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Impacts of climate change on water security in Uganda: A review

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Abstract

Billions of people globally live in countries experiencing high water stress attributable to growing climatic changes with greater impacts on water resource sustainability, an increase in water user conflicts, growth in newly inundated land, and rapid declines in the surface water area of rivers, lakes, reservoirs, wetlands, floodplains, and seasonal water bodies. The extreme climatic variability leads to serious water insecurity, with the poorest and most vulnerable people particularly at risk of water scarcity. Water availability in Uganda is likely to become more variable and unpredictable, with unsustainable access to adequate quality water for human health and a rising association between water insecurity, food insecurity, and gender-based violence. Uganda's overreliance on direct rainfall has not been spared by climatic variability that threatens the distribution of rainfall and water availability. This review seeks to establish the implications of climate change on water security in Uganda. A literature search of online resources and databases on the implications of climate change on water security was used. The findings will contribute to a better understanding of the impacts of climate change on water security and the measures that can be taken to address these challenges, with the view of providing policymakers and stakeholders with insights on the specific actions to be taken to enhance water security and build resilience to climate change.

1.0 Introduction

Globally, water resources constitute an essential element of Earth's ecosystem providing vital support for all living organisms (Phan *et al.*, 2021; Falkenmark, 2020). Water is a crucial source of raw materials for crafts, fishing, domestic usage, industry, agriculture, transportation, sanitation, hydration, and supporting eco-tourism (Saturday *et al*., 2022; Onyena and Sam, 2020). Nonetheless, Bayatvarkeshi *et al.* (2021) pointed out that there has been limited research evaluating the impacts of climate change on water resources despite the documented adverse effects of climate change on water (Schilling *et al*., 2020) which agrees with Cosens *et al.* (2017) where they mentioned that information was scarce regarding the influence of climate change on water resources. However, Bastiancich *et al.* (2022) clarified that there is a strong relationship between climate change and the integrity of water resources worldwide. The concern is growing over climate change's impact on vulnerable global water resources (Turyasingura *et al.,* 2022). The Intergovernmental Panel on Climate Change (IPCC) notes uncertainties in water supply and management due to a 0.6 ± 0.2 ^{o}C increase in global mean surface temperature since 1861 and projected 2 to 4 ^{o}C rise (Scientist *et al.,* 2012). Hssaisoune *et al.* (2020) predict a 2 to 4^{o}C temperature increase and 53% less precipitation, altering precipitation patterns and affecting water flow and storage (Scientist *et al.,* 2012). Globally, around four billion face water scarcity due to drought (Mukasa *et al.,* 2020).

Over 2 billion people in 53 nations face water scarcity, with 31 countries at 25-70% and 22 nations exceeding 70% scarcity (Gurera & Bhushan, 2019; United Nations, 2019). Water insecurity is rising in developing countries, particularly impacting the most vulnerable (Cooper, 2020). Unsustainable human actions, exemplified by Saudi Arabia, exacerbate climate-driven strain on water resources (Denicola *et al.,* 2015). Growing population, urbanization, land use changes, and climate shifts are heightening water demand, stress, and scarcity globally (Cooper, 2020). Predictions indicate a concerning future, with nearly 5 billion people living in water-scarce areas by 2050 (World Health Organization; London School of Hygiene and Tropical Medicine, 2017). Around 20% of the world's basins experience significant changes in surface water, indicating either flooding or drying up (Tallman *et al.,* 2023). The United Nations predicts an increase in flood-risk population from 1.2 billion to 1.6 billion by 2050, reaching 3.2 billion (United Nations, 2020). The United Nations (UN) highlights that climate change is altering the global water cycle, leading to increased variability and unpredictability in water availability (UN, 2019). This is further supported by Scientist *et al.* (2012), who emphasize the direct impact of temperature increases on the hydrologic cycle, causing heightened evaporation of surface water and transpiration from vegetation. Due to the uncertainty regarding future water availability owing to climate change, robust and flexible water management strategies are deemed essential (Smith *et al*., 2019; Cooper, 2020).

Nkiaka *et al.* (2021) stress the importance of considering climate change impact, economic and population growth, pollution, and sustainable development in the context of the food-water-energy (FWE) nexus, with water security being a vital component for achieving Sustainable Development Goals (SDGs). Marcal *et al.* (2021) highlight the ongoing relevance of researching water security and its improvement, as reflected in the sixth SDG target focusing on clean water and sanitation. Understanding the dynamic relationship between climate change and water resources is crucial for effective water supply and quality management projects, particularly in Sub-Saharan Africa (SSA) (Muringai *et al.,* 2021). Nkiaka *et al.* (2021) emphasize the substantial challenge of achieving Food, Energy, and Water (FEW) security in SSA, where millions lack access to electricity, and reliable drinking water, and a significant portion of the population is undernourished. The study identifies 41 FEW insecure countries in SSA, with Burundi being the most affected, especially in the West African sub-region (Nkiaka *et al.,* 2021). Despite the critical situation, assessments of FEW security at the country and sub-regional levels are notably lacking. In Morocco, the combined effects of rising water requirements and reduced precipitation due to climate change are exerting significant pressure on groundwater resources (Hssaisoune *et al.,* 2020). The United Nations Environment Programme (UNEP) report underlines water scarcity as a pressing issue in Sub-Saharan Africa, exacerbated by population growth, rapid urbanization, climate fluxes, and deficient water infrastructure (UNEP, 2020).

Uganda's water resources are crucial for socio-economic development and poverty eradication. However, they are unevenly distributed, with direct rainfall being the primary source. The variability in rainfall threatens resource distribution and availability. The rapid depletion of these resources necessitates assessment to determine their current status (Nsubuga *et al.,* 2014) According to Mukasa *et al.,* (2020) about 10% of Uganda's population experiences drought-related water scarcity annually. A study in Kasali from 1987 to 2017 assessed drought trends and households' adaptive capacity (AC) to manage water scarcity. Results showed a decrease in average annual rainfall in certain seasons, while temperatures increased significantly. Lake Victoria's water level rose from 12 meters to 13.32 meters in just six months, indicating a gradual change in the known dry and wet seasons in Uganda. This indicates erratic conditions gradually setting in (Mukasa *et al.,* 2020).

2.0 Methodology

A literature search and selection process was carried out using Google Scholar and research gate, among other pertinent databases. Keywords like Climate change, Water security, Uganda, Rainfall and Sustainability were used to search these databases. Included were studies that used quantitative or qualitative research methodologies, were published in peer-reviewed journals, and were written in English and examined the connection between climate variability and water security. Excluded were studies that had no direct connection to this subject.

3.0 The concept of water security

Water security is a crucial concept for sustainable development and achieving the Sustainable Development Goals (SDGs). However, its definition varies due to its complexity and multifaceted nature. It was first defined by the Dublin Statement on Water and Sustainable Development in 1992 as providing safe, affordable water for essential purposes. Global Water Partnership (GWP) definition of Water security on the other hand involves "the sustainable availability of adequate quantities and qualities of water for all people, coupled with an acceptable level of water-related risks." Stockholm International Water Institute (SIWI) defines Water security as "the sustainable use and protection of freshwater resources to meet basic human and environmental needs, coupled with the socioeconomic development that ensures the resilience of the society and ecosystems." In addition, the World Health Organization (WHO) defines Water security as "the capacity of a population to safeguard access to adequate quantities of acceptable quality water for sustaining human well-being, livelihoods, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability" (WHO, 2013).

The definitions emphasize sustainable water access, human needs, ecosystem protection, and risk management, reflecting diverse organizational perspectives and evolving understanding of 21st-century challenges in water security.

3.1 Impacts of climate change on availability and access to water by communities

a. Climate change and water availability

Agenda 2030's sixth goal aims for universal access to water and sanitation, but many countries struggle with climate change's impact on water security (Mishra & Padhi, 2021). For instance, Iraq's annual water supply is below the 1700 m3/cap/year threshold, with 6% of months experiencing insufficient supply between 1998 and 2018 (Governorate *et al.,* 2022). The 2019 UN report indicates that despite low per capita water use in developing countries, substantial water stress indicates substantial use of resources, impacting resource sustainability. According to Hssaisoune *et al.* (2020), climate change in Morocco and Nigeria has led to a decrease in surface water availability, causing extensive groundwater use, and jeopardizing water security. Adeyeri (2020) and Turyasingura *et al.* (2022) also noted similar effects. A study conducted by Rankoana (2020) in South Africa revealed that the community's water supply, sourced from the Mutale River and borehole, was negatively impacted by drought, rainfall changes, and increased temperature, leading to unsustainable water levels. This issue, largely due to climate variability, was observed in the Thi-Qar governorate (Governorate *et al.,* 2022). The reliability of climate and water resources in Sub-Saharan Africa (SSA) is influenced by both natural factors like water availability and human activities, as highlighted by Banda (2021). Bello *et al.* (2017) supported this view, emphasizing the potential impacts of climate change and land-use changes on tropical rivers and ecosystems. Undesirable effects such as reduced stream flows, lower groundwater recharge rates, decreased water storage inflows, and heightened droughts are linked to rising temperatures and reduced rainfall (Mahmood *et al.,* 2016). Tanzania, part of East Africa, is experiencing an increasing demand for groundwater, particularly in drier regions, underlining its critical role in human development efforts (Ligate *et al.,* 2021; Turyasingura *et al.,* 2022).

Climate change can result in altered patterns of rainfall, including changes in intensity and distribution. In Uganda, this can lead to shifts in the timing and amount of precipitation, affecting water availability for agriculture, domestic use, and hydropower generation (World Meteorological Organization, 2020). In addition, the retreat of glaciers in the Rwenzori Mountains, attributed to climate change, impacts river flow patterns. Reduced glacier melt contributes to lower water levels in rivers, affecting water availability for both agricultural and domestic purposes (Huggel *et al.,* 2010). Rising temperatures due to climate change lead to increased evaporation rates from lakes, rivers, and reservoirs. This can cause a reduction in water levels and availability in major water bodies like Lake Victoria (IPCC, 2014).

b. Climate change and health effects of water insecurity

Shifting climate patterns, rising temperatures and extreme weather events contribute to an increase in waterborne diseases like dengue fever and chikungunya, disproportionately affecting vulnerable populations (Ahmed *et al.,* 2020). This accentuates the critical issue of Water, Sanitation, and Hygiene (WASH) inadequacies, particularly evident during the COVID-19 pandemic and past outbreaks like Ebola, underscoring the urgent need for safe water to prevent and treat contagious diseases, especially for disadvantaged communities (Cooper, 2020). The rise in waterborne diseases due to climate change has significantly threatened human well-being over the last five decades, with underprivileged and marginalized communities bearing the harshest impacts on water supply and subsequent health challenges (Noureen *et al.,* 2022). The threat is particularly pronounced in developing nations like Pakistan due to factors such as inadequate sanitation and sewerage systems, improper water management, limited healthcare facilities, and challenging social and environmental conditions (Noureen *et al.,* 2022). The increasing frequency of diseases like diarrhea, hepatitis, cholera, and malaria underscores the urgency of addressing these interlinked issues.

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Extreme weather events like heavy rainfall can lead to increased runoff, carrying pollutants from the land into water bodies. This can include fertilizers, pesticides, and sediments, impacting both surface water quality and groundwater recharge (Nasr-Azadani *et al.,* 2017). Climate change can cause rising sea levels and saltwater intrusion into coastal aquifers, leading to increased salinity in groundwater. This salinization can render groundwater sources unusable for drinking and irrigation (Custodio *et al.,* 2017).

c. Climate change and Water conflicts

Governorate *et al.* (2022) highlighted a rise in user conflicts due to the growing demand for water resources in developing countries and emerging economies. Concurrently, Tallman *et al.* (2023) noted an association between water insecurity and gender-based violence, particularly focusing on Sub-Saharan Africa (SSA) and South Asia. The primary manifestation of this relationship was an increased risk of sexual and physical violence against women who had to travel long distances to access water. Additionally, intimate partner violence often stems from the inability to fulfill domestic duties due to inadequate household water (Tallman *et al.,* 2023). Stoerk *et al.* (2020) hinted at the role of water shortages in conflicts by underlining the escalating competition for water across different sectors. Changes in precipitation and temperature patterns can affect grazing lands and water availability for pastoralists. This can lead to conflicts between farmers and herders over access to water sources and grazing areas, particularly during droughts and dry spells (Adger *et al.,* 2002). Rural communities in Uganda face challenges due to climate change-induced alterations in precipitation patterns. This can result in conflicts over water access for domestic use, agriculture, and livestock, further exacerbated by growing populations and competition for limited resources (Gertrud & Mburu, 2009) similarly, Uganda's Ministry of Water and Environment (2019) reported that Climate change-induced changes in rainfall patterns and increased evaporation can result in reduced water availability. This can intensify competition among various stakeholders, including communities, farmers, industries, and urban areas, leading to conflicts over access and allocation of limited water resources. The Karamoja region in northeastern Uganda is known for experiencing frequent droughts and increasing water scarcity due to climate change. This has led to conflicts between different communities and pastoralists over access to limited water resources, which are vital for their livestock and livelihoods (UNDP, 2016). Also, changes in rainfall patterns and increased temperatures, attributed to climate change, affect water levels in Lake Victoria and the Nile River. As countries like Uganda, Kenya, Tanzania, Rwanda, and Burundi share these water resources, disputes can arise over water allocation and usage (UN Environment,2012; Turton, A. R., & Meissner, R., 2002).

d. Climate change and time lost due to water insecurity

Mukasa *et al.* (2020) reported that in Kasali Uganda, there was a notable occurrence of extreme dry years and moderate dry spells between 1987 and 2017. During these periods, over 70% of households spent significantly more time collecting water, adversely affecting their Adaptive Capacity to cope with water scarcity. The droughts and dry spells led to severe water scarcity, with over 85% of households requiring more than an hour to collect water, compared to 19% during wet seasons. Notably, the average time spent collecting water in Kasali during dry years exceeded the United Nations' goal of 30 minutes, indicating a serious water supply shortage (Mukasa *et al.,* 2020).

In areas where water sources are distant or access is limited due to climate change impacts such as droughts, individuals, particularly women, and children, may spend a significant portion of their day collecting water. This time spent affects other important activities, including education, income-generating work, and household responsibilities (WHO and UNICEF, 2019). Water insecurity can have a detrimental effect on education, particularly for girls. Girls may miss school or drop out due to the time spent fetching water, which affects their academic progress and future opportunities (UNESCO, 2017). Water-related illnesses resulting from water insecurity due to climate change can lead to increased healthcare visits and reduced productivity in both adults and children. Time spent seeking medical care and recovering from waterborne diseases impacts overall productivity (Prüss-Ustün *et al.,* 2019).

e. Climate change, water, and food insecurity

Water insecurity not only affects the community's access to water but also has broader impacts on critical sectors like food security, health, livelihoods, and the country's ability to achieve UN Sustainable Development Goals (Mukasa *et al.,* 2020). Additionally, Richard Kwame *et al.* (2022) pointed out that globally, climate change worsens water and food crises, significantly impacting agricultural production and exacerbating water insecurity due to extreme climatic events.

f. Climate change, water security, and migration

Climate change is now a significant global driver of migration, and water insecurity is believed to be a critical factor (Stoler *et al.,* 2021). Household water insecurity serves as a compelling reason for household members to migrate, affecting their physical and mental health, livelihoods beyond agriculture, and social relationships. The experiences of household water insecurity have the potential to profoundly impact people's lives (Stoler *et al.,* 2021). In the current climate change scenario, it is projected that between 24 million and 700 million individuals may be compelled to leave their homes by 2030 due to water scarcity, particularly in arid and semi-arid regions (World Health Organization; London School of Hygiene and Tropical Medicine, 2017).

Increased intensity and frequency of extreme weather events, such as floods and droughts, can displace communities and individuals. Flooding can force people to migrate temporarily or permanently from affected areas, impacting their access to water and overall water security (Internal Displacement Monitoring Centre, 2020). Changes in rainfall patterns and prolonged droughts can disrupt agricultural activities, affecting livelihoods and income. In response, individuals and communities may migrate to seek alternative livelihood options, impacting water security both in the areas of origin and destination (International Organization for Migration, 2018) this has also been witnessed in Uganda where the Karamojong people have left their homes to seek for alternative livelihoods in Neighboring towns of Soroti city, Mbale city, Iganga district and Kampala city.

3.2 The effect of climate change on Surface and water groundwater quality

Ensuring safe drinking water remains a significant challenge, particularly in developing and underdeveloped countries worldwide, where a large portion of the population lacks access to safely managed drinking water (Mukanyandwi *et al.,* 2019). The United Nations reported that approximately 2.2 million people globally lack access to safely managed drinking water (UN, 2020). Deteriorating water quality in these regions is attributed to various sources, including agriculture, industry, human waste, and wastewater, contributing to widespread pollution (Cooper, 2020). Moreover, climate change is predicted to further worsen water quality by altering the composition of river water, reducing freshwater's self-purifying capacity, and escalating sediment, nutrient, and pollutant loadings due to heavy rainfall and floods, disrupting treatment facilities and causing saline intrusion in coastal areas (UNESCO, UN-Water, 2020; Cooper, 2020).

Water quality assessments conducted by Governorate *et al.* (2022) revealed high levels of contaminants in drinking water, with biological pollution present in 55% of yearly samples due to irregular rainfall causing the water to appear muddy, acidic, and turbid (Turyasingura *et al.,* 2023). Anthropogenic activities like urbanization, industrialization, and sewage discharge contribute to water pollution, further exacerbating the problem (Turyasingura *et al.,* 2022; Ram and Irfan, 2021). Increased rainfall variability and subsequent shifts in water quality parameters, notably during the rainy season, have been observed, often resulting in a transition from clear to turbid water (Bastiancich *et al.,* 2022). Additionally, water scarcity amplifies toxin concentrations in water bodies, highlighting the intricate interplay between climate variations and water quality (Khalid *et al.,* 2020).

Human activities near water resources, particularly in coastal areas and lake borders, have a detrimental impact on water quality, posing a threat to both the environment and the ecosystem (Turyasingura *et al.,* 2022; Waithaka *et al.,* 2020). Varying electrical conductivity levels and fluctuations in water quality parameters were noted in different Ugandan rivers due to seasonal rainfall variability, underlining the influence of climate change on water quality (Wilbera *et al.,* 2020). Furthermore, the study of groundwater chemistry in Ghana revealed that groundwater quality is affected by a range of factors, including seawater intrusion, solid waste influx, precipitation chemistry, and agrochemicals due to extended residence time, further emphasizing the complexities of water quality management (Daanoba *et al.,* 2019).

Compromised water quality not only poses health risks to individuals but also harms the environment (Republic, 2019). Inadequate access to treated drinking water forces households to rely on potentially contaminated natural water sources, highlighting the urgent need to address this issue (Mukanyandwi *et al.,* 2019). Trans-boundary water pollution, as seen in the river Kasai receiving contaminated water, is a critical issue and calls for international cooperation to mitigate its effects (Blessing, 2018). However, addressing pollution challenges related to shared rivers, particularly those impacted by mining companies, necessitates overcoming corruption, impunity culture, and conflicts of interest, underscoring the importance of impartial international intervention (Dandison, 2021).

3.3 The resilience and adaptation strategies to water insecurity in the face of climate change

Effective water resource management in the face of climate change necessitates a comprehensive approach, integrating climate-smart strategies, upgrading infrastructure, and promoting water-efficient behaviors (Turyasingura *et al.,* 2023). These strategies mitigate climate change's impact on water quantity and quality. Collaboration involving governments, organizations, and communities is essential to ensure equitable access to water resources and enhance resilience (UNESCO, 2018; UNDP, 2021). Nature-based solutions (NBS) and a combination of green and gray infrastructure can substantially enhance water quality and reduce treatment costs (Cooper, 2020). This includes interventions like water source protection, constructed wetlands, and urban green infrastructure (Cooper, 2020). Improving affordable sanitation in urban areas is crucial for reducing water source contamination and improving public health outcomes (Satterwaite *et al.,* 2019; Cooper, 2020). Alternative sanitation solutions such as waterless toilets and container-based sanitation services should be considered, particularly in informal settlements where traditional infrastructure is less feasible (World Bank, 2019; Cooper, 2020).

Nature-based solutions (NBS) imitate natural methods to enhance water quality and availability, offering sustainable means to mitigate climate change impacts (United Nations, 2019). Protecting and restoring ecosystems like mountains, forests, and wetlands are crucial steps (Mishra & Padhi, 2021). Managed groundwater recharge and techniques like managed aquifer recharge (MAR) and underground taming of floods for irrigation (UTFI) are sustainable strategies to enhance water security (WWAP/UN-Water, 2018; Cooper, 2020). Halting deforestation and promoting sustainable land management is imperative for climate adaptation (Turyasingura *et al.,* 2023). A holistic interdisciplinary approach involving various stakeholders is vital to developing practical climate adaptation and mitigation strategies (Falloon and Betts, 2010; Turyasingura *et al.,* 2023). International cooperation and legal agreements are essential for managing shared water resources effectively (Schmeier and Vogel, 2018).

Preserving and rehabilitating wetland ecosystems are vital for climate adaptability and can act as a protective barrier against floods while aiding in freshwater purification (Turyasingura *et al.,* 2022; United Nations, 2019). Watershed restoration through improved land management can enhance urban water security and provide benefits to both urban and rural areas (Cooper, 2020). Effective water management in Africa, especially regarding climate change, demands robust institutions, upgraded infrastructure, and technological advancements (Ngene *et al.,* 2021). Investments in emission reduction technologies for water infrastructures like drinking water supply, wastewater treatment, and agricultural water pumping are crucial climate change mitigation strategies (Otingi, 2019). A multifaceted approach involving governance, infrastructure, technology, and community engagement is vital for effective water management and climate change adaptation. Community participation is a crucial component in effectively managing water resources, particularly within sub-catchments (Republic, 2019). The success of Integrated Water Resources Management (IWRM) is closely tied to the ability to make decisions at the lowest levels, emphasizing the need for active participation from local communities in problem analysis and solution proposals (Republic, 2019). This participatory approach integrates indigenous knowledge that exists on the ground, often serving as foundational principles for potential solutions. It stresses the importance of bottom-up planning processes and involving communities in improving water and sanitation management (Mishra & Padhi, 2021).

In addressing water security challenges, integration emerges as a pivotal approach that spans the entire water cycle, policy frameworks, and various sectors (Marcal *et al.,* 2021). The integration provides comprehensive benefits in addressing the complexities of water-related issues, incorporating different aspects such as sustainability, resilience, and water security within a holistic framework (Marcal *et al.,* 2021). It extends beyond mere metrics and encompasses broader aspects like science-policy exchange, stakeholder consultation, and research dissemination to policymakers, advocating for a collaborative and inclusive approach. Moreover, focusing on bolstering water infrastructure resilience, expanding sanitation coverage, and ensuring water quality is highlighted as vital for enhancing water security and quality, particularly in rapidly growing urban areas (Lorenzo and Kinzig, 2020). Additionally, successful initiatives like the creation of water authorities in regions like Uganda underscore the potential for effectively managing multiple water schemes to serve significant populations and adapt to climate change (Metcalfe *et al.,* 2021). This collaboration and targeted improvements in water supply systems highlight the importance of addressing vulnerabilities and ensuring continued water supply for the well-being of communities (Metcalfe *et al.,* 2021).

4.0 Conclusion and Recommendation

4.1 Conclusion

Climate change poses a significant threat to Uganda's water security, causing extreme weather events, changes in rainfall patterns, and increasing vulnerability of the poor people, rural communities, and women's water-dependent sectors. The Ugandan government has developed a National Climate Change Policy and Adaptation Plan, but more is needed to ensure safe, reliable water access for all Ugandans.

4.2 Recommendations

The Ugandan government needs to develop models to study pathogen exposure and disease outcomes during flush floods. This requires systematic investigations and process-based models that integrate demographic, health, engineering, meteorological, and environmental data. The government should prioritize investments in climate change adaptation measures for the water sector, including improving water storage and distribution infrastructure, promoting water-efficient agriculture practices, and protecting water resources from pollution. The private sector should invest in water-efficient technologies, and non-governmental organizations should raise awareness about climate change impacts on water security.

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