FEDERAL UNIVERSITY OF TECHNOLOGY, AKURE
JOURNAL OF ENGINEERING AND ENGINEERING TECHNOLOGY

OVERVIEW OF THE NEXUS BETWEEN CLIMATE CHANGE AND POTABLE WATER IN NIGERIA: CHALLENGES AND MITIGATION STRATEGIES

[1]Rotimi, I.M., [1,*]Ajibade, T.F., [2]Femi-Fadeyi, O.O., [1]Ajibade, F.O. and [1]Adewumi, J.R.

[1] Department of Civil and Environmental Engineering, Federal University of Technology, Akure, Nigeria
[2] Department of Civil Engineering, Federal Polytechnic Ile-Oluji, Ondo State, Nigeria.

*Corresponding author: tfotun@futa.edu.ng

Rotimi, I.M., Ajibade, T.F., Femi-Fadeyi, O.O., Ajibade, F.O. and Adewumi, J.R. (2026): Overview of the Nexus Between Climate Change and Potable Water in Nigeria: Challenges and Mitigation Strategies. FUTA Journal of Engineering and Engineering Technology 20(special), 182-197

Received Date: 15.01.2026 **Accepted Date: 11.03.2026**

Abstract
The current state of climate change presents a serious threat to the supply of clean water sources throughout the world. Moreover, the adverse effects of climate change pose a potential risk not only for the availability but also for the quality of drinking water. The aim of this paper is to conduct a research on the issue of the interrelation between climate change and the accessibility of drinking water under the conditions of changing weather. This research analyzes the problem from the perspective of the current developments within Nigeria, where the effects of climate change are highly detrimental due to the insufficiency of water management infrastructure. In addition, the research provides insights into the increasing rate of occurrence of water-borne illnesses as the consequences of climate change. Based on the results of the analysis of the existing research on the topic, the importance of implementing climate-resilient technologies is emphasized

Keywords: *Climate Change; Potable Water Security; Water Resource Management; Adaptation Strategies; Nigeria*

Introduction

Climate change represents a severe challenge to the global environment and human societies. Apart from having an ecological impact, the phenomenon poses serious socio-economic risks to different aspects of human life, especially with regards to the issues of the growing water demand despite various global mitigation efforts on the international, state and sub-state levels (Abbas et al., 2022). The negative consequences of climate change have already been observed in terms of lower food security and decreased access to clean water in Nigeria (Anabaraonye et al, 2021; Niyi-Odumosu et al., 2025).

An essential relationship exists between the processes of climate change and the accessibility of drinking water, which is defined as clean water that is considered appropriate for human use and consumption and is derived from surface and underground water resources (Omokaro et al., 2024). Indeed, the negative effects of climate change exacerbate the challenge of having enough potable water in Nigeria. According to the projections provided by (Ogunbode et al., 2025), the climate effects will pose a significant obstacle to obtaining clean water by 2030, which will make the achievement of SDG 6 problematic.

Insufficient access to potable water increases the prevalence of waterborne and vector-borne diseases such as diarrhea, cholera, and malaria, among others (Sogbanmu et al., 2020; Agbasi et al., 2024; Ayejoto et al., 2024). These adverse health outcomes also result in an economic burden because they increase the pressure on the healthcare system of Nigeria. Shehu & Nazim (2022) emphasize the high economic costs of climate-related illnesses. For instance, a study carried out by the Johns Hopkins Bloomberg School of Public Health revealed that annual economic losses in Nigeria due to cholera total approximately $271 million (JHU, 2022).

Nigeria is a country with abundant water resources, amounting to 286.2 km³ of water per year (Ngene et al., 2021). However, the uneven geographical

distribution and the marked seasonality of these water resources create a serious impediment to achieving the SDG 6. In addition, the ineffective water management caused by institutional failure and conflict among different stakeholders complicates the problem of accessing water further.

Considering these difficulties, the present literature review aims to identify the effects of climate change on potable water supply in Nigeria. It further proposes targeted, actionable strategies to mitigate these impacts, with particular emphasis on strengthening governance frameworks and promoting equitable utilization of the nation's abundant water resources

Global Attempts at Climate Change Mitigation

A staggering 3.6 billion people are currently vulnerable to climate change impacts from droughts, floods, storms, heat stress and food insecurity (Paz *et al*., 2024; Haber *et al.,* 2025). This number will only continue to rise as long as global temperatures keep climbing. The G7 summit made the global governance of climate change. This effort metamorphosed through three stages, the first environment regime was between 1979 to 1989; that strategized on leadership of an increasingly effective inclusive environment. The second phase was witnessed between 1992 to 2004; which harped on deference to the UN's ineffective, selective, development-first regime and a return to an increasingly effective, G20-supported, inclusive, environment-first regime from 2005 to 2015 (Kirton *et al*., 2018). This attempt failed due to non-compliance and accountability. Furthermore, (Hickmann *et al*., 2021) pointed that in the past few years, the United Nations Framework Convention on Climate Change Secretariat has expanded its original spectrum of activity by engaging different sub-national and non-state actors into a policy dialogue which is important to achieve progress in the international climate negotiations. The UN went further to institute the UN Water Action Decade (2018-2028) to support the achievement of water-related SDGs to avert the global water crises due to climate change. The EU is also playing a leading role in international climate negotiations. Conferences such as the 26th United Nations Climate Change Conference of the Parties (COP26) in Glasgow in 2021 demonstrated the strive for action to combat climate change and help vulnerable nations. The Intergovernmental Panel on Climate Change reports (IPCC) highlights a number of climate change impacts that could be avoided by limiting global warming to 1.5°C which by 2100 will reduce global sea level rise by 10 cm lower compared with 2°C (IPCC, 2018). Africa is ascribed as the most vulnerable continent to climate change impacts under all climate scenarios (AFDB, 2025). The African Group of Negotiators (AGN) has become a much more significant bargaining coalition in the global climate change negotiations (Roger, C., and Belliethathan, 2016). Many countries are developing their own plans to adapt to the expected impacts (Okon *et al*., 2021). For instance, Olujobi and Odogbo (2024) expressed that the National Climate Change Policy for Nigeria 2021-2030 is to assist the country in hugely reducing greenhouse gas (GHG) emissions and mitigate the socio-economic impacts of adverse effects of climatic change including potable water availability and. However, the plethora of legislation enacted to regulate climate change as reducing the potential adverse effects of climate change most especially on the country's potable water sources for citizens' wellbeing and national development is not effective (Daudu and Idehen, 2024).

3. Sources of potable water in Nigeria

Groundwater and surface water constitute the two principal categories of natural water resources, serving as the primary sources of water for human and environmental needs worldwide. These resources are vital for sustaining life, agriculture, industry, and ecosystems. In Nigeria, the potential of surface and groundwater resources is considerable. Omokaro *et al*., (2024) estimates that the country possesses approximately 267.3 billion cubic meters of surface water and 51.9 billion cubic meters of groundwater. Despite the abundant water resources available in the country, the sources of surface and ground water represent the most convenient ways to obtain water in the context of developing countries such as Nigeria (Adelagun et al., 2021).

Climate change has several direct and indirect impacts on groundwater and surface water resources. First, it affects their recharging processes as it influences such hydrological processes as evapotranspiration and precipitation. Second, climate change has indirect effects on groundwater as it promotes activities that result in deforestation and excessive water withdrawal, which adversely impacts the replenishment of groundwater resources

(Swain et al., 2022; Mishra, 2023; Rotimi et al., 2024). The surface water supply can also be negatively affected by climatic change as temperature variations, increased evaporation, precipitation rates, and runoff volume can alter the water supply (Mafimisebi and Martins (2024)). A number of studies in Nigeria have explored the usage of ground water and surface water as drinking water resources. Namadi et al., (2024), who conducted a research in Zuru – a town situated in the southern part of Kebbi State, found out that both groundwater and surface water were used by local people. Nevertheless, the authors concluded that the former was preferable as the water quality exceeded WHO standards. A similar conclusion was reached in another study carried out by Raimi et al., (2018), where the water sources used in the Central District of Bayelsa State were analyzed. They found out that rain water (61%), river (13%), pipe-borne water (33%), boreholes (91%) and hand-dug wells (3%) represented the main sources. Moreover, the authors mentioned that these water sourcing patterns were characteristic of other regions in the area.

In Edo State, in the Ikpoba Okha Local Government Area, Omoregie et al., (2025) discovered that approximately 83.6% of local households relied on boreholes to meet their domestic needs. The reason behind the prevalence of this source was that the area possessed a unique geological composition that allowed the existence of ground water. In their research in the Akure North Local Government Area of Ondo State, Famose and Olajuyigbe (2023) revealed that the majority of inhabitants used protected hand-dug wells as their water source. Nevertheless, as the authors note, these wells were rather unreliable as they lacked water during the dry periods.

In addition to the conventional sources of water, many communities across Nigeria tend to use commercially packaged water. Indeed, the increasing number of businesses treat the water from various sources and pack it in sachets and plastic bottles, providing people with an option to buy water. This tendency is justified by affordability and easy access to such bottled water (Olanipekun et al., 2024; Oniyefu et al., 2024).

4. Climate Change Factors and water availability in Nigeria

Climate change is usually manifested through such phenomena as rising global temperatures, changes in rainfall, rising sea level, and desertification (Table 1). Currently, the climate of Nigeria features rising temperatures as a consequence of global warming, which is mostly connected to the accumulation of greenhouse gases (GHGs) such as carbon dioxide (CO_2) and methane (CH_4). These GHGs result from industrial activities and deforestation. As a consequence of their constant emission, the climate changes in terms of temperature and other crucial parameters (Ayejoto et al., 023).

While Agbasi *et al*., (2023) observed a moderate correlation between maximum temperature and annual water supply, more conclusive findings were reported by Abaje & Oladipo (2019). Their longitudinal study analyzed temperature and rainfall data from 1971 to 2016 across three meteorological stations situated along a geographic transect in Kaduna State. The results revealed a significant temperature rise of 1.03°C within the study period, coupled with an acute shortage of water supply, thereby reinforcing the direct impact of rising temperatures on water availability. In addition to rising temperatures, climate change has also led to increased variability and instability in rainfall distribution across Nigeria. Both northern and southern regions have experienced irregular and unpredictable rainfall patterns, which have far-reaching implications for freshwater availability. (Udeh *et al*., 2025) emphasized that high temperatures further complicate water quality by increasing the solubility of minerals and other substances in water bodies, which can alter their chemical composition and potentially make them unsafe for consumption.

Omopekunola *et al*., (2023) examined precipitation variability across Northeast Nigeria from 1991 to 2021 using ECMWF ERA5 reanalysis datasets. According to them, there are negative rainfall trends in cities such as Jalingo, Yola, and Bauchi, which vary in range from –0.0153 mm/year to –0.247 mm/year. At the same time, positive rainfall changes were observed in such cities as Maiduguri, Yobe, and Gombe and ranged between 0.043 mm/year and 0.243 mm/year. Such geographic differences reveal that the effect of climate change on rainfall patterns varies widely. Another study carried out by Salami et al., (2025) based on data collected by the Nigerian Meteorological Agency (NiMet) also demonstrates regional disparity in the precipitation pattern. Indeed, Tropical Wet (Mangrove and Swamp) region has the greatest mean annual rainfall (>2,300

mm), whereas the Sahel Savannah region has the lowest rainfall (<450 mm). Moreover, according to the researchers' projections, there will be a decrease in rainfall in the next ten years (-0.057 mm/decade).

One of the most devastating outcomes of climate change is the phenomenon of drought. As stated by Engelman et al., (2025), combined with geopolitical risks, drought leads to the shortage of water. Indeed, the prolonged droughts in Nigeria cause desertification, which results in the spreading of sand dunes, lack of surface water, and siltation and negatively impacts water quality (Udeh et al., (2025). Drought and desertification represent significant environmental and socio-economic threats as they account for approximately 38% of Nigeria's territory (Lawal & Gbadegesin, 2022; Yahaya et al., 2024).

Floodings represent yet another adverse outcome of climate change with a strong effect on the availability of water sources. According to Omokaro et al., (2024), about 20% of Nigeria's population is prone to flood. These populations are located mainly in the lowland and riverine areas that include downstream parts of the Niger, Benue, Cross River and Lagos State. Climate predictions suggest the further decline in the level of precipitation over northern territories and increasing number of intense floods in the south. Floodings obstruct access to conventional surface water such as rivers, streams, and lakes as well as groundwater, deteriorating their quality (Akinluyi et al., (2022). In the course of their analysis of the physicochemical properties of ground water in a coastal community of Bayelsa State affected by flooding, the researchers found alarming results. According to their findings, 43.34% of the studied water samples had poor water quality, and 5.44% – very poor. In addition, the researchers noted that 3.33% of boreholes had unsuitable water for consumption, and thus, needed special processing.

The process of rising sea level that follows global warming and climate change affects the coasts of Nigeria and contributes to flooding. As a result, the region faces serious consequences such as coastal erosion, wetland inundation and, finally, intrusion of saltwater to the freshwater aquifers. According to Olorunlana (2024), such consequences lead to water quality degradation and to an increased need for expensive desalination or filtration technology. In turn, Agbasi et al., (2025) conducted a study on the environmental and water quality impacts of floodwater intrusion to boreholes and domestic wells and found that the quality of ground water had been severely deteriorated. In addition, Meye et al., (2025) note the vulnerability of groundwater to microorganism contamination due to the process of eluviation.

Table 1: Climate change factors and evidences from Nigeria.

Climate Change Factor	Impact on Water Availability	Reference
Rising Temperatures	Increased evaporation Reduced water levels impaired water quality	Ayejoto *et al*., 2023 Agbasi *et al*., 2023
Changes in Rainfall Patterns	Prolonged droughts Intense rainfall causing flooding and Inconsistent rainfall patterns	Abel & Amachigh 2024 Salami *et al*., 2025
Desertification	Reduced groundwater recharge Lower Water Quality Water scarcity	Akinluyi et al., 2022 Ladan et al., 2024
Sea Level Rise	Saltwater intrusion Contamination of groundwater High cost of water treatment	Olorunlana, 2024 Agbasi *et al*., 2025 Meye *et al*., 2025

State of Accessibility to Clean Water in Nigeria

State of Accessibility to Clean Water in Nigeria Access to potable water is universally regarded as a basic human right, and everyone has the right to enjoy adequate and safe water without being discriminated against based on gender, age, social or economic background. Nonetheless, the present global situation indicates that access to clean water is quite difficult because millions of people across the globe do not have access to this basic human need. It is evident that this challenge is mostly prevalent in developing countries such as Nigeria.

For instance, according to UN (2019), Nigeria is considered one of the countries with poor access to potable water. Shehu & Nazim (2022) supported this view, adding that wide accessibility to clean water remains to be another problem experienced in Nigeria.

The already challenging water situation is now further aggravated by climate change since it causes water insecurity through irregular rainfalls, heat wave occurrences, floods, among others. In Ado-Odo Ota, Ogun State, for example, most of the residents depend entirely on the private sources of water because of the poor qualities of the public supplies in the locality, according to Emenike et al., (2017). Similar trends have been observed in other states, whereby the access to the potable water is through individual means as opposed to relying on the municipal water facilities. In the same way, Solihu & Bilewu (2021) indicated that in Oyo State, the accessibility to the clean water depends on personal initiatives. Therefore, the growing reliance on private measures indicates that access to safe drinking water in Nigeria remains to be a huge concern.

In the rural communities of northern Nigeria, water scarcity is also quite a challenge for the inhabitants. For instance, in his study, Sawyerr et al., (2024) reported that the rural communities within the north are currently facing difficulties in accessing potable water due to either poor or non-functioning water facilities in such regions. There are also differences in access to improved water sources among different regions in Nigeria. Adelagun et al., (2021) conducted a geographical assessment on the improvement in drinking water accessibility among different geopolitical zones within the country. In the North Central, North Eastern, and North Western zones, the respective proportions are 52.2%, 27.3%, and 42.5%. Conversely, the South West and South East zones have higher percentages of access at 72.27% and 54.1%, respectively. Hence, there are disparities among the geographical regions of the country in terms of water accessibility.

This inequality in access to clean water is attributed to the rural-urban divide by scholars in this field. Nonetheless, in the case of Nigeria, Adedotun et al., (2024) argued that socioeconomic factors such as household income, level of educational attainment, infrastructural development, and governmental interest are the main reasons for the difference. Based on this analysis, it becomes clear that there are several reasons for the lack of potable water in Nigeria. Therefore, there is a need for concerted efforts from the government and other relevant parties to come up with practical policies to deal with the current water problem. Besides expanding the infrastructural coverage of water facilities in rural communities, upgrading and repairing existing and obsolete water supplies in the whole country is a priority.

Effect of Climate Change on water infrastructure and supply systems in Nigeria

Climate change is anticipated to bring about a number of adverse effects on the water infrastructure systems. Fan et al., (2023) suggested that climate change has several negative impacts on the sustainability and resilience of the water infrastructure systems. In Nigeria, water infrastructure management is conducted through a collaborative approach among the Federal Ministry of Water Resources (FMWR), National Water Resources Institute (NWRI), River Basin Development Authorities (RBDAs), the Nigeria Hydrological Services Agency (NIHSA), and Nigeria Integrated Water Resources Management Commission (NIWRMC). All these institutions collaborate with state and local government agencies to formulate and implement water policies as well as ensuring provision of service to different communities. However, the success of these policies and activities is hindered by several challenges which include, but not limited to, technical, institutional, social, financial, political, and environmental issues. In addition, the increasing influence of climate change poses some additional obstacles to overcoming the problems of water management and failing infrastructure in Nigeria, according to Adeoti et al., (2023).

There are many facilities that form part of water infrastructure system in Nigeria. The dams are considered to be very important in the country because of the crucial tasks such as bulk water supply, hydropower production, and flood mitigation among others. Generally, the dams constructed after 1960 have mainly served the purpose of providing water for domestic uses, not irrigation. However, the last few decades have seen the construction of multipurpose dams whose purpose is to serve as the sources of water supply, irrigation, power production, and ecosystem services, Adeniran et al., (2021). Unfortunately, these facilities have become more vulnerable to climate change. Kainji Dam in Nigeria serves as an example of such facilities. This is Nigeria's oldest and largest hydroelectric dam located on the river Niger. Machina and Sharma (2017) conducted a comprehensive study concerning rainfall, temperature, power generation, reservoir inflow, average turbine discharge, and storage capacity of the Kainji Hydropower Station. According to their findings, the trends in temperature are rising whereas rainfall amounts are declining, indicating climatic change in the region. This has caused the decrease in reservoir inflow and storage capacity of

the dam, thereby affecting its power generation capabilities. Therefore, there is a need to develop and incorporate resilient water infrastructure management mechanisms to cope with climate change in Nigeria.

Water infrastructures at the state and local government levels are mostly represented by boreholes, which are established by State Ministries of Water Resources in places where municipal water supply is not available. Over time, however, poor maintenance, lack of funds, and other governance issues have affected the provision of potable water through these institutions. Due to this, the majority of the inhabitants in the community have resorted to private measures including drilling of boreholes to meet their water requirements. According to Okhuebor and Izevbuwa (2020); Ojo et al., 2025, a lot of households drill their own boreholes to ensure their accessibility to clean water. On the effect of climate change on boreholes, Aribisala et al., (2015) found that in the Ondo State, there was no climatic impact on boreholes based on the information collected for this study. Fadare & Okonofua (2024) indicated that climatic changes have influenced boreholes' yield in Benin City. They reported that climatic changes in the area led to the rise of the ground-water level from 136.80 meters to 81.10 meters. In turn, this implies changes in the water table in the area as a result of climate change.

Water distribution infrastructures are crucial for the reliable delivery of water sources to people. In Nigeria, however, most of the piping infrastructures are poorly maintained or nonexistent. Fan et al., (2023); Wols & Van Thienen (2016) noted that piping infrastructure experiences structural integrity issues due to the increased temperature which makes them burst or leak, leading to inconsistency in water pressures. In addition, climate-induced temperature changes have a negative impact on the structural strength of pipe material and can contaminate the water inside. To make things better, it is important to protect water infrastructure from the negative consequences of climate change. Every aspect of the water supply needs to be taken care of.

Climate Change Impacts and Diseases Outbreak in Nigeria

It goes without saying that the availability and quality of the country's water resources for consumption have continuously declined due to water scarcity and pollution by multiple contaminants. Climate change adds up to this issue, being one of the main environmental factors having a negative impact on water availability, quality, and use. This climatic phenomenon is responsible for the increase in occurrence of different diseases associated with contaminated water sources. Some of the life-threatening conditions are cholera, typhoid fever, diarrhea, schistosomiasis, salmonellosis, dysentery, and giardiasis. All these illnesses are associated with drinking water contaminated with pathogens.

Microclimatic conditions have a significant effect on the survival of different waterborne pathogens because they influence the reproduction and dissemination of these microorganisms. According to Ahmed (2020), fluctuations in precipitation and temperature can be used as predictors of the occurrence of waterborne infections because they serve as the triggers for the outbreaks of these pathogens. The presence and stability of Escherichia coli, Salmonella, Shigella, Cryptosporidium, Campylobacter, and other bacteria causing waterborne diseases has risen as a result of climate change, Noureen et al., 2022; Adabara et al., 2024; Bello et al., 2024. Temperature influences the reproduction rate of different pathogens whereas precipitation contributes to their dissemination in the environment through rain.

One of the examples of the influence of climate change on water resources and subsequent public health can be traced in Borno State, Northern Nigeria. Extreme rainfall has resulted in severe floods, a phenomenon that is believed to be caused by climate change in the region. The consequence of these natural disasters has been the formation of many water ponds in the camps of internally displaced persons. As a result of flooding, Aborode et al., (2025) found that IDPs face serious problems related to the outbreak of waterborne diseases because of unsanitary conditions in their temporary homes. Thus, floods increase the risk of such diseases as cholera and typhoid. Moreover, they are at risk of contracting vector-borne diseases such as malaria because of the favorable environment created in their camps.

In another study conducted by Agbasi et al., (2023), it was stated that climate change affects the physico-chemical properties of surface and groundwater resources, including such parameters as pH, turbidity, conductivity, and heavy metals and microbial loads. Besides, there are significant fluctuations in precipitation and temperature that contribute to contamination of water sources with different hazardous substances. In turn, these phenomena act as a predictor of diseases that can occur as a result of contaminated water. This indicates that accurate climate monitoring is needed to predict climatic anomalies. In addition, it would be helpful to develop surveillance systems which can track changes in climatic and environmental parameters and link them to water quality and occurrence of certain illnesses. In conclusion, climate-informed public health measures are

necessary to control the occurrence of waterborne diseases.

Recent Projections of Water Availability by Climate Models

Climate and hydrological models play a significant role in studying the impacts of climate change on water resources, including the issues related to water availability and quality. Through these models, researchers and policymakers are able to conduct simulations of future climatic conditions to determine the impacts of these events and formulate corresponding adaptation policies. Economic, environmental, and social factors can help assess the possible consequences of particular policies or environmental change, Jobe (2025). Climate models have been used in Nigeria to determine how climate change will affect water resources. According to Shiru et al., (2021), General Circulation Models (GCMs) have revealed the decrease in precipitation and water storage during the rainy season and increase during the dry season. In another simulation study on the streamflow response of the Ala River in Akure, Nigeria, (Akinwumi et al., 2021) concluded that due to climate change and its impact on precipitation in the region, the increase in surface runoffs will be persistent. Hence, it will be important to adopt appropriate water management policies in this region to mitigate the adverse impacts of climate change.

Kanoma & Abdulkadir (2021) developed Regional Climate Models (RCMs) with 0.5° × 0.5° spatial resolution for projecting climatic changes in Gusau, Zamfara State, Nigeria. The findings revealed an increase in temperature by 1–3°C by 2040, 3°C by 2070, and 2–5°C by 2100. There would be also increases in rainfall by 6.7–20% by 2040, 10-20% by 2070, and 10-30% by 2100. These climatic changes are likely to lead to the increase in surface runoffs and aquifer recharge. On the contrary, water quality in such cases may be negatively affected by high surface runoff and flooding. Therefore, investment in stormwater storage facilities for government agencies and large-scale water consumers is recommended in this area. Another similar study was conducted by Animashaun et al., (2023), where the Soil and Water Assessment Tool (SWAT), forced by Coordinated Regional Climate Downscaling Experiment (CORDEX_RCMs), was used for analyzing climate-induced changes. Simulations have been conducted during 1971-2000 and 2100 in four global warming levels (GWLs). It was projected that the increase in annual rainfall would be accompanied by runoff, evapotranspiration, and potential evapotranspiration. The study also projected the water shortage during the beginning of rainy season which indicates the importance of having sufficient water storage. Besides, Olasehinde et al., (2024) used the dynamically downscaled GCMs from Coupled Model Intercomparison Project Phase 5 (CMIP5). This model allowed for simulating the impact of climate change during 2100 using multimodal ensemble approaches, which is very valuable to provide accurate forecasts of future climatic conditions.

In addition to surface water models, groundwater models are also used to project climate changes in relation to water resources. In order to identify the patterns of groundwater contamination risk in Nigeria, Nwozor et al., (2025) applied GIS-based hydrological modeling. The study emphasized the importance of protecting recharge zones to ensure the long-term sustainability of groundwater resources for potable use. Despite the progress made with traditional modeling techniques, one significant gap remains: the limited integration of machine learning algorithms into climate and hydrological modeling efforts in Nigeria. Advanced machine learning techniques offer the potential to enhance model accuracy, uncover hidden patterns in large climate datasets, and support the development of more responsive and adaptive water resource management strategies. Their integration could greatly improve the predictive capacity of existing models and inform more strategic, real-time interventions to safeguard potable water availability under evolving climate conditions. In summary, climate and hydrological models are vital for anticipating climate change impacts on Nigeria's water systems. However, their full potential, particularly in the area of machine learning, has yet to be realized. Expanding the use of these advanced tools will be critical in developing resilient water supply systems capable of adapting to the uncertainties of a changing climate.

Specific Strategies for mitigating the impacts on Water Availability in Nigeria

Integrated Water Resources Management (IWRM) was officially adopted in Nigeria in 2004 as part of the National Water Resources Policy. The IWRM framework was designed to promote a sustainable, coordinated, and holistic approach to water resource management by balancing the social, economic, and environmental dimensions of water utilization. The ultimate goal is to ensure equitable and efficient use of water resources while preserving them for future generations. However, despite its adoption, the practical implementation of IWRM across Nigeria has faced several setbacks. Chief among these is the absence of a comprehensive legal and institutional framework capable of enforcing

IWRM principles at a national scale, as the required legislative approval remains pending. In addition to legislative gaps, climate change and administrative inefficiencies have been identified as critical obstacles hindering the successful implementation of IWRM principles in the country (Martins *et al*., 2025). This review, therefore, explores innovative and actionable strategies aimed at strengthening water resource management systems in Nigeria, particularly in light of the increasing challenges posed by climate change. The objective is to mitigate its adverse impacts on potable water availability in both rural and urban areas across the nation (Table 2). Among the key strategies proposed are: rainwater harvesting (RWH), seawater desalination, wastewater recycling, and sustainable groundwater management.

Table 2: Specific strategies for mitigating climate change impart on water availability

Strategy	**Implementation Challenges**	**Modifications for advancement**	**Reference**
Rainwater Harvesting	Storage infrastructure Water quality concerns	Smart Control System Infusion of advanced filtration system	Zhang *et al.,* 2019 Wartalska *et al*., 2024
Desalination	High energy cost	Green Desalination	Hindiyeh *et al*., 2021 Khondoker *et al*., 2023.
Water Recycling	Public perception Secondary Pollutants	Constructed wetland Electrocoagulation coupled system	Bao *et al*., 2023 Ajibade *et al*., 2023
Sustainable Groundwater Management	Over-extraction Regulation enforcement	Artificial Intelligence (AI) aided remote sensing technologies	Singh & Sharma (2023) Sadeghi-Jahani *et al*., (2024)

Rainwater Harvesting (RWH) emerges as a viable and adaptive strategy that enables the collection and reuse of rainwater, particularly for domestic consumption. As a decentralized and sustainable water supply option, RWH is highly effective in mitigating water scarcity, reducing dependency on conventional water sources, and improving climate resilience. Performance indices for RWH systems such as water saving efficiency, reliability, and stormwater capture efficiency, demonstrate the technique's potential for broad application. However, given the expected changes in rainfall patterns due to climate change, there is a pressing need to scale up RWH systems as a life-saving intervention (Zhang *et al*., 2019; Wartalska *et al*., 2024). Wartalska *et al*., 2024 further noted that RWH also reduces flood risks and prevents surface water contamination. In arid and drought-prone regions, RWH provides an alternative source of potable water and helps to buffer communities against the effects of prolonged dry seasons (Kuzucu & Gökçen, 2024). The practice of harvesting rainwater dates back to centuries ago. With innovations of technology, however, rainwater harvesting today is not only possible but highly effective. Thanks to technological advancement in terms of smart technologies, sustainable construction materials, architectural designs, and water filtration techniques, it is possible to decontaminate and purify collected rainwater, making it safe for drinking.

One innovative way of securing high-quality potable water from the adverse effects of climate change is through seawater desalination. Seawater desalination is emerging as an important option in the context of increasing water scarcity. This

method involves removing contaminants such as salts and other ions from seawater, rendering it suitable for consumption. Desalination is particularly relevant in light of rising temperatures, salt intrusions into freshwater sources and sea level rise. New technologies for desalination are increasingly geared towards sustainability, commonly referred to as "greener desalination" (Hindiyeh et al., 2021; Khondoker et al., 2023). The establishment of strategically-placed desalination facilities in coastal areas would serve to reduce the pressure on inland water resources, cater to increased urban population demand and mitigate the impact of rising sea levels and coastal erosion. The major limitation of conventional desalination technologies is the amount of energy used in the process. To make these technologies viable and cost-effective, renewable energy sources must be used.

Recycling and reusing treated sewage and industrial effluents also plays an important role in water security. This practice is consistent with UN SDG 6, Target 6.3, aimed at reducing untreated wastewater by half and encouraging the safe reuse of water in households. Recycling of wastewater reduces freshwater demand and mitigates environmental pollution, helping to sustain water availability during times of drought. However, public opinion and lack of public awareness stand as major obstacles to wastewater reuse in Nigeria. People remain hesitant of using recycled water for fear of health hazards that may result from secondary pollutants in the water (Alade, 2019; Rotimi et al., 2021). Fortunately, significant progress is being made towards the development of technologies capable of eliminating these contaminants from treated wastewater. In particular, research is showing remarkable success in employing constructed wetlands and electrocoagulation coupled systems as the most efficient ways to treat domestic and industrial wastewaters (Ajibade et al., 2023; Phu et al., 2025; Ajibade et al., 2021; Mmonwuba et al., 2024). Groundwater management is yet another critical component of an effective climate-resilient water strategy. Groundwater is the most important source of potable water, especially in rural and semi-urban settings. Overextraction and groundwater contamination are some of the main problems affecting groundwater availability in the region. However, groundwater management strategies, such as artificial recharge and banking, along with protection of recharge zones (Singh & Sharma, 2023; Sadeghi-Jahani et al., 2024; Sadath et al., 2021). Additionally, technological advancement in the field of Artificial Intelligence (AI), geographic information systems (GIS) and remote sensing has transformed the way we manage groundwater in the region. These technologies allow water managers to assess groundwater contamination, replenish depleted groundwater aquifers, and predict their dynamics, thereby contributing to the sustainability of potable water supplies.

Overall, the key to securing a sustainable water supply amidst climate-induced water stress in Nigeria relies in embracing technology-driven and environmentally friendly methods.

Future Research Direction

To effectively mitigate the adverse impacts of climate change on the availability and accessibility of potable water in Nigeria, future research should embrace a multi-disciplinary and holistic approach. One research focus should be the resilience of existing water infrastructure such as dams, boreholes, pipeline networks, and facilities for water treatment and processing in case of severe weather phenomena. An assessment of the performance and resilience of these facilities would contribute to the development of appropriate climate resilient water management strategies. Secondly, nature-based solutions should also be considered in the search for long-term sustainable strategies for potable water provision. In particular, research needs to be done on the potential of restoring watersheds, conserving wetlands and managing aquifers as sustainable sources of potable water. These ecosystem-based measures would not only help recharge aquifers and improve water quality but would also reduce runoff and restore wildlife. They would further contribute to the community's resilience against climate change. Moreover, future research should also focus on socioeconomic studies, including an examination of the complex interactions between climate change and potable water in rural and urban settings. Such research would investigate topics such as the influence of water scarcity on migration patterns and urbanization and the disproportionate effect of water scarcity on the vulnerable populations in the

region. This area of study would help develop appropriate adaptation strategies that are socially inclusive and environmentally sustainable. Finally, the current state of water governance in Nigeria vis-a-vis international climate and sustainability agreements, such as the Paris agreement and UN SDGs, needs to be analysed. It is necessary to determine the strengths and weaknesses of the current legal and institutional arrangements in the context of climate change, in the context of achieving sustainability.

Conclusion

To sum up, climate change emerges as a major and increasing threat to the availability, accessibility, and quality of potable water in Nigeria. Despite the natural endowments of water in the country, including surface and groundwater reserves, the ongoing process of climate change and the negative effects associated with it pose a threat to water security. Rising temperatures, changing rainfall patterns, desertification, sea level rise and frequent droughts and flooding adversely affect the quality and accessibility of drinking water for millions of people. However, among these risks lies the opportunity for transformation. Rainwater harvesting, seawater desalination, wastewater reuse and AI-enabled groundwater management strategies present promising solutions. These methods can not only improve resilience but also have beneficial implications for health, sustainable development and international climate and sustainability targets.

Recommendations

Based on the foregoing, the following strategic recommendations are made to enhance climate-resilient water management in Nigeria:

a) Policy revision and enforcement: The Federal Ministry of Water Resources, together with relevant institutions, needs to revise water management policies. The policies should explicitly integrate adaptation and mitigation strategies for climate change within the IWRM and National Water Resources Policy.
b) Investment in Infrastructure: Significant investment is required in water infrastructure, including
    i. rainwater harvesting systems,
    ii. wastewater treatment and recycling facilities and
    iii. improved networks for water storage and delivery.

    These upgrades are required to guarantee adequate supplies of drinking water during times of drought or floods.
c) Regional Cooperation: Nigeria must enhance regional cooperation with neighbouring countries and work towards adopting common water management, conservation and distribution strategies.
d) Community engagement and public awareness: Communities should be actively engaged in water conservation and climate adaptation. National Orientation Agency (NOA) should launch sustained public information campaigns with regard to
    i. Climate impacts on water availability,
    ii. Saving water and
    iii. Protecting local sources of water.
e) Scientific Research: More money should be invested in universities and research institutes to undertake scientific studies with regard to
    i. Impacts of climate change on water availability in Nigeria
    ii. Adaption and mitigation strategies for climate change.

References

Abaje, I. B., and Oladipo, E. O. (2019). Recent changes in the temperature and rainfall conditions over Kaduna State, Nigeria. Ghana Journal of Geography, 11(2), 127-157.

Abbass, K., Qasim, M. Z., Song, H., Murshed, M., Mahmood, H., and Younis, I. (2022). A review of the global climate change impacts, adaptation, and sustainable mitigation measures. Environmental science and pollution research, 29(28), 42539-42559.

Abel, J., and Amachigh, D. M. (2024). Climate Change, Rainfall Trends and Variation in Yola, Adamawa State Nigeria. Asian

Research Journal of Current Science, 86-95.

Aborode, A. T., Otorkpa, O. J., Abdullateef, A. O., Oluwaseun, O. S., Adegoye, G. A., Aondongu, N. J., Oyetunji, I.O., Akingbola, A., Scott, Y.G., Kolawole, O.B. and Komakech, J. J. (2025). Impact of Climate Change-Induced Flooding Water Related Diseases and Malnutrition in Borno State, Nigeria: A Public Health Crisis. Environmental Health Insights, 19, 11786302251321683.

Adabara, E. F., Sadauki, A. H., Usman, A. B., Nweke, H., Ogunbode, O., Gimba, P., Hassan, M., Egwuenu, A., Abdullahi, Y.Y., Erojikwe, O. and Balogun, M. S. (2024). Cholera outbreak in Niger State Nigeria, May to August 2021: An unmatched case-control study. Journal of Interventional Epidemiology and Public Health, 7(38).

Adedotun, S. B., Ogundahunsi, D. S., Ibrahim, R. B., Adedotun, D. O., and Yakubu, D. A. (2024). Analysis of Households' Water Access and Consumption in Differential Urban Neighbourhoods of Osogbo, Nigeria. Ghana Journal of Geography, 16(1), 256-283.

Adelagun, R. O. A., Etim, E. E., and Godwin, O. E. (2021). Application of water quality index for the assessment of water from different sources in Nigeria. In Promising Techniques for Wastewater Treatment and Water Quality Assessment. IntechOpen. https://doi.org/10.5772/intechopen.98696

Adeniran, A., Daniell, K. A., and Pittock, J. (2021). Water infrastructure development in Nigeria: Trend, size, and purpose. Water, 13(17), 2416.

Adeoti, O. S., Kandasamy, J., and Vigneswaran, S. (2023). Water infrastructure sustainability in Nigeria: a systematic review of challenges and sustainable solutions. Water Policy, 25(11), 1094-1111.

AFDB (2025). Climate Change in Africa. https://www.afdb.org/en/cop25/climate-change-africa. Accessed on 12th March, 2025

Agbasi, J. C., Abu, M., Pande, C. B., Uwajingba, H. C., Abba, S. I., and Egbueri, J. C. (2025). Groundwater Salinization in Coastal Regions and the Control Mechanisms: Insights for Sustainable Groundwater Development and Management. In Sustainable Groundwater and Environment: Challenges and Solutions (pp. 165-191). Cham: Springer Nature Switzerland.

Agbasi, J. C., Egbueri, J. C., Ayejoto, D. A., Unigwe, C. O., Omeka, M. E., Nwazelibe, V. E., Igbalo, J.O. Pande, C.B. and Fakoya, A. A. (2023). The impact of seasonal changes on the trends of physicochemical, heavy metal and microbial loads in water resources of Southeastern Nigeria: a critical review. Climate change impacts on Nigeria: environment and sustainable development, 505-539.

Agbasi, J. C., Ezugwu, A. L., Omeka, M. E., Ucheana, I. A., Aralu, C. C., Abugu, H. O., and Egbueri, J. C. (2024). More about making profits or providing safe drinking water? A stateof-the-art review on sachet water contamination in Nigeria. Journal of Environmental Science and Health, Part C, 42(4), 255-297.

Ahmed, T., Zounemat-Kermani, M., and Scholz, M. (2020). Climate change, water quality and water-related challenges: a review with focus on Pakistan. International journal of environmental research and public health, 17(22), 8518.

Ajibade, F. O., Wang, H., Guadie, A. A., Ajibade, T. F., Fang, Y., Sharif, H. M. A., Liu, W., and Wang, A. (2021). Total nitrogen removal in biochar amended non-aerated vertical flow constructed wetlands for secondary wastewater effluent with low C/N ratio: Microbial community structure and dissolved organic carbon release conditions. Bioresource Technology, 322, 124430. https://doi.org/10.1016/j.biortech.2020.124430.

Ajibade, F. O., Yin, W. X., Guadie, A., Ajibade, T. F., Liu, Y., Kumwimba, M. N., Liu, W.Z., Han, J.L., Wang, H.C. and Wang, A. J. (2023). Impact of biochar amendment on

antibiotic removal and ARGs accumulation in constructed wetlands for low C/N wastewater treatment. Chemical Engineering Journal, 459, 141541.

Akinluyi, F. O., Adeyeye, J. A., and Agbo, S. (2022). GIS-based groundwater quality assessment for domestic and irrigation purposes in Ogbia local government area of Bayelsa State, Nigeria. International journal of health sciences, 6(S8), 206-229.

Akinwumi, A. M., Adewumi, J. R., and Obiora-Okeke, O. A. (2021). Impact of climate change on the stream-flow of Ala River, Akure, Nigeria. Sustainable Water Resources Management, 7, 1-11.

Alade, A. D. (2019). Water resources and sub-Sahara African economy: anthropogenic climate change, wastewater, and sustainable development in Nigeria. Journal of Social Development in Africa, 34(2), 113-138.

Anabaraonye, B., Okafor, J. C., Ewa, B. O., and Anukwonke, C. C. (2021). The impacts of climate change on soil fertility in Nigeria. Climate Change and the Microbiome: Sustenance of the Ecosphere, 607-621.

Animashaun, M. I., Oguntunde, P. G., Olubanjo, O. O., and Akinwumiju, A. S. (2023). Assessment of climate change impacts on the hydrological response of a watershed in the savanna region of sub-Saharan Africa. Theoretical and Applied Climatology, 152(1), 1-22.

Aribisala, J. O., Awopetu, M. S., Ademilua, O. I., Okunadel, E. A., and Adebayo, W. O. (2015). Effect of climate change on groundwater resources in southwest Nigeria. J Environ Earth Sci, 5(12), 2224-3216.

Ayejoto, D. A., Agbasi, J. C., Egbueri, J. C., and Echefu, K. I. (2024). Assessment of oral and dermal health risk exposures associated with contaminated water resources: an update in Ojoto area, southeast Nigeria. International journal of environmental analytical chemistry, 104(3), 641-661.

Ayejoto, D. A., Egbueri, J. C., Agbasi, J. C., Omeka, M. E., Unigwe, C. O., Nwazelibe, V. E., Igbalo, J.O. and Pande, C. B. (2023). Influence of seasonal changes on the quality of water resources in southwestern Nigeria: a review. Climate change impacts on Nigeria: environment and sustainable development, 423-447.

Bao, H., Yin, W., Wang, H., Lu, Y., Jiang S., Ajibade, F.O., Ouyang, Q., Wang, Y., Nie, S., Bai, Y., Gao, H., and Wang, A. (2023). Automated machine learning-based models for predicting and evaluating antibiotic removal in constructed wetlands. Bioresource Technology, 385, 129436. https://doi.org/10.1016/j.biortech.2023.129436

Bello, S., Eberemu, E. C., Orpin, J. B., and Ya'u, S. (2024). Prevalence of Schistosoma haematobium infection among primary school children in Faskari and Funtua Local Government Areas of Katsina State, Nigeria. FUDMA Journal of Sciences, 8(3), 311-315.

Daudu, S. O., and Idehen, S. O. (2024). A Comparative Analysis of Climate Change Laws in Nigeria with Some Selected Jurisdictions. Beijing L. Rev., 15, 1771.

Emenike, C. P., Tenebe, I. T., Omole, D. O., Ngene, B. U., Oniemayin, B. I., Maxwell, O., and Onoka, B. I. (2017). Accessing safe drinking water in sub-Saharan Africa: Issues and challenges in South–West Nigeria. Sustainable cities and society, 30, 263-272.

Engelman, A., Ismail, S., Fenlon, J., Noschese, E., and Farovitch, L. (2025). Water and food insecurity and quality of life for deaf Nigerians: A community-based cross sectional study. Water Security, 24, 100188.

Fadare, B. J., and Okonofua, E. S. (2024). Climate Change Effect on Groundwater Resources in Benin City. Ecofeminism and Climate Change. 5(2). 77-87. DOI:http://doi.org/10.26480/efcc.02.2024.77.87

Famose, O. A., and Olajuyigbe, A. E. (2023). Assessment of Potable Water Supply in

Akure North Local Government Area, Ondo State, Nigeria. Journal of Geography, Environment and Earth Science International, 27(7), 14-29.

Fan, X., Zhang, X., Yu, A., Speitel, M., and Yu, X. (2023). Assessment of the impacts of climate change on water supply system pipe failures. Scientific Reports, 13(1), 7349.

Haber, L. A., Cloud, D. H., Boudin, C., & Williams, B. A. (2025). The intersection of climate justice and criminal justice: extreme heat and health inequities in carceral facilities. JAMA, 333(10), 843-844.

Haque, M. M., Rahman, A., and Samali, B. (2016). Evaluation of climate change impacts on rainwater harvesting. Journal of Cleaner Production, 137, 60-69.

Hickmann, T., Widerberg, O., Lederer, M., and Pattberg, P. (2021). The United Nations Framework Convention on Climate Change Secretariat as an orchestrator in global climate policymaking. International review of administrative sciences, 87(1), 21-38.

Hindiyeh, M., Albatayneh, A., Altarawneh, R., Jaradat, M., Al-Omary, M., Abdelal, Q., Tayara, T., Khalil, O., Juaidi, A., Abdallah, R., Dutournie, P. and Jeguirim, M. (2021). Sea level rise mitigation by global sea water desalination using renewable-energy-powered plants. Sustainability, 13(17), 9552.

IPCC (2018). Intergovernmental Panel on Climate Change (IPCC). https://www.ipcc.ch/2018/10/ Accessed on 12th March, 2025

Ishaque, W., and Zia ur Rehman, M. (2025). Impact of Climate Change on Water Quality and Sustainability in Baluchistan: Pakistan's Challenges in Meeting United Nations Sustainable Development Goal (UNSDG) Number 6. Sustainability, 17(6), 2553.

JHU (2022). How much does cholera cost. https://publichealth.jhu.edu/sites/default/files/202309/how-much-does-cholera-cost.pdf. Accessed on 14th March, 2025.

Jobe, H. (2025). The Effects of Global Policy on Climate Change on Environmental Degradation in The Gambia (Doctoral Dissertation, University of The Gambia).

Kanoma, M. S., and Abdulkadir, M. (2021). The impact of future climate change on water availability in Gusau, Zamfara State, Nigeria. Dutse Journal of Pure and Applied Sciences, 7(4a), 144-154.

Khondoker, M., Mandal, S., Gurav, R., and Hwang, S. (2023). Freshwater shortage, salinity increase, and global food production: A need for sustainable irrigation water desalination— A scoping review. Earth, 4(2), 223-240.

Kirton, J. J., Kokotsis, E., and Warren, B. (2018). G7 Governance of climate change: the search for effectiveness. In The G7, Anti-Globalism and the Governance of Globalization (pp. 90126). Routledge.

Kuzucu, M., and Gökçen, I. S. (2024). Micro-cathcement rain water harvesting technology in conservation agriculture and plant production. Bangladesh Journal of Botany, 53(1), 9-16.

Ladan, S. I., Badaru, S. I., and Mutawalli, B. U. (2024). Accelerating Land Restoration, Drought Resilience and Desertification Progress: A Case For The Completion Of Dallaje Dam Irrigation Project Katsina State, Nigeria.

Lawal, O., and Gbadegesin, A. S. (2022). Combining Remote Sensing and Space-Time Analysis for Desertification Monitoring in the Semiarid Dryland of Nigeria. Ghana Journal of Geography, 14(3), 115-144.

Machina, M. B., and Sharma, S. (2017). Assessment of climate change impact on hydropower generation: a case study of Nigeria. Int J Eng Technol Sci Res, 4(8).

Mafimisebi, P., and Martins, G. (2024) Assessment of Climate Change Impact on Surface Water Quality in Share-Tsaragi and its Environ in Kwara State, Nigeria. International Journal of Trendy Research in Engineering and Technology. 8(3)

Martins, G., Ehinmentan, B., Mafimisebi, P., America, A., and Gbadero, G. (2025). Sustainable Water Resource Management in Nigeria: Challenges, Integrated Water Resource Management Implementation, and National Development. International Journal of Trendy Research in Engineering and Technology. 9(1).

Meye, J., Oyem, M. N., and Rufus, A. (2025). Environmental Impact and Physico-Chemical Analysis of Flood Water Intrusion in Domestic Boreholes and Well Water Quality in Isoko North Local Government Area and Environs in Delta State, Nigeria. Journal of Pollution Monitoring, Evaluation Studies and Control, 4(1), 79-89.

Mishra, R. K. (2023). Fresh water availability and its global challenge. British Journal of Multidisciplinary and Advanced Studies, 4(3), 1-78.

Mmonwuba, N. C., Agunwamba, J. C., Obumneme, A. A., Linus, I. C., and Chukwuemelie, N. A. (2024). Comparing the Performance of Physical, Chemical and Biological Treatment in Waste Water Remediation. Asian Journal of Advanced Research and Reports, 18(12), 571585.

Namadi, A. Z., Anaegbu, J. O., and Yahaya, A. A. (2024). Analysis of Geochemical Parameters for Surface and Groundwater in Zuru Local Government Area of Kebbi State, Nigeria. UMYU Scientifica, 3(2), 80-85.

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

Niyi-Odumosu, F., Ozoh, O. B., Ope, V. O., Ale, B. M., Akinnola, O., Iseolorunkanmi, A., and Adeloye, D. (2025). Exploring the impact of climate change on respiratory health in Nigeria: a scoping review of current research, government policies and programs. Climatic Change, 178(3), 1-24.

Noureen, A., Aziz, R., Ismail, A., and Trzcinski, A. P. (2022). The impact of climate change on waterborne diseases in Pakistan. Sustainability and Climate Change, 15(2), 138-152.

Nwozor, R. N., Bassey, N. E., George, N. J., and Harry, T. A. (2025). Spatiotemporal and Hydrogeological Assessment of Groundwater Flow and Vulnerability in Parts of the Benin Formation, Akwa Ibom State, Southeastern Nigeria. Researchers Journal of Science and Technology, 5(2), 1-15.

Ogunbode, T., Oyebamiji, V., Akinkuolie, T., Oyelami, A., and Adekiya, A. (2025). Trends in water supply variability and the sustainability of household water demand in tropical Africa: a case study. Urban Water Journal, 22(2), 210-222.

Ojo, O. T., Ike, C. J., Aladeboyeje, A. I., Olaseeni, O. G., and Adewumi, O. F. (2025). Hydrochemical assessment of borehole water in Effurun, Delta state Niger Delta, Nigeria: implications for public health and safety. Discover Geoscience, 3(1), 10.

Okeniyi, O. O., and Ajayi, D. D. (2024). Determinants of Household Access to Drinking Water in Nigeria. Ghana Journal of Geography, 16(3), 42-48.

Okhuebor, S. O., and Izevbuwa, O. E. (2020). The quality and effect of borehole water proliferation in Benin City, Nigeria and its public health significance. Adv. Microb. Res, 4(13), 1-5.

Okon, E. M., Falana, B. M., Solaja, S. O., Yakubu, S. O., Alabi, O. O., Okikiola, B. T., … and Edeme, A. B. (2021). Systematic review of climate change impact research in Nigeria: implication for sustainable development. Heliyon, 7(9).

Olanipekun, A., Idusuyi, D., Aiyelokun, O., Saka, Q., and Cole, O. (2024). Determination of Shelf Life of Packaged Water in Selected Water Packaging Factories, Ota, Ogun State, Nigeria. European Journal of Applied Science, Engineering and Technology, 2(5), 88-100.

Olasehinde, D. A., Adeniran, K. A., and Ogunrinde, A. T. (2024). Integrating multimodal ensemble and spatiotemporal analysis for enhanced climate modelling in Nigeria. Preprints, 2024, 2024010607.

Olorunlana, F. A. (2024). Sea Level Rise and its Impact on Ayetoro Community, Ondo State, Nigeria. International Journal of Advanced Studies in Engineering and Scientific Inventions. 5(1) p-ISSN: 2354-4171 | e-ISSN: 2354-418X

Olujobi, O. J., and Odogbo, I. S. (2024). Strategic evaluation of the 2021 Nigeria Climate Change Act: Surmounting challenges, paving the way for success, and envisioning future trajectories. Social Sciences and Humanities Open, 10, 100928.

Omokaro, G., Idama, V., Aireughian, E., and Michael, I. (2024). Water Resources, Pollution, Integrated Management and Practices in Nigeria-An Overview. American Journal of Environmental Economics, 3(1), 10-54536.

Omopekunola, M. O., Abel, J., Oladipupo, G. O., Udeh, I., and John, J. J. (2023). An Assessment of Inter-Annual and Decadal Precipitable Water Vapour Variability and Trends Over North-East Nigeria (1991-2021). Nigerian Journal of Physics, 32(1), 50-59.

Omoregie, A. E., Omoregie, A. P., and Okoro, E. O. (2025). Assessment of Household Hygiene, Potable Water Sources, and Sanitation Practices in Ikpoba Okha Local Government Area, Edo State, Nigeria. Journal of Applied Sciences and Environmental Management, 29(3), 879-887.

Onivefu, A. P., Irede, E. L., Edogun, I. P., and Umanya, O. J. (2024). Physicochemical and bacteriological assessment of the polyethene packaged sachet water (popularly called “pure water”) as a major source of drinking water in Sagamu, Ogun State, Southwest, Nigeria.

Paz, S., Díaz, J., Negev, M., & Linares, C. (2024). Climate change and global health. In Handbook of Epidemiology (pp. 1-35). New York, NY: Springer New York.

Phu, T. K. C., Nguyen, P. L., and Phung, T. V. B. (2025). Recent progress in highly effective electrocoagulation-coupled systems for advanced wastewater treatment. iScience.

Raimi, M. O., Vivien, O. T., Odipe, O. E., and Owobi, O. E. (2018). The sources of water supply, sanitation facilities and hygiene practices in oil producing communities in central senatorial district of Bayelsa state, Nigeria. MOJ Public Health, 7(6), 337-345.

Roger, C., and Belliethathan, S. (2016). Africa in the global climate change negotiations. International Environmental Agreements: Politics, Law and Economics, 16(1), 91-108.

Rotimi, I. M., Adewumi, J. R., and Ajibade, F. O. (2021). Treatment of rubber latex processing wastewater using activated carbon derived from palm kernel shell. Nigerian Research Journal of Engineering and Environmental Sciences. 6(2).

Rotimi, I. M., Ajibade, F. O., and Fakorede, E. O. (2024). Public Health and Environmental Degradation Impacts of Household Fuelwood Consumption in Nigeria: a dual scheme approach as sustainable solution. Public Health, 8(2), 220-232.

Sadath, P. V. R., Kartheeshwari, M. R., and Elango, L. (2021). Sustainable groundwater management under global climate change: mitigation and adaptation measures. In Proceedings of the Earth and Environmental Sciences International Webinar Conference (pp. 187-206). Cham: Springer International Publishing.

Sadeghi-Jahani, H., Ketabchi, H., and Shafizadeh-Moghadam, H. (2024). Spatiotemporal assessment of sustainable groundwater management using process-based and remote sensing indices: A novel approach. Science of the Total Environment, 918, 170828.

Salami, A. A., Olanrewaju, R. M., Bakare, K. O., and Babatunde, O. R. (2025). Spatial distribution of rainfall in Nigeria. Arabian Journal of Geosciences, 18(1), 1-25.

Sawyerr, H. O., Iyanda, Y. A., Salami, O. O., and Bagudu, B. M. (2024). Assessment of drinking water quality in rural northern Nigeria: a case study of Diggi village in Kebbi State, Nigeria.

Shehu, B., and Nazim, F. (2022). Clean water and sanitation for all: study on SDGs 6.1 and 6.2 targets with state policies and interventions in Nigeria. Environmental Sciences Proceedings, 15(1), 71.

Shiru, M. S., Shahid, S., and Park, I. (2021). Projection of water availability and sustainability in Nigeria due to climate change. Sustainability, 13(11), 6284.

Singh, D., and Sharma, V. (2023). Transformative potential of AI and remote sensing in sustainable groundwater management. In Proceedings of International Conference on recent advancements in artificial intelligence (pp. 139-156). Singapore: Springer Nature Singapore.

Sogbanmu, T. O., Aitsegame, S. O., Otubanjo, O. A., and Odiyo, J. O. (2020). Drinking water quality and human health risk evaluations in rural and urban areas of Ibeju-Lekki and Epe local government areas, Lagos, Nigeria. Human and ecological risk assessment: An international journal.

Solihu, H., and Bilewu, S. O. (2021). Availability, coverage, and access to the potable water supply in Oyo State Nigeria. Environmental Challenges, 5, 100335.

Swain, S., Taloor, A. K., Dhal, L., Sahoo, S., and Al-Ansari, N. (2022). Impact of climate change on groundwater hydrology: a comprehensive review and current status of the Indian hydrogeology. Applied Water Science, 12(6), 120.

Udeh, E. L., Mshelia, S. S., and Ikpe, E. (2025). An Analysis of Water Security Impediments in the Drylands Region of Nigeria: A Review of Yobe State, Nigeria. Int. J. Sci. Res. in Multidisciplinary Studies Vol, 11(1).

UN, 2019. United Nations. 2019, Progress on Sustainable Development Goal 6. http://www.undp.org

Wartalska, K., Grzegorzek, M., Bełcik, M., Wdowikowski, M., Kolanek, A., Niemierka, E., Jadwiszczak, P. and Kaźmierczak, B. (2024). The Potential of RainWater Harvesting Systems in Europe–Current State of Art and Future Perspectives. Water Resources Management, 38(12), 4657-4683.

Wols, B. A., and Van Thienen, P. (2016). Impact of climate on pipe failure: Predictions of failures for drinking water distribution systems. European Journal of Transport and Infrastructure Research, 16(1).

Yahaya, I. I., Wang, Y., Zhang, Z., Inuwa, A. Y., Zhao, Y., You, Y., Basiru, H.A., Ochege, F.U., Na, Z., Ogbue C.P., Muhammad, M., Mihertu, Y.F., Tanko, I.A. and Shoukat, W. (2024). Assessing desertification vulnerability and mitigation strategies in northern Nigeria: A comprehensive approach. Heliyon, 10(11).

Zhang, S., Zhang, J., Yue, T., and Jing, X. (2019). Impacts of climate change on urban rainwater harvesting systems. Science of the Total Environment, 665, 262-274.

Żywiec, J., Szpak, D., Wartalska, K., and Grzegorzek, M. (2024). The Impact of Climate Change on the Failure of Water Supply Infrastructure: A Bibliometric Analysis of the Current State of Knowledge. Water, 16(7), 1043.