A systematic review of climate change and water resources in Sub-Saharan Africa

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A Systematic Review and Meta-analysis of Climate Change and Water Resources in Sub-Sahara Africa

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ABSTRACT

Variations in precipitation that affect water resources have drawn a lot of attention to climate change-related water quality issues in recent years. Point and non-point source contaminants have an impact on water quality due to seasonal rainfall variability, and rainfall events are crucial in spreading these pollutants. Sub-Saharan Africa has the least stable access to freshwater supplies. Numerous academics have undertaken extensive research on the connection between climate change and water resources, yielding significant research findings. However, there is a dearth of quantitative analysis and thorough evaluation of research accomplishments. The purpose of the study was to undertake an organized literature review on the topic of examining the relationship between Sub-Saharan Africa's water resources and climate change. In the first segment, Vos-Viewer was used to map, study the literature, and identify any gaps in order to evaluate the impact of rainfall variability on water quality. The adaptation and mitigation strategies for water availability were described in the second section. This report utilizes the VOS-Viewer bibliometric software to create a combative network and keyword co-occurrence map based on the pertinent literature on the topics of climate change and water resources in the core collection of the Web of Science database and dimension. According to the study's findings, cooperation networks are not as prominent as research networks between developed and developing nations. It was also shown that irregular rainfall affects water quality by giving the water a muddy, acidic, and turbid appearance. According to the assessment, the study's conclusions suggest that involving all significant parties and adopting strong rules can facilitate prudent water usage and management. This is crucial for the 884 million people whose survival depends on surface water resources.

Keywords: Aquaculture, Pollution, Rainfall, Relationships, Temperature, Variability

1. Introduction

Water is life, as life on earth cannot survive without it (Al‐Ghussain, 2019; Zhang et al., 2021; Frenkel-Pinter et al., 2021). Water resources provide different goods and services like fishing, eco-tourism, and supply of water for various purposes such as domestic use, irrigation and drinking (Saturday et al., 2022).

Worldwide, water resources are vulnerable to pollution as a result of their ease of access for wastewater discharge and pollutants. Besides, complex anthropogenic activities like urbanization, industrial activities, agricultural activities and sewage discharge and natural processes like climate change, weathering, precipitation and erosion, affect the quality of water and little effort have been done. Water contamination is becoming the most serious threats to human health. It has been estimated that about 80% of all the diseases in mankind are due to one or another unhealthy aspects of water (Kumar et al., 2018).

Due to climate change, one in three individuals who access securely managed drinking water (1.9 billion) reside in rural regions (Fisch-Romito, 2021), leaving over 2.1 million people without access to safe drinking water (UNICEF, 2019; Kong et al., 2020), including over 884 million people (Silva et al., 2020). Unfortunately, weather extremes like heat waves, excessive rain, droughts, and associated fires, as well as coastal flooding, will have a significant impact on people's lives, possessions, and environments (McGregor et al., 2005; Gulzar et al., 2021). The deadliest natural disasters are floods and droughts, which claim lives harm economies, destroy ecosystems and property worldwide (Wijkman & Timberlake, 2021), thus, affecting water resources during heavy rainfall.

Water resources are very vital for the local people in Sub-Saharan Africa (SSA) because these water body areas have wetlands that provide materials for handcrafts (Gopal et al., 2022), fishing (Onyena & Sam, 2020), and mulching (Milder et al., 2011; Yahaya et al., 2022). Freshwater resources are vulnerable to climate change and have the potential to be significantly altered, as evidenced by poor drinking and irrigation water quality, with significant implications for human societies and ecosystems (Abbasnia et al., 2019; Solangi et al., 2019; Zimmermann & Neu, 2022).

In addition, there has been little attention paid to climate change mitigation and adaptation in the Sub-saharan region, where most people are affected by inadequate drinking water (Grasham et al., 2019), approximatelly109 million people use unsafe surface water and over 695 million people still use unimproved facilities (Baye, 2021; Walekhwa et al., 2022) It is estimated that 42 % of the population lack basic water supplies while 72 % lack basic sanitation (Renzaho, 2020). Approximately 57 % have access to safe drinking water management services (Lord et al., 2021). Currently, there is insufficient data in Sub-Saharan Africa about the impact of climate change on water resources"; thus, a gap to fill.

According to Adeyeri (Adeyeri et al., 2020) altering rainfall patterns were noticed in Nigeria which may affect surface water quality during wet and dry seasons. The status of water supply and management in Nigeria is complicated because the bulk of the population is poor and must often travel long distances to obtain potable water for their homes (Gift et al., 2020). Understanding the dynamic link between rainfall variability and water supply in Sub-Saharan Africa is crucial for building future water projects (Muringai et al., 2021). In South Africa and Mozambique, people are fed by surface water or groundwater (Verlicchi & Grillini, 2020). However, many natural and human-made factors including geochemical processes (Akhtar et al., 2021), heavy rain, flooding (Du Plessis, 2019), the release of untreated wastewater (from rural communities) and industrial effluents can pollute water sources.

Ethiopia has surface, underground water, 12 significant stream bowls, 11 freshwater and 9 saline lakes, 4-hole lakes and more than 12 marshes and wetlands. However, approximately 60 % to 80 % of the populace suffer from waterborne and water-related illnesses (Soboksa et al., 2020). Around 80 % of the Ethiopia's population and 20 % of the metropolitan population lack access to safe drinking water during blustery seasons in long periods of dry seasons (Turyasingura & Chavula, 2022). This is in line with the findings of Benson and Ayiga (2022) who revealed that some farmers lack good farming methods (climate-smart agricultural) practices, which combat climate change and its associated problems.

In Tanzania, about 25 % of the population relies altogether on groundwater for drinking (Alarcón-Herrera et al., 2020). Expanding demand for groundwater has effectively been noted in East Africa, like in Tanzania, particularly for individuals living in drier areas (Ligate et al., 2021). As a result, the utilization and nature of groundwater will continue to be critical for the majority of human advancement efforts. Increased rainfall variability has had a significant impact on the quality of drinking water at both the local and national levels (Bastiancich et al., 2022).

Uganda's Vision 2040 promises general use and safe access to drinking water for all Ugandans (Odokonyero et al., 2020). Water resources in SSA provide water for domestic use, irrigation, car, and motorcycle washing. However, the faster-growing population in amalgamation with the agricultural activities (Benson & Ayiga, 2022), in the water catchment areas has had a substantial adverse impact on water quality and the ecosystem (Alex et al., 2021).

In addition, people have historically resided close to freshwater bodies because of the advantages to health and wellbeing, both in Uganda (Saturday et al., 2021), and elsewhere in the world (Hotez, 2021). Within three kilometers of a freshwater body, more than 50% of people on earth reside (Panhwar et al., 2022). Nevertheless, rising population, intensive farming methods, and infrastructure improvements have increased the level of external nutrient loading in the last remaining natural freshwater systems, leading to unsustainable water extraction. As a result, considerable changes in the physical and chemical properties of freshwater bodies have taken place, frequently exhibiting a noticeable transition from the state of clear water to that of turbidity.

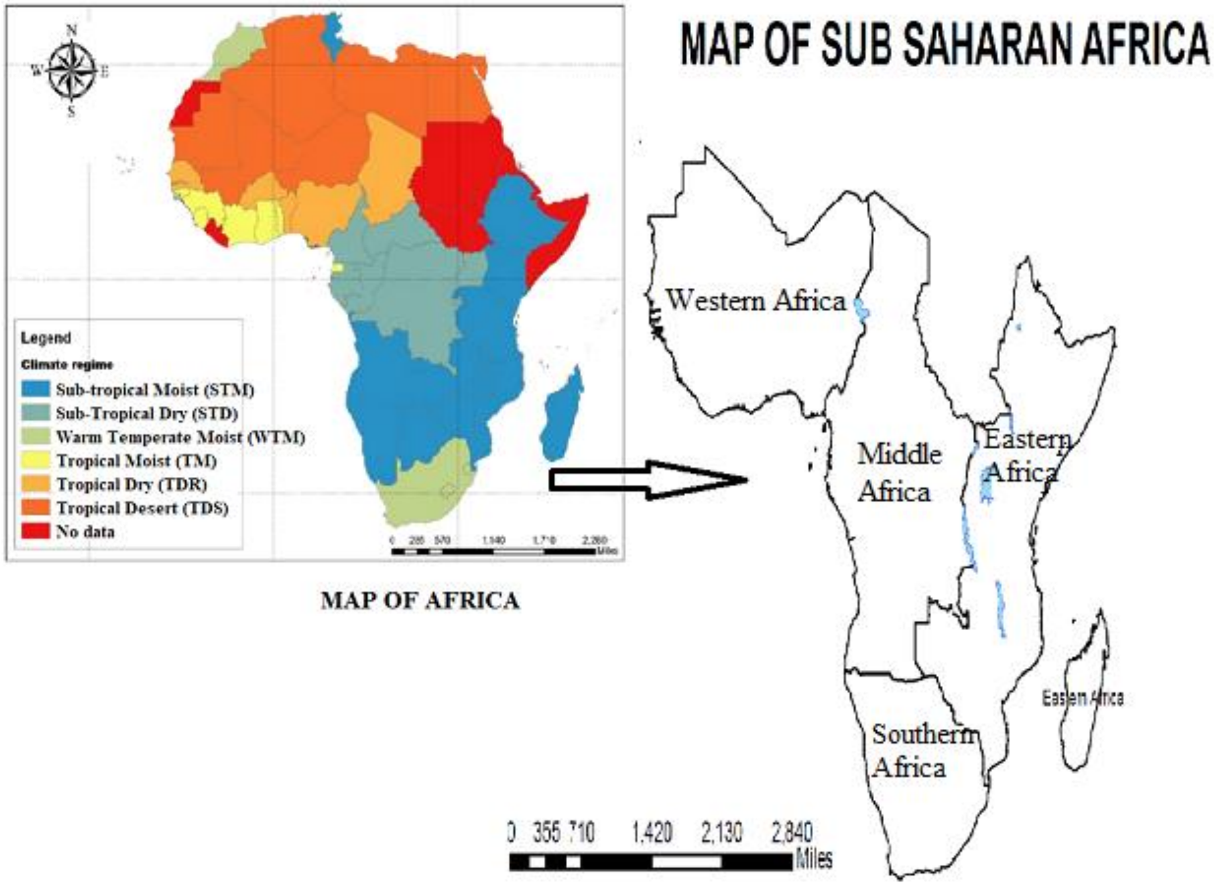
Although several studies have been undertaken on the impact of rainfall variability on water resources (Bwire et al., 2020), data on the implications of seasonal and yearly rainfall variability on rural water supply systems is still missing. As a result, the purpose of this paper is to investigate the relationship between climate change and water resources in Sub-Saharan Africa to facilitate adaptation, mitigation, and water management practices to reduce water contamination and achieve a sustainable environment. This understanding underpins the development of measures to protect the water from further deterioration in quality, thereby protecting the population relying on this resource as well as the environment. It was guided by the following specific objectives, namely: to assess the effect of rainfall variability on the physicochemical water quality parameters (turbidity, temperature, calcium, magnesium, phosphates, pH, and electrical conductivity); and to determine the adaptation and mitigation measures for water availability in Africa.

The study's argument is that growing human activity on lake borders and islands, which has the ability to change the water's physical characteristics, puts the ecosystem services provided by those resources at danger. However, it is unknown whether or not studies on the relationship between climate change and water resources have been conducted to ascertain whether or not human activities have had an impact on the water quality. By evaluating the meta-analysis of climate change and water resources in sub-Saharan Africa, the suggested seeks to close.

2. Method

The SSA comprises two-thirds of the land area of the continent or around 24 million square kilometres and world's area most susceptible to climate change (Junk et al., 2013). Natural disasters are becoming more frequent and more intense, and the geography of the area is dramatically changing, impacting water resources (Van Aalst, 2006). Nearly 60 % of the population of SSA live in rural regions and rely heavily on water supplies for drinking, industrial usage, and agricultural purposes (Fróna et al., 2019). The population of SSA increased from 490 million in 1990 to 1 billion (or around 14 % of the world's population) in 2015, at a growth rate of 2.7 % (Fenta et al., 2020). With over 190 million inhabitants, Nigeria is the most populous nation in Africa; Ethiopia is the second with over 100 million (Olowe, 2021). Although water resources are essential to people's livelihoods, this dependence is most apparent in developing nations like those in SSA, where the majority of the population is impoverished and heavily dependent on natural resources.

Figure 1: Study area map showing regions of Sub-Saharan Africa, (2022).



Source: Google reviews

The purpose of the study was to undertake an organised literature evaluation on the relationship between Sub-Saharan Africa's water resources and climate change. Using Vos-viewer software to map and review the literature and detect existing gaps, the first portion set out to determine the effects of rainfall variability on water quality. The adaptation and mitigation strategies for water availability were described in the second section. The scientific research conducted in SSA that is primarily focused on climate change and water resources is the subject of this study. Using the keywords "Climate-Change" AND "Water resources," searches were conducted in the Web of Science (WOS) and Scopus databases to find the data. Based on the results of the initial search, 70 papers were selected for this study from a total search of 687. In addition, 20 papers from WOS and 50 publications from Scopus were found relevant for this study, papers were selected and discussed in the following, the review focuses on the effects of rainfall variability on water quality, the adaptation and mitigation measures for water availability, from (1945-2022).

2.1 Climate Change and Water Resources in Uganda

Reduced stream flows in important catchments, lower recharging of groundwater, reduced inflows to water storages, or intensified droughts are all consequences of rising temperatures and reduced rainfall (Mahmo od *et al*., 2016), raising competition for water among sectors (Stoerk et al., 2020). Changes in surface runoff and groundwater flows in shallow aquifers are examples of hydrological processes linked to climate change, with implications for permanent and seasonal water bodies like lakes and reservoirs hence, affecting its quality for example river Rwizi in Mbarara district have been affected due to agricultural activities which leads to soil erosion during rainfall thus, affecting aquatic species (Ojok et al., 2017).

Empirical studies on the effects of climate on water resources has been documented as climate change can impact on water supplies by causing greater surface temperatures, melting of snow and glaciers, rising sea levels due to droughts and floods, changes in rainfall frequency and distribution, river drying, water bodies receding, landslides, and cyclones are some of the potential effects of climate change on Uganda's water resources (Yakubu *et al*., 2012). For example, on October 1, 2019, the water level in Lake Victoria steadily rose from 12 meters to its current level of 13.32 meters as of April 30, 2020. The level has increased by 1.32 meters in just 6 months, and it is only 0.08 meters below the greatest level ever observed. This was due to heavy rains that caused rivers and lakes in several parts of Uganda to rise over the limits below which no settlements or development should take place. This had previously occurred between 1961 and 1964, as well as between 1996 and 1998.

Drought has an impact on the quality of fresh water, according to Khalid *et al*. (2020), from the shortage of water to the concentration of toxins in the streams. Drought leads people to use contaminated water for themselves, their crops (which affects productivity) and their animals, resulting in crop wilting and low yield rates. In addition, Kanungu district faced the problem of drought to the extent that people almost eat spear grass due to shortage of food. As a result, farmers in Uganda must be trained on flood management and correct water management methods such as tree planting to limit runoffs, with trees acting as carbon sinks as part of the third pillar of climate wise agriculture, which attempts to reduce greenhouse gas emissions.

Rainfall is a seasonal phenomenon with significant inter-annual fluctuation due to climate changes, extreme climate events, changes in the duration of continuous rain or no rain spells, and the overall amount of water supplied during each wet spell (Rani et al., 2021). As a result, all of these parameters are dependent on the characteristics of the watershed and its geographic location in Uganda, where rainfall is the norm.

The relationship between precipitation and the microbiological quality of lakes such as Mutanda, Victoria, Kyoga in Uganda is complicated, involving a complex interplay between the type of water supply and its management (Howard et al., 2016). Unfortunately, rapid and unplanned urbanization, poor sanitation, erosion, and a lack of upkeep of water catchment regions all contribute to climate change vulnerability (Maskey et al., 2020). As a result, the infrastructural and environmental changes, the study timeframe (yearly, season, or day to day), and the rainfall patterns are all factors to consider (Ogunsanya Dr. et al., 2014).

Local weather, climatic change, and hydrologic conditions, according to (Vinçon-Leite and Casenave, 2019), are examples of elements that affect water quality in Uganda, nutrient loads, and eutrophication of water bodies. Rainfall fluctuation promotes cyanobacteria dominance, exacerbates eutrophication, and affects the stability of lake features such as physical, chemical, and bacteriological stability, as well as the availability of nutrients.

2.2 Effects of Rainfall Variability on Water Quality

This study considered water quality parameters that affect drinking water standards as per (Apha., 1976), resulting from human activities that lead to climate change. For example, cutting down forests for agriculture causes emissions and releases the carbon stored in trees; this leads to global warming and climate change as greenhouse gas emissions blanket the earth by trapping the sun's heat. Water quality parameters that affect drinking water in this study include turbidity, temperature, calcium, magnesium, phosphates, pH, and electrical conductivity.

2.2.1 Turbidity

According to Ojok et al. (2017), the mean turbidity was higher in the rainy season as compared to the dry season. Because of soil erosion in the prepared agricultural areas with a loose top layer of soil, turbidity measurements were greater during the wet season. Particles in the river water could have come from debris swept in by the wind and rain. Variation in turbidity was also influenced by increased agricultural land usage and built-up intensity in the river watershed at the start of the rainy season (Mbaye et al., 2015). Furthermore, because the increased water volume in water bodies may be attributable to resuspended bottom sediments due to high water flow rates, this is critical to this review paper because it is an indicator of the effect of seasonal rainfall variability on water quality.

Waithaka et al. (2020) found that water quality metrics during the rainy season had a higher mean than their similar values during the dry season. He concluded that temporal precipitation inconsistency significantly affects the pH, turbidity, dissolved oxygen, thermal conductivity, and total dissolved solids of water ecology. Therefore, this research needs to make combined water resource management based on what was found to ease water quality among people.

2.2.2 Temperature

According to Fujisaki-Manome et al. (2020), the minimum water temperatures in the winter were near freezing for all five lakes, with minimum daily values ranging from 0.3° C (Lake Erie) to 2.3° C (Lake Superior) and (Lake Ontario). However, in 2015, there was an uncertain warming in Lake Superior, Lake Huron, and Lake Erie from late April to early May. He found that the direct effects of precipitation (snow or rain) on the water surface temperature were rather small when compared to seasonal fluctuations in water surface temperature. Large snowstorms brought direct snowfall to open water areas, which were then cooled by the release of latent heat from the melting snow. Hence, SSA is the region most affected by the increase in temperature.

2.2.3 Calcium

Calcium is essential for both plant and animal bone, nervous system, and cell development (Kozisek, 2020). The majority of this is obtained by food; drinking water accounts for 50–300 mg per day, depending on the hardness of the water and assuming a daily intake of 2 L. Ca is non-toxic in food and water. Many metals are less hazardous to aquatic life when there is enough calcium in the water. As a result, the presence of calcium in water is advantageous, and no Ca restrictions have been set to safeguard human or aquatic health (Dinaol, 2015).

The total hardness of Triveni Lake, according to Khan (Ahmad et al., 2020), ranged from (69.33 to 193.67) mL. Minimum values were reported during the monsoon in the Harsal dam, ranging from (83.8 to 178) mL. Sulfates, calcium chlorides, and magnesium chlorides are all included in total hardness. The study concluded that the most common ions in natural water are bicarbonates, which are primarily related to calcium, to a lesser degree with magnesium, and even less with sodium.

2.2.4 Magnesium

Magnesium is required for the development of bones and cells in both plants and animals (Ben & Morgan, 2017). Manganese in water sources gives beverages an unpleasant flavour and stains sanitary ware and laundry at concentrations greater than 0.1 mL. High quantities are possible due to reducing circumstances in groundwater and some lakes and reservoirs; up to 1.3 mL in neutral water and 9.6 mL in acidic water (Shyamala et al., 2008). Manganese in drinking water, like iron, can develop deposits in the distribution system for lake water users in the area. According to Mbura (Mbura, 2018), during the dry season, the mean magnesium and calcium ions in groundwater were 59.1 mL and 130.1 mL, respectively, and during the rainy season, 67.5 mL and 143.5 mL. The mean magnesium levels were within the guidelines. However, the calcium levels were determined to be greater than the guidelines for drinking water (Sila, 2019). In addition, there was a statistically significant difference ($p=0.05$) in the mean magnesium and calcium levels in the dry and wet seasons. The research location's high levels of calcium ions were related to the geology of the area, which consists of limestone with high calcium levels (Schoeman, 1951). This could potentially be the result of rainwater with magnesium and calcium ions replenishing the aquifer.

2.2.5 Phosphates

According to Ouma Ouma et al. (2016), study results in the Lake Victoria catchment suggested 0.15-1.04 and 1.17-2.23 mL in the dry and wet seasons, respectively; (Ontumbi et al., 2015) study in the Sosiani River, Kenya, indicated (0.010-0.018 and 0.750-1.160 mL) in the dry and wet seasons, respectively. Phosphate levels were found to be high during the wet season due to a high rate of decomposition of organic materials, as well as run-off, surface catchment, and contact between the water and sediments from dead plants and animals at the river's bottom

(Ouma et al., 2016). He concluded that the river's slow and shallow water is due to the overflow of discharge from residential areas and sewers.

2.2.6 pH

This is a measure for detecting whether water is acidic or basic. The pH scale runs from 0 to 14, with 7 indicating neutral, less than 7 acidic, and greater than 7 abase (Tian et al., 2017; Wilbera et al., 2020). Pollution can alter the pH of water, causing harm to aquatic animals and plants. Acid deposition degrades the water quality of lakes and streams by reducing pH levels (raising acidity) and diminishing acid-neutralizing capacity as a result of industrial pollutants (Papadaskalopoulou et al., 2015). In the aquatic environment, dissolved sulphur with a positive factor loading is produced by the oxidation of organic and inorganic sulphur compounds. He concluded that seasonal fluctuations in sulphur were caused by variations in the rate and intensity of weathering as well as rainfall variability. He found that home wastewater, agricultural runoff, industrial effluents, and natural hydrologic processes were the main causes of water contamination. Iron, chemical oxygen demand, and pH (rain season) levels at every research site were higher than the permitted upper limit for surface water. Because of variations in rainfall, some sites have more manganese, biochemical oxygen demand, and total dissolved solids than is permitted.

2.2.7 Electrical Conductivity

According to Alex et al. (2021), Lake Bunyonyi, Uganda's Electrical Conductivity (EC) measurements did not exceed the WHO's 2500 Siemens per centimetre maximum permissible limits, as stated in international national drinking water standards and guidelines. Because of this, the study's conclusions accurately stated that Lake Bunyonyi's water is not strongly ionized and has a low ionic concentration. The study concluded that while the low EC values at Nyombe station suggest an unpolluted aquatic environment, the high EC values at Harutinda station may be caused by pollution from Crater Bay Cottages and Lake Bunyonyi Overland camp.

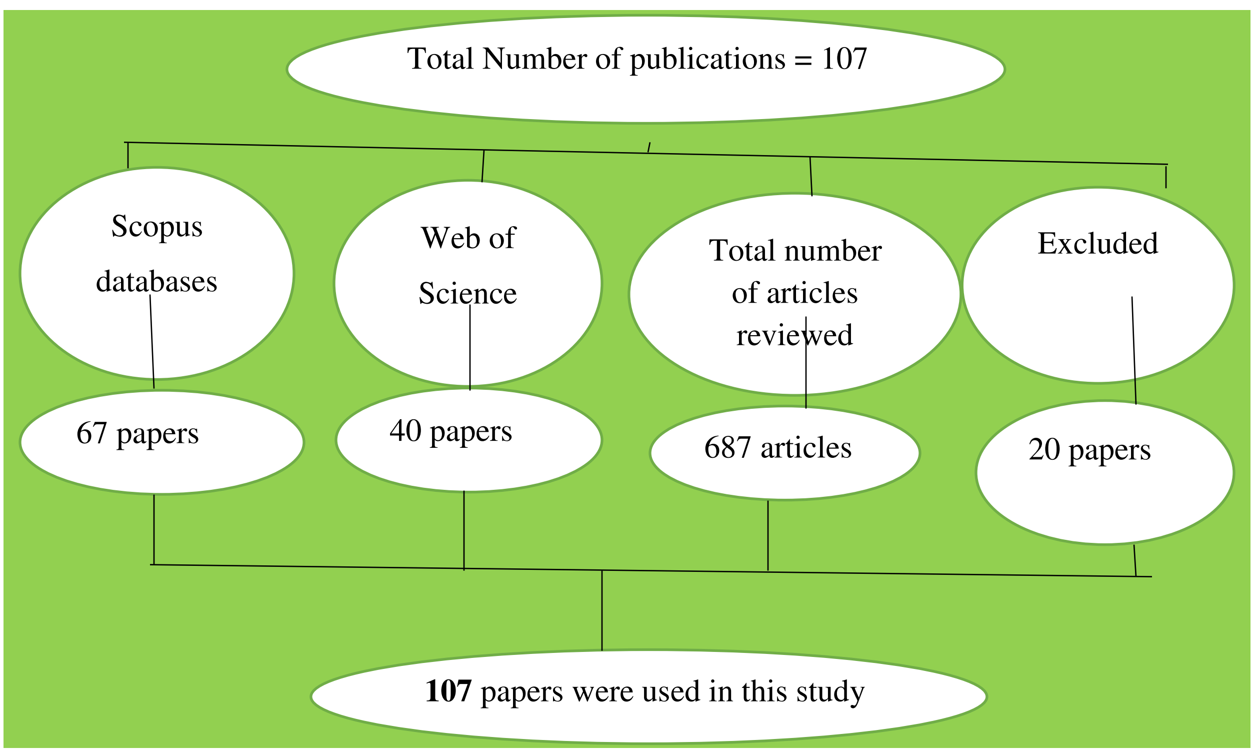
The study's electrical conductivity findings, according to Wilbera and Kasangaki (Wilbera et al., 2020), suggested a relative amount of ions present in water. The river Rwimi has the highest EC (162.831.41 Siemens per *cm*) compared to the rivers Nyamwamba and Mubuku (146.501.93 Siemens per *cm* and 103.061.37 Siemens per *cm*, respectively) in Uganda. The study concluded that the highest EC at Rwimi was due to the use of agricultural and fertilizers, as well as the discharge of home effluents related to the intake of sewage water; hence, litter.

According to Alex et al. (2021), the nutrient and ammonia readings at Akampene (M2) and Heissesero (L1) stations were 0.070.01 mL and 0.130.07 mL, respectively. The Total Nitrogen concentrations at Nyombe (U1) and Rugarambiro (L2) stations were 1.0 0.7 mL and 2.9 2.1 mL, respectively.

Table 1: Searching the Web of Science (WOS) and Scopus databases using "Climate-Change" AND "Water resources."

Search Platform	Total no. of used papers	Total no. of articles reviewed
Papers from Scopus databases	67	287
Papers from WOS	40	360
Papers selected in this study	107	687
Total	**107**	**687 Papers reviewed**

Figure 2: Flowchart for the selection of literature.

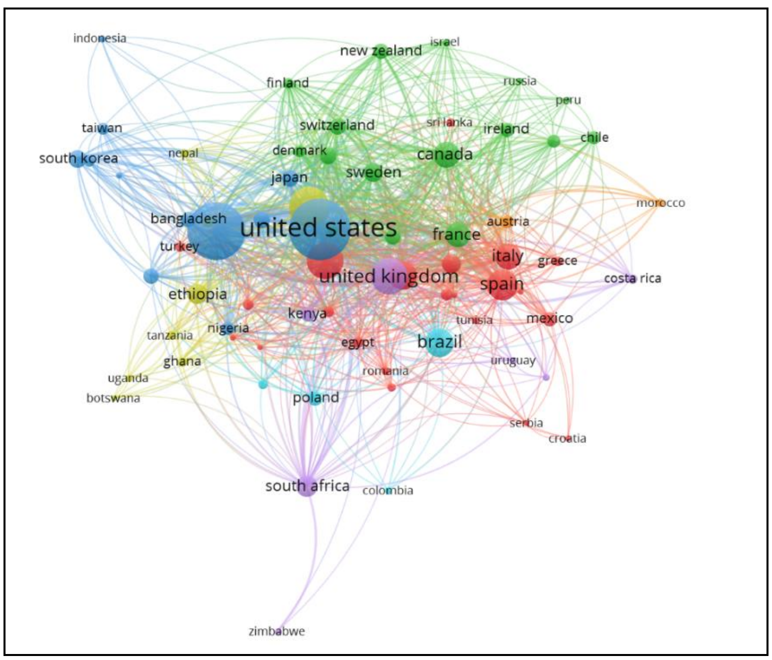


The flow chart in *Figure 2* provides a detailed description. It was confirmed that every search result was exactly on the topic of climate change and water resources in SSA. The total number of articles reviewed was six hundred eighty-seven. Twenty-five papers were obtained from the Scopus database, fifty papers from the Web of Science, and around 20 papers were excluded from this study because they were outside of the search topic and specific objectives. This was justified for this study to reduce bias in the analysed data and to ease data collection.

Publication in each Country

Figure 3 shows that the number of articles published in the USA, Canada, and Brazil is greater than 100, which is much more than in other nations. These three countries were responsible for 31.84 per cent, 19.9 per cent, and 18.15 per cent of all publications in this field, respectively. As a result, linkages between nodes are many and intricate, suggesting that various nations frequently engage in cooperative relationships. The United States is positioned near the leading edge of a few nodes in *Figure 3,* which also suggests that the node holds a significant position within the network structure.

Figure 3: Publication per country.



Author Analysis

The most frequently published authors were identified and analysed to classify the 687 articles that are part of the sample. From this analysis, the topics arising more often in the analysed area stand out. The map represented in *Figure 4* groups the authors into four clusters with different colours. This map highlights, further, that climate change and water resources seem to be the direction the research is taking and where new research opportunities might be arising.

Figure 4: Network Analysis of the author's trends.

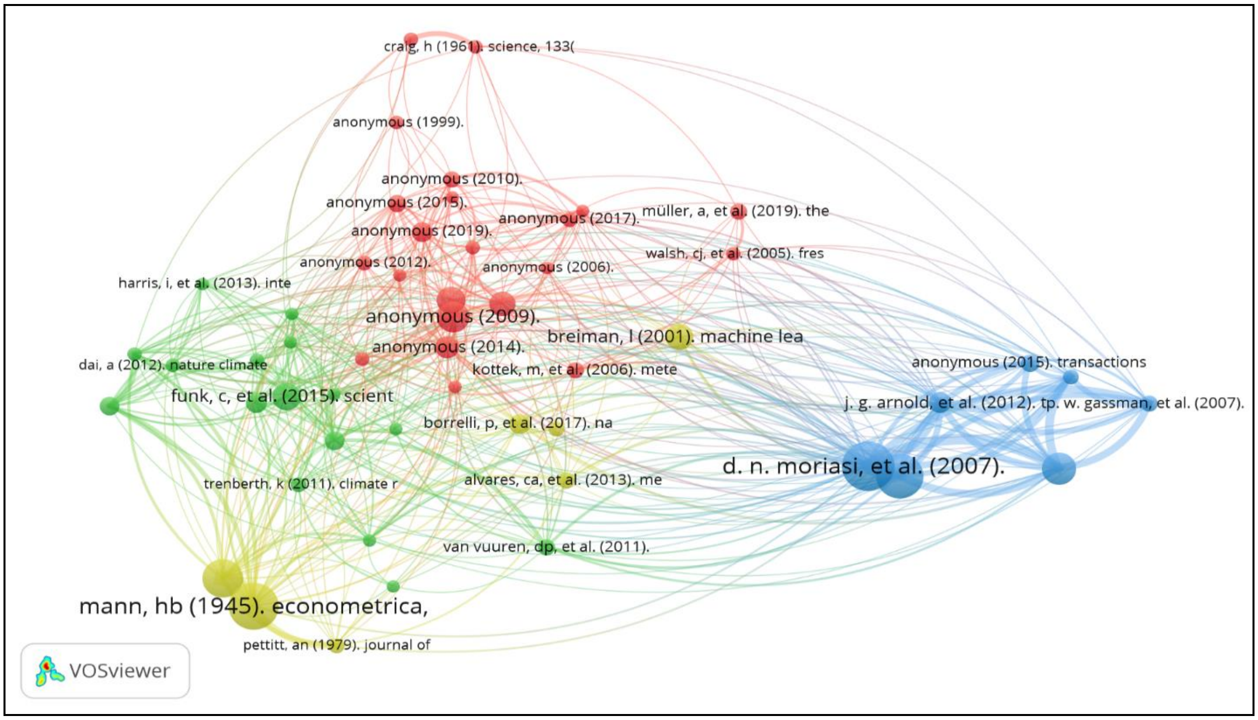
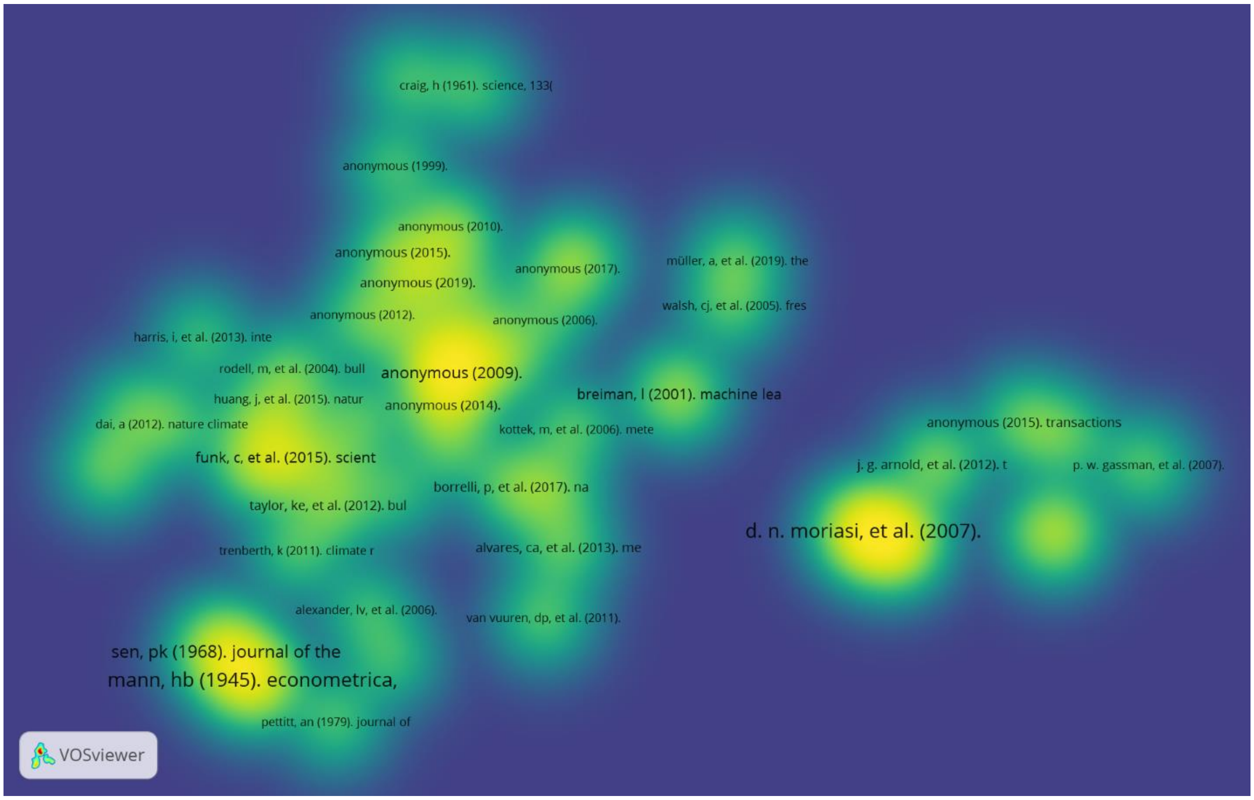


Figure 5: Density visualization of the author's trends.



2.3 Adaptation and Mitigation Measures for Water Availability

2.3.1 Adaptive Measures

To create practical and effective adaptation and mitigation strategies for Africa, it is necessary to use an interdisciplinary and holistic strategy that involves policymakers, academics, practitioners, and the public and private sectors (Turyasingura et al., 2022). There are numerous immediate and long-term implications of climate change on the water on ecosystems and communities in African nations, ranging from economic and social effects to health and food shortages, all of which threaten the survival of many African regions (Fuso Nerini et al., 2019).

Vulnerability, on the other hand, differs depending on individual countries' geographical location and their ability to mitigate or adapt to changes (Thomas et al., 2019). As a result, rethinking climate change adaptation on Africa's water resources to adapt to these changes includes, but is not limited to, water availability through an integrated approach based on African countries' cooperation; water resource sustainability through efficient management, the creation of a new supportive network, and a strong African movement of young people and women to assist throughout the implementation of adaptive activities to increase diversity resilience to withstand with the adverse effects of climate change (Turyasingura et al., 2022). Mitigation actions focused on the reinforcement of strong institutions and infrastructure in Africa should also be encouraged (Fuso Nerini et al., 2019).

2.3.2 Integrative Approach to adapt to Continental water Resources Crisis

An integrated strategy for the water resources crisis is a bilateral and international collaboration between countries, particularly African countries, to address the issue of shared water (M. Fan et al., 2020). This includes not just cooperation, but also binding agreements, the construction of a water climate information network among African countries, the use of technology, and effective communication. This enables countries to consider each other's needs, benefits, advantages, and disadvantages, as well as cooperation, to solve and gain collectively the outcomes of water utilization.

Collaboration, depending on the degree of negotiation of every country sharing the same rivers. Cooperation between countries could provide several benefits, including access to clean water and the prevention of water pollution (Grech-Madin et al., 2018). The usage of dirty water, on the other hand, has all the negative repercussions on public health. For example, because of a lack of bilateral cooperation between the two nations, the river Kasai in the Democratic Republic of the Congo (DRC) is receiving filthy water from Angola's river (Blessing, 2018).

The water climate information platform is crucial for Africa, and most importantly for local, regional and continental collaboration specifically when the resources are shared by several nations (Daron, 2018). Water is a resource that affects every area of the economy, it can be viewed as a source of collaboration and progress, and hence peace and stability in Africa (Zougmoré et al., 2018).

However, based on the experience of shared rivers polluted by mining companies, the platform would face numerous challenges, including structural corruption, impunity culture, influence peddling, and conflicts of interests (Dandison, 2021), all of which would require the involvement of impartial international courts to effectively combat.

As a result, international cooperation would improve not just the quality but also the availability of water for everyone (Shah et al., 2018). It would improve Africa's economy and development by facilitating trade and prudent management of water resources. Non-binding agreements are one of the most difficult aspects of the integrated approach to getting African countries to collaborate based on transboundary rivers or lakes. Africa has 94 international water agreements for cooperation and management of shared water resources, but none of them is in use (Hirwa et al., 2022). As a result, legally enforceable agreements are useful for enforcing cooperation between transboundary countries (Schmeier & Vogel, 2018).

Technological initiatives can also help African countries cooperate more effectively both within and outside of their borders. Traditional and modern water harvesting techniques, water conservation and storage, and better water recycling and reuse are all approaches that have been combined (Bolt, 2019). One of the most essential adaptation requirements has been identified as the significance of building on traditional knowledge relating to water harvesting and utilization (Vyas & Nath, 2021). As a result, Africans who have a traditional approach to dealing with climate change issues such as drought and flooding should be bolstered by new and modern technology to address water scarcity and rainfall availability.

2.3.3 Integrated Water Resources Management and Infrastructure

This is linked to the principles of Integrated Water Resources Management (IWRM), which are essential for the effective and efficient management of water resources (in both current and future climates) and must be facilitated by appropriate policies and institutional frameworks (Al-Jawad et al., 2019). These tactics should be carefully adjusted to the realities of existing institutional arrangements, local people's livelihood plans, and the current low levels of infrastructural development.

New and retrofitted water infrastructure, such as surface reservoirs, multipurpose dams, soil moisture conservation techniques, natural wetlands, rainwater harvesting for storage, rainwater harvesting for infiltration, urban green spaces, conjunctive use of surface and groundwater, managed aquifer charge, and source water, is listed as a priority for adaptation action in over 68 per cent of all Nationally Determined Contributions (NDCs) (Wang et al., 2019).

2.3.4 Water harvesting

Water harvesting is the process of collecting rainfall directly from the sky (Tu *et al.*, 2018). Rainwater can be collected and stored for immediate consumption or returned into the groundwater system. Rain is the first form of water in the hydrological cycle that humans are aware of, making it a key supply of water for humanity. Rainwater harvesting entails absorbing runoff from rooftops, catchment runoff, seasonal floodwaters from local streams, and watershed management (Bennett & Barton, 2018). Therefore, there is need for rain water harvesting in Uganda especially Kigezi and Northern regions to keep water during dry seasons for both domestic use and irrigation to increase productivity as shown in (*Figure 6*).

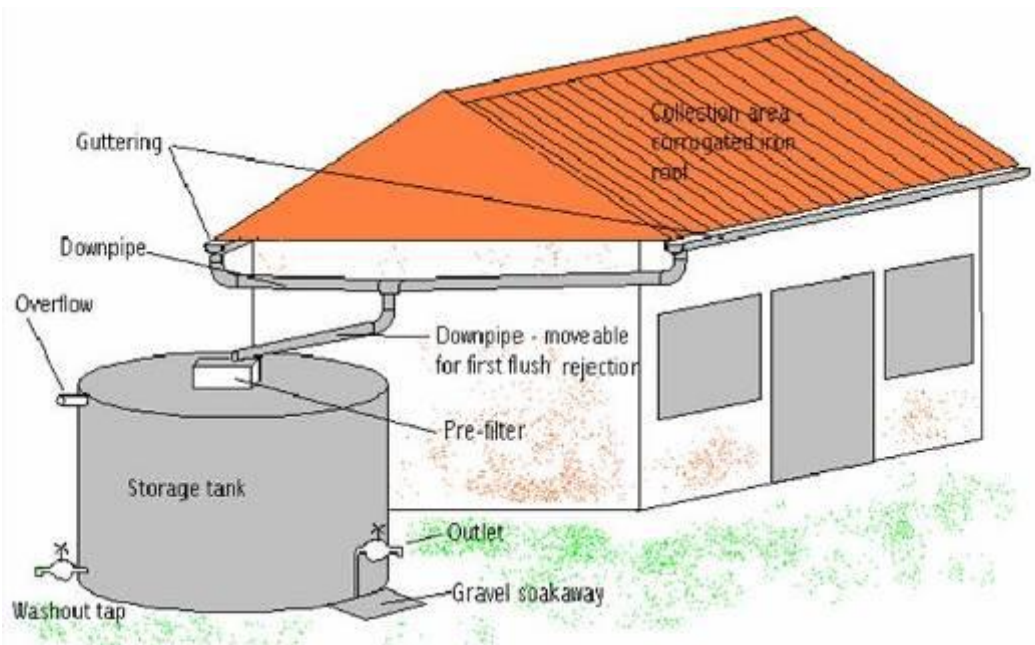


Figure 6: Conceptual sketch of rooftop rainwater harvesting system
Source: http://www.eng.warwick.ac.uk/DTU/rainwa.

2.3.5 Other Adaptive Measures

Wetland ecosystems should be conserved, maintained, or rehabilitated. Wetlands are important for adaptation because they act as a buffer against floods and other extreme weather events, as well as purifying water (J. Fan et al., 2021). Drought resistance and water scarcity can both be improved by co-management, which allows a region's overall water storage capacity to be increased (Zarei et al., 2020).

Protection water efficiency and demand management are two issues that need to be addressed. Progressive pricing, hydrological zoning, water licensing and permits, shifting usage from peak to off-peak periods, and water conservation requirements in building codes are all examples of water conservation measures (Stip et al., 2019). Seawater desalination, solar water distillation, fog harvesting, inter-basin transfers, groundwater prospecting and extraction, boreholes and tube wells, and water recycling and reuse are examples of alternative water sources (Conca, 2021).

Integrated watershed management: Watersheds are natural environmental and land management units that influence a country's overall health. Poor ecosystem management in watersheds has resulted in and will continue to result in reduced watershed functioning, which in sensitive areas can lead to ecosystem collapse (Pourghasemi *et al*., 2020).

If appropriate policies are enacted, watershed management is often successful. Watershed management necessitates the use of the three "Ps": planning, partnership, and stakeholder participation (Karambelkar & Gerlak, 2020). Public-private partnerships are becoming a more typical strategy to increase management success. This bring these two sectors together to work toward a common goal, allowing each to benefit from the skills and resources of the other to more effectively fulfil management goals. Watershed management is mainly based on the study of watersheds, which is a branch of hydrology that analyses the effects of vegetation and land management on water quality, erosion, and sedimentation (Ranjan *et al*., 2020). Many environmental and natural resource management decisions are being predicated on watershed management concepts to increase diversity resilience, as it is becoming increasingly clear that land management decisions cannot be undertaken in isolation (Turyasingura, Mwanjalolo, & Ayiga, 2022).

2.4 Mitigation Measures

Water availability is a difficult issue in Africa that necessitates strong institutions, infrastructure, and technology for successful water management, whether transboundary or within the country (Ngene et al., 2021). Most technology-driven climate change mitigation strategies necessitate investing in reducing emissions from water infrastructures, such as drinking water supply, waste and stormwater treatment, and water pumping for agriculture and other purposes. Different water and sanitation-related mitigation techniques should be considered for planning and management processes in this context (Otingi, 2019).

Infrastructure is one of the most significant problems, as are strong institutions to address the issue of water availability, a specific program to fund and change the mindset of leaders, and the battle against other concerns such as corruption and impunity for this approach to succeed. Infrastructure, for example, will help to distribute water in the Sud-Sahara region using new technologies such as irrigation systems for large rivers such as the Congo River and other rivers, as well as manage water that falls into the sea internally to avoid waste and maximize water availability for African people, lands, and local communities (Baylouny & Klingseis, 2018).

The greatest way to prepare for climate change in the extraction, delivery, and treatment of water is to invest more across Africa in water infrastructure to boost the positive functions and decrease the negative impacts of water. Nature-based solutions (NBS) are a critical way to go beyond business as usual to address many of the world's water concerns while also providing additional advantages that are critical to all elements of sustainable development (Alpízar et al., 2020). NBS use or mimic natural processes to increase water availability (for example, soil moisture retention or groundwater recharge), improve water quality (for example, natural and constructed wetlands), and reduce the risks associated with water-related disasters and climate change.

3. Implications for the Future Research

This report suggests that county governments develop a strategic plan for water quality management based on priorities that reflect an awareness of the economic and social implications of contaminated water. Specific procedures for delivering community-level drinking water monitoring capabilities should be devised.

A regulatory framework with a combination of acceptable water quality objectives and effluent management is required. This will be crucial for the 2.1 million people with no access to safe drinking water, of which more than 884 million individuals have no basic drinking water services and who rely on surface water to survive. By incorporating both traditional and modern expertise, like water harvesting techniques, water conservation and storage, and improved water recycling and reuse, the continent's adaptive capacity to climate change will be enhanced.

The management of surface and groundwater, irrigation systems, the continuum system of water storage reservoirs, infrastructure for water transportation, efficient supply chains for both agriculture and drinking water, and assurance of water availability, sanitation, access, and utilization should all be improved. To develop both small-scale and large-scale water infrastructure, increasing capital investment in water resource management across Africa is the best adaptation strategy.

4. Conclusion and Recommendations

Based on the findings of several reviewers, it has been determined that seasonal rainfall unpredictability brought on by climate change has an overall negative impact on the quality of water in various water bodies. The fact that the mean values for certain of the physicochemical variables under consideration fell within the WHO's acceptable limits for drinking water and recreational waters, respectively, provides further evidence for this. This is demonstrated by the evaluated sample values for temperature, magnesium, pH, DO, turbidity, EC, nitrites, nitrates, and ammonia that were below the acceptable limits and may not pose a threat to the health of either people or aquatic life. As a result, even while the measured physicochemical parameters showed notable temporal variations, dramatic variances were observed in several of the study stations/areas. The results of this investigation showed that pH, turbidity, dissolved oxygen, thermal conductivity, and calcium are all considerably impacted by climate change. To discuss the future of sustainable food production in the face of climate change and variability in the current and future centuries, complex and multidisciplinary solutions involving all stakeholders are required at the local, national, regional, and global levels. These stakeholders include researchers, policymakers, the private sector, national government, international agencies, FAO, World Bank, donors, World Food Program, men, women, and youth. Climate change has an impact on water, the food chain, and the food environment; it is a multidisciplinary issue that necessitates a multidisciplinary approach to designing and implementing potential solutions. Co-author-ship is needed to increase publications and improve the water resources in SSA.

The following are recommendations to African policymakers and NGOs based on the study's findings. Strategies are required, which necessitate various resources such as financial and human resources, as well as political support for the projects. Local and national governments should consider policies and programs to address the local government's lack of financial and human resources.

In the face of climate change, African planners should seriously consider integrating and institutionalizing adaptation with development initiatives. It should not be an afterthought or an add-on. Based on the background and literature assessment, there is currently minimal proof of this, leaving a gap to fill. Long-term policies that satisfy local developmental goals and handle water resource management problems should be implemented, with the government and NGOs playing a key role. This will ensure that, despite the uncertainty of future climate projections, local governments have the necessary adaptive resilience in place to ensure that the communities they serve have adequate clean water to meet their developmental needs.

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Conflict of Interest

The authors state that they have no competing interests in the publication of this research.

Conflict of Interest

Data is available at the request of the author.

REFERENCES

Abbasnia, A., Yousefi, N., Mahvi, A. H., Nabizadeh, R., Radfard, M., Yousefi, M., & Alimohammadi, M. (2019). Evaluation of groundwater quality using water quality index and its suitability for assessing water for drinking and irrigation purposes: case study of Sistan and Baluchistan province (Iran). *Human and Ecological Risk Assessment: An International Journal*, *25*(4), 988–1005.

Adeyeri, O. E., Laux, P., Lawin, A. E., & Arnault, J. (2020). Assessing the impact of human activities and rainfall variability on the river discharge of Komadugu-Yobe Basin, Lake Chad Area. *Environmental Earth Sciences*, *79*(6), 1–12.

Ahmad, I., Tahir, M., Daraz, U., Ditta, A., Hussain, M. B., & Khan, Z. U. H. (2020). 14 Responses and Tolerance of Cereal Crops to Metal and Metalloid Toxicity. *Agronomic Crops: Volume 3: Stress Responses and Tolerance*, 235.

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water*, *13*(19), 2660.

Al-Jawad, J. Y., Alsaffar, H. M., Bertram, D., & Kalin, R. M. (2019). A comprehensive optimum integrated water resources management approach for multidisciplinary water resources management problems. *Journal of Environmental Management*, *239*, 211–224.

Al-Ghussain, L. (2019). Global warming: Review on driving forces and mitigation. *Environmental Progress & Sustainable Energy*, *38*(1), 13–21.

Alarcón-Herrera, M. T., Martin-Alarcon, D. A., Gutiérrez, M., Reynoso-Cuevas, L., Martín-Domínguez, A., Olmos-Márquez, M. A., & Bundschuh, J. (2020). Co-occurrence, possible origin, and health-risk assessment of arsenic and fluoride in drinking water sources in Mexico: Geographical data visualization. *Science of the Total Environment*, *698*, 134168.

Alex, S., Thomas, J. L., John, M., & Siajali, P. (2021). *Spatio-temporal variations in physicochemical water quality parameters of Lake Bunyonyi, Southwestern Uganda*. SN Applied Sciences.

Alpízar, F., Madrigal, R., Alvarado, I., Brenes, E., Camhi, A., Maldonado, J., Marco, J., Martínez-Salinas, A., Pacay, E., & Watson, G. (2020). *Mainstreaming of Natural Capital and Biodiversity into Planning and Decision-Making*.

Apha. (1976). *Standard Methods for the Examination of Water and Wastewater 14ed*. APHA American Public Health Association.

Arroyo, M. C., Fassbender, A. J., Carter, B. R., Edwards, C. A., Fiechter, J., Norgaard, A., & Feely, R. A. (2022). Dissimilar sensitivities of ocean acidification metrics to anthropogenic carbon accumulation in the Central North Pacific Ocean and California Current Large Marine Ecosystem. *Geophysical Research Letters*, *49*(15), e2022GL097835.

Bastiancich, L., Lasagna, M., Mancini, S., Falco, M., & De Luca, D. A. (2022). Temperature and discharge variations in natural mineral water springs due to climate variability: a case study in the Piedmont Alps (NW Italy). *Environmental Geochemistry and Health*, *44*(7), 1971–1994.

Baye, D. (2021). Sustainable development goals (SDG) target 6.2 in Ethiopia: challenges and opportunities. *Open Access Library Journal*, *8*(5), 1–28.

Baylouny, A. M., & Klingseis, S. J. (2018). *Water thieves or Political catalysts? syrian refugees in Jordan and Lebanon*.

Ben, L., & Morgan, A. (2017). Physico-Chemical Quality of Selected Drinking Water Sources in Mbarara Municipality, Uganda. *Journal of Water Resource and Protection*, *9*(07), 707–722.

Bennett, B. M., & Barton, G. A. (2018). The enduring link between forest cover and rainfall: a historical perspective on science and policy discussions. *Forest Ecosystems*, *5*(1), 1–9.

Benson, T., & Ayiga, N. (2022). *Classifying the Involvement of Men and Women in Climate Smart Agricultural Practices in Kayonza Sub-county, Kanungu District, Uganda*.

Blessing, M. (2018). *Migration and Development: A case study of the Democratic Republic of Congo and Sweden*.

Bolt, J. S. (2019). *Financial resilience of Kenyan smallholders affected by climate change, and the potential for blockchain technology*. CCAFS.

Butenschön, M., Lovato, T., Masina, S., Caserini, S., & Grosso, M. (2021). Alkalinization scenarios in the Mediterranean Sea for efficient removal of atmospheric CO2 and the mitigation of ocean acidification. *Frontiers in Climate*, *3*, 614537.

Bwire, G., Sack, D. A., Kagirita, A., Obala, T., Debes, A. K., Ram, M., Komakech, H., George, C. M., & Orach, C. G. (2020). The quality of drinking and domestic water from the surface water sources (lakes, rivers, irrigation canals and ponds) and springs in cholera prone communities of Uganda: an analysis of vital physicochemical parameters. *BMC Public Health*, *20*(1), 1–18.

Conca, K. (2021). *Advanced Introduction to Water Politics*. Edward Elgar Publishing.

Dahlin, A. S., & Rusinamhodzi, L. (2019). Yield and labor relations of sustainable intensification options for smallholder farmers in sub-Saharan Africa. A meta-analysis. In *Agronomy for Sustainable Development* (Vol. 39, Issue 3, pp. 1–18). Springer.

Dandison, J. (2021). *Evaluation of Political Corruption and Strategies for Its Reduction in Nigeria*. University of Portsmouth.

Daron, D. J. D. (2018). *Regional climate messages for East Africa*.

Dinaol, M. (2015). *In Partial Fulfillment Of The Requirements For Master Of Science Degree In Analytical Chemistry*. ASTU.

du Plessis, A. (2019). Primary water quality challenges, contaminants and the world's dirtiest places. In *Water as an inescapable risk* (pp. 79–114). Springer.

Erickson, T. B., Brooks, J., Nilles, E. J., Pham, P. N., & Vinck, P. (2019). Environmental health effects attributed to toxic and infectious agents following hurricanes, cyclones, flash floods and major hydrometeorological events. *Journal of Toxicology and Environmental Health, Part B*, *22*(5–6), 157–171.

Fan, J., Wang, X., Wu, W., Chen, W., Ma, Q., & Ma, Z. (2021). Function of restored wetlands for waterbird conservation in the Yellow Sea coast. *Science of the Total Environment*, *756*, 144061.

Fan, M., Xu, J., Chen, Y., Li, D., & Tian, S. (2020). How to sustainably use water resources—A case study for decision support on the water utilization of Xinjiang, China. *Water*, *12*(12), 3564.

Fenta, A. A., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Yasuda, H., Shimizu, K., Kawai, T., Ebabu, K., Berihun, M. L., & Sultan, D. (2020). Cropland expansion outweighs the monetary effect of declining natural vegetation on ecosystem services in sub-Saharan Africa. *Ecosystem Services*, *45*, 101154.

Fisch-Romito, V. (2021). Embodied carbon dioxide emissions to provide high access levels to basic infrastructure around the world. *Global Environmental Change*, *70*, 102362.

Foo, S. A., Byrne, M., Ricevuto, E., & Gambi, M. C. (2018). The carbon dioxide vents of Ischia, Italy, a natural system to assess impacts of ocean acidification on marine ecosystems: an overview of research and comparisons with other vent systems. *Oceanography and Marine Biology*, 237–310.

Frenkel-Pinter, M., Rajaei, V., Glass, J. B., Hud, N. V, & Williams, L. D. (2021). Water and life: The medium is the message. *Journal of Molecular Evolution*, *89*(1), 2–11.

Fróna, D., Szenderák, J., & Harangi-Rákos, M. (2019). The challenge of feeding the world. *Sustainability*, *11*(20), 5816.

Fujisaki-Manome, A., Anderson, E. J., Kessler, J. A., Chu, P. Y., Wang, J., & Gronewold, A. D. (2020). Simulating impacts of precipitation on ice cover and surface water temperature across large lakes. *Journal of Geophysical Research: Oceans*, *125*(5), e2019JC015950.

Fuso Nerini, F., Sovacool, B., Hughes, N., Cozzi, L., Cosgrave, E., Howells, M., Tavoni, M., Tomei, J., Zerriffi, H., & Milligan, B. (2019). Connecting climate action with other Sustainable Development Goals. *Nature Sustainability*, *2*(8), 674–680.

Gift, R. A., Raimi, M., Owobi, O. E., Oluwakemi, R. M., Anu, B., & Funmilayo, A. A. (2020). Nigerians crying for availability of electricity and water: a key driver to life coping measures for deepening stay at home inclusion to slow covid-19 spread. *Gift RA, Olalekan RM, Owobi OE, Oluwakemi RM, Anu B, Funmilayo AA (2020). Nigerians Crying for Availability of Electricity and Water: A Key Driver to Life Coping Measures for Deepening Stay at Home Inclusion to Slow Covid-19 Spread. Open Access Journal Of*, *4*(3), 69–80.

Gopal, N., M. Raghavan, R., & PS, A. (2022). Traditional access rights and methods of fishing in inland water bodies: Are women slowly losing out? A study from Kerala, India. *Gender, Technology and Development*, 1–22.

Grasham, C. F., Korzenevica, M., & Charles, K. J. (2019). On considering climate resilience in urban water security: A review of the vulnerability of the urban poor in sub-Saharan Africa. *Wiley Interdisciplinary Reviews: Water*, *6*(3), e1344.

Grech-Madin, C., Döring, S., Kim, K., & Swain, A. (2018). Negotiating water across levels: A peace and conflict "Toolbox" for water diplomacy. *Journal of Hydrology*, *559*, 100–109.

Gulzar, A., Islam, T., Gulzar, R., & Hassan, T. (2021). Climate Change and Impacts of Extreme Events on Human Health: An Overview. *Indonesian Journal of Social and Environmental Issues (IJSEI)*, *2*(1), 68–77.

Hirwa, H., Zhang, Q., Li, F., Qiao, Y., Measho, S., Muhirwa, F., Xu, N., Tian, C., Cheng, H., & Chen, G. (2022). Water Accounting and Productivity Analysis to Improve Water Savings of Nile River Basin, East Africa: From Accountability to Sustainability. *Agronomy*, *12*(4), 818.

Hotez, P. J. (2021). *Preventing the next pandemic: Vaccine diplomacy in a time of anti-science*. Johns Hopkins University Press.

Howard, G., Calow, R., Macdonald, A., & Bartram, J. (2016). Climate change and water and sanitation: likely impacts and emerging trends for action. *Annual Review of Environment and Resources*, *41*, 253–276.

Junk, W. J., An, S., Finlayson, C. M., Gopal, B., Květ, J., Mitchell, S. A., Mitsch, W. J., & Robarts, R. D. (2013). Current state of knowledge regarding the world's wetlands and their future under global climate change: a synthesis. *Aquatic Sciences*, *75*(1), 151–167.

Karambelkar, S., & Gerlak, A. K. (2020). Collaborative Governance and Stakeholder Participation in The Colorado River Basin: An Examination of Patterns of Inclusion and Exclusion. *Nat. Resources J.*, *60*, 1.

Khalid, S., Khan, H. A., Arif, M., Altawaha, A. R., Adnan, M., Fahad, S., Shah, A., & Parmar, B. (2020). Effects of climate change on irrigation water quality. In *Environment, Climate, Plant and Vegetation Growth* (pp. 123–132). Springer.

Konapala, G., Mishra, A. K., Wada, Y., & Mann, M. E. (2020). Climate change will affect global water availability through compounding changes in seasonal precipitation and evaporation. *Nature Communications*, *11*(1), 1–10.

Kong, Y.-L., Anis-Syakira, J., Fun, W. H., Balqis-Ali, N. Z., Shakirah, M. S., & Sararaks, S. (2020). Socio-economic factors related to drinking water source and sanitation in Malaysia. *International Journal of Environmental Research and Public Health*, *17*(21), 7933.

Kozisek, F. (2020). Regulations for calcium, magnesium or hardness in drinking water in the European Union member states. *Regulatory Toxicology and Pharmacology*, *112*, 104589.

Kumar, R., Grover, A. S., & Wats, M. (2018). Assessment of water quality status of Lakes in Haryana, Idia. *International Journal of Recent Scientific Research*, *9*(7(B)), 27831–27835. https://doi.org/10.24327/IJRSR

Ligate, F., Ijumulana, J., Ahmad, A., Kimambo, V., Irunde, R., Mtamba, J. O., Mtalo, F., & Bhattacharya, P. (2021). Groundwater resources in the East African Rift Valley: Understanding the geogenic contamination and water quality challenges in Tanzania. *Scientific African*, e00831.

Lord, J., Thomas, A., Treat, N., Forkin, M., Bain, R., Dulac, P., Behroozi, C. H., Mamutov, T., Fongheiser, J., & Kobilansky, N. (2021). Global potential for harvesting drinking water from air using solar energy. *Nature*, *598*(7882), 611–617.

Mahmood, R., Jia, S., & Babel, M. S. (2016). Potential impacts of climate change on water resources in the Kunhar River Basin, Pakistan. *Water*, *8*(1), 23.

Maskey, G., Pandey, C. L., & Shrestha, K. K. (2020). Securing water in the rapidly urbanising global South: insights from critical analysis of 'sectoral policies' in Nepal. *New Angle: Nepal Journal of Social Science and Public Policy*, *6*(1), 9–31.

Mbaye, M. L., Hagemann, S., Haensler, A., Stacke, T., Gaye, A. T., & Afouda, A. (2015). Assessment of climate change impact on water resources in the Upper Senegal Basin (West Africa). *American Journal of Climate Change*, *4*(01), 77.

Mbura, K. S. (2018). Assessment of selected physico-chemical parameters of ground water in Tharaka Nithi County, Kenya. *Masters Degree Thesis. Kenyatta University, Kenya*.

McGregor, G. R., Ferro, C. A. T., & Stephenson, D. B. (2005). Projected changes in extreme weather and climate events in Europe. *Extreme Weather Events and Public Health Responses*, 13–23.

Milder, J. C., Majanen, T., & Scherr, S. J. (2011). *Performance and potential of conservation agriculture for climate change adaptation and mitigation in Sub-Saharan Africa*.

Muringai, R. T., Mafongoya, P. L., & Lottering, R. (2021). Climate change and variability impacts on sub-Saharan African fisheries: A Review. *Reviews in Fisheries Science & Aquaculture*, *29*(4), 706–720.

Ngene, B. U., Nwafor, C. O., Bamigboye, G. O., Ogbiye, A. S., Ogundare, J. O., & Akpan, V. E. (2021). Assessment of water resources development and exploitation in Nigeria: A review of integrated water resources management approach. *Heliyon*, *7*(1), e05955.

Núñez-Pons, L., Avila, C., Romano, G., Verde, C., & Giordano, D. (2018). UV-protective compounds in marine organisms from the Southern Ocean. *Marine Drugs*, *16*(9), 336.

Odokonyero, T., Guloba, M., & Kakuru, M. (2020). *Is Uganda's Middle Class Strong enough to Deliver National Aspirations?*

Ofori, S. A., Cobbina, S. J., & Obiri, S. (2021). Climate change, land, water, and food security: Perspectives From Sub-Saharan Africa. *Frontiers in Sustainable Food Systems*, *5*, 680924.

Ogunsanya Dr., P., Ogansanya, A., Mpagi, D., & Colton, T. (2014). The power of text messaging to reduce missed appointments among 12,000 clients at a comprehensive HIV clinic in Kampala, Uganda. *20th International AIDS Conference, July 20-25, 2014, Melbourne, Australia*.

Ojok, W., Wasswa, J., & Ntambi, E. (2017). Assessment of seasonal variation in water quality in river Rwizi using multivariate statistical techniques, Mbarara Municipality, Uganda. *Journal of Water Resource and Protection*, *9*(1), 83–97.

Olowe, V. (2021). Africa 2100: how to feed Nigeria in 2100 with 800 million inhabitants. *Organic Agriculture*, *11*(2), 199–208.

Ontumbi, G., Obando, J., & Ondieki, C. (2015). The influence of agricultural activities on the water quality of the river sosiani in uasin gishu county, Kenya. *International Journal of Research in Agricultural Sciences*, *2*(1), 2348–3997.

Onyena, A. P., & Sam, K. (2020). A review of the threat of oil exploitation to mangrove ecosystem: Insights from Niger Delta, Nigeria. *Global Ecology and Conservation*, *22*, e00961.

Otingi, V. O. (2019). *When the cup is half full: a plan for Improving Water and Sanitation Services in the Rural area of Kochia Ward, Homabay County in Kenya*.

Ouma, S. O., Ngeranwa, J. N., Juma, K. K., & Mburu, D. N. (2016). Seasonal variation of the physicochemical and bacteriological quality of water from five rural catchment areas of lake victoria basin in Kenya. *Journal of Environmental Analytical Chemistry*, *3*(170), 2380–2391.

Panhwar, A., Abro, R., Kandhro, A., Khaskheli, A. R., Jalbani, N., Gishkori, K. A., Mahar, A. M., & Qaisar, S. (2022). *Global Water Mapping, Requirements, and Concerns over Water Quality Shortages*.

Papadaskalopoulou, C., Katsou, E., Valta, K., Moustakas, K., Malamis, D., & Dodou, M. (2015). Review and assessment of the adaptive capacity of the water sector in Cyprus against climate change impacts on water availability. *Resources, Conservation and Recycling*, *105*, 95–112.

Pourghasemi, H. R., Gayen, A., Edalat, M., Zarafshar, M., & Tiefenbacher, J. P. (2020). Is multi-hazard mapping effective in assessing natural hazards and integrated watershed management? *Geoscience Frontiers*, *11*(4), 1203–1217.

Rani, A., Kumari, A., Singh, R. N., & Kumari, K. (2021). Climate-Smart Agriculture: An Integrated Approach for Attaining Agricultural Sustainability. In *Climate Change and Resilient Food Systems* (pp. 141–189). Springer.

Renzaho, A. M. N. (2020). The need for the right socio-economic and cultural fit in the COVID-19 response in sub-Saharan Africa: examining demographic, economic political, health, and socio-cultural differentials in COVID-19 morbidity and mortality. *International Journal of Environmental Research and Public Health*, *17*(10), 3445.

Saturday, A., Lyimo, T. J., Machiwa, J., & Pamba, S. (2021). Spatio-temporal variations in physicochemical water quality parameters of Lake Bunyonyi, Southwestern Uganda. *SN Applied Sciences*, *3*(7), 1–14.

Saturday, A., Lyimo, T. J., Machiwa, J., & Pamba, S. (2022). Modelling nitrogen transformation in the Lake Bunyonyi ecosystem, South-Western Uganda. *Applied Water Science*, *12*(8), 1–13.

Schmeier, S., & Vogel, B. (2018). Ensuring long-term cooperation over transboundary water resources through joint river basin management. In *Riverine ecosystem management* (pp. 347–370). Springer, Cham.

Schoeman, J. J. (1951). A geological reconnaissance of the country between Embu and Meru. *Rep. Geol. Surv. Kenya*, *17*, 57.

Shah, E., Liebrand, J., Vos, J., Veldwisch, G. J., & Boelens, R. (2018). The UN world water development report 2016, water and jobs: A critical review. *Development and Change*, *49*(2), 678–691.

Shyamala, R., Shanthi, M., & Lalitha, P. (2008). Physicochemical analysis of borewell water samples of Telungupalayam area in Coimbatore district, Tamilnadu, India. *E-Journal of Chemistry*, *5*(4), 924–929.

Sila, O. N. (2019). Physico-chemical and bacteriological quality of water sources in rural settings, a case study of Kenya, Africa. *Scientific African*, *2*, e00018.

Silva, B. B., Sales, B., Lanza, A. C., Heller, L., & Rezende, S. (2020). Water and sanitation are not gender-neutral: human rights in rural Brazilian communities. *Water Policy*, *22*(1), 102–120.

Soboksa, N. E., Gari, S. R., Hailu, A. B., & Alemu, B. M. (2020). Association between microbial water quality, sanitation and hygiene practices and childhood diarrhea in Kersa and Omo Nada districts of Jimma Zone, Ethiopia. *PloS One*, *15*(2), e0229303.

Solangi, G. S., Siyal, A. A., Babar, M. M., & Siyal, P. (2019). Groundwater quality evaluation using the water quality index (WQI), the synthetic pollution index (SPI), and geospatial tools: a case study of Sujawal district, Pakistan. *Human and Ecological Risk Assessment: An International Journal*.

Stip, C., Mao, Z., Bonzanigo, L., Browder, G., & Tracy, J. (2019). *Water Infrastructure Resilience*.

Stoerk, T., Wagner, G., & Ward, R. E. T. (2020). Policy brief—Recommendations for improving the treatment of risk and uncertainty in economic estimates of climate impacts in the sixth Intergovernmental Panel on Climate Change assessment report. *Review of Environmental Economics and Policy*.

Sun, F., & Carson, R. T. (2020). Coastal wetlands reduce property damage during tropical cyclones. *Proceedings of the National Academy of Sciences*, *117*(11), 5719–5725.

Thomas, K., Hardy, R. D., Lazrus, H., Mendez, M., Orlove, B., Rivera-Collazo, I., Roberts, J. T., Rockman, M., Warner, B. P., & Winthrop, R. (2019). Explaining differential vulnerability to climate change: A social science review. *Wiley Interdisciplinary Reviews: Climate Change*, *10*(2), e565.

Tian, J., Zhao, N., Samson, E. L., He, X., & Wang, S. (2017). Circular visualization of virtual-land flows along with international cereal trade. *Environment and Planning A: Economy and Space*, *49*(12), 2695–2697.

Tu, Y., Wang, R., Zhang, Y., & Wang, J. (2018). Progress and expectation of atmospheric water harvesting. *Joule*, *2*(8), 1452–1475.

Turyasingura, B., & Chavula, P. (2022). *Climate-Smart Agricultural Extension Service Innovation Approaches in Uganda*.

Turyasingura, B., Mwanjalolo, M., & Ayiga, N. (2022). Diversity at Landscape Level to Increase Resilience. A Review. *East African Journal of Environment and Natural Resources*, *5*(1), 174–181.

UNICEF, D. (2019). *Infant and young child feeding via https://data. unicef. org/topic/nutrition/infant-and-youngchild-feeding*. accessed 20/7.

Van Aalst, M. K. (2006). The impacts of climate change on the risk of natural disasters.

Disasters, *30*(1), 5–18.

Verlicchi, P., & Grillini, V. (2020). Surface water and groundwater quality in South Africa and mozambique—Analysis of the Most critical pollutants for drinking purposes and challenges in water treatment selection. *Water*, *12*(1), 305.

Vinçon-Leite, B., & Casenave, C. (2019). Modelling eutrophication in lake ecosystems: a review. *Science of the Total Environment*, *651*, 2985–3001.

Vyas, J. N., & Nath, S. (2021). The Role of Government and the Public in Water Resource Management in India. *Pollutants and Water Management: Resources, Strategies and Scarcity*, 399–415.

Waithaka, A., Murimi, K. S., & Obiero, K. (2020). Effects of Temporal Rainfall Variability on Water Quality of River Ruiru, Kiambu County, Kenya. *ChemSearch Journal*, *11*(1), 59–65.

Walekhwa, A. W., Ntaro, M., Kawungezi, P., Nimusiima, E., Achangwa, C., Musoke, D., & Mulogo, E. M. (2022). Water quality of improved water sources and associated factors in Kibuku District, Eastern Uganda. *Sustainable Water Resources Management*, *8*(2), 1–13.

Wang, K., Davies, E. G. R., & Liu, J. (2019). Integrated water resources management and modeling: A case study of Bow river basin, Canada. *Journal of Cleaner Production*, *240*, 118242.

Wijkman, A., & Timberlake, L. (2021). *Natural disasters: acts of God or acts of man?* Routledge.

Wilbera, M., Janea, Y., Morganb, A., & Kasangaki, A. (2020). *Heavy metal pollution in the main rivers of Rwenzori region, Kasese district south-western Uganda*.

Yahaya, M., Damoah-Afari, P., Mensah, C., Kumi, N., Prempeh, N. A., & Anima, P. A. (2022). Climate change adaptation strategies of smallholder farmers in the Mamprugu-moaduri district of Ghana. *Journal of Energy and Natural Resource Management*, *8*(1), 86–94.

Zarei, Z., Karami, E., & Keshavarz, M. (2020). Co-production of knowledge and adaptation to water scarcity in developing countries. *Journal of Environmental Management*, *262*, 110283.

Zhang, Y., Bian, T., Jiang, R., Zhang, Y., Zheng, X., & Li, Z. (2021). Bionic chitosan-carbon imprinted aerogel for high selective recovery of Gd (III) from end-of-life rare earth productions. *Journal of Hazardous Materials*, *407*, 124347.

Zimmermann, M., & Neu, F. (2022). Social–Ecological Impact Assessment and Success Factors of a Water Reuse System for Irrigation Purposes in Central Northern Namibia. *Water*, *14*(15), 2381.

Zougmoré, R. B., Partey, S. T., Ouédraogo, M., Torquebiau, E., & Campbell, B. M. (2018). Facing climate variability in sub-Saharan Africa: analysis of climate-smart agriculture opportunities to manage climate-related risks. *Cahiers Agricultures (TSI)*, *27*(3), 1–9.