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The Role of Climate Services in Managing Climate Risks in Hydropower: Insights from Kidatu Hydroelectric Power Plant, Tanzania

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Abstract

This study employed a qualitative approach to assess the role of climate services in managing climate risks in HEP plants in Tanzania, using the most predominant Kidatu HEP plant as a case study, where approximately 50% of the national grid HEP was generated. The study sought to contribute empirical evidence to the broader body of knowledge on climate risk management and climate change adaptation in HEP plants as the country transitions from fossil fuels to low-carbon renewable energy consumption. A sample of 17 expert staff from the Kidatu HEP plant and Tanzania Meteorological Authority (TMA) was purposively selected, and primary data was collected through in-depth semi-structured interviews and open-ended questionnaires. Secondary data was collected by thoroughly reviewing existing documents from credible sources. The findings showed climate risks facing the Kidatu HEP plant include hydropower output decline and infrastructure damage due to excessive rainfall, prolonged dry spells and severe droughts that are being exacerbated by climate change and variability, since there is a correlation between precipitation, water inflow, and electricity production. The findings indicate that the utility of climate services could be strengthened by the co-production of climate services and sustained engagement between stakeholders and experts. In contrast, Kidatu HEP plant does not engage with or use customized climate services from TMA. The findings showed that TMA can produce and provide customized climate services upon the Kidatu HEP plant's request. Moreover, the findings portrayed the effective implementation of the National Framework for Climate Services (NFCS) as an ideal opportunity to effectively use climate services in climate-risk management at the Kidatu HEP plant. The NFCS promotes an integrated climate risk management approach that involves the co-development of climate services for all users, including the Kidatu HEP plant. We argue that the establishment of a robust user interface platform between TMA and HEP plants, including Kidatu, could facilitate the effective use of climate services and strengthen integrated water resources management in the Rufiji River Basin. Also, further research on quantifying climate risks and engaging more case studies would yield more robust evidence on the use of climate services and management of climate risk in HEPs in Tanzania.

Keywords: Climate risks; Climate risk management; Climate services; Hydroelectric power (HEP).

Introduction

For the past two decades, all potential economic sectors, including energy, particularly hydroelectric power (HEP) in Tanzania, have been experiencing the adverse impacts of climate change (NAPA 2007, IPCC 2019, URT 2019). Climate risks that are currently being accelerated by climate change significantly affect HEP which is one of the cleanest and most cost-effective sources of renewable energy as they distort HEP plant operations, reduce HEP output, and may cause impairment to HEP plant's infrastructure (NAPA 2007, NEP 2015, IFC 2018, REN21 2020).

The observed climate risks, such as intensified rainfall variability, extreme temperatures, frequent severe droughts, floods, and storms in Tanzania, significantly undermine HEP production (Kijazi et al. 2019, URT 2015, URT 2020). Heavy rainfalls increase seasonal river flows and may cause flooding. Flooding causes erosion, sedimentation, and damage to HEP plants' turbines (ADB 2012, NDRI 2016). Intensified rainfall variability increases uncertainty in river flows and dam storage capacity. Prolonged dry spells and recurrent severe droughts reduce the water level in HEP dams, hence declining HEP plants' output. (ADB 2012, Agrawala et al. 2003, URT 2019).

For instance, droughts that occurred in 2006 and 2010 in Tanzania caused severe power supply shortages and a drastic decrease in hydropower contribution from about 65.5% to 35% of the entire capacity (IRENA 2017, URT 2006). Tanzania experienced blackouts and severe power rationing when the highest water level in Mtera Dam went down from 695.8 m asl in 2003 to 690.5 m asl in 2004, 689.5 m asl in 2005 and 688 m asl in March 2006 and when the water level in Nyumba ya Mungu Dam dropped from 686.2 m asl in 2003 to 683.8 m asl, 683 m asl in 2004 and 680 m asl in 2005. Power rationing and insufficient energy for both domestic and industrial uses caused delays, failure, inefficiency, impairment and loss in the production and provision of goods and services; therefore, challenging socio-economic development (NAPA 2007).

The projected future global warming has a consequential implication on the large-scale atmospheric and oceanic circulation, particularly the Intra Tropical Convergence Zone (ITCZ), East African Monsoon, El Nino Southern Oscillation (ENSO), Indian Ocean Dipole (IOD), Tropical Cyclones, Congo Westerlies and Madden Julian oscillations (MJO) that influence rainfall distribution in East Africa. Therefore, it is very likely to intensify the impacts of climate change, alter precipitation and runoff patterns and cause further amplification of climate risks (WMO 2009, TMA 2019, URT 2019, WMO 2023). Uncertainty in the future warming, future rate of greenhouse gases (GHGs) emission, its interaction with the climate system and the magnitude of associated impacts poses a greater risk to HEP plants (NEP 2015, IFC 2018, REN21 2020).

Hence, incorporation of climate services in climate risk management is vital, especially in climate-sensitive sectors including HEP plants (Halsnæs et al. 2021, IFC 2018, NEP 2015). Climate services connect natural and socioeconomic research with practice and address climate-related impacts to facilitate the management of climate risks through the transformation of climate products and/or advice as well as other relevant information into customized products such as projections, trends and analysis (Kijazi et al. 2019, TMA 2017, WMO 2016).

This study disclosed that, although the indispensability of climate services in climate risk management, particularly in HEP plants, is indisputable, this topic has attracted low research interest in Tanzania. The national policy and institutional frameworks for risk management and climate services seem strong. However, the country lacks effective strategies to influence the incorporation of climate services in climate risk management and overall decision-making across climate-sensitive sectors. Moreover, the role of policy experts, decision-makers, and practitioners in promoting the use of climate services also lacked critical assessment. Existing literature focused mostly on studying the causal-effect relationship between climate risks and energy security, with limited flexibility to address the role of climate services in climate risk management in HEP plants, particularly in the face of climate change and increased uncertainties. Therefore, this study addressed the significant knowledge gaps on the role of climate services in the management of climate risks in HEP plants of Tanzania, using the Kidatu HEP plant in Morogoro as a case study to appraise future studies and key stakeholders on the topic.

The conceptual framework
The conceptual framework – Framework for Climate Services depicted in Figure 1 defines and shows the relationship between the independent variables (climate services) and the dependent variable (climate risk management) in this study.

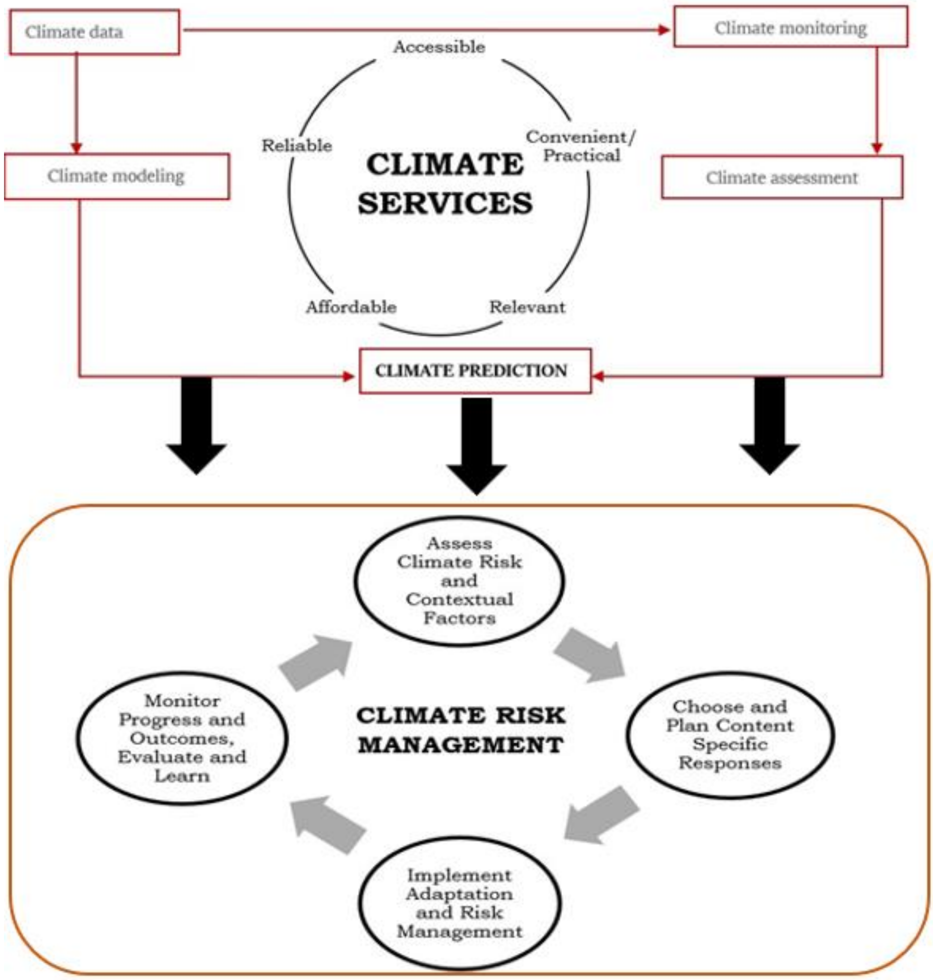

Figure 1: Framework for Climate Services *(Source: Modified from Wang et al., 2020).*

Crucial components of the climate services include climate data, climate modeling, climate prediction, climate monitoring, and climate assessment (Wang et al. 2020, WMO 2016). Climate data consists of a time series of measurements of sufficient length, consistency, and continuity that document past, present, and future conditions of the climate system from which climate variability and change are determined (NRC 2004, Gregory et al. 2017).
Climate models can be described as a numerical representation of the climate system based on the physical, chemical and biological properties of its components, their interactions and feedback processes. Climate models are used for a range of applications, including climate predictions and climate projections, as they simulate and study the climate system behaviour, components, interactions, trends in weather conditions over long periods and future possible evolution (UNISDR 2018, WMO 2018).
Climate predictions are defined as "inherently probabilistic statements about the future climate conditions on timescales

ranging from seasons to decades or longer, and on spatial scales ranging from local to regional and global". Such statements may include predictions of long-lived meteorological disasters, the statistics of high-impact extreme weather events and/ or statistics on the seasonal or annual mean anomaly as well as a measure of its probability of occurrence (North et al. 2014, WMO 2016).

Climate monitoring observes and informs on historical changes in the climate system including the atmosphere, the ocean, hydrology, the cryosphere, and the biosphere hence aiding daily decision-making and establishing a baseline for future changes (Wang et al. 2020, WMO 2023). Climate assessment informs on the climate impact on various sectors, including energy, water resources, agriculture, and human health, based on current and future climates. Assessments of climate impact on HEP include assessments of the impacts of hydrometeorological risk and disasters (Harrison 2001, Wang et al. 2020).

The use of climate services has a direct influence on climate risk management especially in climate sensitive sectors including HEP (Halsnæs et al. 2021, Ramos et al. 2016, REN21 2020, WMO 2016). Climate services incorporate issues of climate variability and climate change in decision making, planning and practices hence facilitating assessment of both the effects of climate variability and change on human activities, and the effects of human activities on the climate system (Kijazi et al. 2019, TMA 2017, TMA 2020, URT 2020, Wang et al. 2020, WMO 2012, WMO 2018).

Climate services underpin risk management cycle by providing information including early warnings, weather and climate forecasts that reinforce risk prevention, facilitate strategic planning for appropriate risk preparedness and response, and strengthen recovery (Street et al. 2019, Swart et al. 2018, URT 2020; Wang et al. 2020) in climate sensitive operations especially HEP (Mimikou et al. 1997).

Effectiveness of climate services in climate risk management is affected by their accessibility, reliability, affordability, relevance and practicality or convenience. Furthermore, engagement of intended users and incorporation of their needs in the development and designing of climate services, fulfilling those needs, and collecting feedback influence successfulness of climate services in producing desired outputs (Street et al. 2019, TMA 2020, URT 2020, WMO 2018).

Materials and methods

Description of the Study Area

The study was conducted in Kidatu HEP plant which is among the most predominant HEP plants in the country, accounting for 204 Megawatts, which is approximately 50% of the national grid's hydroelectricity. Kidatu HEP plant is in Kidatu ward, Kilombero District in Morogoro Region (EWURA 2020). Morogoro Region is in the Mid-Eastern part of Tanzania lying between latitudes 5° 58° and 10° South of the Equator and between longitude 35° 25° and 38° 30° to the East. It is bordered by Dodoma and Iringa Regions to the West, Coast Region to the East, Arusha and Tanga Regions to the North, Njombe, Ruvuma and Lindi Regions to the South (Steven et al. 2015, NBS 2022).

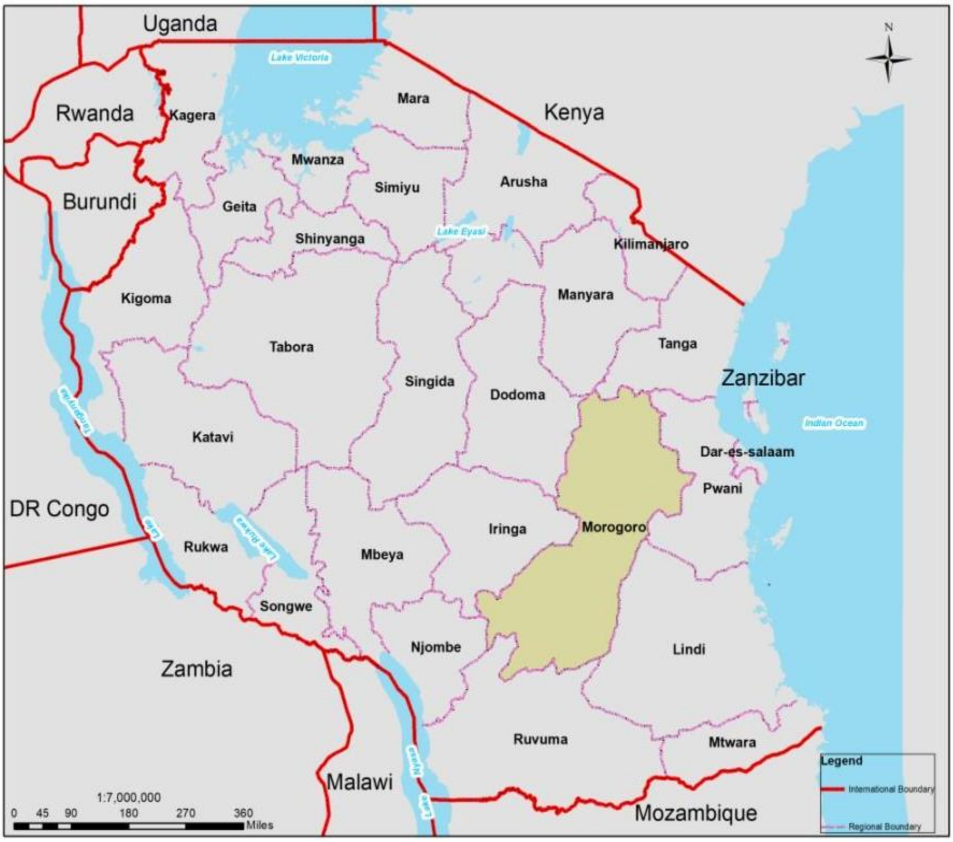

Figure 2: Map showing location of the Morogoro Region in Tanzania. *(Source: NBS 2022).*

Morogoro Region experiences moderate temperature and rainfall, whereby the average annual temperature varies between 18ºC to 30ºC in lowlands normally during the warm season from July to September. Morogoro Region experiences a bi-modal rainfall pattern with long rains between March and May and short rains between November and January. The average annual rainfall varies between 600 mm and 1800 mm, although there are variations from year to year and between ecological zones (NAPA 2007, TMA 2019, NBS 2022).

The Kidatu HEP plant in Morogoro is located on the Great Ruaha River, a sub-basin of the Rufiji River, which is one of the most socio-economic significant River basins in Tanzania. The Great Ruaha River sub-basin facilitates significant socioeconomic activities, including HEP production in the Mtera and Kidatu HEP plants, irrigation and livestock keeping, and hosts the biologically and economically significant ecosystems of Usangu wetlands and Ruaha National Park (Lankford et al. 2009, Makarius et al. 2013, WWF 2017, Nobert 2020). Morogoro Region is among the most susceptible to areas climate risks, in which the daily minimum temperature is rapidly increasing, rainfall has become more erratic and extreme weather events, including heavy precipitation, flooding and dry spells, are becoming more frequent and severe (TMA 2019, EWURA 2020).

Methodology

The study employed a case study design with a qualitative approach. A case study was the most suitable design intended to bring to light multiple realities and gain a comprehensive understanding on the use of climate services in the management of climate risks in HEP plants of Tanzania. Qualitative approach was the most suitable approach since the research questions involved variables that were difficult to quantify. These questions were:

i) What are the climate risks facing the Kidatu HEP plant?

ii) What type of climate services are available in Kidatu HEP plant and how are they used in managing climate risks at the plant?

iii) What are the barriers and opportunities for effective use of climate services in managing climate risks at Kidatu HEP plant?

Primary data was directly collected from the Tanzania Meteorological Authority (TMA) and the Kidatu HEP plant through in-depth semi-structured interviews and open-ended questionnaires. 8 expert staff from Kidatu HEP plant in Morogoro and 9 expert staff from TMA Headquarters in Dar es Salaam were implicitly chosen as key informants based on their experience in risk management at Kidatu HEP plant, and experience in production and provision of climate services at TMA, respectively. The study intentionally spent a considerable time with a small number of participants who provided rich information that could not be accessed through brief interactions.

Secondary data was collected from credible and relevant pre-existing, trustworthy, published and unpublished sources on climate services and climate risk management. Both the primary and secondary data collected in this study were qualitative and well organized in the form of interview transcripts, field notes, audio recordings, images, and text documents. To gain meaningful comprehension of the collected primary and secondary data the researcher employed thematic content analysis to analyze the qualitative data from the in-depth semi-structured interviews, open-ended questionnaires and secondary sources.

Thematic content analysis of the data was a continuous and repetitive process, taking place from the collection of data and carried over to the data entry and analysis stages. The researcher familiarized with the data, thoroughly reading and re-reading it and noted down initial ideas, coded it and searched for themes. The researcher reviewed the themes, defined and named them, further checking specifics of each theme, identifying what aspect of the data each one captured and generated a concise name for each theme. The researcher then assembled, organized, and compressed the data that had been grouped according to themes into a textual and graphic display that permits conclusion drawing and put together an analytic narrative with vivid data extracts as presented in the next section.

Results and Discussion

Climate risks to the Kidatu HEP plant.

The collected data highlighted that the major climate risks that currently face the Kidatu HEP, were such as output decline and infrastructure damage due to increased rainfall variability and severe weather events, particularly excessive rainfalls, prolonged dry spells, and recurrent drought that are being exacerbated by the changing climate.

The respondents from the Kidatu HEP plant stressed that rainfall variability has a significant impact on the plant's operations and output. They explained that low rainfall across the Great Ruaha River reduces water inflows, and increased rainfall increases inflows and may destroy the plant infrastructure therefore affecting electricity production. One of the respondents stated:

"The changing climate has intensified rainfall variability across the Great Ruaha River and amplified extreme weather events within the country. This has increased uncertainty in river flows and the amount of water in the reservoir which in turn affects the plant's output."

The Kidatu HEP plant respondents explained that Kidatu gets its water inflow from the Mtera dam and tributaries of the Great Ruaha River named Yovi River and Lukose River. The Mtera dam gets its water from the Great Ruaha River, Little Ruaha River and Kisingo River. This is in line with the secondary data obtained from Kidatu HEP plant.

Electricity production at the Kidatu HEP plant depends on the water inflows into the reservoir, as depicted in figure 3. Results presented in figure 3 were obtained from secondary data collected at the Kidatu HEP plant and show the trend in average annual inflow and units generated in the Kidatu HEP plant for the past 30 years.

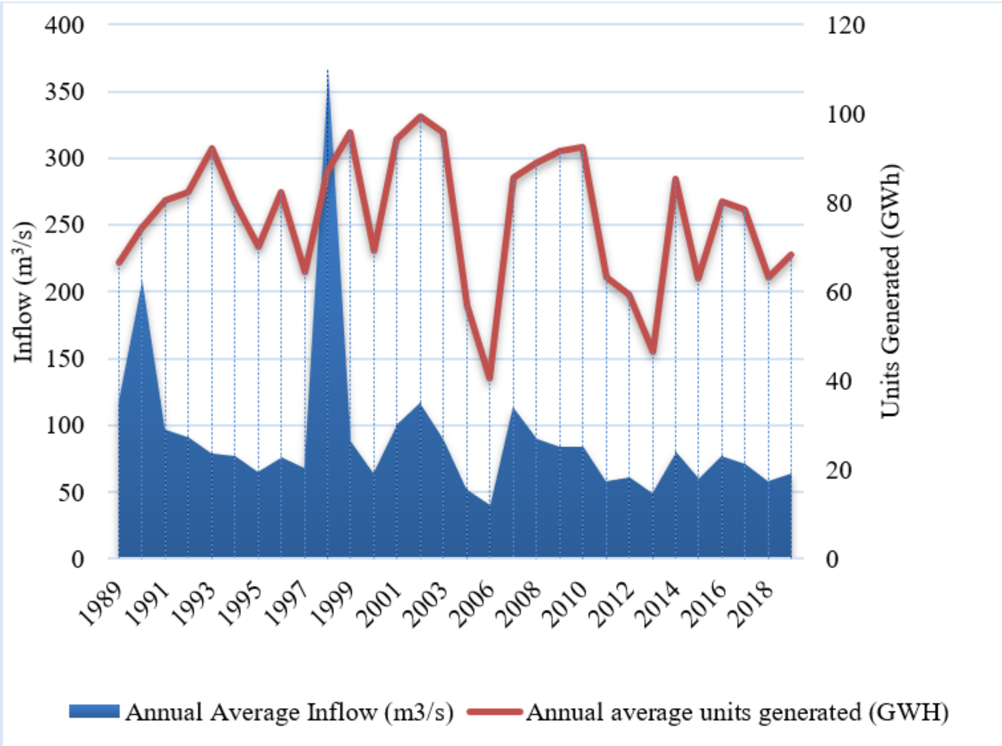

Figure 3: Average annual inflow and units generated in the Kidatu HEP plant from 1989 to 2019.

Furthermore, the respondents at Kidatu detailed that the plant operates at a minimum water storage level of 433 meters above sea level and maximum water storage level of 450 meters above sea level. A Kidatu respondent explained that in 2011, there was a significant decline in the plant's output due to a drought that started around 2010, whereby reduced water inflow into the Kidatu reservoir led to closure of two of the plant's turbines since the dam water level dropped to below 433 meters above sea level. This is evident in Figure 3 where a significant decrease in average annual inflow and average units generated in the Kidatu HEP plant is seen from 2010 to 2013.

The respondents at the Kidatu HEP plant further accentuated the plant's sensitivity to climate and weather conditions. They explained that since the plant's operations are highly affected by water inflow; high rainfall increases output but may cause soil erosion, sedimentation, and damage to the plants' turbines. One of the respondents at the Kidatu HEP plant recounted the following:

"In 2019 and 2020, there were periods of high rainfall that resulted in flooding from January to May. To maintain the maximum storage level of 450 meters above sea level, all spillway gates were opened to let the excess water pass and the plant was operating at its full capacity by then. However, the flooding caused siltation and slight damage to the plant's infrastructure which was rehabilitated after the incident."

The narrated incidence is in harmony with the secondary data obtained from the Kidatu HEP plant as shown in figure 4. Figure 4 shows the trend in monthly average rainfall and units generated in the Kidatu HEP plant from January 2019 to April 2020. It portrays the recounted period of high rainfall and the plant's output from January to May in 2019 and 2020.

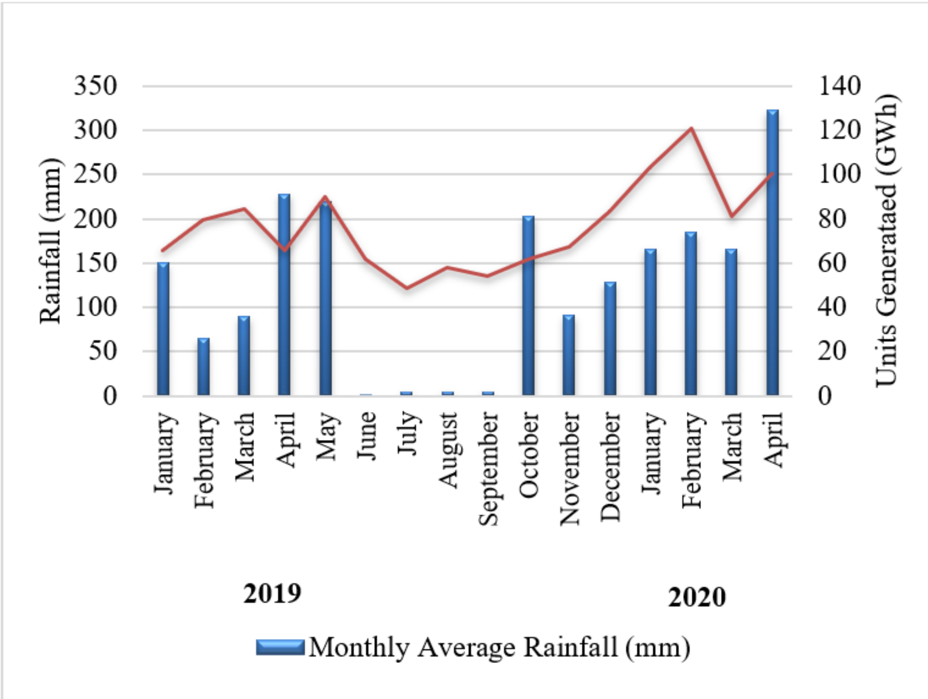

Figure 4: Monthly average rainfall and units generated in the Kidatu HEP plant from January 2019 to April 2020.

These findings are in harmony with Agrawala et al. (2003), URT (2006), ADB (2012), NDRI (2016), IRENA (2017) and URT (2019) underscoring increased uncertainty in river flows and the capacity of HEP dam storage due to intensified rainfall variability, risk of damage and reduced HEP outputs due to prolonged dry spells, and recurrent drought.

Pearson's product-moment correlation was conducted using R Quarto, to examine whether there is a relationship between the amount of electricity generated at Kidatu and two key climatic factors; Monthly Average Inflow (volume of water flowing into the plant) and Monthly Average Rainfall as highlighted in Table 1.

Table 1: Correlation Test Results with P-values

Variable_1	Variable_2	Correlation	P_Value	CI_Lower	CI_Upper	Method
Monthly Average Inflow	Monthly Average Units Generated	0.498	0.100	-0.106	0.834	Pearson's product-moment correlation

Monthly Average Rainfall	Monthly Average Units Generated	0.395	0.204	-0.232	0.790	Pearson's product-moment correlation

The findings disclosed moderate positive relationship between water inflow and electricity generation. This means that, generally, more water inflow tends to result in more electricity being produced. However, the p-value is 0.100, which is above the conventional threshold of 0.05. This means the relationship is not statistically significant, and we cannot confidently claim this observed relationship isn't due to chance. There is a weak positive relationship between rainfall and electricity generation - suggesting that more rainfall might lead to more electricity, but the relationship is not strong. The p-value is 0.204, indicating that the result is not statistically significant. The possibility that this is just a coincidence cannot be ruled out.

Although both inflow and rainfall seem to have some influence on electricity generation, the current data does not provide strong statistical evidence to confirm these relationships. This doesn't mean the factors are unimportant, but rather that more consistent or larger data might be needed to draw firmer conclusions. It may also suggest that other factors (like dam operation, turbine efficiency, or energy demand) could be playing a larger role than inflow or rainfall alone.

The in-depth semi structured interviews respondents from TMA stressed that the Kidatu HEP plant is one of the most exposed and sensitive HEP plants to climate risks since it is in one of the regions that are being affected by climate change the most. They explained that a significant rise in temperature and intensification of extreme weather events, particularly frequent flooding, and prolonged dry spells have been observed in Morogoro. One of the TMA respondents asserted the following:

"Meteorological observations have shown significant changes in the rainfall patterns in Morogoro. Recently, the region has been experiencing extreme weather events, particularly high rainfall and flooding."

Findings by WWF (2017) echoed similar trends whereby the rainy season in the Great Ruaha Basin was reported to become more erratic and unreliable. The study explains that the area used to get rainfall from November to March, but later early or delayed rainfall onset, early cessation, severe rainfall, and dry periods became common.

The open-ended questionnaire respondents from TMA also mentioned potential major climate risks to the Kidatu HEP plant to be distortion in hydropower generation and damage to the plant's infrastructure that may result from increased rainfall variability and extreme weather events particularly severe rainfall, prolonged dry spells, and drought.

These responses correspond to secondary data obtained from TANESCO press release whereby, in November 2021 TANESCO declared a decline of 345 MW equivalent to 68% of the country's hydroelectric capacity. The decline was due to extreme weather and water shortage that had significantly reduced HEP output in Kidatu and two other HEP plants namely Kihansi and Pangani (TANESCO 2021).

Regarding the declared HEP output decline, the Statement on the Status of Climate in 2021 by TMA, reported that Tanzania had experienced prolonged dry spells coupled with high temperatures that led to severe water shortages from September to December 2021. The statement has documented November 2021 as the warmest month of the year that broke a record in historical perspective, the driest month of the year 2021 and the third driest November on record since 1970 in which the recorded rainfall amount was lower than long term average by 55.6 mm (equivalent to 41% of the long-term average) (TMA 2022).

The Statement described 2021 as the fourth driest year on record since 1970 whereby the country total rainfall was 847.2 mm, which was 177.5 mm below the long-term average and equivalent to 82.7% of average (2003 was the first driest year, 2012 the second, and 2005 the third driest year). IRENA (2017), UNISDR (2018) and EWURA (2020) reported similar findings, stressing that climate risks may reduce national energy supplies and threaten the sustainability of HEP industry.

Moreover, all the respondents from the Kidatu HEP plant explained that human activities may pose substantial challenges to the plant's operations in general. They highlighted that agricultural activities that have been rapidly increasing upstream affect the plant's productivity. They explained that most upstream farmers use irrigation methods which consume a large amount of water and in turn reduce the amount of water that flows to the Kidatu reservoir.

One of the Kidatu respondents said:

"Human activities particularly irrigation farming distorts water inflow to the Kidatu reservoir as farmers upstream divert a lot of water to farm fields. These unsustainable farming activities upstream have also led to soil erosion and contributed to degradation of the environment and its resources."

Another Kidatu respondent suggested:

"The government should ensure improved proper irrigation systems upstream and sustainable water use within the Great Ruaha sub-basin, from Mbarali in Mbeya to Morogoro."

These findings are in line with Lankford et al. (2009) and Nobert (2020) who described several competing water users including irrigation, hydropower, and domestic water needs and challenges related to water resource management in the Great Ruaha sub-basin. The population in the Upper Great Ruaha River Catchment increased from below 50,000 to approximately 480,000 people between 1950 and 2003 due to immigration from other regions of Tanzania (Lankford et al., 2009). Moreover, WWF (2017) reported the irrigated agricultural land which is among the major water consumers to have expanded from just over 10,000 ha to 40,000 ha between 1970 and 2000.

WWF (2017) and Nobert (2020) highlighted that overuse of water resources upstream are among major challenges despite establishment of a sub-office of the Rufiji Basin Water Office and Water User Associations (WUAs) at the Great Ruaha River sub-basin and local level to address the water issues. The overuse has been causing water shortage to downstream users especially the Mtera and Kidatu HEP plants, the fragile ecosystems in the Usangu wetlands, and the Ruaha National Park which depends on the Great Ruaha River as the major water source for wildlife during the dry season.

Lankford et al. (2009) explained that the Great Ruaha River used to be perennial with river flow lasting throughout the dry season. However, since the early 1990s, the discharge through the Ruaha National Park has altered, becoming seasonal, with flows ceasing during part of the dry season.

The changes are confirmed by WWF (2017) and Nobert (2020) who reported that since the early 1990s, the Mtera dam which feeds the Kidatu reservoir has been experiencing water shortages due to the water flow decrease during dry season to the extent of stopping HEP production. From 1992 to 1994, the country experienced power rationing due to water shortage in Mtera that resulted from rice irrigation, deforestation and soil erosion in catchment areas, and valley bottom agriculture along streams (WWF, 2017; Nobert, 2020).

However, with adequate plans and effective risk management, HEP can be a source of resilience despite its susceptibility to climate risks. This includes assessing and retrofitting existing HEP plants where necessary to account for increased climate risks, and incorporation of climate risk management in the design of new projects (IRENA, 2023).

The type of climate services and their uses in managing climate risks.

The type of climate services available at the Kidatu HEP plant.

The study findings disclosed that the Kidatu HEP plant does not request or use any climate services from the Tanzania Meteorological Authority (TMA). The respondents from the Kidatu HEP plant explained that the plant does not obtain any climate services from TMA. However, they disclosed that the plant has a weather station that provides climate data including measurements of rainfall and temperature. One of the Kidatu HEP plant respondents explained:

"TMA does not specifically deliver any climate services to the Kidatu HEP plant. I am aware of the climate services provided by TMA to the public, but the Kidatu HEP plant does not obtain any climate services from TMA. Kidatu has its weather observation station that produces daily measurements of rainfall and temperature".

Another Kidatu HEP plant respondent affirmed:

"I understand that TMA provides climate services to the public, especially through Television, but the Kidatu HEP plant does not acquire them. The plant relies on climate data from its own weather observation station."

Another respondent from Kidatu HEP plant said:

"The Kidatu HEP plant neither requests nor receives any climate services from TMA. The plant has a weather observation station that provides climate related services. The weather observation station provides data on temperature and rainfall within the plant's area. The plant's operators rely on this data and measurements of the dam water level for daily operations."

Also, the in-depth semi structured interviews respondents from TMA explained that TMA does not specifically provide any climate services to the Kidatu HEP plant. One of them said:

"TMA does not specifically provide any climate services to the Kidatu HEP plant. However, TMA issues public weather forecasts, early warnings, seasonal outlooks, and other information on a frequent basis. These are usually disseminated via TMA's website and the media. Also, TMA produces and provides customized climate services upon users' requests."

Findings from the open-ended questionnaires filled by TMA experts concurred with the in-depth semi structured interviews' findings, whereby the open-ended questionnaires respondents from TMA affirmed that TMA does not specifically provide any climate services to the Kidatu HEP plant.

All the respondents from TMA indicated that, although TMA does not specifically provide any climate services to the Kidatu HEP plant, TMA has a procedure for issuing and providing customized climate services when requested. They explained that requesters of climate services from various sectors are required to send their requests to TMA specifying the type of the requested climate services, intended uses, location, duration and time frame, and TMA would provide them in accordance with its regulations.

Use of climate services in managing climate risks at the Kidatu HEP plant.

The respondents at the Kidatu HEP plant explained that the daily measurements of rainfall provided by the plant's weather observation station are used to estimate the dam's water level. One of the respondents said:

"The weather observation station at the Kidatu HEP plant provides daily measurements of temperature and rainfall within the plant's area since they influence reservoir inflow and the dam's water level. Kidatu uses the measurements to estimate the level of water in the dam from rainfall intensity."

The respondents explained that the Kidatu HEP plant also communicates with the Mtera HEP plant regarding the level of water in the Mtera dam to ensure proactive action in case of flooding or water deficiency at the Mtera reservoir. However, they were concerned about the lack of weather forecasts or climate predictions for any of the two HEP plants (Kidatu and Mtera) or the Great Ruaha River that feeds them.

Their concerns are in line with UNDRR (2022) that described disaster decision-making to be blind without data, and risk governance to paralyzed without the infrastructure to interpret the data and instrumentalize the decisions. UNDRR (2022) further stressed that if risk management is a fundamental aspect among stakeholders at different levels, and policymakers understand the need to accept uncertainty; data-driven disaster risk reduction systems can help to manage disaster risks and prevent unnecessary suffering.

The respondents at Kidatu explained that the availability of rainfall and temperature measurements within the plant's area is inadequate to guarantee effective management of climate risk. They said that this is because most of the water for electricity generation in the Kidatu HEP plant comes from the Mtera reservoir and upstream rivers compared to the amount contributed by rainfall within the plant. The respondents underscored the importance of customized climate services, especially weather and climate forecasts to facilitate effective management of climate risks. One of them stated:

"Kidatu and Mtera HEP plants need reliable customized climate services, especially daily rainfall forecasts, early warnings, and seasonal climate predictions for effective climate risk management. These will enable us to prepare and take appropriate action to mitigate potential negative impact in case of extreme weather, especially severe rainfall, prolonged dry spells, and drought which have become more frequent these years".

Another respondent said:

"Availability of reliable tailored and actionable climate service to Kidatu and other HEP plants managed by TANESCO would facilitate effective management of climate risks that are increased by climate change and variability and threaten energy security in the country".

These findings align with Wang et al. (2020) and Scaife et al. (2021) who stressed on the indispensability of climate prediction particularly rainfall forecasts in supporting climate risk management in HEP plants especially in mitigating impacts of flood and drought in hydroelectric dams and regulating electricity supply. The findings are also in line with North et al. (2014), WMO (2016) and URT (2020) who accentuated the usefulness of climate prediction for proactively planning and making long-term decisions.

Climate prediction facilitates adaptation to climate variability and changes in various fields including HEP production, early warning of potential hazards, disaster prevention and mitigation (North et al. 2014, WMO 2016, URT 2020). An example can be drawn from Wang et al. (2020) that describes how climate services have been supporting long-term strategic planning, the assessment of water availability and risks, effective water diversion, and distribution on all time scales in China as portrayed in figure 5.

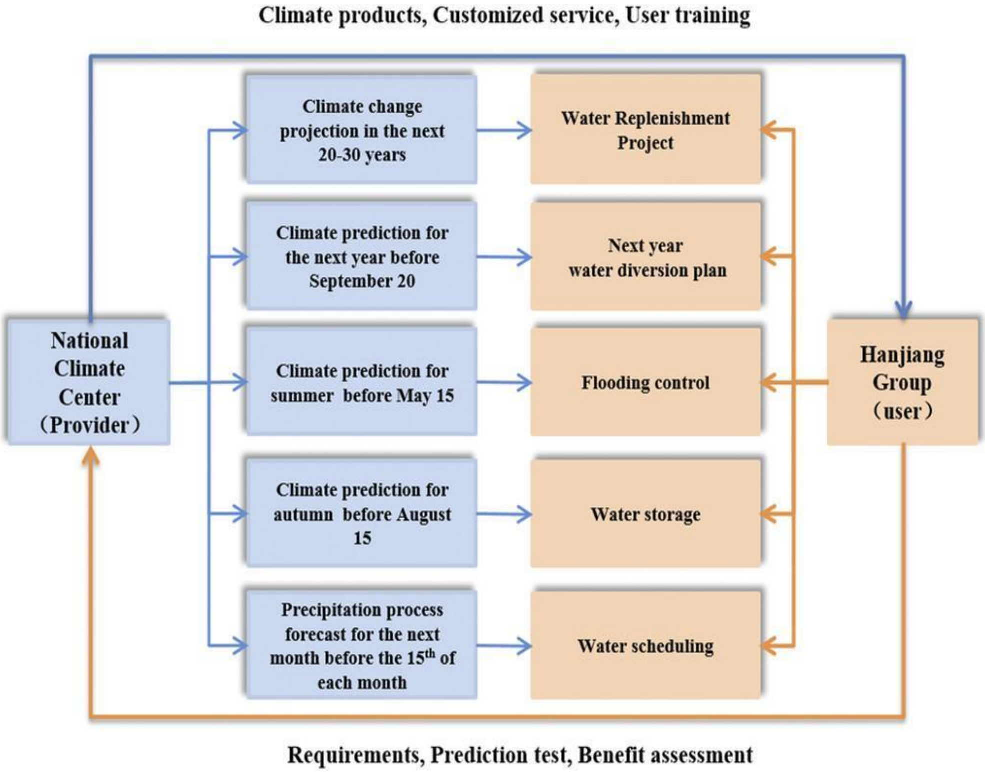

Figure 5: Danjiangkou Reservoir Water Diversion Project climate service process. *Source: Wang et al. (2020).*

The National Climate Centre (NCC) provides customized monthly, seasonal, annual, and decadal climate predictions to the Hanjiang Group that manage Danjiangkou Reservoir Water Diversion Project for several purposes including hydroelectricity generation, domestic water supply and irrigation based on specific needs. The NCC also facilitates improved use of the services through training, communication, and user feedback. The climate services, particularly summer and autumn precipitation predictions provided by NCC were successfully used by the Hanjiang Group to control flooding, and determine reservoir storage timing and volume among other uses (Wang et al. 2020).

Opportunities for effective use of climate services in managing climate risks at the Kidatu HEP plant.

i) **Accessibility of client-tailored climate services from TMA upon user request.**

The study revealed that upon user request, TMA produces and provides client-tailored climate services for various purposes. TMA respondents explained that the Authority has always been producing and providing such client tailored services mostly to aviation, agriculture, and marine sectors.

An in-depth semi structured interview respondent from TMA said:

"Although the Authority neither provides any climate services to the Kidatu HEP plant specifically nor receives any climate services request from the plant, TMA produces and provides customized climate services upon users requests."

Scaife et al. (2021) stated that raw data and knowledge hardly allow effective risk management. Users need to be aided in the uptake and use of climate services through the codesign, development, and delivery of climate services (WMO 2016, Kijazi et al. 2021, Scaife et al. 2021). TMA (2020), URT (2020) and Khosravi et al. (2021) highlighted

identification and understanding of users' specific needs to be a requisite to appropriately tailor climate services.
A good example can be drawn from "Climate Science to Service Partnership (CSSP)" which is a collaborative research and innovation project that has delivered substantial progress in climate observation, understanding, modeling, and prediction by engaging providers of climate services and users to develop climate services that meet decision-makers' needs together (WMO 2016, Scaife et al. 2021). This include the monthly updated real-time probabilistic forecast for summer rainfall in the Yangtze River basin in China which is intended for flood control, water resource management and hydropower generation, in large reservoirs along the Yangtze River including the Three Gorges HEP plant (Scaife et al. 2021).

Replication of such successes in Tanzania has a great potential to enhance effective use of climate service for climate risk management in the hydroelectricity sector which has been highly affected by severe weather events recently. Co-development of climate services with the intended user, particularly HEP plants, facilitates customization of the provided services according to the user's needs. Moreover, the users will gain a better understanding of how climate services can influence decision making and TMA will gain a better understanding of how climate services can create societal benefit and steer further scientific research.

ii) **The National Framework for Climate Services.**

Findings from secondary sources illuminated the National Framework for Climate Services as another significant opportunity for effective use of climate services in managing climate risks at HEP plants, including Kidatu.

New et al. (2022) and UNDRR (2022) described application of a systems-based approach and inclusive, transdisciplinary, and accountable disaster risk governance mechanisms as a method to overcome related underlying risk factors. The National Framework for Climate Services that commits to prioritize protection of the energy sector from an increasingly variable and changing weather and climate, offers such an approach.

The National Framework for Climate Services provides a structured means for climate services users, providers, and climate researchers to interact as depicted in figure 6. The Framework is a vital opportunity to improve TMA's understanding of user needs and enhance the capacity of users including the Kidatu HEP plant to demand, understand and effectively use climate services for climate risk management.

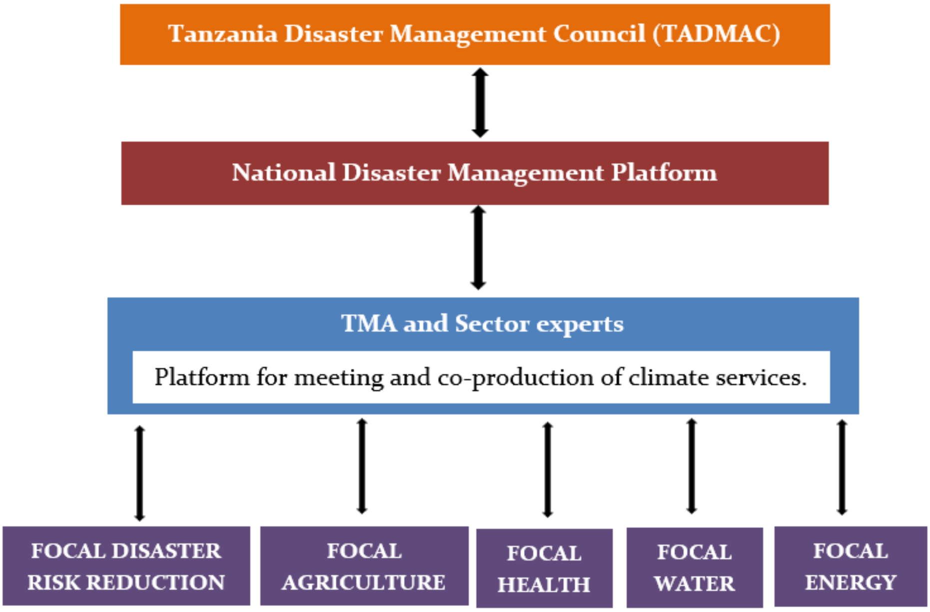

Figure 6: Governance mechanism for implementation of the National Framework for Climate Services in Tanzania. *Source: (URT 2020).*

A collaboration between climate services providers and users adds socio economic value. Such collaboration facilitates the production of advisory climate services that meet users' needs and promotes the effective use of the services. In HEP plants such collaboration guarantees safety and security against climate risks; optimizes energy, production and economic value of water resources, therefore, ensuring robust and sustainable supply and demand in the face of climate change and uncertainty (Ramos et al. 2016, Hakala et al. 2020, Halsnæs et al. 2021). This is in alignment with WM O (2018), Street et al. (2019), TMA (2020), URT (2020); Kijazi et al. (2021) and New et al. (2022) who described effectiveness of climate services to be strengthened by co-production and sustained engagement of intended users and incorporation of their needs in the development and designing of climate services, fulfilling those needs, and collecting feedback.

Conclusion

This study deployed a qualitative case study approach to assess the role of climate services in climate risks management in HEP plants of Tanzania using the Kidatu HEP plant as a case study. The findings highlight climate services in climate risk management as a key component of climate resilient development. It shows the importance of co-production of tailor-made climate services and sustained engagement between key stakeholders particularly, producers and users of climate services, to reinforce climate risk management. Moreover, effective implementation of the National Framework for Climate Services that promotes integrated approach climate risk management is an ideal opportunity for effective use of climate services in climate risk management at the Kidatu HEP plant and across climate sensitive sectors.

The study underscores the effective use of climate services in climate risk management in HEP plants as vital, especially now with the changing climate and growing need for HEP output as the world is transforming to low carbon and renewable energy consumption. It recommends the following:

i. Establish a strong user interface platform between TMA and HEP plants of Tanzania for effective interactions to ensure availability of and effective use of customized climate services for successful management of climate risks in the HEP plants including Kidatu.

ii. Reinforce integrated water resource management in the Rufiji River Basin. This includes increased capacity building to water users upstream to promote sustainable use of the water resources and mitigate negative socio economic and ecological impact of human activities including unsustainable agricultural practices that increases vulnerability to climate risks.
iii. Carry out further research on the role of climate services and management of climate risk in other highly climate sensitive industries and important economic sectors in Tanzania such as other renewable energy sources, agricultural value chains, aviation, mining, and tourism.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

ADB 2012 Climate risk and adaptation in the electric power sector, Mandaluyong City, Philippines.

Agrawala S, Moehner A, Hemp A, Aalst M, Hitz S, Smith J, Meena H, Mwakifwamba SM, Hyera T and Mwaipopo OU 2003 Development and Climate Change in Tanzania: Focus on Mount Kilimanjaro, Organization for Economic Co-Operation and Development, Paris.

EWURA 2020 Energy and Water Utilities Regulatory Authority https://www.ewura.go.tz/electricity-infrastructure/. October 20, 2020.

Gregory G, Stefano N, Andre O, Martin B and Anthony L 2017 Spatially enabling the Global Framework for Climate Services: Reviewing geospatial solutions to efficiently share and integrate climate data & information. *Clim. Serv.* 8: 44-58

Hakala K, Addor N, Gobbe T, Ruffieux J and Seibert J 2020 Risks and opportunities for a Swiss hydroelectricity company in a changing climate. *Hydrol. Earth Syst. Sci*. 24: 3815-3833

Halsnæs K, Bay L, Kaspersen PS, Drews M and Larsen MAD 2021 Climate Services for Renewable Energy in the Nordic Electricity Market. *Climate* 9: 46

Harrison GP 2001 *An Assessment of the Impact of Climate Change on Hydroelectric Power.* PhD thesis, University of Edinburgh.

IFC 2018 Good Practice Note. Environmental, Health, and Safety Approaches for Hydropower Projects, World Bank Group, Washington, D.C.

IPCC 2019. Special Report, Climate Change and Land, IPCC, Geneva.

IRENA 2017 Renewable Readiness Assessment United Republic of Tanzania, IRENA, Abu Dhabi.

IRENA 2023 The changing role of hydropower: Challenges and opportunities, IRENA, Abu Dhabi.

Khosravi F, Taylor A and Siu YL 2021 Chinese water managers' long-term climate information needs. *Sci. Total Environ.* 750: 141637.

Kijazi A, Chang'a L, Luhunga P, Ng'ongolo H, Merchades M and Levira P 2019 The Contribution of the Global Framework for Climate Services Adaptation Programme in Africa (GFCS APA) in National Adaptation Plan (NAP) Process for Tanzania. *Atmos. Clim. Sci.* 9: 650-661

Kijazi A, Chang'a L, Muruke W, Ndaki M, Babyegeya M, Kisama S and Juma O 2021 Best Practices and Lessons Learned in the Implementation of Global Framework for Climate Services-Adaptation Programme in Africa: Tanzania-Experience. *Atmos. Clim. Sci.* 11(4): 749-766.

Lankford B, Tumbo S and Rajabu K 2009 Water Competitions, Variability and River Basin Governance: A Critical Analysis of the Great Ruaha River, Tanzania. *River Basin Trajectories: Societies, Environments and Development* 8: 171-195

Makarius VM and Theresia F 2013 Productivity of Water in Large Rice (Paddy) Irrigation Schemes in the Upper Catchment of the Great Ruaha River Basin, Tanzania. *Water Resources Planning, Development and Management*

Edited Volume (pp. 171-195), CAB International.

Mimikou MA and Baltas EA 1997 Climate Change Impacts on the Reliability of Hydroelectric Energy Production. *Hydrol. Sci. J.* 42(5): 661-678

NAPA 2007 National Adaptation Programme of Action. United Republic of Tanzania, Vice President's Office, Division of Environment.

NBS 2022 Morogoro Region Socio-Economic Profile. Jointly prepared by National Bureau of Statistics, Ministry of Finance and Planning and Morogoro Regional Secretariat.

NDRI 2016 Adaptation to Climate Change in the Hydroelectricity Sector in Nepal. Practical Action Consulting (PAC, Nepal), Global Climate Adaptation Partnership (GCAP, UK), and Climate and Development Knowledge Network (CDKN).

New M, Reckien D, Viner D, Adler C, Cheong SM, Conde C, Constable A, Coughlan de Perez E, Lammel A, Mechler R, Orlove B and Solecki W 2022 Climate Change 2022: Impacts, Adaptation and Vulnerability. In the Sixth Assessment Report of the Intergovernmental Panel on Climate Change: Contribution of Working Group II (pp. 2539-2654) Cambridge University Press, Cambridge and New York.

NEP 2015 The United Republic of Tanzania. Ministry of Energy and Minerals.

NRC 2004 Climate Data Records from Environmental Satellites. National Academies Press, Washington.

Nobert J 2020 Assessment of Water Management and Development Scenarios in the Great Ruaha Catchment, Rufiji Basin. *J. Geogr. Assoc. Tanzania.* 1: 1–20

North G, Zhang F and Pyle J 2014 Encyclopedia of Atmospheric Sciences: 2nd Edition, Elsevier, Amsterdam.

Ramos MH, Castelletti A, Pulido-Velazquez M and Gustafsson D 2016 Weather and climate services for hydropower management. *Hydropower Environ. Sustain.* 5: hal-01357057- 6: hal-02280306

REN21 2020 Renewables 2020 Global Status Report, REN21 Secretariat , Paris, France.

Scaife AA and Coauthors 2021 The U.K.–China Climate Science to Service Partnership. *Bull. Am. Meteor. Soc*. 102: E1563–E1578

Steven S and Mkonda MY 2015 Climate Variability Impacts, Diseases and Human Health: The Case of Morogoro Municipalities, Tanzania. *Arch. Bus. Res.* 3: 78-90.

Street RB, Buontempo C, Mysiak J, Karali E, Pulquério M, Murray V and Swart R 2019 How Could Climate Services Support Disaster Risk Reduction in the 21st Century. *Int. J. Disaster Risk Reduct.* 34: 28-33.

Swart R, Karali E, Mysiak J, Buontempo C, Pulquério M and Street RB 2018 Climate services for disaster risk reduction, Workshop Report, Bologna.

TANESCO 2021 Tanzania Electricity Supply Company https://www.tanesco.co.tz. June 11, 2021.

TMA 2017 Strengthening Climate Information and Early Warning System in Tanzania for Climate Resilient Development and Adaptation to Climate Change Project in Tanzania. Regional Workshop on Towards Sustainability for Climate Information Services: Achievements, Impacts, Lessons Learned and Next Steps.

TMA 2019 Statement on the Status of Tanzania Climate in 2019, TMA, Dar es Salaam.

TMA 2020 Global Framework for Climate Services Adaptation Program in Africa. Phase II Implementation in Tanzania. Agriculture and Food Security, Health and Nutrition, Disaster Risk Reduction. Newsletter Edition 02, TMA, Dar es Salaam.

TMA 2022 Statement on the Status of Tanzania Climate in 2021, TMA, Dar es Salaam.

UNDRR 2022 Global Assessment Report on Disaster Risk Reduction 2022: Our World at Risk: Transforming Governance for a Resilient Future, UNDRR, Geneva.

UNISDR 2018 United Republic of Tanzania Disaster Risk Profile, UNISDR, Geneva.
URT 2006 State of the Environment Report. Vice President's Office, Division of Environment, Dodoma.
URT 2015 Renewable Energy in Africa. Tanzania Country Profile. African Development Bank. World Bank. Climate Investment Funds.
URT 2019 State of the Environment Report 3. Vice President's Office, Division of Environment, Dodoma.
URT 2020 National Framework for Climate Services 2018 – 2025, TMA, Dar es Salaam.
Wang Y, Song L, Hewitt C, Golding N and Huang Z 2020 Improving China's Resilience to Climate-Related Risks: The China Framework for Climate Services. *Weather Clim. Soc.* 12: 729-744
WMO 2009 Flood Management in a Changing Climate. A Tool for Integrated Flood Management. Associated Programme on Flood Management (APFM), WMO, Geneva.
WMO 2012 Global Framework for Climate Services - Innovation and Adaptation, WMO, Geneva.
WMO 2016 Global Framework for Climate Services. Use of Climate Predictions to Manage Risks, WMO, Geneva.
WMO 2018 Weather Climate Water. Guide to Climatological Practices, WMO, Geneva.
WMO 2023 State of the Global Climate 2022, WMO, Geneva.
WWF 2017 Final Report. Great Ruaha River Basin Climate Vulnerability and Capacity Analysis (CVCA). CARE-WWF Alliance in Tanzania.