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EXPLORING THE EFFECTS OF CLIMATE CHANGE ON KAGERA TRANSBOUNDARY RIVER BASIN MANAGEMENT IN TANZANIA

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Abstract. Drastic changes in climatic variables, especially precipitation, have influenced the availability and access to water resources. Climate change affects hydrological processes, such as runoff, groundwater recharge, water demand, and biophysical process patterns within the basins. The study aimed to envisage uneven impacts experienced in water resources management within the basin. It employed a survey method in data collection and Statistical Package for Social Science (SPSS) and Microsoft Excel to analyze the quantitative data and thematic synthesis for qualitative data, including the local community perceptions within the transboundary basin. The results indicate high variability in rainfall, long-term drought, flood, and other extremes—the observed annual mean rainfall of 832 mm with Std. Deviation of 248 with a standard error of 361 and skewness of -945 indicates the high fluctuation in mean rainfall with decreasing trends that signify changes (R^2 = 0.1797 and P = 0.002). The limited and inadequate access to hydrological and meteorological data increases challenges and affects prediction, infrastructure plans, and response measures for water resource allocation and management. Lack of common approaches due to the politics of riparian states, weak coordination, and conflicting and or unclear sectoral policy to govern priorities versus water resources management in the respective country affects transboundary water resources management. Institutionalization and enhancement of efficient and effective water management strategies on available resources, investment in innovative means, and capacity of key stakeholders. Thus, harmonizing and enforcing policies, laws, and regulations govern transboundary water use and management in riparian states. The focus should be on inclusive governance for the sustainability of water resources management, in parallel to a well-coordinated strategy, program, plans, and livelihood practices, without neglecting stakeholder participation in the main aspects of water resources management.

Keywords: Climate Variability, Challenges, River Basin, Transboundary Water, Resources Management

1 INTRODUCTION

The environmental sector poses a security threat mainly due to environmental and climate change problems. Drastic changes in climatic variables, particularly precipitation, have significantly impacted water availability and access. Hydrological processes, including runoff, groundwater recharge, and water demand, have been influenced by climate change, leading to high variability in rainfall, long-term droughts, and floods within the basin. A limitation in its management is that the effects of changes felt in the short and long term; therefore, in many cases, they are not taken into account in everyday political practice, mainly because the cause of the problem and its sufferer in many cases do not match (Balatonyi et al., 2021; Taylor et al., 2021). In the global context, the management of water resources has become a pressing concern due to the profound impacts of climate change and environmental degradation (Balatonyi et al., 2021). Driven by changing climatic patterns, shifts in precipitation, prolonged droughts, and more frequent extreme weather events have disrupted the availability and distribution of water resources worldwide (Munia et al., 2020). These changes are exacerbated by the increasing demand for water resources driven by population growth, urbanization, land degradation, and industrialization (Taylor et al., 2021). As a result, water scarcity and quality deterioration emerged as critical challenges affecting ecosystems, livelihoods, and geopolitical relations internationally (Gwambene, 2017; Munia et al., 2020). The United Nations highlighted the importance of sustainable water

management in its Sustainable Development Goals (SDGs), underlining the need for cross-border cooperation to ensure equitable access to clean and reliable water sources (UN, 2019). The implications of these challenges extend beyond national boundaries, magnifying the importance of collaborative efforts and integrated strategies for transboundary water resource management (Dezfuli et al., 2022).

The implications of extreme climate events are far-reaching, causing lasting socio-environmental impacts at the local level and contributing to transboundary water issues with broader regional and global security implications (Dugassa et al., 2021; Dezfuli et al., 2022; Mkonda, 2022). For instance, in the Middle East, climate-related crises are projected to occur more frequently in the Future (Helman et al., 2020; Dezfuli et al., 2022). Future drivers, including changes in local runoff, natural inflows from upstream regions, and local and upstream water consumption, have global implications, affecting water supply and crop yields, which, in turn, can impact GDP (Gwambene, 2017; Munia et al., 2020; Ziadat et al., 2022). As projections indicate more people will inhabit areas dependent on upstream originating water by 2050, international water treaties and management will be increasingly crucial in ensuring fair management of transboundary water resources in hotspot regions (Munia et al., 2020).

The environmental sector faces a security threat primarily due to environmental and climate change problems (Gwambene, 2017; Ziadat et al., 2022). However, managing these challenges is hindered by a crucial limitation: the effects of changes are only sometimes immediately apparent, leading to their exclusion from everyday political practice. In many cases, the cause of the problem does not directly align with those suffering its consequences (Balatonyi et al., 2021). This effect has significant implications for the governance and management of transboundary water resources in the Kagera River Basin, particularly concerning the political dynamics among riparian states, weak coordination between stakeholders, and conflicts or uncertainties surrounding sectoral policies governing water resources. This discussion shed light on the far-reaching implications of these challenges for transboundary water management.

Recognizing the significance of shared water bodies that traverse multiple nations provides a platform to respond to these challenges. Transboundary river basins, in particular, present complex scenarios where the interplay of hydrological processes and geopolitical dynamics requires innovative approaches for equitable water allocation and sustainable management (Mubiru, 2021; Waithaka et al., 2021). International conventions and agreements, such as the United Nations Watercourses Convention, and regional initiatives like river basin organizations foster cooperation among riparian states, which fosters effective water resources governance (FAO, 2023). However, these efforts often need help with conflicting interests, inadequate data sharing, and political tensions (Mkonda, 2022). Understanding the interactions between climate variability, water availability, and cross-border cooperation is essential in developing adaptive strategies that ensure the long-term resilience of shared water resources (Candau & Gbandi, 2023).

Water issues within river basins and transboundary basins exhibit distinct differences. Transboundary watersheds, in particular, suffer from poor water quality, attributed mainly to global population distribution (Seeteram et al., 2019; Mubiru, 2021; Wang et al., 2022). Within the transboundary river basins, the relationship between upstream and downstream countries becomes politically sensitive due to asymmetries, with the upstream country potentially passing on negative consequences of unsustainable water use to its downstream neighbour (Munia et al., 2020). Changes in water availability and quality brought about by climate change and variability significantly impacted The downstream users (Dezfuli, 2022). Furthermore, the downstream regions heavily depend on upstream water resources, especially during water scarcity and drought, leading to potential flood risks that can affect homeland security, water infrastructure, and management strategies (Balatonyi et al., 2021).

Climate variables, particularly precipitation patterns, influence water resources' availability and access. It impacts the basin's hydrological processes, such as runoff, groundwater recharge, water demand, and biophysical process patterns. Global climate change significantly affects the physical environment, and water quality and quantity problems, including shortage of drinking water, necessitate collective action among states and individuals to address sectoral challenges (Balatonyi et al., 2021; Taylor et al., 2021).

Unlike river basins confined within a single country, transboundary river basins are complex socio-physical systems involving the interests of multiple geopolitical entities (Waithaka et al., 2021; Mkonda, 2022; Wang et al., 2022). Each country manages the water resources within its borders, but transboundary river basins require collaborative efforts to maintain equitable water rights and interests (Mubiru, 2021; Wang et al., 2022). However, such collaborations often face challenges and conflicts from international water management disputes (Waithaka et al., 2021; Wang et al., 2022). Managing these shared resources demands sustainable, equitable, and collaborative approaches. Effective management strategies address the politics of riparian states and their effects on formulating and implementing common approaches for water resource management.

In the context of transboundary water management, it is essential to consider the roles of local versus upstream changes in water use and availability (Seeteram et al., 2019; Munia et al., 2020). While upstream changes primarily impact local water consumption and availability, managing local demand becomes critical in avoiding user conflicts. Transboundary water managers must advocate for inclusive governance, stakeholder participation, and coordinated strategies, programs, plans, and livelihood practices to ensure sustainable water resources management (Gwambene, 2017; Munia et al., 2020). Climatic conditions, such as higher temperatures and lower precipitation, can have political implications at the national level, leading to the potential signing of water treaties in response to extreme weather events (Dugassa et al., 2021; Taylor et al., 2021; Candau & Gbandi, 2023).

This study provides an overview of its findings, analysis, and discussion on the implications of climate change on Kagera Transboundary River Basin management. Additionally, it offers recommendations for addressing the identified challenges. Understanding climate change impacts and extreme events at regional and local scales is crucial for developing feasible adaptation strategies. Luhunga and Songoro (2020) predict significant challenges in socioeconomic livelihoods for people in the Kagera region due to climate-related stresses, thus emphasizing the need for appropriate planning and effective adaptation policies for disaster risk prevention.

While several studies have explored Transboundary River Basin issues focusing on water quality, quantity, ecological stability, human health, and cooperation among stakeholders (Helman et al., 2020; Munia et al., 2020; Waithaka et al., 2021; Wang et al., 2022; Gökçekuş et al., 2023), this study analyzes the implications of climate change specifically on water availability, access, and management within the basin. The objectives are to comprehend the implications of climate variability and change on water resources within the Kagera Transboundary River Basin, analyze the observed shifts in climatic variables and their direct impact on water availability and access, identify the challenges inherent in water resources management within the basin, and investigate strategies and mechanisms that can facilitate effective and sustainable water resource management in the face of evolving climatic conditions and associated challenges.

2 METHODOLOGY

2.1 Study Area

The study was conducted in The River Sub-basin in Ngara District, Kagera region, within the Lake Victoria Basin in the west of Tanzania (Figure 1). The Kagera river basin spans four countries: Burundi, Rwanda, Tanzania, and Uganda. The basin comprises diverse agroecology, including extensive agropastoral systems, intensively mixed banana and annual cropping systems, coffee-farming systems, and natural and planted forests.

Specifically, the study was conducted in three villages of Katerere, Kasange, and Rusumo) in the upper stream and one village downstream where the two rivers join in Ngara District, Tanzania. Ngara District is a strategic point that borders Rwanda and Burundi to the West. The district is bordered to the North by Karagwe District, the East by Biharamulo District, the South by Kigoma Region, and the North-East by Muleba District. Ngara district is between a longitude 30^{o} 15'E and latitudes 2^{o} 10' and 3^{o} 0'S. The altitude ranges from 1,320m (the level of River Kagera) to about the mean sea level (Ndyeshumba, 2000; URT, 2019). The district has main rivers: the Kagera, which marks the north-western border with Burundi and Rwanda, and the Ruvubu River, which flows around the southern border and crosses the district to join the Kagera River. The district falls in a series of dissected plateaus at different altitude levels. Subsequent erosion and dissection have resulted in hills and valleys. The rainfall pattern shows a distinct dry season from June to September with high variations in rainfall amount mainly due to high relief intensities and consequent rain shadow area. The main land use types of Ngara district are upland agriculture, wetland agriculture, silviculture, game reserve, and livestock.

2.2 Approach and Data Collection

The study employed a comprehensive approach to gathering and analyzing data, combining quantitative and qualitative techniques to provide a holistic understanding of the complex interactions between climate change, water resources, and the communities in the study area. It used the Household Questionnaire (Hh), Key informants Interview (KI), Focus Group Discussion (FGD), and literature review to understand the water resources management dynamics in the Kagera. The Cross-sectional data were collected from upstream and downstream farmers using Hh, KI, and FGD. In this context, literature review, household survey, focus group discussions, and key informant interviews identified historical trends in water resources management perceptions of impacts of climate variability and change on water resources availability and management.

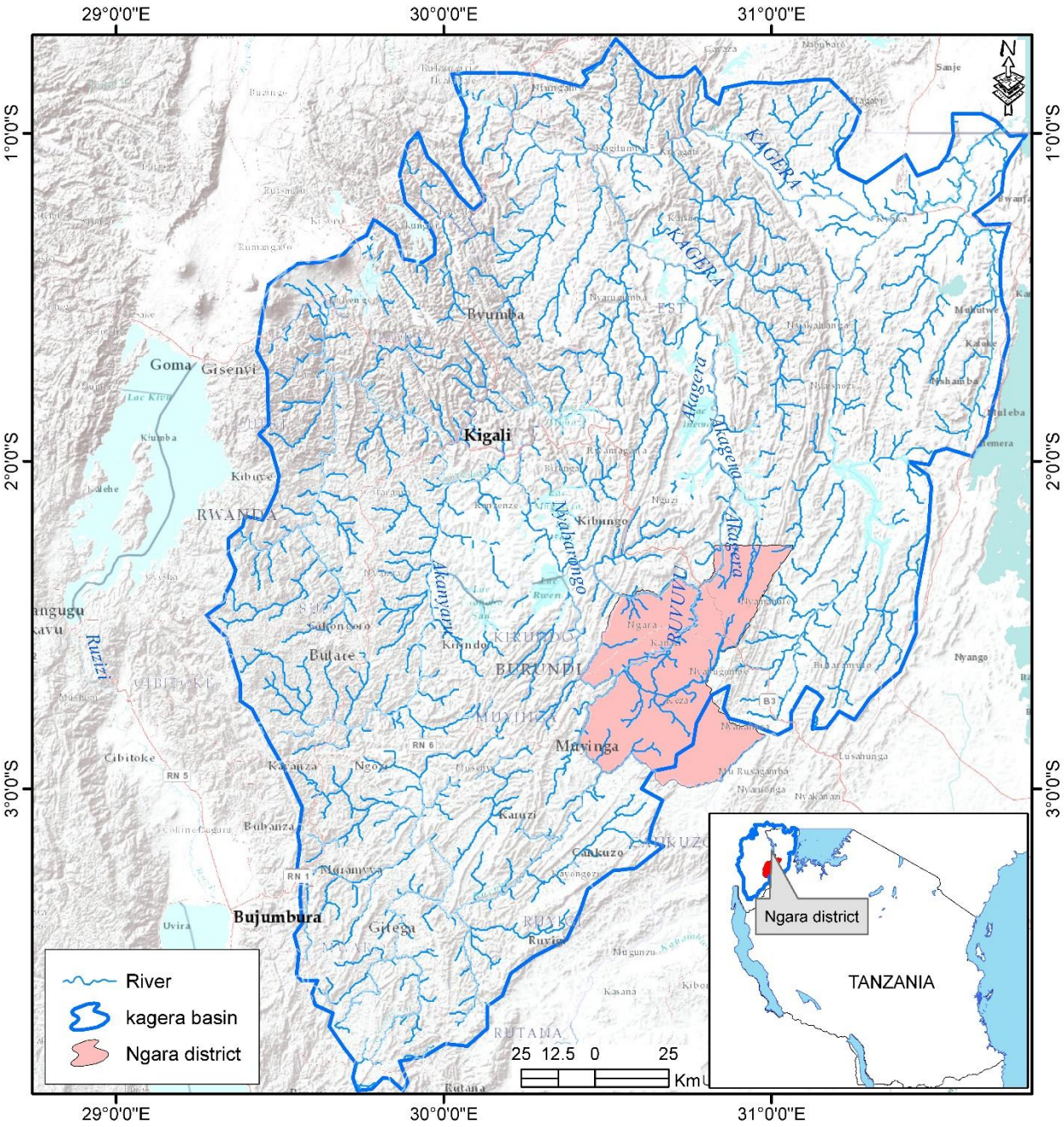

Figure 1. Map of the Kagera River showing the location of the study area

Household questionnaire: The study used a structured questionnaire to gather data from 210 randomly selected households. It gathered information through interviews with the heads of households. In cases where the head of the household was unavailable for any reason, we interviewed a close relative who was familiar with household activities, income, and expenditure instead.

Focus group discussions: The study conducted 06 focus group discussions were conducted in three villages of Ngara District. FGD comprises village Government and Water Users Association groups of 10 to 15 participants with different social and economic characteristics. Focus group discussion involve all other groups based on socioeconomic factors (age, gender, education, and marital status.) in the selected area. The objective was to have their expressed needs and the constraints they face and gather their perception on inclusive management, adaptation, access to and management of water resources, and the challenges in water resources management.

Key Informant Interview: KI with key respondents guided by a checklist administered to different key/target groups. This method targeted key respondent groups, including expertise from the basin water board, Ministry of Water, Natural resources, land, environment, and local government at districts, wards, village level, and the community.

Literature review: The data were collected by reviewing different documents and literature from previous studies on the impacts and adaptation to climate change and variability, community livelihood, institutional framework, water resources availability and management, and inclusion management. The secondary sources, including the Internet, the library, and official reports from the Basin Water Board and Government offices, provide secondary information on climate variability and water resources management.

2.3 Data Processing, Analysis Methods, and Presentation

Quantitative data analysis employed the Statistical The study explored various aspects, including statistical measures related to rainfall data, such as mean rainfall, standard deviation, standard error, skewness, and trends. These statistical analyses provided insights into the high variability in rainfall patterns, including long-term droughts, floods, and other extreme events. Qualitative data analysis was conducted through thematic synthesis, capturing the perspectives and perceptions of the local communities within the transboundary basin. This qualitative approach allowed for a deeper understanding of the impacts of climate change on water resources management and the challenges faced by the communities. The results from quantitative and qualitative analyses highlight the observed changes in rainfall patterns and their significance. The find interpretation of findings aimed to underscore the implications of these changes on water availability, access, and management within the Kagera Transboundary River Basin.

3 RESULTS AND DISCUSSIONS

3.1 Climate Variability and Change

3.1.1 Perceived and Observed Changes in Climatic Variables

The study reveals significant variability in rainfall patterns within the Kagera Transboundary River Basin, with long-term droughts, floods, and other extreme events. The analysis of annual mean rainfall, with a standard deviation of 248, standard error of 361, and skewness of -945, highlights the substantial fluctuation in mean rainfall with decreasing trends, indicating significant changes in the region (R^2 = 0.1797 and P = 0.002). Figure 2 presents climate variability and change indicators in the basin as the local communities perceive.

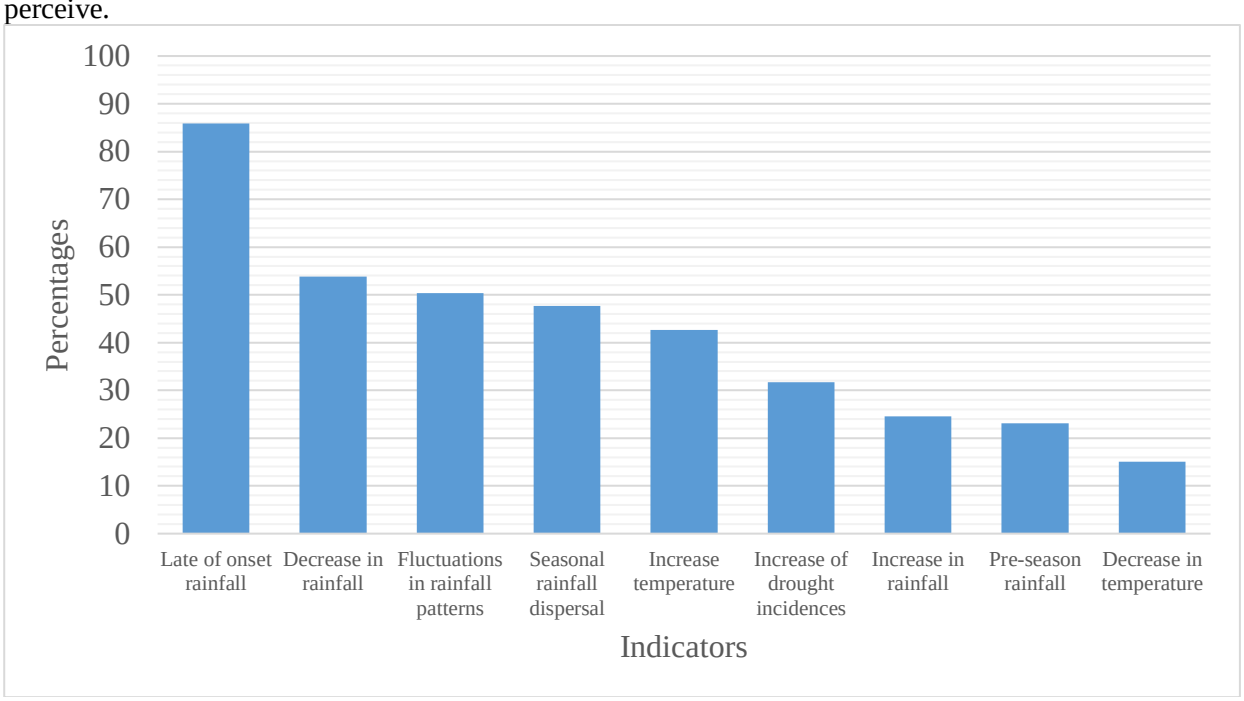

Figure 2. Indicators for climate variability and change in the basin

Among the leading indicators, the study identifies late onset rainfall (85.9), decreased rainfall (53.8), fluctuations in rainfall patterns (50.3), seasonal rainfall dispersal (47.7), increased temperature (42.7), increased drought incidences (31.7), increased rainfall (24.6), pre-season rainfall (23.1), and decreased temperature (15.1). These changes in precipitation and temperature are evident both upstream and downstream within the Kagera Transboundary River Basin.

The community's perceptions align with the observed changes in Ngara District over the past 40 years. ERA5, the fifth-generation ECMWF atmospheric reanalysis covering the period from 1979 to 2021 with a

spatial resolution of 30 km, was used as the data source (Meteoblue.com, 2023). An increase in temperature is noted in the area, as depicted in Figure 3, which illustrates the mean yearly temperature change in Ngara District (Meteoblue.com, 2023).

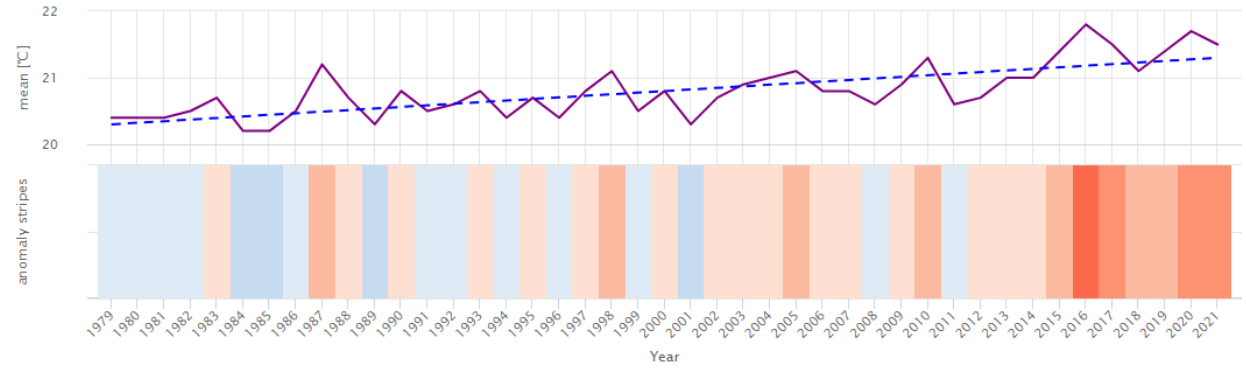

Figure 3. Mean yearly temperature change in Ngara District, 1979-2023

The graph indicates a positive linear climate change trend, signifying that temperatures in Ngara are getting warmer due to climate change. The warming stripes below the chart represent the average temperature for each year, with red indicating warm years and blue indicating cold years. The study also found changes in rainfall patterns over time, as shown in Figure 4, which presents the mean yearly precipitation change in the Ngara, Kagera River sub-basin (Meteoblue.com, 2023).

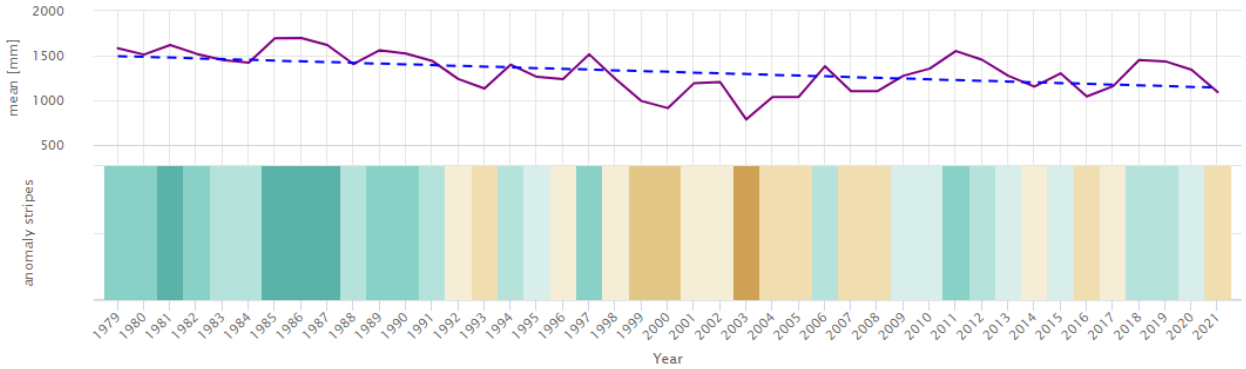

Figure 4. Mean yearly precipitation change in Ngara, 1979-2023

The Figure reveals a downward linear climate change trend, indicating drier conditions in Ngara over time. The precipitation stripes below the graph represent the total precipitation for each year, with green denoting wetter years and brown representing drier years.

Furthermore, monthly anomalies for temperature and precipitation were analyzed, as depicted in Figure 5 (Meteoblue.com, 2023). The analysis of monthly anomalies in temperature and precipitation further strengthens the findings of increasing temperatures and fluctuating precipitation patterns. The presence of more warm and fewer cold months reflects the influence of global warming associated with climate change. Similarly, the precipitation anomalies indicate varying wet and dry months compared to the 30-year climate mean of 1980-2010.

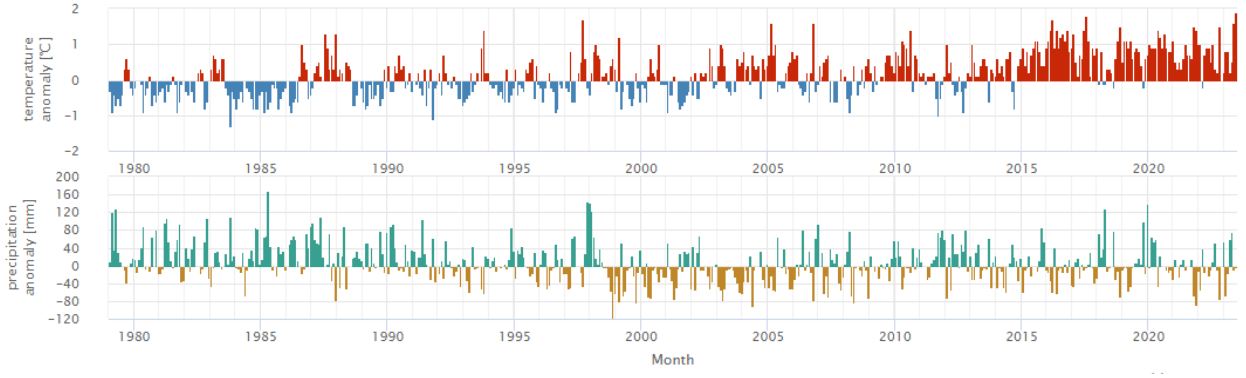

Figure 5. Monthly anomalies for temperature [°C] and precipitation [mm], 1979-2023

In Figure 5, the top graph illustrates temperature anomalies for every month since 1979, with red months warmer and blue months colder than the 30-year climate mean of 1980-2010. The results show an increase in warmer months over the years, consistent with global warming trends associated with climate change. The lower graph presents precipitation anomalies every month since 1979, with green months being wetter and brown months drier than the 30-year climate mean of 1980-2010.

Explicitly focusing on June and December, Figures 6 and 7 display the temperature and precipitation anomalies for each June and December since 1979 (Meteoblue.com, 2023). The results indicate an increasing trend in temperature for both June and December, alongside a decreasing trend in precipitation during these months. The impact of these changes is evident in water resource management within the basin.

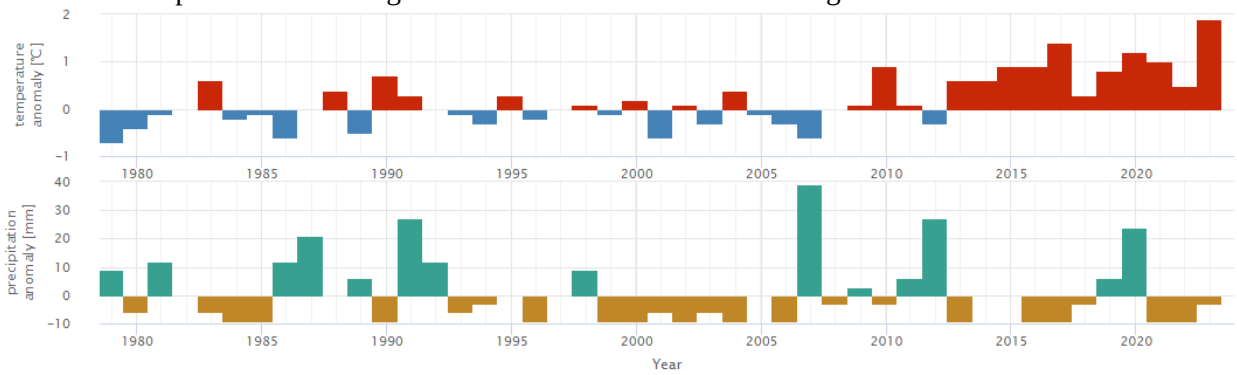

Figure 6: June monthly anomalies for temperature and precipitation, 1979-2023

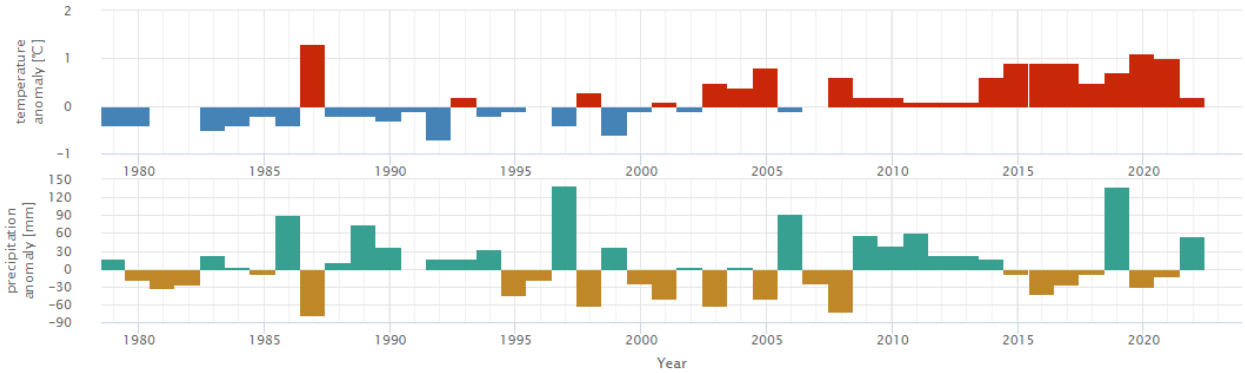

Figure 7. December monthly anomalies for temperature and precipitation, 1979-2023

The analysis indicates an increasing trend in temperature for both June and December, as well as decreasing trends in precipitation since 1979. These changes affect water resource management within the basin, with an increased frequency of warmer and drier years.

The climate variability and change analysis findings underscore the significance of observed shifts in temperature and precipitation patterns within the Kagera Transboundary River Basin. These changes have critical implications for water resource management and warrant careful consideration in developing sustainable strategies for the basin's communities.

3.1.2 Impact on Water Resources

The effects of climate variability and change are becoming increasingly evident through a range of observable phenomena, such as rising air temperatures, melting glaciers and polar ice caps, escalating sea levels, desertification, and more frequent extreme weather events like droughts, floods, and storms. However, it is essential to acknowledge that climate change does not affect all regions uniformly; some areas experience more pronounced effects than others. In the Kagera Transboundary River Basin, these effects manifest in changes to hydrological processes, including runoff, groundwater recharge, and water demand. Furthermore, climate variability and change influence precipitation patterns, temperatures, and other climatic factors, impacting biophysical processes within the basin.

Figure 8 illustrates the observed impacts of climate change on the basin's availability and access to water resources. The main effects identified include an increase in temperature (47.5%), a decrease in temperature (13.1%), decreased rainfall leading to droughts (56.6%), reduced water volume (20.7%), impaired groundwater discharge (8.1%), loss of biodiversity (27.8%), increased incidence of diseases (35.9%), a decline

in agricultural production (68.2%), and alterations in growing seasons (66.7%). These impacts are not uniform across the basin, resulting in uneven water resource management consequences.

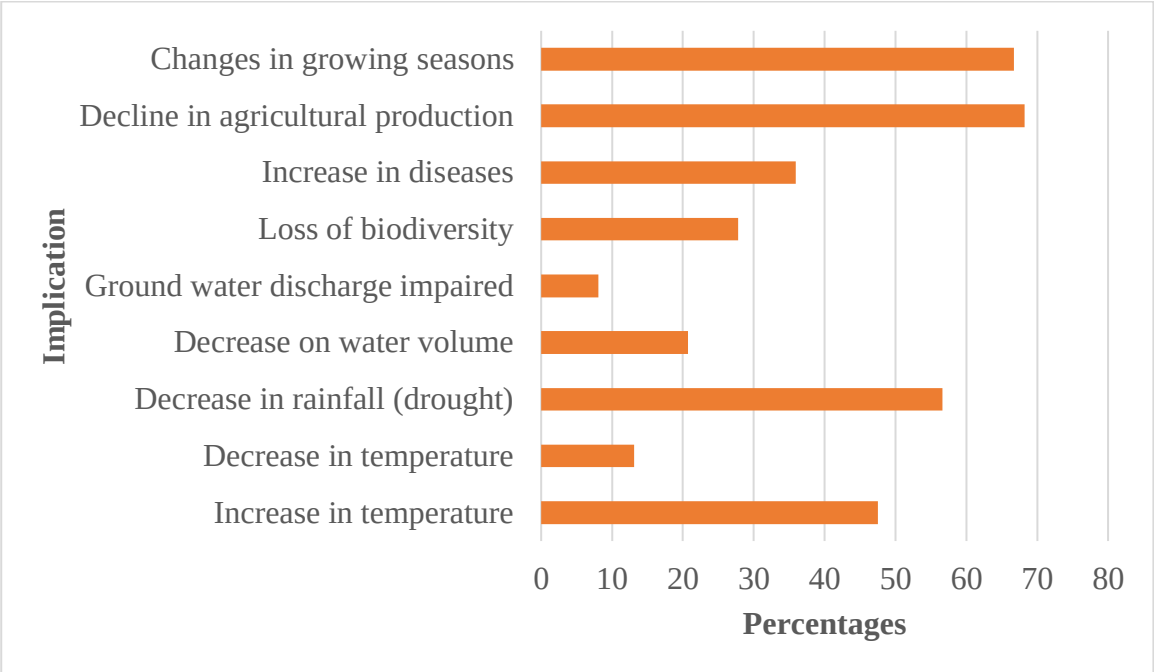

Figure 8. The observed implication of climate change on availability and access to water resources

The data from Focus Group Discussions (FGD) and Key Informant Interviews (KI) reveal noteworthy changes in biophysical processes influenced by climate variability. The Specific reported changes include changes in river banks, altered water flows, shifts in water sources, fishing patterns, and water source management practices.

The observed effects of climate change on water resources have far-reaching implications for water management strategies in the basin. Decreased water availability, shifts in water-related activities, and alterations in agricultural production patterns demand proactive and adaptive management approaches. Addressing these challenges requires collaborative efforts among all stakeholders to ensure sustainable water resource management that can withstand the impacts of climate change. Integrating local knowledge, community involvement, and scientific expertise will be essential in developing effective strategies to cope with the consequences of climate variability and ensure the resilience of the Kagera Transboundary River Basin's water resources.

3.2 Data Availability and Prediction Challenges

The study emphasizes the critical issue of limited and inadequate access to hydrological and meteorological data, which poses significant challenges for accurate prediction, infrastructure planning, and response measures related to water resource allocation and management. With comprehensive and up-to-date data, it becomes easier to understand and anticipate the availability of water resources, especially in the context of climate change impacts.

FAO (2023) has also recognized the knowledge gap arising from insufficient data and knowledge on the short-, medium--, and long-term benefits derived from various water resource management practices at both farm and broader catchment scales. This lack of data hinders the ability to fully assess the potential benefits and effectiveness of different management approaches, making it challenging to develop sustainable infrastructure plans and formulate appropriate response measures.

Furthermore, data limitations also impact the quantification and assessment of benefits. The absence of implemented or piloted payment schemes for watershed services based on downstream benefits from improved land management further highlights the implications of data limitations. The study recognizes the urgent need to address the limited and inadequate access to hydrological and meteorological data in the basin. Data availability provides opportunities to overcome the challenges posed by data gaps and improve the accuracy of predictions, infrastructure planning, and response measures related to water resource allocation and management.

Addressing these data challenges requires collaborative efforts among stakeholders, including governments, research institutions, and international organizations. Investing in data collection, monitoring, and sharing mechanisms is crucial for developing effective strategies to sustain water resources in the face of climate variability. By closing the data gap and promoting data accessibility, the basin's stakeholders can make informed decisions and implement evidence-based policies to ensure water resources' long-term resilience and availability in the Kagera Transboundary River Basin.

3.3 Strategies for Effective Management

The study presents crucial recommendations and strategies to enhance water management in the context of climate change. These measures include conserving water resources through tree planting, adhering to environmental laws and by-laws, conducting reforestation campaigns, and promoting alternative energy sources (Figure 9).

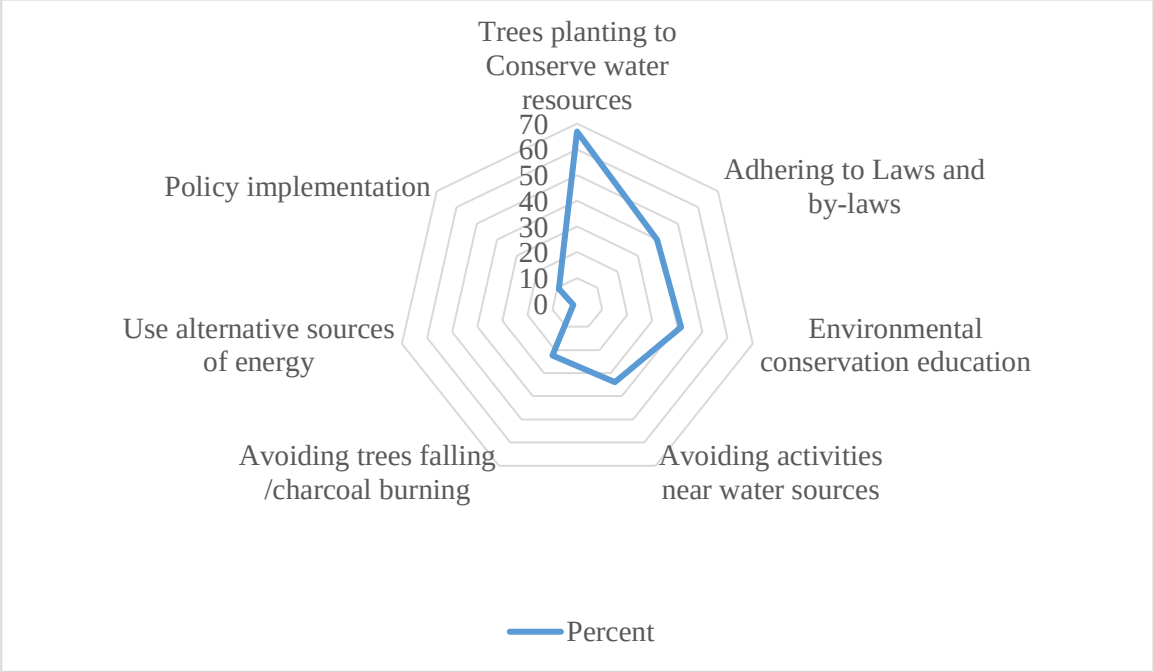

Figure 9. Measures in addressing the implication of climate change in water Resource

Figure 9 outlines the proposed measures to address the implications of climate change on water resources, indicating the importance of tree planting to conserve water resources (66.9%), adherence to laws and by-laws (39.8%) for environmental management, environmental conservation education (41.4%), avoiding activities near water sources (33.9%), refraining from tree falling or charcoal burning (22.3%), exploring the use of alternative energy sources (1.7%), and implementing appropriate policies (9.1%).

Harmonizing policies, laws, and regulations governing water use and management among the riparian states emerge as a key recommendation. The study emphasizes the significance of inclusive governance, stakeholder participation, and coordinated programs for sustainable water resource management. FAO (2023) highlights multiple ecosystem services supported by enhanced agroecosystem management, focusing on practices such as agroforestry, improved cook stoves, erosion control, and soil fertility management, all of which contribute to improved water resources management and groundwater sustainability in the basin (Figure 10).

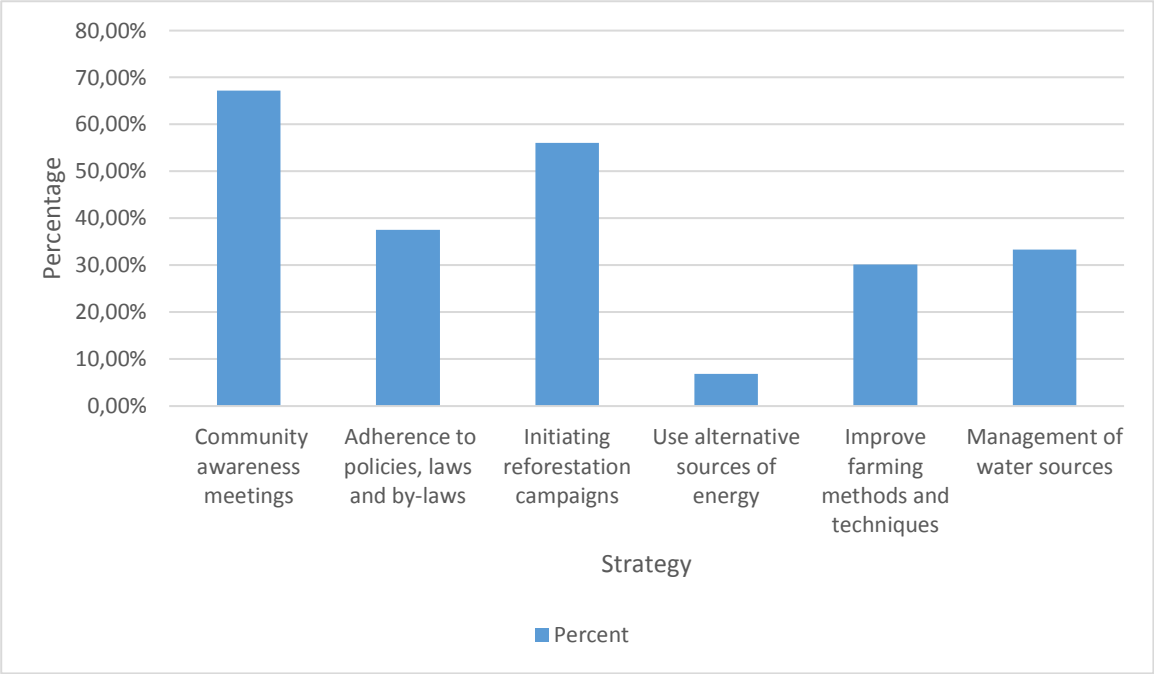

Figure 10. The proposed strategies for enhancing water management within the basin

Figure 10 illustrates the proposed strategies for enhancing water management within the basin, including community awareness meetings (67.2%), adherence to environmental policies, laws, and by-laws (37.6%), initiating reforestation campaigns (56.1%), promoting the use of alternative energy sources (6.9%), improving farming methods and techniques (30.2%), and implementing better water source management (33.3%). These strategies underscore the importance of incorporating innovative means and capacity-building for key stakeholders. The study also highlights the significance of institutionalization and the need for efficient and effective water management strategies. The strategies may involve harmonizing policies, laws, and regulations to govern transboundary water use and management.

The proposed strategies encompass a comprehensive and multi-faceted approach to address the challenges climate change poses on water resources in the Kagera Transboundary River Basin. These measures emphasize the importance of collaboration, community engagement, and sustainable practices to ensure the resilience and adaptability of water resource management systems in the face of a changing climate. Implementation of the strategies makes significant strides towards sustainable water management and safeguarding vital water resources for the benefit of present and future generations.

3.4 Inclusive Governance, Management, and Stakeholder Participation

The study emphasizes the crucial role of inclusive governance in ensuring the sustainability of water resources management within the Kagera Transboundary River Basin. This inclusive governance entails adopting a well-coordinated strategy, program, and plans considering local communities' livelihood practices and needs. Stakeholder participation in decision-making processes related to water resources management is essential for effective and equitable water resource management.

Figure 11 illustrates suggested measures to address and improve water resources management in the basin. These measures include providing knowledge on legal restrictions regarding activities near water sources, emphasizing conservation efforts, and maintaining a distance of 60 meters from the water sources. Such initiatives aim to protect and preserve water resources while involving and empowering local communities.

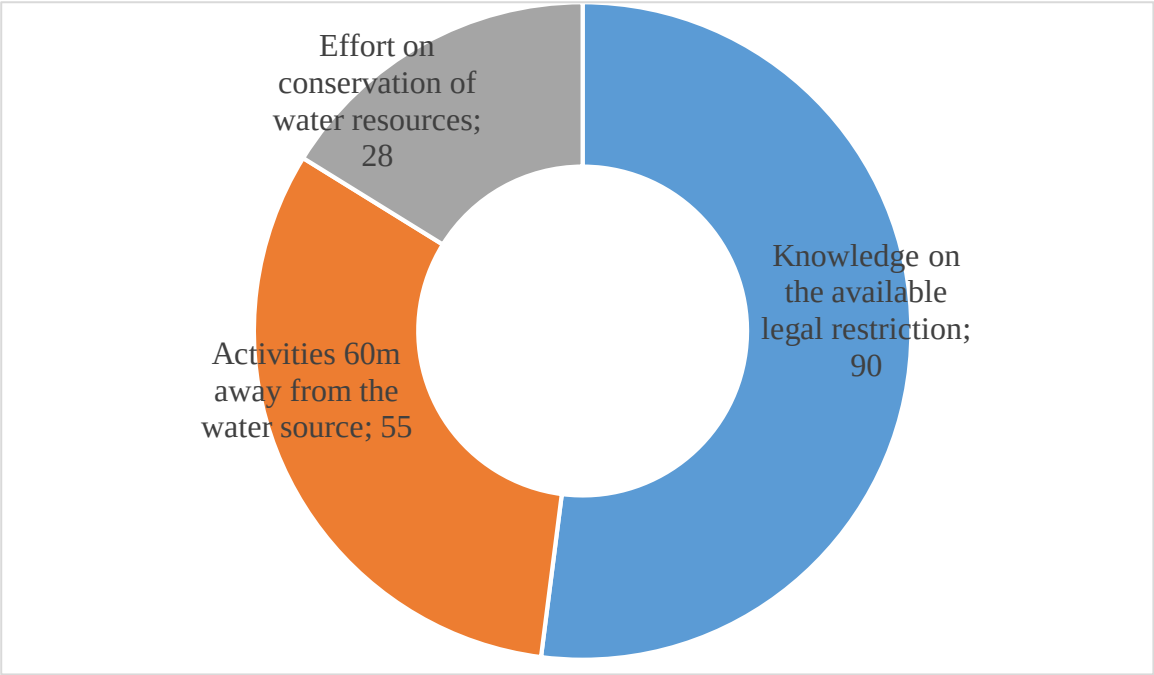

Figure 11. Suggested measures to address and improve water resources management in the basin

The study acknowledges that politics influence the need for standard approaches among riparian states, weak coordination, and conflicting or unclear sectoral policies. These factors hinder effective water resources management and highlight the need for harmonizing and enforcing policies, laws, and regulations to govern transboundary water use and management.

Figure 12 presents suggested measures for Basin Water Boards (BWB) to improve management efforts. These measures include clarifying the responsibilities of BWB to the community, establishing BWB offices at the district level, providing support to local communities for water access, and cooperating with the community in environmental conservation efforts. These steps aim to bridge the gap between water management authorities and local communities, fostering mutual understanding and collaboration.

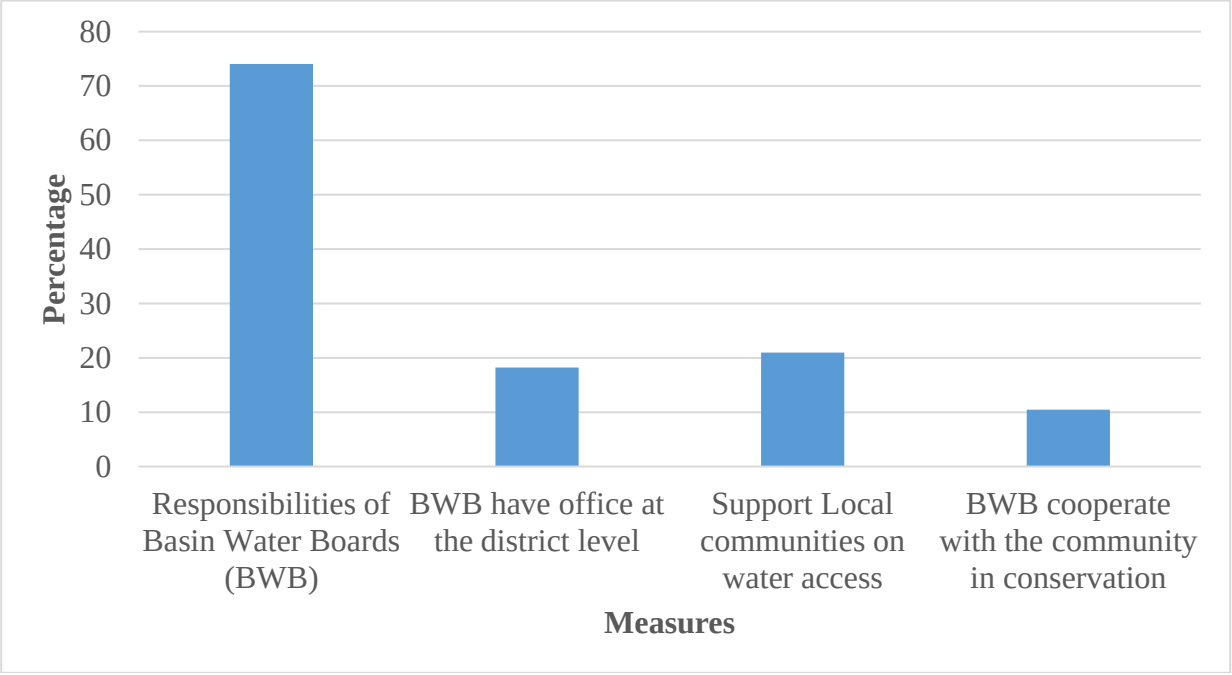

Figure 12. Suggested measures for Basin Water Boards to improve management efforts.

It is essential to address the water resources management challenges in the basin by advocating for inclusive governance and stakeholder participation—sustainable water resource management achieved by involving local communities and key stakeholders in decision-making. Additionally, Basin Water Boards play a significant role in coordinating and implementing water management efforts. Creating awareness about the

responsibilities and functions of these boards can enhance transparency and accountability in water resource management.

The study's statistical data, such as mean rainfall, standard deviation, skewness, and trends, provide insights into the variability in precipitation within the basin. This data is crucial for understanding climate patterns and informing effective water management strategies. Thus, promoting inclusive governance, stakeholder participation, and well-coordinated management strategies are vital components of sustainable water resources management in the Kagera Transboundary River Basin. Collaborative efforts among riparian states, water management authorities, and local communities are essential to address the challenges of climate change and ensure the availability and equitable distribution of water resources for present and future generations.

4. DISCUSSION

The study aimed to understand the ramifications of climate change on water resources and explore effective management strategies to address the challenges of changing climatic conditions. The discussion focuses on the key themes from the research, highlighting their importance and relevance for sustainable water resource management. It sheds light on the complex interplay between climate change and water resources in the Kagera Transboundary River Basin. The observed variability in rainfall, temperature, and hydrological processes underscores the urgency of adapting water resource management strategies to changing climatic conditions. Inclusive governance, stakeholder participation, and data-driven decision-making are paramount in formulating effective management plans that address the challenges posed by climate variability. The study provides a roadmap for policymakers, water management authorities, and local communities to collaborate and implement sustainable practices for safeguarding water resources.

Climate Variability and Impact on Water Resources

The study's findings confirm the high variability in rainfall, long-term drought, floods, and other extreme weather events within the basin (Munia et al., 2020; Luhunga & Songoro, 2020; Meteoblue.com, 2023). The observed annual mean rainfall and temperature trends indicate significant changes over the past few decades (Munia et al., 2020). The increasing temperatures and fluctuating rainfall patterns profoundly affect water availability and access. These climatic changes pose challenges for water resource management, impacting hydrological processes, such as runoff, groundwater recharge, and water demand. The results align with global climate change trends, showcasing the region's vulnerability to climate-related crises (Munia et al., 2020; Dezfuli et al., 2022). The observed changes in temperature and precipitation are consistent with the broader context of climate change, indicating the urgent need for adaptive and mitigation measures to safeguard water resources.

The basin's impacts of climate variability and change on water resources are evident. The study identifies various effects, including changes in water volume, impaired groundwater discharge, the distraction of water infrastructures, loss of biodiversity, increased diseases, and declining agricultural production (Seeteram et al., 2019; Mkonda, 2022; Gwambene, 2017; Dugassa et al., 2021). These findings emphasize the urgent need for proactive water resource management to mitigate the adverse effects on communities, ecosystems, and livelihoods. The observed changes in biophysical processes, such as river banks, water flows, and water sources, further highlight the direct influence of climate variability on the hydrological system (Mkonda, 2022; Gwambene, 2017; Seeteram et al., 2019). Such changes demand careful consideration when formulating management strategies to ensure sustainable water availability and use.

Data Availability and Prediction Challenges

The study reveals the limitations and challenges of accessing hydrological and meteorological data. The results align with Munia et al. (2020), who noted constraints, impediments, and complexities associated with procuring hydrological and meteorological data. Adequate data availability is needed to predict water resource availability, infrastructure planning, and response measures accurately. The lack of comprehensive and up-to-date data presents challenges in evaluating the efficacy of water management practices, leading to knowledge gaps that hinder informed decision-making and strategic planning. Addressing data limitations becomes essential for informed decision-making and effective management of water resources. Improved data collection, monitoring, and analysis can enhance prediction models and support evidence-based policy formulation. Enhanced data collection, monitoring, and analysis refine prediction models, enabling the formulation of evidence-based policies, well-informed choices, and strategic initiatives.

The implications of the challenges for transboundary water management include political dynamics among riparian states, weak coordination between stakeholders, and conflicts or uncertainties regarding sectoral policies governing water resources (Dezfuli et al., 2022). Limited and inadequate access to hydrological and meteorological data have significant implications for predicting and planning infrastructure and response measures for water resource allocation and management. The political dynamics among riparian states, weak coordination, and conflicting sectoral policies affect transboundary water resources management.

Strategies for Effective Management

The study proposes essential strategies for enhancing water resource management in the face of climate change. These strategies encompass conservation efforts, policy adherence, environmental education, alternative energy adoption, and harmonizing policies among riparian states. Institutionalization, efficient management strategies, innovation investment, and stakeholder capacity-building are crucial for successful water resource management. Inclusive governance and stakeholder participation are critical elements for sustainable water resource management. Collaborative efforts among riparian states and local communities are essential to foster cooperation, address conflicting priorities, and ensure equitable and efficient water allocation and management.

These proactive strategies encompass implementing conservation initiatives, aligning policies, robust environmental education, adopting renewable energy sources, and harmonizing policies among riparian states (Candau & Gbandi, 2023). The study accentuates the pivotal significance of institutionalization, the deployment of efficient management strategies, the infusion of investments into innovation, and the enhancement of stakeholder capacities as integral components for steering effective water resource management (Meteoblue.com, 2023). The imperativeness of inclusive governance and the active participation of stakeholders emerge as critical facets for the enduring management of sustainable water resources. The study underscored that collaborative ventures between the riparian states and local communities become indispensable, catalyzing cooperative synergies, reconciling potentially divergent priorities, and establishing an equitable and highly efficient framework for allocating and managing water resources.

By exploring data availability and prediction challenges, the study described the critical role of accurate and up-to-date data in informed decision-making and effective water resource management. The implications of data limitations for transboundary water management, the study underscores the importance of overcoming these challenges to enhance predictive models and policy formulation. The study's emphasis on political dynamics among riparian states, weak coordination between stakeholders, and conflicting sectoral policies further underscores the need for collaborative efforts and harmonization of policies to address transboundary water management challenges.

The study's proposals for strategies to enhance water resource management in the face of climate change hold practical value for policymakers, water management authorities, and local communities. The recommended approaches, including conservation initiatives, policy alignment, environmental education, and stakeholder participation, provide a roadmap for improving the resilience of water resources in the region. Moreover, the study's call for inclusive governance and collaborative endeavors between riparian states and local communities highlights the potential for cooperative solutions that can lead to equitable and efficient water allocation and management. Overall, this research contributes to the broader understanding of climate change's impacts on water resources and provides actionable insights for sustainable water resource management in the Kagera Transboundary River Basin.

5 CONCLUSIONS AND RECOMMENDATIONS

The study highlights the significant ramifications of climate change on water resources management in the Kagera Transboundary River Basin. The observed high variability in rainfall, long-term droughts, and extreme weather events underscore the urgency of addressing climate variability's impacts on the basin's hydrological processes. Limited access to hydrological and meteorological data presents a significant challenge in accurately predicting water availability and formulating effective response measures. The lack of standard approaches, weak coordination, and conflicting sectoral policies among riparian states further hinder effective transboundary water resources management. To ensure sustainable water resource management, adopting inclusive governance, enhancing stakeholder participation, and implementing well-coordinated strategies is imperative. Investing in comprehensive data collection and capacity-building initiatives for key stakeholders will improve the understanding of water resource challenges and foster adaptive measures in the face of climate change.

The study proposed several recommendations based on the findings to enhance water resource management in the Kagera Transboundary River Basin. First, riparian states must collaborate and harmonize policies, laws, and regulations governing water use and management to foster cooperation and equitable resource allocation. Second, investing in data collection, monitoring, and analysis is crucial to address the current data limitations and support evidence-based decision-making for infrastructure planning and response measures. Third, promoting stakeholder participation and community engagement is essential to ensure that water resource management efforts consider local communities' needs and livelihood practices. Fourth, implementing climate-resilient strategies, such as tree planting, conservation practices, and alternative energy sources, can contribute to water resource sustainability. Lastly, they prioritize capacity-building initiatives to empower key stakeholders with the knowledge and skills to tackle climate change challenges and enhance water resource management's effectiveness within the basin. Thus, navigate the complexities of climate change and secure its water resources for present and future generations.

CONFLICTS OF INTEREST

The author declares that there are no conflicts of interest regarding the publication of this paper.

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