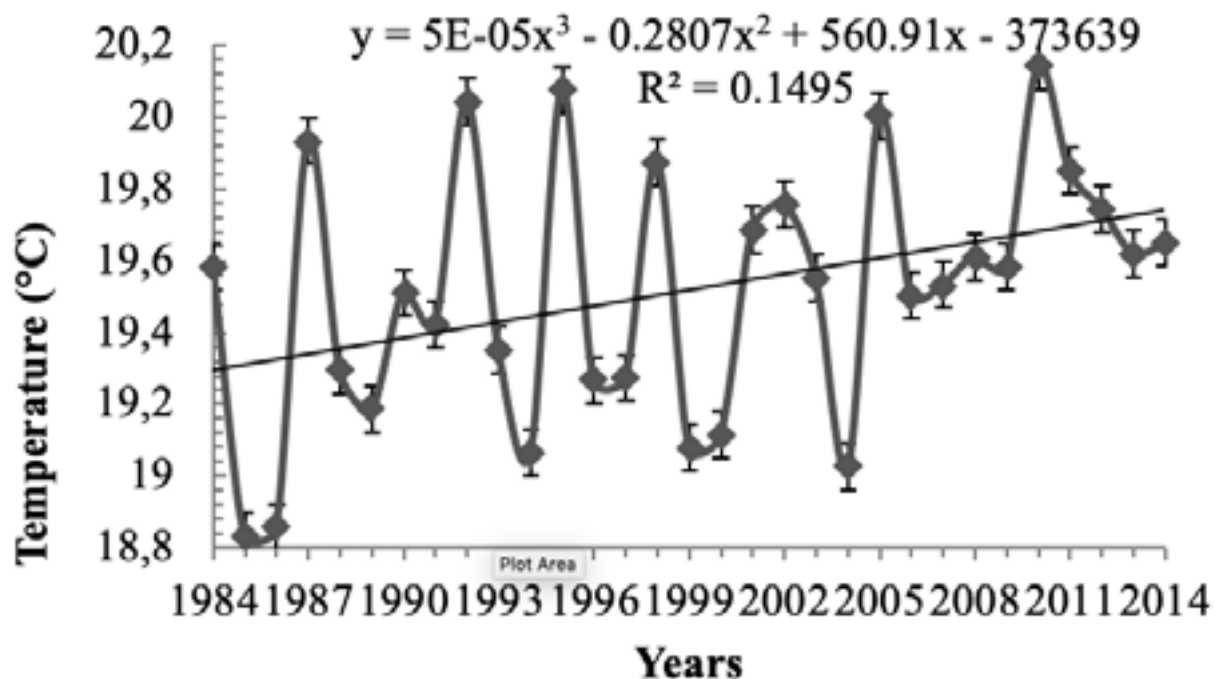


Figure 1. Harare mean temperatures from 1984 to 2014 (Source: Zimbabwe Metrological Service Department, Harare)

Rainfall patterns for Harare indicated a high variability of 29%. Time series analysis of rainfall using TTA indicated a non-significant trend ( $P = 0.86$ ) in rainfall for the period 1984/1985 to 2014/2015.

Key informants reported that there has been a decrease in rainfall over the years and this matched with historical rainfall analysis which indicated a decrease in rainfall although it was statistically insignificant. Key informants also reported that there has been an increase in the occurrence of droughts and this matched historical rainfall analysis which indicated an increase in the occurrence of droughts as depicted by three consecutive seasons post the year 2000 which were in the dry season range, with one season being an extremely dry one.

Key informants also reported non-climatic but related risks which included outbreak of diseases due to inadequate water supply, population expansion which puts pressure on water resources and less productivity within industry and households, among others. Multinomial logistic regression indicated that 66.7% of respondents perceive the water they use to be safe for drinking. Being located in a low-density suburb and having basic education level has a positive impact on the perception that the water being used is safe. The majority of households in low density areas use boreholes as compared to households in high density areas. This can be a contributing factor as to why they perceive their water to be safe. Respondents from low density areas do not treat their water as they perceive it to be safe. These respondents have boreholes as their main source of water and the perception that water from boreholes is safe poses a health risk (by contracting diseases such as typhoid and cholera). Although boreholes are now widely used in low density areas, Misi et al. (2018) report that there is pollution of groundwater sources in the Upper Manyame sub catchment in which Harare lies [6]. In addition, residents from high density areas are more vulnerable to the impacts of climate change mainly because of their limited access to water resources. In most cases they rely on unsafe water sources such

as protected wells. Residents in high density areas also have less income, less education as compared to residents in low and medium density areas. Barriers to effective decision making at both national and municipal level included reactive decision making, financial constraints, planning and budgeting issues, overlap of stakeholder roles, lack of transparency and accountability and out-dated infrastructure.

## Conclusion

There has been climate change in Harare indicated by historical climate trends. In addition, rainfall trends indicate high variability which has planning implications for water resources. Furthermore, water service delivery in Harare is affected by multiple stressors and the already existing challenges in the water sector make residents especially in high density areas more vulnerable to climate change. This provides lessons to other cities on the need for building resilience to climate change, taking into account the already existing stressors which are likely to exacerbate the impacts of climate change. This indicates the need for proactive adaptation planning as climate change in order to reduce vulnerability to the impacts of climate change and also achieving SDGs linked to water. Although there are several challenges to effective decision making in Harare, the city provides lessons on existing opportunities for effective decision making. These include existing platforms for engagement with stakeholders which provide an opportunity for involving communities in decision making and funding opportunities for projects and work that tackle environmental challenges such as climate change.

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## Mid-Century Daily discharge scenarios based on climate and land use change in Ouémé river basin at Bétérou

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This study evaluates the impacts of land use and climate changes on daily discharge in Ouémé river basin at Bétérou outlet. To estimate the future discharge, corrected rainfall and temperature data, under RCP4.5 and RCP8.5 scenarios, of the regional climate model REMO and two land use scenarios of RIVERTWIN project were used as forcing inputs for LISFLOOD hydrological

model. The first one land use scenario, Land Use A (LUA), is characterized by stronger economic development, controlled urbanization, implementation of large-scale irrigation schemes, and 3.2% population growth per year. While Land Use B (LUB), is characterized by a weak national economy, uncontrolled settlement, and farmland development as well as 3.5% population growth per year. Calibration and validation of LISFLOOD model showed a high ability to reproduce historical flows of Ouémé River at Bétérou outlet with Nash–Sutcliffe efficiencies greater than 90%. Future discharges simulations show general increase for all land use and climate combined scenarios for all time horizons until 2050. This increase is more exacerbated under the combined scenarios using LUB than the ones using LUA and varies between 7.1% and 52% compared to the mean of the reference period 2002–2004. These findings highlight growing challenges for water resources managers and planners. Moreover, they emphasize the need to address potential climate and land use changes' impact on water resources. Then, developing water management plans, strategies to reduce flooding risks must be considered.

**KEY WORDS:** Discharge scenarios; Land use scenario, LISFLOOD; REMO, Ouémé basin.

## Introduction

Managing future fresh water resources under a changing climate with vastly uncertain future atmospheric greenhouse gas emissions is an important challenge faced by human society today. One of these challenges is riverine floods management which is the second highest death-causing natural disaster worldwide [1]. Many studies have indicated that increased exposure of people and assets, as a result of population increase and economic growth, has caused more damage due to weather-related natural disasters, including flooding [2, 3]. For Africa, the number of flood-related casualties affected people and associated economic losses have significantly increased since the middle of the 1990s, due to an increase of human settlements in flood-prone areas [4]. Furthermore, the long-term observational records and climate projections provide abundant evidence that freshwater resources are vulnerable and have the potential to be strongly impacted by climate change, with wide-ranging consequences for human societies and ecosystems [5]. These consequences are more severe in regions dominated by an arid and semiarid climate such as West Africa [6].

In 2010, 15 West African countries were hit by damaging floods, 3,135,702 people were affected, 232 losses of lives were recorded [7] and the worst hit countries were Benin, Nigeria, Togo, Niger and Burkina Faso. For Benin, 2010 events seemed to be Benin's worst flood which had overwhelmed two-third of the country (55 municipalities out of 77). Significant damages were recorded: 831,000 people affected; 15,000 homeless; 46 losses of lives and massive losses of houses, harvests and properties. The estimated economical damage was US \$ 100 Mi [8]

Thus, more investigations are needed to assess the impact of climate and land use/cover changes on flow regime in the Ouémé basin at Bétérou using new IPCC climate scenarios (RCP4.5 and RCP8.5) combined with land use change scenarios.

## Materials and Methods

### Study Area

The present study focuses on Ouémé river basin at the outlet of Bétérou (Figure 1). This basin is located between the latitudes 9°12' North to 10°12' North and longitudes 1°30' East to 3° East and covers an area of 10,076 km<sup>2</sup>. Rainfall is characterized by two seasons: a dry season from November to March and a rainy season from April to October with the peak of rainfall in August. The annual rainfall average is 1200 mm/year. Average discharge is approximately 50 m<sup>3</sup>/s at Bétérou hydrometric station.



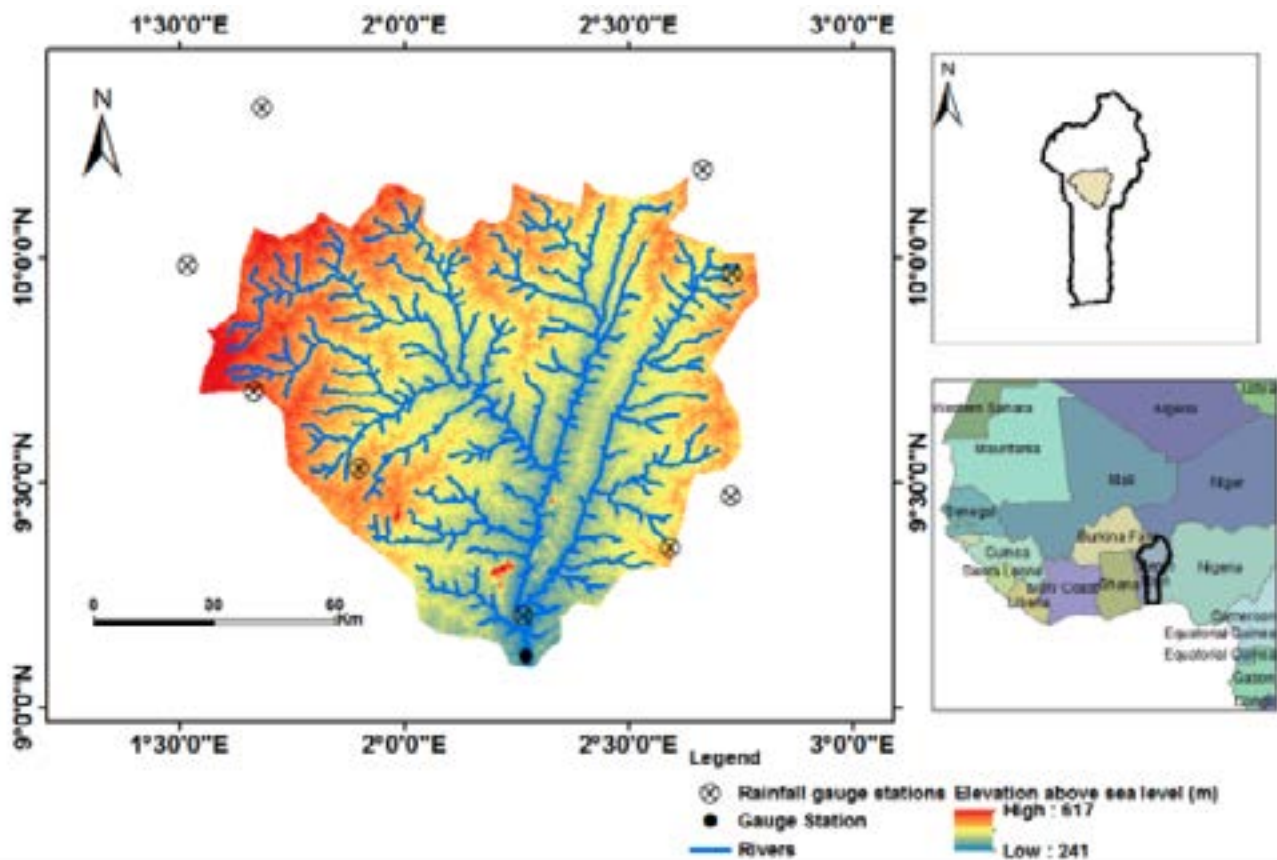


Figure 1. Catchment of the Bétérrou River.

## Data

Two types of climate data were used in this study: (i) daily rainfall and temperature data which were obtained from the National Meteorology Agency of Benin (Météo Bénin) and (ii) daily rainfall and temperature data from a set of simulations (scenario) conducted with the regional climate model REMO. The REMO simulations are forced with data from the global climate model MPI-ESM-LR following the IPCC Representative Concentration Pathways (RCP). We used these predictions following the mean RCP4.5 and the most extreme scenario RCP8.5. All these data are available in the CORDEX database online ([www.cordex.org](http://www.cordex.org)). Because of systematic biases that characterize the raw data of the regional climate models (RCMs) [2], we proceeded to bias correction of these data. The bias correction method used in this study is a new quantile-quantile calibration method based on a nonparametric function that amends mean, variability, and shape errors in the simulated cumulative distribution functions (CDFs) of the climatic variables, developed by Amengual *et al.* [9].

The land use/land cover map used in this study was established within the RIVERTWIN project. As the major factor for land use change is population growth, two socio-economic scenarios were set up: Land Use A (LUA) is characterized by a stronger economic development, controlled urbanization, the implementation of two large-scale irrigation schemes and by 3.2% population growth per year; Land Use B (LUB) is characterized by a weak national economy, uncontrolled settlement and farmland development, and a 3.5% population growth per year [11]. These scenarios are also used in the national planning administration of Benin [5]. In overall, land use scenarios were defined for three horizons (2017, 2022, and 2027) for the watershed [10].

## Methods

LISFLOOD is a GIS and physically based and spatially distributed hydrological rainfall runoff model, which is developed by the Joint Research Centre (JRC) of the European Commission. It is designed to simulate all hydrological processes that occur in a catchment [11]. LISFLOOD model was run at 5×5 km<sup>2</sup> spatial resolution. All spatial data (DEM, Land use/cover, soil map) were resampled to this resolution. Because of land use/cover reference period is 2003; we calibrated the model over the period 2002–2004. The period 2006–2008 was used to test model with land use/cover data of 2007. For future discharge assessment, we combined both climate change scenarios (RCP4.5 and RCP8.5) with both land use/cover change scenarios (LUA and LUB). Two objective functions were used to evaluate the model's performance. The first one is the Nash–Sutcliffe coefficient (NSE) and the second one is the Root Mean Square Error (RMSE).

## Results and Discussion

### Model Calibration and Validation Results

The model was calibrated over the period 2002 – 2004 and the period 2006 – 2008 was used for validation. The performances in calibration and validation. LISFLOOD performance in calibration (RMSE = 37.21 m<sup>3</sup>/s, NSE = 92%) and validation (RMSE = 32.3 m<sup>3</sup>/s, NSE = 90.5%) are close. Figure 1 presents the overview of daily discharge as simulated by the model.

### Daily Discharge Scenarios

From the simulated daily discharge, the monthly and annual means discharges were computed for each scenario and compared to the baseline observed monthly and annual mean discharges. Figure 2 presents the monthly hydrographs while Figure 3 shows the annual mean discharge change for different time horizons following the four climate and land use/cover combined scenarios LUA + RCP4.5, LUA + RCP8.5, LUB + RCP4.5, and LUB + RCP8.5. These figures show a slight decrease over the time horizons according to the four scenarios.

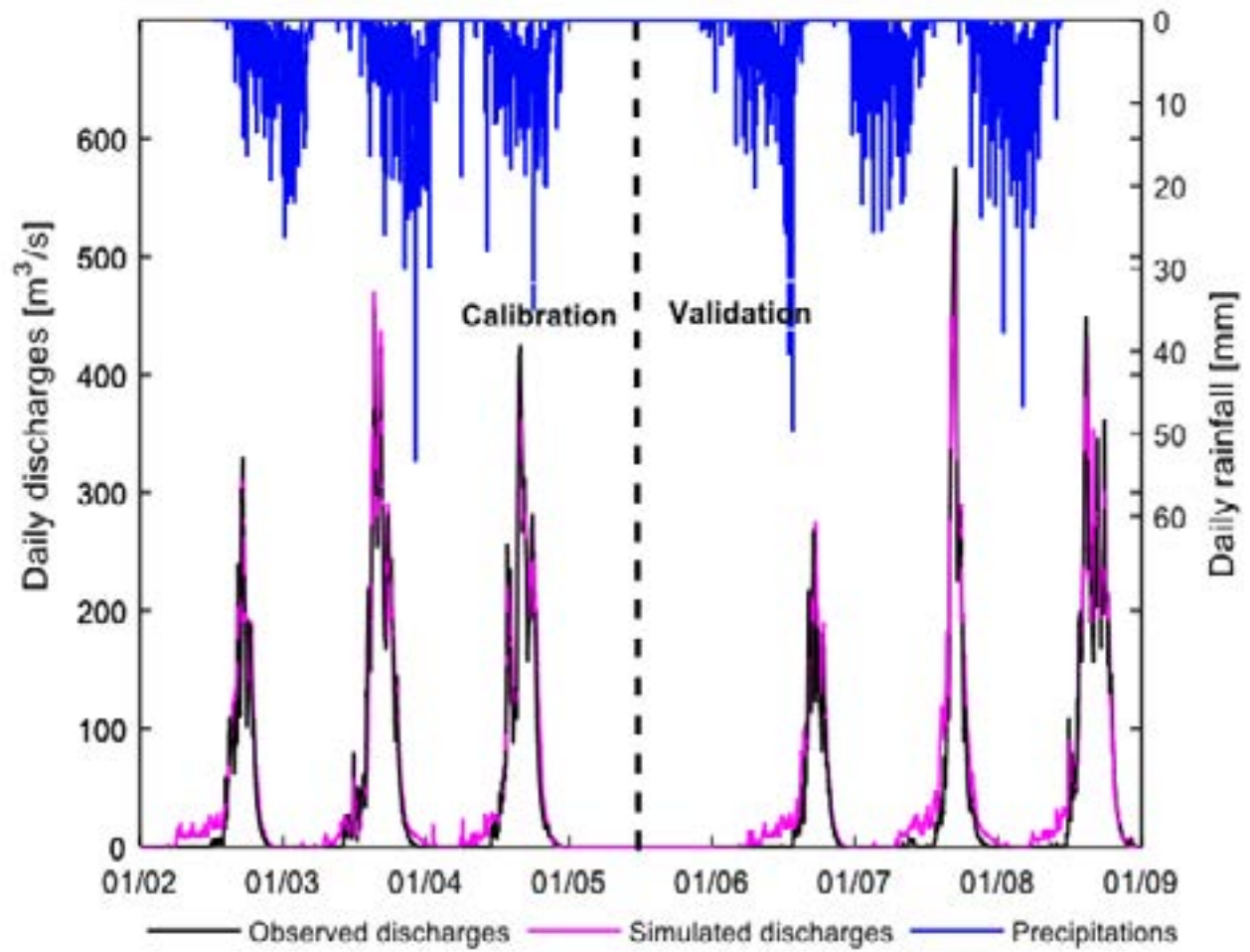


Figure 2. Comparison between simulated and observed hydrographs.

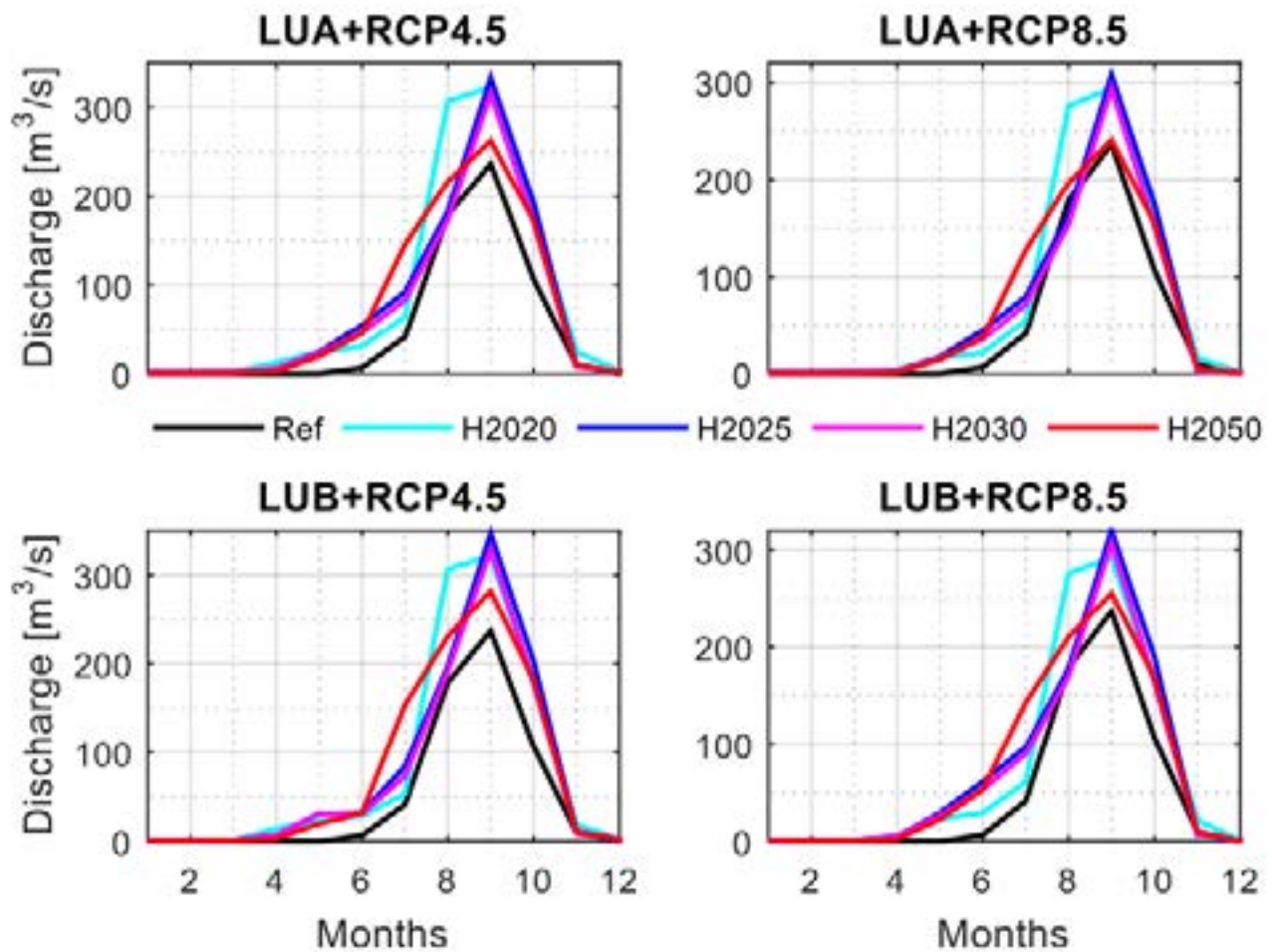


Figure 3. Monthly mean discharge scenarios based on climate and land use/cover combined scenarios

The change depends on the scenario and the time horizon. It is worth mentioning that discharge increase is more important following climate scenario RCP4.5 than scenario RCP8.5 (Figures 4 and 5). In fact, discharge increase under scenario LUA + RCP4.5 is more important than discharge simulated following the scenario LUA + RCP8.5. Also, the increasing discharge is more exacerbated under the scenario LUB + RCP4.5 than LUB + RCP8.5. On average, discharge increase following climate scenario RCP4.5 is estimated at 40% versus 25% under the scenario RCP8.5.

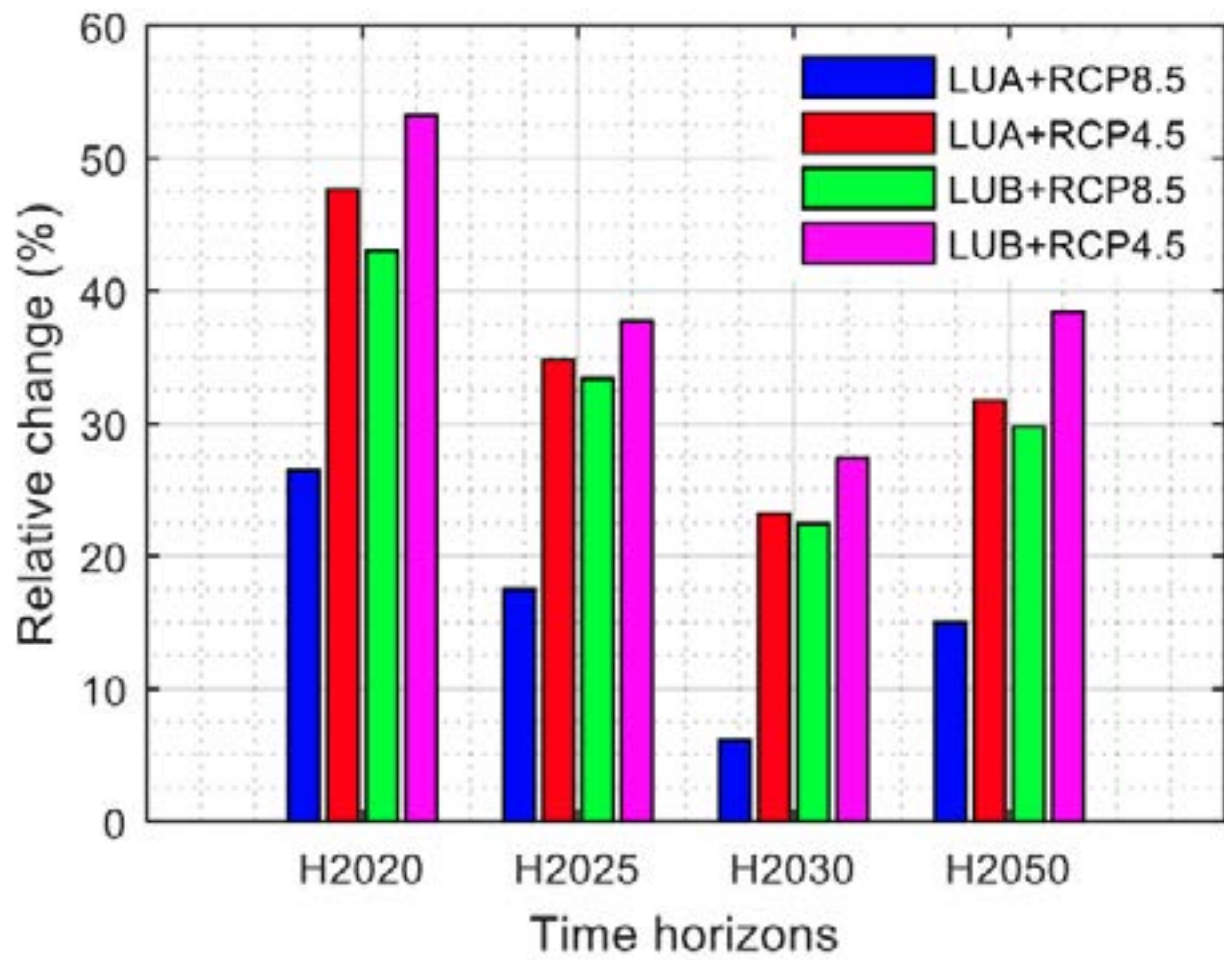


Figure 4. Time horizon annual total runoff relative change



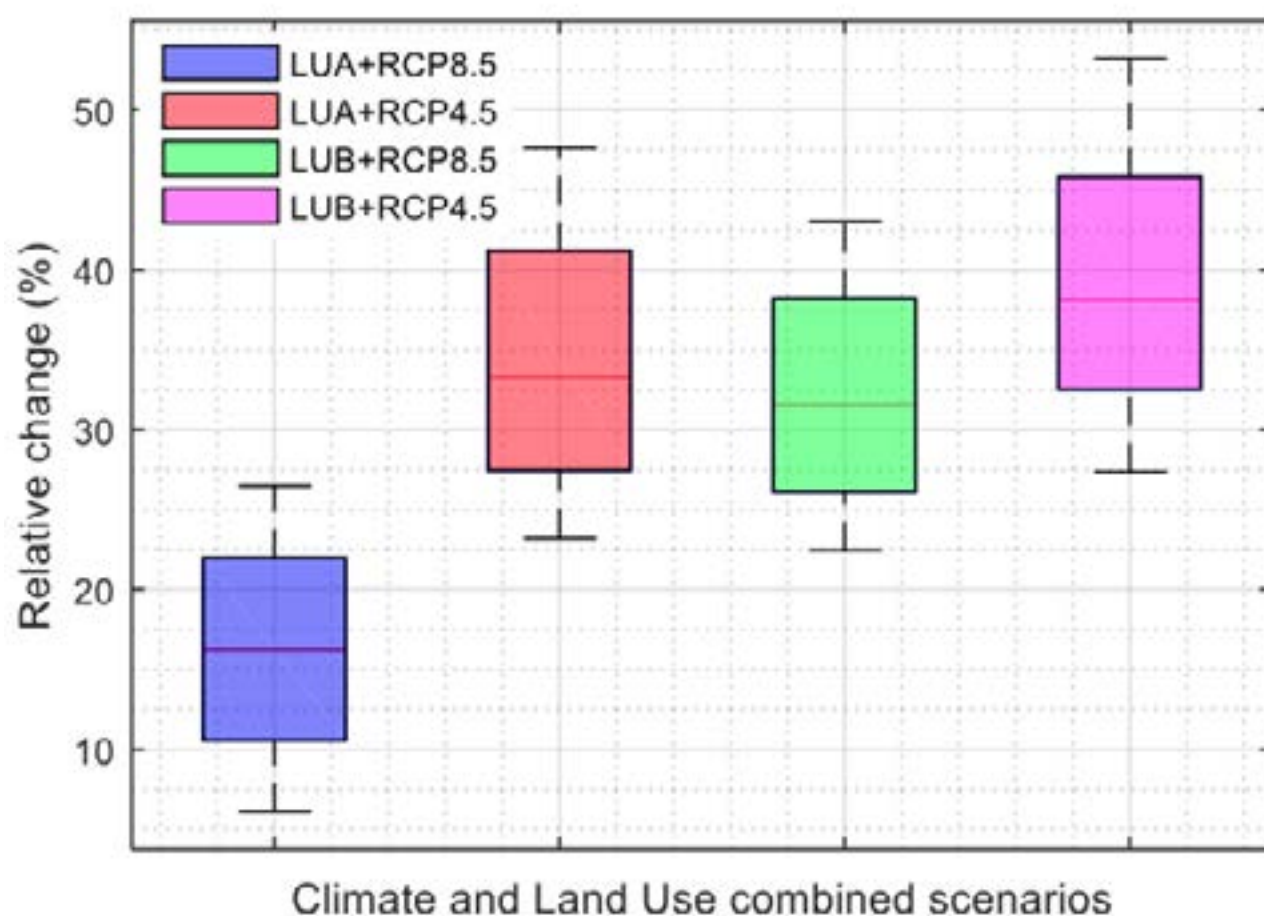


Figure 5. Annual total runoff change based on climate and land use combined scenarios.

Annual surface runoff may change from +17.5% to +37% for all the scenarios (Figure 4), driven by climate and land use change. Figure 5 shows the impact of land use/cover change on discharge. Indeed, compared to reference period, discharge may increase by about 17.5% under scenario LUA + RCP8.5 and this increase is 30.3% for the scenario LUB + RCP8.5. Considering the scenarios LUA + RCP4.5 and LUB + RCP4.5, increasing discharge is estimated as 36% and 48%, respectively. It means that, discharge increase is more exacerbated under land use/cover change scenario LUB.

Considering the main characteristics of LUA and LUB, the higher increase of runoff under LUB is due to strong conversion of natural vegetation to agricultural land. Indeed, increasing agricultural activities is correlated with deforestation and alteration of local soil properties, specifically infiltration. So, land use/cover change leads to infiltration reduction in the soil top layer due to soil crusts at the soil top surface and thus to increasing Hortonian runoff. Runoff increase due to land degradation has already been reported in several basins over West Africa. In Nakambé basin, Burkina Faso, runoff has increased, despite rainfall decreases since 1970 [12]. This increase of flows has been linked to agricultural land area increase. The same observation was made in Niger river basin, where runoff increase was related to increased cultivated area [13].

Assuming an unchanged land use after time horizon 2026–2030, we have produced the discharge scenarios until 2050. Increase of discharge compared to the reference period 2002–2004 was noted. This change varies between 15% and 37.1% depending on the scenario (Figure 5). These findings are in line with of the study of Bossa et al. [14].

## Conclusion

In this study, an assessment of climate and land use change impacts on future flows in Bétérou basin has been carried out. Land use scenarios produced by the RIVERTWIN project and the regional climate model (REMO) corrected outputs were used for forcing LISFLOOD hydrological model to estimate the future discharges in Ouémé River at Bétérou outlet. Based on the combination of climate change scenario RCP4.5 and RCP8.5 with land use/cover change scenarios LUA on the one hand and climate scenarios RCP8.5 and LUB, the future flows in Ouémé River at Bétérou outlet were estimated. Compared to the reference period of 2002–2004, Ouémé River at Bétérou outlet will experience the increased discharge for all time horizons until 2050 and for all climate and land use change combined scenarios. This increase varies from 7.1% to 52% and is exacerbated in scenario LUB + RCP4.5, confirming the high sensibility of discharge to land degradation due to extension of agricultural areas. This study provides important information about the future of water resources in the basin. It is also an invitation to water resource managers for the design of mitigation strategies to cope with the negative effects of discharge increase, mainly flooding in the study area. These adaptation and mitigation measures must include updating flood protection infrastructure, improving population awareness and preparedness, urban planning, discouraging human settlement in flood-prone areas, and reinforcing flood forecasting systems.

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## Impacts of Climate Change Adaptation Strategies on Fish Catchability: The Case of Inland Artisanal Fishers along the Volta Basin in Ghana

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The pattern of the climatic conditions in the fisheries sub-sector is currently alarming and has interfered with many productive fishing activities. In response to this, fishers have resorted to using certain climate change adaptation strategies (CCAS). This study assessed whether or not climate change adaptation strategies used by inland artisanal fishers along the Volta Lake in Ghana improve fish catchability. The study used primary cross-sectional data. A conditional mixed-process (CMP) with ordered probit outcome was used to estimate the effects of climate change adaptation strategies on fish catchability. The climate change adaptation strategies used by fishers in the study area are increasing daily fishing time, increasing fishing efforts, changing fishing time, aquaculture production, migrating to another fishing area, fishing further away or deep inside water, catching smaller fish, participation in alternative non-fishing livelihoods and taking a moratorium in fishing. It was evident that the more climate change adaptation strategies fishers use, the more fish they catch per unit man effort. It is prudent for stakeholders promoting climate change adaptation strategies and sustainable fishing, especially the Ministry of Fishery and Aquaculture to promote climate change adaptation strategies in fishing. More emphasis should be given to sustainable climate change adaptation strategies such as aquaculture production and close fishing seasons.

**KEY WORDS:** Adaptation Strategies, Catchability, Climate Change and Conditional Mixed-Process

### Introduction

In Ghana, fishing is practiced on small scale by rural fishing communities, largely along the Volta basins. In Ghana, artisanal fishing occurs in the Volta and Bosumtwi lakes (lacustrine), lagoons (estuarine), rivers, streams, dams etc. The contribution of inland capture fisheries to national fish production was 21% in 2014 with majority of the resources from the Volta Lake, which is the main source of freshwater fish in Ghana [7]. The fishery sector provides jobs to over 2.7 million men and women as fishers, processors, boat owners and builders, as well as other ancillary jobs in Ghana [8]. Irrespective of this, the country is 50% insufficient in meeting fish demand per annum [7]. This problem is being compounded by adverse climatic conditions. The country is expected to experience rising temperatures, increasing rainfall variability and sea level rise [3], which can affect aquatic resources. In order to minimize the effects of climate change on freshwater artisanal fishing, most fishers adopt adaptation strategies. As noted by Belhabib et al. (2016), adaptation responses of fishers to climate change impacts are scarce and not well studied unlike in the area of crop and livestock production [1]. Also, it is not clear whether climate change adaptation strategies adopted by fishers improve fish catchability in Ghana. This study will answer the question of what climate change adaptation strategies are used by fishers and whether or not these adaptation strategies significantly help fishers to increase catch/yield.

### Theory and Methods

#### Study Area and Data Requirements

The study was conducted along the Volta Basin in Brong Ahafo Region of Ghana. A simple random sampling technique was used to select Sene East and Pru East Districts from four Volta Basin Districts (Kintampo North, Pru East, Sene East and Sene West Districts). In each of the

selected Districts, 16 fishing communities were randomly selected. In each of the communities, 13 houses were selected using systematic sampling technique. Using Slovin's sample selection formula, a population of 80,000 fishers and a 5% margin of error gave a sample size of 397. Primary data was collected using semi-structured questionnaire.

### Identification of Climate Change Adaptation Strategies

Climate change adaptation strategies used by fishers were obtained from respondents with the help of questionnaires. Percentage frequency was used to analyse the data.

### Impacts of Climate Change Adaptation Strategies on Fish Catchability

The theory underpinning adaptation to climate change is the theory of utility maximization. An inland artisanal fisher will adapt to climate change if and only if he/she perceived that adapting will yield higher benefits (higher catchability) than not adapting. It is hypothesized that the more number of climate change adaptation strategies a fisher uses, the greater the quantity of fish catch per unit effort. In order to identify the determinants of climate change adaptation strategies and estimate their impacts on fish catchability, this study used a Conditional Mixed Process (CMP) framework. CMP as noted by Roodman (2011) is a system of equations which can be used to evaluate impact of a decision or participation in something on a certain outcome for non-experimental data[11]. This is because, CMP has the ability to deal with the problems of sample selection bias and endogeneity. Following Makate et al. (2015), the ordered probit equation that examines the determinants of number of climate change adaptation strategies is given as:

$$No.Adap_i = \beta_0 + \sum_{j=1}^{j=J} \beta_j X_{ij} + \varepsilon_i \quad (1)$$

Where  $No.Adap_i$  = number of climate change adaptation strategies used by  $i$ th fisher,  $X_j$  =  $j$ th explanatory variable and  $\varepsilon_i$  = error term for  $i$ th fisher[6]. With CMP, the outcome equation which measures the effects of number of adaptation strategies on fisher catchability is expressed as:

$$Catchability_i = \alpha_0 + \alpha_j No.Adap_i + \sum_{k=1}^{k=K} \alpha_k Z_{ki} + \eta_i \quad (2)$$

Where  $Z_{ki}$  =  $k$ th explanatory variable affecting the catchability of  $i$ th fisher.

## Results

### Climate Change Adaptation Strategies

Table 1 illustrates percentage frequency distribution of climate change adaptation strategies used by inland artisanal fishers to minimize the effects of climate change on fishing. As shown in the table, increasing fishing efforts is the climate change adaptation strategy with the highest percentage (95.5%). This observation confirmed the findings of Daw et al. (2009) and De Silva & Soto (2009)[2][4]. Another significant climate change adaptation strategy used by fishers is fishing further away or deeper inside water. It recorded a percentage of 88.9% making it the second. Fishing further away or deep inside water has been identified by Kabisa & Chibamba (2017) and Sereenonchai & Arunrat (2019) as a strategy fishers use to get more fish in the face of the changing climatic conditions[5][9].

The third most used climate change adaptation strategy is changing fishing time, as it recorded a percentage frequency of 78.6%. Changing fishing time here means fishers changing the time of fishing or the season of intense fishing. Due to climate change, hot spells make fish hide under

shade during certain times of the day and sometimes at night. As such, fishers study and know when to go for fishing and get enough catch. This finding is a confirmation of Kabisa & Chibamba (2017) and Sereenonchai & Arunrat (2019)[5][9]. Out of 397 respondents, 72.7% catch smaller fish to compensate for the unavailability of bigger fish due to climate change. This finding is not different as Kabisa & Chibamba (2017) came out with the same adaptation strategy being used by fishers in Lake Kariba of Zambia[5].

Spending more time on fishing or increase daily fishing time, migration to another fishing area, adopting alternative non-fishing livelihoods, taking a moratorium on fishing and engaging in aquaculture are other important climate change adaptation strategies used by fishers. Whilst Shelton (2014) identified changing locations of fishing in response to species shifting to new areas due to climate change[10], Daw et al. (2009) identified aquaculture infrastructure investments especially nylon netting and raised dykes flood-prone pond systems are key to adapting to reduced fish catch[2].

### Determinants of Climate Change Adaptation Strategies

From Table 2, the negative sign and statistical significance of *atanhrho\_12* implies that there are some unobserved factors which affect number of climate change adaptation strategies and fish catchability [6]. Hence, there is evidence of selectivity bias and the estimates would have been bias if ordinary least square (OLS) was used rather than CMP. Also, the likelihood ratio test value of 470.16 is statistically significant at 1%. This means that there is a strong correlation between the error terms of the number of adaptation strategies and catchability model and hence the two could not have been estimated individually.



Table 2. Determinants and Effect of Climate Change Adaptation Strategies on Fish Catchability

Variables	Determinants of CCAS		Effects of CCAS on Fish Catchability	
	Coef.	Std. Err.	Coef.	Std. Err.
Number of climate change adaptation strategies			2.8854***	0.9060
Formal education (years)	0.0137	0.0109	0.1360**	0.0609
Age of household head (years)	-0.0070	0.0065	0.0332	0.0394
Fishing experience (years)	0.0160**	0.0060	-0.0540	0.0443
Household size (number of persons)	-0.0604*	0.0315	-0.2350	0.1806
Adult household size (number of persons less than 18years)	-0.0140	0.0486	2.3585***	0.3109
Number of wards in JHS	0.1648***	0.0457		
Access to agricultural extension service (1=yes, 0=no)	0.3722*	0.1959	1.9807*	1.1944
Amount of credit received (GH¢)	0.0001***	0.0000	-0.0004	0.0003
Size of unmotorized canoe (0=no canoe; 1=small size; 2=medium size; 3=big size)	-0.1358	0.0875	1.6190***	0.5649
Ownership of motorized canoe (1=own; 0=otherwise)	0.0348	0.1501	0.0991	0.9417
Availability of electricity in the community (1=yes; 0=no)	-0.3677**	0.1530		
Quality of mobile phone network (1=good; 0=poor)	0.0266	0.1136		
monitoring of weather information (1=yes; 0=no)	0.4838***	0.1319		
Distance from community to fish selling market (Km)	-0.0022***	0.0005		
District (1=Pru East; 0=Sene West)	0.1841*	0.1104		
Average distance covered in fishing per day (Km)	-0.0007	0.0070	0.0505	0.0445
Motorability of road to market (1=motorable; 0=otherwise)	0.3971***	0.1125		
Climate change reduces quantity of fish catch (1=strongly disagree, 2=disagree; 3=no change; 4=agree; 5=strongly agree)	0.2390***	0.0866		
Depreciation (annual value of fixed capital inputs) (GH¢)			0.0004***	0.0001
Value of variable inputs (GH¢)			-0.0004	0.0002
Netsize (yards)			0.0033***	0.0004
Mesh size (cm <sup>2</sup> )			-0.1201*	0.0717
cons	-24.1744	5.3105		
/atanhrho_12	-0.5693***	0.1790		
rho_12	-0.5148	0.1315		
Log likelihood = -1050.46; LR chi2(33)=470.160; Prob > chi2 = 0.000				

Source: Analysis from field data (2019)

\*\*\* and \*\* at 1% and 5% significance level respectively, CCAS = climate change adaptation strategies

Fishing experience, number of wards in Junior High School, amount of credit received, access to agricultural extension service, monitoring of weather information, district dummy, motorability of roads and perception on reduction in quantity of fish catch are the factors which positively and significantly influence the number of adaptation strategies fishers use.

#### Effects of climate change adaptation strategies on fish catchability

From Table 2, it is clear that the number of climate change adaptation strategies used by inland artisanal fishers has significant effects on fish catchability. Climate change adaptation strategies is highly statistically significant at 1%. The positive coefficient implies that as the number of climate change adaptation strategies increases, fish catchability increases. The coefficient value of 2.9 implies that a unit increase in climate change adaptation strategy increases fish catchability by 2.9Mt/efforts. Other factors that have positive significant effects on fish catchability are value of fixed capital, size of canoe, size of net, years of education, adult household size and access to agricultural extension services.

## Conclusions

The three major climate change adaptation strategies used by fishers are increasing fishing efforts, fishing further away from the community and changing fishing time. The number of climate change adaptation strategies increases with fishing experience, number of wards in Junior High School, amount of credit received, access to agricultural extension service, monitoring of weather information and motorability of roads. Fishers who perceived that there has been a reduction in the quantity of fish catch due to climate change and those who stay in Pru East District adapt using more strategies. Climate change adaptation strategies are important in minimising the effects of climate change on fish catchability and hence should be promoted among inland artisanal fishers. Though, sustainable climate change adaptation strategies such as aquaculture production and close fishing seasons are lowly patronised in the study area, their promotion should be intensified.

## Acknowledgements

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## Evidence of drought events over Congo basin since 1970

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### Introduction

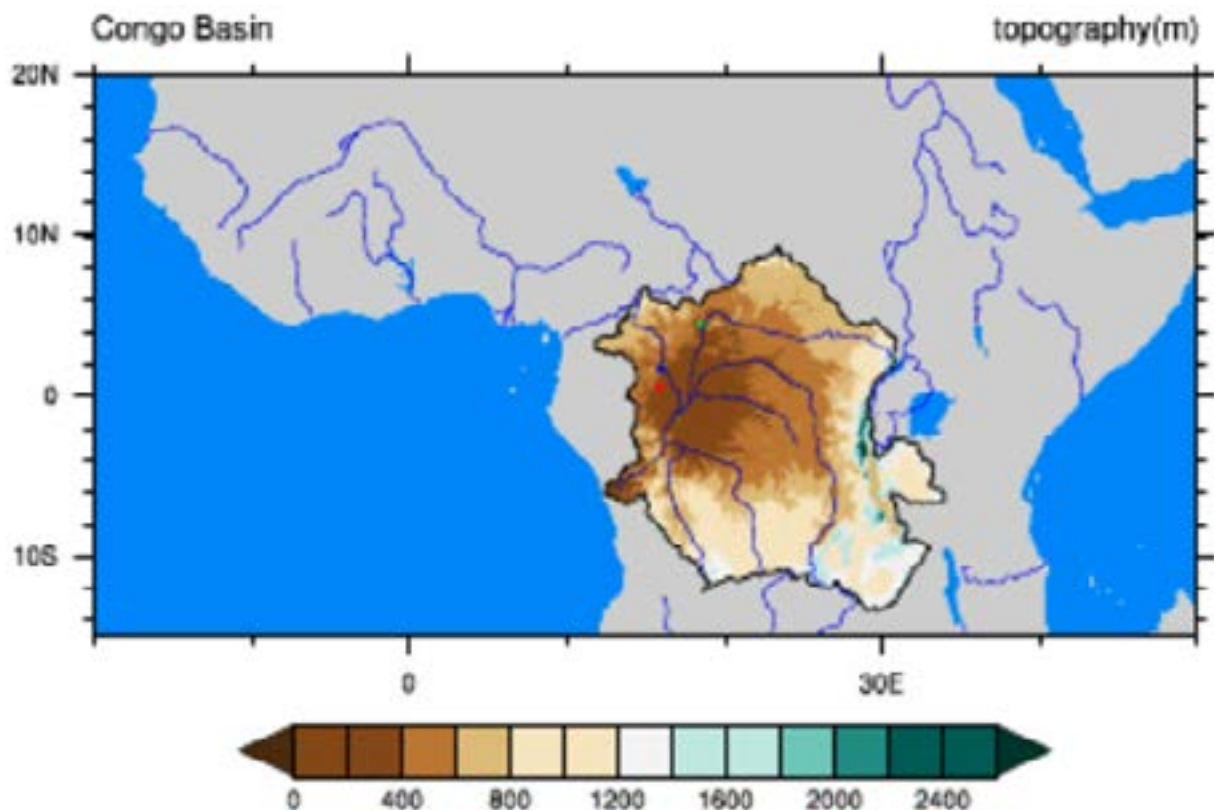
In recent decades, Central Africa, specifically the Congo Basin (CB) has experimented severe droughts that has been related to the changes in hydrologic cycle—decrease in rainfall in relation with the increasing of temperature [5]. The understanding of physical process responsible of such a hydrological event remains a current issue in the scientific community. Up to date, to our knowledge, no study has investigated the drought recurrence in CB using the self-calibrated Palmer Drought Severity Index (scPDSI). The goal of this study is to highlight the changes in characteristics of droughts events referring to severe and extreme droughts (SED) information deduced from scPDSI conditions over CB throughout 1905–2014 period.

**KEY WORDS:** Severe droughts, self-calibrated Palmer Drought Severity Index, hydro-climate regime, watershed.

### Study area, Data used and Methods

#### Study area

The CB extends between latitudes 14°S–10°N and longitudes 11°–35°E (Fig. 1). With a complex topography that ranges from low to high land, it contains the second largest forest and river in the world. The CB domain is characterized by dipolar climate regimes from north to south.



**Figure 1.** The Congo Basin (CB) topography (in m), Congo River tributaries (blue line) and the locations of four majors right river hydro-metric stations

## Data used

For the analysis the following data are used:

- The self-calibrated Palmer Drought Index (scPDSI) (0.5x0.5 resolution, 1901–2016) monthly data based on Climate Research Unit
- The monthly Congo River flow data at Brazzaville catchment from 1901 to 1995.

## Methods

We used the self-calibrated Palmer Drought Severity Index (scPDSI) because it is a simplified water balance model with a two-layer generic soil based on the Penman–Monteith parameterization, to compare moisture departure and the characteristics of the local climate on CB (delimited by CB shape file) during 1905–1969 and 1970–2014 periods. To better highlight the evidence of SED in temporal and spatial reference as defined by Palmer [1965] (Table 1), we represented Time-Latitude/Longitude CB SED and Congo River discharge coupled analyzes with water deficit/SED every ten years average. We also calculated CB SED fractional area (drought frequency) using statistical classic method (Probability Distribution Function) – tested with method of trends. The 25th and 30th percentiles are the extreme and severe threshold values that we have chosen in our study (Table 2) to observe spatial S.E.D trends. We evaluated SED after 1970 for two reference periods (1905–1969 and 1970–2014. We have deliberately suggested – by successive tests – extreme (severe) drought with spatial scPDSI values below the 25th percentile (between the 25th and 30th percentiles).

**Table 1.** Classification of dry conditions as defined by Palmer [1965] for the PDSI

scPDSI values	Drought category
-0.49 to 0	Near normal drought
-0.99 to -0.50	Incipient drought
-1.99 to -1.0	Mild drought
-2.99 to -2.0	Moderate drought
-3.99 to -3.0	Severe drought
lt. -4.0	Extreme drought

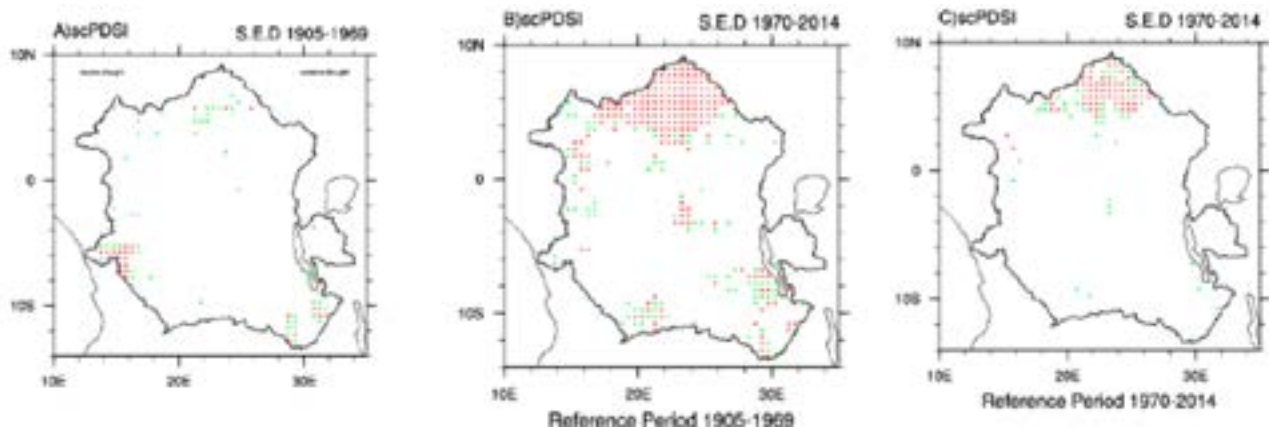
**Table 2.** CB 25th and 30th percentiles values for 1905–1969 and 1970–2014 periods

Percentiles	1905-1969 period	1970-2014 period
30th	-1.024	-0.78
25th	-1.562	-1.306

## Results and discussion

### Comparing CB S.E.D characteristics changes during 1905–1969 and 1970–2014 periods

Figure 2A shows sparsely packed and isolated S.E.D, less represented within the watershed from 1905 to 1969. In contrast, in Fig 2B, we observed a greater number of S.E.D clustered in northern CB after 1970 for 1905–1969 reference period compared to 1970–2014 reference period. This situation is more related to water deficit anomaly (figure not shown) and its high impact on soil moisture (input data of scPDSI model), especially as the mean temperature of the basin has risen steadily since 1940 (table not represented).



**Figure 2.** Trends variations of S.E.D over CB in A) 1905–1969 B) 1970–2014 at reference period 1905–1969 C) 1970–2014 at reference period 1970–2014. Red dots (green dots) are designed for extreme (severe) drought.

In Fig 3a, scPDSI time series shows significant inter-annual drought after 1970 with a minimal index value ( $-2.25$ , January 1997). The consecutive S.E.D from 1970 to 2014 “ $R_c = -1.4\%$  (red line)” were more representative than those from 1905 to 1969 “ $R_c = 1.19\%$  (green line)” and the most important occurred around the year 2000. This negative change reduced the coefficient of regression from 1905–2014 to “ $R_c = -0.3\%$  (blue line)”. In Fig 3b, before 1970 we observed a minimum percentage of S.E.D area per year (2.60%, 1962) “ $R_c = -4.7\%$  / year (green line)” and after 1970 the maximum (14.70%, 1997) “ $R_c = -1.1\%$  / year (red line)”. From 1905 to 2014, the trend coefficient of regression is “ $R_c = 4\%$  / year (blue line)” which has adverse effects on agriculture and water resources sectors within the watershed.



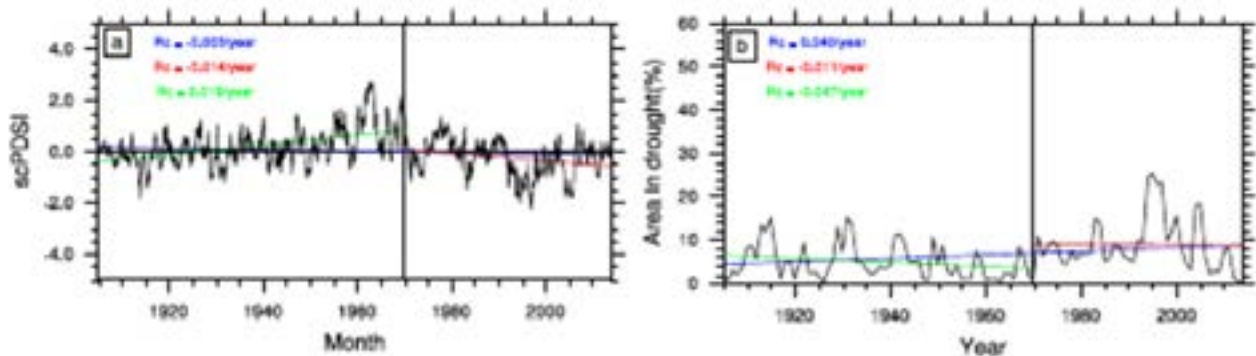


Figure 3. a) Time series plot of scPDSI over CB from 1905 to 2014 b) Temporal variations plot of S.E.D area coverage in (%)

We observed changes in the frequency cumulated of CB drought (values of scPDSI less than 0) in both periods, despite constant changes in moisture Figure 4 a. When we limit to the S.E.D values, the maximum frequency (12%, 1970–2014) and (9%, 1905–1969), this corresponds to the largest frequency deviation estimated at -3%. In Fig 5, CB was arbitrarily divided into three zones at latitude (14°S–4°S), (4°S–3°N) and (3°N–10°N) to observe and compare variations of S.E.D frequencies during both periods. In the northern part of CB (3°N – 10°N), the surface where the scPDSI index less than -3.0 for the period 1970–2014 is about twice that of 1905–1969. This means that in this zone, the frequencies of S.E.D are more repetitive after 1970, in accordance with the observations of Fig 2A, 2B and 2C. Peak frequency decreased from -1.0 (1905–1969) to -2.0 (1970–2014). In the central (4°S – 3°N) and south (3°N – 10°N) CB zones, S.E.D frequencies did not vary too much.

NB: We notice that the frequencies differences are significant in the range of  $[-5, 5]$ .

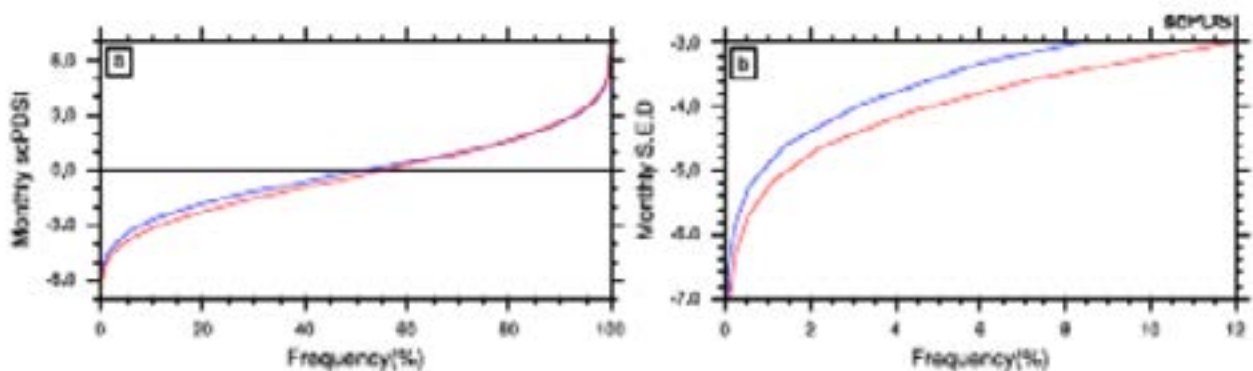


Figure 4. Time series plot of CB frequency distributions cumulated from 1905 to 2014 a) scPDSI all index values b) restricted to S.E.D

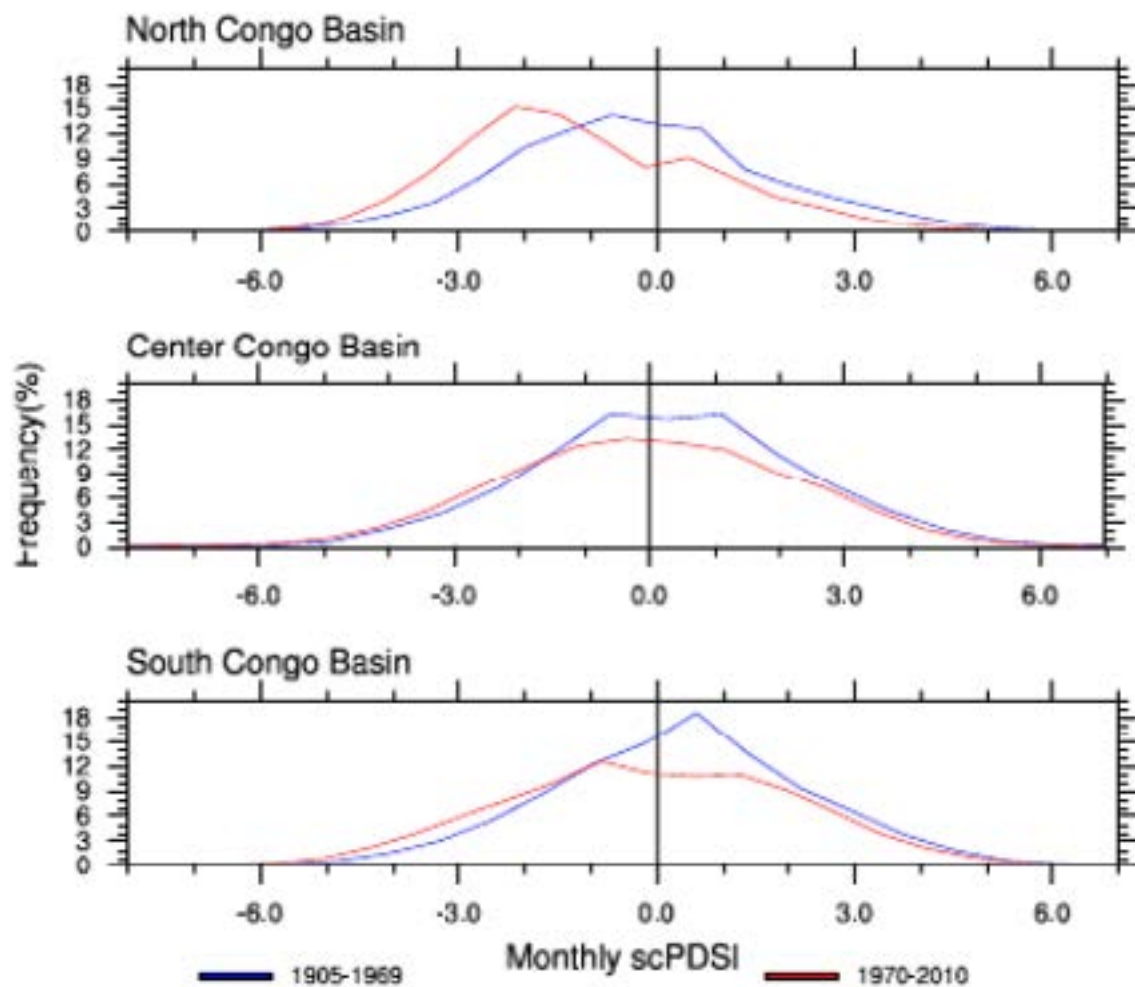
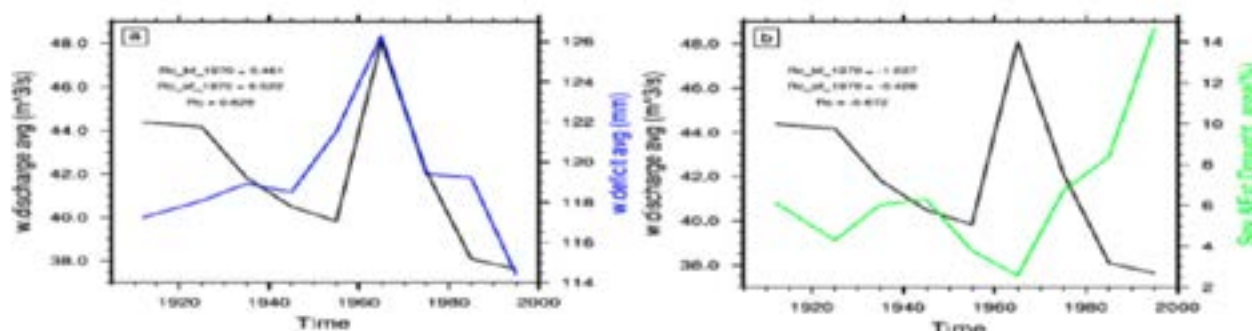


Figure 5. Distribution plots of the mean frequency of scPDSI values from 1905 to 2014 at north center and south CB

### Methods of analysis of evidence

Time-Latitude/Longitude analysis revealed two bands of continuous severe droughts and the disturbance of extreme droughts. In latitude, when the south severe band decreases in intensity, the north increases. In longitude, the central severe band shows a composite variation in intensity since 1905. Extreme droughts in latitude and longitude show two disturbed bands. The northern and central bands were interrupted from the early 1960s to the mid-1990s, however the southern and western disrupted after 1920. As a result, the question is why is the northern CB region occupied by S.E.D since 1970.

Coupled analyzes (Congo River flow - water deficit / S.E.D) - Fig 6a - allow to verify if the CRU dataset has been uncertain since 1990 [3]. We have shown that the water deficit is related to the flow of the Congo River (observed data) after 1970 (52.2%). The peak of the two graphs coincided during the 1960-1969 decade - an extremely intense period of precipitation on CB, which corresponds to an extremely low S.E.D period (Fig 6b) - and the correlation of S.E.D with the flow of the river Congo was estimated at (-67.2%).



**Figure 6.** From 1905–2000 ten years Congo river discharge coupled with a) Ten years average water deficit (in blue) b) Ten years average S.E.D (in green)

## Conclusion and forthcoming Research

In recent decades, higher evaporative demand and decline in precipitation increased the severity of climatic droughts which contributed to the decrease in surface water resources in particular at the north CB.

In future work, we will examine the multi-scalar drought index as standardized precipitation evapotranspiration index (SPEI) “coupled to SPI and scPDSI” for understanding the mechanisms of presence of S.E.D related to different climatic parameters and types of drought over CB.

## Acknowledgements

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## Vulnerability Assessment of Fisheries-Based Livelihood to Impacts of Climate change. A case of Lake Bangweulu fishery, Zambia

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The impacts of climate variability and change on natural resources based livelihoods has increased in magnitude, frequency and intensity and fisheries based livelihood is no exception. Vulnerability assessment has significant policy implication in prioritizing adaptation assistance,

allocation of resources and monitor progress over time. However, fisheries based livelihood have not been sufficiently examined to ascertain its level of vulnerability. The method included; Focus group discussions, Key informants and household questionnaires which were used to collect socio-economic variables for vulnerability assessment. Three IPCC vulnerability dimensions: adaptive capacity, sensitivity and exposure were examined. Results indicated higher vulnerability in Iyongolo (0.157) than Katanshya (0.042) due to higher exposure (0.424) and sensitivity (0.676) while adaptive capacity was lower (0.191). It was concluded and recommended that Livelihood Vulnerability Index (LVI) is a versatile tool that can be used to isolate attributes of vulnerability and possible interventions that can be proposed for reducing vulnerability through adaptation options.

**KEY WORDS:** Fisheries, vulnerability, Climate variability and change.

## Introduction

The impacts of climate variability and change on natural resources based livelihoods has increased in magnitude, frequency and intensity and fisheries based livelihood is no exception [4]. In Zambia, the mean annual temperature has increased by 1.3°C and annual rainfall has decreased by 1.9mm per month since 1960 [6]. The increase in temperature and reduced rainfall limits primary production, affects the fisheries ecosystem and ultimate fish production [5]. These impacts are likely to increase the vulnerability of fisheries based households. The current adaptation discourse which has taken root in the advent of climate variability and change has insufficiently addressed the vulnerability and adaptation of fisheries based livelihood [1]. The LVI will provide policy makers, fisheries managers and funding organizations a useful tool to comprehend biophysical and socio-economic aspects that contribute to climate vulnerability at the community and household level. It further guides on the prioritization and prudent application of scarce resources among various needs of adaptation [2]. The objective of this study was to assess the vulnerability of fisheries based livelihoods to the impacts of climate variability and change. This study used the Livelihood Vulnerability Index as developed by Hahn et al., (2009) to assess the vulnerability of fisheries based livelihood [3].

## Methods

### Study sites

The vulnerability assessment of fisheries based livelihood was undertaken in Katanshya fishing communities of Samfya district (11°15'S; 29°17'E) and Iyongolo fishing communities (12°25'S; 29°07'E) at the peripheral of Lunga district.

### Livelihood Vulnerability Index (LVI)

The vulnerability of fisheries based livelihood to impacts of climate variability and change was assessed by the LVI developed by Hahn et al. (2009) [3]. The vulnerability dimensions were aggregated according to Inter-governmental Panel on Climate Change (IPCC) recommendations. The total of 27 sub-components were combined into ten (10) major components which was later grouped into three (3) dimensions (Exposure, Sensitivity and Adaptive Capacity). Exposure; Natural Disasters and Climate Variability. Sensitivity; Dependence on Food and Income, Health, and Water. Adaptive capacity; Socio-Demographic Profile, Livelihood Strategies, Social Networks, Physical and Natural Assets, Knowledge and Skills. The computation of each indicator value followed the process of standardization adopted from the computation of the life expectancy index of the HDI [3]. Once values for each of the ten (10) major components was calculated, it was averaged to obtain the LVI at sampled area level of the fishery. Each of the nine major components was viewed as having an equal contribution to overall vulnerability [3]. The formula:  $LVI-IPCC = (E - A) * S$  was deployed. LVI-IPCC is the LVI for the area as within the IPCC framework, E represented the score for Exposure, A is the score for Adaptive capacity, and

S is the score for Sensitivity. The LVI was scaled from 0 (least vulnerable) to 1 (most vulnerable) [3]. Descriptive statistics were performed on quantitative data from the household questionnaire to obtain means, frequencies and standard deviations. ANOVA was conducted to reveal the significant difference in actual sub-components (vulnerability indicators) among the two sampled areas.

## Results

The Overall Livelihood Vulnerability Index according to IPCC was higher in Iyongolo (0.157) compared to Katanshya (0.042) (Table 1). The results imply the higher vulnerability in Iyongolo community and lower vulnerability in Katanshya community. The results indicated significant differences in adaptive capacity and sensitivity between communities ( $p < 0.05$ ). The higher vulnerability level in Iyongolo was attributed to higher levels of sensitivity (0.676) and lower levels of adaptive capacities (0.191).

Table 1. LVI-IPCC contributing factors calculations for the sites

Major Component		Katanshya	Iyongolo
Natural Disaster and Climate Variability	Exposure	0.360	0.424
	<b>Exposure</b>	<b>0.360</b>	<b>0.424</b>
Food and Income	Sensitivity	0.438	0.728
Health		0.448	0.535
Water		0.345	0.765
	<b>Sensitivity</b>	<b>0.410</b>	<b>0.676</b>
Socio Demographic Profile	Adaptive	0.330	0.268
Livelihood strategies	Capacity	0.292	0.305
Social Networking		0.120	0.112
Skills and Technology		0.178	0.088
Physical and Natural Assets		0.370	0.183
	<b>Adaptive Capacity</b>	<b>0.258</b>	<b>0.191</b>
<b>Overall Livelihood Vulnerability Index</b>		<b>0.042</b>	<b>0.157</b>

## Conclusion

It was concluded that fisheries based livelihoods is currently vulnerable to impacts of climate variability and change. The levels of vulnerability experienced in fisheries based households is influenced by household's overdependence on fisheries resources for their food and income. Further, vulnerability was attributed to low adaptive capacities among households. A number of biophysical and socio-economic factors were at play to influence and determine the level of vulnerability. The simultaneous application of strategies that are aimed at reducing sensitivity and increasing adaptive capacity can be of great benefit to the vulnerable system.

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## Future human exposure to dangerous heat in African cities

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Being located in hot regions and showing high rates of urban population growth, African cities appear particularly likely to face significantly increased population exposure to dangerous heat in the coming decades. We combined projections of urban population under five socioeconomic scenarios – Shared Socioeconomic Pathways (SSPs) – with projections of apparent temperature under three Representative Concentration Pathways (RCPs) in order to explore future exposure to dangerous heat across 173 large African cities. Employing multiple SSP\*RCP combinations, we demonstrate that exposure to dangerous heat in African cities will increase by a multiple of 20–52, reaching 86–217 billion person-days per year by the 2090s, depending on the scenario. The most exposed cities are located in Western and Central Africa, although several Eastern African cities also showed a very high increase in exposure due to the emergence of dangerous heat conditions combined with steady urban population growth. In most cases, we found future exposure to be predominantly driven by changes in population alone or by concurrent changes in climate and population, with the influence of changes in climate alone being minimal. We also show that shifting from a high to a low urban population growth pathway can halve future exposure to extreme heat, hence emphasizing the critical role that socioeconomic development plays in shaping future heat-related health challenges in African cities. This extended abstract is a synthesized version of a longer published article [9].

### Introduction

As recently highlighted in the 2018 Revision of World Urbanization Prospects – WUP [10], African cities are currently experiencing unprecedented growth. Global warming will pose serious threats to many urban populations in Africa [8]. The frequency, duration, and intensity of extreme heat events are expected to increase considerably in the 21st century over the African continent, particularly in subtropical areas [1]. Such an increase has significant implications for human health, as extreme temperatures are strongly linked to heat stroke and mortality [2].

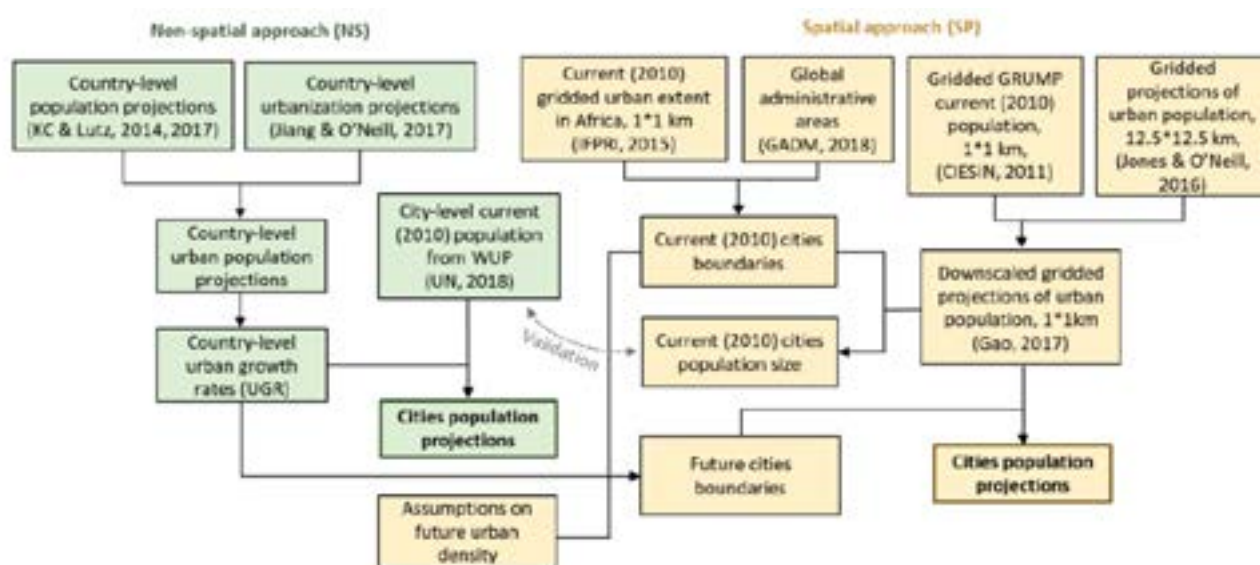
Driven by both high population growth and significant changes in climatic conditions, future exposure to dangerous heat in Africa is projected to show the highest increase worldwide during the 21st century [4]. Recent regional studies conducted in Eastern Africa [3] have provided a closer look at the effects of changes in socioeconomic and climatic conditions on future exposure to dangerous heat in some parts of Africa. However, the effects of such factors on the urban populations of the large African cities remain to be explored. In this study, we project the future population of African cities under the SSPs [7] and combine these future population estimates with projections of extreme temperature under different RCPs in order to assess future human exposure to dangerous heat in African cities under different SSP–RCP combinations.

## Methods

### Future population projections

We focus on large African cities that have a total population exceeding 300'000 inhabitants for the year 2014, yielding a sample of 185 cities. Due to the merging of several contiguous cities, the initial sample was reduced to 173 different cities. These are located across 43 different African countries, covering the wide diversity of climatic zones across Africa.

We employed two separate approaches to project the future urban population size of the sample cities under the SSPs, namely one spatial (SP) and one non-spatial (NS) approach (Fig. 1). The use of these two distinct approaches enabled us to account for uncertainties in both the modelling technique and the practical delimitation of cities' boundaries – based on administrative areas (NS approach) or on contiguity of the urban extent (SP approach).



**Figure 1.** Schematic workflow of the spatial (SP) and non-spatial (NS) approaches to compute cities population projections, repeated under each of the SSPs. Adapted from Rohat et al. (2019).

### Heat Index projections

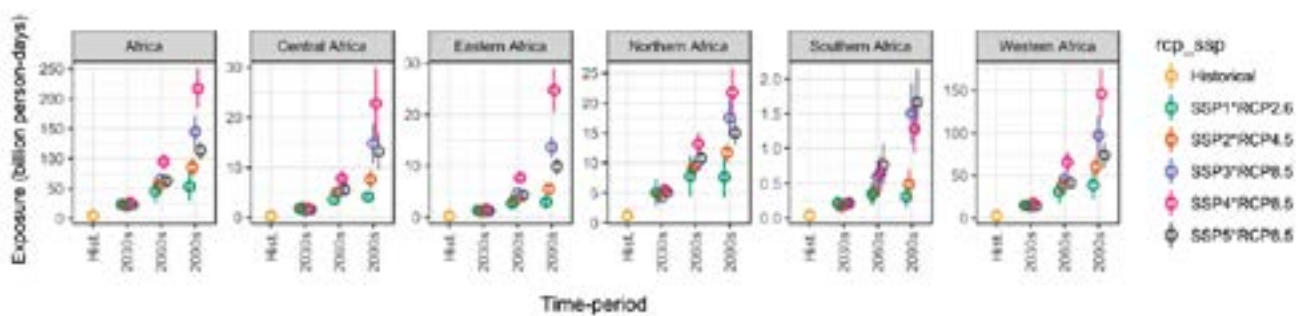
Uncertainties in climate change were accounted for by three climate scenarios, namely RCP2.6, RCP4.5, and RCP8.5. We employed a collection of 22 high-resolution RCMs from the multi-model CORDEX-Africa ensembles, which have recently been used to explore future changes in climatic conditions across Africa. We retrieved historical data from 1981 to 2005, and projected data under the three RCPs from 2006 onwards. We considered the nearest climatic grid points of each city to be representative of the cities' climatic conditions and bias-corrected projections of temperatures using quantile mapping with parametric transformations. We employed the apparent temperature (*AT*) and defined the annual heat index (*HI*) as being the number of days for which the daily maximum apparent temperature exceeds a given threshold, being set at 105°F (i.e. 40.6°C). The latter is based on the US National Weather Services (NWS) threshold of dangerous heat, widely used in the literature [5]. To compute the apparent temperature, we employed the NWS equation with adjustments when required [6].

## Exposure assessment framework

We defined exposure as being the number of people exposed to dangerous heat – that is, the annual *HI* (i.e. number of days when  $AT > 40.6^{\circ}\text{C}$ ) multiplied by the number of people exposed [4]. The unit of exposure is therefore person-days. For each city and each year, we computed the annual number of person-days of exposure to dangerous heat and averaged them over the baseline period (1985–2005) and future time-periods, namely the 2030s (2020–2040), the 2060s (2050–2070), and the 2090s (2080–2100). Exposure was computed under each climate model run and for both sets of urban population projections (SP and NS). We employed the multi-model mean to explore the results (one model being the combination of one climate model run and one set of population projections) and accounted for the inter-models variation through interquartile ranges (IQR).

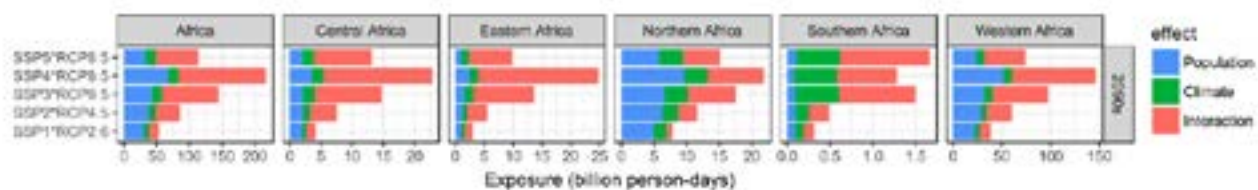
## Results

During the historical period (1986–2005), exposure to dangerous heat – aggregated at the continental level (i.e. sum of exposure of all the investigated cities) – was on average 4.2 (IQR=0.9) billion person-days per year. Our projections (Figure 2) show that this figure will increase under all scenario combinations, reaching from 20 (6) to 26 (7) billion person-days per year in the 2030s, from 45 (39) to 95 (25) in the 2060s, and from 86 (33) to 217 (66) in the 2090s, depending on the scenario combination. For the end of the 21<sup>st</sup> century, such figure represents a 20- to 52-fold increase in exposure compared to the historical period. Results also showed that exposure is unevenly distributed across the African continent, with the most affected region – in absolute terms – being Western Africa, due to numerous and highly populated urbanized areas and to increasing extreme temperature events. In this region, Nigeria suffers the most as it makes up ~3/4 of the regional exposure due to its high number of large cities (39 were included in our sample). Thanks to a slow – and partially decreasing – urbanization and population growth as well as to a milder climate, Southern Africa remains relatively unscathed, with a mean annual exposure of less than 2 billion person-days per year in the 2090s under all scenario combinations.



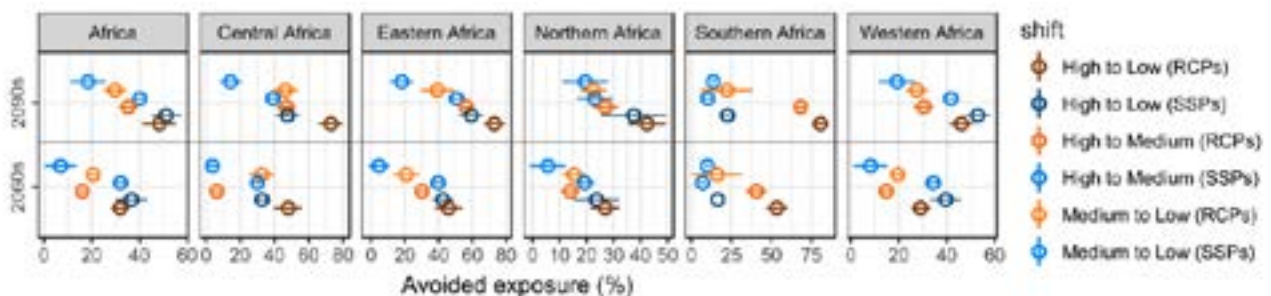
**Figure 2.** Projections of exposure (in billion person-days) averaged over different time-horizons, for the whole continent and regions. Adapted from Rohat et al. (2019).

Combining both historical figures and projections of urban population and dangerous heat, we assessed the individual contribution of changes in climatic and socioeconomic conditions – respectively the population and climate effect – as well as the interaction effect (Figure 3). Results showed that at the continental level, exposure to dangerous heat is primarily driven by the population and interaction effects, with the climate effect alone being negligible in all cases, meaning that climate change has limited influence on future exposure if not accompanied by urban population growth. At the regional level, all regions follow similar patterns, except Northern Africa (to some extent) and Southern Africa, for which the climate effect plays a substantial role (particularly under RCP8.5), partly due to the relatively limited urban population growth expected in these regions.



**Figure 3.** Population, climate, and interaction effect under five selected SSP-RCP combinations, for Africa and the five regions. Adapted from Rohat et al. (2019)

Results aggregated at the continental level showed that a shift from a high (SSP4) to a low (SSP1) urban population growth pathway would reduce exposure by ~51% (IQR=12) in the 2090s (Figure 4), regardless of the climatic conditions. This is slightly higher than the reduction in exposure triggered by a shift from a high (RCP8.5) to a low (RCP2.6) radiative forcing pathway, which is of ~48% (13) by the 2090s, regardless of the socioeconomic conditions.



**Figure 4.** Relative avoided exposure triggered by shifts in RCPs and by shifts in SSPs. Error bars represent the IQR. Adapted from Rohat et al. (2019).

## Discussion

We have shown in this paper that exposure to dangerous heat in African cities will gradually increase throughout the 21st century to reach 86–217 billion person-days per year in 2090s at the continental-level. We also corroborated the significance of the population effect and demonstrate that it is much higher than the climate effect alone – and of same magnitude as the interaction effect – in the context of African cities.

Provided with estimates of future exposure under varying climate and socioeconomic scenarios, policy-makers can already grasp the extent to which urban populations will be impacted by dangerous heat in African cities, as well as pinpoint the kind of socioeconomic pathways that should be favored in order to mitigate heat-related health risks. Findings of this study therefore (i) raise awareness about the potential co-benefits – in terms of decrease in exposure to dangerous heat in urban areas – of shifting toward a more sustainable, less populous, and less urbanized world, (ii) underline the necessity to mainstream climate change impacts and adaptation into spatial planning and urban development plans, and (iii) call for the integration of population and urbanization policies into the wide range of potential climate adaptation options.

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## Development and Use of Agronomic Weather Indices in Assessing Intra-Seasonal Climate Change Risks to Rainfed Cropping Systems.

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To answer the fundamental question of “adapt to what” within the context of climate-smart agriculture investments, staff and partners of the Food and Agriculture Organization of the United Nations (FAO) have developed and applied a set of 69 agronomic weather indices to identify trends in the frequency and intensity of intra-seasonal weather events associated with climate change. These indices, when applied to daily historical and downscaled projected temperature and precipitation data, provide a robust, empirically-driven means of identifying the principal attributes of climate change to which crop agriculture must adapt. Research completed with national teams in Malawi and Zambia used the indices with the daily weather station records from the National Meteorological and Hydrological Services and gridded climate data. Individually, and in combination, the indices allow the identification of important trends in seasonality, the crossing of critical crop tolerance thresholds, extreme weather events and the responsiveness of some adaptation options. The projection of these trends into the near-term future helps to guide climate-smart agricultural investments in research programmes, extension field activities and climate change adaptation efforts more broadly. Using daily temperature and precipitation data, the established indices can be used with any crop for which a basic physiological understanding exists, covering spatial scales ranging from individual weather stations to national and regional coverage.

### Background

In the context of climate change research, climatological indices have been developed and used as observational benchmarks to detect and track changes to key weather parameters (e.g., those of the ETCCDI). Historically, agricultural applications of indices-based research have predominantly focused on discrete weather phenomenon, most notably determining the start of the rainy season [1][4], and more recently the crossing of crop-specific temperature thresholds [2] and the impact of major weather anomalies such as el Nino, with lesser attention given to those associated with outbreaks of certain crop diseases.

To extend the use of weather indices in assessing climate change impacts on crop agriculture, staff of the FAO developed an initial set of 38 agronomic weather indices in 2014. The indices were created to support analysis of historical daily temperature and precipitation records for trends in



weather patterns associated with climate change that impact rainfed agriculture. These indices have undergone subsequent refinements, expansion and testing, resulting in the current set of 69 indices that have been used in assessing the historical and projected downscaled weather records at national scale [3]. The indices are organized into three levels of increasing specificity – general climatological indices (e.g., annual and monthly means); general agronomic (e.g., seasonality, intra-seasonal extreme events); and crop specific indices (e.g., related to crop phenology). The indices effectively serve as search terms used to interrogate historical and projected daily weather records for the occurrence of specific anomalies. Each of the indices includes one or more default values regarding the magnitude and/or temporal occurrence of a specific precipitation (mm) or temperature (°C) attribute, and are written to allow the user to replace default values to carry out more advanced types of analysis.

Within the context of capacity strengthening efforts in Malawi and Zambia, part of FAO Modeling System for Agricultural Impacts of Climate Change (MOSIACC) supported and associated projects, the agronomic weather indices were introduced and sub-sets selected in each country to assess specific weather features. A beta-version of an on-line global agronomic indices tool was released in July 2019 at a Southeast Asia regional workshop organized by FAO in Bangkok, Thailand, and is being refined for general release prior to the end of 2019.

## Methods

The initial coding of the indices used Matlab software, and is under conversion to R for greater accessibility. In both countries, historical daily weather data were used in the analysis. In Malawi the indices were directly applied to the national archive of weather station records, with 41 stations reporting precipitation, and 21 and 19 stations reporting maximum and minimum temperature data respectively, covering the period from 1960 to 2012. In Zambia, a 3km grid cell data layer for daily precipitation and temperatures, covering the period 1981 to 2014, was resampled to 50km and used in the analysis. A validation of the grid cell data layer was conducted comparing a sample of individual station records with data in the corresponding grid cells and deemed acceptable (R values of  $> 0.7$  and  $> 0.8$  for precipitation and temperature respectively). For the future projections, two emission scenarios, RCP 4.5 and 8.5, were considered over three time-periods: near future (2011–2040); medium future (2041–2070); and far future (2071–2100). Statistical downscaling techniques were used comparing four global circulation models: GFDL, MIROC, IPSL and NORESM. The analysis in both countries produced means, covering the date range of weather data, historical and projected, as well as year-to-year trends (Mann-Kendall) for all of the indices used in each country.

## Results

Analysis involving the 28 indices selected for use in Malawi on the national precipitation and temperature station data provided a number of insights on how changing weather patterns are impacting agriculture. In key locations in the country significant trends are observed in the increasing frequency of large storm events ( $> 50\text{mm}$ ) associated with high rates of soil erosion, the crossing of high temperature thresholds for important economic crops (e.g., Arabica coffee) and increased consistency in some locations to the start to the agriculture season. The indices also proved useful as a tool in assessing the potential of adaptation responses to avoid detected climate change stressors, such as the use of shorter maturing varieties to avoid the occurrence of dry-spells during reproductive period of maize.

In Zambia, using the national gridded dataset, analysis focused on assessing changes to the start, end and length of the growing season, as well as the number of days of with average temperatures over  $30^\circ\text{C}$  affecting maize productivity. Results of the analysis (below) detected a trend in an increasingly early start to the growing season, a later ending, with an overall lengthening of the growing period, yet with increasing variability.

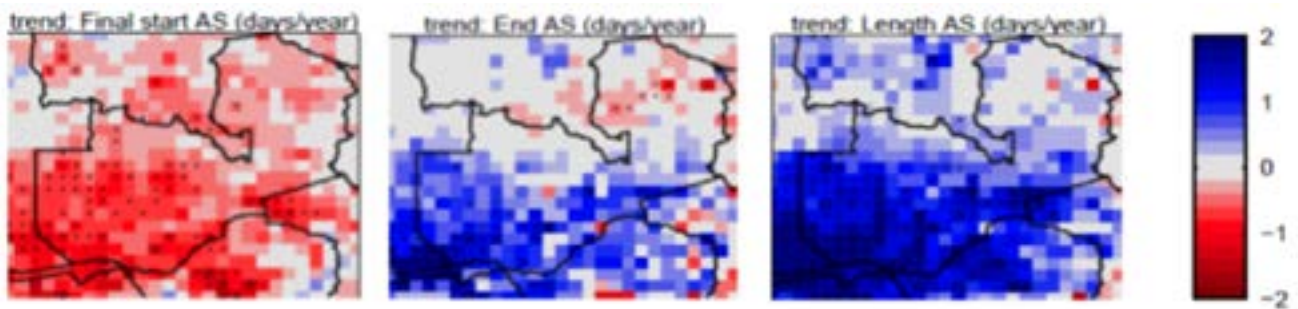


Figure 2. Start/End/Length of the Maize Growing Season (days/year)

The analysis also detected an important trend in the number of days within the maize growing season with temperatures exceeding 30 °C. The findings of Lobel et al., (2011) show a physiological response of maize to temperatures above this threshold leading to a nearly one percent decline in maize yields for each day above 30 °C, assuming the absence of other stressors[2]. The trends detected by the indices, in terms of geographic location and year-to-year change, indicate that a serious decline in the productive potential of maize is occurring within the country. Such trends will continue as temperatures continue to rise.

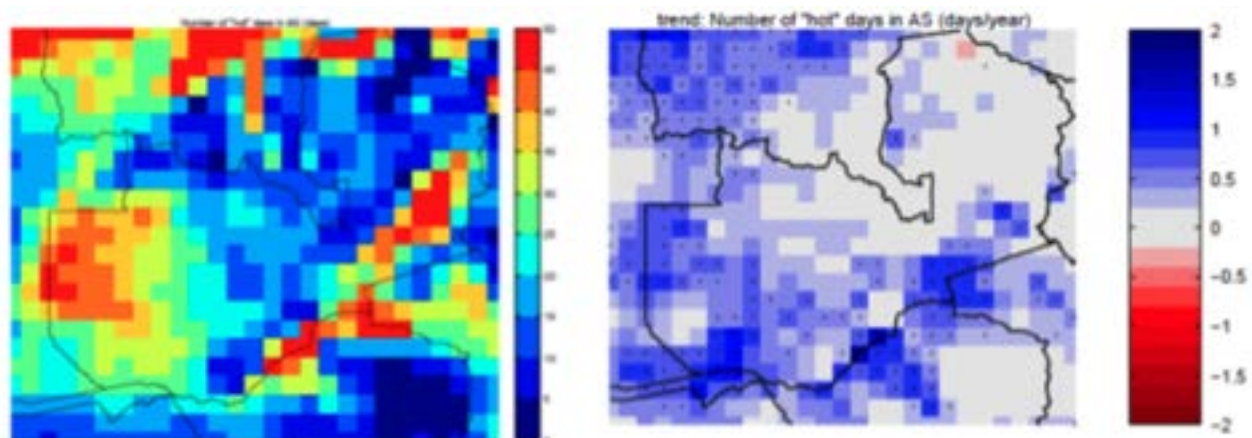


Figure 3. Average and Trend in the Number of Days > 30 °C During the Maize Growing Season

## Conclusions

The agronomic weather indices have proved successful in detecting changes to important intra-seasonal weather parameters (precipitation and temperature) affecting agriculture at sub-national scales. The ability to look within the agricultural season at changes to weather patterns allows the identification of specific weather stressors where adaptive responses are required. The indices, through user defined adjustments to threshold values, also allowed the initial screening of certain adaptive responses for their potential of avoiding or responding to the stressors identified.

Use of the indices to detect climate change impacts on agriculture requires agronomic interpretation in at least three ways. First, is in setting the basic default and user determined parameters of the indices search terms (e.g., conditions defining the start of the agricultural season). Second, is the interpretation of the results for potential impacts on specific crops (e.g., number of days with high temperatures above critical thresholds), and agricultural systems more generally where adaptive actions may be required, such as the potential impact of increased frequency in large storm events exacerbating soil erosion in areas already subject to erosion threats. Third, is the ability to conduct an initial screening of adaptive responses to

observed trends in specific weather threats (e.g., avoiding dry-spells during the reproductive period of maize through use of shorter maturing varieties). When applied to downscaled weather projections, use of the indices also provides the ability to assess the future prospects of the key food and cash crops in contributing to national food security and economic growth objectives.

The ability to conduct detailed, agriculture specific analysis of changes to weather patterns provides critical information and guidance for national research efforts, agricultural extension field programmes and national policy planning. The established indices can be used with any crop for which a basic physiological understanding exists, and for any location for which daily precipitation and temperature data is available, covering spatial scales ranging from individual weather stations to national and regional coverage.

An initial set of the agronomic indices is included in an on-line platform launched by FAO and partners in Bangkok, Thailand, July 2019. The platform currently covers 28 countries in South and Southeast Asia. Global coverage, including the full range of agronomic weather indices, will be available before the end of 2019. FAO staff will continue to support the future development, maintenance and expanded use of the agronomic weather indices.

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## Estimation of Flood damage for housing in flood-prone areas in ouagadougou (Burkina FASO)

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Floods regularly cause huge damages to population, environment and socio-economic infrastructures in West Africa. Burkina Faso experiences a variety of natural hazards, including floods with significant socio-economic impacts across the country and in Ouagadougou in particular. Flood management is now based on a good knowledge of the phenomenon. Due to the significant costs of building flood protection, policy-makers need an estimate of the potential damages in order to evaluate the relevance of investments. The objective of this research is to estimate the cost of flood damage by first estimating the potential damages in terms of flood depth. A survey of two hundred and forty-three (243) households located in flood-prone areas in Ouagadougou commune allowed to construct some empirical relations of damages depending on submersion. Thus, three relationships between flood depth and likely damage are established depending on the housing building material (poor material, semi concrete and concrete). The results indicate that the cost of damages for the major flood of 2009 (1<sup>st</sup> September) is amounted to over 329 million XOF corresponding to a mean flood depth of 0.6 m. The estimated cost

functions for damage to housing in flood-risk areas in Ouagadougou commune are considered appropriate ( $R^2$  satisfactory). These functions could be served as a useful support tool in the computation of flood damage.

**KEY WORDS:** urban flooding, depth-damage curves, flood-prone areas, Burkina Faso

## Introduction

Flooding is among the most damaging natural disasters in the world [1]. In West Africa in particular, after the drought that strongly affected Sahelian zone during the 1970s and 1980s, major urban centres of this zone experienced an increase in floods occurrence [2]. In Burkina Faso, between 1986 and 2016, 77 flood events were reported [4]. For example, 2009 flood event centred in the city of Ouagadougou has caused considerable damage [9]. Flood damage depends on flood characteristics such as flood depth, extent and duration, the flow velocity and the frequency of heavy rainfall. The damage can be tangible and intangible. Tangible can be subdivided into direct and indirect damage. Direct damage result from the contact of flood water with damaging property and the extent of damage is assumed to be the cost of property restoring or current market value if the restoration is impracticable. Indirect damages are losses caused by the disruption of physical and economic links, including loss of production, loss of revenue, loss of business and delays in the transportation system. Intangible damage includes fear, anxiety, annoyance, health, and loss of life [6].

Thus, the assessment of potential ex-ante damage is a powerful indicator of vulnerability, which could enable decision-makers to judge the relevance of flood management initiatives [3]. This study aims to evaluate in monetary terms the direct damage of flooding on the housing structure in the flood-prone areas in “Grand Ouaga” zone in Burkina Faso.

## Material and methods

### Study area

This study focuses on the area called “Grand Ouaga” which is located between the latitudes 12.05°–12.68° and the longitudes (–1.83°)–(–1.04°). “Grand Ouaga” is an administrative zone covering the urban commune (Ouagadougou) and seven (7) rural communes around Ouagadougou, the capital city of Burkina Faso [8] (Figure 1). This zone covers an area of about 3048 km<sup>2</sup> and stretches on a perimeter about 326 km. It has a largely urban population (83% of the population). This population increased from 649,373 in 1985 to 2,532,311 in 2015 [5].



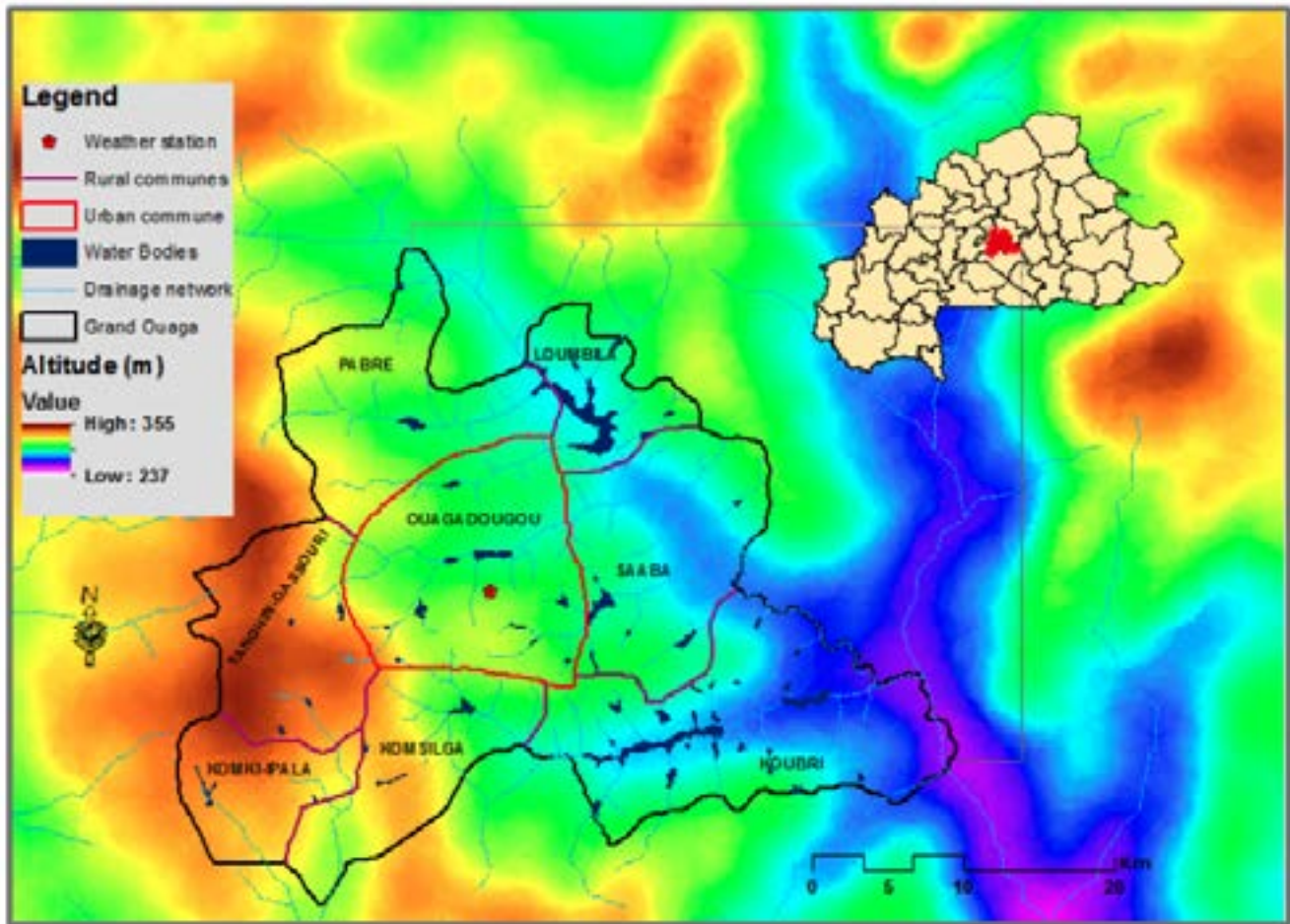


Figure 1. Location of the study site: administrative boundary lines of « Grand Ouaga » as well as those of the communes

The climate is characterized by a single rainy season from May to October, with a peak rainfall recorded generally in August, and a dry season from November to April. The mean annual rainfall was 770 mm/year over the period 1961–2015.

### Construction of the damage function

Potential damages due to flooding are generally expressed through damage curves. A damage curve is a damage function that combines damage costs established for a type of issue based on the physical variables of hazards. These variables can be: water depth, submersion time and flow velocity [7]. Damage estimation methods concern mainly direct damage. Other types of damage are difficult to evaluate economically. The damage function considered for this study is expressed as follows:

$$Tx_e = a \exp(-b \exp(-k.H))$$

where  $T_x_e$  and  $H$  are respectively the damage rate and the submersion depth.

$a$ ,  $b$  and  $k$  are model parameters to determine. These parameters were obtained using the Statistical software package SAS Release 9.2. The criterion  $R^2$  (coefficient of determination) was used to assess the performance of each damage function.



## Data for the study

Data for this study comes from the household survey conducted in July and August 2016. This survey was conducted mainly in flood-prone areas in "Grand Ouaga". Data collection was done using questionnaire administered to heads of households. Thus, 243 heads of households were interviewed. Data processing allowed us to finally retain 190 households for the realization of this study. Households which are not regarded are those that were not affected by floods or who no longer remembered the value of damage or the water depth in the dwellings.

## Results and discussion

Table 1 shows the parameter values obtained for damage functions depending on the type of house. The performance criterion seems to be satisfactory ( $R^2 > 0.5$ ). The higher performance observed for the concrete houses could be explained by the fact that this type of housing is regulated and respect the building standards due to the important investment.

Table 1. Parameters fitting by housing type

Type of housing	Number	a	b	k	R <sup>2</sup>
Poor material	122	0.923	2.165	2.855	0.55
Semi-concrete	28	1.136	1.783	0.991	0.64
Concrete	40	1.943	3.444	0.730	0.98

The resulting flood-damage functions are shown as in Figure 2. Damage rate values vary between 0 and 1. Damage rates show that houses constructed with poor material are the most vulnerable to flooding. The water depths that can cause 100% damage to the housing structure are approximately 2m, 4m and 5m respectively for housing in poor material, semi-concrete and concrete.

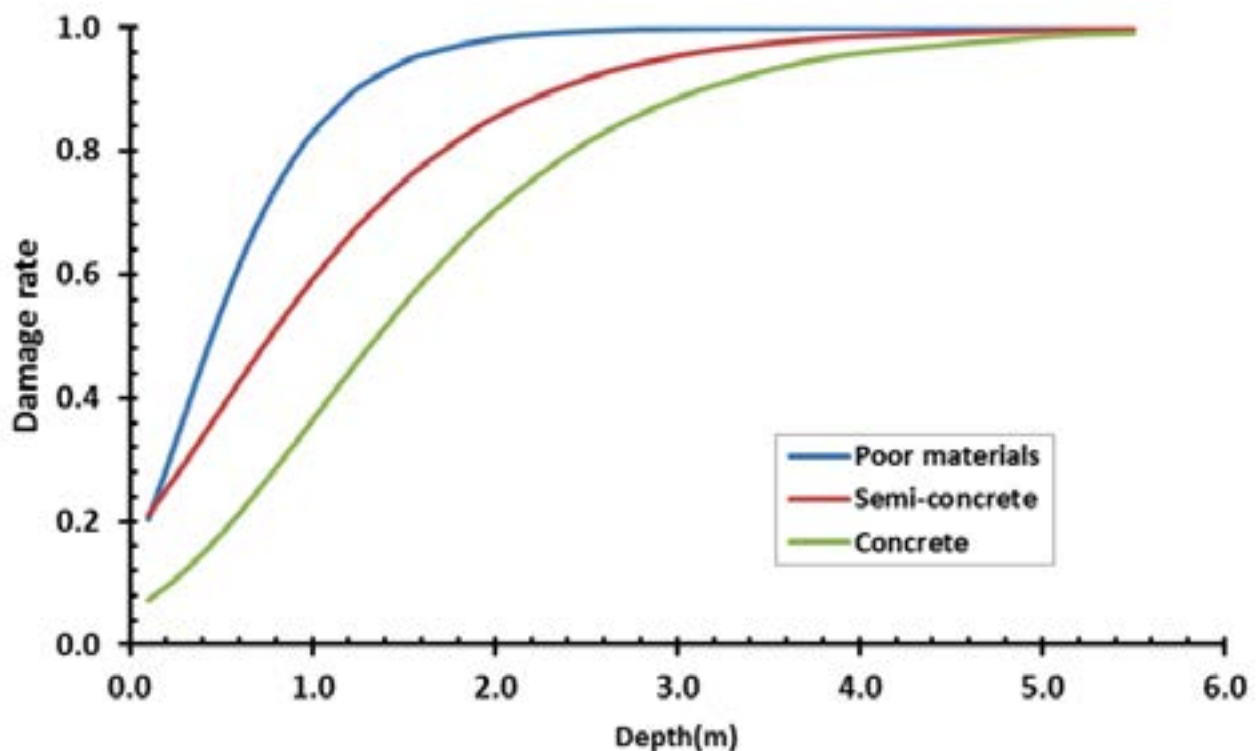


Figure 2. Submersion depth-damage curves for housing

Using average housing markets values and established damage functions, the costs of potential damage to the housing structure for the flood-prone areas around the dams in the city of Ouagadougou are provided in Table 2.

**Table 2.** Estimated potential damage in XOF for houses in flood-prone areas around the dams in the city of Ouagadougou.

Typology of housing	Number of housings	Estimation of potential damage according to the water depths (H)			
		H= 0.5 m	H= 0.6 m	H= 1 m	H= 1.5 m
Concrete	814	144 767 464	171 306 265	300 749 173	499 589 239
Semi-concrete	192	48 748 172	54 008 617	74 520 242	96 511 116
Poor material	267	91 278 190	103 846 653	135 468 619	148 930 742
<b>Total</b>	<b>1 273</b>	<b>284 793 827</b>	<b>329 161 537</b>	<b>510 738 036</b>	<b>745 031 098</b>

A flood with a similar magnitude as that of 2009 flood (1st September) in Ouagadougou (average water depths about 0.6m) could cause damage to the housing structure estimated to 329,161,537 XOF. This amount, even if it is only indicative, gives an idea of the importance of the exposure issues (housing) to the flood risk and could serve as guidelines to the choices in terms of public policies of flood prevention.

## Conclusion

This study focused on the construction of submersion-damage curves of housing in flood-prone areas in "Grand Ouaga" zone. Three types of housing were classified according to the nature of the building material. The analysis revealed that water depths that can cause 100% damage to the structure of housing are approximately 2m, 4m and 5m respectively for houses in poor material, semi-concrete and concrete. The robustness of damage curves strongly depends on the quality of data. These tools could be used as decision support tools to contribute to the reduction of flooding risks.

## Acknowledgments

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## Understanding Small-Scale Farmers' Perception and Adaption Strategies to Climate Change Impacts: Evidence from Two Agro-Ecological Zones Bordering National Parks of Uganda

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Agricultural production by small-scale farmers in Uganda is vulnerable to climate change because the agricultural regime is rain-fed and subject to climatic changes and variability with significant impact on agricultural productivity, livelihoods and food security. This study analysed small-scale farmers perceptions and impacts of climate change on agricultural production and livelihoods and adaptation options to tackle the adverse effects of climatic changes in Karenga (lowland agro-ecology) and Kapchesombe (highland agro-ecology). Both study areas are adjacent to Kidepo Valley and Mount Elgon National Parks (which are highland and lowland agro-ecologies) respectively. Analysed by using data obtained from 607 households, (41.5 percent males and 58.5 percent females) and were multi-staged and purposively sampled. The study found out that that the small-scale farmers were aware of climate change events. Meteorological data analysed confirmed the climate warming and change. The largest proportion (97.7%) of the respondents was affected by climate change effects with more impacts felt in Kapchesombe (highland agro-ecology). The major coping strategies employed include: planting different crops, different planting dates, different crop varieties, soil conservation and crop diversification. Coping strategies employed to contain extreme weather events included terracing, tree-planting, digging drainage channels, planting cover crops, and food storage and regulating number of meals served each day. Other challenges associated with climate change included: food insecurity due to crop failure, soil erosion, shift in spread of diseases and land degradation. Government should provide effective and productive agronomic farm inputs and production assets and working farm-to-farm extension programme so as to build the adaptive capacity of the vulnerable and improve production. This should be intertwined with relevant traditional methods.

**KEY WORDS:** climatic variability, small-scale farmer, adaptation, national parks

### Introduction

Agriculture has for a longtime been the cornerstone of Uganda's economy and it is predominantly rainfed. It comprises of about 23.7 percent of the total GDP, employs about 73.0 percent of the labour force, and accounts for 47.0 percent of the country's total export [6][3]. The sector is dominated by small-scale farmers with low productivity undermined by traditional farming practices such as lack of soil and water conservation practices, poor complimentary services such as farm-to-farm extension services and occurrence of extreme weather events like prolonged drought, flash-floods and soil erosion [6][3]. This study postulates that these factors could undermine the adaptive capacity of the small-scale farmers and hence increase their vulnerability to the adverse effects of climate change.

Climatic models for Uganda have shown that the country experiences high variability in temperatures and rainfall and increased rainfall variability reduces crop yield and threaten food and livelihoods security[3]. Various studies observe that Uganda is vulnerable to climatic

changes and variability and this situation could amplify and worsen food security, households' poverty, and poor health[1][7]. This study postulates that climate is changing, and given that it has in the past, and will continue in the future, therefore underpins the urge to understand how the small-scale farmers' perception is and adaptation to adverse effects of climate change in areas near protected areas.

Studies have shown that African farmers have perceived and responded differently to tackle the adverse effects of climatic changes and rainfall variability in Tanzania and South Africa through a variety of coping strategies: planting different crop varieties, changing land size, irrigation, crop diversification and changing from farming to non-farming strategies[4][5]. However, none of these illustrates the responses from small-scale farmers in areas adjacent to national parks and the studies were done at regional level and not in Uganda. Yet effects of adverse climatic changes are at local level and require area-specific adaptations based on ground factors.

This study examined the actual adaptation strategies undertaken by the farmers in the study area and contended that this had conservation implications. Farm-level studies in areas adjacent to national parks and how the farmers perceive climate change and are responding to climate change impacts are limited. Also, there is limited knowledge on how small-scale farmers perceive climate change and are coping with it in the study area. Perceptions of poverty stricken, non-equipped with adaptive technology and resource-constrained small-scale farmers in Karenga, and Kapchesombe near protected areas are not documented. This study postulates that, understanding farmers' perception and adaptation strategies gives insight in guiding and supporting them in adopting relevant coping strategies that are site-specific in areas adjacent to the national parks. This study investigated how changes in climatic variables affected crop production and how farmers are addressing climate change challenges. It also examined factors that influence perception and adaptation strategies. It also offered opportunity for the validation of farmers' claims on climate change and the meteorological data is used to confirm that.

## **Materials and Methods**

### **Survey Design and Study Area**

The study was done in Karenga and Kapchesombe sub counties, chosen purposely because of being in lowland and highland agro ecologies and adjacent to Kidepo Valley and Mount Elgon national parks respectively. Both qualitative and quantitative data was collected whereby questionnaires were administered to 607 respondents. The questionnaire was structured and thematic with sections on socio-economic and demographic characteristics, perceptions of and adaptation to climatic change impacts.

### **Sampling and statistical Analysis**

By gender, males were 41.5 percent and female 58.5 percent. In this study, multi-stage and purposive sampling techniques were employed to select the respondents in Eastern and Northeastern Uganda. Data was coded and entered using MS Excel and analysed by the statistical package for social sciences (SPSS) version (13.0) and later exported to STATA (version 10.0) for multinomial logit regression analysis together with Chi-squared and t-test as the major statistical tools employed to analyse small-scale farmers perception and adaptation strategies to tackle adverse effects of climate change.

Linear regression was used to analyse trends in climatic variables (temperature and rainfall) to establish change in climatic variables. Factors that influence perception and the adaptation strategies included gender, the agro-ecological location, age, education, years of stay in the community, family size asset value and main source of income. Seasonal variations in weather (precipitation and temperature) by standardization of seasonal and annual weather data helped

in the determination of the climate change variability and trend to give a picture of the behaviour of rainfall and temperature in comparison with the 30 years climatological period under review and is determined by:  $Y = MX + C$ ; Where, M is the gradient and takes the value of negative or positive; when M is negative this shows that the trend is declining and when M is positive, the trend is increasing;  $R^2$  indicates the statistical significance of the trend process. Significance is great from 50% or more ( $R^2 \geq 0.5$ ) and significance is less from below 50% ( $R^2 \leq 0.5$ ); Y = the y axis and X is the x axis of the trend graph.

### Coping Strategies Undertaken to Adapt to the Effects of Climatic Change and Variability

Dependent and Independent Variables:

Independent variables were climatic attributes (rainfall and temperature) and factors that influence perception and adaptation (gender, agro-ecological area, age, education, year in community, family size, assets, and income). The dependent variables were effects of climate change (whether a small-scale farmer has or not perceived climate change, whether a farmer has or not developed coping strategies to adverse effects of climate change).

#### Agro-ecological characteristics of study area

Table 1. Agro-ecological zones (AEZ) and Characteristics of Karenga and Kapchesombe study areas

Sn	Agro-ecology	Characteristics	Agricultural practice
1	Eastern highlands (Kapchorwa)	Covering the ranges of mt. Elgon, rainfall over 1400 mm; 1300-3600m asl; rich volcanic soil	Rainfed mixed farming, stall-fed cattle, vegetable production, cereals such as barley and wheat in Kapchorwa, and Arabica coffee
2	Karamoja wet zone	Northeastern; (Acholi, Teso, and Kapchorwa and Lango sub regions; reliable rainfall; rainfall -1100mm; altitude at 970-1420m asl; good soils	Limited livestock rearing; crop cultivation; rainfed sorghum, millet, early maturing maize, sweet potato, some beans, groundnut and pigeon pea production

Sources: <http://www.fao.org/agriculture/seed/cropcalendar/aezone.do?iscode=UGA>

## Results

### Small-Scale Farmers Perception on Long Term Changes in Climatic Variables.

The climatic variables examined are the long-term temperature, rainfall and the occurrence of weather shocks and extreme events in the past twenty years as experienced by small-scale farmers. The largest proportion (97.7%) of respondents perceived seasonal changes in rainfall amounts and timings, at significant level ( $X^2 = 102$ ;  $p = .000$ ). Changes in rainfall were more reported by farmers in Kapchesombe (97.7%) than Karenga where 66% respondents observed this change.

In relation to temperatures, over 50 and 90 percent of farmers in Karenga and Kapchesombe respectively perceived seasonal changes in temperature. Respondents reported this had implications for agricultural production. The observed differences were statistically significant  $X^2 = 113.8$ ;  $p = .000$  at 0.05 level of significance. The general perception however, was, that more rainfall was received in the past ten years and this is consistent with Hepworth (2010) that stated that eastern Africa including Uganda will experience extreme weather events including high amounts of rainfall, in spite of the precipitation variability in the past years[3].

Analysis of seasonal rainfall and climate change variability revealed significant ( $X^2 = 102.35$ ;  $p = .000$ ) level of seasonal change in rainfall over the past 10 whereby 93.7%. The general perception



was, that there is seasonal variability and more rainfall was received in the past ten years with significant changes in dry spell durations. Socio-Economic and Demographic Factors influenced Adaptation to Climate Change.

For gender variable, male (79.2%) and female (70.9%) farmers have been able to address the challenges of climate change, the result of chi-square ( $X^2 = 4.999$ ) show significant differences ( $p < 0.05$ ) where male adapted more than female counterparts. This is male dominated society and are favoured in terms of land ownership, access to loans, credit and agricultural inputs such as agro-chemicals, fertilizers and extension services. This undermines the central role of women as the sole providers of bread to feed the family. The influence of age on perception and adaptation to climate change can have mixed influence on perception and adoption of adaptation strategies[5].

In this study, the findings revealed that age is a highly significant factor ( $p < .05$ ) in explaining farmers' adaptation to climate change. There was more likelihood of adaptation by small-scale farmers in the age bracket of 15–44 years. This age bracket is educated, better informed, better planning ability and horizon to take agricultural production step further than their 'parents' and address climate change challenges. Income as adaptation to climate change was found to be statistically significant ( $p = .000$ ). The level of adaptation for farmers who were dependent on farming only was 72.3%; whereas homesteads with off-farm income had 80.0%. Farmers that practiced mixed crop and livestock farming had 80.2%. Broadening income base, farming and off-farming ventures are effective coping strategies to counter climate change challenges.

Seasonal Trend for Temperature behaviour within the seasons in the past 30 years (1963–2008) indicate considerable changes in temperatures in Kotido (Karenga) increasing at a significant rate ( $y = 0.1716$  positive trend;  $R^2 = 0.7021$  high significance). In other words, the local atmosphere in Kotido is warming up. With low amounts of rainfall, and unpredictable onset and cessation of rainfall, this causes a shortage of water and with limited groundwater to support irrigation; this could harm crop production significantly.

### **Coping Strategies Undertaken to Adapt to the Effects of Climatic Change and Variability**

The study revealed that coping changes were made in crop agronomy, water and soil conservation. For instance, 84.1% households planted different crops, 71.3% used different planting dates, 64.3% planted different crop varieties, and 61.5% made changes in soil and water conservation, 52.1% diversified crops and 45.4% used crops with shortened growing period. The changes made were climate-smart strategies adopted to off-set adverse effects of climate change and variability. However, most farmers are poor unable to effectively adapt to climate change challenges. Their adaptive capacity needs to be enhanced.

### **Discussions and conclusions**

Study revealed significant negative impact of climate change on households' livelihood, food and nutrition security, income, water, and the excessive need for resources from the national park. It exacerbated soil erosion, pests and diseases, wind, excessive rainfall, drought, landslides and soil erosion. The poor crop yields and harvests in the study area is largely related to erratic rainfall and extreme weather events, unpredictable onset and cessation of rainfall. Strategies should aim at climate-smart agriculture, water and soil conservation, provision of extension services and agronomic inputs farmers; coupled with dissemination of adaptation information; and integrated with traditional adaptation techniques for sustainable development.

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## THEMATIC AREA 4

### Delivering resilience in the face of climate change uncertainty

This theme covers the way in which we can address management of risks and uncertainties of climate change by building societies, ecosystems and long-lived infrastructure that are resilient to environmental and socio-economic change. It includes risk and uncertainty assessment; scenario development and planning participatory modelling; and developing transformative adaptation pathways that can cope with a wide range of future conditions. Sector Specific options for improving resilience are also covered within the theme on crosscutting issues. This will present tools and guidance that support climate-risk management from pilot studies and real-life applications.



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## LIST OF PRESENTERS AND TITLES OF PRESENTATIONS

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**Zerihun Amare**

Barriers To And Determinants Of The Choice Of Crop Management Strategies To Combat Climate Change In Dejen District, Nile Basin Of Ethiopia

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**Happison Chikova**

Improving climate change adaptation through viable beef markets for Mwenezi livestock smallholder farmers

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**Elhadji Iro ILLA**

Measuring vulnerability of rural households to food insecurity and climate stress in Niger by econometric and indicator methods

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**Caroline King-Okumu**

A global review of approaches, tools and guidance that support climate risk management under increasing water stress

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**Rivaldo Kpadonou**

New crops for a new climate: how do gender and ethnicity matter for the adoption of sesame crop in the West African Sahel?

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**Constansia Musvoto**

Climate resilience through resource efficiency in smallholder vegetable production in South Africa

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**Martha Kidemu Negassa**

Climate smart soil and water management practices in drylands of Ethiopia: Challenges and opportunities. A review

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**Felix Olorunfemi**

Resilience Index of Flood Prone Communities in Ibadan, Nigeria

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**Tara Southey**

Assessment of the grapevine and environmental interactions in the context of climate change for improved adaptation strategies in South Africa.

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## Barriers To And Determinants Of The Choice Of Crop Management Strategies To Combat Climate Change In Dejen District, Nile Basin Of Ethiopia

Zerihun Amare<sup>1\*</sup>, Johnson Ayoade<sup>2</sup>, Ibidun Adelekan<sup>2</sup>, Menberu Teshome Zeleke<sup>3</sup>

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Climate change without adaptation is projected to impact the livelihoods of rural communities. Adaptation to climate change is crucial for developing country like Ethiopia due to high population and dependency on agriculture. Hence, this study was initiated to examine the barriers to and determinants of the choice of crop management strategies to combat climate change. The Intergovernmental Panel on Climate change (IPCC) concepts of climate change adaptation provided the framework. Stratified and snowball sampling techniques were employed to select a sample of 398 households. The household survey was employed to collect data on current adaptation strategies. Logistic regression was used to analyse the determinants of choice of adaptation strategies. Logistic regression analyses were carried out at  $p \leq 0.05$ . Small farmland size, agro-ecology, farmland location, financial constraints, and lack of skills were the major barriers to adoption of crop management strategies. Age, farming experience, income, family size, government experts' extension services, agro-ecology, and crop failure history of households were significantly related to the choice of most of the crop management strategies. Socio-economic and institutional factors determined rural communities' ability and willingness to choose effective adaptation strategies. Policy priority should be given based on agro-ecology and households demand of policy intervention such as providing extension services and subsidizing the least adopted strategies due to financial constraints.

**KEY WORDS:** Climate change; adaptation; crop management; Blue Nile of Ethiopia

### Introduction

The scope of the study was limited to barriers to and determinants of the choice of crop management strategies to combat climate change in Dejen district, Nile basin of Ethiopia. The rural communities included were those who were engaged in farming and off-farm activities like livestock rearing and bee keeping among others who reside in the rural areas. According to Food and Agricultural Organization, due to climate change and variability almost one billion people experienced hunger in 2010 globally [3]. There are many reasons or convincing arguments for a more comprehensive consideration of adaptation as a response measure to climate change. Firstly, given the amount of past greenhouse gas emissions and the inertia of the climate system, we are already bound to some level of climate change, which can no longer be prevented even by the most ambitious emission reductions [4]. Second, the effect of emission reductions takes several decades to fully manifest, whereas most adaptation measures have more immediate and sustainable benefits [11].

Third, adaptations can be effectively implemented on a local or regional scale such that its efficiency is less dependent on the actions of others, whereas mitigation of climate change requires international cooperation. Fourth, most adaptations to climate change also reduce the risks associated with current climate variability, which is a significant hazard in many world regions. There are two adaptation assessment approaches namely, top-down and bottom-up assessment approaches [5]. The top-down approach starts with climate change scenarios, and estimates impact through scenario analysis, based on which possible adaptation practices are identified. Most of the top-down adaptations represent possible or potential measures, rather than those that have been used [5].



## Methods and Analysis

The study employed a cross-sectional research design with both quantitative and qualitative research methods. This study used a multi-stage sampling technique to select the agro-ecology, Kebeles (the lower administrative unit next to district), and households. Based on the formula provided by Yamane (1967) at the 95% confidence interval and 5% level of precision. 398 households were selected at the six kebeles of the district.

Both descriptive statistics and inferential statistics were used for analysing the quantitative data collected from primary and secondary sources. SPSS (Statistical package for social science version 20) was used to perform data entry and statistical analysis. The descriptive statistics used in this study were percentage, mean, maximum, minimum, and frequencies to summarise and categorize the information gathered. Inferential statistics used in this study was binary logistic regression. The logistic regression was used to analyse the determinants of the choice of crop management strategies. The fitness of the logistic regression model to the data was measured by applying the SPSS classification table (crosstabs), and the Hosmer-Lemeshow test.

## Results

### Barriers to adoption of crop management strategies.

Changing crop management practice is one of the adaptation practices to climate change impacts. For this study using crop diversification, improved seeds, changing planting date and replanting failed crops were selected in the context of the study sites. The applications of these strategies have been determined by a number of socio-economic, biophysical, and institutional factors (see Table 1).

Table 1. Determinants of choice of crop management strategies

Predictor variables	Crop diversification		Improved seed		Changing planting date		Replanting	
	Sig	Exp(B)	Sig	Exp(B)	Sig	Exp(B)	Sig	Exp(B)
Sex_HHH(1)	.170	1.850	.983	.991	.055	.376	.104	.332
Age_HHH	.035		.039		.102		.008	
Age_HHH(1)	<b>.010*</b>	3.506	<b>.011*</b>	4.115	.092	2.360	<b>.005*</b>	5.416
Age_HHH(2)	.110	3.662	.111	3.886	<b>.038*</b>	5.985	<b>.014*</b>	32.143
Edu_HHH(1)	.731	1.149	.226	1.690	.725	.867	.456	1.513
Farm_exp_HHH	.233		.004		.046		.603	
Farm_exp_HHH(1)	.108	2.384	<b>.000*</b>	10.166	.120	.428	.261	2.246
Farm_exp_HHH (2)	.884	.917	.238	2.100	<b>.007*</b>	.209	.496	1.796
Farm_exp_HHH(3)	.533	.636	.078	3.943	<b>.018*</b>	.190	.880	.864
Income_HHs	.000		.013		.097		.697	
Income_HHs(1)	<b>.000*</b>	8.481	<b>.012*</b>	3.408	.639	1.378	.558	1.490
Income_HHs(2)	<b>.000*</b>	17.510	<b>.029*</b>	3.632	.051	4.163	.241	2.701
Income_HHs(3)	<b>.000*</b>	18.539	<b>.002*</b>	9.064	.281	2.275	.444	1.998
Family_size_HHs(1)	.820	.902	N/C	N/C	.416	1.490	<b>.002*</b>	.101
Weather_inf_HHH(1)	.364	.668	.182	.526	.102	.533	.774	.848
Farmer to farmer extension (1)	.809	1.118	.424	1.455	.658	.806	.093	3.286
Government experts extension (1)	<b>.003*</b>	.271	.635	.815	.124	.520	.064	.290
Agro_ecol_HHs	.005		.000		.000		.022	
Agro_ecol_HHs(1)	<b>.036*</b>	4.082	.055	5.446	<b>.002*</b>	5.412	.200	2.922
Agro_ecol_HHs(2)	.093	.496	<b>.002*</b>	.218	<b>.000*</b>	145.815	<b>.006*</b>	11.247
Farmlandsize(1)	<b>.001*</b>	4.286	.865	.931	<b>.000*</b>	.150	<b>.02*</b>	4.570
Crop failure	N/C	N/C	.205	1.656	<b>.044*</b>	.345	.211	0.146
Constant	.121	.245	.305	.347	.002	23.795	.894	1.196

Source: Computed from household survey, March-October (2016), "N/C" stands for not computed, "HHH", stands for household head and "HHs" stands for households

## Discussion

The rural communities of Dejen district adopt crop management strategies to combat climate change impacts. However, the key barriers identified in the study district of Nile Basin of Ethiopia were shortage of money, lack of access to information, and small land size. Previous studies stated that financial barriers are one of the barriers that restrict implementation of adaptation strategies [1][7][10]. This implies every form of adaptation requires some direct or indirect costs. For instance, the use of improved varieties of crops has been reported as one of the key adaptation strategies for farmers in Dejen district, Nile basin of Ethiopia. When improved seeds varieties are available, their price may be prohibiting making it difficult for many rural households to access. Thus, farmers have often sought to use their own saved seeds. One of the possible causes of financial barriers in the study area could be due to lack of credit facilities to rural

communities.

Access to information on climate change characteristics is an important tool that can be used to enhance the adaptation and implementation of adaptation strategies by rural communities of the study area. Access to information is particularly important for Africa [6] and Ethiopia in particular, where there are few climate projections due to lack of appropriate climate data. This is crucially important considering that most farming systems in Dejen District depend on rain-fed agricultural systems. Hence lack of appropriate climate information could be crucial for rural communities' food security. Age of households head significantly determined crop diversification, improved seeds and changing planting date, and replanting failed crops. Crop diversification and replanting of the failed crops requires more energy and experience. Thus, adult household heads are more matured and active in sowing different crops than old and young household heads. The probable reason for the positive and significant association is due to the fact that age is the proxy indicator that may be likely to endow the farmers with the requisite experience that enables them to make a better decision in the choice of climate change impact adaptation strategies. This is in line with studies by found that an increase in age does mean an increase in farming experience which would increase rural communities' local knowledge to respond to hazards resulted in climate change and variability[2].

Farming experience is one of the significant variables that affect the rural communities' choice of adaptation strategies. Farming experience is a proxy indicator of age. Like crop diversification, the middle age farmers have ability and willingness to adopt improved seeds to adjust climate change impacts. This implies as one become more experienced in farming, the probability of one to use improved seeds increases more than a farmer with less farming experience.

As expected, income is positively and significantly associated with the household decision to pursue crop diversification and improved seeds. This means crop diversification and purchasing of improved varieties of seeds requires money. This implies the rate of using crop diversification and improved seeds is increased as income of households increased.

Access to government extension services has a negative and significant association with the likelihood of choosing crop diversification to combat climate change impacts. This result is in contrary with previous studies who noted that farmers who obtain agricultural extension services through extension workers are more likely informed about the climatic situation and the responses followed.[8][9]. The contributing factors for this inverse relationship could be barriers to adopting crop diversification such as inadequate extension services, constraints of money, labor, skills, and farmland locations.

The midland and highland agro-ecologies have a significant and positive effect on adoption of crop diversification. This is because the suitability of highland agro-ecology to sow different types of crops and access to government extension services due to proximity to the administration. For instance, in this study finding, the midland agro-ecology has got more access to extension services (77%) than the lowland agro-ecology (47%) communities by the government extension experts in the past cropping season. The lowland agro-ecology has a negative and significant effect on adoption of improved seed varieties. The possible explanation is that lowland households did not use improved seeds because of a suitability problem of the lowland agro-ecology and topography to use improved seeds to their farmland. This was confirmed by household reports on the barriers to adopting adaptation strategies. On the other hand, the lowland agro-ecology has a positive and significant effect on pursuing changing planting date to combat climate change impacts. This is due to lowland agro-ecologies characterized by erratic rainfall and other extreme events that led households to change their planting date. The mid and lowland agro-ecologies have a significant effect on employing replanting failed crops as climate change adaptation measures. This is due to the fact that, the midland and lowland households

are characterized by climate variabilities such as erratic rainfall than the highland agro-ecology zones. The exposure of climatic variability led them more experienced in adopting replanting their failed crops than highland households.

## Conclusions

Rural communities have tremendous ideas to mitigate for current and future climate change impacts with a strong motivation to move out of poverty. However, the mere willingness to adopt climate change adaptation strategies was not enough. Their ability to adapt is constrained by many internal and external factors. Rural communities who did not employ adaptation strategies gave many reasons for their failure to adopt. These includes; poor access to water sources, limited knowledge, and skill, shortage of labour, lack of and/or shortage of land, lack of money, lack of information, lack of agricultural extension services, and other institutional factors. The most significant determinants of adopting crop management strategies were age, farming experience, income, agro-ecology, and farmland size. Agro-ecology has a significant effect on all adaptation strategies. Due to the soil characteristics, the lowland agro-ecology zones were not suitable for adopting improved seeds. However, the government bodies in the office of agriculture did not realize the problems.

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## Improving climate change adaptation through viable beef markets for Mwenezi livestock smallholder farmers

Happison Chikova<sup>1</sup>, Collen Chikova<sup>1</sup> and Godfrey Chatsakama<sup>1</sup>

<sup>1</sup> Kupakwashe Cattle Fattening Society

Kupakwashe Beef Value Chain Model, is a model designed by Happison Chikova under Kupakwashe Cattle Fattening Cooperative Society. The Model is meant to link small holder farmers beef producers with retailers and beef consumers thereby improving their revenue

per livestock by more than 100%. The model eliminates middle men and private abattoirs that prejudice farmers of more than 100% of their revenue. The model invest in the community where the revenue and profits obtained at the abattoir level is invested in the breeding and heifer exchange programme. Profits realized at the wholesaling and retail is given to farmers as bonuses.

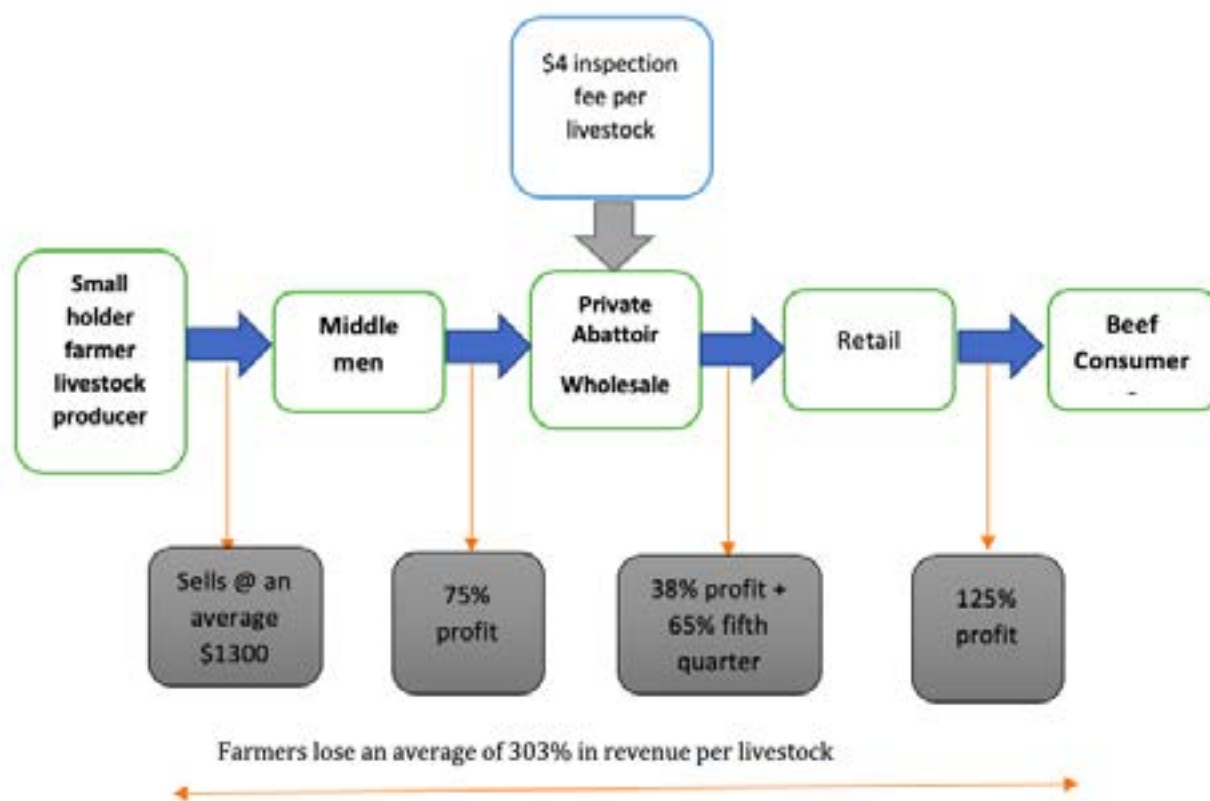
The Model used an experimental study to test the Kupakwashe Beef Value Chain Model. 250 households were used in the study. The baseline information was used for comparison purposes. The model was then tested where the 250 were linked direct to retailers and beef consumers for the period of a year. The results were that, their revenue per cattle had increased by 60% to 100%, the households were able to invest in the breeding of cattle and small households with each household investing an average of 5-7 cattle and goats per year through the money obtained from selling of their livestock.

Before the testing of the Kupakwashe Beef Value Chain Model, the 250 households were selling their livestock through the middle men who charges very low prices and sell to private abattoirs at 60-70% marker up, the Private abattoirs slaughters and sells the meat to retailers at 40% marker up thereby in this value chain prejudicing farmers of more than 100% of their revenue. The small holder farmers were living below USD1 per day and eating 1 meal, and were not able to send their children to school and meet other expenses therefore being exposed to more scourge of climate change.

## Background

Zimbabwe's smallholder farmers are faced with continued recurrent droughts due to Climate change. Droughts have caused farmers in Mwenezi district to shift from the growing of maize to improved cattle production. Farmers in Mwenezi have poor markets to sell their cattle for a meaningful investment hence are failing to adapt to climate change resulting in poor safety nets [2]. In 2017, Kupakwashe Cattle Fattening Cooperative Society came up with a beef value chain model known as Kupakwashe Beef Value Chain Model that is meant to increase the adaptation to climate change by smallholder farmers through improved markets.





**Figure 1.** The beef value chain in Mwenezi District, Masvingo province, Zimbabwe. The value chain depicts a scenario where there are many players including the middle man, private abattoirs and retailers.

### Mwenezi Beef Value Chain

According to European Union 2018 report on beef value chain in Zimbabwe, it echoes that the Cattle are sold to abattoirs through middlemen which results in the small-holder farmers losing an average of 303% in revenue per each livestock sold. Poor markets are exacerbating the effects of climate change on small holder farmers due to low revenue being generated. The farmers are unable to reinvest or plough back in cattle breeding, pasture production and threatening the viability of improved beef production and economic wellbeing of the farmers. Farmers need to be organized and have direct linkages to retailers and beef consumers for better markets.

Players in the beef value chain that include the middle man and private abattoirs are not able to invest back in the breeding programs and pasture production as mechanisms for climate change adaptation and mitigation by small-holder farmers. When the beef players buy cattle from farmers, there is no replacing stock by farmers therefore exposing them to the scourge of climate change.

### Kupakwashe Beef Value Chain Model

In a bid to improve the adaptation to climate change by smallholder farmers, Kupakwashe Cattle Fattening Cooperative Society came up with the Kupakwashe Beef Value Chain Model as shown in figure 2. The Model links smallholder beef producers with retailers and beef consumers improving the revenue earning per livestock by more than 228%. The model eliminates the middle man and private abattoirs that prejudice farmers of more than 228% of their revenue. Mavedzenge et al. (2011) noted that communal farmers resort to the informal way of marketing their cattle where pricing is based on an arbitrary scale, with reference to visual assessment of the animal [3]. Middlemen are the main buyers and purchase live animals from farmers for

resale at cattle auction points and to abattoirs in towns often benefiting more than the farmers themselves. Homann and Van Rooyen (2007), concurred that farmers do not have ready markets where they can take their animals to if they need to sell their animals therefore usually end up underpricing their animals in cases of emergencies[4].

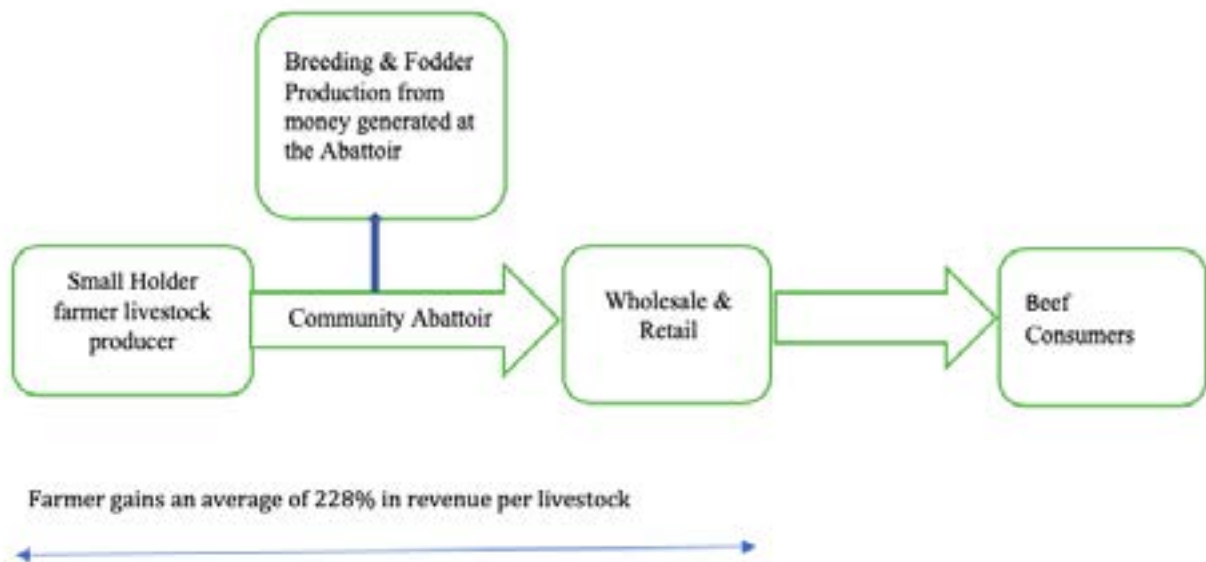


Figure 2. Kupakwashe Beef Value Chain Model

Kupakwashe Beef Value Chain Model invested in the community abattoir where the revenue and profits obtained at the abattoir level are ploughed into the breeding, cattle management and pasture production the quality of beef being produced thereby improving climate change adaptation and mitigation by farmers. The community abattoir links the community with markets as well as providing better markets for farmers. 25% of the Profits realized at the wholesaling and retail in the Kupakwashe Beef Value Chain Model are ploughed back to farmers as bonuses as a way of increasing the adaptation to climate change by farmers.

## Methodology and Results

A baseline survey was done before the implementation of Kupakwashe Beef Value Chain Model. 250 households were randomly sampled and used were used as respondents in the study. Tools that were used include questionnaires, observation, in-depth interviews, focus group discussions and business reports.

The results of the baseline information showed poor markets in the beef value chain. Farmers revealed that the beef value chain markets were characterized by many beef value players hence low revenue generation per each livestock sold as the money intended for the farmer is lost within value chain players. The results also showed that farmers have poor breeds, poor cattle management skills and poor pastures as this is affecting the quality of beef being produced for the markets hence low revenue generation resulting in poor climate change adaptation. The European Union 2018 report on beef value chain in Zimbabwe noted that the average animal size has also fallen (reflecting a return to more traditional breeds), bringing the average carcass weight of animals slaughtered from 200kg/animal to 167kg/animal[1]. This in turn reduces the amount of high-grade meat available from each slaughtered animal.

The mid-term evaluation survey was carried out after a year Kupakwashe Beef Value Chain Model revealed improved markets as farmers satisfied that they now have viable lucrative markets. The model was then tested where the 250 were linked direct to retailers and beef consumers for the period of a year. The respondents further highlighted that they are now linked direct to beef wholesale and retail. 98% of the livestock farmers said that their revenue production per livestock has increased by an average of 228% and as a result they are now able to adapt to climate change. Farmers pointed that they now have improved breeds, improved pastures and skills for cattle management hence improved breeds that fetches high prices on the market. Profits generated at the abattoir level were invested in the breeding, pasture production and cattle management programme in order to improve the quality of beef produced by the farmers hence increased revenue generation.

## Conclusion

In conclusion, smallholder farmers under the Kupakwashe Beef Value Model have adapted to climate change due to improved markets. Farmers are realizing real value from their livestock due to better markets because of improve revenue per livestock. Improved pastures have allowed farmers to mitigate the effect of climate change thereby reducing the mortality of cattle during droughts and dry seasons. Farmers were able to acquire better breeds for improved income generation. Farmers have adapted to climate change under the Kupakwashe Beef Value Chain Model.

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## Measuring vulnerability of rural households to food insecurity and climate stress in Niger by econometric and indicator methods

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We studied the determining factors that are significantly linked to food insecurity in rural areas using multinomial logistic regression model. The most affected households are those having large size, those who devote a part of their expenses in the education of their children in the year preceding the food insecurity occurrence, and those who have experienced flood and drought events in the year preceding the food insecurity occurrence. From the model results, we learn that animal possession, the number of cultivated fields, expenses on agricultural tools and seeds reduce the risk of exposure to food insecurity.

This study is also based on vulnerability resilience indicator across regional levels method developed by Deressa et al. (2008) [5]. The vulnerability resilience indicator is computed as the net effect of exposure and sensitivity on adaptive capacity and the higher the net value of the indicator the lesser vulnerability. The result shows that rural households of the regions of Dosso

and Tahoua are relatively less vulnerable because of their high adaptive capacity than those of the five other regions of which those of Zinder and Niamey are the most vulnerable due to their high sensitivity and exposure to climate stress.

**KEY WORDS:** Food insecurity, climate stress, rural households.

## Introduction

A Sahelian-landlocked country in West Africa, Niger covers an area of 1,267,000km<sup>2</sup> and three-quarters of the country is desert. The rainfall is characterized by a high variability in space and time from south to north as follows: The Sahel Sudan zone, which represents 1% of the total land area and receives between 600 and 800 mm of rain in normal years. It is conducive to agricultural and livestock production. The Sahelian zone covers 10% of the total land area with 350 to 600 mm of rain per year and is dominated by agro-pastoralism. The Sahel Saharan zone receives 150 to 350 mm of precipitation per year on average and covers 12% of the total land area, it is characterized by moving live stock. The Saharan zone receives less than 150 mm of rain per year and extends over 77% of the total land area.

The level of vulnerability of different social groups to climate change is determined by both socioeconomic and environmental factors. The socioeconomic factors most cited in the literature include demography, gender, infant mortality, education, the level of technological development, infrastructure, institutions, and political setups [3][4].

Figure 1 shows that households in food secure are larger than those at risk and only few of them are in severe or moderate food security. Figure 2 shows that 57% of male and 49.4% of female are food secure, but the situation is worrisome given the proportion of those whose food security status is at risk.



Figure 1. Food insecurity in rural areas by regions and Figure 2. Food insecurity by household gender.

## Objective

The main objective of this paper is to assess the vulnerability of rural households to climate stress, based on estimating the probability that the income of rural households lies below the poverty line due to climate and socioeconomic shocks through econometric methods. We also intend to calculate the resilience of rural households to climate stress across regional levels as the net effect of adaptive capacity, exposure and sensitivity to climate stress through the vulnerability resilience indicator method. This study considers that, in addition to socioeconomic factors, vulnerability is linked to climate stress, raising the following research question: To which

extent are rural households vulnerable to climate stress and what are the climate stress related factors of vulnerability and the related regional variations?

### Methodology on food insecurity

Multinomial logistic regression model to regress food insecurity on climate and socioeconomic variables. The dependent variable, food insecurity status is a categorical variable: 0 = secure; 1 = moderate; 2 = at risk; 3 = severe. The interpretation of our results concerns the relative risk ratios (RRR) instead of regression coefficients, the probability threshold is set at 10%.

The relative risk is the ratio of two risks (the risk for the exposed and the risk for the unexposed). Hence, a  $RRR < 1$  indicates a beneficial effect, a  $RRR > 1$  indicates a negative effect, a  $RRR = 1$  indicates that the event frequency is the same for the exposed group and the unexposed group. The numerical values of the coefficients do not have direct interpretation; however, their positive or negative signs are interpretable.

The sign indicates whether the probability of observing a particular category of the dependent variable is an increasing or decreasing function of the corresponding predictor or explanatory variable.

### Results on food insecurity

The coefficient regression of household size is significantly positive: the number of household members increases the probability for a household to be severely food insecure. The interpretation is the same for all factors which coefficient regressions are significantly positive and these factors have their  $RRR > 1$ . The coefficient regression of animal possession is significantly negative meaning that animal possession reduces the probability for a household to be severely food insecure. The interpretation is the same for all factors which coefficient regressions are significantly negative and these factors have their  $RRR < 1$ .

The most affected households are those having large size, those who devote a part of their expenses in the education of their children in the year preceding the food insecurity occurrence, and those who have experienced flood and drought event in the year preceding the food insecurity occurrence. From the model results, we learn that animal possession, the number of cultivated fields, expenses on agricultural tools and seeds reduce the risk of exposure to food insecurity. In view of these results, for the effectiveness of the fight against food insecurity, a political from authorities that strives to master the control factors associated with it is needed. Policies and strategies that involve the control of agricultural input prices and subsidies on chemical fertilizers and seeds are essential to sustain the fight against food insecurity

### Methodology on vulnerability resilience indicator

In the IPCC framework, the vulnerability resilience indicator is the net effect of adaptive capacity on exposure and sensitivity to climate stress as following:  $Vulnerability = adaptive\ capacity - (exposure + sensitivity)$  and the higher the net value of the indicator the lesser vulnerability[2]. PCA (Principal Components Analysis) is run on the indicators of exposure, sensitivity and adaptive capacity with STATA software and then weights loaded from the components that explain the most the total variance were assigned.

### Results on vulnerability resilience indicator

Running PCA on the indicators with STATA, the data set on vulnerability indicators showed five components with eigenvalues greater than 1 and explains 95.01% of the total variation in the data set.



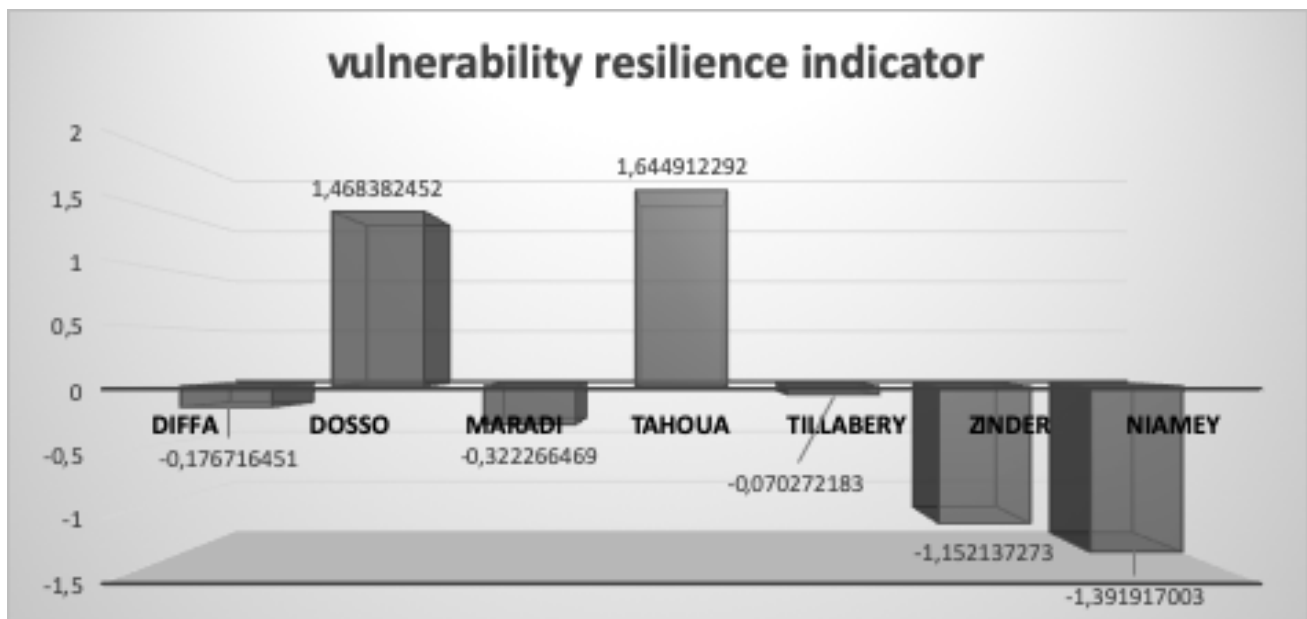


Figure 3. Vulnerability resilience indicator

The first principal component explained most of the variation (34.70%), the second principal component explained 27.53% of the variation, the third principal component explained 14.72% of the variation, the fourth principal component explained 11.5% of the variation, and the fifth principal component explained 6.56% of the variation. As the first principal component explains most of the variation in the data set, the weights used in constructing vulnerability indices are those of that component, given the initial argument when it comes to the use of PCA. The factor analysis shows that the first principal component correlates positively with almost all indicators related to adaptive capacity and correlates negatively with all related to exposure and sensitivity. The result shows that rural households of the regions of Dosso and Tahoua are relatively less vulnerable because of their high adaptive capacity than those of the five other regions of which those of Zinder and Niamey are the most vulnerable due to their high sensitivity and exposure to climate stress.

## Conclusion and policy implication

The result of our analysis on the link between food insecurity and climate change is line with the following finding of Fekadu Beyene and Mequanent Muche (2010) in Ethiopia[1]. In view of these results, for the effectiveness of the fight against food insecurity, a policy from authorities that strives to master the control factors associated with it is needed. Policies and strategies that involve the control of agricultural input prices and subsidies on chemical fertilizers and seeds are essential to sustain the fight against food insecurity. The lack of such a policy could make it difficult for households to purchase agricultural inputs if there is a rise of input prices because of the depletion of food supply as a result of drought or flood. It is important to study the determinants of food insecurity but it is also interesting, for further research, to find out what are the strategies developed firstly by households in food security to address food insecurity and secondly by those who suffer. Non-governmental organizations aiming at sustainable rural development can both help people overcome poverty and hedge against climate change, especially rural areas in the regions of Niamey and Zinder. Moreover, community systems for responding to climate shocks such as drought, and floods, and to high prices for food and agricultural materials, can save rural households from hunger and food insecurity by granting them a supply of fertilizers and seeds, water harvesting, investment in technology and infrastructure and other natural resources. These are actions that may boost the adaptive capacity in rural areas while lowering the exposure and sensitivity to climate risk.

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## A global review of approaches, tools and guidance that support climate risk management under increasing water stress

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A proactive approach to manage the global risks of climate change should build the capacities of the necessary agencies in drought affected countries. This presentation draws on a rapid review of practitioner experiences in the application of available methods for drought impact and vulnerability assessment in different parts of the world that was commissioned by the UNCCD. In Africa, the review found that socio-economic aspects of drought vulnerability have received considerable attention from the international humanitarian community, but the hydrological impacts of droughts and floods still do not receive the same level of attention as they do in other regions. As a result, opportunities for resilience-building are systematically overlooked and avoidable socio-economic impacts continue to multiply unnecessarily.

An example of a successful international capacity building approach led by the World Bank to improve drought resilience in Latin America was highlighted in this global review. An ongoing initiative is also strengthening national capabilities to assess hydrological drought impacts and reduce vulnerability in China and India with support from the UK government. Similar sharing of national capabilities could enhance drought vulnerability assessment in other regions, particularly in Africa. These could be integrated with emerging global systems for hydrological monitoring that are under development by the WMO. The UNCCD offers an international negotiation process for governments to agree on global priorities and cooperative actions needed to reduce vulnerability to drought and build resilience on the ground. Under predicted climate changes and increases in water stress, this opportunity to pool the available national hydrological capabilities should not be ignored.

### Introduction & purpose

Collecting, applying, adapting and reviewing best practices in drought vulnerability assessments can improve the use of the assessment approaches and generate practical insights to reinforce drought risk management. Learning from the experience of drought-affected communities is the best way for drought managers to spot gaps and good practices, to weigh the likely effectiveness of new vulnerability assessment methods and to evaluate the impacts of risk reduction strategies and investments. Observing and analysing the experiences of the past and from different locations can help avoid oversights and recurring mistakes. The objective is to extract lessons from the global review that could be of interest for addressing future climate risks in Africa, especially drought risks.

## Methods

The review was carried out in consultation with the World Meteorological Organization (WMO), the United Nations Convention to Combat Desertification (UNCCD), the Global Water Partnership (GWP) and the Food and Agriculture Organization of the United Nations (FAO). As a first step, two bibliographic searches were carried out. These included gray literature in the form of reports available on the websites of the Global Forum for Disaster Risk Reduction (GFDRR) and the Integrated Drought Management Programme (IDMP), as well as a series of keyword searches of peer reviewed scientific publications available via the SCOPUS database.

Care was taken to include a range of practitioner perspectives from drought-prone regions in Africa, Asia and the Americas. Interviews were conducted by skype and telephone with expert practitioners who shared their experiences in the application of existing approaches and methods for drought impact and vulnerability assessment. These insights were then followed up through further reading and collection of background information. Preliminary findings were compiled and synthesized for discussion and review with colleagues [1]. These were presented and discussed with a focus group of practitioners taking part in a workshop on drought risk reduction tools held by the UNCCD Secretariat in Antalya, Turkey, 2-4 May, 2019<sup>1</sup>

Supplementary interviews with practitioners in the Sahel and the Horn of Africa have added depth to examples and case studies particularly from across Sub-Saharan Africa. Discussion of climate change vulnerability assessment processes and predicted dry spells in West Africa draws on an ongoing thesis project, supported by DfID through the AMMA2050 project. The authors were also able to deepen the Horn of Africa case study, thanks to previous collaborative work in Kenya [2], and ongoing insights generated through the sharing of lessons within the IGAD region [3]

## Results

Across sub-Saharan Africa, experiences of drought vulnerability assessments are emerging from international programmes that focus on building the resilience of vulnerable households. In both East and West Africa, where vulnerability assessments are carried out by international NGOs [4], they do not often refer to national water resource databases and planning scenarios. Instead, they more often focus on rapid appraisal methods that are more popular with the international development community [e.g. 5,6,7]. These describe the plight of the drought-affected communities and their needs for social change and financial assistance. This information can inform assessments focusing on the economic returns on external investments in drought relief or preparedness [8,9].

On the other hand, the hydrological impacts of droughts and floods still do not receive the same level of attention in drought vulnerability assessments carried out in this region as they do elsewhere. In the most drought-prone parts of Africa, physical monitoring of water resource availability and quality is not systematically recorded and analysed. Although water resource users in the drought-affected regions often have a rich knowledge of the condition and trends in their resources, additional systems may be needed to share this information amongst local stakeholders and to feed relevant indicators into cross-scale and cross-sectoral governance processes. For example, in Kenya, national databases and information management systems for drought management include some locally collected meteorological information [3]. But they do not yet include hydrological observations (except qualitatively). Furthermore, local resource user associations often remain poorly integrated within the national governance systems [10].

<sup>1</sup> <https://www.unccd.int/news-events/new-drought-toolbox-validation-workshop-kicks>

In Senegal, climate change vulnerability assessments have identified likely drought impacts, not only in terms of occasional abnormal seasonal crop production (agricultural drought) [11–13], but also deepening long term deficits in the availability of water resources for human needs across all sectors of the economy [14–17] (hydrological drought). Current decision-making for water resource management will have significant impacts on future economic development prospects [18] and ongoing vulnerability to drought, land degradation and desertification in the Sahel.

There have been progressive improvements in national environmental information systems for sustainable development decision-making over the past decade in Senegal [19–22]. Capacities for meteorological prediction are also growing. However, inter-departmental barriers, internal cost-recovery policies and other institutional capacity issues still prevent the establishment of impact-based forecasting, hydrological decision support and drought early warning systems to enable climate risk management. These are needed to connect land and water resource development decision-making to the available climate information and scenarios, improve drought preparedness and increase resilience to hydrological drought.

In other parts of the world, the review identified examples of national drought vulnerability assessment processes that are driven from the sub-national level of water basin councils through the national drought monitoring programmes in Mexico [23] and Brazil [24]. An example of a successful international capacity building approach led by the World Bank to improve drought resilience in Latin America was highlighted by the global review [24]. This enabled practitioners from Brazil to learn from colleagues in Mexico how they had established their drought early warning system. Both systems draw selectively on other North American models, adapt them to the basin contexts and conditions, and focus on encouraging water basin councils to make use of all capacities and knowledge that are available to them for observation of the condition and trends in the available water resources.

In South and West Asia, drought managers are also gradually building the national and sub-national capacities needed to observe and manage deepening vulnerability due to growing groundwater deficits. For example, in India, responsibility for drought vulnerability assessment is decentralized to the level of states [25]. The review of expert practitioners' experiences revealed problems faced in India to monitor and assess the long- and short- term impacts of drought on water availability [1]. However, an ongoing initiative supported by the UK government is encouraging Indian drought managers to exchange knowledge and explore examples of scientific drought indicators used in other parts of the world, including in the UK, China, and Southeast Asia, as well as Australia, Europe and the US.

## Discussion and Conclusions

This review identified a major gap in drought vulnerability assessments as currently applied in Africa due to institutional barriers preventing the integration of impact-based forecasting, hydrological monitoring and decision-support tools. There is a need to establish systems and capacities to work across sectors and scales so that water management decision-making for the future can draw on both local knowledge and increasing global capacities for drought prediction. The review also identified examples of how these aspects of drought vulnerability assessment have been strengthened in other parts of the world through knowledge exchanges, including South-South and North-South-South-Global knowledge exchanges. Since drought affected communities across Africa do already have considerable natural resource management knowledge, there is no reason why such approaches should not be applied through a cooperative co-learning approach.

Evidence from other regions suggests that the best way to approach this challenge is to launch a hands-on learning-by-doing approach enabling local research centres and universities to

work together with basin management committees and national institutions. Locally adapted indicators of drought effects on the status of water resource availability in basins across Africa could play an essential role in informing and guiding the development of emerging global systems for hydrological monitoring that are under development by the WMO. The UNCCD offers an international negotiation process for governments to agree on global priorities and actions needed to reduce vulnerability to drought and build resilience on the ground. Under predicted climate changes and increases in water stress, this opportunity should not be ignored.

A proactive approach to manage the global risks of climate change should build the capacities of the necessary agencies in drought affected countries. In Africa the hydrological impacts of droughts and floods should receive the same level of attention as they do in other regions. Without this essential aspect of drought vulnerability assessment, opportunities for resilience-building are systematically overlooked. This is allowing the avoidable socio-economic impacts risks from drought to continue to multiply unnecessarily.

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## New crops for a new climate: how do gender and ethnicity matter for the adoption of sesame crop in the West African Sahel?

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As new climate conditions are taking over in over most regions in sub-Saharan Africa, farmers need to shift from climate-sensitive crops to other crops that are better adapted to the new conditions. In this paper, we investigated the gendered patterns of household decisions concerning switching to new climate-smart crops in the Sahelian area, and how ethnicity-based norms affect the decision to adopt sesame crop and women's participation in that decision. We show that the adoption of sesame is not gender neutral. We found a negative sex divide among sesame growers: female-headed households are less likely than male-headed households to shift to cultivating sesame to deal with drier and unpredictable climate conditions in the Sahel. However, in male-headed households, women's control over land leads to greater probability of adopting sesame, pointing to a strong role played by adult women in male-headed households when it is about to shift to new climate-smart crops. We also show that the gendered patterns of the adoption of sesame are fundamentally driven by ethnicity-based differences among households on one hand, and, by specific gender-based forms of discrimination that further disfavor women's access to land, inputs and information, on the other. This study highlights the importance of carefully addressing unequal ethnicity-based norms that affect productive resources and of improving women's access to information in order to improve livelihoods and advance the adaptation agenda, not only for women, but for all households and communities in dryland areas.

**KEY WORDS:** Climate change, intersectionality, drylands, ethnicity, collective action, women.

### Introduction

Climate change is a real threat for African agriculture, which still represents the basis for the livelihoods for the overwhelming majority of the people across the continent. Global average temperatures have risen by 0.85°C, and a further increase of about 1.5°C by 2050 is almost

certain (IPCC 2007). The impacts of global warming on agricultural resources are already felt across all regions in Africa. According to Burke et al. (2009), new climate conditions are already taking over in SSA and by 2050, new climate regimes will be established over at least half of the current cropping area in the majority of African countries.

As temperatures rise, rainfall patterns change and variability increases, farmers need to be prepared for ongoing change by investing more in soil and water conservation practices, shifting from more climate-vulnerable crops to other crops that are better adapted to the new climate conditions [14][4]. Thus, several neglected and underutilized cash crops have slowly been attracting the farmers' attention, particularly their ability to perform under increasingly unpredictable and drier climate conditions. Interest in sesame has increased significantly over time, and today sesame is seen as an alternative export and cash crop to cotton or groundnut for Sahelian farmers [1][2][9][8][16]. The farmers' increasing interest in sesame is driven by its climate-smart attributes [2][8][16]. But, knowing women's interest in household food security (Quisumbing et al. 1995), one could expect that any decision to shift already limited household's resources from staple food crops to a new cash crop in an area where people live under the permanent threat of hunger would entail some gendered arrangements and trade-offs between adult women and men within the household.

Very few studies have also been interested in the interplays between gender, ethnicity and land rights in shaping adaptation choices as well as in the intrahousehold dynamics underlying farmers' decisions to shift to a new climate resilient crop, and particularly in how gender and ethnicity matter in such adaptation dynamics. This research is a contribution to the literature on the gender, adaptation and ethnicity nexus. We particularly look at the role of women in adaptation dynamics in male-headed households. Specifically, we investigated the gendered patterns of the decision to adopt sesame in the context of drier climate conditions in the Sahel region in West Africa, and how that decision is shaped by ethnicity and women's control over agricultural land.

## Data and study area

The study is conducted in the Sahelian region of Burkina Faso, an area facing greater climate aridity and variability and very asymmetric gendered institutions that have different impacts on women's and men's lives. The region is characterized by a dry climate with very variable and uncertain rainfall. Over the 10 last years, average annual rainfall in the region was  $480 \pm 135$  mm, with a downward trend. Compared to other regions of Burkina Faso, the Sahel region is also known for being strongly patriarchal with strong ethnic diversity and an overwhelming dominance of the Muslim religious culture, resulting in the fact that women's roles and responsibilities in the communities are diversely appreciated and influenced by a number of customary and social norms. This also applies to access to and control of productive resources including land and livestock assets.

The study was conducted in November 2013. Data was collected in 500 households randomly selected in 16 villages in all four provinces of the region. The villages were chosen to reasonably cover the entire research area, all the social groups and agroecological characteristics of the region. In assessing farmers' coping and adaptation strategies to climate risk, respondents were primarily asked whether their household had started growing a new crop on their farm in the preceding ten years. If so, what new crops had been introduced on the farm and the reason why each of these crops had been adopted? The household's responses to these questions were used to compute a dichotomous variable indicating whether the household adopted sesame as a new crop in the ten years preceding the survey.

## Econometric analysis

Our methodological approach draws on the gendered lenses of earlier work on cooperative bargaining models [3][5][10] collective action in the context of natural resources management [7] and on intersectionality [17][6] to run different specifications of a multivariate regression model in order first to test the existence of a gender effect on the household decision to grow sesame, then to progressively understand the influence of other household characteristics on that effect. An intersectionality framework examines how an individuals' characteristics, such as gender, power, class, ethnicity and other forms of social difference interact to shape people's identity, professions and livelihood options [6].

Our empirical approach first consists in multivariate regressions in which the outcome variable is a dichotomous variable measuring the adoption of sesame by farm households. The generic regression model takes the following form:

$$A_i = \alpha_0 + \alpha_1 D_i + \alpha_2 X_i + \epsilon_i$$

where  $A_i$  is the household's decision to crop sesame,  $D$  is a gender dummy variable set to 1 for female-headed households and otherwise to 0,  $X$  is a set of control variables comprising other household characteristics, such as demographics, access to inputs and information, land and livestock assets, agro-ecological zones, and ethnic background,  $\alpha_1$  and  $\alpha_2$  are vectors of parameters to be estimated and  $\epsilon$  is the error term.

## Results and discussion

### Is the adoption of sesame crop gender neutral?

Table 1 presents different empirical estimates made using the theoretical model described in the preceding section. It can be seen across the first five specifications that the gender of household head is consistently significant, but with a negative sign, pointing to a negative sex divide among sesame growers. Basically, female-headed households are less likely than male-headed households to grow sesame in the Sahel (Model 1).

Estimates made using Model 2, in which we only controlled for the socio-demographic characteristics of the household, confirmed the negative effect of the gender of the household-head (HH) on the adoption of sesame. The gender of the HH still holds its significant negative sign, suggesting that only controlling for socio-demographic characteristics of the households has no influence on the negative sex divide among farmers who decide to crop sesame. In the following specification (Model 3), various indicators for land and livestock assets ownership are added to the model. We realized that controlling for land and livestock assets, in addition to socio-demographic characteristics of the household, does not affect the reported negative effect on the sex of the HH in the previous models. One can therefore conclude that differentiated control over productive resources in our sample is not specific to the sex of the HH, but rather to the differences between poor and rich farmers in terms of ownership of assets. Model 3 findings, however, added some gendered patterns to the story of the adoption of a new climate-smart crop in dryland areas. While the amounts of land and the number of livestock owned by the whole households has no influence on the decision to crop sesame, the proportion of land and of small ruminants under control of the woman in the households are significantly associated with increased probability of adoption. These findings look very insightful and point to a potential role for women in male-headed households, particularly when it comes to growing a new crop.

In Model 4, we added different proxies for household access to inputs and extension services. The effect of the sex of HH which, though holding a negative significant sign, lost its explanatory power (5% versus 10% in previous models). In contrast, the amount of land controlled by women control kept its positive sign and also gained in explanatory power. These findings suggest that the negative sex divide among sesame growers is partially explained by the differences between male- and female-headed households in access to inputs, market information and extension

services, and that the effect is partially controlled for once proxies for these variables are included in the model. The findings further confirm the importance of the role played by women in the process of adopting a new climate-resilient crop.

### **How do ethnicity-based norms and land rights impact the adoption process of sesame and women's participation in the household decision to grow a new climate-smart crop?**

Ethnicity-specific norms and rules have been shown by some scholars to shape women's participation in adaptation and livelihood options in West Africa [15][12], and the northern part of Burkina Faso is known for its highly diversified ethnic groups. We consequently hypothesized that ethnicities and norm-based land control are the main factors shaping the gendered patterns of the adoption of sesame, and consequently women's participation in that process. To test these hypotheses, we first controlled for ethnicities in the multivariate regression model using both pooled and fixed-effects approaches. The data strongly support the hypothesis of ethnicity-based norms. The estimates made by Model 5 (Table 1) in which we controlled for ethnicities using a pooled approach, strongly support our expectations of a direct impact of ethnicity on the adoption of sesame. In columns 6 and 7, we report the estimates of the fixed-effect models. Model 6 presents the estimates of ethnicity-level fixed-effects model performed on the whole sample. The finding that captures the most attention here is related to the coefficient of the gender of the HH that has completely lost its significance, while the amount of land under women's control has gained explanatory power. These findings support those reported in the previous section, and strongly confirm the substantial role of the women in the household when the household is about to grow a new crop for better resilience to climate. The findings also support the assumption that the negative sex divide among sesame growers is strongly driven by ethnicity-based discrimination against women in the community, and that effect disappears once the ethnic diversity within the sample is controlled for. To increase confidence in these findings, we disaggregated the data by sex and performed a restricted fixed-effects regression for only male-headed households<sup>5</sup> (Model 7). Indeed, if the aforementioned findings are to be believed, one would expect the effect of women's access to productive resources, including land assets, to be more pronounced among male-headed households than in the whole sample, where the estimates could be obscured by the presence of the female-headed households. The results, as reported in Model 7, are consistent with our expectations and strongly support a role for women in the decision to adopt sesame in male-headed households. The coefficient of the share of land under women's control as estimated with the restricted sample (Model 7) is higher than estimates based on the whole sample (Model 6), and has also gained explanatory power (5% versus 10% in the previous estimates). Women's access to land therefore appears to be more discriminating for the decision to crop sesame when the sample is restricted to male-headed households than with the whole sample, confirming that male-headed households in which women are granted access to land are more likely to shift to a new climate-resilient crop. First, these findings strongly confirm the role of women in the decision to crop sesame, and second, further support the hypothesis of collective action and intrahousehold arrangements between women and their husbands in the male-headed households when it comes to adopting a new crop to cope with drier climate conditions in the Sahel. As a result, providing women in male-headed household with greater access to productive resources is crucial to efforts to implement adaptation agenda and enhance resilience to climate change in the Sahel and other less favorable areas in SSA, as this will increase the capability of the household to take more risks and undertake more actions toward adopting alternatives climate-resilient technologies. These findings also suggest an important influence of ethnicity on the other control variables through ethnicity-specific effects that we were unable to control for in pooled models.

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## Climate resilience through resource efficiency in smallholder vegetable production in South Africa

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Most of the vegetables grown in South Africa are irrigated. Smallholder vegetable farmers face water shortages and other constraints including low yields and high energy costs. This study sought to assist smallholder farmers to address these constraints through enhanced resource use efficiency. It also assessed relevance of these practices for building climate resilience. Data was collected from commercial smallholder vegetable farmers in Limpopo Province and analysed thematically. Farmers recognise the constant fluidity of their environment, noting shifts in rainfall patterns and amounts, increasing temperatures, frequent droughts; and increasing shortages of irrigation water. Higher temperatures necessitate more irrigation and exacerbate water shortages while increasing energy consumption. Competition for water from non-agricultural users is also an issue.



Interventions instituted through the study include water conservation through mulching, efficient irrigation management, accurate irrigation scheduling; use of suitable infrastructure and equipment and good crop management. These interventions reduced water consumption and energy use while increasing yield and reducing production costs; and thus enhanced both water, energy and general resource use efficiency. Enhancing water, energy and general resource use efficiency are appropriate responses to climate change as they build resilience and could help sustain production in the face of climate change induced water shortages and rising energy costs. Impacts could be scaled up and sustained through training and capacity building targeted at individual farmer needs and bolstered by information and technical support. Agricultural advisory service providers need to be cognisant of opportunities for building climate resilience presented by generic problems faced by farmers.

## Introduction

About 90% of the vegetables grown in South Africa are irrigated [3]. Limpopo province is an important vegetable production area, producing 60% and 40% respectively of the country's tomatoes and potatoes[1] and a variety of other vegetables. Smallholder vegetable production is an important livelihood activity in Limpopo province, contributing to household food security and local economies. Shortages of water affect smallholder vegetable production. Some areas of the province note a decline in agriculture which is ascribed to drought and water shortages (Greater Giyani Municipality, 2010). This situation is likely to worsen as climate change projections for Limpopo province indicate an increase in temperature (maximum, minimum and average) a decrease in summer rainfall, increased evapotranspiration and decreased soil moisture in the long term (up to 2100)[2]. Reduced recharge of groundwater and falling water levels in boreholes are also indicated [2]. Some of the implications of changing climatic conditions for agriculture include increased crop irrigation requirements due to increased temperature, decreased soil moisture levels as a result of changed runoff patterns and high vulnerability of certain crops due to decreased water availability and increased temperature[2]. Other climate change impacts include increased water demand for irrigation and an increase in the spread of pests and pathogens, and an increase in extreme precipitation events which can cause crop damage[4]. This study aimed to assist smallholder vegetable farmers to address the constraints they currently face through adopting practices that enhance water and general resource use efficiency; and to identify opportunities for building resilience to changing climatic conditions through practices which enhance resource use efficiency.

## Methods

Thirty smallholder vegetable farmers in the Mopani, Capricorn and Waterberg Districts of Limpopo Province participated in the study. The research process entailed (1) assessing the biophysical, economic and social operating environment of each farm, 2) documenting constraints, risks and vulnerabilities of each farm; (3) implementing interventions to address them; and (4) assessing opportunities for climate change adaptation and climate resilience linked to the interventions. A questionnaire survey, semi-structured interviews; farm observations and a desktop review were used to collect data. Thematic analysis was used for data analysis. For each farm constraints were discussed with the individual farmers concerned and interventions identified and immediately implemented whenever possible. Implemented interventions include water conservation through mulching, efficient irrigation management, accurate irrigation scheduling; use of suitable infrastructure and equipment, maintenance of infrastructure to minimise water leakages and improved crop management such as use of organic soil amendments, applying fertilisers on the basis of soil analyses and crop requirements. Farmers were also encouraged to keep records of income and expenditure and to use these to track financial performance on a regular basis.

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## Results

The farmers grow spinach, beans, tomatoes, okra, squashes, cabbage, cucumbers, onions and a variety of peppers. All the farmers produce for sale. Production occurs on plots ranging between 2 and 10 hectares. All the vegetables are irrigated, with boreholes being the main source of water and drip irrigation the most used method (Table 1). Most farmers use electricity (supplied through the national power grid) to pump water, and they are billed for the electricity they use. The attributes of the farms at the beginning of the study are summarised in Table 1. While all farmers noted that costs of inputs such as electricity were increasing, most (80%) did not keep records of their water use and spending on inputs such as electricity, fertilisers and pesticides. Those who filed their electricity bills and kept records of their spending on various inputs, did not analyse the records to identify fluctuations; and could therefore not link their practices or specific events in the production process with input costs.

Table 1. Baseline situation at the beginning of the study

Attribute	Situation at the beginning of the study
Area under cultivation on each farm	2.5 to 10 ha
Source of irrigation water	<ul style="list-style-type: none"> <li>· Borehole only (83%)</li> <li>· River only 11%</li> <li>· Borehole and river: 6%</li> </ul>
Source of energy for pumping irrigation water	<ul style="list-style-type: none"> <li>· Electricity (grid): 89%</li> <li>· Diesel: 11%</li> </ul>
Irrigation method	<ul style="list-style-type: none"> <li>· Drip only: 89%</li> <li>· Furrow only: 0%</li> <li>· Drip and furrow: 11%</li> </ul>
Basis of irrigation decisions (when to irrigate and duration of irrigation)	<ul style="list-style-type: none"> <li>· Routine and discretion of farmer: 100%</li> <li>· Soil water measurements or crop water requirements : 0%</li> </ul>
Marketing	All farmers sell produce to informal and formal markets
Inorganic Fertiliser use	All farmers use inorganic fertilisers
Organic soil amendment use	<ul style="list-style-type: none"> <li>· 83% use (mainly chicken and cattle manure)</li> <li>· 17% do not use organic amendments</li> </ul>
Basis of fertilisation decisions	<ul style="list-style-type: none"> <li>· Soil analysis results: 17%</li> <li>· Farmer discretion: 72%</li> <li>· Generic fertiliser manufacturer recommendations: 11%</li> </ul>
Use of water conservation practices	<ul style="list-style-type: none"> <li>· 28 % use mulches</li> <li>· 72% do not practise water conservation</li> </ul>
Water pumping practices	<ul style="list-style-type: none"> <li>· 53% always pump into reservoir and then irrigate</li> <li>· 29% have pump directly from water source to crop field</li> <li>· 28% sometimes pump into reservoirs and at other times irrigate directly from water sources</li> </ul>
Pest control	100% chemical pesticide use
Basis of pesticide application decisions	<ul style="list-style-type: none"> <li>· Scouting (precise assessment of pest pressure and state of crop): 67%</li> <li>· Schedules recommended by pesticide suppliers: 11%</li> <li>· Scouting and recommended schedules: 22%</li> </ul>

Farmers recognise that the environment they operate in is constantly changing and they note a shift in rainfall patterns, increasing frequency of droughts, increasing temperatures and frequency of heat waves. A general decline in water availability from both boreholes and surface reservoirs was noted over the years irrespective of rainfall. Farmers also reported an increase in the frequency and severity of crop pest and disease outbreaks. The costs of energy (for pumping water) are increasing; while higher temperatures necessitate more frequent irrigation, and exacerbate the water shortages and further increase energy costs.

Farmers face two categories of risk and vulnerability: (i) those emanating from environmental conditions such as water shortages; and (ii) those that are related to the way farmers manage their operations, and these include the ad hoc irrigation decisions which compromise both water and energy efficiency and lax agronomic management and poor record keeping as detailed in Tables 1 and 2. The risks emanating from environmental conditions are expected to worsen under changing climatic conditions characterised by lower rainfall and increasing temperatures. One year after implementing the interventions, farmers noted changes (these varied from farm to farm) (Table 2). There was a decline in water consumption (this ranged from 5 to 50%). Yields increased by 20 to 200% while gross income increases ranged from 13% to 192%. Electricity costs fell and the range for different farms was 17% to 64%. The interventions improved resource use efficiency and could improve climate resilience (Table 2).

**Table 2.** Implications of interventions to address issues currently faced by farmers for resource efficiency and climate resilience

Current Situation	Interventions to address current situation	Result	Implications for Resource efficiency	Implications for resilience in a warmer and drier climate
Increasing frequency and duration of irrigation due to high temperatures	<ul style="list-style-type: none"> <li>· Mulching to reduce soil water loss</li> <li>· Irrigation during coolest part of day to reduce evaporation</li> </ul>	Reduced water consumption	Increased water use efficiency	Minimising soil water loss contributes to meeting crop water requirements
Increased energy costs due to increased frequency and duration of irrigation	<ul style="list-style-type: none"> <li>· Mulching</li> <li>· Irrigation during coolest part of day</li> </ul>	Reduced energy consumption	Increased energy use efficiency	Improved production stability
Pumping water directly from boreholes to fields and using pumps during whole duration of irrigation	Pumping water into storage reservoirs and using gravity to convey water to fields	Reduced duration of pumping, reduced energy use	Increased energy use efficiency	Reduced energy costs lower, production costs – increased production stability
Shortages of irrigation water	Water conservation – mulching and irrigation during coolest part of day	Reduce water consumption	Increased water use efficiency	Reduced water use – sustaining production in a drier climate
Ad hoc irrigation (not informed by crop water requirements)	Conduct basic tests to determine necessity to irrigate and only irrigate based on crop water requirements	Adequate water supply to crops	Increased efficiency of use of water and other inputs	<ul style="list-style-type: none"> <li>· Reduced water use</li> <li>· Optimal yields</li> </ul>
Poor infrastructure maintenance – leaking pipes & tanks	Maintaining equipment and infrastructure to minimize water losses	Reduced water losses	Increased water use efficiency	Reduced water use – sustaining production in a drier climate
Low use of water conservation practices	<ul style="list-style-type: none"> <li>· Use of mulches</li> <li>· Appropriate timing of irrigation</li> </ul>	Reduced water losses	Increased water use efficiency	Reduced water use – sustaining production in a drier climate
Poor agronomic practices: <ul style="list-style-type: none"> <li>· Ad hoc fertiliser application</li> <li>· Random pest control</li> <li>· Little use of organic soil amendments</li> </ul>	<ul style="list-style-type: none"> <li>· Correct fertilisation</li> <li>· Accurate and timeous pest control</li> <li>· Use of organic soil amendments</li> </ul>	Optimum crop growth and yield	Increased efficiency of use of water and other resources	Sustaining optimal crop production in a drier climate

The interventions instituted to address problems currently faced by farmers resulted in reduced water and energy consumption and enhanced yields, and these factors are relevant for climate change adaptation and building climate resilience in farming operations (Figure 1).

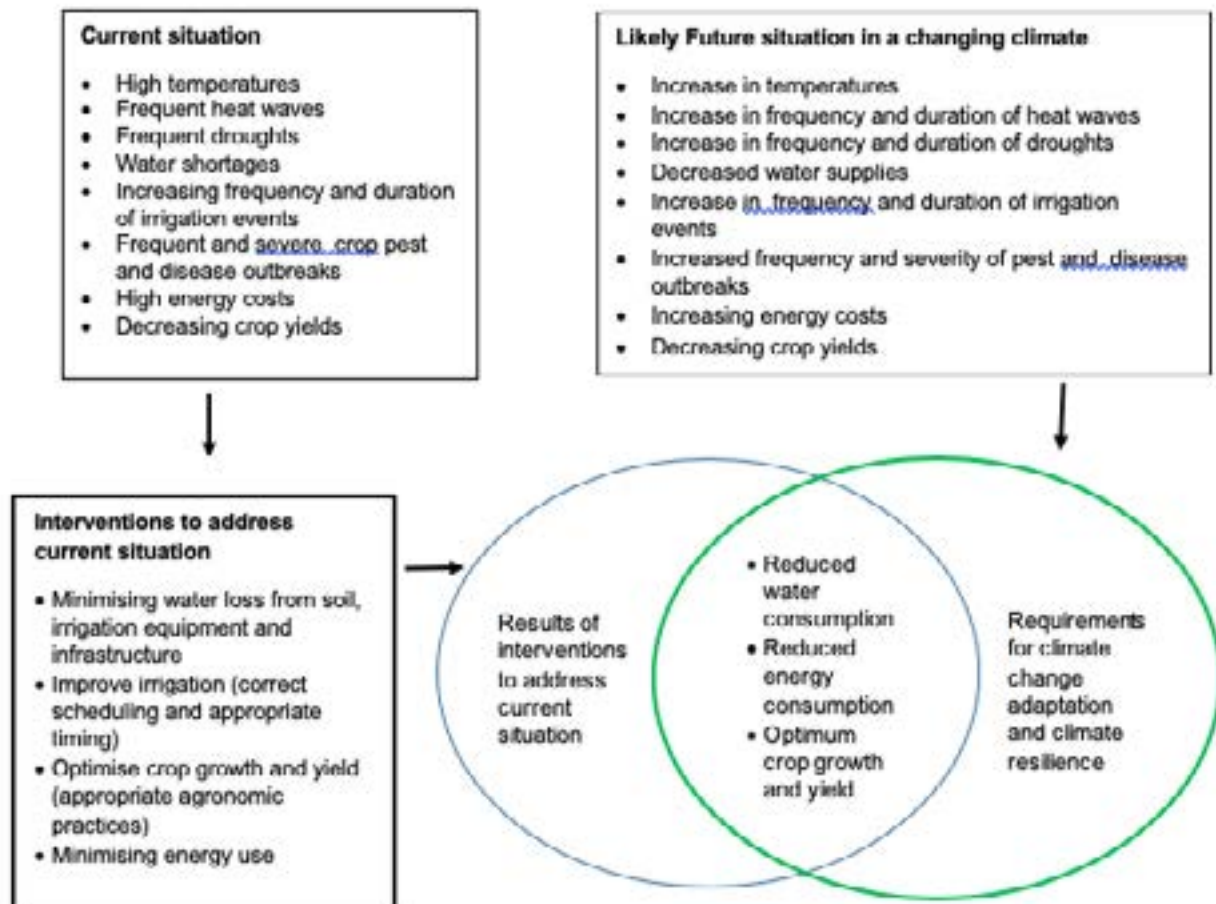


Figure 3. Convergence of outcomes of interventions to address current issues with requirements for climate change adaptation and climate resilience

## Conclusions

Interventions which address immediate problems faced by farmers could facilitate building climate resilience in farming systems. Agricultural advisory service providers need to be cognisant of opportunities for building climate resilience presented by generic problems faced by farmers.

Interventions to address current problems faced by farmers included lowering water consumption and consequently energy use, resulting in enhanced water and energy use efficiency. Enhanced water and energy use efficiency, coupled with improved management incorporating appropriate agronomic practices and better irrigation management through accurate scheduling increased yield while reducing costs of inputs such as energy. These interventions not only address current problems faced by farmers, but are also appropriate responses to climate change as they built resilience and could sustain production in the face of climate change induced water shortages and rising energy costs. Identified interventions are achievable through training and capacity building targeted at individual farmers' needs and bolstered by information and technical support. Interventions which address immediate problems faced by farmers could facilitate building climate change resilience in farming



systems. Agricultural advisory service providers need to be cognisant of opportunities for building climate resilience presented by generic problems currently faced by farmers

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## Climate smart soil and water management practices in drylands of Ethiopia: Challenges and opportunities. A review

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The purpose of this study was to review climate smart (CS) soil and water management practices, challenges and opportunities focusing in drylands of Ethiopia. The review identified: tied ridge with mulching, grazing land management, agroforestry, conservation agriculture and integrated watershed management were adopted climate smart soil and water management practices in the area. The challenges in adoption of the practices were higher initial cost, lack of strong rangeland management and forest protection by laws and regulatory, lack of integration between sectors, lack of knowledge, lack of reliable climate information and, competition for crop residue among incorporation in field, livestock feed and fuel for cooking. The opportunities were presence of policies and strategies which are pertinent to climate change adaptation and mitigation, presence of international development organizations and numerous NGOs involved in CSA, UN conventions (CCD, CCC, CBD) which share a common goal of proper management of soils to increase soil carbon. However, most of the technologies were not widely adopted by farmers. Therefore, there is a need for integration of sectors and efforts to break the multiple barriers; in addition, financing at initial adoption and giving incentive to ecosystem services are crucial for effective adoption and up scaling of the climate smart practices.

**KEY WORDS:** climate smart; drylands; soil organic carbon; adaptation; mitigation ;CSA

## Introduction

Agriculture is the main economic sector[5] as well as the most vulnerable[9] sector to climate change in Ethiopia. According to FAO's report on annual greenhouse gas (GHG) emissions, 50 percent of estimated (150 Mt CO<sub>2</sub>e in 2010) emissions came from the agricultural sectors[5] in the country. Nevertheless, about 89% of the potential technical mitigation potential of agriculture (5.5–6 Gt of CO<sub>2</sub>e per year by 2030) could be achieved through soil C sequestration[7]. Soil

carbon has the critical role in the drylands as a fundamental driver of ecosystem services and contributes to increasing resilience to climate change and variability[3] contributing to CSA agriculture. But low attention was given to the role of soil in climate agendas. The objective of this review was to identify the existing climate smart soil and water management practices, the challenges and opportunities focusing in drylands of Ethiopia.

### **Agricultural management practices pertinent for climate smart soil**

The available published literatures on climate smart agricultural management practices, which result in climate smart soil, in drylands of the country were reviewed to the best. Experts experience was also added where relevant. The identified practices were described and discussed in the following sections.

#### **Tied ridges**

UNDP stated that tied ridges as water harvesting technique has proven to be very effective for soil and water conservation[12]. It increased grain and straw yield of crops by 150 percent and 90 percent, respectively, compared to traditional methods of planting in the flat seedbed in many semi-arid areas of Ethiopia including other East African countries. When a combination of tied ridges and maize stalk mulch were used, a crop of maize was realized for a season of extremely low rainfall (171 mm); whereas no yield was obtained from the conventional practice. However the technology is not widely practiced according to the report.

#### **Grazing land management**

Conservation of grazing resources by reducing herd size, natural pasture improvement, integration of forage legumes into cereal production systems and utilization of various forms of feed resources for livestock production[12] are climate smart grazing land management practices practiced in dryland areas of the country. The report showed drought-resistant forage crops, such as pigeon peas, saltbush, Senna and Opuntia, are grown in watershed areas in many districts in semi-arid areas, where rainfall is as low as 200 mm per year. These are important for livestock feed, C sequestration and soil water storage [11][1].

#### **Agroforestry**

In traditional agroforestry in many dryland areas, trees are kept by small-farmers on farmland for various uses. Parkland agroforestry system has a crucial role in social, economic and environmental value[10]. There is substantial evidence to show that alley cropping can result in higher productivity, and can safeguard against unfavorable conditions, including climate change and variability. These systems improve the health of soil by improving soil organic matter hence contribute much to climate change adaptation and mitigation.

#### **Conservation agriculture (CA)**

CA is one of the key climate smart agriculture(CSA) activities conducted in Ethiopia from 1998 onwards[5]. CA improve yield, can help mitigate climate change by reducing existing emission sources and sequestering carbon in soils and plant biomass. Conservation tillage globally could sequester 25 Gt C over the next 50 years[2]. Scaling up of conservation technology is currently under way. In southern part of the country at Humbo district, CA+(CA plus is CA combined with agroforestry) adoption supported by local NGO called TDA(Terepeza Development Association) changed life of farmers; who adopted the practice, from food insecurity to surplus production for income generation (source: from a farmer response during field visit for practical course work at Abena Langena KA(Kebele Association))

## Integrated watershed management

Ethiopia is one of the countries seriously affected by land degradation, and has been striving to address this problem by integration of multiple techniques. Soil organic C sequestration was achieved by implementing sustainable land management practices that can improve incorporation of biomass to the soil, to conserve soil and water, and enhance activity and species diversity of soil fauna[5]. A far integrated dryland management program, that considered the complexity of the challenges in dryland areas, and planned appropriate measures, helped to produce promising outcomes through integrated approaches involving multiple sectors[12].

## Challenges and opportunities of climate smart soil and water management practices

The challenges of climate smart practices are multi-faceted and include numerous socioeconomic and bio-physical problems. The costs of adopting practices the practices can be quite significant for smallholders, particularly in the initial and transition phases[6]. In Ethiopia smallholder farmers often do not have the financial resources and have limited access to credit[8]. Other challenges include weak integration into existing extension planning[5], lack of knowledge on appropriate cropping systems[4], lack of climate information, lack of recognition of indigenous knowledge, lack of land tenure security, and lack of strong rangeland management and forest protection by laws and regulatory. Other important challenge is competition of crop residue for multipurpose utilization. Crop residues are collected and stored as dry-season feed resource or grazed in-situ ;sorghum and maize straw is used as fuel for cooking[8].

Opportunities are the good policy environment[6], involvement of numerous NGOs in CSA related activities, existence of a large national research networks, and several UN conventions (the convention to combat desertification(CCD), the Climate Change Convention(CCC), the Convention on Biological Diversity (CBD) which share a common goal: the proper management of soils to increase soil carbon[4]. Drylands, due to their high potential for further carbon sequestration, are good opportunities to incorporate soil carbon in global carbon credit.

## Conclusions

Scaling up best practices and approaches of the climate smart interventions by addressing the challenges will not only contribute to the climate change mitigation target but also to food security of the country. Climate change could result in an expansion of the area classified as drylands, by as much as 20 percent under some scenarios, for the region as a whole, with much larger increases in some countries (World Bank, 2016). These need strong adaptation and mitigation actions by adoption of technologies adapted to the local biophysical and socio-economic conditions by integration of multiple stakeholders. In addition, providing incentives for the adoption of those systems at most at the initial point is necessary for poor farmer with small land holding.

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## Resilience Index of Flood Prone Communities in Ibadan, Nigeria

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Despite a history of rather devastating flood disasters, Nigeria have not established effective mechanisms to reduce the risk of flood disasters from occurring and also manage them at local and national levels. Consequently, the negative impacts of the severe floods have continued to increase in affected communities due to low flood risk resilience. This study was conducted in Ibadan, one of the most frequently flooded non-coastal cities in the country with a history of devastating flood disasters. The aim is to develop Flood Resilience Index (FRI) for some selected flood prone communities. The FRI is conceptualized to address numerous issues related to physical, social, economic and institutional dimensions of resilience. A structured questionnaire was designed to assess the level of flood resilience focusing on four dimensions (physical, social, economic, and institutional). Each of the dimensions have three parameters and each parameter have three variables (4×4×3 matrix). The results show that the FRI was less than 2.0 for all the six communities indicating low resilience and about the same figure for all the four dimensions. This study is useful in that it provides a valuable tool to effectively reduce flood risk and associated disasters in Ibadan. The study can be replicated in other cities for effective flood risk reduction in Nigerian cities.

**KEY WORDS:** Flood resilience index, disaster, communities, Institutions, flood risk.

### Introduction

'Urban flooding is an increasingly important issue which may shape the destinies of cities or substantially change the face of them for decades to come'. This opening statement of the World Bank commissioned paper titled 'Cities and Flooding in the 21<sup>st</sup> Century' aptly describes the big challenge that cities face now and in the future in respect of climate change and the resultant extreme weather events especially flooding. Climate change may cause floods to occur more frequently and severely.

Most Nigerian cities especially those in the central and southern parts of the country are highly vulnerable to flood disasters. The reported cases of flooding in the cities like Ibadan, Lagos, Port Harcourt and Lokoja have increased both in frequency and intensity in recent years[4]. In particular, Ibadan in Oyo State has been frequently ravaged by flood disasters over the years. The city suffered one of its worst flooding in August 2011 resulting in high numbers of lives that were

lost and properties destroyed. The estimated amount to fix the culverts and bridges damaged was put at 2.1 billion Naira by the State government.

Understanding the dimensions, designing, implementing and investing in solutions which minimize floods and the impacts must become part of flood risk management in the metropolis. One of such tools that promotes this understanding is Flood Resilience Index (FRI). It is in this context that this study developed FRI for six flood prone communities in Ibadan metropolis.

### Conceptualizing Flood Resilience

There are two main discourses on flood disasters. The first, and dominant view, is that flood disasters are inherently a characteristic of natural hazards [2]. Disasters arise inevitably when the magnitude of a hazard is high. This contrasts with the second, alternative discourse that sees flood disasters as being jointly produced by interaction of the physical hazard and social vulnerabilities. This alternative discourse brings into the fore social relations, structures, institutions and governance in understanding flood disaster. This view posits that flood disasters are not only the result of natural hazards, but also of socioeconomic structures and political processes that make individuals, families and communities vulnerable [2]. In the context of flood risk management, the definition of resilience increasingly focuses on community resilience and community's ability to withstand external shocks and sustainability of livelihoods.

### Methodology

The FRI, as used in this study was largely adapted from Batica and Gourbesville (2014), and is conceptualized to address numerous issues related to physical, social, economic and institutional dimensions of resilience [1]. Since quantitative data for these dimensions are not available, this research relied on respondents' perception. Six communities were used for the study including Apete, Agbowo, Olorungunwa, Oki, Oke Ayo Titun and Odo Ona. A total of 300 questionnaires, 50 in each location was used.

A structured questionnaire was designed to assess the level of flood resilience in the selected communities focusing on the four dimensions of resilience. The questionnaire contained a total of 48 questions (Four indicators, 4 parameters and 3 variables. The questionnaire was designed using likert scale using a four-point rating scale to assess the resilience level for each variable, where 1 means "poor" and 4 means "very good". Based on the perceived scores of resilience, the following weighted mean formula was used to calculate the FRI for the six communities.

Weighted mean formula for the parameters is given as follows:

$$\frac{\sum w_i X_{ini}=1}{\sum w_{ini}=1} = \frac{W1X1 + W2X2 + W3X3 + W4X4}{W1 + W2 + W3 + W4}$$

Where: W is the weighted mean and X is the number of respondents

### Results and Discussions

#### Socio-Economic Characteristics of Respondents

The results of the analysis shows that both males and females are fairly equally represented in the sample with males just a little of half of the total number of respondents (51.3%) while females



made up the remaining 48.7 percent. More than two third of the respondents are married (87.0%). The average of household size is 5 which also implies that the households are fairly large in numbers with implications for disaster impacts. The average age of the respondents is 45 years while the number of years the respondents have lived in their communities range from 1 to 40 years with an average of 8.3. A large proportion of the respondents (43.3%) earn just between N20,000 to N50,000 monthly and just 4.6 percent earn above N100,000 monthly. The implication of this is that most of the respondents are poor which, again, have implication for flood disaster impacts.

### Overall Flood Resilience Index of the Six Communities

Flood resilience is the weighted mean of the four parameters used to derive the index. These are physical, economic, social and institutional. For all the four dimensions studied, the communities showed high levels of vulnerability. Some of these perceived responses were further corroborated by assessments of the physical conditions of the communities during the field survey and also through the community risk assessment conducted with groups in Apete and Olorungunwa.

All the communities are rated fair as seen in the results of the analysis presented in Figure 1, implying that they have low resilience index. The FRI are 1.5 in Oki, 1.7 in Agbowo and Oke Ayo Titun, 1.9 in Omirin/Olorungunwa, 2.0 in Apete and 2.1 in Odo Ona. These results indicate that the communities performed very poorly on all the four indicators.

### FRI Scores of Physical, Economic, Social and Institutional Dimensions

As shown in Figure 2, none of the communities scored up to 2 all the four indicators that were used to measure the FRI. The FRI obtained for the four indicators are 1.93 for institutional, 1.8 for physical, 1.83 for social and 1.63 for economic. The result obtained for economic resilience, for instance, was not surprising given the fact that income, savings and assets of the respondents are very low. In other words, the respondents are very poor and consequently, this makes them more vulnerable to the impacts of flood disasters and many cannot easily recover after a flood disaster incident. Also the FRI scores in all the communities across the four dimensions do not vary significantly. The comparison of the FRI across the communities using the four indicators is presented in Figure 2.

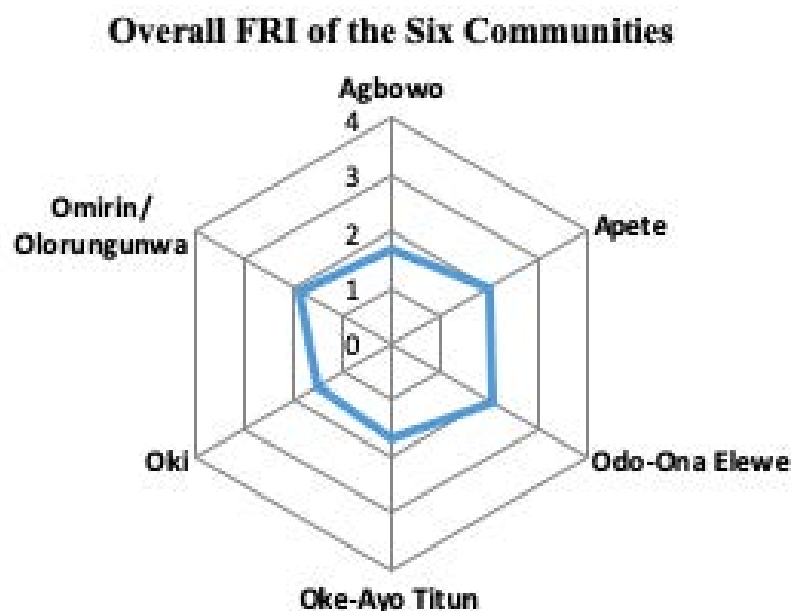


Figure 1. Overall Flood Resilience Index of the six communities

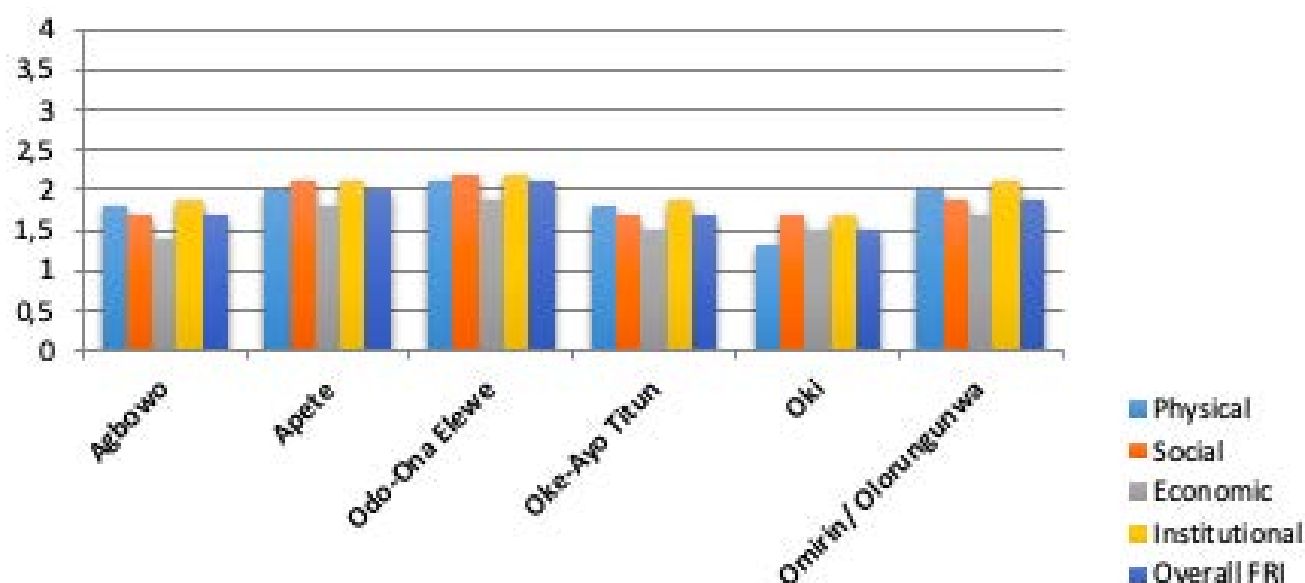


Figure 2. Comparison of FRI in the six communities across the four dimensions

## Conclusions

All the six communities studied have very low flood resilience index. The impact of flooding can actually be seen in the communities. Bad drainages/bridges, roads and poor water supply were rated high among the hazards in the community. This is due to flooding resulting from excessive rainfall during the raining season. The high susceptibility to flooding due to physical vulnerability, economic, social and institutional vulnerability of these communities may limit the effectiveness of all interventions to reduce flooding.

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## Assessment of the grapevine and environmental interactions in the context of climate change for improved adaptation strategies in South Africa.

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Climate change at a global scale continues to increase in heat units, driving the plants physiological responses, hence there is a need to better understand what aspects within the

climatic profile are warming and affecting the grapevine to aid adaptation strategies. South African wine grape terroirs, situated in the Western Cape have an intrinsic climate variability between sites and seasons dictated by latitude, distance from the ocean and complex topography. The study focused on the vineyard and environment interactions at high resolution over six growing seasons selected over a climate gradient in the Western Cape. Multivariate analysis highlighted seasonal variability as the driving factor affecting the grapevine responses over and above extreme climatic differences. Frequency analysis highlighted specific months within seasonal summations shifting, normally masked within traditional bioclimatic index descriptions. These shifts related to increases in December, January and decrease in March temperatures, which could affect the grapevine's response. Hence, using the climate profile based on hours at specific classes with no set margins provide better insights to guide adaptive strategies for the future, in the context of climate change and the complexity of the Western Cape. Emphasising the need for an online spatial decision making tool hosting high resolution spatial and temporal datasets to aid adaptive strategies at farm and field level to leverage change and build resilience in the face of climate uncertainty in the Western Cape.

**KEY WORDS:** Climate, Seasonal variability, Viticulture, Western Cape

## Introduction

Global warming is scientifically and widely accepted, with consistency across observations worldwide and the last three decades successively warmer at the Earth's surface than any preceding decade since 1850 [10]. Annual global warming driven by increased temperature in the first and last four months of the year, impacting the agricultural production of summer ripening crops in South Africa. Africa had its fourth highest continental temperatures on record in 2018, followed by 2010, 2016 and 2015, and many coastal countries experienced droughts in recent times. South Africa lies in one of the regions of the world most vulnerable to climate variability and change, getting hotter over the past four decades, average annual temperatures have increased, with varying increases across the seasons, and an increase in the number of warmer days [9][12]. Future climate projections indicate benefits for some regions and challenges for others [11]. Future temperature increases may shift grape phenology, ripening and consequently also harvest dates, and may affect grape quality and yield [4][16].

Climate in the Western Cape is dynamic due to the variation of topography, proximity to the ocean and the sea breeze effect. The current meteorological network is not a dependable source in terms of distribution and consistency of data accuracy due to factors such as financial constraints, vandalism of some stations, out-dated equipment, and lack of efficient monitoring of stations. Hence, there is a need for an alternative temperature resource to supplement current weather station networks. The application of traditional geospatial interpolation methods in complex terrain such as the Western Cape also remain challenging and difficult to optimise, and accuracy will be highly dependent on station network inputs [13][2]. Intrinsically spatialised thermal remote sensing data, such as the MODIS LST (Land Surface Temperature) product, can be used as an alternative, with reconstructed daily time series being potentially useful in many cases to substitute meteorological temperature observations. One of the most important potential applications of the land surface temperature (LST) retrieved from satellite data is to validate and improve the global meteorological model prediction after appropriate aggregation and parameterization [6][15].

The study aimed to provide new insights into the subject of climate change in the Western Cape and to the grapevine's response to climate, namely for *Vitis vinifera* cv. Cabernet Sauvignon. In the study, climatic parameters were processed on different temporal and spatial resolutions. The availability of climate and weather data at an applicable spatial and temporal level is crucial to support studies on grapevine phenology, growth, and ripening models, which can be achieved by integrating existing weather station networks and remote sensing resources[3][4][18]. Hence,

the study aimed to evaluate the use of remote sensing sourced land surface temperature as an alternative and supplementary source for weather station temperature which can be used in future climate change adaption strategies. In view of climate change, economic pressures and limited water availability in the agricultural sector, integrated information about the suitability of land for agriculture is paramount to aid long and short-term decision making at farm and field level.

## Materials and methods

### Study Area and Grapevine Monitoring.

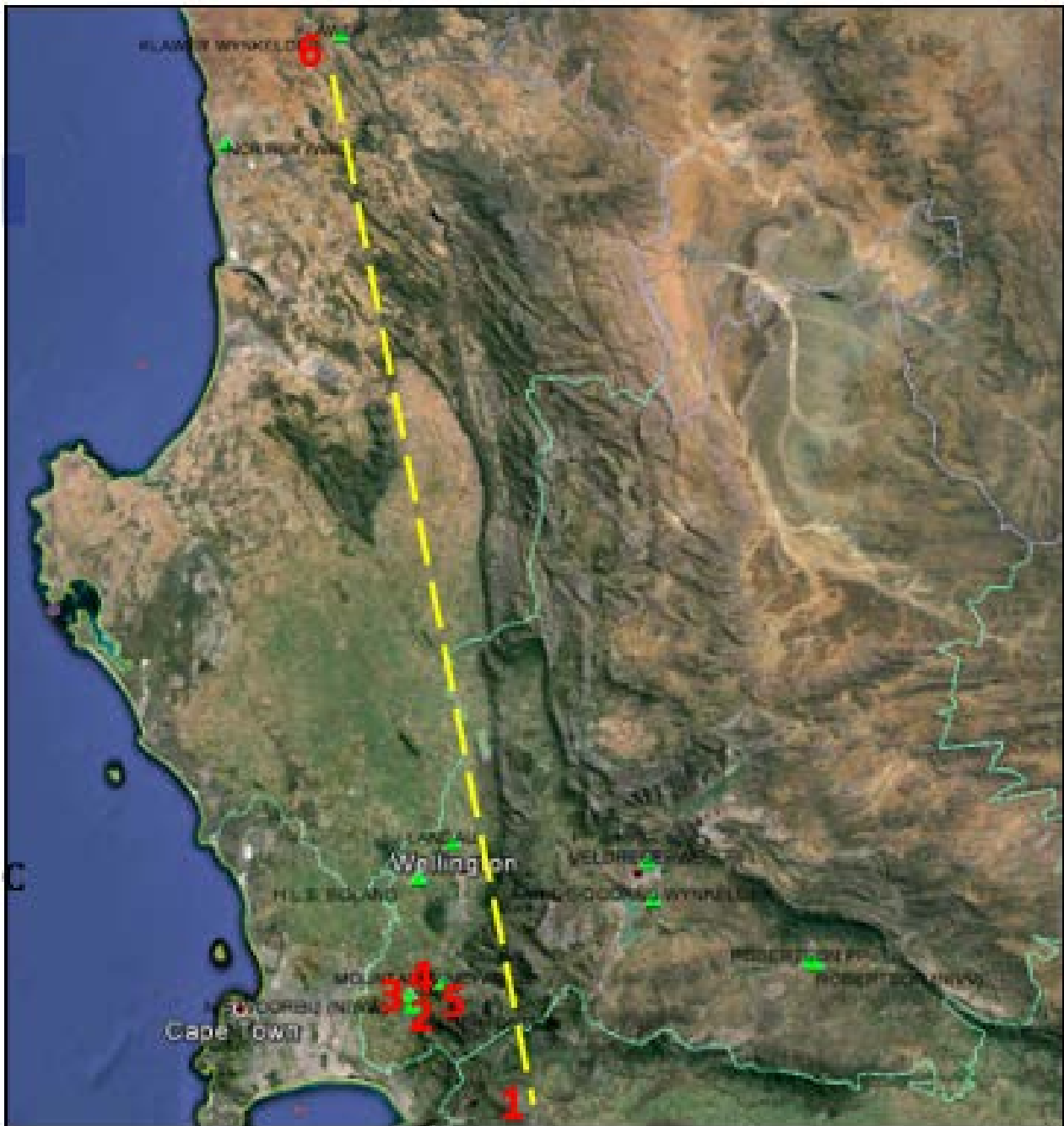
The study areas selected over a spatial climatic band within the Western Cape wine regions, namely the winter-rainfall Coastal Region (Somerset West & Stellenbosch), Cape South Coast (Elgin) and the semi-arid Olifants River Region (Vredendal). The selected sites and their detailed descriptions (slope, elevation, aspect, and distance from the ocean) are given in Table 1, the Stellenbosch area is represented by three sites due to the complexity in topography inducing mesoclimatic variability across the viticultural area. Two red grapevine cultivars were selected for the study, namely Cabernet Sauvignon and Shiraz, as they are popular and two of the later ripening cultivars planted in the Western Cape. The ripening of Cabernet Sauvignon is normally considered a “late” cultivar, and Shiraz can, in some cases, even ripen with it. The grapevines vegetative and reproductive responses were monitored in detail over the six growing seasons (2012–2017). The beginning of each phenological stage was determined visually for every site, defined according to the E-L phenological system developed by Eichhorn & Lorenz as adapted by Coombe (1995)[5].

**Table 1.** Descriptions of sites selected over a climatic band within region and districts of the Western Cape extent

Region/ Locality	Distance from ocean (km)	Altitude (m)	Aspect	Slope (%)
Cape South Coast/ <b>Elgin (1)</b>	15.4	196	ESE	6.3
Coastal/ <b>Somerset West (2)</b>	7.7	136	W	6.5
Coastal/ <b>Stellenbosch_1 (3)</b>	21.0	112	S	5.5
Coastal/ Simonsberg-	25.1	413	SSE	11.0
Coastal/ Simonsberg-	25.5	359	SW	6.2
<b>Olifants River/ Vredendal (6)</b>	34.9	74	NNW	2.3

### Climate data collection.

Meteorological data was sourced from the Institute of Soil, Climate and Water (ARC-ISCW) of the Agricultural Research Council for long-term climate change analysis. Weather stations (, N=70) were selected over a large spatial area distributed throughout the wine growing regions of the Western Cape to quantify the long-term climate. Temperature and rainfall were selected as the descriptors to define the climate over decades. Additional hourly meteorological data sourced from iLeaf (<http://www.ileaf.co.za/>) and logger networks for generating hourly spatial maps for a study extent within the Western Cape.



**Figure 1.** Descriptions of sites selected over a climatic band within region and districts of the Western Cape extent.

## Land Surface Temperature Acquisition & Processing.

Daily temperature data sourced from meteorological stations ( $N=16$ ,  $WS_T$ ) acquired for three years (2012–2015), selected in extreme locations over a climatic band from a cooler to a warmer region within the Western Cape to validate the use of Land Surface Temperature maps. The land surface temperature ( $LST_T$ ) and weather station ( $WS_T$ ) data for  $T_m$ ,  $T_x$  and  $T_n$  were divided into calibration and validation datasets using 70% and 30% proportions of the datasets, respectively, and each one was defined by randomly resampling the entire observation set several times. The model optimisation was based on the larger dataset of three years, with the calibration (analysis sample) and prediction (validation sample) independently evaluated within the study period of three years, calculating for both a set of performance statistics. A set of statistical measurements were calculated to evaluate the model adjustments needed to use  $LST_T$  to supplement WST.



### Climate analysis.

The *daily datasets* from the weather stations, loggers and land surface temperature maps were used as the input for the calculation of climatic indices [17][7][1] to quantify the growing season over the climatic band and seasons. *Hourly data* was separated into a set of threshold ranges (classes) for temperature (T:  $0 < X < 5$  to  $40 < X < 45$ ), relative humidity (RH:  $0 < X < 20$ ;  $20 < X < 40$ ;  $40 < X < 80$  to  $90 < X < 100$ ) and wind speed (U2:  $0 < X < 2$  to  $18 < X < 20$ ). The observed number of hours at each level was used and compared for sites, seasons and months.

### Statistical analysis.

Mean comparisons of measured variables between sites and season were compared using one-way and mixed model ANOVA. Multivariate relationships between blocks of variables were described using multiple factor analysis (MFA). RV coefficients were calculated between blocks and used as inputs for cluster analysis with the purpose of clustering similar blocks of variables to identify the driver variables in the climate profile influencing the grapevines response. Analyses were conducted using Statistica 13<sup>®</sup> software (Statsoft, Tulsa, UK) and R function "MFA" within the package "FactoMineR".

### Integrated Database: Online Spatial Decision Support System.

The continuous climate database (in collaboration with weather station custodians) was integrated and used in conjunction with very high resolution digital elevation models (DEMs) developed by Stellenbosch University and GeoSmart Space, to interpolate wall-to-wall climate layers at a high enough resolution to inform decision making at a field level. The spatial layers are presented within an easy-to-use online mapping tool, for viewing and drawing reports of environmental and climatic variables at a field or farm level.

## Results and discussion

Over all temperature elements, there was a warming trend from 1984 to 2015 in the Western Cape. Warming trend driven by maximum temperature increases of  $1^{\circ}\text{C}$  to  $2^{\circ}\text{C}$  over the last three decades, rather than minimum temperature increases of  $<0.6^{\circ}\text{C}$ , over all regions. Rainfall was not well explained by specific trends over decades, but recent years indicate a rainfall shift into the summer season of the Western Cape. A trend of increase in seasonal growing degree day summations was noticed for the period 2010 to date, represented by a general increase of up to 200 units over the 30 year period of the study, confirming that the growing season is warming. The most significant shift to warmer temperatures was noted in December, January and March, with increasing rainfall in January and March, which could speed up ripening and affect grape composition as well as the possibly of diseases if rainfall occur during ripening.

The correct spatial distribution of reliable stations is key for accurate analysis and to quantify climate change as well as highlighting the possible regional influence on climate change, with some regions possibly more affected than others. Topography and distance from the ocean seemed to drive regional shifts over the three decades, as there seemed to be a more pronounced effect on temperature in the coastal region, with some regions being more prone to change, emphasizing the need for finer scale demarcation when climate aspects are considered. The study showed that daily land surface temperature images can be used to improve the global meteorological model prediction, as the images are spatiotemporal in nature. The results are promising; LSTm and WSTm had good correlation coefficients of  $R^2 \geq 0.80$ .

The study highlighted seasonal variability as the prominent driver in grapevine responses, changing the tempo of growth and ripening, grape composition, and occurrence of diseases. Flowering is one of the phenological variables most affected by temperature and relative humidity (flowering date set from 1st September). Low relative humidity resulting in an earlier

season and high relative humidity in a later season. Flowering had a good correlation with temperature; warmer seasons resulted in earlier flowering over all sites and cultivars. Frequency analysis highlighted that more hours observed at 35–40°C in the summer months resulted in earlier phenology in coming season. Flowering tended to “set the pace” for phenology in the seasons, flowering had a strong correlation with harvest date. Overall, the phenological stages showed to have a correlation with heat summation indices for the season, cooler seasons resulted in later season and a warmer seasons resulted in earlier season for all seasons and sites in the study, comparable to other studies [11].

The study showed higher temporal and spatial resolution climate data is needed in the context of climate change to quantify the complexity of the Western Cape driven by topography and distance from the ocean. Seasonal variability was highlighted as the driving factor influencing the grapevines response, emphasise the need for more semi-real time climate data that can be used within season for decision making at farm and field level. The integration of climate and terrain data in an online web application at a field level is a platform that brings researchers, consultants, and farmers together to discuss subjects such as remote sensing, geography, climate, and crop responses to aid adaption to a changing environment and mitigating (possibly even harnessing) its effect on production.

## Conclusions

This study proved that within a general warming trend, the climate in the Western Cape could be both warming and cooling, depending on the area or months in the context of the long-term mean, emphasising the need for more semi-real time climate data that can be used for within season decision making. The study confirmed the hypothesis that grapevine will respond to climate change and continue to do so in the expression of phenology, growth and ripening, as the grapevine; performances are affected by the constant environmental parameters despite the differences on vineyard and site level.

The collation of existing and new information into an integrated climate database using in situ data from meteorological stations; logger network; remote sensing land surface temperature layers combined with high resolution and terrain derivatives, increases the integrity of data for adaptive decision making. The integrated database will allow for dynamic mapping, statistical interrogation, data mining, machine learning, and climate change analyses over time.

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## THEMATIC AREA 5

### Co-production of knowledge between science, business, policy, practice and local communities

This theme explores collaborative processes for developing climate services and aims to encourage interactions between the policy, practice and research communities, including the private sector and local community groups. It showcases different approaches that demonstrate how these groups can work together to co-produce knowledge around climate change information and adaptation options. Included here are approaches to achieve a cohesive ethical framework to govern development and application of climate services (quality assurance and ethics).



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## LIST OF PRESENTERS AND TITLES OF PRESENTATIONS

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Protecting Reproductive Right as a Pathway to Environmental Sustainability and Climate Compatible Development In Africa

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**Bruce Currie-Alder**

Building climate resilience in Africa & Asia: lessons on membership, organization and collaboration from CARIAA on multi-consortia research programme

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**Richard Graham**

Forecasts to services: building global-regional-national partnerships to strengthen seasonal forecasts and service coproduction in the Greater Horn of Africa

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**Idowu Olagoke Kunlere**

Combating climate change in Africa by strengthening public participation: making policy count by making every voice count

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**Kornelia N. Ipinge**

The Story of Water in Windhoek: A Narrative Approach to Interpreting a Transdisciplinary Process

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**Bob Manteaw**

Climate-Informed Decision Making in Data-Poor Environments: Enhancing Climate Risk Management Through Knowledge Co-Producing Networks in Africa.

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**Inga Menke**

ISIpedia, the open-access climate-impacts encyclopedia: The contribution of stakeholder-scientist-dialogue to the development of user-friendly climate services

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## Protecting Reproductive Right as a Pathway to Environmental Sustainability and Climate Compatible Development In Africa

Oluwatoyin Adejonwo-Osho<sup>1</sup>

<sup>1</sup> Faculty of Law, University of Lagos

Population size is one of the factors that creates an anthropogenic impact on the environment. However, linking family planning or reproductive rights to population growth and environmental degradation is controversial, especially in Africa. Conversely, access to family planning pathways can be used as an important tool to achieve emission reductions, environmental sustainability and a climate change adaptation tool. It has therefore become necessary to reconcile and integrate these fields in an effort to advance both reproductive rights and environmental sustainability. Global emission scenarios demonstrate that slowing population growth could lead to substantial emission reductions and play an important role as a climate change adaptation tool and help to avoid dangerous climate change. However, to achieve this scenario, it becomes necessary to integrate reproductive rights and environmental sustainability through normative and discursive change as these fields are currently operating in silos, mainly because reproductive rights is mostly framed as individual rights that are private in nature.

Although carbon emissions tend to be low in countries where population growth rates are high, such as in developing countries in Africa, current evidence shows that per capita emissions rise as nations develop. This paper seeks to highlight the necessary normative and discursive change that is imperative in Africa and explore family planning and climate change connections from a woman-centered and rights-based approach.

### Introduction

Population explosion and size is one of the factors that creates anthropogenic impact on the environment [6]. However, linking reproductive rights to population growth and environmental degradation is unconventional for policymakers, still at a developmental stage [8][5] and further hampered by cultural and religious beliefs, particularly in Africa. According to the United Nation, the world population has reached 6.8 billion with 5.6 billion (82%) living in the less developed regions. The UN further projects that world population will reach 9.1 billion by 2050, an increase close to the combined populations of China and India today and that most of this growth will be in developing countries, where population is projected to more than double, from 835 million inhabitants in 2009 to 1.7 billion in 2050 [7]. The Intergovernmental Panel on Climate Change (IPCC) estimates that by 2100, global temperatures could rise by 1.1–6.4 °C and sea level by 28–79cm. In addition, weather patterns will become less predictable and extreme climate events, such as storms, floods, heat waves and droughts, will occur with increasing frequency and severity [2].

Population and reproductive health have rarely been linked in climate policy discussions or in those related to improving access to family planning. Research has, however, linked population, reproductive health, and climate change, and demonstrated that helping women achieve their own aspirations for planning pregnancies and family size would put the world on a path to slower population growth, leading to substantial reductions in future carbon dioxide emissions [8]. According to the report by the United Nations Population Fund (UNFPA) and the Danish Institute for Human Rights, despite an increased focus and funding on voluntary family planning in many countries, among other interventions, there are still major gaps in the availability of contraceptive services, especially in sub-Saharan Africa and certain other developing countries where unmet need is close to 25 percent while the global average is around 11 percent [8]. The Report further highlights that more than 120 million women have unmet needs for family planning services and such women do not have the option or choice to decide whether to have children and the number and timing of child bearing.

It has therefore become necessary to reconcile and integrate these fields in an effort to advance both reproductive rights, environmental sustainability and climate compatible development as these fields are currently operating in silos, mainly because reproductive rights are mostly framed as individual rights that are private in nature. Global emission scenarios demonstrate that slowing population growth could lead to substantial emissions reductions and play an important role as a climate change adaptation tool and help to avoid dangerous climate change. However, to achieve this scenario, it is necessary to discuss reproductive rights, environmental sustainability and climate compatibility through normative and discursive change.

This paper seeks to reconcile and integrate these fields in an effort to advance both reproductive rights and environmental sustainability. It examines legislative interventions that may be required and whether there are adequate legislative frameworks conducive for the fulfilment of obligations arising from reproductive health rights. This is important because the spectrum of reproductive rights is broad and legislative interventions and frameworks may be needed to address a range of issues, such as access to reproductive health information and education, voluntary choice in marriage, family formation and determination of the number, timing and spacing of one's children; the right to have access to information and means needed to exercise voluntary choice, and health systems financing. The paper seeks to explore the potential of highlighting reproductive rights as an expedient tool for responding to the effect of unsustainable population growth and its anthropogenic impact on climate change. It interrogates the following questions; should climate change and global environmental degradation crises impact the way in which we frame reproductive rights? This paper seeks to highlight the necessary normative and discursive change that is imperative in Africa and explore family planning and climate change connections from a woman-centered and rights-based approach.

### Reproductive Health, Population Growth, and Climate Change

Population is arguably the most neglected dimension of climate change. Fast population growth places an unsustainable burden and demand on natural resources, weakens infrastructure and negatively affects the ability to adapt to the effects of climate change, especially in developing countries where the impact of climate change will be worst on poor people[7]. Population and climate change can be linked in two distinct ways, through mitigation and adaptation strategies. However, because the total human impact on the earth system is influenced by population, rapid population growth will throw up greater challenges than a sustainable population growth will. The IPCC list reproductive health among the health measures that would achieve the co-benefit of reducing emissions in addition to improving health [1]. Recent research indicates that climate change and environmental degradation threatens to undermine 50 years of progress in global health. Population dynamics has therefore become more relevant for reproductive rights policy and programming and climate change.

Rapid population growth has a negative impact on human development, provision of basic services and poverty eradication. These effects are magnified and become more urgent in the context of climate change. According to Stephenson *et al* [7].

Rapid rates of population growth in sub-Saharan Africa are impeding its ability to contain the number of people living in extreme poverty. Although there has been a significant reduction in the percentage (from 45% in 1990 to 41% in 2004), the actual number of people living in extreme poverty continues to rise (by more than 55 million) due to population growth. High population growth, fueled by high fertility, impedes progress towards achievement of the Millennium Development Goals (MDG) and sustains poverty, the central phenomenon underlying vulnerability to climate change [7].

Population, reproductive health and family planning have rarely been linked with climate

compatible development in climate policy discussions[5]. Research has however demonstrated, that promoting reproductive health, particularly those of women, in order to achieve their desire for planning pregnancies and family size would put the world on a path to slower population growth and therefore contribute to mitigation and adaptation strategies [3]. Sustainable population growth will make a significant contribution to global emissions reductions. Furthermore, research suggests that reducing unintended pregnancies would also have multiple health, education, and economic benefits for women and their households, improvements that could potentially reduce vulnerability to climate change impacts. Reproductive right and its enhancement is often negatively impacted by factors which include ignorance, cultural and religious restrictions on women's decision-making power, a lack of access to contraceptives, including contraceptive information, the general absence of accountability in healthcare delivery. Therefore, the protection and enhancement of reproductive health and improved access to family planning in countries, particularly in developing countries, can act as a pathway to environmental sustainability and a climate change adaptation tool [3].

### Policy opportunities for linking Population and Climate Compatible Development

There are policy opportunities for linking population and climate compatible development, especially because there is evidence of the connections between population, reproductive rights, family planning, and climate change. For instance, the domestication of the International Convention on the Rights of the Child, raise awareness about trends in unintended pregnancy and address unmet needs and access to family planning. Create an enabling environment for connecting these issues and advancing these policy opportunities by fostering more cross-sector dialogue and action among health, family planning, climate, and development sectors. Implement policy opportunities and programmes to ensure that universal access to family planning is part of climate compatible development strategies. Improve access to finance that is available for both climate change and family planning programmes, especially financing for family planning within climate compatible development plans.

### Conclusions

A better understanding of the interconnectedness between population dynamics and reproductive health to climate change is essential for a robust climate change mitigation and adaptation strategy, especially in developing countries.

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## Building climate resilience in Africa & Asia: lessons on membership, organization and collaboration from CARIAA on multi-consortia research programme

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During 2014–2018, the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) supported four transdisciplinary research consortia involving more than 40 institutions across 15 countries. Drawing on participant surveys, technical reports and focus group discussions, this paper identifies three sets of lessons. The first concerns partners, leadership, and relationships. Consortia bring together partners with different competencies, differing levels of capacity, and diversity related to culture, gender, age, hierarchy, professions, and expertise. The principal investigator and coordinator positions are vital and require individuals able to demonstrate leadership and dedicate sufficient time. Partners need to be accountable to each other and to leadership within a consortium. The second set of lessons concerns teamwork, management, and collaborative research. Consortia must understand what motivates partners and define each partner's role. Nested levels of management permit consortia to coordinate diverse partners across multiple countries. Consortia can create collaborative spaces through thematic working groups, additional funding for emergent subprojects, and common platforms for engaging stakeholders. The final lesson concerns transaction costs. There are benefits and costs to working in consortia. Complexity of coordinating a consortium increases with the number of partners, dispersed locations, and operating in diverse cultural settings. The CARIAA experience suggests that the size, authority and duration of the consortia contribute to research uptake and impact. Moving forward, further study of research consortia can seek to identify how much structure is required to foster collaboration, and detect when a research consortium has reached or surpassed an optimal size.

### Introduction

More than two billion people live in deltas, semi-arid lands, and glacier- and snowpack-dependent river basins in Africa and Asia, hotspot regions that are among the most vulnerable to climate change. The Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA) was a seven-year programme (2012–2019) designed around four transdisciplinary research consortia that sought to build resilience in these hotspots (figure 1). This paper draws lessons from the experience of implementing a large-scale collaborative research programme under CARIAA, to critically reflect on the initial expectations of the consortium model and inform the design of future research programmes. CARIAA defined consortia as models of collaboration bringing together multiple actors (individuals or institutions) who are otherwise independent from one another outside of the context of the collaboration, to address a common set of questions using a defined structure and governance model [3]. The programme saw consortia as “boundary-spanning” in that they form collaborations that include not only diverse disciplinary contexts, but also diverse geographic settings, identities and practices.



Figure 1. Network of CARIIA structure

## Methods

This paper draws on programme documentation, including participant surveys, as well as evaluations, working papers, and technical reports over the full lifespan of the CARIIA programme (see references). Other evidence comes from focus group discussions organised during consortia or programme-level meetings, and open ended interviews with consortium participants and IDRC programme officers, predominantly in the final year of the programme.

## Results

### Consortia increased research uptake and impact by external actors

Based on a partial sampling of activities, the summative evaluation identified that CARIIA contributed to the development of over 20 local or national plans and strategies, and to over a dozen policies in 11 countries that now are using research and credible evidence for decision making [4]. Meanwhile, programme staff compiled a list of over forty outcomes, including: piloting adaptation technologies such as flood-resistant housing, informing the Bangladesh delta plan 2100, enhancing the capacity for vulnerability and risk assessment at the district level in Botswana, identifying investments to improve climate-resilience in livestock value chains, and distinguishing the different impacts of +1.5C and +2C warming in hotspots [7]. These outcomes speak to uptake of the research results by external actors, which were enabled by consortia investing significant time in engaging various external actors.

The size, authority and duration of the consortia contributed to research uptake and impact. Consortia were obviously “large scale” in terms of research activities or diverse geography. Yet equally important was the scale in terms of the number of partners, and their standing in the communities of research and practice. Participants not only enriched consortia with their skills and expertise, but their reputations and access to diverse communities and stakeholders. For example, collectively consortia partners had ready access to villagers in remote locations as well as national officials in diverse countries. The sizable budgets and five-year duration of the



projects also helped to build and sustain relationships with external actors over time, which does not happen overnight.

### **Consortia facilitated interaction across diverse activities and teams**

Consortia enabled CARIAA to realize the benefits of interactions of disparate activities across a research portfolio. Beyond mere organisational arrangements, consortia framed overarching adaptation research and policy questions. These provided a cohesion and common logic, or “interoperability” across disparate research activities, that allowed findings to contribute towards a larger, collective mass of evidence that drew from the experience of diverse locations. Participants readily acknowledged that working in a consortium involved substantial additional burden in terms of administration and coordination. Achieving such benefits clearly involved transaction costs in managing diverse activities and facilitating communication and learning among numerous researchers. Transaction costs were significant and were largely borne by consortium leadership, particularly principal investigators in the 18 core partners, the consortium coordinator in each of the four lead organisations, and the lead researchers at the activity level. Convening and arranging consortium meetings and annual learning reviews represented additional efforts on top of an already substantial workload for the day-to-day operation of each consortium. The individuals involved in these positions report dedicating a large portion of their time to such tasks, exceeding the amount allocated in consortium budgets or provided by their home organisations.

Moving forward, this expectation could be restated to define the benefit expected to be gained, and identify who bears the related transaction costs. As mentioned earlier, the most useful aspects of working in a consortium were tied to the multi-disciplinary collaborative design, the ability to exchange perspectives and approaches across different geographical regions, and the networks established with researchers across the world.

### **Consortia managed projects through nested levels of coordination**

Nested levels of management provided the key for coordinating a diverse portfolio of research activities. Together these nested levels of coordination created a pattern of relationships akin to a scale-free network. Each node or partner had detailed information from one level down, understanding a discrete set of activities and strategic partners. These subsidiary levels also enjoyed some autonomy, while higher levels assembled the larger picture of consortium- and programme-wide progress. Yet rather than working in isolation with each activity, layers of collaboration within and across consortia created additional linkage among participants. Whilst it is important to recognise and resource the additional transaction costs, nested levels of coordination and layers of collaboration provided a structure that facilitated the consortia and programme to function. Thus practical elements of consortium design that can create opportunities for collaborative transdisciplinary research to emerge.

## **Conclusions**

This paper identifies lessons and insights from a set of four transdisciplinary research consortia as part of the Collaborative Adaptation Research Initiative in Africa and Asia (CARIAA). Each consortium included a different set of partners and field sites, a unique approach to organising its research activities, and produced a distinct combination of outputs. Some partners had worked together previously, yet all four consortia represented a new level and intensity of collaboration, which ultimately required members to negotiate roles, and design systems to manage and coordinate themselves. The programme also sought to foster collaboration around cross-consortia functions, in-country engagement, and specific research ideas that emerged during implementation aided by a dedicated budget for collaborative activities among consortia.

Drawing on participant survey, technical reports, and focus groups, the bulk of the paper delved into seven lessons.

The first three lessons are to seek diverse partners, invest in leadership and coordination, and strengthen relationships among partners. Consortia bring together diverse partners with competencies required to bridge science, geography and practice. The principal investigator and coordinator positions are vital and require individuals able to demonstrate leadership and dedicate sufficient time. PIs and coordinators need to be empowered with ready access to financial information and the ability to deal with performance issues. Partners need to be accountable to each other and to leadership within a consortium. Consortia confront different levels of capacity among its partners, as well as diversity related to culture, gender, age, hierarchy, professions, and expertise.

The next three lessons are to nurture teamwork, foster collaborative management, and enable collaborative research. Foster norms of behavior or working practices among participants, and understand and respond to various incentives that motivate different partners. Power dynamics shape various issues consortia needed to confront through careful work planning and defining each partner's role. Periodic consortium meetings or learning reviews can bring participants to build relationships, identify synergies, and to identify opportunities to pursue research impact. Having a shared knowledge management platform and regular internal communication fosters transparency and a sense of belonging among participants. Nested levels can help to manage the complexity of a consortium, providing a distinct set of responsibilities and creating some degree of autonomy for lower levels. There are advantages to providing funding directly to each partner, while also fostering a willingness to share resources across the consortium. Consider different layers of collaboration, such as thematic working groups, additional funding for emergent subprojects, and common platforms for engaging stakeholders.

The third set of lessons concern how to manage transaction costs. There are benefits and costs to working in consortia. Bigger is not necessarily better, as the complexity of coordinating a consortium increases with the number of partner organisations or participating individuals. Having partners working in dispersed locations and operating in diverse cultural settings creates difficulties for working together effectively. Consortia can manage the transaction costs of coordination by limiting the size of each level of organisation.

Revisiting programme expectations and learning questions, the CARIIA experience provides additional insights on the potential of research consortia. The size, authority and duration of the consortia contribute to research uptake and impact. Consortia facilitate interaction across a research portfolio, providing an overarching framework that enabled disparate activities to contribute towards a common agenda. Nested levels of management permit consortia to coordinate diverse partners across multiple countries. Moving forward, further study of research consortia can seek to identify how much structure is required to foster collaboration, and detect when a research consortium has reached or surpassed an optimal size.

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## Forecasts to services: building global-regional-national partnerships to strengthen seasonal forecasts and service coproduction in the Greater Horn of Africa

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The Strengthening Climate Information Services – East Africa (SCIPEA) project ran for 18-months as part of the WISER Phase 1 programme. SCIPEA focused on strengthening seasonal forecasting and its application for coproduced user services in the Greater Horn of Africa (GHA) region and four countries within the region. The underlying rationale was to bring advances through strengthened partnerships: global, regional and national generators and providers of seasonal predictions – to make enhanced use of climate-model based seasonal predictions from international centres; and between climate providers and users of forecast information to accelerate uptake and use of climate services.

The project delivered step-change increases in access to climate model-based predictions as well as in their use in preparing seasonal forecast outlooks. It implemented coproduction processes between forecast providers and users – leading to trial of three new seasonal climate services; and developed training modules on appreciation of climate model-based forecasts to aid embedding of capacity within the region's universities and training centres.

These achievements are being further advanced as part of the WISER Phase 2 Support to ICPAC Project (W2SIP). Additionally, W2SIP, in collaboration with other projects, has enhanced ICPAC's facilities for postprocessing of model forecast outputs and increased understanding of the skill of their seasonal predictions for the GHA region – both activities are leading to optimisation of seasonal forecast procedures, with downstream benefits to services for forecast users.

### Introduction and Overview

The WISER Phase 1 project SCIPEA (Strengthening Climate Information Partnerships – East Africa) grew out of discussion on research and development needs for improved resilience to climate variability held at the African Climate Conference held in Arusha in 2013 (ACC2013). SCIPEA, an 18-month project running over 2016/17, aimed to strengthen capacity for regional- and national-level climate early warning by a) improving seasonal forecasts through increased access to and use of climate model-based prediction outputs; b) facilitating engagement between providers and users of climate information as well as development and trial of co-produced climate services; and c) embedding the means for sustained in-region capacity training on model seasonal prediction systems through development of training modules designed for implementation at national and regional training centres. The project partnered with four countries in the Greater Horn of Africa (GHA): Kenya, Tanzania, Uganda and Ethiopia – with in-

region project activities coordinated by ICPAC. Key outcomes of the SC�PEA project include:

- A step-change improvement in access to seasonal forecasts from the Global Producing Centres (GPCs) of long-range forecasts and other climate data needed in the forecast process through a new (SC�PEA) data portal hosted at ICPAC, and demonstration of the benefits of using the GPC forecasts to seasonal forecast quality;
- A substantial and growing network of climate scientists across the region's National Meteorological and Hydrological Services (NMHSs) that is better equipped to process and interpret the monthly-updating forecast data streams from the GPCs and use them in production of issued forecasts;
- A set of interactive training tools and materials introducing the concepts of ensemble forecasting and the principles of generating and evaluating GPC-based probability forecasts;
- Establishment and trial of user engagement and coproduction procedures (based on Service Development Teams, SDTs) – leading to trial of 3 new climate services based on GPC outputs.

Some aspects of the SC�PEA project are being further developed as part of the wider WISER Phase 2 Support to ICPAC Project (W2SIP). Some completed activities so far include: updating of the SC�PEA data portal with 5 new GPC models from the Copernicus Climate Change Services (C3S) as well as with sub-seasonal forecast data; application of the training modules as part of a revised training strategy at ICPAC, as well as trial implementation at University of Nairobi; continued facilitation to strengthen user-engagement and coproduction in the region (led by CARE). W2SIP is collaborating closely with the GCRF SWIFT (Science for Weather Information and Forecasting Techniques) on development of enhanced ICPAC post processing of seasonal forecasts and with SHEAR-ForPAC (Towards Forecast-based Preparedness Action) on a systematic evaluation of the prediction skill of GPCs for the GHA. These activities have contributed to production and release of the first in ICPAC's long series of seasonal outlooks for the GHA to be based on objective combination of GPC postprocessed outputs (specifically for the June–September 2019 season) – in line with WMO recommendations for Regional Climate Outlook Forums.

### Further details on the three project themes

Further details are provided for the three themes referred to above.

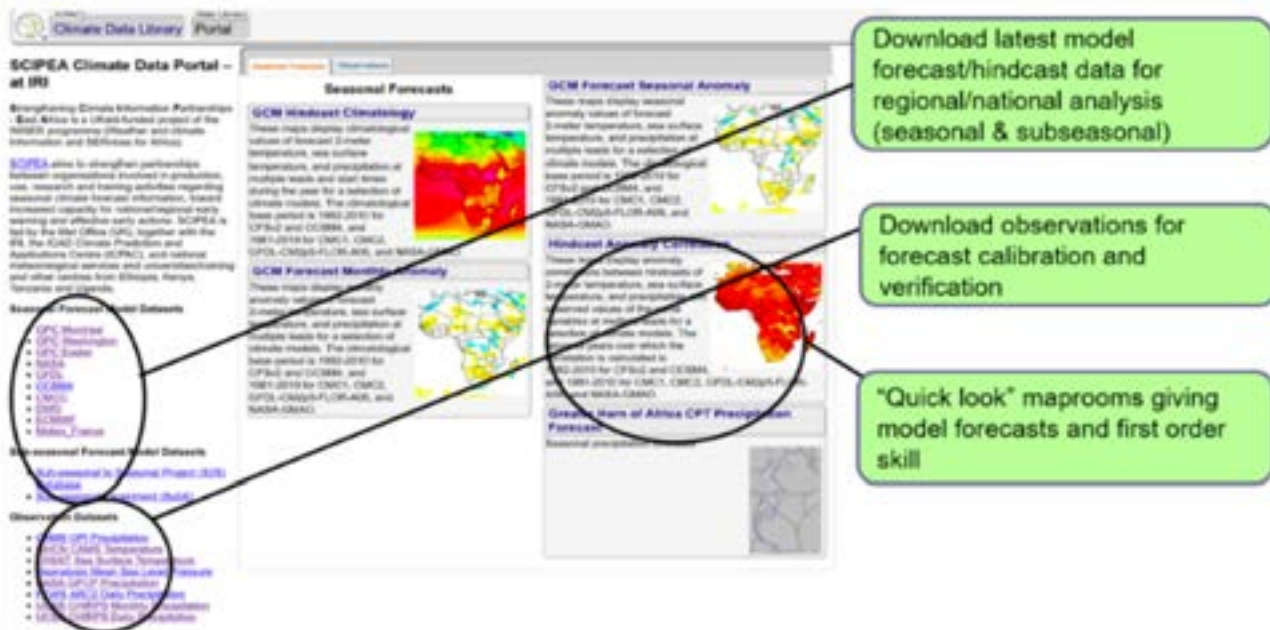
1. Strengthened access to and use of dynamical seasonal forecasts from international centres (GPCs): GPC forecasts from current state-of-the-art systems have been shown to be more skilful than the consensus approach, based primarily on statistical/empirical methodologies, that is widely used for operational seasonal forecasting in the region (e.g. [2]). Until recently, access to GPC outputs has been limited. A step-change increase in accessibility of GCM forecasts has been achieved through development of a dedicated sub-seasonal to seasonal data portal to the IRI Data Library installed at ICPAC (Figure 1). The portal is facilitating NMHSs of the region to download and process GPC outputs for guidance in preparing national seasonal climate services. The principle tool used for post-processing, forecast downscaling and tailoring in SC�PEA was the Climate Predictability Tool (CPT, developed by IRI: <https://iri.columbia.edu/our-expertise/climate/tools/cpt/>). The procedures followed are outlined in Colman et al. (2019)[1]. The data portal has reduced dependence on semi-subjective visual interpretation of online products and greatly enhanced capabilities for “in-house” user-customised product development at NMHSs using objective approaches. Associated ICPAC-led training initiatives in interpretation of GCM outputs has contributed to increased use of GCM-based information over empirical/statistical methods in operational seasonal forecasting. In W2SIP, use of GPC outputs has been further strengthened through the enhanced post-processing of GPC data at ICPAC, with facilities for

regional NMHSs to access products centrally from a new ICPAC HCP cluster.

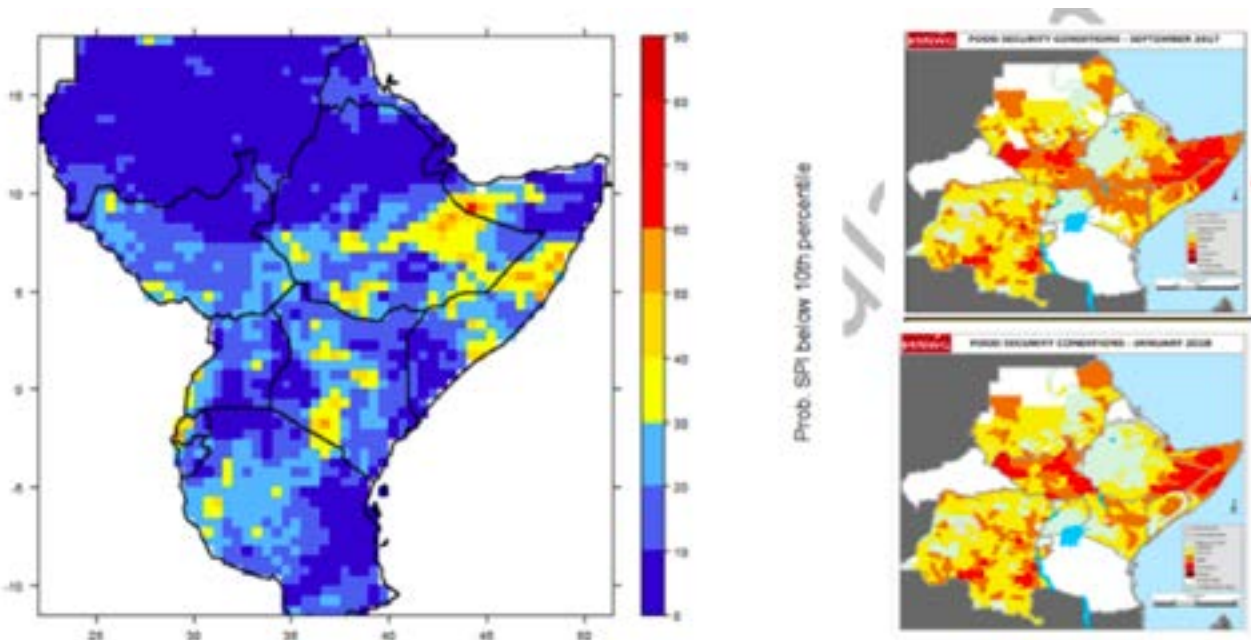
2. Coproduction of climate services: A coproduction process based on establishing dedicated climate Service Development Teams (SDTs) has been trialled and refined. The composition of the SDTs has primarily been the forecast provider and the specified user, but has also extended in some cases to other “downstream” users. An iterative procedure was employed including exploration of the user’s decision-making context, service co-design, development, trial and revision – following WMO recommended service development guidelines. Forecast products co-developed as components of services include:

- For Kenya Red Cross Society (KRCS), codeveloped with the Kenya Meteorological Department (KMD): probability of a season equal in severity or more extreme than a 1-in-5-year dry or wet event, to aid KRCS early action planning based on a developing protocol of “triggers” for action.
- For the Food Security and Nutrition Working Group (FSNWG), codeveloped with ICPAC: the predicted probability that the 10-month, March to December, Standardised Precipitation Index (SPI – a commonly employed drought index) will be more severe than a 1-in-10-year dry event (Figure 2). The product provides an indication of the cumulative impact of rainfall deficits across two consecutive seasons. Failure of consecutive seasons can trigger severe drought in the region – as in 2010/11 and 2016/17.
- For KenGen (the Kenya Electricity Generating Company), codeveloped with KMD: prediction of water inflow into the Masinga reservoir – a key component of Kenya’s Seven Forks cascade hydropower network. The prediction methodology is based on regression of GPC predictions on the observed inflow timeseries. The correlation skill of the predictions is relatively high (0.7) and the regression method provides a more physically-based approach relative to the current strategy of estimating inflow using an “analogue year”: i.e. predicted inflow in the upcoming season is estimated to be similar to that of an analogue year in which the large scale climate drivers (e.g. El Niño/La Niña, Indian Ocean Dipole) were in a similar state of evolution as in the current year.
- For the Network of Climate Journalists of the Greater Horn of Africa (NECJOGHA), codeveloped with ICPAC: A climate education and communications service is evolving. The service aims to equip media journalists with the necessary skills in basic climate science needed for effective communication of climate issues, and build capacity in effective use of media channels. The media sector is a major partner in communication of seasonal forecasts and the service seeks to facilitate increased accuracy and timeliness in reporting on national and regional forecasts. A novel element includes workshop sessions at the Greater Horn of Africa Climate Outlook Forums (GHACOFs), started at GHACOF52, in which journalists are invited to consult in depth with the climate scientists involved in the forecast preparation.





**Figure 1.** Leading forecast page of the SCIEPA portal into the IRI Data Library (<http://sciepa.icpac.net/> & <http://sciepa.iri.columbia.edu/maproom/index.html>). The left-hand column provides links to download seasonal hindcasts and forecasts from 10 GCMs from the Copernicus Climate Change Service (C3S) and the North American Multi-Model Ensemble (NMME); sub-seasonal forecasts from the NOAA SubX and WWRP-THORPEX/WCRP Subseasonal to Seasonal (S2S) projects; and gridded observational datasets of rainfall, surface temperature and SST – used for example in forecast bias correction as well as verification. The right-hand two columns provide maprooms with interactive graphics for visualising forecasts, hindcasts, model climatology, and hindcast verification as well as graphical displays of observed monthly and seasonal climatology and departures from climatology. The portal was established by IRI, with partner inputs, as part of the SCIEPA project and is being further developed within W2SIIP



**Figure 2.** Left: predicted probability that March–December 2017 accumulated rainfall will result in SPI-10 lower than a 1-in-10-year low (SPI-10 < -1.3). The baseline probability is about 10% (dark blue). The forecast, prepared in September is based on combining observed rainfall for March to August with (post-processed) GPC predicted rainfall September–December. A dedicated facility within the Climate Predictability Tool (CPT), developed by IRI, is used. Right (top): FSNWG/FEWS-NET Food Security classification in September 2017 (yellow=Stressed; orange=Crisis; red=Emergency). Right (bottom): FSNWG/FEWS-NET Food Security status classification January 2018. Forecast probabilities for September–December favoured above normal rainfall over the northern Kenya/southern Ethiopia region contributing to low forecast probabilities of a 1-in-10-year SPI low – despite rainfall deficits in March–May 2017. Above normal rainfall was observed in this region, and is likely to have contributed to alleviation of crisis conditions (compare right-hand side, top and bottom), although non-climate factors (e.g. economy- and conflict-based issues) are also important.

## Project challenges

Key challenges to progress have included those of working remotely with project partners. Climate model-based seasonal prediction is a relatively new discipline and effective partnerships between the GPCs (represented in SCIPPA by Met Office and IRI), ICPAC and NMHSs are challenging to build with solely a traditional, intermittent training workshop approach. This was anticipated, and GPC/ICPAC/NMHS interactions were enhanced through 1-month visits to IRI and the Met Office, as well as by sustained (remote) sharing of the results of GPC forecast analysis by email and an online platform (so-called “on the job” learning). However, even greater sustained interaction would have been beneficial, though funding for extended scientist exchange visits has been challenging to secure in subsequent projects.

Challenges in user-engagement and developing climate services have been similar. Building strong mutual understanding of the forecast user’s and forecast provider’s disciplines requires sustained interaction. New and important insights into the user’s decision context were invariably made at Service Development Team (SDT) meetings; likewise, SDT meetings have provided opportunities for users to absorb climate science basics and familiarise with the probabilistic expression of prediction uncertainties. However, since SDT meetings were facilitated only once or twice a year, development of mutual understanding has advanced relatively slowly. A coordinated programme to equip users with basic appreciation of climate prediction science, its strengths and challenges is needed.

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## Combating climate change in Africa by strengthening public participation: making policy count by making every voice count

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Climate change poses imminent threats to Africa, although its manifestation and severity may differ from place to place. Some mitigation and adaptation strategies developed to reduce greenhouse gas emissions and help communities build resilience failed or underperformed due to weak community participatory processes. Although public participation is gradually becoming a popular objective in decision-making in climate change adaptation, it is still often overlooked. In Africa, critical public participation gaps exist. This paper employs an integrated literature review to investigate harnessing public participation to combat climate change in Africa. We argue that climate change is a shared risk and conceptualizing climate change policies should involve appropriate, “context-specific” public participation and a Shared Strategic Climate Change Vision where everyone can claim ownership and feel a part of the process. First, the study interrogates climate policy planning and public participation interlinks by analyzing different paradigms on public participation in climate change policy setting and implementation. It then draws a nexus between public participation in decision-making processes, and outcomes of public policies on climate change. It also identifies critical vulnerable community and public

segments that must be engaged, and challenges to active public participation in climate change policy in Nigeria, Kenya and Botswana. The study reveals that poor public participation adversely affects policy outcomes, however, cities where citizens actively participate, experience better outcomes. Thus, it strongly advocates for inclusion in climate change policies. It concludes by recommending best practices, adaptable in the African context, to strengthen participatory decision-making on climate change adaptation and mitigation.

**KEY WORDS:** climate change, public participation, public policy, mitigation and adaptation strategies.

## Introduction

The concept of public participation in public policy is not a new one per se. Since the 1950s, there had been a growing movement for more involvement of local populations in the design and implementation of public policies and projects. This movement evolved from the assumption that more public participation led to better outcomes and followed a realization that the top-down approach in vogue in many countries around the world at the time had failed. Over time, public participation has been adopted for development programs by the international community, including the Food and Agriculture Organization [6], the World Bank [13], United Nations Development Programme [12], and many others. As global attention focused on combating climate change, a participatory (bottom-up) approach to climate policy has also been adopted at various international forums, including Rio Declaration's Principle 10, 1992 UNFCCC's Article 6, and UNFCCC Bonn National Adaptation Plans [11].

Public participation is still often overlooked. Records show that its absence or poor implementation is one of the factors responsible for the failure or underperformance of some climate change mitigation and adaptation strategies. In Africa, critical public participation gaps exist in climate policy process, yet, limited research has been done in this area on the continent. It is therefore the purpose of this study to intrinsically consider the concept of public participation in climate change policy in Africa as well as why public participation has remained relatively low in Africa. In subsequent parts of the study, we analyze different paradigms on public participation in climate change policy setting and implementation. Using examples from Nigeria, Kenya and Botswana and Bangladesh, the study identifies critical challenges, and draws a nexus between public participation in decision-making processes and outcomes. It concludes by proposing ways of improving public participation in climate change policy in Nigeria.

## Conceptual clarifications and theoretical frameworks

Public participation means different things to different people in different settings. But one of the key definitions that this study explores is by Arnstein (1969) where she described public participation as a holistic process of redistribution of power in which the have-nots of society, who aforesaid had been excluded from the political and economic processes, are given power to have control and influence over matters that affect their lives [2]. In terms of climate policy, public participation is empowering the have-nots to take part in how information is shared, in how goals are set and policies are arrived at, as well as in determining how benefits are shared in various mitigation and adaptation projects and programmes.

Africa is the most vulnerable continent to climate change although it is the least contributor to GHG emissions. Africa is also the least prepared to address the challenges of climate change. At risk across Africa are critical sectors like agriculture, biodiversity, health and water resources which individual African economies almost solely depend on. In terms of water crisis alone, by 2020, close to 150 million Africans would face severe water stress and displacements arising from rising sea levels [9][7]. In Nigeria alone, by 2020, a total of N15 billion (~ 2-11% of her GDP), and by 2050, N69 trillion, (~ 6-30% of its GDP), is expected to be lost annually to the combined impacts of climate change [7]. Already in sub-Saharan Africa, the loss of almost two-third of water in the

Lake Chad due to climate change is having chilling effects on populations in Chad, Cameroon, Niger and Nigeria.

One of the reasons Africa is vulnerable to climate change is the weak governance structure across its member States. Years of oppressive, suppressive, colonial, dictatorship, monarchical and military rule has eroded once vibrant indigenous community structures of leadership. This toxic mentality has, over the years, spread to various segments of public life, particularly – deep inequalities, poverty, lack of access to opportunities, healthcare facilities etc. Thus, rather than a robust public participation method where citizens voice count, policies are driven only by the politically powerful or connected, the rich and “scientific experts”. However, as climate awareness continues to grow, there has also been a growing interest to reverse this trend by encouraging more public participation in public climate policy. If climate change policies must be about inclusion, about reducing inequalities and ensuring every voice counts, then, there is a pressing need to give room for different perspectives from stakeholders, including from vulnerable communities. Although the physical manifestations of the impacts of climate change may significantly differ from place to place, everyone is at risk. Addressing the threats of climate change in a community is a shared risk where everyone has a stake. The concept of Shared Strategic Climate Change Vision has been proposed where every stakeholder sees and understands how climate change affects them, and is empowered to play their own “little bit” to help their community build resilience.

There are two main justifications for public participation: first as an inalienable right in a democracy and second, as a viable tool for improving public policies. Public participation focuses on both the actors and the processes through which mutually satisfactory communal decisions are made. Public participation is a process that carries along the entire community/public, or that involves only representatives of the community or organization in question [11].

## Methodology

This paper employed an integrated literature review to investigate harnessing public participation to combat climate change in Africa. It relied on a wide range of existing resources from government records, institutional reports, previous published works in book and journals and online materials.

## Results and discussion

Asides pinpointing and emphasizing what climate adaptation measures may matter, suit and would benefit the people the most in a given instance, public participation at local levels also creates feedback channels that escalate concerns, fears and misgivings about a climate mitigation project or climate policy process to higher authorities. This system also enhances the capacity of local authorities in ensuring that limited public resources are equitably allocated and distributed to meet existing priority needs that strengthens climate mitigation or adaptation. Thus, it prevents waste. Rather than so called political leaders or experts taking all the climate mitigation and adaptation decisions themselves, public participation enables officials to reasonably delegate authority and responsibility towards the achievement of shared goals and it also strengthens the ability of local officials to effectively engage stakeholders [5]. Public participation allows the visions of citizens to be translated into viable basis for decision-making, builds local capacity, strengthens self-reliance, minimizes the tendency to continuously depend on foreign interventions for aid and enhances sustainability. A bottom-up approach enhances the quality of assessment options and decisions, improves trust in public institutions, reduces friction amongst opposing camps, reduces implementation costs, strengthens capacity building at the grassroot, takes into confidence, the concerns of the community, allays their fears and seeks to win them over as “co-owners”.



Public participation ensures climate policy is done in a public needs-oriented way which addresses present and future needs of the public while also taking into cognizance, local realities like historical climate change contexts, local experiences, understanding and perceptions of risks, and traditional knowledge, adaptation responses and survival strategies. It improves our understanding of how the outcomes of various climate change impact assessments can be adapted into location-specific impact outlooks and livelihood adaptation practices such that mitigation and adaptation technologies can be tested and implemented in a way that elicits maximum cooperation from the public and where outcomes of test exercises can be fed back to fix loopholes, avoid wrong repetitions and enable improvement, scaling and replications of success stories.

One reoccurring question in harnessing active public participation in climate public policy processes and planning is on how to seamlessly integrate formal and informal processes and organisations as well as contrasting layers of stakeholders and groups. Birkmann et al (2010) argues that this indeed is an important question[4]. This important question, however, must be answered in the context of the project/policy at hand, type of community involved and other important parameters. Critics like Li (2006) assert that participation does not lead to locals' empowerment because participatory methodologies conceal traditional local relationships of power and fail to challenge or change the bureaucratic, centralized and administrative structures that control decision-making and resource allocation[8]. They opine that what is considered local knowledge through public participation might mask complex micropolitics of knowledge production and use in local communities and that simple participatory techniques do not address local cultures that allow one group dominate others, hindering robust public participation. Although it is true that active participation may be difficult to conceptualize or implement in community projects in developing countries, those loopholes can be addressed. Increasing public participation is not only about the willingness of authorities to delegate power or share responsibility with the public or about increasing the number of participants, workshops or town hall meetings but also about improving the quality of participation. For example, how equipped and informed are participants in climate science and related matters or how well can they communicate their opinions, particularly in places with past histories of public resistance, apathy, poverty, "illegitimate" rule, incriminations, corruption, cultural and religious bias, or overbearing dominance of certain groups[1][10].

There is evidence that public participation encourages community-based action. For example, in a project on improving adaptive capacity to climate change for sustainable livelihoods in the agriculture sector in Bangladesh, characterization of sources of livelihood of residents, profiling of vulnerable groups, assessment of past and current climate impacts; understanding of local perceptions of climate impacts, local coping capacities and existing adaptation strategies were some of the public participation tools used. Based on those findings, the project then designed and built programs that improved capacity of farmers-focused institutions while also helping farmers adapt better [3]. Already in countries like Australia and Botswana, community consultation and engagement are now included in risk assessment processes by local governments. This study further explores various examples of emerging public participation initiatives Botswana, Kenya and Nigeria and how to improve public participation in climate public policy in Africa.

## Conclusion

This study has succeeded in establishing the intricate nexus between public participation in decision-making processes and the outcomes of public policies on climate change. It also identified critical vulnerable community and public segments to be engaged. This study concludes by proposing steps to improving public participation in climate change policy setting and implementation.



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## The Story of Water in Windhoek: A Narrative Approach to Interpreting a Transdisciplinary Process

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The aim of the paper is to present a story about the 2015 to early 2017 Windhoek drought in the context of climate change while using the narrative approach. The story that is presented here is derived from the engagement of participants in a transdisciplinary, co-productive workshop, the Windhoek Learning Lab 1 (March 2017), as part of the FRACTAL Research Programme. The results show that the story starts with the 'complication' where the drought had reached crisis levels where the water demand increasingly exceeded the supply in the face of the drought. The City of Windhoek (CoW) was unable to address the problem, particularly the recharging of the Windhoek aquifer due to lack of funding. Phase 2 then shows four reactions to the drought: water conservation by water demand management; a Water Saving campaign; the Windhoek Managed Aquifer Recharge Scheme; and, the setting up of the Cabinet Technical Committee of Supply Security. The resolution of the story, Phase 4, is when the national government instructs NamWater to provide the funds for CoW to complete the recharging of the aquifer, which supplied water to the city at the last minute at the end of 2016. The final situation of the story is that ongoing collaborative work by CoW with FRACTAL on the city's burning issues is planned to integrate climate change into future decision making for the longer term.

## Introduction

This paper aims to understand the contested nature of water that is present in the narrative or 'story' of the water problems and challenges in the city of Windhoek in the context of climate change. The use of narratives to present the stories of events or issues is becoming more prevalent in urban climate research, as they provide an understanding of urban issues as a form of evidence that is accessible to practitioners and civil society [1]. Furthermore, they help to capture the range of voices necessary to understand complex problems. The story presented here is told by the participants of a transdisciplinary, co-productive workshop, the Windhoek Learning Lab 1 (14 to 15 March 2017), organised as part of the FRACTAL Research Programme. The participants of the Learning Lab (LL) were multi-scalar state and non-state actors in Windhoek, as well as academics who engaged collaboratively to co-produce knowledge about the 'burning issues' in Windhoek and to deliberate the potential pathways to address them in the context of climate change.

The paper adopts the concept of a narrative to the structure of the 'story of water'. The narrative consists of five phases: the initial situation, the complication, the reactions, the resolution, and the final situation. As the narrative of water is a situated narrative, which is in the semi-arid region of Windhoek, the focus of the narrative is on water insecurity and drought. The paper shows that the concept of the city narrative provides an intuitive framework for telling the story of water as viewed by local stakeholders, and highlights the main actors, their discourses and the technologies and decision-making processes that have taken place in this period of Windhoek's water history.

The narrative approach as presented in the literature has been predominantly applied to narratives within policies [1], while this paper aims to apply the approach to understand the 'story' that emerges from a transdisciplinary process of public engagement. The issue of water as a developmental problem was highlighted as the main "burning" issue in the city of Windhoek by participants of the LL. Since the Learning Lab 1 was held shortly after the 2015–2016 drought, the story presents the City of Windhoek's (CoW's) struggle in the context of very low rainfall, to ensure water security for the residents to survive the drought. Hence, the 'story' that is being told here is about water as a critical challenge facing the Windhoek City Council and Namibian national government with its overall mandate to provide water to Namibian citizens in the face of climate change.

## The Description of theory or method

Narrative analysis [1] (was used to analyse the WLL1 Report and the related presentations and flipcharts and reveal the sequential phases of the story using the content of the WLL1 Report. Using the five stages of the narrative (see Figure 1), the WLL1 Report is explored to provide information about each stage of the story. As part of the ethos of co-production, the paper is co-authored by a range of diverse authors from different institutions who attended the first participatory Windhoek.

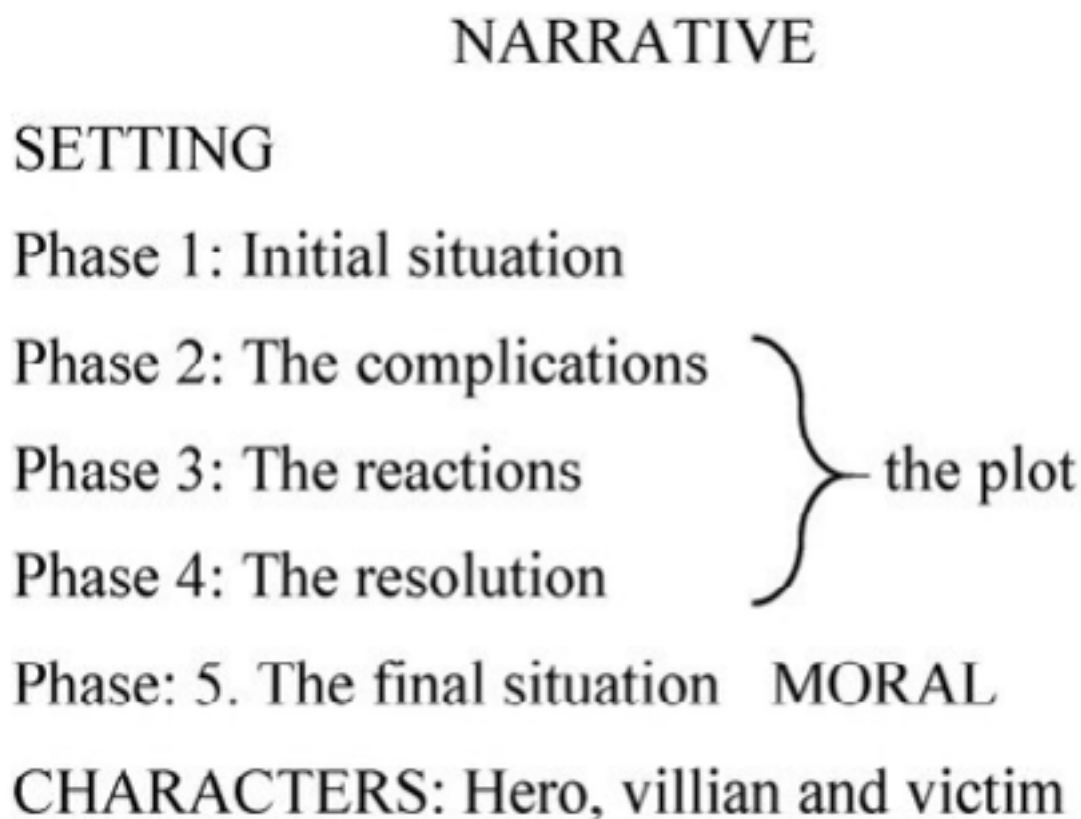


Figure 1. The sequence of phases and features of a narrative (Source: Adam, 2008)

The literature used in this paper on the narrative approach focuses on examining the narratives apparent in policy documents, but qualitative storytelling has also been used to provide insights into climate adaptation in grassroots communities. According to Slocum, the narrative provides a 'situated' story, which embeds water and its link to weather and climate change "within a relational context that may include the places people live, their histories, daily lives, cultures or values" in Windhoek. There are plans to present the 'story of water' to the City of Windhoek at a future LL, and, in this way, the story will be folded back into the transdisciplinary process for ground-truthing and providing knowledge for decision-making. The significance of the paper is that it demonstrates the value of narratives as a concept in water and climate change research in that they provide a vehicle for simplifying the complexity of the nexus between water and climate change.

It is proposed here that with increasing interest in transdisciplinarity and the co-production of knowledge between scientists and societal knowledge holders, the value of narratives is increasing. Narratives offer "increased comprehension, interest and engagement" as a form of scientific communication but have a 'bad reputation' within the natural sciences due to their qualitative format, although this is shifting [4]. The proposition here is that transdisciplinary, participatory processes do not necessarily present a linear narrative or argument and that the discussions and debates are 'messy' and incomplete. It is argued therefore that by presenting the substantive content of the deliberations as a 'story', the narrative will create a more accessible body of knowledge about the issue at hand providing a temporal framework for the deliberations of the process. The authors argue that qualitative storytelling, as presented in this paper, has the potential to offer insight into climate adaptation processes in other cities.

## Discussion and Conclusions

The research presented here contributes an additional empirical example to research using a narrative approach. The analysis shows that the major focus of the LL was the burning developmental issue of water insecurity. However, the narrative of the impact of climate change, promoted by the FRACTAL research project was a minor, albeit an urgent focus, which was threaded through the workshop emerging as central in the questions posed by the local participants at the end of the LL. Since the 1st Learning Lab was the start of the FRACTAL/CoW/UNAM engagements and activities to provide climate information for decision-making, it was an open-ended workshop, concluding with the research questions that this FRACTAL consortium might pursue together. The questions suggested by local partners demonstrated that participants were receptive to the notion that climate information is a critical component of urban developmental decision-making.

The setting for the story was the dire situation of the City of Windhoek, situated in a semi-arid region and experiencing a drought from 2015 to early 2017. The story of the drought has a clear plot, that of the urgency of the drought and its potential impacts on the residents and economy of Namibia's capital city, and how national and local state engaged to put in place a range of reactions to ensure water security for the city. The plot concludes with the resolution of the drought crisis by the MAWF, which instructed NamWater to finance the CoW aquifer recharge scheme and provide water security at the last moment just before the water supply dried up. The process of the Windhoek LL provided a platform for different stakeholders to share their knowledge and experience about an issue of common interest. It became apparent during discussions at the LL that participants were not only involved professionally in the issues of water and climate change based on their expertise and experience, but these issues helped to highlight what they all were personally involved the issue of water shortage in their everyday lives, namely, due to drought.

Residents in informal settlements were identified as the major victim of the water problem. The participants decided that in addition to a lack of water supply for the city as a burning issue, the lack of services, particularly water, in the informal settlements was an equally important burning issue. The CoW is portrayed as the hero of the narrative as much of the story tells of the efforts of the municipality to respond and adapt to the drought. The governance of water is multi-scalar and necessitates the actions and co-operation of national and local actors. So, to some extent, the national government also appears as a hero towards the end of the drought. At the same time, there is a recurring discourse of co-operation throughout the story as the MAWF, NamWater, and CoW can also be viewed as heroes for co-operating to provide measures for effective use of water, reduction of wastage and provision of unconventional water sources. However, there was some reference to the national government as the villain for not being forthcoming until the last moment of the drought with the funding necessary funding to secure the Aquifer Recharge Scheme, despite many requests from CoW. This serves to cast the MAWF as both a hero and a villain in this case. The narrative therefore provides a way of understanding the drought issue as a contradictory process with the various actors playing overlapping roles in the story.

The phases of the story from 2015 to early 2017 show the build up to the drought with the decrease in rainfall over two years, the conditions it was giving rise to and the complication of CoW getting adequate funding for alternative sources of water (aquifer recharge scheme) for Windhoek. Part of the plot included the range of reactions of local and national government to the critical drought conditions, with several potential solutions that were deliberated and could still be implemented. The plot ends with national government funding the recharge of the aquifer as a longer-term source of alternative water, completed just before the drought was broken by rain in early 2017.

The main learnings from this paper are twofold. The first is that what we have found confirms literature that reports that decentralization is weak in southern African cities with national governments retaining decision-making power and resources in relation to water and energy. However, the evidence shows that the CoW has been proactive and innovative in its approach to securing non-conventional water sources, despite the lack of response of the national government to its repeated requests for financial support. The second lesson is that the application of the narrative approach to a participatory process provides a lens to make clear the actors who were involved in the process and the events that occurred during the crisis of the drought. This provides both important and accessible information about the issues of water and climate for decision-makers in a simplified and intuitively understandable form. This, in turn, demonstrates the value of collaboration that is engendered through participatory processes of co-production.

However, the narrative approach drawing on knowledge that has been co-produced in participatory processes is not without its challenges. Collaborative processes of co-production are very time and resource consuming. Because of the need to get academics, who in a consortium such as FRACTAL come from distant locations, civil society and municipal officials together at a dedicated location and time, a large amount of resources is necessary for travel, administration and accommodation. However, besides this more logistical challenge, it is very important to manage and reveal the underlying power relations among participants. The workshops are facilitated on the principle that all participants are equal and should be respected; and that their knowledge is equally valuable. Participant observation showed powerful actors steering the debate and dominating discussions on occasions, hence influencing the storyline of the narrative. This is a critical challenge and it is suggested that future work should focus on examining the contribution of diverse knowledge and how the consensus narrative is negotiated among participants. This challenge also calls for a revisiting of the design and content of participatory, collaborative workshops to more successfully 'equal the playing fields' among actors. It needs to be ensured that co-production be more of a disruptive process, to shift the dominant and business-as-usual technical approaches to water and climate change to consider issues of social justice in the impacts of climate risk and water insecurity. It is proposed that the receptivity of participants to the 'story of water in Windhoek' when presented at a future Learning Lab will surely raise awareness about the 'story' that is contained in a policy-making process.

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## Climate-Informed Decision Making in Data-Poor Environments: Enhancing Climate Risk Management Through Knowledge Co-Producing Networks in Africa.

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Climate change impacts have become a verifiable reality in most communities in Africa and has already demonstrated potential to derail current efforts towards sustainable development. Climate change, therefore, threatens sustainable development processes in Africa's different communities. While evidence of climate change impacts, especially in agricultural practice continues, it has also become worryingly evident that most people living and acting in their different places have no knowledge or capacity to respond to such impacts proactively and appropriately. This is partly because climate information services have not been prioritized in Africa's climate governance regime. Most of Africa has what this paper describes as a 'data-poor' culture which, subsequently, has contributed to the creation of a climate-information knowledge and adaptation learning deficit. This work focuses on smallholder agricultural practices in Ghana. It examined how formal and non-formal peer-learning mechanisms could facilitate climate risk knowledge development and information diffusion among farmers at the local level in Africa. In the process, the paper also looked at the role of citizen science—indigenous knowledge systems—in the management of climate risk at the local community levels. The result is that when conscious processes are initiated, innovative knowledge co-producing mechanisms emerge to bring science and traditional knowledge into convergence.

### Introduction

Impacts of climate change have become pervasive and verifiably evident in many local communities in Africa and presents significant challenges to people, communities and institutions. Nowhere is the threat and challenges more acute than in Africa where most countries and their communities are struggling with chronic poverty and persistent vulnerabilities [3]. From food production, water resources, health systems and livelihoods, climate change impacts do not only portend to disrupt sustainable development processes, but have already proven pernicious in disrupting normalcy in their functionality.

These disruptions are widespread and ongoing and are projected to be exacerbated as climatic changes continue. The risks of these ongoing changes to sustainable development processes in Africa are real they threaten to derail modest gains made and particularly in the agricultural sector [2][8]. Climate change impacts are also likely to undermine socio-economic processes and environmental sustainability to deepen conditions of poverty and vulnerability. While current manifestations of climate change impacts and related risks continue in many parts of Africa, it is also becoming a matter of great concern that not many people, especially rural farmers, living in their different places know, understand or have the requisite capacity to respond to accordingly and timeously to climate change impacts.

This paper foregrounds climate risk knowledge development in local communities in Africa. The paper frames climate change risk knowledge as a learning issue and problematizes the lack of dependable and accessible climate information services delivery mechanisms in Africa as a barrier to effective climate risk management and ultimately to adaptation. Focusing specifically on Ghana, the paper explores how local community-based climate knowledge and learning networks might facilitate collaborative social learning for climate risk management, as well as build the capacity of local people and institutions to respond proactively and accordingly to both current and anticipated future climate risks.

The paper, therefore, begins with a discussion on the general lack of data and climate information services in most African communities and to explore how this omission impedes effective management of climate risk and in that regard adaptation. Poor data management and the lack thereof of readily accessible climate information in most of Africa is what this paper describes here as 'climate risk knowledge gap with attendant adaptation learning deficits'. It is the view of this paper that poor attitudes and approaches towards climate data and information services have had and continue to have significant ramifications for adaptive capacity building, especially in the agricultural sector and of farmers. The paper, therefore, examines community-based knowledge co-producing mechanisms as an avenue to establish how citizen science and social anticipatory learning processes could enhance climate-informed decision-making in data-poor environments.

### Africa as a Data-Poor Environment

Data poverty is an existential reality of many African countries and affects climate risk management and decision-making processes. The lack of data implies a lack of information which could serve as the requisite knowledge base for adaptive learning and actions [6]. The lack of climate data to support decision-making in diverse sectors has had consequential impacts on adaptation processes in many sectors, but most especially in the agricultural sectors. Adaptation processes, for the most part, have been slow or none at all in many sectors as decision-making processes to live and act in an era of climate and environmental changes are devoid of climate change considerations [5].

This, as it is currently evident in most of Africa, is partly because most countries and their communities lack the institutional capacity, as well as commitment to develop the requisite infrastructural base to support the creation of a data-driven culture to inform development processes [4]. In particular, the lack of well-packaged and readily-accessible climate data or information to serve as the requisite knowledge base to inform efforts to manage climate change risks threaten sustainable development processes.

It is worrying that even at a time of improved weather forecasting and better understanding of climate change and socio-ecological systems change dynamics, most countries in Africa remain noncommittal to recognizing the critical importance of climate services and to give it the needed attention. As stipulated at the launch of the Global Framework for Climate Services (GFCS) by delegates of 155 nations in 2009 to use climate services to support climate risk management in areas such as agriculture, disaster risk reduction, health, water management, energy and a variety of other vulnerable and climate risk-prone sectors, many African countries lack capacity "to strengthen the production, availability, delivery and application of science-based climate prediction services". They lack the capacity to observe and create the requisite weather or climate data services to inform decision-making processes to address climate change risk.

### Climate Risk Knowledge Gap

The absence of readily available and usable climate information in local communities has created a knowledge gap in community-based climate risk management. Most people living in their places and facing diverse climate change risk lack the requisite scientific information to support their actions and inactions [5]. This is especially the case in the agricultural sector where poor and vulnerable farmers rely on traditional knowledge systems or what is now known as 'citizen science' [9]. The lack of data and science-based knowledge has also created a tendency for the over-reliance on so-perceived blue-print or ready-made adaptation solutions. Such solutions, for the most part, ignore locally-relevant climate information services and context-dependent particularities that require specific adaptive responses.

Such tendencies, as have increasingly become prevalent, are based on flawed understandings and assumptions of climate change impacts and a situation which has resulted in the rarefication of the adoption and application of generic adaptive solutions that ignore locally-specific particularities and context-dependent socio-ecological conditions.

The reality, therefore, is that most Africa countries are data-poor; they lack the relevant and requisite scientific data that should necessarily inform climate-risk decision making processes in all sectors and contexts. This omission has become seemingly entrenched and one that has, and continue to define current attitudes and approaches to climate-risk management risk [1]. The culture of data-poverty is a knowledge problem and, ultimately issue which requires conscious processes of knowledge development and learning to build capacity, especially at the local community level to address issues around climate-risk.

The challenge now is how to build climate-informed adaptive capacity in a data-poor environment. It is a widespread challenge across Africa, but largely taken for granted. Even though most farmers have come to terms with the reality of climate change and its implications for their farm practices and livelihoods, they still lack the ability to respond to impacts coherently and appropriately. This has a direct bearing on levels of adaptive capacity and also the ability of people and communities to manage climate change risk [10]. It is also what this paper sees as a knowledge deficit and a learning affair which must be addressed through climate-risk knowledge co-producing networks in local communities.

### Knowledge Co-Producing Networks

Producing knowledge for climate services requires commitment from government and at the policy level and also the engagement of various stakeholders at different levels. However, it is a widely known fact that most African governments have given little attention to climate adaptation issues in local communities and more so in the collection and utilization of climate information. The current climate governance regime in most of Africa has, however, not been particularly engaging and has in the process left out significant constituents who as a result have lack the requisite knowledge to address climate change impacts in their different sectors.

This is particularly the case in the agricultural sector where farmers lack adaptive capacity due to the lack of access to readily-available climate information services. Agriculture as one of the primary livelihood sources for most farmers in Africa is highly exposed to weather and climate risks. Farmers rely mostly on traditional knowledge systems and other coping mechanisms [7]. Even though governments have attempted to minimize climate impacts in the agricultural sector through programmatic responses, such as irrigation infrastructure for water storage, precision of accessible and climate information to farmers at the local farm level has remained problematic.

Building on the concern over the fragmented nature of climate change adaptation governance across Africa and also the lack of climate information services, this work explored place-based or community-based approaches to knowledge co-producing climate change knowledge mechanisms to building citizens' capacity to address climate risk and to make decisions on adaptation in selected farming communities in Ghana. With a particular interest in smallholder farming, the paper examined the application and utilization of citizen's science in weather forecasting, as well as to address emergent changes in farm practices. In particular, the paper looks at how formal and informal peer learning and information diffusion networks among farmers enhance the co-production of climate knowledge and adaptive learning responses.

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## ISlpedia, the open-access climate-impacts encyclopedia: The contribution of stakeholder-scientist-dialogue to the development of user-friendly climate services

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ISlpedia is a project that aims at developing a user-friendly online “encyclopedia” for observed and projected information on the impacts of climate change, based on data and scientific knowledge generated within the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP, [www.isimip.org](http://www.isimip.org)) that covers a wide range of sectors (agriculture, freshwater systems, energy, health, etc.). Launched in September 2017, the first half of the project had a strong focus on stakeholder engagement in order to ensure that the platform fulfils the needs of various stakeholder (user) groups, such as government officials, representatives of international organisations, consultants, private company employees, and NGO workers. This included a widely distributed stakeholder survey that helped define and shape the content and design of the future ISlpedia platform. The outcomes of the survey and the responses from the ISIMIP modelling community can be found [online](#).

Furthermore, two climate-impact indicator development workshops were organized, and brought together stakeholders and climate impact modellers in Eastern Europe (Krakow, Poland, December 2018, just before COP24 in Katowice) and in West Africa (in Ouagadougou, Burkina Faso, February 2019) – the two focus regions of ISlpedia. The outcomes of the workshops contributed additionally to the development of the ISlpedia portal, of which the beta-version will go online in summer 2019. The results of the stakeholder engagement process in building a user-friendly platform will be shared in this oral presentation with concrete examples. In addition,

participants will have the chance to give feedback on the beta-version for further improvement of the portal.

### Extended abstract

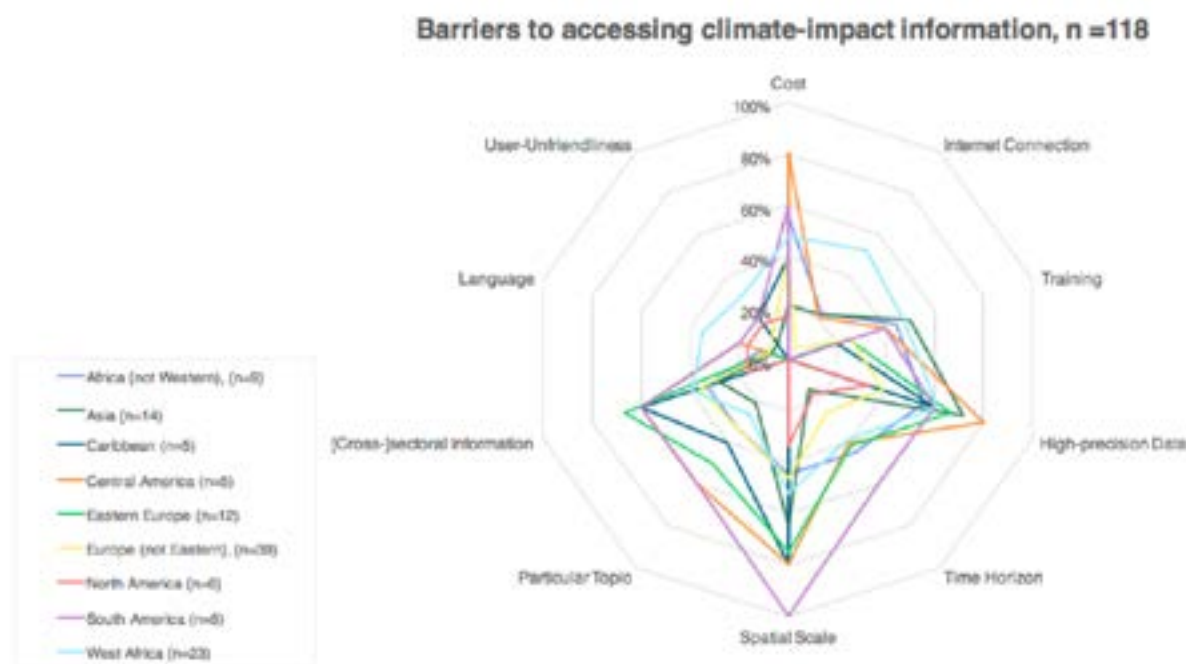
The ISIpedia project aims at developing a user-friendly online “encyclopedia” for observed and projected information on the impacts of climate change, based on data and scientific knowledge generated within the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP, [www.isimip.org](http://www.isimip.org)), which covers a wide range of sectors (agriculture, freshwater systems, energy, health, etc). Launched in September 2017, the first half of the project had a strong focus on stakeholder engagement, ensuring that the platform fulfils the needs of various stakeholder (user) groups, such as government officials, representatives of international organisations, consultants, private company employees, and NGO workers. The session “ISIpedia, the open-access climate-impacts encyclopedia: The contribution of stakeholder-scientist-dialogue to the development of user-friendly climate services” will share ISIpedia’s stakeholder engagement process through which a new portal on climate-impacts information relevant and accessible to various user groups was created and introduce the newly available beta-version of ISIpedia.

The Stakeholder Engagement Team at Climate Analytics has been working with different stakeholder groups for the past two years to gather input on the needs related to the ISIpedia climate-impacts information portal. In addition to an extensive stakeholder mapping and a kick-off workshop where ideas for a portal were initially discussed and the scope of the stakeholder engagement process was defined, a survey was conducted to gather input on expectations and needs regarding content and design. Two indicator development workshops in the two focus regions, Eastern Europe and West Africa, were organised to further consolidate the content of the portal and foster the stakeholder and climate-impacts modeler dialogue. The key challenges and findings are also included in this oral presentation. Additionally, the beta version that will be online as of summer 2019 will be presented briefly to demonstrate the integration of stakeholder input into the design and content presentation of the portal.

The ISIpedia survey collected 131 usable answers from 27 questions, which guided the development of the ISIpedia portal. The respondents were from various regions in the world, with a big share from Europe due to the existing networks of project partners and a strong presence of people from the focus regions of the project – 19.3% from West Africa and 10% from Eastern Europe. Key topics covered in the survey included the scope of work where climate impact information is needed, the existing barriers to use climate impact information, the needs for further modelling focus areas, and the request for feedback on different optional features for the website.

The key findings from the survey provided a better overview of the barriers and the preferred features of the portal and signaled the importance of open data access. Barriers varied across different organization types and geographical locations. Certain barriers, like the internet connection only affects specific regions, such as West Africa, while others, such as the lack of high precision data or spatial scale, poses a barrier to many stakeholders (see Figure 1).





**Figure 1.** Topics presenting the barriers for the survey respondents (nregion=118), by region where the respondents are based.

Even though almost all participants were in favor of any optional features to some degree, some were rated more important than others, particularly like the option to compare and to access full data. Raw data was rated useful mostly by modelers, whereas the data behind graphs was of high interest to all stakeholders. These barriers and needs of stakeholders have been taken into consideration when designing the website. Further details can be found in the report, including the outcomes of the survey and the responses from the ISIMIP modelling community.

The indicator development workshops took place in Krakow, Poland in November 2018, with 14 stakeholders (from 10 countries) and 4 modelers and in Ouagadougou, Burkina Faso in February 2019 with 41 stakeholders (from 15 countries) and 4 modelers. Both workshops followed a similar structure that consisted of common vocabulary building session, modeler-led review of existing indicators and indicator frameworks, the “From needs to indicators” discussion (which was the main interactive session dedicated to developing indicators addressing the needs for climate-impact information of the participating stakeholders), and participant presentations.

Key findings included the importance of a two-way dialogue and capacity building. Facilitating the environment where scientists/modelers understand what the needs of stakeholders are and how the scientific findings are being understood by stakeholders was as important as informing stakeholders of what climate impacts are and how they can use the future ISlpedia portal. The common understanding was built through participants assessing the current indicators and brainstorming potential new indicators to be included in the portal. The workshops resulted in several new climate impact indicators for the energy, biodiversity, forests, and health sectors, which will be assessed by different modeling groups to be included in the ISlpedia portal. Additionally, there was a strong interest in gender issues and gender-related indicators. Another valuable outcome of the workshop was the necessity to build a common vocabulary to ensure that modelers and stakeholders actually speak the same language. The workshop also surfaced more challenging issues, such as the lack of local level detail, which was further discussed within the ISIMIP modeling community. Further details on the outcomes of the workshop can be found in this report.

The two examples of stakeholder engagement process show that it is essential to involve stakeholders throughout the entire process when developing a climate service that is sustainable and relevant for future users. During this presentation, further feedback on the beta version of the ISIpedia portal will be collected from the audience as an extension of this process. To get a first glimpse of the website, see Figure 2.



Figure 2. First look of ISIpedia website.

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## THEMATIC AREA 6

### Information distillation and communication

Information distillation relates to the process of constructing climate information within a broader co-production context. In contrast to the co-production theme, this theme focuses directly on how science engages with the broader context and process. Particular issues that fall under distillation are: determining the underlying problem and question framing and how this impacts choices around data, models, methods, and communication; identifying and determining assumptions and their consequences for the resultant information, communication, and uptake; dealing with contradictions and disagreements within disciplines (e.g. datasets, models, method), between disciplines, and between disciplines and practice/experience; involving other disciplines and practitioners in the distillation process; and transparency of the process and resultant communication methods.



## LIST OF PRESENTERS AND TITLES OF PRESENTATIONS

**Tufa Dinku**

**ENACTS: Transforming Climate Services in Africa**

**Hassana Gambo**

**Influential Mediums: An Effective Tool For A Nigerian Narrative Of Climate Change.**

**Amy Pieterse**

**Communicating dense scientific evidence: The Green Book experience**

## ENACTS: Transforming Climate Services in Africa

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Effective management of climate variability and change requires that climate information be used in planning and that climate knowledge and risk associated to it be incorporated routinely into development decisions. As a result, availability of and access to climate data and information products is critical to achieving climate resilient development. Unfortunately, climate information is not widely used in Africa, and many other parts of the world, to make development decisions. This is mainly because useful information is often not available or, if it does exist, is inaccessible to those that need it most. The ENACTS (Enhancing National Climate Services) approach strives to overcome these challenges by delivering robust climate data, targeted information products and training specifically relevant to the needs of decision makers at multiple levels. It empowers diverse range of actors to use past, present and future climate information. ENACTS has so far been implemented in 15 countries and at two Regional Climate Centers.

## Introduction

Almost all development sector requires climate data and information system. The use of climate data for research and applications in Africa has been scanty because availability of and access to climate data is very limited. In many parts of Africa, weather stations are sparse and their number has been declining. Besides, the distribution of existing stations is uneven, with most located along major roads. Where data exist, they are often of poor quality with many gaps. Thus, useful climate information is often not available or, if it does exist, is inaccessible to those that need it most. There are different efforts underway to overcome these challenges. One of these efforts is the ENACTS (Enhancing National Climate Services) initiative (<https://iri.columbia.edu/resources/enacts/>) lead by the International Research Institute for Climate and Society (IRI) at Colombia University [1][2]. This initiative works with National Meteorological Services (NMS) in order to improve the availability and quality of climate data as well as access to and used of climate information products. The engagement with the NMS is critical to this approach as NMHS are the nationally mandated organizations for the creation, management and dissemination of meteorological observation and are the custodians of the historical records.



The ENACTS approach enhances the use of earth observations and geospatial technologies for sustainable development through local policy and practice engagement at the country level and through the blending of the best available national and global climate and environmental products needed for climate resilient decision-making in key development sectors. It enables NMS to generate and delivers targeted climate information products relevant to the needs of decision makers at multiple levels. ENACTS has so far been implemented in 13 countries and at two Regional Climate Centers in Africa and two countries in Asia and South America.

### The ENACTS approach

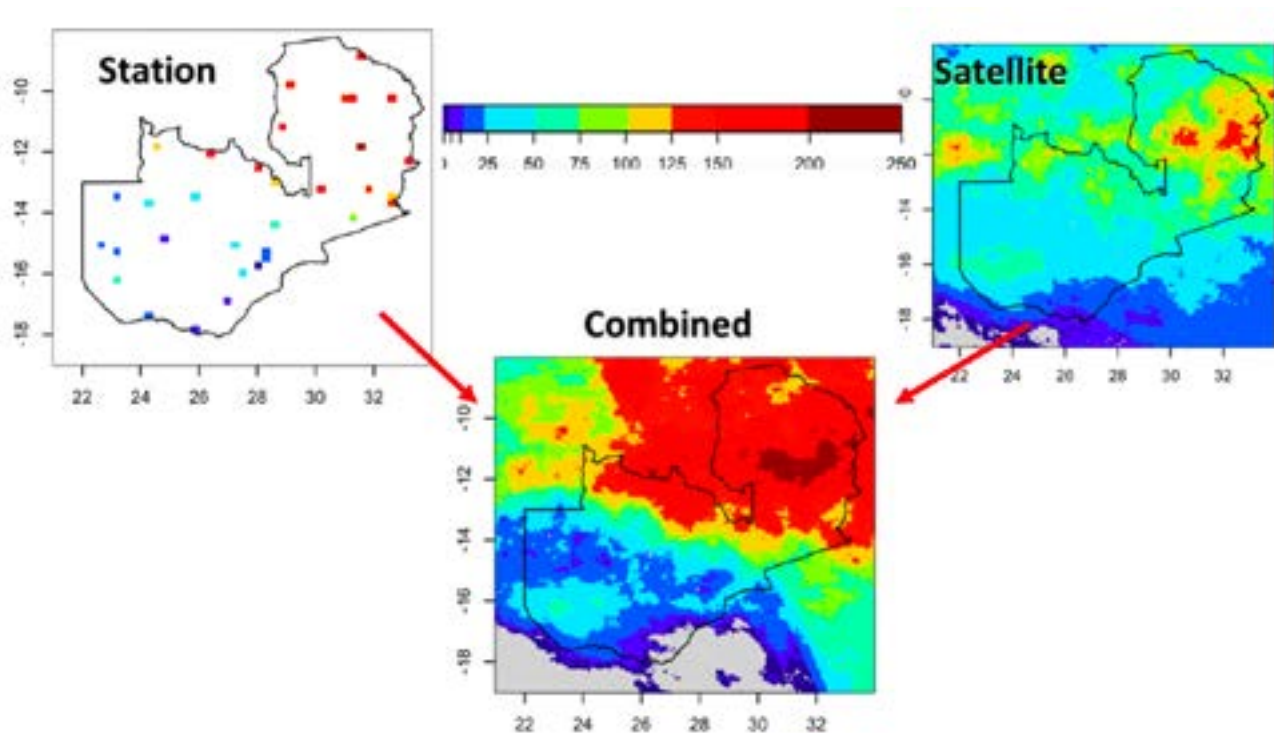
The goal of ENACTS is to transform how decision makers take climate sensitive decisions at the local, regional, and national levels. This is done by improving the availability of timely, relevant, high-quality climate information at relevant spatial and temporal scales, and working to promote the effective use of this data [1].

This goal is accomplished through the three ENACTS objectives:

- i. Improve the availability and quality of climate data and information products at the local, national, and regional levels.
- ii. Enhance access to climate data, information products, and services relevant to the needs of the public, national and local practitioners in climate sensitive sectors, policy makers, the private sector, and researchers.
- iii. Promote the widespread use of climate information and services by pursuing effective stakeholder engagement and unleashing pent up demand for climate information.

### Generating Climate Datasets

Availability of climate data is improved by the process that involves quality-control of data from the national observation network, and then combining the quality-controlled station data with satellite estimates for rainfall, and digital elevation models and reanalysis products for temperature. The main advantages of the satellite and climate model reanalysis products are that they: (i) offer spatially complete data; (ii) are freely available; (iii) have relatively long time series (over 30-years for satellite rainfall products and over 50 years for reanalysis products). However, these products are not as accurate as the station observations. Therefore, station observations are used to evaluate and correct the error bias in the spatially complete products, which in turn are used to fill spatial and temporal gaps in station observations [3]. The approach thus combines the spatial information from the proxies with the accuracy from point station measurements (Figure 1). The final products are datasets with over 35 years of rainfall and temperature time series for every 4km grid across each country. The quality of these new national products greatly exceeds global products which rely on the limited ground-based observations made available through WMO's Global Telecommunication System.



**Figure 1.** Station observations (top left) from the operational network in Zambia are combined with satellite rainfall estimates (top right) to produce a spatially complete and more accurate product (bottom).

### Enhance access to climate data, information products

The ENACTS approach enhances access to climate information products by making information products available online. This is accomplished by customizing and installing the very powerful IRI Data Library(<http://iridl.ldeo.columbia.edu/>) at the National Meteorological Agencies and developing an online mapping service(maprooms) that provides user-friendly tools for the analysis, visualization, and download of climate information products (Figure 2). Users can access location-specific products for any selected grid cell or administrative boundary.

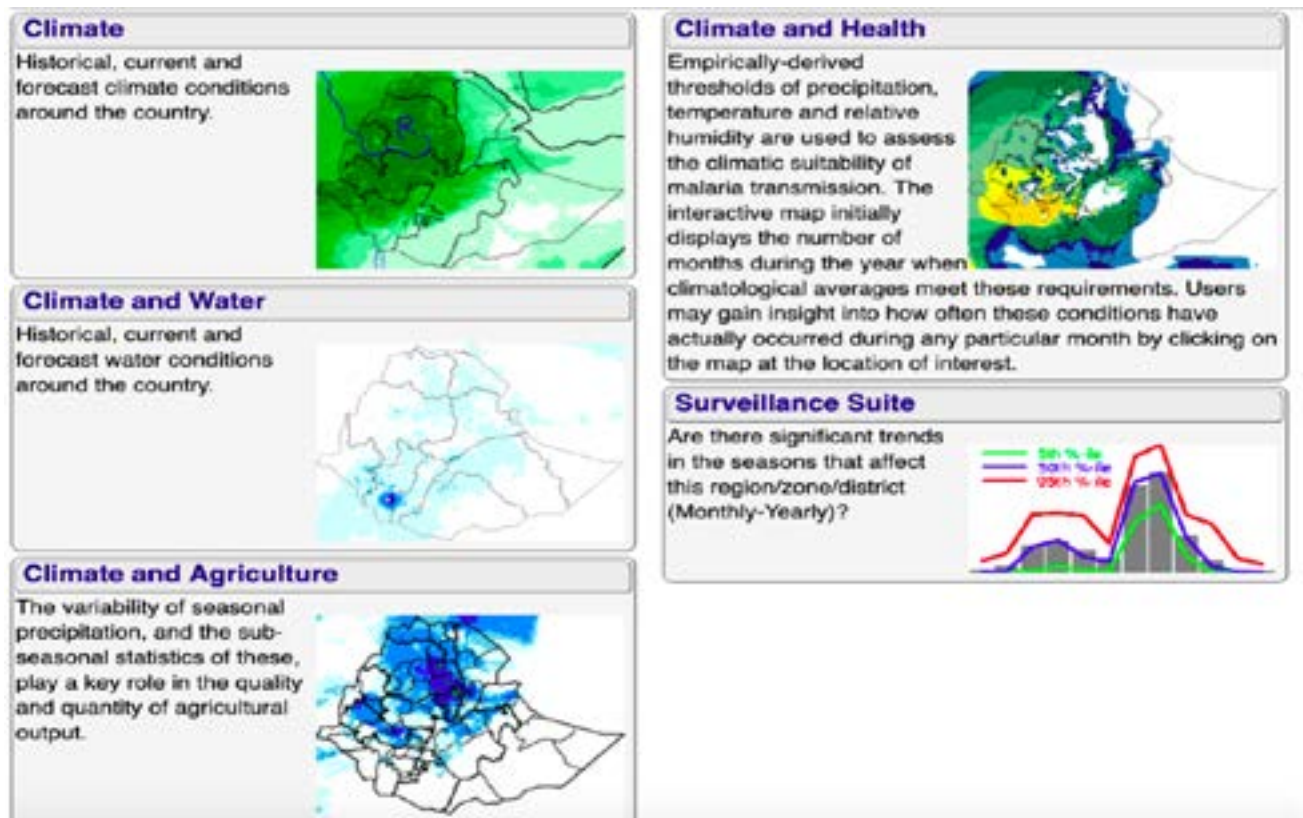


Figure 2. ENACTS maproom for Ethiopia (<http://213.55.84.78:8082/maproom/>)

### Promote the widespread use of climate information

While generating climate information products and making them available online makes it easier for people to access climate information, it does not necessarily lead to uptake. Users need to be made aware of these products, their value and their use. This requires training and hands-on experience as well as an effort to include users in the refinement of existing products and development of additional ones. ENACTS promotes the use of climate information by facilitating this engagement and collaborating with users to maintain constant dialogue and iterative interactions with different user groups.

### Conclusion

ENACTS has proven to be a feasible and cost-effective approach to building the capacity of National Meteorological Services to overcome constraints to providing climate services that are relevant to the local scale of different decision-making at national and sub-national scales. Over a dozen countries in Africa and two countries in Asia and South America are now able a range of online climate products that has transformed climate services in those countries. There is growing interest in expanding the ENACTS approaches to more countries in Africa, Asia and South America. It should be notes that ENACTS is a process, not a product or a project. As a result, it has been evolving over time, and will continue to evolve.

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## Influential mediums: an effective tool for a Nigerian narrative of climate change.

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African nations such as Nigeria, are faced with major setbacks in their struggle at industrialization and agricultural advancements, due to the effect of climate change. The challenges of climate change effects everyone and can only be mitigated through the effort of everyone. This paper enumerates the impact of using public influencers as a medium towards changing the narrative of climate change for easier acceptance and adaptation by grassroots Nigerians. Meanwhile, influencers are those mediums and individuals that have the ability and skills to influence the thoughts and action of a large volume of people, such as media professionals, traditional and religious leaders. This paper shall use primary and secondary sources to enumerate the impact of using popular influential mediums to enumerate the challenges of climate change, reflecting its effect to agricultural, economic and social development. The article pays a cursory look at the effective ways the vast majority of the population can embrace the situation of the challenges of climate change. Towards igniting new possibilities in adaptive and preventive measures that reflects the realities of Nigerian lifestyle.

**KEY WORDS:** Climate change, Influencers, Grassroots, African lifestyles, Communication, Media.

### Introduction

The impact of global warming as one of the biggest universal challenge is proven to have a devastating effect on African nations. The impact of climate change will affect the pace and impact of development initiatives of most African nations. The underlying challenges of hunger, diseases and corruption will be further aggravated with the emergence of the effects of climate change.

In Nigeria, the most vulnerable regions are the desert prone Northern states and the coastal regions of the South eastern states. Climate change will directly affect major economic and social sectors of the nation such as agriculture, food security, water resources and public health. Meanwhile the vulnerable grassroots Nigerians, constituting over 53% of the population, are ill equipped to protect themselves from the eventualities of climate change or partake in measures that can mitigate the situation.

The grassroots of Nigeria can be considered as those living below the global approved poverty line, which is \$1.90 (approximately N700) daily living capacity. This constitutes people residing in rural areas or shanty areas in cities, where there is limitation of good health services, decent shelter, quality education, employment and nourishing food.

The Nigerian government, departments, private organisations, NGOs and pressure groups are actively involved in providing the required structure towards providing adaptation and mitigation measures. There have been initiatives such as afforestation programs and establishment of tactical groups such as the National Climate Change Policy and Response Strategy (NCCPRS). The primary medium of communication, for public awareness and involvement are expert

led workshops/seminars, campaigns and media exposure on newspaper, T.V, Radio and documentaries. One of the major barriers for adaptation in response to climate change in Nigeria include insufficient knowledge and skills to adopt a sustainable alternative. Indigenous people, particularly farmers are fairly conversant with basic facts on climate change, yet the information and communication gap on the implication of their lifestyle to the prevailing situation is wide.

The involvement of the Nigerian grassroots in the implementation of lifestyle changes towards mitigating and adapting to Climate Change is essential. The communication gaps and mediums have to be modified to reflect their realities and abilities. From research conducted between two cities in United States of America, it was evident that people tend to resist behavioral change based on the belief that the person's behavior will make minimal difference or the lack of time and money to adopt a new behavior.

Organisations such as Regional Centres of Expertise-Minna (RCE) have been involved in extensive climate change and environmental awareness programs for over 8 years in Nigeria. These programs involved expert based awareness programs such as lectures, seminars or campaigns in Niger State, Kano State and FCT Abuja. RCE-Minna is strategically positioned to provide education on sustainability, adopting the bottom-up approach for educating and creating awareness, which is a direct means of connecting with the most vulnerable and least represented people. The diverse platforms and mode of outreach for years has shown a distinct pattern in the response of the public towards emerging issues. The participation and involvement of influential persons in recent activities of the organization, clearly indicated an upsurge in general involvement towards Climate Change, as against the usual abysmal attitude and slow rise in participant attendance or involvement.

Therefore, this paper examines the effect of using influential tools or persons that have a strong followership for climate change awareness against the Expert based technique practiced by RCE-Minna in Nigeria.

### Communication for climate change

One of the popular means of communicating climate change and its effect to society is through the media. The initiatives of government either through campaigns, enacting policies or establishing schemes usually requires the publicity from the media through T.V radio programs or newspaper articles. This is primarily targeting the public, particularly those involved with activities that propel the situation or those that are most vulnerable to the effect of climate change.

In Nigeria, the basic tool for creating awareness on climate change is mainly through the academic environment, which are the primary schools, secondary schools and higher institutions. This clearly indicates the alienation of those without access to education. Organizations that are involved in environmental or Climate Change activities often organize seminars or programs that are usually science based and expert led platforms. Therefore, the beneficiaries of such awareness effort were similarly for the academically inclined or educated Nigerians. It has been suggested that the media should refine its scientific reporting terminologies on climate change, towards easier absorption by the public. It was observed that the use of indigenous language will be an effective tool in promoting response from the grassroot, which will identify practical behaviors that can be adopted and practiced with ease.

A target campaign on climate change awareness was created in Japan, named "team minus 6% ". Some of the major lifestyle change the program initiated was the change of work and school clothing, to lighter fabrics towards reduction of emission through lower cooling temperatures. Despite such achievements, it was generally concluded that mass media campaign has minimal effect on global warming issues particularly on engaging and adopting new behaviors or lifestyle



modifications.

Some have emphasized the apparent communication disparity between local farmers and the Climate Change communicators. The farmers understood the effect of climate change in their own local terms and perceptions, contrary to the scientific based content available on media and formal programs. Climate Change awareness effort on T.V, Media provided positive influence on every day climate related behavior where efforts are observed and realized immediately. Meanwhile, the effect on long term behavior change, where the effect will be visible over a long period was very low. It is evident that the mainstream communication channel through the media is not easily understood at the grassroots level. The ease in adoption of new behaviors that are responsive to the awareness effort on Climate Change was abysmal.

Regional Centres of Expertise – Minna has evolved its climate change awareness efforts towards capturing diverse groups. The usual approach adopted by most climate change or environment influenced organization was usually through organised lectures on salient issues, workshops, seminars and tree planting campaigns. The number of participants was between 14 to 200 people, while an average of 70% of the participants were already conversant with climate change issues, mostly from academic sources.

In 2017, RCE-Minna organised a program on environmental and climate change awareness, where a popular religious and motivational speaker made an extensive paper presentation. The speaker emphasized the value of general involvement in the adaptation and mitigation effort on climate change. The number of participants in the event was a record high of 315 people. However, the participants were mostly from informal (not academic background) sectors with fair knowledge or exposure to climate change concerns.

In 2019 another program was organised by RCE-Minna in collaboration with (AFAWNSO) Association of Women Appointees and Wives of Niger State Officials, which was founded and led by the wife of the executive governor of Niger state. AFAWNSO was an association that mobilizes relief and support to masses in Niger state though the collective effort of women in influential positions in the state. The popularity and influence of AFAWNSO's founder and members inspired a large public turn out, where majority of the participants were politicians or community representatives. The event recorded the largest number of participants approximately 420 people, with only 27% having prior knowledge on climate change formally or otherwise.

### **Influential mediums in climate change communication**

Influential mediums are people or channels that have strong influence on a large number of people, either due to their skills, personality or popularity. These mediums connect with their audience usually through community networks or online platforms, which ranges from entertainment celebrities to religious and traditional leaders.

In Nigeria, these mediums have initiated deep conversations across different issues, which were usually reflecting the culture, lifestyle and humor of grassroots followers. The speed in spread of the information triggers reactions and discussions that often leads to intervention by the government or civil societies.

For instance, in the 2019 general elections, entertainment stars such as Tuface Idibia were endorsed as spokesmen for peaceful election. This involved use of posters across the nation and intensive commercials on T.V. Today, Nigeria is the 2nd nation with the largest use of internet. There have been instances where local issues became national trends that captured the attention and interest of the public nationwide. The access to internet has created a wide outreach and speed in sharing information, usually reflecting the Nigerian humor, culture or perception.

Recently, a sporadic subject which became a national sensation was the jollof rice controversy. This was a mundane affair on origin of a local dish recipe that evolved into an international discussion between Nigerians and Ghanaians. Another incidence was the sterling performance of a police officer that became an overnight super hero, from an interview on his effort to fight election violence. These are incidences that have proven the possible outreach of captivating stories that reflects the situation of Nigerians. The mainstream media that are most accessible to a larger population of the nation today are T.V and internet content. The print media is affordable to higher income earning people with some reasonable level of education. There have been campaigns and endorsements on political issues or health awareness programs that have penetrated all levels across ranks through mediums of entertainment or sports.

The endorsement of celebrities for climate change awareness campaigns is popular, where they emphasise the need to partake in activities towards achieving a certain goal. However, it is alleged that the involvement of celebrities in Climate change awareness for pressure groups or industries was a new approach from the usual scientific based image, popular in the 1970's. The involvement of celebrities in communicating climate change awareness tends to mobilise public awareness on the subject while its impact on stimulating behaviour change is low. The organisations that promote these campaigns were at a risk of having their message misunderstood by the public, become muted or framed in a negative way, leading to doubts in the authenticity or legitimacy of the message.

### Conclusion and recommendations

The involvement of Nigerian grassroots in the adoption of new behaviours or lifestyle towards mitigating and adapting to climate change is essential. The mode of communication should educate and provide solutions that are realistic to the target audience, towards active participation

Apparently, the traditional scientific based events or media exposure does no connect with a large population of the nation, who have limited knowledge or finance to access and understand these platforms. While the celebrity led campaigns have a tendency of altering the content and intent of the information, often failing to instigate the desire to adopt new behavior.

The activities of RCE-Minna in promoting climate change awareness for over 8 years has indicated a pattern of response and type of persons that responded to either expert led or influential medium based programs. In the expert led programs, the number of participants was few, yet the awareness on climate change was high, educational level was high, majority of the participants worked in formal sectors and finally their willingness to extend or promote the knowledge acquired towards a long term achievement was low.

Meanwhile the influential mediums programs had a huge participation number, their awareness of climate change matters was very low, majority of the participants were from the informal sectors and they were interested and willing to commit to a long-term plan or project that can influence the involvement of more people in the scheme.

To overcome the challenge of appropriate communication that perpetuates behavioral change on Climate Change by the grassroots, its essential to properly absorb indigenous grassroots by providing information that reflects the climate change challenges in particular locations. Furthermore, the language, culture and lifestyle should be infused in the message towards creating a connection with the target audience. The study further recommends strategic partnerships with influential mediums in informal approaches towards infusing consciousness and adoption of new behaviors for climate change, particularly for the Nigerian grassroots.

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## Communicating dense scientific evidence: The Green Book experience

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The Green Book was a multi-year interdisciplinary research and development project to produce scientific evidence related to current and future climate, risk, and vulnerability and provide adaptation support. The Green Book ([www.greenbook.co.za](http://www.greenbook.co.za)) was developed as an open-access online planning tool to support local government in South Africa with developing climate-resilient cities and towns. As input to the Green Book, extensive research and development took place in a number of fields namely: climate change projection downscaling, hydro-meteorological hazard modelling, population growth modelling, and adaptation action development. The evidence produced as part of the Green Book was packaged into a Risk Profile Tool, an Adaptation Actions Tool and Story Maps. The Risk Profile Tool provides temporally dynamic risk profiles for each municipality in the country and covers the socio-economic vulnerability of settlements and neighbourhoods, expected development trajectories, changes in climate, and the impacts thereof on the intensity and magnitude of a number of hydro-meteorological hazards as well as important resources. The Adaptation Actions Tool offers detail on local adaptation actions relevant to settlement planning that can be implemented in response to the risks and vulnerabilities identified in risk profiles. Story Maps are used to relay the main findings and methodologies in a concise and interactive way. Together these components offer access to

rigorous scientific evidence in a coherent and interactive system. The novelty of the Green Book lies in the distillation and communication of complex and dense scientific evidence beyond the domain-specific scientific advancements that were used as input.

## Introduction

The Green Book is the result of a three-year initiative in which the CSIR collaborated with the South African National Disaster Management Centre (NDMC) and a number of stakeholders and reviewers in co-producing the methods and reviewing the research findings. The work was co-funded by the Canadian International Development Research Centre (IDRC) and the Council for Scientific and Industrial Research (CSIR). The ultimate goal of the Green Book is to contribute to resilient, sustainable and liveable South African settlements through climate change adaptation. To achieve this goal, the Green Book was developed as an online tool to support local government in South Africa with the planning and design of climate-resilient settlements. The interdisciplinary nature of the Green Book, which combines high-resolution scientific evidence with adaptation solutions, makes this one of the most novel, innovative and information-dense research outcomes about disaster risk and climate adaptation planning on the African continent. The depths and scale of information provided in the tool are unprecedented in South Africa.

## Scientific evidence produced through the Green Book

The Green Book project followed an interdisciplinary applied research methodology that combined various research techniques, analyses methods, models and approaches into a coordinated and coherent whole. The research is conceptualised from a strong disaster risk reduction and climate change adaptation science base, in line with the conceptual framework and definitions of the United Nations Intergovernmental Panel on Climate Change [1]. The Green Book places risk and adaptation at the centre of its research design, where the interaction between vulnerability, natural hazards and exposure exists and the need for adaptation arises [2].

Each component of the research design concept was explored to produce scientific evidence to reflect on the current situation as well as future (2050) changes. Some of the most significant scientific outputs from the project were:

- A set of detailed projections of future climate change covering South Africa at an 8x8 km resolution, offering the most detailed projections of future climate change ever available for the entire South Africa.
- Hazards assessments that quantify the exposure of South African settlements to drought, wildfires, inland flooding and coastal flooding.
- The impact that various climate scenarios might have on South Africa's key resources such as surface- and groundwater availability, economic production and the agricultural sector specifically (as a proxy for food security).
- A vulnerability assessment framework and set of indicators to profile all 213 local municipalities in South Africa based on four unique statistically developed indicators, the 1637 settlements across South Africa based on six unique indicators, and two spatial multi-criteria indicators that capture vulnerability at a neighbourhood level.
- A population potential growth model that forecasts settlement growth across South Africa at a 1x1 km resolution.
- A typology of adaptation actions relevant to municipal planning and design for adapting South African settlements to reduce their vulnerability and exposure to climate risks and to exploit opportunities for sustainable development.

## Communicating dense scientific information

The challenge was to communicate all the dense and information-rich findings from the various research activities in a way that would be accessible and functional to potential users. Based on input received from stakeholders and potential end-users, it was determined that an online planning support tool would be most appropriate. A website was developed and structured into four different components. The first is the main website which provides project-specific information and support content, and also operates as a portal to the rest of the components, namely the interactive story maps, a municipal Risk Profile Tool, and an Adaptation Actions Tool.

### Story Maps

The story maps were developed with the purpose to communicate the main findings from the various project research streams. There are 11 interactive national story maps that provide information about the research methodology, findings and recommendations for coastal flooding, inland flooding, wildfires, drought, settlement vulnerability, urban growth, climate change, the economy, agriculture, forestry and fisheries, surface water, and groundwater. The story maps were developed using the ESRI Story Map application which allowed a narrative around scientific findings to be supported by custom maps, images and statistics. All the story maps are available online at <https://greenbook.co.za/story-maps.html>

### Risk Profile Tool

The Municipal Risk Profile Tool combines scientific evidence produced from multiple domain-specific research streams into interactive, composite profiles covering current and future (2050) climate risks, impacts and vulnerabilities for all municipalities in South Africa and their settlements.

The Risk Profile Tool allows each municipality access to:

- Maps of the current climate and future climate change for a low mitigation (RCP 8.5) and a high mitigation (RCP 4.5) scenario, representing the range of uncertainty from six suitable climate models.
- Comparative bar graphs showing municipal vulnerability trends for socio-economic, economic, physical and environmental vulnerability.
- Comparative spider diagrams showing settlement vulnerability based on six multi-dimensional indicators.
- Population growth estimates for a medium and high growth scenario, on a municipal and settlement level, as well as expected growth pressures. Information is communicated through maps and line graphs.
- Maps showing hazard exposure in the present and the future for wildfire, drought, inland flooding, coastal flooding, and heat stress.
- Assessments reflected through tables, line graphs and maps, of the current and future impacts of climate change on water supply, surface water and groundwater availability, the economy, and agriculture, forestry and fisheries.

Making use of different data communication methods, the Risk Profile Tool offers distilled information on different spatial scales, to local municipal actors to support evidence-based planning and decision-making. The Risk Profile Tool is available online at <https://riskprofiles.greenbook.co.za/>



## Adaptation Actions Tool

The Adaptation Actions Tool provides access to a collection of 81 different planning and design actions for municipalities to adapt their settlements and environments to the likely impacts of climate change, as provided through their municipal risk profile. In the tool, users can filter through the list of adaptation actions by climate risk, impact, adaptation strategy, or planning function (i.e. spatial planning, land use management, infrastructure and engineering services, and environmental planning). Interlinkages between adaptation actions are highlighted and users are able to identify multiple actions that are able to support each other when implemented. Descriptive information on what the adaptation action entails, its benefits and co-benefits, possible costs and implications, and an image is provided for each adaptation action. The Adaptation Actions Tool is available online at <https://adaptationactions.greenbook.co.za/>

## Conclusion

The communication and dissemination of research are crucial for contributing to the latest developments in research. It serves as a progressive method of receiving feedback, and allows for various groups outside of the research and academic world, including public bodies, to be reached. One of the major achievements of the Green Book is the bringing together of an interdisciplinary team of more than 50 researchers, and their findings, to produce very technical results, communicated in a comprehensible way that is of great value to end-users. Together, the different components of the Green Book online planning support tool offer access to rigorous scientific evidence in a coherent system. The novelty of the Green Book lies in the distillation and communication of complex and dense scientific evidence beyond the domain-specific scientific advancements that were used as input.

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## THEMATIC AREA 7

### Mobilising investment in climate and weather services

This theme reflects on the importance of increasing investment to enhance the development and delivery of weather and climate services in Africa, by the private sector, alongside the state and voluntary sectors. It will also focus on demonstrating the value of weather and climate services to donors and investors. These entail sharing weather/climate services business models for private sector, research, academia and practitioners to learn and innovate together and create scalable services. This covers risks, opportunities, financing and business solutions, as well as exhibition of successful creative solutions to share experiences; and methods for valuing weather and climate services to determine the socio-economic benefits such as development opportunities, avoided losses, reduced disaster risks, and enhanced productivity of economic sectors.



## LIST OF PRESENTERS AND TITLES OF PRESENTATIONS

**Dumisani Chirambo**

Enhancing meteorological monitoring and climate change impacts monitoring through community science and social innovation: Policy prospects for Sub-Saharan Africa

**M. Issa Lele**

Integrating climate information into adaptive social protection

**Daniel Tsegai**

Drought Risk Insurance and Sustainable Land Management: What are the Options for Integration?

**Enhancing meteorological monitoring and climate change impacts monitoring through community science and social innovation: Policy prospects for Sub-Saharan Africa**

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Attaining the Sustainable Development Goals (SDGs) will arguably be the hardest in sub-Saharan Africa (SSA). Despite the increases in natural disasters and climate change vulnerability in the region, many governments are decommissioning existing networks for meteorological monitoring and remote sensing due to competing demands for limited resources and due to the failure to recognise the importance of these networks for climate change predictions and resilience building [4].

In this exploratory study, analyses of case studies, project reports, policy reviews, policy briefs and academic literature were undertaken in-order to determine the roles to which social innovation and community science could take to improve the development and delivery of weather and climate services in SSA. The study identified that climate change vulnerability in SSA is not only exacerbated by a lack of infrastructure for climate modelling and prediction but also because climate change adaptation policies and programmes focus on engineering solutions hence ignore the socioeconomic factors for reducing vulnerability such as empowering less powerful actors like rural residents, community organisations and people in the informal sector in the co-production and monitoring of climate data and services. It was therefore concluded that community science could be utilised as a cheaper method for collecting, monitoring and storing climatic data, and that climate change vulnerability could be reduced by using South-South Climate Finance modalities to build capacity on the use of community science for enhancing climate change services and communication.

## Introduction

Climate change is a global development challenge and a source of double injustice as developing countries, while having contributed the least to global greenhouse gas emissions, bear the brunt of climate change impacts, and at the same time have the least resources and

technologies for climate change adaptation [1][2]. Accordingly, many countries in Africa are at great risk to climate-related disasters and suffer from them frequently to the extent that over the last ten years climate-related disasters affected on average 16 million people and caused US\$ 0.67 billion in damages across the continent each year [3]. Unfortunately, despite the increases in natural disasters and climate change vulnerability in the region, many African governments are decommissioning existing networks for meteorological monitoring and remote sensing due to competing demands for limited resources and due to the failure to recognise the importance of these networks for climate change predictions and resilience building [4]. Arguably, reducing climate change vulnerability and ensuring that the Sustainable Development Goals (SDGs) can be attained in Africa requires the development of new innovations and systems to increase investments in climate and weather services.

## Methodology and Theoretical Framework

Effective climate change management essentially consists of four inter-connected response actions - mitigation, adaptation, monitoring and prediction[5], hence it may be argued that a plausible option for reducing climate change vulnerability in Africa could encompass the development and implementation of novel strategies to improve climate change data collection, monitoring and information dissemination. In an assessment by Angelidoua and Psaltoglou (2017), it was determined that social innovations are new solutions (products, services, models, markets, processes, etc.) that simultaneously meet a social need (more effectively than existing solutions) and lead to new or improved capabilities and relationships, and better use of assets and resources [6]. Similarly, community science in scientific research is a growing movement that enlists the public in scientific discovery, monitoring, and experimentation across a wide range of disciplines [7]. Arguably, through social innovation and community science, African countries can develop new modalities and strategies for mobilising investments in climate and weather services. Accordingly, in this exploratory study, analyses of case studies, project reports, policy reviews, policy briefs and academic literature were undertaken in-order to determine the roles to which social innovation and community science could take to improve the development and delivery of weather and climate services in Africa.

## Case Studies on Mobile Phone Environmental Services

One of the main challenges in the climate change and climate services domain is that in Africa governments underinvest in climate information services which are meant to provide location-specific, reliable, and user-friendly weather forecast information and provide modern hydrology and meteorology services. This has consequently led to Africa having less than 300 weather stations, corresponding to only one-eighth of the required density to meet the World Meteorological Office observation standards [3]. In-order to address these challenges, the Sustainable Development Solutions Network [8] suggested that African nations can be ingenious by using mobile phones/smartphones for data gathering such as point source information. Arguably, this suggests that climate services providers need to explore the possibilities of using community science and mobile phones/smartphones as compliments to conventional systems and infrastructure for climate data collection, monitoring and information-processing.

## Mobile Phone Apps for Climate Services

In the field of environmental management, a mobile phone App called Leafsnap was designed for the automatic identification of 220 tree species from the North eastern region of the United States of America and to monitor the migration of native and exotic trees in North America through the use of non-scientists to collect data on the current location and distribution of both native and exotic tree species. In its initial three years after its release, the App was downloaded by more than 1 500 000 users from five continents and 181 countries who recorded over 3 056



684 leaf images [9]. Similarly, it can be argued that there is potential for innovators in Africa to develop special Apps for climate services or climatic data collection and monitoring which community members can use to collect, store and disseminate climatic data. This example therefore demonstrates that advances in Information and Communications Technology (ICT) and the development of made for purpose mobile phone Apps on climate change facets and weather data can simplify the process of utilising community science for collecting and monitoring data related to climate change phenomenon and impacts, and be used for providing climate services.

### **SMS Service for Climate Services**

Droughts and floods are arguably the greatest disaster challenges in Sub-Saharan Africa (SSA) as it has been reported that droughts and floods alone account for 80% of the loss of life and 70% of the economic losses in SSA [10]. Notwithstanding the direct and indirect impacts of climate change on water sources and water availability, and the occurrences of floods and droughts, Official Development Assistance (ODA) funding commitments to the water sector have dropped by more than 25% between 2012 to 2016 [11]. This arguably also means that it is probable that between 2012 to 2016 there have also been decreases in climate change and water sector infrastructure investments related to recording, monitoring and disseminating hydrological information and services. However, in a research by Weeser et al. (2012), it was determined that community members and citizens were able to report water levels for a remote catchment regularly and increase the data pool in understudied regions with high quality by using a bespoke SMS service for sending and recording data and readings[12]. Arguably, such an approach for using SMS services can equally be adapted in-order to improve climate services where the SMS services can be tailored towards recording, monitoring and disseminating hydrological information and services, and relaying specific climatic/meteorological data or warning messages to people and communities.

### **Augmenting investments in Climate Services through South-South Climate Cooperation Modalities**

Community science can be utilised as a cost effective mechanism for reducing costs related to collecting and relaying data and services. For example, from a total of 388 biodiversity research projects using community science, there were 1.3 million volunteers participating and contributing up to US\$ 2.5 billion in-kind annually [7]. Similarly, by using community science with SMS and mobile phone/smartphone technologies as highlighted in the previous section, the costs related to delivering climate services could be reduced. On the other hand, with the declining ODA levels, it might be prudent for African governments to focus on increasing their investments in climate services by utilising Global South led climate change modalities and South-South bilateral relations.

In-order to determine the value and scale of South-South Climate Change Cooperation modalities, South-South Climate Finance modalities and other Global South bilateral relations, reference can be made to the cases of China, Indonesia and South Africa. For example, China has established a South-South Climate Co-operation Fund to the sum of CNY 20 billion (around US\$3.1 billion) to support climate action in other developing countries, hence estimates are that, as a share of Gross Domestic Product, China's pledge overtakes the pledges of many developed countries, including the United States of America, Canada and Australia [13]. Furthermore, (i) three developing countries that are part of the Group of 20 — Indonesia, Mexico and Korea — have provided voluntary contributions to the Green Climate Fund (GCF), as did six other developing countries; and (ii) eight developing countries have provided financial contributions to the Global Environment Facility, one of the operating entities of the financial mechanism under the United Nations Framework Convention on Climate Change (UNFCCC). Similarly, African countries also



support each other through various modalities. For example, South Africa, in absolute financial terms, is a significant development partner in the Democratic Republic of Congo (DRC) in that its financial contributions to the country even exceeds the traditional Global North donors when its aid is measured in proportion to Gross National Income (e.g. between 2001 and 2015 South Africa spent at least ZAR 8.5 billion (over US\$1 billion) on DRC-related South-South Cooperation) [14]. Arguably, climate change policymakers in Africa have now got new opportunities to augment investments in climate services by exploiting South-South Climate Change Cooperation modalities.

## Concluding Remarks

Climate change has the potential to constrain development in many African countries. Unfortunately, at national level, in some countries only about 3.5% of government spending goes to climate change, disaster and water issues, despite them being priority areas in the national policies [15]. Accordingly, there are now concerns that there is a need for policymakers to consider developing new modalities for financing, managing and delivering climate services. In this paper, some of the strategies to augment climate services based on South-South Climate Change Cooperation modalities, social innovation, community science and mobile phone/smartphone Apps and Services were presented. However, there are some suggestions that a weakness in policies to manage climate risks and disaster risks in developing countries is their emphasis on engineering solutions as mechanisms for managing climate change impacts, as this often times marginalises some communities [16], and ignores the socioeconomic factors for reducing vulnerability such as empowering less powerful actors like rural residents, community organisations and people in the informal sector in the co-production and monitoring of climate data and services. On the other hand, the effectiveness of local collective action is considered as a major determinant of the ability of societies to adapt to climate change [17]. These two issues therefore help to highlight that strategies such as community science, that engage and mobilise citizens and community organisations in the collection and monitoring of climatic and environmental data may not only help in the provision of climate services but also have potential to reduce climate change vulnerability in communities. Arguably, improving the delivery of climate services in Africa is not only an issue of promoting investments in conventional systems and infrastructure for climate services but is equally about diverting existing resources into the development of new technologies such as mobile phone/smartphone Apps and Services for climate services, and mobilising communities and citizens to become participants of community science programmes focusing on new modalities for providing climate/ meteorological services.

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## Integrating climate information into adaptive social protection

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The ASPIRE (Adaptive Social Protection – Information for Enhanced REsilience) project, funded by DFID under the WISER programme, aims to identify how climate and livelihoods information can inform social protection programmes in the Sahel in West Africa. The two-year project, due to end in December 2019, is being delivered by a consortium including the UK Met Office, the Walker Institute at the University of Reading, and the Norwegian Refugee Council. Here, we discuss the challenges and opportunities of integrating climate information into the World Bank and other national Adaptive Social Protection programmes in the region. This includes work to strengthen the links between climate information providers and social protection organisations, including research into interactions between providers and users of climate information; research on the reliability of seasonal forecasts; examination of the potential of seasonal forecasts to support social protection initiatives; engagement with climate centres in Africa (ACMAD and AGRHYMET) and the PRESASS regional climate outlook forum; and the identification of training needs and key training activities with national meteorological agencies and social protection stakeholders. We reflect on lessons learned and discuss recommendations for how climate service providers and users can better communicate and meet information requirements for social protection. This includes the need for improved mechanisms for collaboration and dialogue across government agencies, better coordination and information exchange with non-government agencies working at community level, and better understanding of the links between climate variability and the impact across livelihood zones and population sub groups within these zones. Underlying this is the need for investment in national meteorological agencies and Higher Education Institutes to enhance capabilities, services and investment in the national collection and updating of

livelihood information to understand the potential impact of seasonal forecasts at community level.

## Introduction

The vast majority of the West African Sahel region's people are semi-nomadic small-scale farmers or pastoralists who depend upon land for their livelihoods. Exposure to periodic severe weather, mainly droughts and floods, is a major concern and is linked to chronic food insecurity. The increased frequency with which these events are now occurring gives the most vulnerable insufficient time to recover to their pre-event status and gradually erodes their ability to survive in the face of natural disasters and political and economic uncertainty.

To help the Sahel nations of Burkina Faso, Chad, Mali, Mauritania, Niger, and Senegal move away from expensive emergency aid, to steadily reduce poverty, and to build long-term food security and climate resilience, the World Bank launched a new multi-donor Sahel Adaptive Social Protection Programme (ASPP). The aim of the ASPP is to build the resilience of these populations so they can prepare for drought and be supported in times of need in order to protect their assets and livelihoods and lessen humanitarian crises. Feeding into the World Bank's ASPP, the DFID funded ASPIRE (Adaptive Social Protection – Information for Enhanced RESilience) technical assistance project, aims to integrate weather and climate information into social protection decision making in the Sahel to enable the region to become resilient to climate shocks. Over the past two years, ASPIRE implementation team members have worked closely with social protection and climate stakeholders in the region and have gained an understanding of some of the key opportunities and challenges of how climate information can inform social protection and other resilience initiatives in the region.

## Adaptive Social Protection

Social Protection (SP) programmes are designed to enhance the capabilities of individuals and groups to meet the needs of everyday life. They can also break down economic and social barriers limiting the access of people to services and benefits of development. Examples of social protection include mechanisms such as social assistance (e.g. cash transfers, school meals and public works programs), insurance (e.g. maternity, unemployment or illness cover), pensions (i.e. state pensions) and labour market interventions (e.g. maternity and sickness benefits). Adaptive SP (ASP) programmes aim to protect poor households from climate and other shocks before and during the occurrence through measures such as advance transfers, building community assets and other coping mechanisms. The World Bank's ASPP, a major multi-donor trust fund, aims to increase access to effective ASP systems for poor and vulnerable populations in the Sahel.

## Key Learnings

The main learnings from the ASPIRE project are:

- Many SP programmes in the Sahel are nascent and fragmented across different government institutions. It has therefore been challenging to identify clear entry points for climate prediction to inform social protection (SP). Whilst it is recognised as important by stakeholders to use climate information in the implementation of SP programmes, this is not necessarily prioritised. Ongoing dialogue between weather and climate service providers and SP stakeholders facilitated by the ASPIRE embedded consultant and the wider ASPIRE team, is contributing to paving the way to equitable and inclusive co-production of weather and climate services and to making a sustainable change.
- Sahel countries have established and integrated information systems on food security, nutrition and early warning, such as the Cadre Harmonisé, however there is

an absence of the necessary climate predictive modelling to provide the necessary complement to the satellite imaging available. There are also challenges in the timeliness and comprehensiveness of livelihoods information that is available to the Cadre Harmonisé.

- At present, SP stakeholders find it challenging to engage with their National Meteorological and Hydrological Services (NMHSs) to get the information they need. The reasons for this are both institutional and financial. This needs to be addressed to ensure food security analysts have timely information for livelihood impact modelling and a well targeted, early response. Currently the predictive aspect remains mainly qualitative, which may also increase the risk of political considerations in the examination of results.
- Observed data and seasonal forecasts are likely to be most relevant to informing forecast based early action (including ASP) but the availability and quality of this information is variable. Pirret et al (2019), as part of the ASPIRE project, compared the performance of seasonal forecasts from four dynamical models and the consensus seasonal forecast produced at the Soudano-Sahel Regional Climate Outlook forum known as the PRESASS (Prévisions Climatiques Saisonnières en Afrique Soudano-Sahélienne). Whilst the results indicated that the models generally show positive skill and reliability, the skill is better in the eastern Sahel compared to the western Sahel (partly due to the reduced influence of teleconnections (El Nino-Southern Oscillation) in the west). Seasonal forecasts tend to be at a coarse scale and there is a role for NMHS to provide more detailed information. Senegal is generally more advanced in terms of availability of impacts data and ability to run models than the other countries, however climate data availability is similar across the region.
- There is limited understanding of impacts of weather on livelihoods, food security and poverty. Understanding of the 'what the weather will do, rather than what the weather will be' is key for those in the region to be able to take action and prepare for weather and climate extreme events. Impact Based Forecasting is a way of delivering a weather and climate services which is designed with and therefore meaningful to the user. However, for reliable impact-based forecasting, the same effort must be made to improve the quality of quantitative, downscaled livelihoods information as we have seen in relation to climate information.
- There is limited understanding of Adaptive Social Protection by weather and climate providers and of the value of weather and climate information by SP stakeholders. E.g. NMHSs and Disaster Risk Managers and links to Government Sectors. The ASPIRE team has worked to bridge this gap through SP stakeholders and climate providers training sessions. This has enabled stakeholders to provide frank and realistic feedback about their experience of the social protection process. The Dakar stakeholder workshop highlighted the need for relevant contextual livelihood data, based on agro-ecological zones, regularly updated with additional indicators including 'season to date' crop conditions and market price information to allow impact modelling that can be aligned with climate and other relevant data.
- The Training Lab highlighted the need for the multiplication of information dissemination hubs in order for "knowledge interpreters" to be able to share targeted information to extension services and farmer groups in a timely manner. This requires extensive and sustained training of government and extension workers in climate and livelihood information assimilation and communication. The Higher Education Institutes in the region are critical partners for long-term interdisciplinary training leading to sustainable social protection services in the region. This requires sustained and significant investment in education across the region beyond which is possible for most national governments.
- The regional level is very important to the early warning early action agenda. Food security remains a priority in the region, with existing early warning and response

- systems, such as the Cadre Harmonisé. Investment into the regional forecasting capability and dialogue between regional and national institutions is a priority.
- Several drivers of food insecurity in the Sahel hinder early action and complicate the design and implementation of climate-informed social protection. These include conflict, migration and displacement; limited institutional capacity; lack of historical hydrological / meteorological data etc.
  - The national and regional institutional landscape is overcrowded. This poses challenges to coordination, value addition, and to raising the profile of under-represented areas such as flood-affected communities and pastoralists.
  - Limited understanding of how precisely shocks and variability are experienced by the populations targeted by SP as compared to the general population (e.g. the impact of drought on non-farming day labourers or persons with no labour capacity)
  - The PRESASS continues to have challenges in obtaining funding and in the coordination and organization of the annual events well ahead of the monsoon season. As a result, it continues to be held close to the onset of the monsoon (e.g. late May / early June) leaving little time for comprehensive intervention planning by government agencies (river basin authorities, met services etc) and DRR and humanitarian organisations.
  - Seasonal forecasting techniques used by the Soudanian-Sahel NHMS are largely considered to be outdated. The PRESASS Regional Climate Outlook Forum (RCOF) remains a significant influencer and training venue, so it is vital that secure sources of funding are found. The UK Met Office, DRR and humanitarian organizations and university partners (including the Walker Institute and the linked RAINWATCH Alliance) have been supporting the RCOFs for many years across Africa and all remain keen to continue this support.

## Conclusion

Weather and climate information only has value when it is combined with up to date livelihood information and used to inform preparedness and action. The needs of users should guide investments in weather and climate science and services in the Sahel to ensure they are pulled through to support resilience building. This will require close cooperation and dialogue between those who produce climate information (NMHSs) and those who produce food security and livelihoods information (humanitarian actors, SP stakeholders, food security sector, NGOs etc). It will require more inter-disciplinary training involving technicians and analysts using climate and livelihoods information and better understanding of the links between climate variability and change and key livelihoods. Investment is needed in national meteorological agencies to enhance capabilities and services, and in national food security assessment systems to understand needs and sensitivities of different populations. Finally, learnings can be drawn from the DFID WISER programme on how to achieve this through a process of co-production and from the co-funded DfID projects such as the SHEAR NIMFRU and FCFA HyCRISTAL projects in East Africa as well as the UPGRo BRAVE project in West Africa



## Drought Risk Insurance and Sustainable Land Management: What are the Options for Integration?

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### Introduction

Designing an innovative insurance product which addresses not only ex-post drought impact but also combats land degradation through the adoption of appropriate ex-ante strategies is crucial to forming holistic policies for reducing vulnerability of small holders to drought. To achieve the twin goals of land sustainability and enhancing countries' abilities to cope with drought, sustainable land management (SLM) practices can be used as a condition or a contractual obligation to provide a premium free insurance scheme to farmers who decide to participate in the insurance scheme.

The paper attempts to address the importance of designing such an innovative insurance product which does not only address drought impacts but also minimizes land degradation through the adoption of appropriate Sustainable Land Management (SLM) approaches. The paper also provides options to fund various incentives to ease the financial burden on governments and local communities. For an insurance scheme to be financially sustainable in the long run, it is critical to develop strategies which avoid diverting funds from public resources.

### Linking Sustainable Land Management and Drought Insurance

Sustainable land management (SLM) practices can be used as a condition or a contractual obligation to provide a premium free insurance scheme to farmers who decide to participate in the insurance scheme. Community level insurance is more practical for this purpose as community level insurance is expected to reduce the need for assessment of individual farms for SLM practices compliance, as defined by contractual obligations.

Farms, during audit of pre-determined and agreed upon observable characteristics, can be selected randomly for assessment and vouchers, stating compliance level which can be issued to the communities. These vouchers can then be utilized for receiving payouts as and when drought occurs. It is expected that the value and reduction in transaction cost achieved because of implementing index insurance may get diminished as a result of integrating insurance with SLM compliance audit model. However, in the long run, the benefit derived from continued use of SLM practices is expected to outweigh the costs associated with the integrated model.

After a few years of premium subsidized assistance, targeted farmers can be graduated from the integrated premium free insurance scheme with improved agroecological conditions and infrastructure such as watersheds for water harvesting. After the termination of this scheme, farmers can continue to sustain their livelihoods with lesser impact of climatic variations and standard index insurance schemes without premium subsidy.

It is important to note that premium subsidy schemes are effective in developing countries if they can be maintained over a long term without draining public resources. The scheme should also be able to promote wide scale adoption of SLM practices leading to improved agricultural productivity and soil quality which continues even after the termination of the integrated and subsidized insurance scheme.

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## Conclusion

Integrated approaches towards drought insurance should be adopted. Efforts should be made in educating farmers about benefits and costs of adopting SLM practices and losses incurred due to weather related extreme events. SLM practices, if effectively implemented, have the potential to address land degradation and mitigate the effects of drought. The key is to support the development of comprehensive land use policies, providing training to farmers and offering right incentives for wide scale adoption. SLM practices are likely to be adopted where SLM has the potential to reduce drought impact, increase crop yields and subsequently farm income. Therefore, policies which provide means to mitigating drought risk, tangible benefits with right mix of incentives and a potential role for reducing the frequency of future droughts are likely to be effective in the long run. Such integrated policies are also better suited to achieve the twin goal of combating drought risk and land rehabilitation, rather than adopting isolated approaches, which are likely to be more expensive.

## THEMATIC AREA 8

### Cross-cutting issues: water-energy-food-health nexus

This theme considers climate change adaptation actions in various sectors (water, energy, food security, health, DRR) in terms of practical methods and policy guidelines that enhance resilience, taking into account the interconnections and interdependence among the sectors. It includes potential synergies, trade-offs, and a broader framework for making adaptation responses and decisions more effective at multiple scales (including approaches to decision-making under uncertainty). Research, policy and practice that attempt to take this wide view across multiple sectors or scales will be covered. Sectors under this theme includes, but not limited to:

**Agriculture and Rural Livelihoods** – Will focus on the use of weather and climate information in decision-making to enhance adaptive capacity of local communities through increased resilience of agriculture, including linkages with food security and livelihoods.

**Urban Planning, Energy and infrastructure** – Includes the design, implementation and assessment of options to increase resilience to climate change impacts on energy and urban infrastructure (including water supply and sanitation); energy supply and demand management; transport; as well as planning for disaster risk reduction in these sectors.

**Surface and groundwater resources** – Will consider how adaptation to changes in extremes (floods and droughts) and longer-term water availability can be delivered through improved risk assessment methods, catchment management, behavioral change (e.g. demand management), technological solutions (e.g. storage or improved water treatment), and improved groundwater and surface water quantity and quality assessment (including scenario planning).

**Health** – Provides a venue for work that focuses on the way in which adaptation can address climate impacts on human health and wellbeing, with a view to increasing resilience to disasters, and advancing our understanding of temperature-related health impacts, air quality impacts, impacts of extreme events on human (and animal) health, vector-borne diseases, water-related illnesses, nutrition, mental health and populations of concern.



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Resilience in water service delivery value chain in Kenya through risk analysis and creating adaptation solutions

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### **Ernestina Asiamah Agyei**

Information Access and Adaptable Climate Strategies for Food Security; the case of Ada Fisher Folks.

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### **Thomas Idemudia Aneni**

Climate Variability Impacts on the Population of the Oil palm Leaf miner

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### **Maïmouna BOLOGO/TRAORE**

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### **Eromose E. Ebhuoma**

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### **Narcisse Gahi**

Integrated Approach to Sustain Community Livelihoods. Resilience to Hydrometeorological Risks in West Africa

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### **Kashimana Ivo**

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### **Tawina Mlowa**

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### **Ashenafi Manaye**

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**Kennedy Muthee**

Ecosystem Services in Climate Change Adaptation Projects in The Least Developed Countries of West Africa

**Usman A. Raheem**

Adaptation to flood induced health externalities by mothers around urban drainage basins of Ilorin, Nigeria

## **Resilience in water service delivery value chain in Kenya through risk analysis and creating adaptation solutions**

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Kenya is a water scarce country and water service delivery is threatened by frequent climatic risks. This study investigates the climatic risks on water service delivery in Kenya and proposes potential adaptation solutions along the value chain. In developing an adaptation plan we gain a better understanding of how climatic risks, in combination with other stressors, impact water production, abstraction, treatment, storage, distribution and consumption on infrastructure and operational efficiencies by water service providers. Our climate-risk analysis on water service delivery showed that stakeholders are aware of the climate change impacts and risks, yet do little to incorporate adaptation solutions. Key among the major challenges is the high rate of non-revenue water that threatens the financial sustainability of water service providers. It has been identified that both droughts and floods impact heavily on water safety and availability leading to rationing that creates high expenditure for consumers, associated health impacts for consuming contaminated water and high cost of treatment due to high turbidity. Water sector is infrastructure-dependent, and climatic shocks damage infrastructure such as distribution pipes and storage tanks. For water service providers to adapt to climate change, there is a need for addressing the risks along the value chain such as input source stabilization through watershed management, investment in diversified sources such as boreholes and rainwater harvesting, storage enhancement and flood mapping for siltation control. Key adaptation and mitigation options include climate-proofing the infrastructure in piping and storage, mobile billing, smart metering and solar water pumping to reduce diesel costs.

### **Introduction**

Changes in climate, together with other stressors, are exacerbating the vulnerability of African water systems and in turn this is increasing risks of food insecurity and reduced water availability [3]. By 2050, floods and droughts are projected to cost Kenya 2.4 percent of GDP annually and another 0.5 percent resulting from degraded water resources [6]. Specifically, the costs of floods are estimated to be about 5.5% of GDP every seven years, while droughts account for 8% of GDP every five years [2]. As such, climate change poses a threat to development and economic growth in Kenya, increasing risks faced by water service providers and leading to impacts across all sectors of the economy. The combination of reduced surface water availability resulting from increasing effects of climate change and groundwater depletion poses a significant threat to the long-term water security in Kenya, and more-so, food security and human health [5][1].

The Safe Drinking Water Foundation highlighted that 80% of all illnesses in developing countries are attributed to unsafe drinking water and the spread of waterborne diseases[7]. Both droughts



## Methodology

This study was a rapid assessment through review of climate risks and adaptation options literature, historical information, case studies and interviews with key informants. It was an extended qualitative and summative review from a country-wide study on 'Assessment of Climate Change Adaptability levels in selected water utilities,' [4]. In addition, using available data on water service providers' response to climate change and commercial viability, the study was carried out following a two-step methodology of mapping climate change risks and identifying adaptation options – climate smart innovative solutions.

Step 1: An assessment and mapping of climatic risks and related impacts along the water service delivery value chain.

Step 2: Identifying possible climate smart innovative solutions / adaptation options along the water service delivery value chain.

The climate smart innovative solutions were identified depending on their ability to: (1) build adaptive capacity of beneficiaries, (2) reduce greenhouse gases and (3) lead to efficient management by water service providers.

## Results

Our climate-risk analysis on water service delivery value-chain approach showed that stakeholders are aware of the climate change impacts and risks, yet they do little to incorporate adaption solutions. One of the major challenges is the high rate of non-revenue water due to infrastructure damage during flooding, that threatens the financial sustainability of water service providers. Watershed management, involving all stakeholders was identified as a key component in achieving desired quantities and quality of water to be supplied. Stakeholders such as farmers, through their land management techniques have a critical influence on the ground water recharge and water treatment costs by service providers. While watershed management is a critical factor in mitigation of climate change and water supply, there has been no keen intervention by majority of the water service providers in Kenya to actively implement watershed protection.

One of the most common impacts noted was the frequency of power black-outs, which disrupts operations creating short term water shortages. This is particularly common during the heavy rains when Kenya records a higher than average interruption of grid power and in dry seasons when power rationing is imposed by Kenya Power Company. The most common form of back-up was the use of diesel generators as observed in many of the service providers.

It was observed that the source to demand ratio is significantly larger than the storage to demand ratio for large service providers. It was observed that most of these large utilities use their storage tanks more for pressure balancing than for storage purposes to serve them during dry seasons.

## Conclusion

To enable resilience to climate change by water service providers, there is a need for addressing the risks along the value chain, investment in diversified sources and use of climate smart approaches. An effective and low-cost method of reducing water demand is to implement water conservation programs that will cut down on waste and inefficiencies along the value chain. Inadequate water storage is a major constraint for water utilities to continuous supply water during floods and droughts, especially with increased population. Kenya is among countries with the lowest water storage capacity per capita and therefore needs a policy intervention to review

of the storage manuals. During flooding, much water is lost as run-off, while during frequent droughts service providers cannot meet the demand. There is therefore a case for interventions to increase storage capacity while diversifying the water sources to improve the resilience and reliability of systems.

Because of the critical role of efficient management in ensuring sustainable operation of water service providers, there is a need to invest in technologies that allow for robust data management, billing systems, client databases (including GIS mapping) and operations Information Management Systems (IMS) were identified as the three key interventions under this category.

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## Information Access and Adaptable Climate Strategies for Food Security; the case of Ada Fisher Folks.

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With a rapid increase in the world population, there is a need to continuously make food available to meet this increase. Climate change has been one of the factors affecting food security mainly in developing countries. Governments, development partners, farmers and other stakeholders are all seeking to find adaptive strategies to combat issues of food security. Sub-Saharan African countries like Ghana is dominated by fishermen who are mostly engaged in small and medium scale fishing. Some characteristics of these fishermen are the continuous use of agrarian fish farming practices. The study explored how fishermen are able to access information in order to build adaptive strategies to ensure the continuous production of fish. The study also examined how information has affected fishermen's livelihood outcomes. The study was conducted in Ada District Assembly in Ghana. Using a qualitative research approach, data was collected from 120 fishermen using a questionnaire. The study revealed that, climate and weather information sources available to fishermen mainly include local community radios and extension services from the district assembly. The fishermen had very little access to climate and weather information from these sources. This information includes the appropriate harvest practices

suitable for particular seasons. Fishermen also lacked information that could improve their well-being. Some had to leave their homes because the sea was pushing into the mainland. In an era where climate has become a major concern, the study recommends that, the Fisheries sector focus on the provision of adaptable climate strategies and resilient information management centres.

## Introduction

With a rapid increase in the world population, there is a need to continuously make food available to meet this increase. Governments, development partners, farmers and other stakeholders are all seeking to find adaptive strategies to combat issues of food security. Globally fish catch has been declining and the impact can be felt by various communities close to coastal areas and water bodies [4]. In view of this, it is said that 32% of the world's fisheries are overexploited, depleted or recovering while 53% are fully exploited [10]. Climate change is one of the recent causes of unprecedented reductions in fish communities in addition to overfishing. A lot of evidence shows that most stocks are heavily overexploited [1]. Sub-Saharan African countries like Ghana are dominated by fishermen who are mostly engaged in small and medium scale fishing. Some characteristics of these fishermen are the continuous use of agrarian fish farming practices. Many scholars have attributed the above issues to the lack of information on the part of the fish farmers to adapt to climate change issues to ensure the sustainable production of fish [9][2][3]. This study therefore explored how fishermen are able to access information in order to build adaptive strategies to ensure the continuous production of fish. The study also examined how information has affected fishermen's livelihood outcomes.

## Climate change effects on Fisher Folks

Fishing has been an important source of living for the people settling along the coast [8]. As such, the absence of fishing activities decreases the livelihood standards of the rural folk along the coastal areas. According to the Interim Poverty Reduction Strategy Paper (2000–2002) issued by the Ghana ministry of Finance, the government of Ghana overall strategy (fostered and encouraged by both the World Bank and IMF) is to produce a middle income country by the year 2020. Globalization of markets and supply chains, combined with climate change has affected livelihoods in the fishing communities.

## Information channels in the fishing industry

Ugandan fisheries is primarily a fresh-water artisanal capture system. There are numerous other lakes and small rivers that are used in fish production [6]. However, due to fishing pressure both legal and illegal and serious pollution problems, total fish harvest and value have declined since 2005 [7]. In view of this, the government of Uganda established a community based fisheries management scheme or fisheries management unit called BMU. However, the BMU is a group communication method that is being used to address the fish stock depletion in Uganda. The fisheries management focuses on technical measures and stakeholder representations comprising of boat owners, crew and fishmongers.

## Methodology

This research employed a qualitative method due to the nature of the research questions to be addressed. A total of hundred and twenty (120) respondents were selected out of the fishermen selected from the community. The hundred and twenty respondents selected from the coastal areas were being affected by climate change at the Ada District Assembly. A questionnaire was used to conduct a face-to-face interview with the fishermen. Due to the low educational background of most of the respondents who couldn't read and understand some of the

questions, the researcher had to read and translate the questions to the fishermen to answer. Data collected from the fisher folks and were analysed. Occurring themes were generated from the response of the fishermen.

## Findings

### Information Access

Access to reliable information pertaining to adaptable climate strategies for fish farmers has been reportedly scarce in both urban and rural areas. The study revealed that in the Ada District, climate and weather information sources available to fishermen mainly include local community radios and extension services from the district assembly. This information includes the appropriate harvest practices suitable for particular seasons. With this kind of information, they only receive it once in a very long time. The challenge that most of the farmers reported is that, due to the variation in the seasons, they are unable to determine which of the farming practices that they have to apply at what point.

With the local community radios, they sometimes have people informing them about the season that we are in and how to manage life entirely and not specific to fishing practices. This is because these community radios are for some individuals who are into profits and who do not pay particular attention to fishing issues but however to issues that will generate profit to them. To the farmers, they only hear about fishing issues once in a while when these community radio bring the chief fisherman or other people. This therefore does not give them frequent information that they may need to ensure sustainable production of fish.

Also, with the information from the district assembly, it is done by the extension officers who are situated in the district assembly. They sometimes visit these communities to talk to the fishermen about the best fishing practices. These visits are not very often to the extent that some of the fisher folks indicated they had not had any visit for almost a year. As a result, they are either using the previous information that was given to them or they were using their own strategies in fishing. It was indicated by some of the fishermen that they were advised to sometimes go on a fishing vacation at a particular season where they can leave the fish to reproduce before getting back to fish. Most of them however indicated they could not adhere entirely to this information as they also needed to survive.

### Information access and livelihood

The study also examined how information has affected fishermen's livelihood outcomes and found that with the change in climate pattern over a period and the lack/inadequate information to these fishermen, it was affecting their livelihoods negatively. This is because the fishermen reported about times where they have been to the sea and couldn't get fish. This affects them as fishermen who depend largely on the catch they make with their families. However, access to information could make them plan on when to save towards a non-fishing season and when to spend towards a fishing season. Because there is no information, they are usually hit with surprises when they meet the absence of fish.

Again, fishermen also lacked information that could improve their well-being not directly related to their work on sea but in their homes. As fishermen, most of them and their families had settled along the coast of the sea for easy access to the sea. Some of these fishermen have had to leave their homes because the sea was pushing into the mainland.

## Conclusion

The study concludes that access to information is key in the fight against climate change and its related issues which in this study is fishing. Access to information by these fishermen in the

Ada district will be relevant in ensuring the continuous production of fish and ensuring food security. It will also be relevant in improving the livelihood of these farmers which is paramount to achieving sustainable development. In an era where climate has become a major concern, the study recommends that the Fisheries sector with its stakeholders should focus on the provision of adaptable climate strategies and resilient information management centres.

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## Climate Variability Impacts on the Population of the Oil palm Leaf miner

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This study contributes to understanding insect pest-climate relationship in broad agricultural and food security terms. This paper evaluates climate change and variability from 1961–2010 and projections up to 2050 and its impacts on the oil palm leaf miner – *Coelaenomenodera elaeidis* (Coleoptera: Chrysomelidae), in the study area.

The study involved direct field insect pest surveys and assessments at the Nigerian Institute for Oil Palm Research (NIFOR) main station. A complete randomized design (CRD) was utilized. The leaf miner was sampled during 2009–2010 in oil palm fields and records from previous surveys from 1976–1980 were utilized. Climate variability projections up to 2050 were evaluated and impacts on the leaf miner evaluated. Time series analysis was conducted using Minitab 14.0. Least square method was used to estimate the trend in the series and the trend equations. Computed models for temperature, rainfall and relative humidity were  $Y_t = 30.6174 + 3.51E^{-02}t$ ;  $Y_t = 163.829 - 0.112521t$  and  $Y_t = 68.8473 - 230E^{-02}t$  respectively where  $t$  is time. On this basis, a forecast up to 2050 was generated indicating an upward trend in temperature and a downward trend in rainfall and relative humidity. Specific forecast indices for 2050 were: Temperature: 33.8°C; Rainfall: 153.70mm; and Relative humidity: 66.8%. The study has established an upward increase in temperature, attributed to climate change; with concomitant increase in leaf miner abundance.



The integration of weather forecasting with farmer action has great potential for control of insect pests in oil palm growing areas.

## Introduction

The leaf miner – *Coelaenomenodera elaeidis* (Coleoptera: Chrysomelidae), a hispid, is a serious defoliating pest of the oil palm. Leaf miner outbreaks are sporadic and difficult to predict. There is need for increased knowledge of the leaf miner and its dynamics to guide environmentally sustainable integrated pest management methods. In order for growers to move away from over reliance on pesticides, dependable tools to time pest management activities are needed. In Nigeria, climate change causes higher temperatures and relative humidity, which increases the likelihood of such stressors as pest infestations and diseases. There is a clear need to advance knowledge on pest response to weather and climate variability. A key justification of this work is that the linkage between climate variability and pest response is poorly understood. This study contributes to the understanding of the insect pest-climate relationship in broad agricultural and food security terms. This paper focuses on the sensitivity of the leaf miner to climate variability. The objectives include: Evaluation of climate change and variability from 1961–2010 and projections up to 2050; and Impacts of climate variability on *Coelaenomenodera elaeidis* in the study area.

## Methods

The study involved direct field insect pest surveys and assessments at the NIFOR main station. Criterion for site selection was a plot 5–12 years of age. Data was collected monthly over 24 months. It involved observing and counting of *C. elaeidis*. No pesticides were applied during the study period to simulate a natural ambience in the sample plot. The study field 54 was made up of 443 palms (2.95 hectares). It was divided into 7 blocks (1 – 31 palms; 2 – 58 palms; 3 – 68 palms; 4 – 68 palms; 5 – 72 palms; 6 – 63 palms and 7 – 83 palms). In this study, the census system used sample counts within specified blocks. Census on the basis of damage by *C. elaeidis* was done monthly by walking the full length of a planted line, assessing damage on each palm and cutting 5 severely damaged leaflets from a palm frond with a harvesting knife and taken to the laboratory where the leaflets were opened up and immature stages of *C. elaeidis* counted. Sampling was conducted monthly between 7am–11am. Insect sampling was done by the use of insect sweep net, direct handpicking and leaflet sampling.

## Secondary data collection

Leaf miner field data surveys from 1976–1980 were obtained from NIFOR Entomology division.

## Climatological Data

Climatological data (temperature, rainfall and relative humidity) were obtained from NIFOR meteorological station. The weather station is within 1km radius of the field. The data were monthly averaged records.

## Statistical Analysis

Time series analysis was conducted using Minitab 14.0. Least square method was used to estimate the trend in the series and the trend equations.

## Results

### Leaf miner trends: 1976 –1980

Trends of leaf miner adult from 1976 – 1980 is presented in figure 1. The time trend shows an increasing trend.

#### a. Adult leaf miner

The trend line in adult abundance shows an observed increase (figure 1). The trend is represented by the model:  $Y_t = 117.180 + 1.50646*t$ ; Where  $t$  = time;  $Y_t$  = Adult at any time forecasting is needed

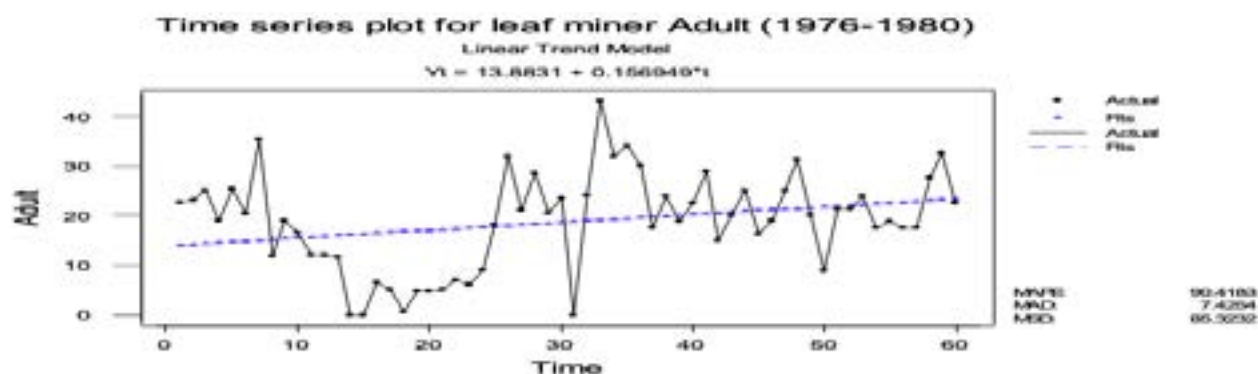


Figure 1. Trend of adult leaf miner between 1976 and 1980

### Leaf miner trends: 2009 – 2010

Trends of leaf miner (larvae, pupae, adult) from 2009 – 2010 are presented in figures 2 – 4. Generally, the time trends are varying showing increasing or decreasing trends.

#### a. Larvae

The trend line in larvae abundance shows an observed gradual increase (figure 2). The trend model is represented by the model:

$$Y_t = 4.766812 + 4.52E-02*t$$

Where  $t$  = time

$Y_t$  = Larvae at any time forecasting is needed

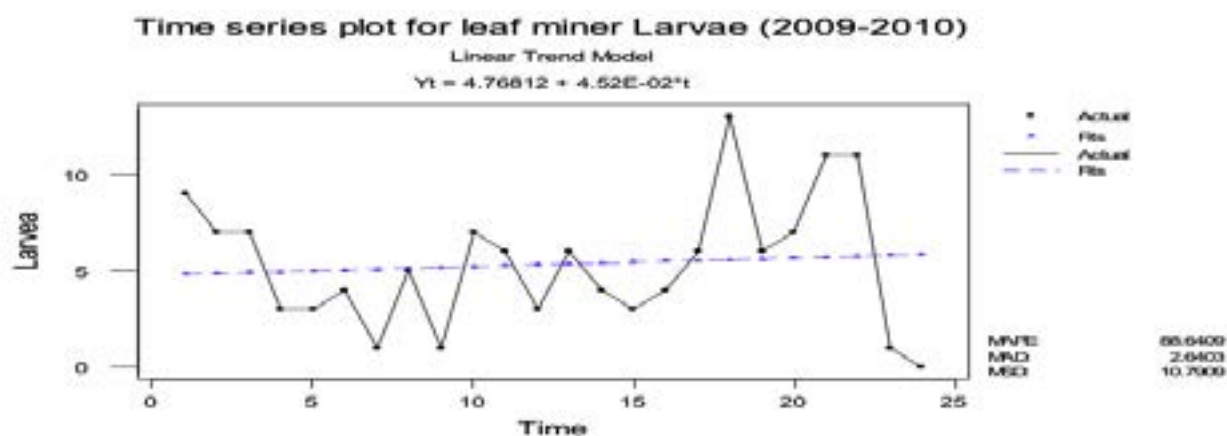


Figure 2. Trend of larvae between 2009 and 2010

### b. Pupae

The trend line in pupae abundance shows an observed gradual decrease (figure 3). The trend model is represented by the model:

$$Y_t = 4.88043 - 2.04E-02 \cdot t$$

Where  $t$  = time

$Y_t$  = Pupae at any time forecasting is needed

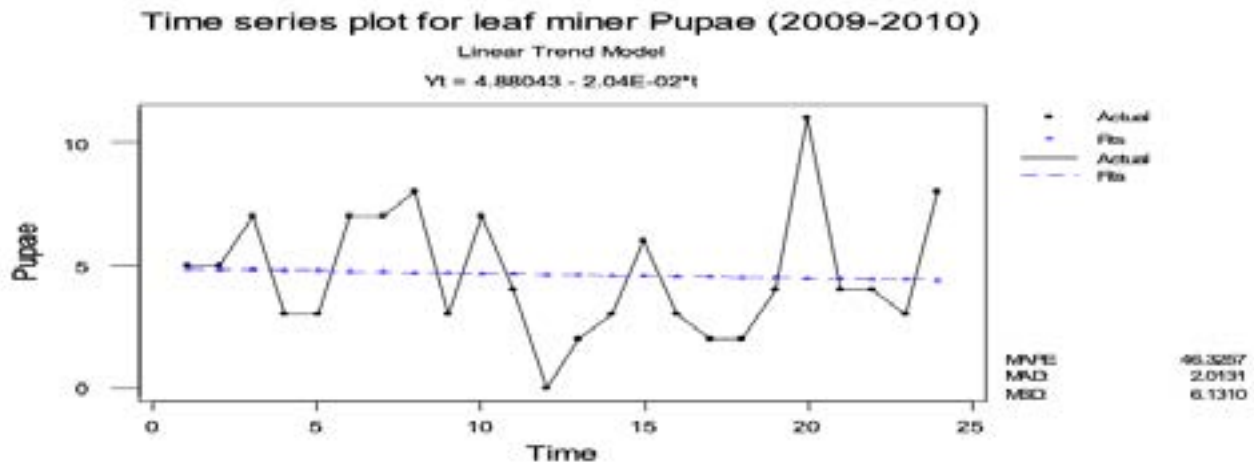


Figure 3. Trend of pupae between 2009 and 2010

### c. Adult

The trend line in adult abundance shows an observed increase (figure 4). The trend model is represented by the model:

$$Y_t = 17.5399 + 4.35E-02 \cdot t$$

Where  $t$  = time

$Y_t$  = Adult at any time forecasting is needed

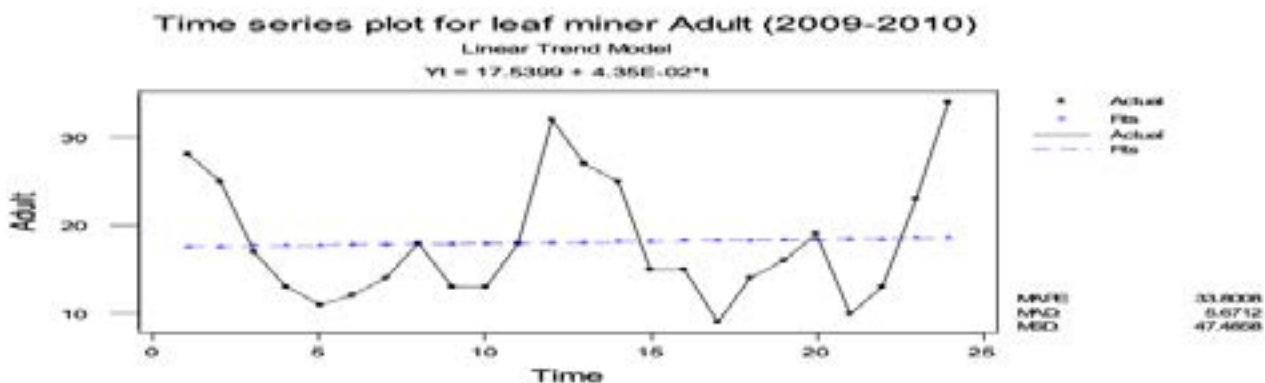


Figure 4. Trend of larvae between 2009 and 2010

### Climate forecast trends: 2011 -2050

Decadal forecast on yearly average temperature, rainfall and relative humidity from 2011-2050 is presented in table 1. It shows the average value of temperature, rainfall and relative humidity forecasted for the respective decade. It indicates increasing trends of temperature and decreasing trends in rainfall and relative humidity values throughout the period under review. Specific forecast indices for 2050 are: Temperature: 33.6°C; Rainfall: 154.21mm; and Relative humidity: 66.9%.

Table 1. Decadal forecast on yearly average temperature, rainfall and relative humidity from 2011–2050

Decade (D)	Temperature (°C)	Rainfall (mm)	Relative humidity (%)
D1 (2011-2020)	32.6	157.58	67.7
D2 (2021-2030)	32.9	156.46	67.3
D3 (2031-2040)	33.3	155.33	67.0
D4 (2041-2050)	33.6	154.21	66.9

## Conclusion

The forecast up to 2050 indicates an upward trend in temperature and a downward trend in rainfall and relative humidity. This follows the climate trend between 1961 and 2010. Rising temperatures were observed between 1961 and 2010 with 2001 – 2010 being the warmest period. In this study, temperature forecast is projected to increase by 1.4°C by 2050 based on trend analysis using 2001 – 2010 as baseline values. This could imply further proliferation of the leaf miner by 2050. The study has established an upward increase in temperature, attributed to climate change, with concomitant increase in leaf miner abundance between 1980 and 2010.

## Analysis Of Occupancy Logics And Practices In Flood Risk Areas In The City Of Ouagadougou, Burkina Faso

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Since the floods of September 1<sup>st</sup>, 2009, Ouagadougou frequently suffers floods despite the delimitation of easement areas. The purpose of this study is to contribute to the reduction of the vulnerability of populations to flood risks through solutions allowing controlling, mitigating and adapting to its effects. To this end, household-level surveys were conducted. With regard to the reasons for living in these areas, 45.9% of the households surveyed mentioned the inheritance of their plots; followed by 27% who indicated the proximity of these areas to their workplace. For the sanitation of the living environment, 77% of households do not have garbage cans for pre-collection of waste and are located within 100 m of watercourses. This study revealed that floodplain occupants develop a risk culture through flood adaptation strategies. This is manifested by measures such as improvement of building materials and realization of the protection belt at the habitat level. In addition to these adaptation strategies, we recommend an adequate storm water drainage system and the installation of a solid waste disposal system.

**KEY WORDS:** Adaptation strategies; Areas at risk; Burkina Faso; Ouagadougou; floods.

## Introduction

High variability in rainfall recorded during the last century raises concerns about climate at distant horizons with an increase in the intensity of daily rainfall [3]. The city of Ouagadougou, the political and cultural capital of Burkina Faso, has suffered recurring floods in recent decades with that of 1st September 2009 described by all the experts in the field as exceptional climate [2]. Associated with this phenomenon of climate change, the anthropic factors such as strong urbanization, insufficiency of rain water evacuation works, mismanagement of solid waste are

factors which contribute to explain the occurrence of recurring floods in this city during the winter season [5][1]. The level of infrastructure development in Ouagadougou is relatively low with unplanned extension to peripheral areas beyond the control of relevant authorities. Despite the recurrence of floods, these areas are still inhabited by people. Several attempts to relocate those people (allocation of plots and grant of construction equipment) have failed. In the context of the Urban-WASH component of the AMMA2050 project, we wanted to understand the reasons why people keep staying in flood areas, their practices regarding household waste management and the initiatives they are developing locally to increase their resilience level to risk.

## Materials And Methods

To carry out this study, we mobilized materials and methods whose presentation will be preceded by that of the study area.

### Study area

Ouagadougou is the largest and capital city of Burkina Faso, which is located between the latitudes 12.05°–12.68° and the longitudes (–1.83°) – (–1.04°) with a population of 2.5 million in 2015 [4]. It is the cultural, economic and administrative center of the country. The climate is characterized by a single rainy season from May to October, with a peak of rainfall usually recorded at the end of the season and a dry season from November to April. The average annual precipitation was 770 mm / year over the period 1961–2015. This city has been facing floods in the recent decades.

### Data collection

In the flood areas, socio-economic data were collected using a questionnaire administered to 196 heads of households. For the choice of these households, regular distance steps were determined for the different sites of the study. The first individual is chosen at random and the remainders in a systematic way along the route taking into account the proximity of households to rivers (Table 1).

Table 1. Sampling plan by site

Distance (to water course)	Paspanga- Dapoya- Ouidi (6200 m)	Kossodo (1600 m)	Rimkièta (1020 m)	Kilwin (750 m)
100 m	125 m (49 households)	100 m (16 households)	60 m (17 households)	50 m (15 households)
200 m	250 m (25 households)	200 m (8 households)	120 m (9 households)	100 m (8 households)
300 m	250 m (24 households)	200 m (8 households)	120 (8 households)	100 m (7 households)

## Results and Discussion

Figure 1 shows that the main reasons for settling households surveyed in flood risk areas are inheritance (45.9%), proximity to the workplace (27.6%) and parcel allocation (19.4%). In fact, the proportion of surveyed households that received their plots by inheritance is 46.9% for the site of Paspanga/ Dapoya/ Ouidi. This high proportion (46.9%) is linked to the particularity of this site, which is one of the first human settlement areas in the city of Ouagadougou due to its proximity to the northern marigots that were developed as dams in the 1950s.



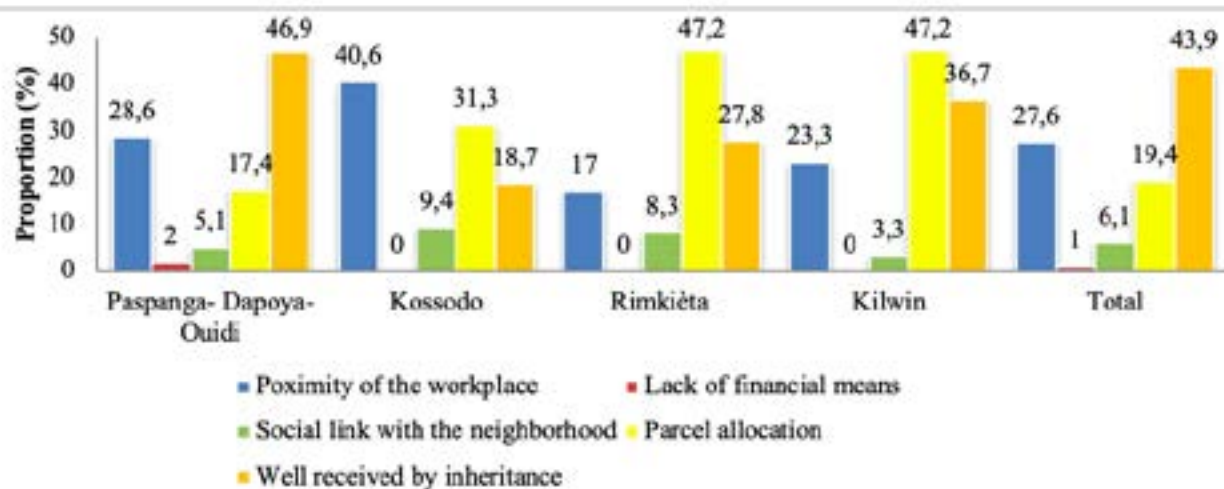


Figure 1. Reasons for occupying flood areas by the household surveyed

On these flood sites, the waste management method is not suitable. In fact, in addition to the use of buckets and plastic bags, 26% of surveyed households do not have garbage cans for pre-collection of their solid waste (Figure 2). 77.3% of households without bins are located within 100m of primary canals and streams and use them as garbage dumps.

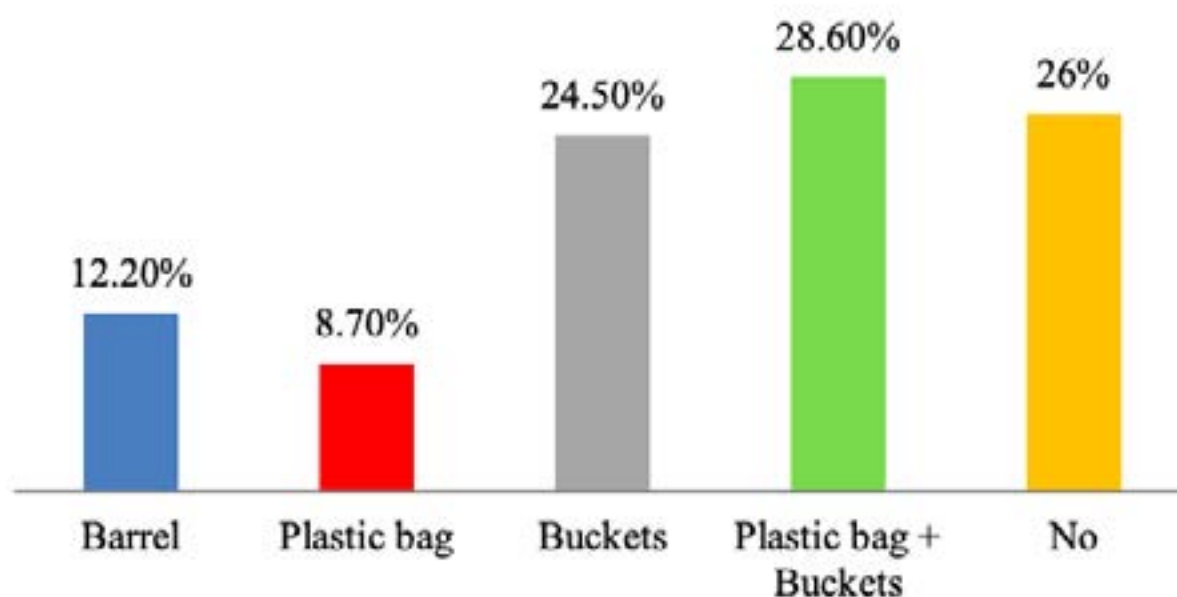


Figure 2. Typology of garbage cans available in the households surveyed

To adapt to floods, populations adopt several techniques which go from course backfills (13.3%), to the containment of the surroundings of gates thus creating a barrier against the submersion of dwellings, by digging trenches for rainwater drainage (Figure 3).

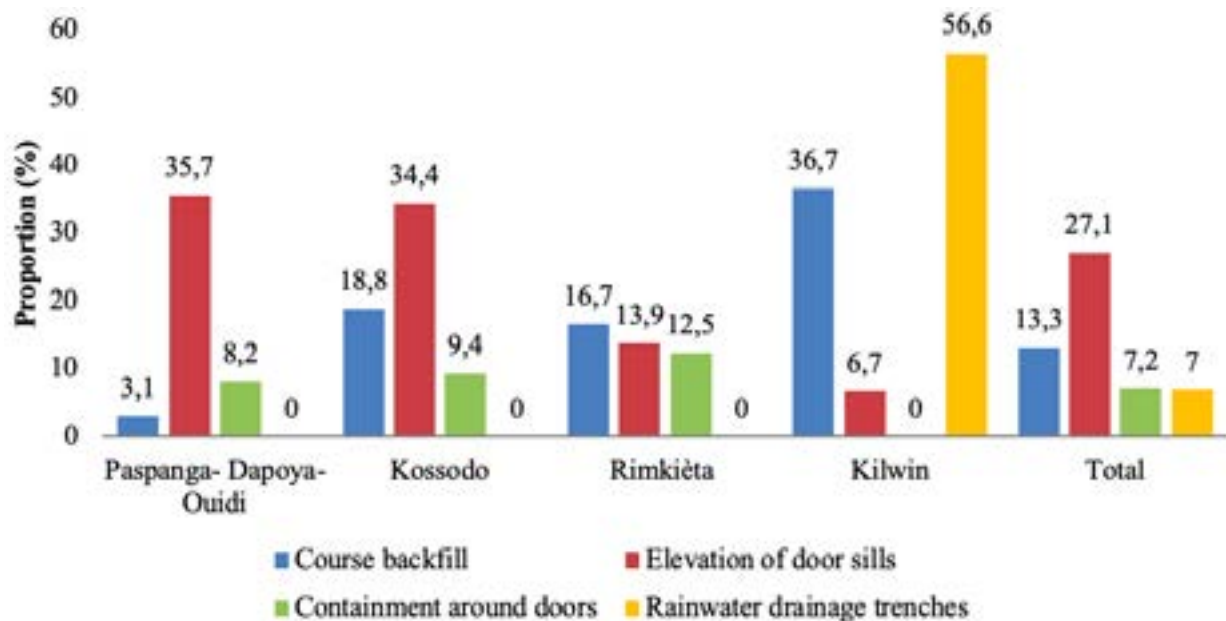


Figure 3. Adaptation strategies achieved during the rainy season

## Conclusion

This research revealed that the main reason for floodplain occupation by surveyed households is the inheritance of plots of land. Solid waste management mode is not suitable and the vast majority of households that do not have garbage cans are located within 100 m of waterways and use them as garbage dumps. This latter situation amplifies the risk of flooding by their size. In order to be more resilient to flood risks, people living in flood areas have developed strategies. To support these endogenous initiatives, it would be advisable for urban managers and planners to install gutters to facilitate stormwater drainage and to take into account these flood areas in the waste management master plan. Awareness-raising should be made towards the populations of these areas to stop assimilating dams and storm drains to garbage disposal channels.

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## **'No room for science here': roadblocks to the utilisation of seasonal climate forecasts by indigenous farmers in the Delta state of Nigeria**

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Indigenous knowledge systems (IKS) have, for decades, played a pivotal role in determining when, where, and how subsistence farmers in sub-Saharan Africa (SSA) produce their food. In recent times, however, food production has been adversely compromised partly due to the increased occurrences of climatic risks. This has overwhelmed IKS ability to predict the weather accurately. With future projections suggesting that climatic risks will become more pervasive and erratic in SSA, scholars are optimistic that seasonal climate forecasts (SCF) can facilitate effective food production by enabling farmers to make informed farming decisions. Despite intensified investment in SCF, farmers in SSA still rely heavily on IKS. Drawing on fieldwork conducted through qualitative approaches in purposively selected communities in the Delta state, Nigeria, this paper highlights the factors that impede farmers' use of SCF. Results reveal that being victims of an imprecise flood warning, and SCF not being a climate service, among others, have contributed to the farmers continued reliance on IKS. This paper argues that co-production of SCF by ensuring it compensates for IKS limitation may facilitate its utilisation because the continued reliance on IKS by farmers, despite its inconsistencies, partly stems from understanding the mechanism of production.

**KEY WORDS:** Climate services; climate variability; indigenous knowledge; Nigeria; sub-Saharan Africa

### **Introduction**

Indigenous knowledge systems (IKS) such as sky and astronomical observations, animal and plant behaviours have informed agricultural decisions made by subsistence farmers in sub-Saharan Africa (SSA) for decades. With future projections suggesting that climatic risks will become more pervasive and erratic in SSA, there are growing concerns that IKS ability to predict weather outcomes accurately would be severely compromised. This, in turn, would severely undermine subsistence farmers' potential to obtain their livelihood. Scholars are, however, optimistic that if farmers plug into seasonal climate forecasts (SCF), they will be able to make more informed decisions and produce their food efficiently. The advocacy for farmers to utilise SCF have gained significant traction due to atmospheric scientists' ability to generate SCF a few weeks to a year ahead and impressive results from pilot studies [2]. These, coupled with the threat to food security and rural prosperity, have triggered investment in SCF. However, the literature suggests that farmers in SSA continue to rely heavily on IKS, despite increasing inconsistencies.

For example, in the aftermath of the 2012 flood disaster that plagued various farming communities in 30 of the 36 states in Nigeria, one would expect that subsistence farmers will, henceforth, utilise SCF when making farming decisions. This is because their IKS failed to predict the flood, which the Nigerian meteorological agency (NIMET) accurately predicted. However, fieldwork conducted in Igboide, Uzere and Olomoro communities in the Delta state, where some households fled their homes to seek shelter in internally displaced camps (IDP), suggests otherwise. A respondent from Uzere, in his 40's, stated:

- If the government is keen on improving our welfare, they should provide loans for us so that after we have planted, harvested, and sold some of the produce we can remit the loan. This would make more positive impacts on the lives of farmers instead of 'wasting' resources on SCF. 'We know our terrain'.

Against this background, this paper seeks to identify the factors that prevent farmers' use of SCF in the Delta state.

## Materials And Methods

The study was conducted in Igbiide and Uzere communities and Uruabe district in Olomoro community, situated *Isoko* south local government area (ISLGA) in the Delta state (Figure 1). This paper draws on 11 focus group discussions, five semi-structured one-to-one interviews conducted between June and October 2015, and July 2016. Two-thirds of the respondents, which comprised women because they are the primary drivers of food production, were between 42 to 85 years. Specific criteria used to select eligible respondents for the study included those that have been farming for a minimum of 10 years, gender, those whose household assets and livelihoods were adversely affected by the 2012 flood disaster, and those that produce most of their food on the low-lying farmlands. The low-lying farmlands are usually inundated around June to October annually. Also, 12 agricultural extension officers working in ISLGA were administered open-ended questionnaires to ascertain the role they play in the interpretation of climate information to farmers, among others. The data were analysed using thematic analysis.

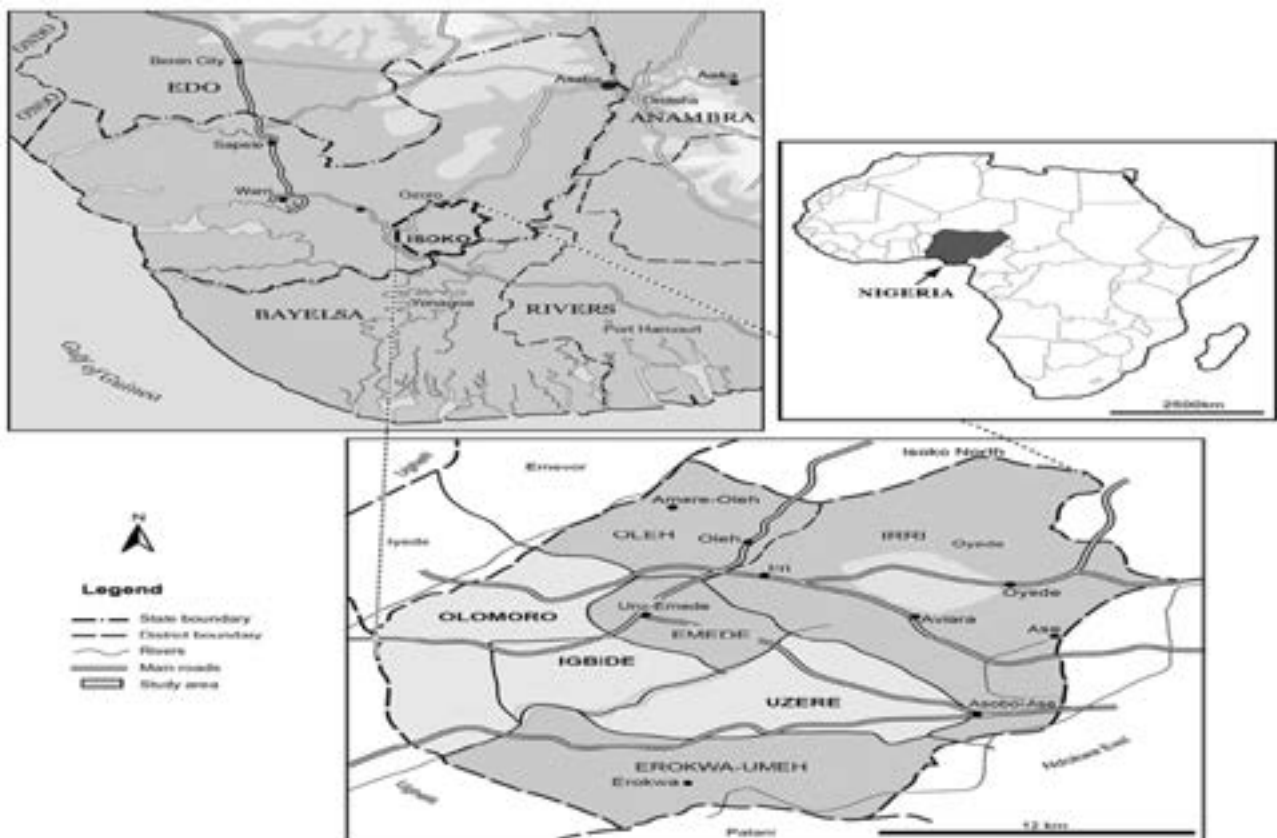


Figure 1. Map of the study areas (2016).

## Results

The reasons for farmers continued reliance on IKS are:

### a. Victims of an imprecise flood warning

Due to the 2012 flood, most houses in ISLGA were either partially or totally submerged. Respondents argued that most community residents had to flee their homes to reside with relatives and friends in unaffected neighbouring communities, while others sought shelter in IDP camps. Barely five months after the flood, NIMET predicted that another flooding, expected to be of the same wavelength to what was experienced in 2012, was imminent in 2013. The Delta State was identified as a potential hotspot. Since IKS – ducks flapping their wings, croaking of frogs, flowering of rubber trees, etc. – failed to predict the 2012 flood, respondents explained that they disregarded indigenous forecast, which suggested that 2013 will be a normal farming season. Another reason for disregarding their IKS forecast was because they could easily reimagine the reoccurrence of another flood disaster immediately after receiving the 2013 forecast. Sadly, after undertaking various precautionary measures, including not planting cassava – the major staple consumed – on their low-lying farmlands, the anticipated flood never occurred. Consequently, respondents (79%) stated that in the event of a future flood warning which contradicts their IKS forecast, they would disregard the scientific forecast. This is not only because they were disenfranchised by the forecast, but also because they were not incentivised for relying on SCF. It can be argued that their continued reliance on IKS despite its failure to predict the 2012 flood is hinged on traditional beliefs and because they understand the mechanism of production. Thus, the co-production of SCF – through collaboration between meteorologists and end-users – by ensuring it addresses the limitations of IKS may facilitate its utilisation.

### b. Lack of climate services

It is important to highlight the difference between SCF and climate services. SCF provide a 'probabilistic indication of how average conditions (such as temperature and rainfall) may develop in the future' [1]. Climate services, on the other hand, refer to the 'timely production, translation, and delivery of useful climate data, and information to enhance decision-making' [3]. From the respondents' perspective, coupled with the responses of extension officers, it can be asserted that households are provided with SCF. SCF are not downscaled specifically to their community, and local communication channels (town-hall meetings and use of town criers), which are useful in disseminating vital information to community members, are not used to communicate SCF. Instead, the mass media is the preferred communication channel. This is problematic as most households in the regions are illiterate, and therefore, can hardly make sense of such information. Also, lack of constant power supply and extreme poverty severely undermines the effectiveness of mass media to communicate SCF. The 2013 flood warning, for example, spread like wildfire via word of mouth. For SCF to become a climate service, the Delta state ministry of agriculture must collaborate with NIMET to generate tailored forecast for agrarian communities and prioritise local communication channels to disseminate such information.

### c. Trust issues

A key issue brought to the fore was the overwhelming distrust respondents have for both the state and federal governments. This could, arguably, result in farmers interpreting SCF heuristically, which can have huge implications for the utilisation of SCF. When messages are interpreted heuristically, enormous emphasis is placed on the messenger's identity or source of the information. For the respondents, heuristic interpretation stems from their communities being inconceivably underdeveloped – lack of good roads and constant power supply – regardless of the enormous contribution crude oil, which has and is still being obtained in substantial quantities in the study areas, has made to the nation's foreign revenue for over four decades.



The respondents explained that lack of rural infrastructures and inability to access resources needed to scale-up food production compromised their fight to transcend living under the global poverty line. Thus, they questioned the rationale behind channelling resources on SCF. From the respondents' lenses, easy accessibility to farm loans and farm machinery, for example, far outweighs the benefits of SCF.

#### d. 'It will not happen again' syndrome

When historical matrix exercises were conducted with the respondents, they asserted that with the exception of 2012, the seasonal floodwater has never transcended the low-lying farmlands. Consequently, they are optimistic that their communities will not be inundated by another flood disaster that can agonisingly impact their assets and livelihoods in a similar magnitude as experienced in 2012. Their unwavering viewpoint was reinforced by the 2013 and 2014 seasonal floods that inundated the low-lying farmlands. Thus, the 'it will not happen again' syndrome hinged on historical narratives has become ingrained in the minds of the people.

### Conclusion

SCF can facilitate informed decision making which would enable farmers to produce food more efficiently in the face of climatic risks. From this study, however, subsistence farmers in the Delta state rely predominantly on IKS because they were victims of an imprecise flood warning in 2013. Other reasons include lack of trust in both arms of the Nigerian government, SCF not being translated into a climate service, and the fact that a flood disaster, which had devastating consequences for household assets and livelihoods, had only occurred once in their lifetime (in 2012). Thus, there is no 'justification to rely on SCF'. It is, therefore, recommended that the relevant stakeholders and policymakers must devote critical attention to these issues that could serve as a stumbling block to SCF in the future, especially because Nigeria has been identified as a nation where extreme weather conditions will become the norm by 2050. In this light, co-production of SCF – which would entail finding out farmers' needs and aspirations, and also ensuring it compensates for IKS limitations – may facilitate its utilisation.

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## Integrated Approach to Sustain Community Livelihoods. Resilience to Hydrometeorological Risks in West Africa

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In West Africa's Sahelian Region, a challenge resulting from climate change is the promotion of approaches to enhance the resilience of rural communities. This necessitates more integrated, simplified and robust innovative methods, which can contribute to the security of rural community livelihoods throughout the year. In fact, in the region, current initiatives for climate

information and services (CIS), which are mainly based on rainfall, are practically useful only over the 4–5 months of the rainy season. Although this approach supports communities to face climate-related risks in the growing season, it can undermine long term adaptation, particularly the transformational resilience in these communities where livelihoods are also largely dependent on groundwater. Therefore, integration of groundwater information into existing climate service tools could significantly enhance the adaptation capacities of these populations, allowing informed decisions to be made about the best use of groundwater along with rainfall trends to improve livelihoods. An approach to community-led climate and groundwater monitoring utilising low-cost technology, has been developed and tested on the UK UPGro-funded BRAVE project through participatory approaches and successful practical experiences in communities in Burkina Faso. It is based on 4 key pillars including rainfall information connected to groundwater status, socioeconomic impact monitoring and a science-citizen interactive learning alliance platform. Preliminary added-value shows improvement of land management, better water use, increase of crop and livestock production, and an improvement of health status and family relationship.

**KEY WORDS:** Groundwater levels, integrated approach, Climate services, BRAVE impacts, West Africa.

## Introduction

Climate risk impacts on natural resources, singularly on water resources and land undermining community livelihoods and well-being as well as their security [2][3]. Approaches and tools have emerged to overcome this challenge. In recent years, climate information and services (CIS) are growing around the world and applicable in diverse sectors. The Global Framework for Climate Services (GFCS) is currently focusing on five sectors. These include health, energy, disaster risks, water resources and agriculture and food security. In the Sahelian (Western Africa) rural areas, most of climate services developed are related to rainfall-based information and are more dynamic on the agricultural and food security sector in the context of rainfed agriculture-based livelihoods. Existing approaches and tools related to CIS that can contribute to enhancing community resilience are, inter alia, Participatory Integrated Climate Services for Agriculture (PICSA), Rainwatch, Participatory Scenario Planning (PSP), ICTP approach, Water Security Approach (WSA). It has been proven that if well-applied they can contribute to support small farmers in terms of best planning for their wet season's agricultural activities [1][5]. They inform, among other, about the start and end of the wet season, the occurrence and length of drought and wet spells, the total amount of the annual rainfall, the length of the rainy season, the performance of the season or month. However, apart from the newly developed Water Aid WSA approach (<https://washmatters.wateraid.org/water-security>), all are rainfall information-based services to reinforce crop production and food security. As for WSA it is not directly connected rainfall to groundwater services even it integrates both information in the process.

In Centre-Western Burkina Faso, the persistence of climate negative effects forces farmers to intensify vegetable activities, singularly in the dry season (onion, cabbage, etc) when groundwater is the unique resource for watering their crops (during the dry seasons and dry spells periods in the wet season). However, there is competition for this resource for gardening, drinking, brick making, local beer making. These sources also dry up during the dry seasons leading to limited access to water and loss of vegetable amplifying the threat of food and livelihoods insecurity. In fact, in the area climate related disasters, in particular droughts are still jeopardizing farming systems. In addition, rainfall last only 4–5 months (June–October) during a year making climate information useful in the wet season only. Furthermore, similar to the Sahel, future rainfall trend in the area is difficult to predict, due to climate variability and limited understanding of future rainfall trends [4]. This rainfall-based climate information only associated to uncertainties can undermine long term adaptation, particularly the sustaining resilience in communities where livelihoods are largely dependent on groundwater. In this context, a challenge resulting from climate change is the promotion of approaches that connect

rainfall information to the use and planning of groundwater for improving the resilience of rural communities in the face of droughts.

Recent studies found that land use management strategies can increase groundwater availability [7]. Clarkson et al. (2019) and Tall et al. (2018) mentioned that climate services can help plan agricultural water use and innovation behaviours for food security[1][5]. In addition, engaging users in the process, particularly outreach to informal networks and communicating information pathways for early actions can spread climate services and allows end-users to provide valuable feedbacks [6].

The approach being developed through the BRAVE research project (Building understanding of climate variability into planning of groundwater supplies from low storage aquifers in Africa (<https://braveupgro.org/>), jointly funded by DFID and NERC) can be a starting point to overcome such challenges.

## Objectives of the paper

The paper aims to present the theoretical integrated approach incorporating groundwater-based information as an essential ingredient in delivering CIS to allow informed decisions to be made for combatting droughts in Burkina Faso's communities. First, the framework is presented along with how it helps community to be engaged in the implementation process. Second, how it impacts on farmers' access to water and improve their livelihoods is summarised. Third, challenges influencing its implementation are raised.

## Methods

The development of the Integrated Climate Service Framework is based on three main processes:

- Assessing climate information available in community and how it is used to overcome climate risks, particularly droughts and their needs in terms of resilience capacity building;
- Documenting (gaps and challenges) the existing tools and approaches (PICSA, Rainwatch, ASP, WSA) pertaining to the climate services in the view of the BRAVE project aim and community needs. The challenges were how our approach can complement the services already provided by these existing tools. On this basis the theoretical approach has been built.
- Co-testing and validating with stakeholders and scientific community the theoretical approach in four farming Burkinabé communities. This includes co-implementing the approach and assessing the impacts via participatory approaches (field observation, discussion with farmers and household interviews).

## Results

### Challenges in communities in terms of climate information and services

The communities lack specific climate information and services about their areas; the challenge is, how to use it to reinforce their resilience. In addition, they expressed the needs of how to manage their wells so that these can serve in the dry season for their different activities, with priority to their vegetable. Figure 1. shows how groundwater recharge is dependent on rainfall amount and distribution, and how quickly wells in communities dry up in the dry season.

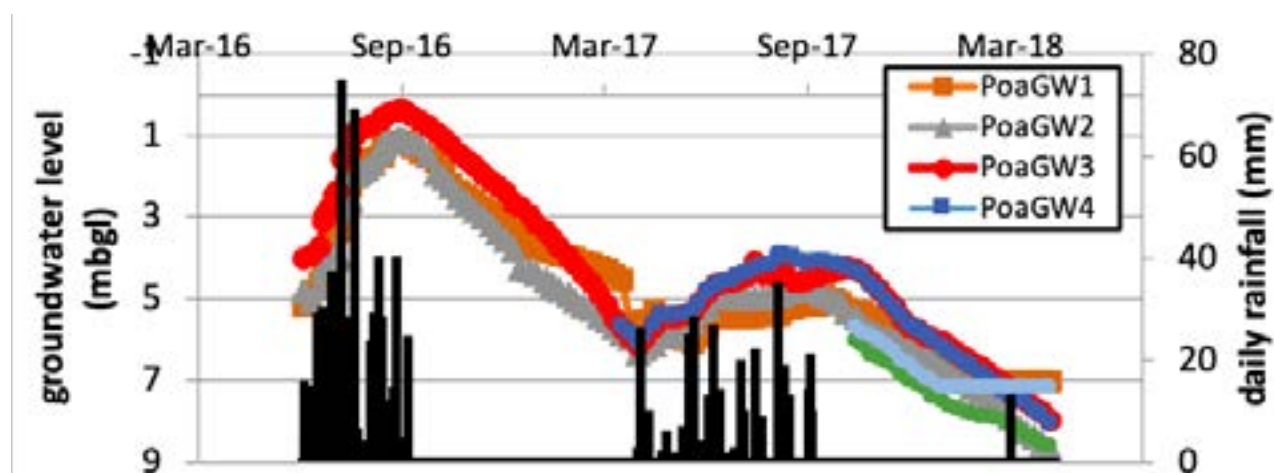


Figure 1. Daily Rainfall-GWL trends at Poa -Burkina Faso- (BRAVE, 2018)

### Theoretical framework, and its implementation with engagement of stakeholders

The Pillars of the framework include a sciences-community interactive learning platform, a radio listening programme, rainfall information, connected to groundwater status and a farmer socioeconomic impacts monitoring. The approach aims to increase awareness of local communities and increase their resilience to extreme weather events. This 4-pillars framework is presented by Figure 2.

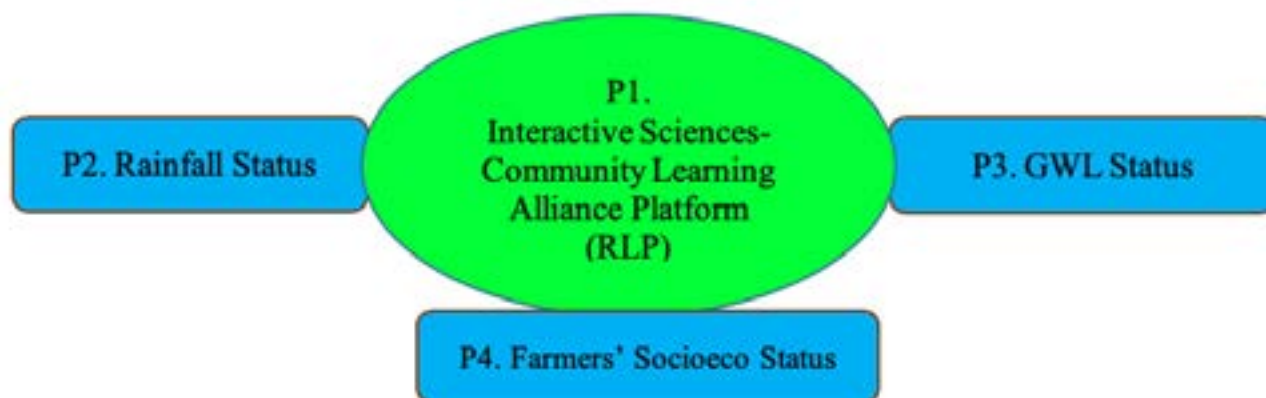


Figure 2. 4 Pillars-based smart approach for delivering climate services in BRAVE's Communities

The Pillar P1 "Interactive and dynamic learning platform" is a science-community knowledge exchange platform. This is the core of the approach. It includes the BRAVE research scientists (both physical and social scientists), International NGOs that support the national and local associations actively involved in the project. These are Christian Aid Sahel, International Water and Sanitation Centre, Lorna Young Foundation, Réseau Marp, UGF/CDN (women farming association) referred to as practitioners in the rest of the paper. In the process, data collection is planned and conducted by all the team. The BRAVE researchers provide insights about understanding of groundwater and rainfall trends, and community vulnerability. Solutions are then co-identified. These are those likely to contribute to reducing community vulnerability and sustain their resilience along with climate services value chain, around groundwater. Through this partnership, data infrastructure, identifying and training local rainfall and groundwater data monitors, and how to interpret the data is a scientific matter when how to aware community, setting learning group platform relate to practitioners. Community defines their needs that lead to the co-definition of themes discussed later (during the radio emissions) and then

implement by themselves, best times to record and broadcast emissions. Communities also share knowledge gained and experiences with peers. Local radio selected by community themselves conducts the emission and broadcasts it. The radio also writes down the scripts so that each techniques and strategies discussed and the process can be well documented. The **Radio Extension Program** is key for communicating resilience-based information and training via knowledge exchange among farmers in each community. The knowledge exchanges include:

- improving access to groundwater by promoting rain harvesting techniques, proper use of groundwater for multiple use;
- promoting sustainable land management practices which improve soil fertility and water retention on the farms, the use of organic fertilisers, and can increase groundwater levels;
- improving crop yields, by providing information on drought resistant and adapted crops in line with agricultural calendars;
- improving health and nutrition by promoting information on prevention of water related diseases such as cholera, increase of sources of revenue (eg. diversifying livestock).

#### Rainfall information (Pillar P2).

Here, based on historical record and ongoing data monitored by community members, indicators from Rainwatch tool (<http://www.rainwatch-africa.org/>) are used to inform community behaviour. In addition, yearly PRESAO meeting conclusions associated to ICTP quarterly forecast bulletins have been connected to help in planning growing seasons.

#### GW status (Pillar P3).

This pillar corresponds to groundwater level trend-based information. The levels of groundwater inform the prioritising of use of groundwater. For example, for gardening activities, when the groundwater level gets low (2/3) for a specific well, the gardeners use the remaining water for only irrigating their crops. For any other uses, other sources are advised. The groundwater levels also used to decide on when to start vegetable activities.

In practice, rainfall and groundwater level data analysis are connected. For instance, relatively intense rainfall means (in this case) high groundwater levels at the end of season; early cessation of rainfall means early start of vegetable gardens to avoid losing water from wells through abstraction for other uses (brick, local beer, drinking) and natural groundwater recession.

#### Monitoring socioeconomic impacts on Farmers (Pillar 4).

Consists of monitoring impacts. This is through observatory surveys: how crops are developed compared to traditional farming techniques, crop productivity. This component helps measure the power of the framework, the gaps and how to improve it.

### IMPACTS

Preliminary added-value shows an improvement of better use of water, land management, and increase of crop and livestock production, health status and family relationship.



## KEY FACTORS INFLUENCING THE PROCESS

The performance of the approach is influenced by factors including:

1. Local partners including local-based associations (their influence in communities and initiatives in the area, engagement).
2. Good year of rainfall and availability of gwl/rainfall data.
3. Capacity building (of all stakeholders) in terms of how radio listening program works, the use of knowledge and sharing experience with peers;
4. Local radio credibility: how community perceived the radio, its area of broadcast and capacity in such a program;
5. The perceptible added-value on farming activities in terms of agricultural and livelihoods impacts.

## Conclusion

The approach developed through the BRAVE project improves the resilience of farming communities to droughts and their access to water which impacts on both livelihoods and health in Burkina Faso. This can be a start point of a strategic approach to future national disaster risk reduction and resilience to support increased water security for the poorest farmers for the wider Sahel region and Western Africa. Further work involves scaling up the approach.

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## Reconciling Agricultural and Forestry Systems for Food Security in Nigeria: A land use optimization-modelling approach

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Climate change and population growth in Nigeria is exerting pressure on its agricultural and forestry systems triggering land use conflicts. This pressure is primarily from deforestation further enhanced by a lack of integrated policy and management for both agricultural and forestry systems resulting in food insecurity. To understand land use conflicts in Nigeria, I use the General Algebraic Modelling Systems (GAMS) to construct an integrated assessment model for the agricultural and forestry sectors in Nigeria. This quantitative model jointly assesses the implication of changes in land use systems and policies on agricultural production and forest conservation taking into consideration important natural and societal developments. Stakeholders' perceptions are included in depicting farmers' motivations, restrictions, and options in a changing environment and society to identify plausible land use adaptation and conflict mitigation options. Options for reconciling agricultural and forestry systems differs across Nigeria. Food insecurities differ among population groups primarily because of differences in income. Integrated rather than fragmented land use options are most feasible in jointly achieving development goals for Nigeria with lesser externalities.

**KEY WORDS:** Food security, Agricultural and forestry targets, Land use optimization, Climate adaptation

### Introduction

Two hundred million persons at an annual population growth rate of 2.5% in addition to uncertainty in climate and societal changes challenges development goals particularly food security in Nigeria. Food security challenges primarily originate from conflicts in agricultural and forestry land systems causing changes in the systems. Agricultural and forestry land systems constitute 77.7% and 7.7% of land area in Nigeria. However, pressured by an increasing population and a changing climate, society and even seemingly divergent policy objectives, these systems have failed to ensure food security. The challenge for Nigeria is to simultaneously maintain a 5% annual increment in food production and conserve 10% of its land area as forest. With agriculture already occupying 77.7% of the total land area, what will a 5% annual increment in food production and a 10% conservation of land area mean for both agriculture and forestry systems? Would these targets require an expansion or intensification or an integration of both systems? This paper provides insights into opportunities and trade-off for optimal land use systems in Nigeria by answering questions such as how can its land use be optimized for biodiversity conservation and agricultural production targets? Amidst the aforementioned targets what plausible governance, management technologies and policy adjustments can aid food security in Nigeria and at what cost?

### The Nigeria Agricultural and Forestry Systems

The Nigerian agricultural and forestry systems are suboptimal [7]. This does not only stress the need for integrating both systems but stakeholder perceptions in a food security assessment. However, existing assessments are purely quantitative [3][1] and neglect stakeholder perceptions while other assessments in addition to this, neglect forestry systems [4][2][6]. These gaps spur from data and technological deficiencies.

## Methodological Framework

Qualitative and quantitative research tools from natural sciences, engineering, agricultural economics, social sciences, and other disciplines and combined the methodology (figure 1) is explained hereunder.

### Case Study Description, Data Collection and Processing for Integrated Food Security Assessment

To overcome data deficiency and to understand salient issues for the construction of the Nigerian Food Security (NiFS) model in this paper, I combined primary and secondary data sources. I engaged in key informant interviews, questionnaire administration and focused group discussions with stakeholders such as farmers, herdsman, hunters, gatherers, foresters, loggers, food trade intermediaries, agriculture extension workers, agronomists, policy makers, land decision makers, landowners, natural resource experts, researchers, farmer associations, nongovernmental organizations, and government ministries and agencies. These interviews and discussions essentially gave a deeper understanding of food security issues in Nigeria. Questionnaires yielded data on stakeholder's preference and perceptions on relevant issues. I consulted archives of relevant international, governmental, nongovernmental and private organizations, agencies, research institutes and local associations across Nigeria. I collected robust dataset on climate, climate change impacts and adaptations, agricultural and forestry management technologies, food production, consumption and loss, deforestation, afforestation, biodiversity, nutrition, food trade, food value chain, livelihood, income, food production, biodiversity conservation, food trade policy, and other data. The NiFS model is programmed in GAMS. It is a statistical model thus required quantitative data. All data were converted to quantitative data, saved in Microsoft excel and transferred to GAMS using the general data exchange. A similar model proved useful in assessing impacts of oil palm yields in Nigeria[5].

### Model Based Scenario Analysis

The NiFS model analyzed at the state, geopolitical, ecological and socio-economic resolutions. The model components include indices, parameters, tuples and equations. Equations used for the NiFS model include welfare, resource, process, consumption, production, ecosystem services, habitat requirement, and nutrition equations with constraints and coefficients. Using linear programming, NiFS model use these equations to find options for jointly ensuring food security and optimizing land use for biodiversity conservation and food production in Nigeria. The base year for NiFS model is 2010 and it is calibrated with data for the same year. NiFS model starts with maximizing welfare from agriculture and forestry land uses using observed values. It then enforces agricultural and forestry targets and food security constraints. Model scenarios include a variation of presence or absence of management technologies and policies drawn from national policy documents and stakeholder perceptions gotten during surveys. The fully calibrated NiFS model runs from 2010 to 2070 with analysis for every 5 years. Model based scenarios for same timeline include:

1. Business as usual (BAU) scenario with management technology and policies unchanged.
2. Target enforced scenario either confines the model to all targets or a combination of certain targets alternatively. These included minimum nutrient by human populations, 5% annual food production increment, habitat requirements for endangered mammals and ecosystem and food production targets.
3. Governance scenario controls governance for agricultural and forestry systems. Governance options comprised food sovereignty through controlled trade, provision of services such as farm input, storage and transportation facilities, market access, food price regulation, management technologies, conservation of 10 % and 25% of total land area as forests representative of all ecological regions.

## Evaluation of Scenario Results

Food insecurities in Nigeria result from a mix of intertwined factors, the most dominant factors being income and reduction in crop yield. About six out of every ten Nigerians are food insecure. The rural population in Nigeria is twice as vulnerable to food insecurity as the urban population. Majority of habitats for endangered mammal species in Nigeria are fragmented. Strict protection enforcement will mitigate fragmentation, connecting adjacent habitat fragments through corridors and including stakeholders in managing these habitats will ensure more protection. There is an inverse relationship between food security and biodiversity conservation, however, with sustainable management technologies, both land uses can be optimal with lesser externalities.

Business as usual approach to land use systems will reduce about 11% of forest cover by 2070 and more intensive inputs will be required for agriculture over the years. Assessing the efficiencies of management technologies and interventions especially input subsidies in Nigeria reveal the need for a shift to more sustainable systems. Hence, the need for improving subsistence farming constituting 80% of the Nigerian farming systems. A simultaneous rather than sequential optimization of agricultural and forestry policy targets show a lesser requirement for land area thus the need for integrated management of both systems.

## Conclusion and Next Steps

NiFS model although challenging to construct allowed for a holistic assessment of food security in Nigeria hence provided more reliable insights on trade off needed for achieving food security in Nigeria. This model will be scaled to assess impacts of extreme climate events on food security in Nigeria. Also leveraging on economy of scale, the model will be used in finding options to improve smallholder farming in Nigeria.

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## Effectiveness of seasonal forecast based recommended farm management practices in small-scale farming systems of South Africa

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An 'Integrated crop model and seasonal forecast information' approach has been utilized to improve decision capacity in climate variability management. There is however limited knowledge on the effectiveness of the decision formulation process. The study therefore evaluated the effectiveness of the decision formulation process and seasonal forecast-based recommendations in South Africa. The study used seasonal forecast information from the CFSv2 model and historical weather data (2011–2017). DSSAT 4.7, a crop model was calibrated based on farmers in Limpopo and Eastern Cape, South Africa. Different combinations of farm management practices were evaluated: organic amendments, fertilizer, varieties and irrigation. DSSAT model simulated yields of different crops and combinations of practices under a range of seasonal forecasts and measured data. Two decision scenarios were realized: high decision capacity and low climate sensitivity scenario, predominant in the Eastern cape. The high decision capacity and high climate sensitivity scenario, predominant in Limpopo. Most of the recommended farm management practices leading to high yields contained organic amendments, long seasoned varieties, fertilizer and irrigation. Seasonal forecast based recommendations were effective in Limpopo compared to the eastern cape for cereal and vegetables compared to legume crops. There is greater confidence in the use of seasonal forecast-based recommendations in Limpopo where forecasting skill is high.

### Introduction

Small-scale farmers have highlighted climate change as one of the major threats to their livelihood [3]. Climate variability is characterized by unpredictability in the onset, cessation of the rainy season. This leads to extreme crop yield variability and food insecurity in Southern Africa. This therefore increases the need for improved decision making to improve climate variability management [4]. Use of seasonal forecast information enhances decision making leading to improved climate variability management. Such decision support can be improved through integrating seasonal forecast information and crop models. Significant research has been undertaken evaluating a range of farm management practices such as crop types, varieties, fertilizers and different planting dates on productivity using 'integration of seasonal forecast information and crop models' [1]. Analysis of the farm management strategies resulting from such research can therefore be used to stream line farm management decision making. Potential farm management decision scenarios applicable for Southern African conditions are categorized into (1) low decision capacity and low climate sensitivity, (2) High decision capacity and low climate sensitivity, (3) High decision capacity and high climate sensitivity, and (4) Low decision capacity and high climate sensitivity. The decision scenarios do not provide information of the corresponding specific recommended farm practices. From research, a wide range of management practices can be recommended to farmers. Such practices include conservation agriculture, different planting dates, organic ground cover, and intercropping [2]. There is however need for further research to assess the conditions under which such recommended practices are effective in the future.

This study therefore sought to assess the effectiveness of the decision formulation process and the seasonal forecast based recommended farm management practices under varying conditions. This was undertaken through comparative assessment of the seasonal forecast information based recommended farm management practices in the context of the response



of such practices under historical measured weather data for Eastern Cape and Limpopo, South Africa under different farmer types.

## Materials and methods

### Site characteristics

The study was based on Nkonkobe and Lambani communities in the Eastern Cape and Limpopo provinces in South Africa. Farmers in both locations were categorized into classes using the farm typology approach. In Lambani, Limpopo, farmers were classified into mixed farming, horticultural farming and off farm income-dependent. In the Nkonkobe, Eastern Cape, farmers were classified into social welfare-dependent, enterprising pensioners, struggling subsistence, horticulture-dependent and cooperative crop farmers.

### Integrating seasonal forecast and crop models

The DSSAT 4.7 crop model was calibrated, for the different crop types, farmers and locations. The calibrations were based on the bio-physical and socio-economic characteristics for the different farmers from Limpopo and Eastern Cape. The crop model was coupled with seasonal forecast information from the CFSv2 model [5] and historical weather data for Nkonkobe, Eastern Cape and Lambani, Limpopo (2011–2017). Crop yields were derived from simulating the interaction between the different sets of seasonal forecast information and combination of farm practices using the DSSAT crop model for different seasons, crops, farmer types and locations. The combinations of practices contained multiple levels of major farm management practices: organic amendments, different varieties, fertilizer and irrigation.

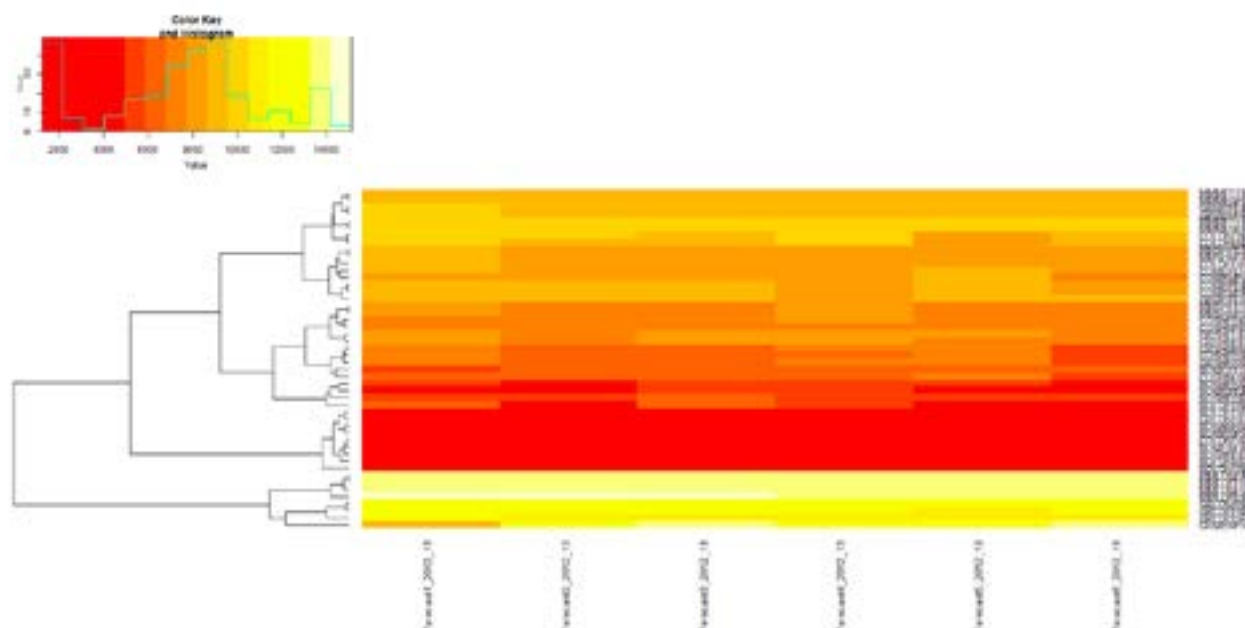
### Assessing effectiveness of farm management practices

The seasonal forecast-based recommendations were derived from selecting the combination of farm practices leading to the highest yields. The simulation yield outputs of the different farm management practices and varying seasonal forecasts for each case were plotted in 'heat maps' with farm practices against seasonal forecasts. The different yield patterns were identified by the different colour codes, with 'red', 'yellow' and 'white' denoting 'low', 'high' and 'higher' yields respectively. Decision scenarios were formulated based on assessing the pattern of yield response to the interaction between seasonal forecasts and the different combination of farm practices. The recommended practices leading to high yields, identified from each heat map were denoted by the 'white' and 'yellow' colour codes. Assessment of the effectiveness of the seasonal forecast-based recommendations was measured using percentile ranking. High percentile ranking of the seasonal forecast based recommended practices indicated effectiveness of the recommendations as well as the process.

## Results and discussion

### Seasonal forecast-based decision scenarios

The study realized 2 major decision scenarios. The most predominant decision scenario for the eastern cape was the high decision capacity and low climate sensitivity where there is noticeable change in crop yields resulting from a change of management practice (Figure 1). The high decision capacity and high climate sensitivity where there is noticeable change in crop yield response resulting from a change of management practice as well as noticeable change resulting from the seasonal forecast considered was predominant in Limpopo. Such decision scenarios have the potential to improve the decision-making capacity to enhance climate variability management. In most cases the recommended practices contained long seasoned varieties, fertilizer and irrigation in both locations (Figure 1).

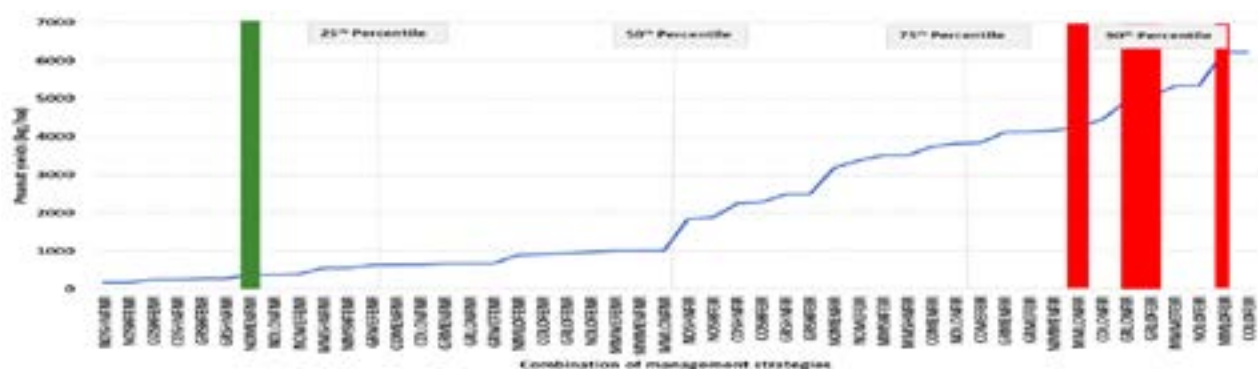


**Figure 1.** Maize yields amongst the different climate variability management strategies and seasonal forecasts for horticulture farmers in the Eastern Cape, South Africa (2012/13) (*high decision capacity and low climate sensitivity*).

### Assessment of potential for crop yield improvement

Farmer modelled yields were lower in the Eastern Cape compared to Limpopo. The pattern was more noticeable in legume crops such as dry bean compared to other crops. In most cases the highest yields were derived from seasonal forecast-based recommendations. On the contrary, farmer modelled yields were the lowest in most cases especially for legumes crops. Seasonal forecast-based recommendations led to crop yield improvements of at least 100% in legume crops such as peanut.

*Seasonal forecast-based recommendations Vs similar practices under historical weather data*  
Most of the seasonal forecast-based recommendations (red columns) were above the 50<sup>th</sup> percentile. About 12% of the recommendations were below the 50<sup>th</sup> percentile. In about 86% of the cases the recommended practices led to higher productivity compared to the current farmer practices. The pattern was more specific in the 2014/15 season, amongst social welfare dependent farmers for the peanut crop in the Eastern Cape, South Africa (Figure 2).



**Figure 2.** Seasonal forecast based recommended and farmer practices and yields in the context of the performance of the same practices under historical measured data for social welfare dependent farmers, Eastern Cape, South Africa (2014/15).

NB: Green Bar: Current farm practices and corresponding yields. Red Bar: Seasonal forecast based recommended practices. Blue line: Yields based on historical weather data.

### Comparative decision making under different climate conditions

There were no notable differences of the percentile ranking between the different farmer groups in both locations. The study however showed a generally higher percentile ranking in Limpopo compared to the Eastern Cape. This was manifested through a relatively higher percentile ranking of about 70 across all seasons in Limpopo. In the eastern cape, there was however relatively lower percentile of as low as 29 (Table 1).

The percentile ranking differed with crops and locations. The percentile ranking ranged from 60–96 in Limpopo for cereal and vegetable (maize, cabbage, tomato). For legume crops, such as peanut and dry bean, the percentile ranking value fluctuated from 60–94 (Table 1).

**Table 1.** Percentile ranking values of the seasonal forecast-based recommendations in the context of the response of the practices under historical measured weather data for cabbage in South Africa (2011–2017).

NB: 0–25: Blue; 25–50: Green; 50–75: yellow; 75–100: Orange.

Year	Eastern Cape		Limpopo	
	enterprising pensioners	horticulture dependent	cooperative crop	horticultural
2011-12	29	58	48	71
2012-13	37	28	63	85
2013-14	40	85	85	85
2014-15	90	38	69	83
2015-16	35	54	41	83

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### Decision Processes To Curb Challenges In Water Quality And Adequacy In Blantyre City In A Changing Climate

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A learning lab on exploring decision processes to limit challenges in access to adequate and safe water in Blantyre city, as a case study, in a changing climate was conducted. The aim was

to guide policy direction in mitigating against shortages of safe water in the context of changing climate. The outcome will guide choice of best practices for policy formulation to ensure adequate access to safe water. The research project brought together stakeholders in water service delivery in Blantyre city. Through rich, facilitated group discussions among stakeholders in the learning lab, data was collected and analysed. The need to build and enhance resilience for climate variability and extreme events is more urgent today than ever before. This must be based on strengthening the following: forecasting of climate and weather, adequate information sharing, partnerships of institutions functioning on projects with related objectives, research capacity in water service delivery decision processes, and linkages between research results and decision. It is evident that stakeholder commitment and participation, harmonization of legislation and institutional arrangements on environmental management and a strong political will are necessary for the success of creating resilience towards impacts of climate change and extreme events. Disaster preparedness and recovery from such extreme events requires budgetary support. Resource identification and requisite management of such resources are paramount in this process.

**KEY WORDS:** sustainable development, weather, climate variability, governance

## Introduction

Although progress has been made in the development of water resources, there are environmental issues that the country of Malawi needs to address in order to conserve resources from further depletion and degradation. The Population Action International (2010), reports that Malawi is one of the world's most water stressed and least climate resilient countries, facing considerable challenges of declining agricultural production as well as rapid population growth rates. Blantyre city receives most of its potable water from the walkers Ferry pond, which is located near Shire River in the Southern part of Malawi. The amount of water received in the city, therefore depends greatly on the water levels in the Shire River. The available total renewable water resources were estimated at 1,617 m<sup>3</sup> capita<sup>-1</sup> year<sup>-1</sup> in 2004 and at less than 1,400 m<sup>3</sup> capita<sup>-1</sup> year<sup>-1</sup> in 2008[3]. The per capita water availability is declining due to rapid population growth. Water demand has been on the rise in Blantyre city as exemplified by the increase from 78,000 m<sup>3</sup> day<sup>-1</sup> to 85,000 m<sup>3</sup> day<sup>-1</sup>.

Issues that contribute significantly to the depletion and degradation of water resources in Malawi include poor management of catchment areas, environmentally unfriendly agricultural practices, rapid population growth, inappropriate discharge of industrial wastes and the weak institutional structures for enforcing the Water Resources Act [2]. Over 70 percent of Blantyre urban population lives in informal settlements with poor living conditions, characterized by minimal access to social infrastructure or basic urban services [4]. Climate change is expected to worsen the vulnerability of these communities through impacts on water availability and quality leading to water stress, energy crisis, food insecurity and human health in cities as well as destruction of infrastructure [5]. The high increase rate in urban populations such as in Blantyre, urban poverty and water-insecurity calls for urgent attention towards climate change adaptation vis-à-vis water service delivery in cities.

The objective of the discussion was to explore the decision processes to curb challenges in water quality and adequacy in Blantyre city in a changing climate.

## Methods

To achieve this objective, a situational analysis was conducted in Blantyre which identified existing gaps in relation to water under the guises of a changing and variable climate. Further to that, the project brought together stakeholders to explore the decision processes to curb

challenges in water quality and adequacy in Blantyre city in a changing climate. Through rich, facilitated group discussions among stakeholders in the learning lab, data was collected and analysed to understand the decision processes that would curb water quality and adequacy challenges. This activity decided to focus on the water situation because it is a cross-sectoral issue and also it was one of the most relevant issues identified in the situational analysis undertaken prior to the learning labs.

### Guiding Questions

The learning lab proceedings and information consolidation were guided by the following questions:

- What are the decision pathways and/or mechanisms in water supply quality and distribution (adequacy)?
- How can we overcome the challenges in water quality and distribution management with respect to climate change?
- What are the desirable scenarios in water service delivery? What could be the best practices in decision making processes?

## Results

### Challenges and decision pathways

Table 1. Challenges and decision pathways

Challenge	Implication(s)	Decision
Deficient Water catchment management	<ul style="list-style-type: none"> <li>Deforestation leading to siltation</li> </ul>	<ul style="list-style-type: none"> <li>Annual tree planting</li> <li>Tree survival rate monitoring</li> <li>Acquisition of dredgers to increase dam capacity</li> </ul>
Unpreparedness for extreme events	<ul style="list-style-type: none"> <li>Loss of lives</li> <li>Floods causing infrastructure damage</li> <li>Droughts leading to low water levels</li> <li>Virement of resources that would have been used for other developmental projects</li> </ul>	<ul style="list-style-type: none"> <li>Development of reliable computer-based early warning systems</li> </ul>
Multiple land ownership in the catchment area	<ul style="list-style-type: none"> <li>Lack of land control in the catchment area by the relevant stakeholders, for example, water-related utility companies</li> </ul>	<ul style="list-style-type: none"> <li>Acquisition of land along the rivers by institutions in the water sector, and compensation of the locals</li> <li>Engagement of local communities in problem solving (participatory approach to problem solving)</li> </ul>
High water pumping cost	<ul style="list-style-type: none"> <li>Inadequate and unreliable water supply</li> <li>High cost to the consumer</li> </ul>	<ul style="list-style-type: none"> <li>Generation of alternative energy to augment the existing hydro-electric power.</li> </ul>
Trans-boundary water resources management	<ul style="list-style-type: none"> <li>Difficulty in controlling water catchment areas that transcend international boundaries, e.g., some of the water flowing into Lake Malawi comes from Tanzania and Mozambique</li> </ul>	<ul style="list-style-type: none"> <li>Strengthening of trans boundary cooperation and integrated natural water resources management for the water users sharing the same water source</li> <li>Development of a common water resource management plan to achieve sustainable water adequacy and quality.</li> </ul>
Political interference	<ul style="list-style-type: none"> <li>The front-liners of water service delivery receive inadequate resources to implement their decisions.</li> <li>Sometimes, political influence negate on efforts to efficiency in water supply.</li> </ul>	<ul style="list-style-type: none"> <li>Prioritization of the water sector as an important aspect in development so that enough human and financial resources should be allocated to the sector.</li> <li>Positive political will to support the development of an efficient water supply system</li> </ul>



## Desirable scenarios and Best practices in decision making

Table 2. Desirable scenarios and best practices in decision making

Desirable scenario	Best practices in decision making processes
Reliable power for water pumping	Exploring alternative sources of energy with stakeholders
Sustainably conserved catchment area	Engagement of stakeholders from problem identification to solution implementation
Supportive political will	Harmonizing conflicting legislation and lobbying the government through parliamentary committees
Evidence-based, research supported solutions	Academic institutions partnerships

## Conclusion

The decision processes to moderate challenges in water quality and adequacy in Blantyre city, in a changing climate, call for multi-sector participation and knowledge-based approaches. The policy direction in this context must focus on options available to enhance communities' resilience towards impacts of climate variability and extreme events. This must recognize the nexus among access to water, public health and climate change. Best practices in policy formulation and implementation will thus be informed by knowledge generated from research and significant practices that have yielded confirmatory outcomes. Emphasis should be located on collaborations of the City Council, water utility based organisations and research institutions with various water users such as commerce, institutions, households and the public health sector. The resourcing of such mechanisms need to be well-defined at the onset to avoid delayed implementation of critical decisions in the nexus of water, climate and public health.

## Recommendations

- a. Need to enhance / create resilience for climate variability and extreme events.
- b. Strengthen forecasting and climate & weather information sharing.
- c. Need partnerships of institutions working on projects with similar deliverables / objectives to optimize resources use and create synergy.
- d. Strengthen research capacity in water service delivery decision processes.
- e. Enhance and support linkages between research results and decision.
- f. Stakeholder engagement to begin from initial stages i.e. problem characterization and solution pathways identification.
- g. Harmonisation of relevant laws on water service delivery by the Ministry of Agriculture, Irrigation and Water Development (MoAIWD).
- h. Rearrange the institutional platform for environmental issues so that all environmental management issues fall under one platform.
- i. Concerted efforts are needed to accelerate implementation once decisions are made.
- j. Decision pathways should include identification of funding mechanisms / resource support.

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## Contribution of dry forests and forest products for climate change adaptation in Tigray Region

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Despite the ecological role of dry forest, the contribution of dry forest for climate change adaptation is overlooked. Hence, the objective of this study was to assess the socioeconomic contribution of dry forests and forest products to climate change adaptation in Tigray region, Ethiopia. A total of 170 households, 15 key informants and one focus group from the existing three dry forest vegetation type were surveyed. For this study, an integrated qualitative and quantitative data analysis approach was used. More than 94% of the total household visited at least once a month to access the forest and forest products. There is Significant difference in terms of dry forest income ( $p < 0.05$ ). Overall, dry forest contributes about 16.8% of the total household income. Dryland forest income reduced the area between the line of equality and the Lorenz curve, and the Gini- Coefficient by 21% in dry evergreen Afromontane forest users, 3.02% in Combretum-Terminalia woodland users and 3% Acacia-Commiphora woodlands users. Gender, occupation, wealth status and distance of the forest from their house were variables that significantly affected the income level from Combretum-Terminalia woodland users. Age of the respondent in Acacia-Commiphora woodlands users while family size of the household in dry evergreen Afromontane forest users influenced dry forest income level. Therefore, dry forest income has been becoming crucial livelihood strategy in response to the changed climate in the study area.

**KEY WORDS:** Climate Change, Dry forest income, Livelihood resilience, Vulnerability, Tigray

### Introduction

Currently, climate change is one of the serious environmental, social and economic threats facing our world. Adaptation and mitigation are two broad strategies for tackling the resulting problems. In the recent international and national negotiations, sustainable forest management is one of a key strategy promoted to reduce the negative impact of climate change [1]. Forest contributes on sustained provision ecosystem goods and services which can help people to adapt to the local consequences of changing climate, while carbon storage on the above and belowground can contribute as climate change mitigation [4].

Dry forests are Africa's largest vegetation formation. Dry forests are an integral part of the ecological and social-cultural framework of smallholder farmers and pastoral social groups. The role of forest and woodlands are both biologically and socioeconomically important in the arid dry lands than the elsewhere [3]. Ethiopia owns one of the largest dry forests in the continent, rich in biodiversity of high value tree species such as commercial gums and resins bearing species. Recent professional discourses show that, strategic integration of dry forests in Ethiopia and in the sub-Saharan Africa at large would profoundly contribute to poverty alleviation, climate change adaptation and mitigation, biodiversity conservation and combating desertification. Despite its

diverse social and ecological contributions, various factors undermine mainstreaming dry forests in the dry zone development plan in Ethiopia and many other African countries. Among others, there are little empirical evidences demonstrating the actual and potential contribution of dry forests to climate change adaptation and mitigation. In spite of some efforts, there is limited studies on the role of dry forest for climate change adaptation. Therefore, this study was initiated to assess the socio-economic contribution of dry forests and forest landscapes for climate change adaptation.

## Methods

The study was conducted in the semi-arid dry land of western, eastern and northern Zone of Tigray regional state geographically bounded 12°15' to 14°57' N latitude and 36°27' to 39°59' longitude of the Northern, Ethiopia. The mean annual rain fall varies from 500 to 900 mm and temperature ranges from 15°C to 25°C. Topography of the region from massif highland of 3900 m a.s.l to the north-western lowlands where the elevation is as low as 500 m a.s.l.

Multistage sampling techniques was employed to select study villages and respondents. Based on their vegetation type, accessibility, dry forest endowment and existance of high value dry forest species. Three study villages were selected from Kafta Humera (KH), Atsibi Womberta (AW) and Raya Azebo (RA) district which are characterized by Combretum-Terminalia woodland, by dry evergreen Afromontane forest and Acacia-Commiphora woodlands. A total of 170 households (i.e. 51 from Kafta Humera, 58 from Atsibi Womberta and 61 from Raya Azebo), were randomly selected for household surveys. In addition, from each district 15 key informants and one focus group (6 members) were purposely selected for an in-depth case study and discussion. Primary data were collected through semi structured questioners, focus group discussion and key informant interviews undertaken on May 2018. Based on the local key informant and focus group discussion, wealth status was categorized into four. During household survey, the price of forest products and crop data was recorded using Birr (the local currency in Ethiopia).

Data was analyzed using various descriptive and statistical tests, including ANVOA and t-tests, were employed to examine variation in dry forest income levels of households with different socio-economic characteristics. Both Lorentz curve and Gini coefficient were computed to assess the income equalizing effect of dry forests income [2]. Different explanatory variables hypothesized to affect dry forest income dependence were tested using multilinear regression model.

## Results

### Socio-economic characteristics

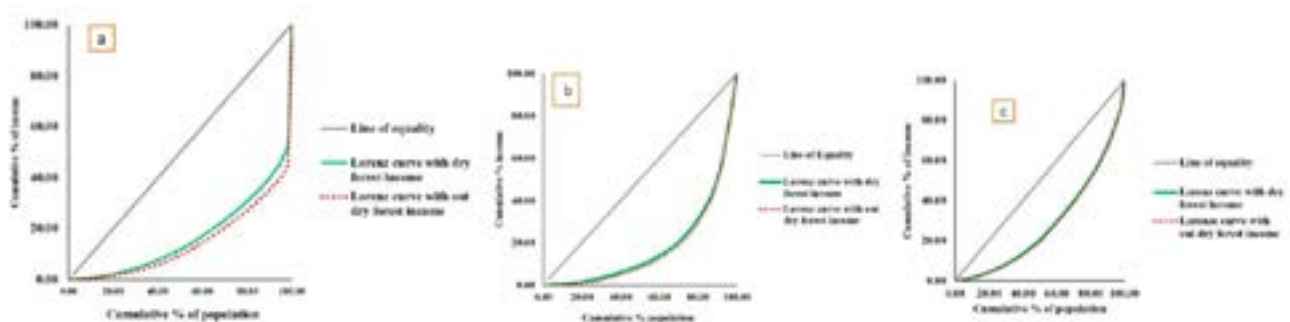
According to their place of origins, the sampled district originated from different vegetation types, namely from Combretum-Terminalia woodland (30%), dry evergreen Afromontane forest (34%) and Acacia-Commiphora woodlands (36%). On average, the walking distance from residence to the nearest forest boundary takes about 90 minutes. Only 5.4 % of the households are rich while the rest was medium (53) to poor and very poor (41.6%).

### Contribution of dry forest for the livelihood climate change adaptation

Over all, four major sources of income: crop, livestock, forest and off-farm-activities (casual work and petty trade) were identified. There was a significant association between the district ( $\chi^2(10) = 21.27$   $p < 0.05$ ) income source type. There is significant difference in terms of dry forest income ( $p < 0.05$ ). More than 94% of the total household visited at least once a month to access the forest and forest products. About 43.5% and 35.5% of the households were collected forest and forest products once a month followed once a week, respectively. The contribution of dry forest for the

household income were about 24.4% in AW, 22.15% in KH and 4.93% in RA. More than 34% of the dry forest is assessed by the women to support their livelihoods of the rural households. In the study districts dry forest used for risk reduction, such as, income gap, by way of diversification of income sources and assisting saving before the onset of drought. Similarly, several responds reported dry forest also helps the livestock asset by using as feed and by way of protecting the remaining livestock from being sold. In general, the dependency of households on dry forest income was increased.

Overall, a total of 48 major species of dry forest used for timber, fire wood, charcoal, wild edible fruits, animal feed, and gum and incense. Dry forest contributing on minimizing the variation in total household incomes. The quantitative analysis of the different dry land forest type however showed a positive effect. The contribution of dryland forest income reduced the area between the line of equality and the Lorenz curve (Figure 1), and the Gini- Coefficient by 21% in AW, 3.02% in KH and 3% RA.



**Figure 2.** Schematic presentation of the Lorenz curve showing income equalizing effect of dry forests in Atsbi Womberta (a) Kafta Humera (b) and Raya Azebo Districts

Spearman bivariate correlation analysis showed that the level of dry evergreen Afromontane forest income was positively and significantly correlated with income from livestock ( $p < 0.01$ ) and crop productions ( $p < 0.05$ ) in AW district. The income from Acacia-Commiphora woodlands had positive and significant correlation with income from livestock production ( $p < 0.05$ ) but negative and significant correlation with income from direct aid and food for work program ( $p < 0.05$ ) in RA district. Moreover, the income from Combretum-Terminalia woodland had not significantly association with the other sources of income.

## Conclusion

This study reveals that dry forest plays critical role on the improving of the adaptive capacity of the drought prone households. There is also relation between the income from the semi-arid dry forest, poverty reduction, income equality and coping with the negative effect of droughts. Beside to the provision of ecosystem service to human the dry forest contributes feed for livestock during the drought season. The contribution of dry forest for the household income were about 24.4 % from Afromontane ever green dry forest, 22.15% in Combretum-Terminalia woodland and 4.93% in Acacia-Commiphora woodlands. Therefore, since the dry forest have crucial role on climate change adaptation strategies the communities and government should give attention on sustainable management of the dry forests and forest products of this ecosystem.

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## Ecosystem Services in Climate Change Adaptation Projects in The Least Developed Countries of West Africa

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This paper assessed the role and place of ecosystem services in climate change adaptation projects in the Least Developed Countries of West Africa, and their redesigning options to enhance community wellbeing and adaptation, as well as ecosystems health.

A desktop survey approach was used to review 168 National Adaptation Programmes of Action projects from 13 West African countries listed as Least Developed by the United Nations. It analyzed the thematic foci of various adaptation projects and the extent to which they have incorporated ecosystem services. Gaps and barriers identified were used as a set of variables to suggest resigning options using the Community Based Risk Screening Tool Adaptation and Livelihoods Tool.

Results showed that the adaptation projects are dominated by actions in the agricultural sector accounting for 32% of the total studied. These projects were in most case small grants with 63% of them having a budget of lower than one million USD. Further, adaptation projects were mostly a short-term engagement with 46% of projects with three years implementation period. A bigger portion of projects (55%) mentioned directly one or more ecosystem services, with provisioning services expressed in 50% of the cases. Cross-cutting link among water, energy, food and health is weak in the studied projects. Adaptation projects with ecosystem services components are more sustainable and beneficial to the community. Connecting the link between water, energy, food and health through the nexus approach has the potential to promote community and ecosystems wellbeing. Hence, recommends more consideration of nature benefits to improve ecosystems' adaptation capacity, more financial consideration and project to address immediate community needs and ultimately realize the global adaptation goal.

**KEY WORDS:** Adaptation, Climate Change, Ecosystems Services, National Adaptation Programmes of Action (NAPA), West Africa

### Purpose of the paper

Ecosystems play an irreplaceable role in supporting life through provision of ecosystem services, which maintain, strengthen, and enrich different elements of livelihood on the planet. The functional dependency between trees, water, soil, vegetation, animals, and humans support sustained values for life on the planet. Despite the essential services provided by ecosystems, most of them are under threat globally as a result of their degradation. Some of the major threats facing the existence and services provision of ecosystems include ecosystem conversion, climate change, loss of biodiversity as well as destruction and unsustainable extraction of resources from sensitive ecosystems such as forests and wetlands. Some of the factors leading to this degradation include a high demand for timber and wood products, fuel, water, and food according to the Intergovernmental Panel on Climate Change reports. The Least Developed Nations (LDCs) globally have the highest rates of ecosystems degradation due to their over-



reliance and dependency on the ecosystems for the survival of their citizens. To support the adaptation processes, the United Nation Framework Convention on Climate Change (UNFCCC) passed a policy instrument to assist them in the process of designing the National Adaptation Programme of Action (NAPA) based on the country-specific urgent and immediate adaptation needs. The primary purpose of this paper is to determine the extent in which the climate change adaptation projects listed under National Adaptation Programme of Action (NAPA) in selected countries in West Africa have incorporated ecosystem services and their redesigning options. This was in cognizant to the fact that adaptation projects with ecosystem services components are more sustainable and beneficial to the community. Specifically, the paper assessed different dimensions of adaptation projects in West Africa, evaluated the extent to which they have incorporated ecosystem services, and identified areas of redesigning and improving adaptation projects to enhance ecosystem services.

### **Research methodology**

A desktop survey approach was used to review 168 National Adaptation Programmes of Action projects from 13 West African countries listed as Least Developed by the United Nations. These projects went through a vigorous process involving different stakeholders and are deemed to be the accurate reflection of the adaptation needs in different countries in West Africa. It analyzed the thematic foci of various adaptation projects and the extent to which they have incorporated ecosystem services. The tools used were ArcGIS tool in creating, analyzing and displaying geographical information and maps. Gaps and barriers identified were used as a set of variables to suggest resigning options using the Community Based Risk Screening Tool Adaptation and Livelihoods Tool. 3

### **Summary of results**

The study revealed that there was notable change in the ecosystems of the least developed countries in West Africa between 2000 and 2010, with a decline forest cover and increase in savanna land, which eventually paves way for desert ecosystems. This change was highly attributed to anthropogenic factors such as logging and clearing forests for commercial usage. This change contributed to the climate change effects as tree covers that acted as carbon sinks were removed from the ecosystems leading to increased accumulation of greenhouse gases in the atmosphere that are responsible for climate change.

Table 1. Project distribution per county and thematic areas

	No. of projects	Thematic areas								
		Agriculture	Coastal resources	Early warning system	Capacity building	Energy	Health	Water resources	Forestr resources	Cross cutting themes
Burkina Faso	12	5	0	1	0	1	0	3	2	0
Benin	5	0	1	0	1	0	1	1	0	1
Cape Verde	3	1	1	0	0	0	0	1	0	0
Gambia	10	3	1	1	1	1	1	1	1	0
Guinea	25	7	4	0	3	0	0	5	6	0
Guinea Bissau	14	3	3	1	3	0	1	2	1	0
Liberia	3	1	1	1	0	0	0	0	0	0
Mali	19	10	0	0	2	3	1	2	1	0
Mauritania	28	9	4	0	2	0	0	8	3	2
Niger	14	7	0	1	2	0	1	2	0	1
Senegal	4	0	1	0	1	0	0	1	1	0
Sierra Leone	24	5	4	1	3	1	4	3	2	1
Togo	7	2	1	1	0	0	1	2	0	0
Total (No.)	168	53	21	7	18	6	10	31	17	5
Total (%)	100	32	13	4	11	3	6	18	10	3

❖ The highlighted thematic areas are related to the Water-Energy-Food-Health Nexus.

Climate change adaptation projects in the least developed West Africa Countries exhibited a predictable trend, with more focus on the agricultural and water sector at 32% and 18% respectively. Energy and health sector among the least prioritized areas. These projects were in most case small grants with 63% of them having a budget of lower than one million USD and were mostly a short-term engagement with 46% of projects with three years implementation period. The extent to which the climate change adaptation projects incorporated ecosystem services revealed that 55%, 36% and 9% of the projects had directly, indirectly or had no incorporation of ecosystem services respectively. The dominant category of ecosystem services was provisioning at 50% while 61% of the projects provided single ecosystem service.

The study established that there are several areas of redesigning and improving climate change adaptation projects to enhance ecosystem services which include increasing the natural resources management, increasing the use of alternative livelihoods that are less dependent on natural resources and increasing the financial incentives towards sustainable usage of natural resources.

## Conclusions and recommendations

1. There is a significant change of the ecosystems in the least developed countries of West Africa within the study period of between 2000 and 2010
2. The climate change adaptation projects are largely within agricultural and water sector, have short-term implementation duration, low budgetary allocation and at sub-national scale of implementation. Health and energy among the least prioritized sectors. The cross-cutting link between and among water, energy, food, and health remains weak, posing a major challenge in the achievement of sustainable and integrated development. To address this gap, the study recommends a nexus (integrated) approach that integrates water, energy, food and health aspects at global, national and local scales. More studies are also recommended to assess how the interactions result in tradeoffs (synergies) or conflicts at both policy and execution levels.
3. Most of the climate change adaptation projects studied had ecosystem services elements but only a small percentage of them considered the multiplicity of ecosystem services in a single project. There lacks a holistic approach in the project design to ensure that diverse ecosystem and ecosystem services needs are met by a single project. This can be achieved by using nexus approach, where every project is designed with consideration on how it meets ecosystem services on food security, energy security, water security and population's health. Linking of these diverse ecosystems within a single project can promote achievement of economic, social and environmental goals under Sustainable Development Goals and their broad targets.

## Adaptation to flood induced health externalities by mothers around urban drainage basins of Ilorin, Nigeria

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## Introduction

Vulnerability and adaptation to climate change are urgent issues among many developing countries, especially as relates to the urban poor. With increasing concentration of people in cities, there is a corresponding pressure on the urban environment and urban residents are faced with accelerating environmental risks. Floods have increasingly been found to be associated with extreme weather events. Flood water from excessive rainfall is a serious threat to human health with children being most vulnerable. The most common health hazard in Nigeria today is the risk to health posed by flooding [2]. This study examines the adaptation practices of mothers to the health impacts of flood in Ilorin, Nigeria. Spatial analysis increases our understanding of disease pathogenesis through identification of how populations adapt and relate to their environment by suggesting casual factors and revealing the inherent traits of the population that make them more susceptible to disease in the first instance [7]. More importantly, spatial analysis provides a veritable tool for isolating strategies of adaptation among a population of adopted as a response to environmental challenges [3]. The study therefore adopts the framework of Urban Geographies of Risk adapted from Jerrett and Finkelstein, (2005)[4].

The environmental health geography of cities in Africa may be conceptualized into a framework which has underlying geographies – namely exposure, susceptibility and adaptation. More often none of these domains provides an apt explanation or representation of the vulnerability of urban population to health hazards and health threatening disasters. Instead, environmental impact of these phenomena is better captured by the perimeter of the areas of maximal overlap in these three components.

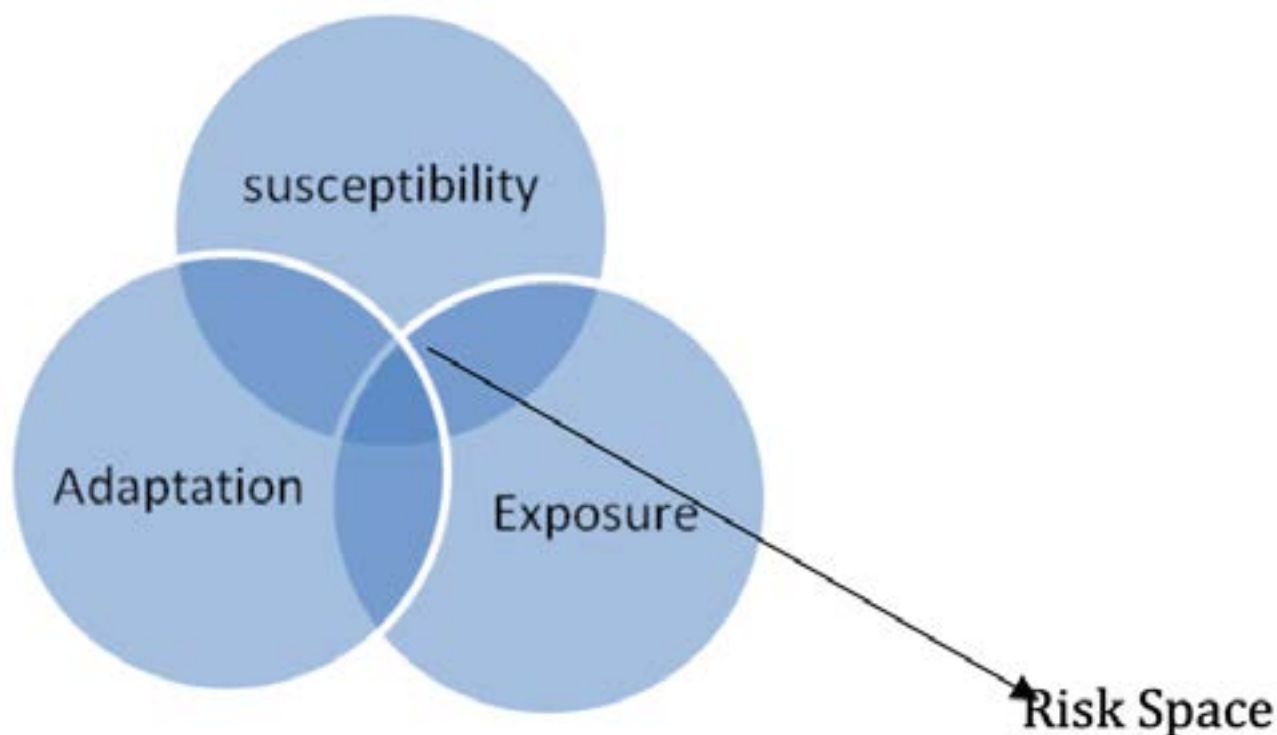


Figure 1. Risk conceptual framework

In figure 1, the areas where 2 or more of the circles on the Venn diagrams overlap are referred to as the geographies of risk or the urban risk space.

The essence of this framework is that health implications of meteorological events cannot be understood in isolation of other related concepts of susceptibility, exposure as well as the points of intersection in time and space between these three.

## Methods

Ilorin, the capital city of Kwara State, Nigeria, is the setting for this study. The city is located on latitude 8° 10'N and longitude 4° 35'E marking a divide between the Southern forest Zone and the Northern grassland of Nigeria. The vegetation, in most parts, is guinea savanna interspersed by trees of different species. The dominant streams are Asa, Aluko, Okun, Agba, and Agba. The Asa River is of particular influence on the direction of growth of the city. The situation of the city between the dry North and the wet South of Nigeria gave Ilorin an apt description as the "gate way" between the North and the South of the country" [1]. The climate is therefore tropical wet and dry characterized by a distinct wet and dry seasons. The mean annual temperature is about 26.800c with five hours average daily sunshine. The mean annual rainfall is about 125mm. It is important to note that the above locational and physiographic characteristics possess (sometimes significant) implications for human health on one hand and economic and social development on the other.

Ilorin is a typical traditional African city whose urban history predates colonialism in Nigeria. The city therefore falls into the category of third world cities described as reputed for their dualistic internal structure [5]. The physical development of Ilorin also translates into significant change in the population of the city. For instance, from 36,300 inhabitants in 1911, Ilorin has a population of about 208,546 in 1963, 532,088 people in 1991 and about 765,791 by the year 2006 [6]. The growth rate is about 2.84% annually. The facts of urbanization, development of the modern commercial/ industrial economy and the multiplier effects of these factors on natural increase had combined to produce the changes in population described above. This study adopts an environmental epidemiologic approach to analyze potential disease exposure pathways. A 50m buffer around

basins of urbanized rivers was defined as the most marginal land and used to determine most vulnerable areas. Questionnaires were purposively administered to nursing mothers in 250 households within the four urbanized drainage basins in Ilorin metropolis, in North-Central Nigeria. Descriptive statistics and chi square test were used to assess epidemiological variations within study area. The dormant rivers within Ilorin metropolis are Asa, Agba, Aluko, Osere, Okun and Alalubosa. Four of these (Asa, Agba, Osere and Alalubosa) were sampled.

## Results

Flood victims were emotionally attached to the flood sites as 184(73.6%) were owner occupiers or lived in family compounds making relocation difficult. Variation in the observed health impact from flooding across the drainage basins was not statistically significant  $\chi^2(5, N=245) = 16.63$   $p > 0.05$ . Diarrhea in children was overwhelmingly the most serious health concern observed among nursing mothers in the event of floods with 97 (39%) mothers. Mothers also believed that it was safer to drink from unpolluted sources however only 18(8.2%) of the mothers were able to change their water sources after flood linked pollution. As shown in the Figure 2, Osere basin flood plain was responsible for 30% of all reported diarrhea followed by Asa and Agba with 24% then finally Alalubosa with 22% prevalence.

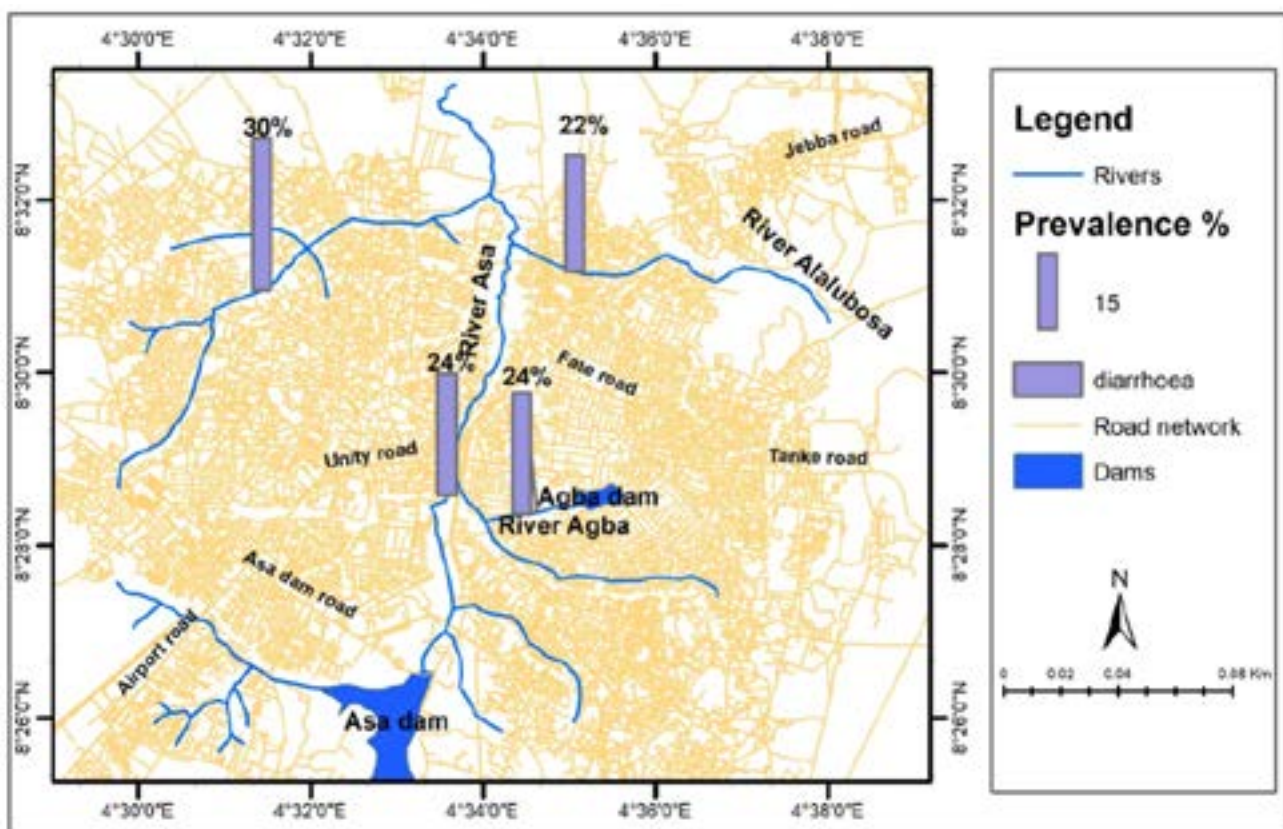


Figure 2. Risk conceptual framework

## Conclusion

Difficulty in restraining children to safer areas and mothers' inability to take decisions on seeking medical attention for their wards, as well as reluctance to change residence were major constraints to successful adaptation.



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