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Climate change impacts – implications for policy and practice in Tanzania's Rufiji River Basin

Overview

This brief synthesises the results of undertaking a climate risk analysis for the Rufiji River Basin, Tanzania. The basin supports extensive socio-economic and environmental services and is targeted for major development via hydropower infrastructure and investment through the Southern Agricultural Growth Corridor of Tanzania. The implications of climate risk for development objectives that cut across the water-energy-food-environment sectors are outlined and recommendations proposed to help achieve climate resilient sustainable development.

The brief is for practitioners and technical policy-makers with a detailed interest in understanding development processes and the impacts of climate change in the Rufiji River Basin. The approach is relevant for other large river basins undergoing rapid development.

Headline messages: Rufiji Basin development

- Major decisions require careful planning; in cases involving large investments, long life-times and irreversibility, there is a strong argument for assessing resilience to future climate change. The Rufiji River Basin exemplifies this as it is targeted for development via a major new hydropower infrastructure project (the Julius Nyerere Hydropower Project – JNHPP) and investment in agricultural value chains through the Southern Agricultural Growth Corridor of Tanzania (SAGCOT).
- Under current climate conditions there is considerable potential for energy and irrigation expansion at the full basin scale, however, there are many trade-offs depending upon the extent of development. Hydropower reliability in the JNHPP is affected by the higher projections of future expansion of formal and informal irrigation. Monthly and annual supply reliability degrades with the last 50,000 ha of irrigation expansion, which if unregulated could constrain additional energy generation from the basin.
- Development scenarios that prioritise energy production adversely affect environmental performance downstream of the JNHPP, although part of the negative impacts can be minimised through release rules designed to replicate the natural variability of flow, without major sacrifice of hydropower. As the JNHPP is likely to generate surplus energy initially it should be possible to reduce environmental and livelihoods impacts. Greater use of groundwater, taking into consideration observed volatility in recharge events could reduce trade-offs between agriculture, energy and the environment in dry years.
- Many sub-basin scale trade-offs associated with increasing water use are not explored here. For example local scale water scarcity (long-term and seasonal) already exists in some upstream tributaries, generating tensions over access and use of water, and threats to achieving environmental flow requirements (river flows required for supporting nature) at specific locations.

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Climate impacts on Rufiji River Basin services

- Analysis of historical climate variability shows that had the JNHPP reservoir been built in 1900 it would have buffered dry years but its reliability would have been compromised by multi-year droughts during the 1920s and 1930s.
- Future climate projections show continued warming (by roughly 0.8 °C to 1.8 °C by the 2040s) and mixed patterns of change in future rainfall. Most climate models (23 out of 28) project a modest to high increase in annual rainfall and an increase in variability that would be associated with both increased frequency of droughts and floods.
- The changes in Rufiji streamflow are more pronounced, ranging from approximately -30% to over +60%, but with a roughly even split between drier and wetter futures due to the effects of higher evapotranspiration. Daily rainfall intensity is projected to increase, and about three quarters of the climate models suggest an increase in year to year variability.
- Uncertainty about the future climate can be compounded by the ad hoc nature of information provision and advice about climate change risks, leading to low consistency and confusion about the reliability and legitimacy of information – clear accessible summaries with periodic updates of climate model projections for the basin would be useful to establish a common understanding of the situation (for example, Conway et al., 2017).

Management implications of climate risk

- Important knowledge gaps exist for many aspects of the Rufiji River Basin. As development proceeds there is a clear need to improve understanding of how the basin functions. This includes improved monitoring and reporting at strategic locations and coordinated modelling to simulate the crucial interdependencies between the water-energy-agriculture-environment sectors.
- The impacts are cross-cutting and therefore multi-agency coordination will be vital (e.g. through Multi-Sectoral Platforms), both for long-term planning and for shorter-term decisions, such as drought management. High level dialogue to this effect should be encouraged, alongside increases in the productivity of land and water as promoted by the SAGCOT initiative via improved irrigation schemes and better input use. Priorities include focus on improving local irrigation water use and reduction in non-recoverable irrigation losses through management and regulations.
- Given underlying questions about the ability of climate models to confidently simulate rainfall behaviour in the region, it may be too early to base expensive decisions only on the basis of potential impacts. Nevertheless our climate is changing and strategies need to be considered now to manage existing and future climate risks as the world warms further. We therefore recommend it would be prudent to select options that align with other considerations (such as cost effectiveness, desirability) and to design and implement contingency planning for sequences of extreme years and strengthened capacity for cross-sectoral management.
- Contingency plans for the JNHPP should include modified operating procedures and water allocation under both drier and wetter conditions and development of a multi-agency drought management plan for single and multi-year events. This would involve sequences of decision points across years, with increasingly stringent restrictions on releases after successive years of drought. Such plans would require careful analyses to identify trigger points for decisions and greater cross-sectoral coordination, particularly between agencies responsible for water resources, energy and agriculture.

Governance implications of climate risk

- Model-based decision-support should be seen as part of a wider process of decision-making. Wider and deeper consultation processes allow exploration of these linkages, varying management actions, and associated impacts, leading to more informed decision-making. For example, there are local scale trade-offs that should be considered alongside our basin-scale analysis, such as trade-offs between irrigation expansion and local nature conservation values.
- The governance frameworks that Rufiji River Basin management operates within are crucial areas to focus on, particularly for enhanced coordination and capacity to implement what will become increasingly complex management responses as development progresses. Political will and budget allocation to address the problems highlighted above and to deliver effective and equitable policies, will be critical to the viability of proposed developments.

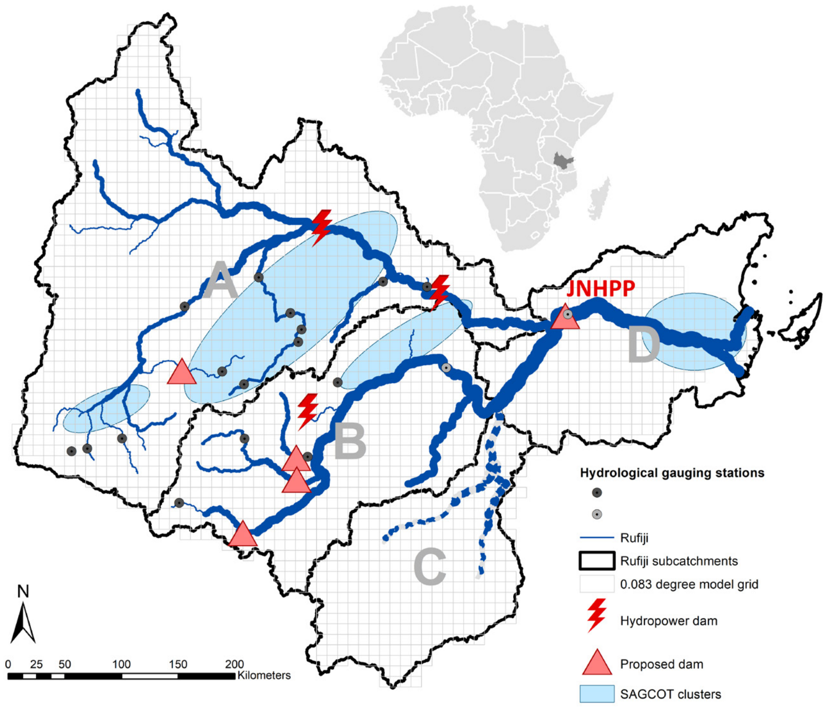
Complex impacts of development plans in the Rufiji River Basin

The Rufiji River Basin supplies water for around 4.5 million people, generates 80% of Tanzania's hydropower and covers roughly 20% of the country (Figure 1). The basin includes several major wetland systems rich in biodiversity, formal and informal irrigation schemes, several hydropower reservoirs and areas of high conservation value, including National Parks. Biennial flooding of the downstream delta is important for maintaining deltaic lakes, wildlife, fisheries and flood recession agriculture. Much of the basin is targeted by the Government of Tanzania for socio-economic development as part of the Southern Agricultural Growth Corridor of Tanzania (SAGCOT). The SAGCOT aims to attract domestic and foreign investment to strengthen agricultural value chains to promote economic growth through increased agricultural transformation. In addition, a recent development has been the decision in 2017 to go ahead with the massive Julius Nyerere Hydropower Project (JNHPP) at Stiegler's gorge on the Rufiji mainstem. The cost of constructing the JNHPP is estimated at 4.7 billion US dollars against 2016 prices (Government of Tanzania, 2016). Sustainable water resource management is viewed as key to its success which has profound implications for future economic and social development trajectories, and as such the JNHPP reservoir can be considered to be a 'high stakes' decision.

The basin is estimated to have two million hectares (ha) of medium to high potential irrigable land, with 4.5% currently under irrigation. An estimated 2.4 billion cubic meters of water (BCM) is abstracted per year, primarily for irrigation, and this is projected to increase to 7.6 BCM per year to support expansion of irrigation from 110,000 ha to an upper estimate of 400,000 ha by 2035 (WREM International, 2015).

There are strong interdependencies between critical uses of water throughout the basin, particularly between irrigation, energy generation from hydropower and requirements for environmental purposes. Transparent consideration of trade-offs between multiple objectives can be helpful in defining acceptable compromise plans in river basins characterised by conflicting performance objectives and opposing stakeholder interests.

Figure 1: Hydrological model representation of the Rufiji River Basin system overlaid with ~9 by 9 km grid and areas identified for irrigation expansion (SAGCOT clusters) (Siderius et al., 2018). A is Great Ruaha, B is Kilombero, C is Luwegu and D is the Main Rufiji channel. Shapes of cluster areas are just indicative. Actual coverage follows the administrative boundaries.



What are the main basin-scale trade-offs under different river basin development scenarios?

The major trade-offs in the basin development aims comprise the extent of irrigated agriculture expansion versus the reliability of energy from the JNHPP, and their impact on environmental flows at locations with high environmental and/or economic importance. Trade-offs between water use through smallholder expansion and planned irrigation sites are also expected.

Multiple stakeholder consultations were used to establish key development scenarios and identify and prioritise important river basin performance metrics to assess impacts (Geressu et al., 2020). Seven indicators were selected: Energy from hydropower; annual total, firm (reliable) annual and firm monthly; irrigation; total irrigated area, irrigation water demand deficit; environment; area flooded by the JNHPP and river flow disruption downstream in the lower Rufiji.

A basin hydrological model was coupled with a water resource system model that simulates the operation and effects of dams and irrigation in the basin (Geressu et al., 2020). Many thousands of simulations were used to test different combinations of options (e.g., new dams and irrigation developments) and their management (e.g., by varying reservoir release policy) to identify options that perform well across the different performance indicators.

The four development scenarios considered in our case study were informed by published government plans and workshop discussions about different trajectories of basin development. The first one considered the 'Current' river basin and the second the addition of the JNHPP. A third 'Synergistic' scenario optimises a combination portfolio of irrigation expansion, whereby only those options are implemented that contribute to an optimum solution (known as pareto optimal). The fourth 'Full' development scenario assumes the complete development of all planned infrastructure expansion. We also considered the possibility of reducing the storage size of the JNHPP and a situation where, with better management and stronger enforced regulations, local non-beneficial irrigation consumption and non-recoverable return flows can be reduced to become available for downstream use (Geressu et al., 2020).

Results show considerable potential exists for energy and irrigation expansion under the climate conditions of the past 30 years. Designs that prioritise energy production adversely affect environmental performance; however, part of the negative impacts can be minimised through release rules designed to replicate the natural variability of flow, with relatively small sacrifices in energy generation. The reliability of monthly energy generation is more sensitive to environmental-oriented management than the cumulative annual energy production. Improvement in irrigation water supply (lower deficits) can be achieved with further dams, although supply reliability degrades with the last 50,000 ha of irrigation expansion, which if unregulated could constrain additional energy generation from the basin, in one case by up to 2 Twh/year.

With rapid change underway in large parts of the basin, irrigation governance is challenging, however, if local non-beneficial irrigation water consumption and non-recoverable return flows are reduced through better management and stronger enforced regulations, the impact of upstream development on downstream energy production and environmental conditions can be minimized (Geressu et al., 2020).

Box 1. Land use futures for Kilombero co-created through participatory scenario planning
(Thorn et al., in review)

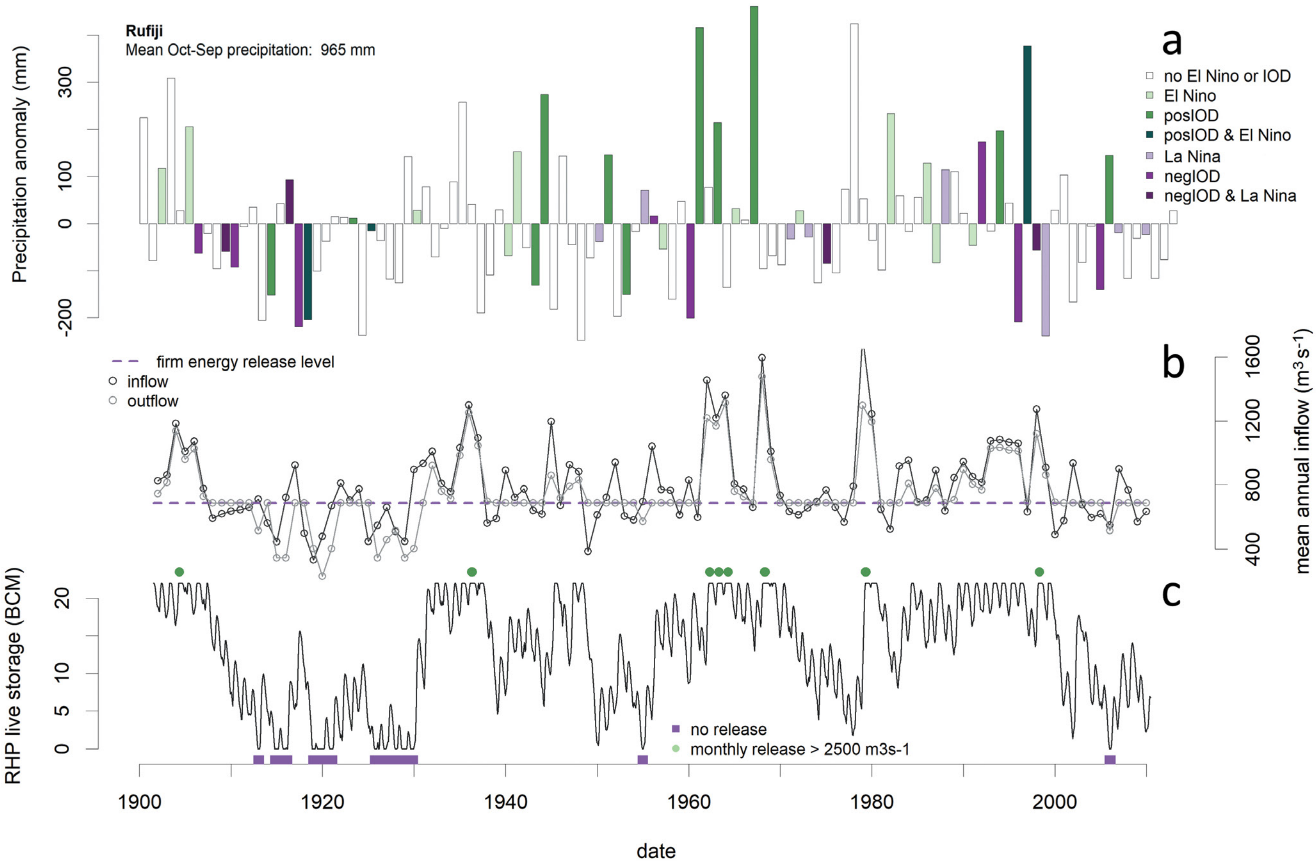
Four different land use scenarios were developed with multiple stakeholders across the Kilombero catchment of the Rufiji River Basin in 2019 and 2020. These land use futures can be used to explore drivers of change and envision plausible pathways and impacts of different development agendas and horizons. Potential land use and land cover changes were simulated for the years 2030 and 2063 and compared against the year 2019; these future years were chosen to resonate with the Sustainable Development Goals and the 'Africa 2063' Development Agenda of the African Union. This analysis highlights the importance of considering the interaction of future land use management decisions and resulting land cover changes to mitigate some of the impacts of potential climate change, particularly around regulating increasing rainfall variability through catchment forest, conservation tillage and riparian buffer zones. The land use futures suggest a range of tensions over land use are likely to increase or appear during the next fifty years. They include:

- Recent in-migration from pastoralists has led to land scarcity and encroachment of wetlands and Game Protected Areas and impacts on water courses with likely future knock-on effects on agriculture, fishing and hydroelectric power;
- Conflicts between wildlife conservation managers and infrastructural (especially road) developers over the location of transport routes that obstruct key migration routes of elephants and other mammals; and with pastoralists being resettled from Ramsar wetlands sites or farmers being resettled from protected areas. Success will largely depend on adequate compensation, engagement and ensuring conflicts do not spill over into other areas;
- Conflicts related to land use planning process in an attempt to clarify ambiguous boundaries, depending on enforcement and the negotiation power of local communities;
- Conflicts between corporate and smallholder farms, and the transition from food crop production (mainly rice, maize, fruits and coconuts) to cash crop production (mainly sugar cane, teak and cocoa) with associated mechanisation and labour trade-offs, and agrochemical seepage into rivers;
- Conflicts from local corporates withdrawing from economies, not meeting supply chain due diligence and a lack of transparency of spending of public infrastructure funds;
- Conflicts prior to general elections arising from political interference that cause tension around land, livelihoods and politics with a surge of encroachments;
- Conflicts associated with cultural change, assimilation and gender equity;
- Conflicts related to the illegal extraction of fuelwood, poaching, and human wildlife conflict especially adjacent to protected areas or wildlife corridors; and
- Conflicts between land use especially between urban and agricultural land with no spatial planning and social services including health, education, housing and infrastructure.

Sub-basin scale environmental impacts

There are many sub-basin scale trade-offs associated with increasing water use for agriculture, with impacts on the natural environment at key locations with high ecological value. While assessment of such impacts is beyond the scope of this basin-scale study, the Development Corridors Partnership project has explored several examples including the impacts of afforestation in upstream catchments and stakeholder perspectives on development trajectories in sub-catchments (development clusters in the SAGCOT, see DCP and Box 1). Furthermore, ongoing changes in the basin have been associated with important points of contestation such as tensions in the Great Ruaha sub-catchment over smallholder agriculture and pastoralists, irrigation expansion, land-grabbing and conservation (Kashaigili et al., 2005; Walsh, 2012). This has resulted in competing explanations between climate, upstream resource use and management, of low levels in the Mtera reservoir that caused electricity shortages during the early 1990s and the roles of large, centrally controlled irrigation schemes and smallholder farmers (Lankford et al., 2004).

Figure 2 a.) Annual rainfall (October – September period) for the Rufiji River Basin (source: CenTrends), with years with modest to strong El Niño/La Nina and with strong positive/negative IOD highlighted. b.) Simulated mean annual Rufiji inflows and outflows; c.) simulated monthly live storage of JNHPP reservoir (assuming it was built in 1900). Risk of failure, i.e., not being able to release sufficient water to maintain firm energy flow is indicated by the purple bars, while green dots highlight years with sufficient release of water to satisfy downstream flood requirements of the delta ecosystem (adapted from Siderius et al., in press).



Securing investments in the face of climate change

Rapid development in the Rufiji River Basin is occurring against a back-drop of climate change. As the world continues to warm so do eastern and southern Africa, bringing changes in the climate patterns people are familiar with and disruption to livelihoods and infrastructure. In cases involving large investments, long lifetimes and irreversibility, there is a strong argument for climate risk assessment – damages and losses from new combinations of extreme weather are an increasing problem. The following sections set out key findings from our work to assess climate risk and identify responses suitable for maintaining sustainable development for different stakeholders in the basin.

How has past climate variability affected the basin?

Analysis of recent climate variability and its effects on water resources can provide helpful insight about the types of problems that arise and how to manage them. Recent climate is described in detail in an earlier Country Brief (Conway et al., 2017). A clear warming trend is apparent in annual temperature (roughly 0.03°C per year).

Rainfall is highly seasonal, averaging 935mm per year with a large gradient across the basin, from 500mm per year (northern part of the basin) to more than 1500mm per year (central part of the basin, Kilombero valley, Figure 1). Between 1981 and 2016 there were areas of modest drying in northern parts of the Basin (up to around 2mm/year) and areas of modest wetting in the central part of the basin, particularly the Kilombero valley and Lower Rufiji (around -2 to -4mm/year). A prolonged dry period occurred between 1906/07 and 1929/30 with just six years in 23 wetter than average. Since a very wet year in 1997/1998 (a major El Niño and Indian Ocean Dipole event) rainfall over whole the basin has been generally lower than the long-term average (Figure 2).

Using a hydrological model of the Rufiji River Basin (Siderius et al., 2018), a simple reservoir simulation model and gridded climate data products, we examined the impact of long-term climate variability (since 1900) on the JNHPP (Siderius et al., in press). Historical simulations driven by observed climate since 1900 represent a 'what-if scenario' of how the reservoir system would behave, as if the hydropower and planned irrigation expansion had been present from 1900 onwards. Rainfall variability causes high variability in stream flow with persistence of sequences of wet and dry years (see Figure 2a). Storage in the JNHPP buffers the effects of individual dry years, however, multi-year dry conditions would have led to the JNHPP – assuming it was built and operated to prioritise firm (reliable) electricity production and no contingency actions were implemented – failing to meet its potential firm energy level for consecutive years on several occasions (Figure 2b and 2c).

The second half of the 20th century recorded wetter periods especially in the 1960s, similar to much of East Africa. The simulation shows that under these conditions the JNHPP would have just managed to maintain the firm energy output level due to its large storage size, but only if upstream irrigation expansion was managed to ensure recovery of irrigation water return flows. Uncontrolled upstream irrigation expansion and greater reuse of return flows by smallholder farmers is ongoing, which would put greater pressure on the performance of the JNHPP downstream.

The present relatively undisturbed natural flow regime in the Rufiji comprises biennial bank overflows which rejuvenate one of the world's largest deltaic wetland systems in the Nyerere National Park (formerly the Selous Game Reserve) and support downstream flood recession irrigation. The JNHPP dam will alter this pattern, particularly if operated primarily for hydropower purposes. In our simulation the peak flow threshold of more than 2500m^3 during a whole month (Figure 2b and 2c) would reduce the frequency of delta flooding from one in two to less than one in ten years, with long periods of insufficient flows. This would impact the delta ecosystem, fisheries and farming; however, it is possible that the JNHPP dam could be operated to mitigate this risk but at the expense of reliable energy production (Siderius et al., in press; Geresu et al., 2020).

The potential impacts of future climate change

We reviewed the range of climate projections available from the leading source of climate model results and whilst continued warming is highly likely (roughly 0.8 °C to 1.8 °C by the 2040s) projections of future rainfall averaged across Tanzania are mixed: out of 34 models used in the last IPCC report roughly one third project lower rainfall and two thirds higher rainfall (Conway et al., 2017).

The range of rainfall change across the 34 models is fairly modest, with 20 models projecting changes of less than +/-5% by the 2040s. Changes in daily rainfall suggest more variable conditions, with both higher likelihood of dry spells and a higher likelihood of intense rainfall events that are likely to increase the frequency and intensity of flooding.

Figure 3 (a) Projected change in rainfall, (b) river basin runoff at the JNHPP site near the outlet with 28 different climate models.

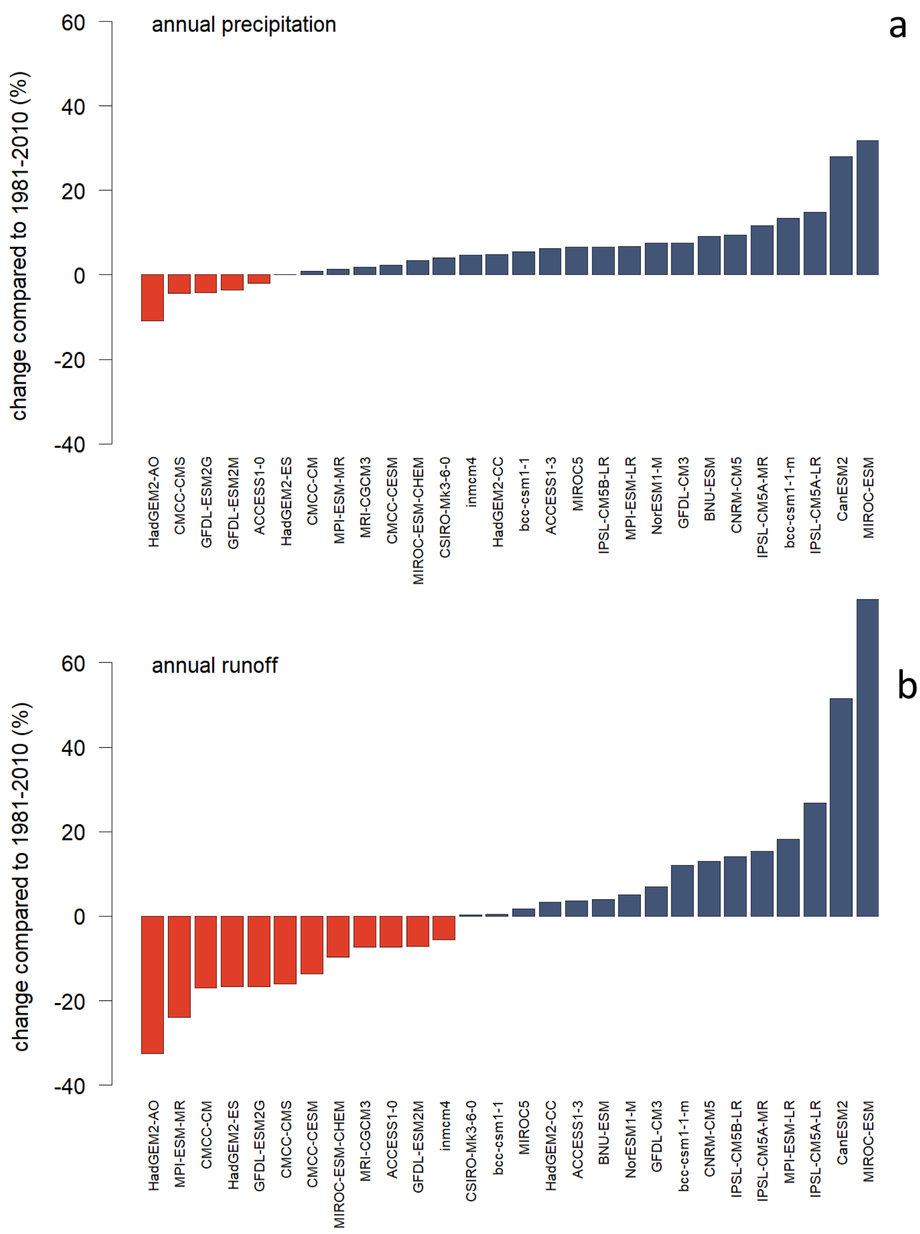


Figure 3 shows for the 2040s period rainfall change for the Rufiji River Basin and impacts on the main river flows using an equal weighting of 28 climate models, based on their projections of changes in temperature and rainfall (Kolusu et al., in review; Siderius et al., 2021). Most (23 out of 28) models project a modest to high increase in annual rainfall; the rainfall change for 2021-2050 compared to the near-present day (or baseline) period of 1980-2010 ranges between -10% to +30%. This climate uncertainty is amplified and modified by hydrology (compare Figures 3a and 3b); the largest changes in runoff are more pronounced, ranging from approximately -30% to over +60%, and while the majority of models project an increase in rainfall, the impacts on runoff are more evenly distributed between drier and wetter futures (12 models simulate reduced runoff). Increased transpiration by plants and crops due to higher temperatures can offset a projected increase in rainfall in some cases.

Impacts of climate change on river basin performance indicators

Simulated risk of failure to achieve performance indicators across the water-energy-food sectors are shown in Table 1 for past and future climate (Siderius et al., in press). Under near present-day climate (1981-2010), the risk of failure with the JNHPP assumed built, irrigation expanded, and no adaptive management applied is already substantial. Using this particular indicator for ecosystem services in the Rufiji, environmental flow failure rate could be as high as ~85%. For irrigated agriculture in upstream rice producing areas in the Rufiji River Basin performance shows a failure rate >40%. Here, irrigation is vulnerable to climate variability due to lack of storage. In contrast, firm-level hydropower requirements could be met reliably under present conditions and risk of failure would be low.

Regarding future risk, our analysis demonstrates considerable uncertainty (Table 1 and Figure 4). For the majority of projections, with this hydrological model and at this scale of analysis, the risk of hydropower failure increases. Design characteristics of the JNHPP may be influenced by the limited observational river flow records of the late 1950s, 1960s and early 1970s, a relatively wet period (Figure 2), and climate projections with drier conditions increase the risk of failure. However, as many model projections of drying also exhibit high variability in rainfall, wet years alternate with dry years and add to live storage, thereby keeping hydropower risk of failure in most projections at 15% or below. For a subset of wet climate projections the risk with regards to firm energy decreases drastically in the JNHPP hydropower system (Siderius et al., in press).

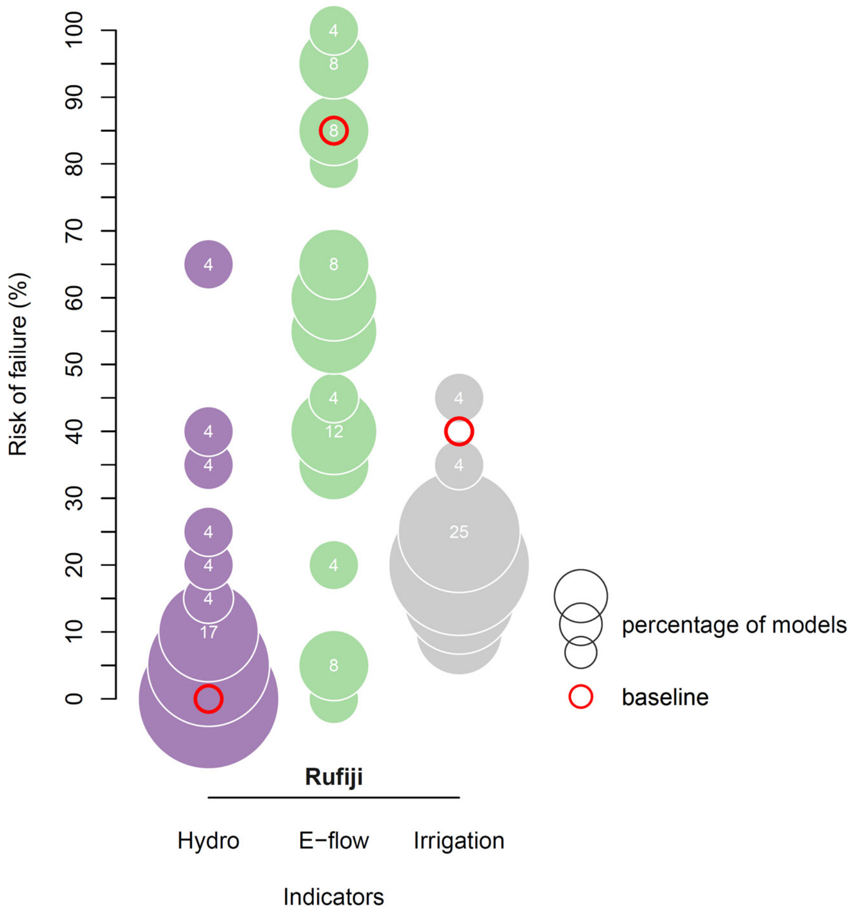
Positive impacts occur for the environmental flow indicator, with increased variability in rainfall and runoff increasing the chance of high releases during the wet season, though considerable risk remains. Specific adaptive environmental flow management measures, a topic worthy of further research and development, will be necessary to reduce the expected negative impacts, which will involve a trade-off between total energy production and environmental flows. Upstream irrigation water supply deficits in the basin might reduce in future with high model agreement for slightly wetter future conditions in the mountainous areas to the west of the basin.

Table 1 Risk of failure (in %) in three performance indicators for different periods in the Rufiji River Basin. Future risk is the multi climate model average. Note: risk is based on hypothetical simulations which include planned investments in irrigation and hydropower that are yet to be implemented. The results are therefore illustrative and should be interpreted with care. (Siderius et al., in press.)

	Period	*Rufiji Hydropower*	*E - Flow*	*Irrigation*
Historic risk	**1900 - 2009**	12	78	43
	1900 - 1929	38	79	51
	1910 - 1939	30	80	48
	1920 - 1949	10	80	44
	1930 - 1959	3	87	43
	1940 - 1969	3	73	41
	1950 - 1979	0	67	41
	1960 - 1989	0	67	39
	1970 - 1999	0	87	40
Present risk	1980 - 2009	3	87	41
Future risk; mean (SD)[Ŧ]	**2020 - 2050**	**4 (7)**	**57 (28)**	**22 (7)**

[Ŧ] Mean risk and standard deviation of 29 bias-corrected climate projections

Figure 4 Climate change impacts on failure rates in three Rufiji River Basin performance indicators in three sectors, summarizing reliability of infrastructure under current baseline (1970-2010) and future climate (2020-2050), with projected change in variability. Size of circles and number (plotted if not overlapped by a circle) represent the percentage of climate model projections in this category of risk (in this case a total of 24 models). 'Hydro' indicates the risk of not meeting firm energy requirements; 'E-flow' indicates the risk of not meeting bi-annual flooding requirements in the Rufiji River Basin, and 'Irrigation' indicates risk of not meeting monthly demand, given the assumptions underpinning our scenarios. (Siderius et al., in press).



The full climate risk profile is important in advising policy makers and guiding further research; under this model setup the most serious potential hydropower risk in the Rufiji River Basin (e.g., over 35%) occurs with just three outlier models, which, depending on stakeholder risk appetite could be further scrutinized for their representation of regional climate drivers and teleconnections and discounted if found unsatisfactory, to avoid making expensive modifications on the basis of unreliable information. Other risk profiles are either characterised by a concentration of models around a certain risk or by an even spread from low to high risk, such as for the environmental flow indicators, with uncertainty less likely to be easily constrained.

Is it possible to reduce uncertainty due to climate projections?

The uncertainty created by having many different projections of rainfall can be a challenge to decision-making. There is no established method for deciding upon which climate models to use for impact and risk assessment, although it is widely agreed that using only one model (or the average of many) and ignoring the range suggested by other available models is poor practice. Generally, the accepted source is the CMIP5 ensemble of models compiled for the IPCC Fifth Assessment (now updated to CMIP6 with results just beginning to appear). While there are many options available for selecting models, there is limited guidance and many questions arise, for example, should we use: all available models? Early versions and later versions of models? Exclude some models deemed to be poor performers or weight them less? (Kolusu et al., 2021; Siderius et al., in press). There are of course other practical considerations such as time, expertise, and costs associated with applying model selection.

We tried one approach to try to narrow the range; to assess climate model realism (or skill) in simulating key features of African climate and use this to rank (give different levels of influence to models with differing levels of skill) model selections (sub-samples) and exclude the weakest performing models, from a sample of 24 climate models available from CMIP5. We considered three methods of model weighting, noting that others could be used. We found that in our example the model weighting approaches do not greatly reduce the inter-model uncertainty, but the analysis gave insights into the causes of uncertainty (Kolusu et al., in press; Siderius et al., 2021). Of note is that there is more agreement on the projected change in future rainfall variability, with about three quarters of the climate models suggesting an increase in year-to-year variability, however, despite advances in understanding plausible mechanisms of future climate change, there is still much uncertainty on how exactly this will affect climate variability over the region.

Addressing key knowledge gaps

Important knowledge gaps exist for many aspects of the Rufiji River Basin. As development proceeds there is a clear need to improve understanding of how the basin functions, including the crucial interdependencies between the water-energy-agriculture-environment sectors.

In the modelling we have had to make a number of assumptions due to the complexity of the basin and data sparsity. A priority for future water resources management is to rehabilitate or establish and maintain gauging sites at critical points in the basin, particularly on the Rufiji main channel and the Kilombero and Luwegu tributaries that supply the bulk of the water to the JNHPP.

Given the overriding importance of Kilombero streamflow to Rufiji flows and the rapid development of this valley, better understanding of its wetland systems and the hydrological and wider impacts of land conversion and agricultural management is crucial.

There are assumptions and values incorporated within any analysis of performance metrics. Our selection of performance indicators is heavily constrained by data availability and practical concerns about making the analysis manageable and communicable to broad audiences. For comprehensive basin management a much larger suite of performance indicators is necessary.

We restrict our analysis of environmental flows to two indicators at one location. However, we note that environmental flows are a multi-faceted concept that includes other aspects such as (peak) flow duration and water quality. There are many other locations where certain streamflow characteristics are critical for environmental purposes and require further consideration.

While irrigation and land use change are evolving rapidly in parts of the basin, government targets are likely to be highly optimistic, given experience before and elsewhere in sub-Saharan Africa. Our Rufiji River Basin development scenarios lie at the upper end of the targets and as such reflect a highly optimistic outcome (in terms of meeting government targets). More consultation is required to verify ongoing rates of change (satellite analysis can also help) and to seek views on alternative scenarios of basin development and their relative merits for different stakeholders and the environment.

We presented risk without considering adaptation. Through adaptive management and well-designed reservoir operating rules and improved irrigation practices, some of the risks, e.g. the impact of the JNHPP reservoir on Rufiji's downstream delta ecosystem, could potentially be mitigated.

Management and governance context

Alongside our work on water resources modelling and climate change impacts, we have examined the institutional and governance dimensions across the water-energy-agriculture sectors in Tanzania, and how climate change is being absorbed into policy processes (Pardoe et al., 2017, 2020; Geressu et al., 2020). At the national level water, energy, agriculture and environment are divided into separate government ministries in Tanzania; the Ministry of Water (MoW), the Ministry of Energy, Ministry of Minerals, the Ministry of Agriculture (MoA) and the Ministry of Natural Resources and Tourism (MNRT). Irrigation has formerly been located within a Ministry of Agriculture and Irrigation. Cross-sectoral collaboration, which is crucial to effective implementation, is not strongly evident. While national policies and plans continue to call for cross-sectoral working, in practice collaboration is limited and largely confined to ad hoc projects and activities. Barriers include institutional structures, resource constraints that dis-incentivise collaboration due to issues around cost recovery, and a need to protect roles and responsibilities to ensure future budgets.

Since coming to office in 2015, President Dr John P.J. Magufuli has prioritised domestic economic growth through emphasis on industrialisation, as outlined in various 5-year plans. The Vice President's Office holds two mechanisms for managing environmental issues and climate change: the Division of Environment (DoE); and the National Environment Management Council (NEMC). Tanzania has a National Climate Change Strategy (NCCS) (URT, 2012), which guides the integration of climate change in sectoral policies and plans. The NCCS draws heavily on the National Adaptation Plan of Action (NAPA, URT, 2007), which includes plans for climate change adaptation for various sectors, including water, agriculture and energy. However, overall, the NAPA tends to emphasise vertical integration and major gaps remain in cross-sectoral collaborative and coordinated efforts in practice. For example, currently the MoW and the Tanzania Meteorological Agency (TMA) incur costs to collect data and whilst the MoW usually provides this freely, TMA charges fees which can stall agreements on provision of data to other parties (Pardoe et al., 2017). A platform for sharing data among government departments would help foster collaboration and promote efficiency.

At the river basin level our analysis highlights important interdependencies; upstream – downstream and cross-sector. Balanced development requires governance and management at the development corridor (SAGCOT) and basin scale. Like climate change, a shared vision of basin development needs to achieve internal recognition and ownership by relevant agencies to become legitimate and move to implementation.

Relevant government bodies include the Rufiji Basin Water Board within the MoW, the Ministry of Energy and the Ministry of Minerals regulates the operations of the Tanzania Electric Supply Company (TANESCO) that manages the hydropower dams, and the MoA and the Ministry of Finance and Planning are also important. A Rufiji Basin Development Authority (RUBADA) was dissolved around 2016. Past events in the basin have highlighted issues with coordination of dam releases contributing to reduced electricity generation and limited coordination between water resources and energy sectors.

Planned irrigation in the Rufiji River Basin is set and managed by the National Irrigation Commission under the framing of the National Irrigation Masterplan and supported by aid-funded feasibility studies. Autonomous irrigation development by smallholder farmers is a land use change driver where practical policy influence is more uncertain and is currently expanding in the wetlands of the Kilombero sub-catchment (Figure 1; Box 1), the largest contributor to the Rufiji main stream flows. In practice, enforcement of village land use plans, framed by Village Land Use Plans drawn by the Ministry of Lands, Housing and Human settlements, is weak and poorly coordinated between district and village level. The Water Resources Management Act No 9, of 2009 enshrines into law formal water management in Tanzania and the water allocation is managed by the Rufiji Basin Water Board, but it has limited capacity to enforce regulation of water permits. Any water abstraction without a permit is defined as illegal but in practice, many smallholder farmers abstract with no permit. Water User Associations (WUAs) are to support the formalization of water access for smallholder farmers but have so far led to mixed results as the poorest have been found to leave some farmers behind (Richards, 2019).

While the extent of informal irrigation expansion alongside the planned schemes in the future is unclear, it is an ongoing process that deserves more attention. Any irrigation expansion beyond what is already considered is a concern, given ongoing changes in the basin are already associated with important points of contestation. For example, at various times tensions and competing explanations have played out in the Great Ruaha sub-catchment over the actions and impacts of smallholder agriculture and pastoralists, irrigation expansion, land-grabbing and conservation.

Development and management challenges cut across all these bodies, they all affect and are affected by development throughout the basin. With the construction of the JNHPP and if SAGCOT (or other processes) stimulate extensive agricultural intensification then mechanisms for communication and coordination will be increasingly important; both for long-term planning and for shorter-term decisions, such as drought management.

Reportedly, a high-level dialogue started in April 2019 at the Vice President Office initiative between the ministries of Energy, Natural Resources and Tourism, Agriculture and Water to discuss the issue and propose a solution (Geressu et al., 2020). This, coupled with increased productivity of land as promoted by the SAGCOT initiative via improved irrigation schemes and better input use, could be an avenue for greater water conservation for downstream energy generation.

Moving beyond the Rufiji River Basin scale, if hydropower dams can be integrated in regional power grids, it could reduce systemic risk of drought impacts in the basin itself, by offsetting with hydropower in other regions (with different rainfall variability). This also offers opportunities; with Africa being increasingly connected through new infrastructure corridors such as the SAGCOT, trade can contribute to increased income, food and energy security.

Finally, complementary options, such as solar, thermal or wind power, which can be expanded incrementally, are rapidly becoming cost-competitive and should be considered alongside an open consultation and assessment process for major infrastructure decisions.

This Brief draws heavily on the following papers and briefs;

Geressu, R., Siderius, C., Harou, J., Kashaigili, J., Pettinotti, L. and Conway, D. (2020) Assessing river basin development given water-energy-food-environment interdependencies. Earth's Future, 7, e2019EF001464. https://doi.org/10.1029/2019EF001464

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About Future Climate for Africa

Future Climate for Africa (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.

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Photos by Diego Juffe Bignoli showing scenes from the Ihemi development cluster of the SAGCOT.

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