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ASSESSING THE IMPACTS OF CLIMATE CHANGE ON HYDROPOWER GENERATION AND THE POWER SECTOR IN NIGERIA

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Abstract

The study recognizes the significant challenges climate change poses, including changes in rainfall patterns, altered hydrological cycles, and increased frequency of extreme weather events. The result showed an upward trend in both the annual mean temperature and evaporation rate from 1979 to 2022, and a downward trend for rainfall in the same period. Rainfall has a strong positive correlation with inflow, therefore with a reduction in rainfall and increased temperature and evaporation in the region, there is certainly a reduction in the inflow over time. These factors can potentially disrupt hydropower infrastructure and affect electricity generation in the country. The assessment emphasizes the need for proactive measures to enhance the resilience of hydropower systems. It highlights the importance of considering future climate projections to inform climate-resilient designs and adaptive measures in infrastructure planning, construction, and operation. Diversifying the energy mix appears as a key strategy to reduce dependence on hydropower and enhance the overall resilience of the power sector. Collective efforts between all agencies involved are essential for developing comprehensive adaptation strategies and implementing early warning systems. Nigeria's power sector can achieve a more sustainable and resilient energy system by recognizing and managing the potential challenges of climate change. It is impetuous for Nigeria to develop a strategic planning framework, robust investment in alternative renewable energy, and pay kin attention to the adaptation and mitigation measures to ensure a reliable and sustainable power supply.

Keywords: Hydropower, Climate change, Power generation, Nigeria, Climate resilient. Climate adaptation, water resources, Renewable energy.

Introduction

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Nigeria is one of the major oil-producing countries in Africa and holds substantial oil reserves. The country has both offshore and onshore oil fields, with major production centres in the Niger Delta region. Natural gas reserves are also important, and efforts are being made to increase gas production and utilization. Nigeria is blessed with abundant natural resources, particularly oil and gas reserves, which have traditionally dominated the energy sector. The petroleum industry has historically been the mainstay of Nigeria's economy, contributing a significant share to government revenue and export earnings.

The Nigerian power sector is plagued by various challenges, including inadequate infrastructure, transmission and distribution losses, and inadequate funding as a result, power outages are common, and many businesses and households rely on backup generators (Okeke, 2020). The sector is also characterized by inefficiency, low tariffs, and a high level of customer non-payment, leading to a massive revenue shortfall for power companies (Ahmed & Bashir, 2020). Nigeria, the largest economy in sub-Saharan Africa, has the potential for significant growth, but the power sector limitations still need to be improved. The energy sector in Nigeria is important to the country's economy and plays a crucial role in driving industrial development, economic growth and improving the quality of life for its citizens (Dioha & Emodi, 2018). Nigeria's daily power dispatch is around 4,000 MW, far below the energy needs of over 200 million people, estimated to be approximately 10,000 MW as of 2014, which is far from being met. Despite efforts to address the challenges of the Nigerian power sector, regulatory uncertainty, gas supply, transmission system constraints, and significant shortfalls in power sector planning have prevented it from achieving commercial viability.

Hydropower in Nigeria

Hydropower generation is the process of generating electricity by using the energy of moving water. It is a renewable source of energy that relies on the natural water cycle. Hydropower generation in Nigeria dates to the early 1960s when the Kainji Dam was commissioned in 1968. The Kainji Dam on the Niger River was built to generate electricity and regulate water flow for irrigation and navigation purposes (Okeke, 2020). The dam has an installed capacity of 760 MW, while the Jebba dam, has an installed capacity of 578 MW and Shiroro dam with 600 MW installed capacity (Ahmed & Bashir, 2020). Despite having significant hydropower potential, hydropower generation in Nigeria has yet to be utilized. This is mainly due to a lack of investment in the sector, inadequate maintenance of existing facilities, and frequent operational breakdowns. Nigeria's power sector is heavily dependent on hydropower, which accounts for approximately 30% of its installed capacity (National Bureau of Statistics, 2021). The three major hydropower plants in Nigeria are Kainji, Jebba, and Shiroro (NERC, 2021). The power sector over reliant on hydropower generation, makes it vulnerable to the impacts of climate change. The reliability and sustainability of electricity supply are affected by changes in water availability, which can lead to power outages and disruptions in economic activities. This is important because the power sector is critical to the economic development of Nigeria, and any disruptions in electricity supply can have significant impacts on the economy and the well-being of the population (Adhekpukoli,

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2018). This is important because the power sector is critical to the economic development of Nigeria, and any disruptions in electricity supply can have significant impacts on the economy and the well-being of the population (Adhekpukoli, 2018). Changes in hydrological patterns and extreme weather events associated with climate change could affect the availability of water for hydropower generation and the reliability of hydropower plants.

Table 1: Nigeria hydropower active dams and installed capacities (Abaka et al, 2017)

List of hydropower stations in Nigeria				
Hydroelectric station	**Type**	**Capacity (MW)**	**Year Completed**	**River**
Kainji Power Station	Reservoir	760	1968	River Niger
Jebba Power Station	Reservoir	640	1985	River Niger
Shiroro Power Station	Reservoir	600	1990	Kaduna River

Nigeria faces challenges in meeting the electricity demand of its rapidly growing population despite been blessed with power production resources. The repercussions of climate change are seen in many economic sectors, including the power sector, and they represent a severe threat to humanity today. Changes in temperature, rainfall, and extreme weather events are affecting electricity generation and supply (Kayode, 2021). The energy sector in Nigeria is significant to the country's economy. It plays a crucial role in driving industrial development, economic growth and improving the quality of life for its citizens.

Climate Change in Nigeria

The global context of climate change relates to the changes over time in the global weather patterns and temperature caused by human activities, primarily the discharge of greenhouse gases (GHGs) into the air. These GHGs, such as carbon dioxide (CO2), trap heat and increase the Earth's surface temperature, leading to various impacts on ecosystems and human systems.

In the case of Nigeria's power sector, understanding the global context of climate change is crucial due to its relevance to energy sources and sustainability.

Changes in temperature and rainfall patterns due to climate change can affect the availability of water for hydropower generation. For example, droughts can reduce the amount of water available for hydropower generation, while floods can damage hydropower infrastructure (Okoye & Elkiran, 2022). Climate change is posing significant challenges to Nigeria's power sector, affecting the reliability and sustainability of electricity supply (Ogundipe et al, 2014). This article aims to

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evaluate the implications of climate change on Nigeria's hydropower industry and the electricity sector, emphasizing the causes, consequences, and potential solutions to the issue.

Problem statement

The Nigerian economy relies heavily on energy as a tradeable commodity that generates national income to support government development programs. Due to population growth, industrialization, agricultural production, and improving living standards, Nigeria requires more energy to meet rising demands. This study hypothesizes that the impact of climate change on hydropower generation and the power sector in Nigeria can be reduced by implementing sustainable energy investments. In general, this article discusses the impacts of climate change on water resources and hydropower generation in Nigeria. It highlights that changes in rainfall patterns, reduced water availability due to global warming and droughts, and changes in water quality can have significant implications for hydropower generation and aquatic ecosystems.

Aim of study

The Nigerian power sector faces significant challenges that have prevented it from achieving commercial viability and contributed to its inability to meet the power demand of the nation. However, the country's abundant renewable energy resources allow it to meet its current and future development requirements while complementing its oil-dependent economy. This study aims to assess the impact of climate change on hydropower generation and the power sector in Nigeria. The findings from this study will contribute to the body of knowledge on sustainable energy investments in Nigeria.

Study Area

Nigeria is a West African country which borders with Niger to the north, Chad to the northeast, Cameroon to the east, the Gulf of Guinea (Atlantic Ocean) to the south, and Benin to the west. Nigeria's geographical coordinates is approximately 9.0817° N latitude and 8.6753° E longitude. Nigeria, with over 200 million people, is the most populous country in Africa and covers approximately 923,768 square kilometres (356.669 square miles). Nigeria is also known for its diversity, with more than 250 ethnic groups within its borders. Each with its unique language, tradition, and cultural practices, making it a diverse country. The largest ethnic groups in Nigeria include Hausa-Fulani, Yoruba, and Igbo. Nigeria's rich cultural heritage is reflected in its music, art, literature, and cuisine.

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Figure 1: Map of Nigeria showing the boundary.

For better understanding, the Shiroro hydropower station will be used as a case study for this research. The Shiroro hydropower station is a significant hydroelectric and multipurpose dam located at 9.9751° N, 6.8344° E, Niger State, Nigeria. The Shiroro dam is situated on the Kaduna River in the Shiroro Local Government Area of Niger State, approximately 70 kilometres (43 miles) north of Minna, the state capital. Scenic landscapes and hilly terrains surround it. The construction of the dam began in 1984 and was completed in 1990. It is a concrete gravity dam, standing at about 98 meters (322 feet) and stretching approximately 700 meters (2,297 feet). The dam forms a large reservoir known as Lake Shiroro, which covers an area of about 2,400 square kilometres (926 square miles) at total capacity. The reservoir provides a significant water source for irrigation and supports the surrounding ecosystems. The Shiroro Dam is crucial in Nigeria's energy and water resource management. It operates a hydroelectric power station that houses four turbine units with a combined installed capacity of 600 megawatts (MW). It is an important infrastructure contributing to the country's electricity supply and supporting various socio-economic activities in the region.

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Figure2. Map of Shiroro hydroelectric power plant

Methodology

For this article, the climatic data were obtained from secondary source which is the Climate Engine. Also, suitable literature, books, journals, projects and internet materials and other publications were also consulted to consolidate the result. The collected data were afterwards analyzed using different tools such as Minitab and Excel to get the statistics on this work such as charts, trend analysis, pattern analysis.

Impacts of Climate Change on Hydropower Generation in Nigeria

Climate change can impact hydropower generation in Nigeria significantly and in various ways. The country is already experiencing the effects of climate change, resulting in increased temperatures, climatic extremes, and floods (Enete et al., 2011). These changes are expected to significantly impact water resources and hydropower generation in Nigeria. One of the most significant impacts of climate change on water resources in Nigeria is changes in temperature to the current trend of a high rate of drying up of rivers across the country (Akpodiogaga-a & Odjugo, 2010). The climatic data collected from 1979 to 2022 at the Shiroro hydropower plant location showed a visible upward temperature trend, as observed in Fig 3 below. This is in line with the climate change predictions, and of which the impacts are seen across the nation.

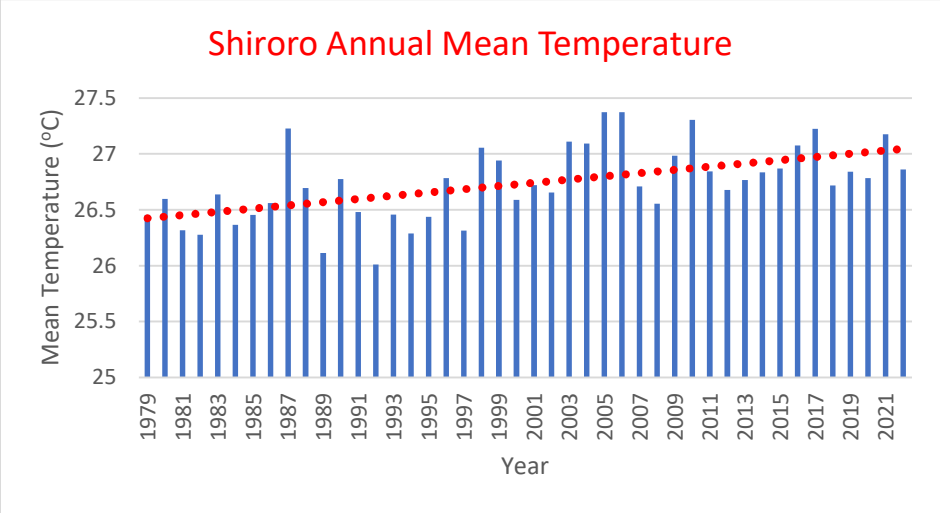

Figure 3. Annual mean temperature rate in Shiroro hydropower station.

Considering the current rate of evaporation of rivers across the country, studies have shown that climate change is likely to cause a reduction in water availability for hydropower generation in Nigeria (Kachaje et al., 2016). Climate change will increase temperature, increasing the evaporation rate from water sources and reducing the amount of water available for power generation. Water turns into water vapor and enters the atmosphere through evaporation. If more water undergoes evaporation, the amount of water available for generating electricity decreases. Even if the same amount of water flows through the plant, the hydropower plant's electricity production can decrease. In addition, climate change can increase water temperatures, which can reduce the efficiency of hydropower plants and cause more evaporation, further decreasing the amount of water available for generating electricity (Olofintoye & Adeyemo, 2011). Nigeria has experienced more frequent and severe droughts in recent years, which can lead to reduced water availability for hydropower generation (Olajuyigbe et al., 2020). This poses a big threat to Nigeria's hydropower generation and increases the costs of operation and maintenance for hydropower facilities. The analysis in Fig3. Below also showed an upward trend in evaporation, indicating the increase in water loss due to climate change.

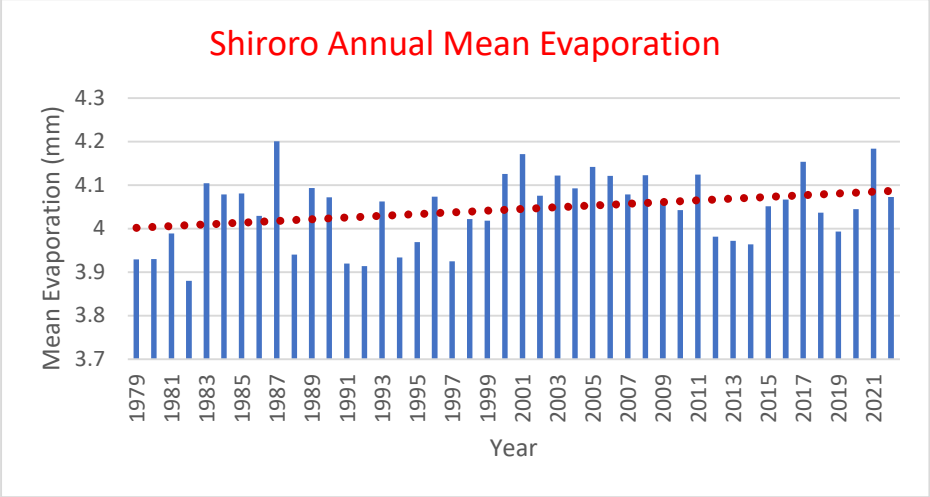

Figure 4. Annual mean evaporation rate in Shiroro hydropower station.

The changes in rainfall patterns caused by climate change may decrease available water for hydropower production. As a result, there could be a reduction in the amount of electricity generated by hydropower plants, as per a study conducted by (Ibrahim et al., 2017). Hydropower plants generate electricity by using the energy of falling water to turn turbines, which then generate electricity. However, if the water temperature increases due to climate change, it could reduce the efficiency of the hydropower plant (Ebele & Emodi, 2016). This means the plant would generate less electricity for the same amount of water flowing through it. The rapid withdrawal of freshwater sources in the country also confirms the implications of climate change in the country, as shown in Fig 6.

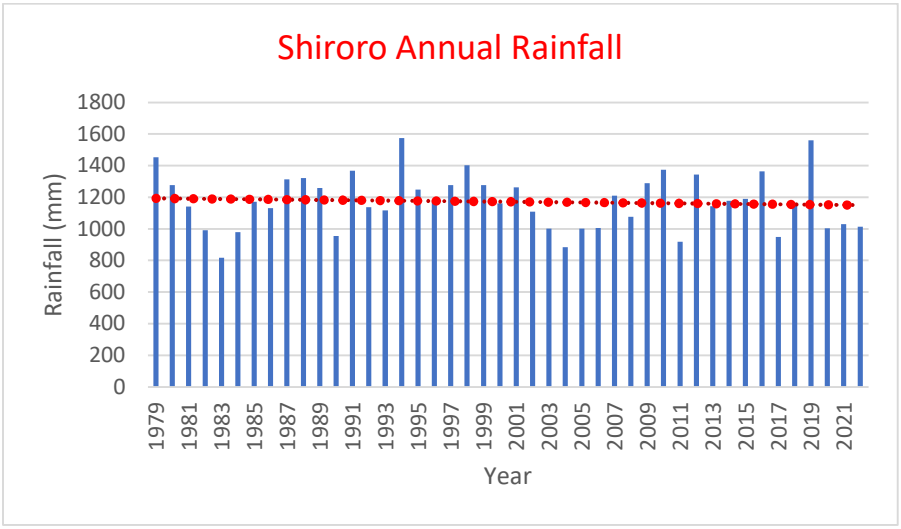

Figure 5. Sum annual rainfall in Shiroro hydropower station.

Nigeria has experienced more extreme rainfall events in recent years, often resulting in flooding and soil erosion (Oladipo et al., 2020). This can have significant implications for hydropower

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generation, as excess rainfall can cause dams to overflow or lead to the erosion of infrastructure that supports hydropower facilities. Extreme weather, like floods and droughts, can harm hydropower infrastructure, lowering its electricity capacity and reducing reliability (Oyerinde et al., 2016). In addition to these impacts, climate change can also lead to changes in water quality, including increased water temperature and nutrient and sediment levels (Oladipo et al., 2020). Hydropower generation in Nigeria is likely to be significantly impacted by climate change, as water availability and quality changes will affect the efficiency and reliability of hydropower plants. The amount and quality of available water for hydropower generation may be affected due to variation in the patterns of rainfall, increase in temperatures, and severe weather conditions like floods and droughts. (Oranrejawu et al, 2018). Additionally, changes in rainfall patterns may cause changes in the timing and magnitude of river flows, leading to a mismatch between water availability and demand for hydropower generation (Oranrejawu et al., 2018).

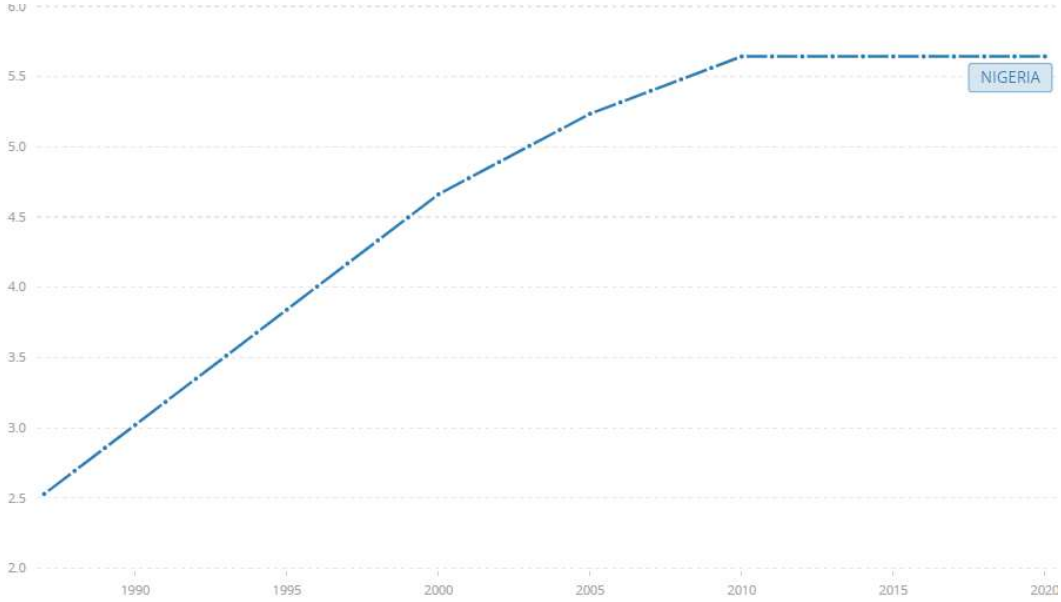

Figure 6: Annual freshwater withdrawals %, total (% of internal resources). Data from World Bank

Nigeria's hydropower infrastructure, and indeed the entire value chain of the energy system – generation, transmission, distribution, as well, and consumption is being increasingly affected by climate events and at risk of damage resulting from climate change, which has caused an increase in severe floods and droughts, resulting in reduced electricity generation and significant losses for the industry (Adejuwon, 2018). Infrastructure is another critical area of the hydropower plant that is adversely affected by climate change. Floods and droughts can seriously affect the generation of hydropower by causing damage to the infrastructure and making the water supply less reliable (Oyerinde et al., 2016). For example, the 2012 flood in Nigeria caused significant damage to the Kainji hydropower plant, reducing its generation capacity by over 50 per cent. All these factors

can significantly determine the success of Nigeria's energy sector, which has suffered enough setbacks already (Adhekpukoli, 2018).

Overall, the impacts of climate change on hydropower generation in Nigeria are complex and multifaceted. Policymakers and stakeholders must consider these impacts when planning for the country's future water and energy needs.

Impacts of Climate Change on the Power Sector in Nigeria

Figure 7: Nigeria's quarterly Electricity Production (GWh) from Mar 2005 to Sep 2022, data from CEIC Data.

The above fig 7 shows the quarterly electricity generation in Nigeria and arrived at the result by taking the hourly average for three months in GWh (CEIC Data). Nigeria installed energy capacity is approximately over 12,000, of which hydropower accounts for 19% and 81% thermal. However, only 58% of the total installed capacity is being utilized, which hydropower accounts for 1,060 MW and thermal for 4,996 MW (Babatunde et al., 2023). The variation in the power sector can be tied to various factors, including introducing new power plants, reduced hydropower generation, maintenance projects, increased energy demand, and disruption of transmission and distribution infrastructure, among others.

Reduced hydropower generation. Nigeria relies heavily on hydropower generation, with major dams like Kainji, Jebba, and Shiroro contributing a significant portion of the country's electricity (Ugwu et al., 2022). Climate change can alter rainfall patterns, leading to droughts or excessive rainfall, which can affect the water levels in reservoirs. The perfect case is the 2022 flood in Nigeria from May to October. The 2022 flood caused much damage to the infrastructure, resulting in lower electricity generation capacity from hydropower plants, leading to energy shortages and increased reliance on other sources (Dai et al., 2022).

Other factors that contributed to the crisis in the energy sectors include increased energy demand **(**urban areas may require more energy for cooling due to rising temperatures. This

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increased demand for air conditioning can strain the power grid and necessitate additional electricity generation capacity (Oyedepo, 2012). If not adequately addressed, it can lead to power shortages and blackouts) Also, disruption of transmission and distribution infrastructure. Climate change can result in severe weather conditions such as hurricanes, storms, floods, and heat waves (Onochie et al., 2015). These events can damage transmission and distribution infrastructure, causing power outages and delays in electricity supply, e.g., the 2022 flood caused much damage to the infrastructure. The repair and maintenance costs for such infrastructure can be significant. Climate change can affect thermal power plants that rely on water for cooling. Rising temperatures can reduce the efficiency of these power plants, requiring more water for cooling or decreasing their power output (Babatunde et al., 2023). Additionally, water scarcity can limit water availability for cooling, further affecting the efficiency and reliability of thermal power generation.

Mitigation and Adaptation

To mitigate these challenges posed by climate change on the power sector, the Nigerian government has embarked on various reforms aimed at attracting private-sector investment and improving the efficiency of the power sector. These include privatizing the power sector back in 2013, by establishing the Nigerian Electricity Regulatory Commission (NERC) to regulate the sector and launching the Power Sector Recovery Program in 2017 (Okeke, 2020).

Designing climate resilient power plants and refurbishing the existing infrastructure to the modern designs that can withstand the effects of climate change. Incorporating climate change considerations into the design, construction, and operation of hydropower projects can enhance their resilience. This includes assessing future hydrological patterns, extreme weather events, and changes in precipitation patterns to inform infrastructure design and capacity planning (Kayode, 2021).

Diversifying energy generation sources can increase energy security and therefore the resilience of the whole energy system investing in renewable energy sources such as solar and wind power is essential to minimize the effects of climate change on Nigeria's power sector. It is also necessary to prioritize these efforts to improve further the efficiency and resilience of the current hydropower infrastructure. (Egbenda & Nwozor, 2020).

Additionally, policies and regulations that encourage energy efficiency, conservation, and the adoption of low-carbon technologies are needed to promote sustainable development in the country (Olugbenga et al, 2021). In summary, Nigeria needs to implement adaptation and mitigation strategies. In this regard, renewable energy infrastructure needs to be improved, energy efficiency should be enhanced, grid reliability should be enhanced, climate-resilient infrastructure needs to be designed, and policies and planning processes should factor climate change factors in. International cooperation and support also play a crucial role in assisting Nigeria in transitioning to a more climate-resilient and sustainable power sector.

Discussion and Conclusion

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Shiroro hydropower station has witnessed a decreasing rainfall trend over the years. The global surface temperature has increased in recent decades, as also the temperature and evaporation trends in the study area in northern Nigeria since 1979. Increasing mean temperature, evaporation rate, and decreasing rainfall amount, as contained in fig3 to fig5, explain the variability in the decreasing reservoir elevation trend over time which was reported by (Olanrewaju et al., 2018). From the study by Olanrewaju, the Shiroro hydropower station generated increasing amounts of hydropower over the years of study 2014. Still, climate change may not have altered this increase since 25% of the variation in hydropower generation is not explained by the climatic variables used in the study. The decrease of the runoff discharge in this area, which should be channelled into the inflow, will impact the overall inflow. This will indirectly alter the hydropower generation in the Shiroro hydropower station. This study clearly showed a decreasing trend in rainfall. Conversely, the temperature and evaporation exhibit increasing trends, which explains the increase in water loss, a decrease in the elevation, and rainfall and inflow are positively correlated. Considering the above factors, it is important to understand the negative impacts of this on the Nigerian power sector. Already the sector has been plagued by its inability to provide sufficient power for the population. If not measured, the impacts of climate change will only worsen the situation at hand.

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