Chapter 8
Cumulative Impacts of Climate Change Variability Around the Goronyo Dam in the Iullemmeden Basin, Northwest Nigeria

Martin O. Eduvie and I. Francis Oseke

Abstract This chapter considers studies of the persistent multi-dimensional impact of climate change variability around the Goronyo Dam and across the Rima River (Latitude 13° 25’ 56”E) in the Lullemmeden Basin of Sokoto state, North West Nigeria. With an initial designed storage capacity of 942 million cubic meters, mainly for water supply and irrigation to Sokoto and Birnin Kebbi states with a total population of over 8.5 million people, recent water level and storage in the dam has been depleted by almost 90% in the past decade of its installed capacity, the biggest decrease since the construction of the dam over 30 years ago. The peak of climate change variability was observed as a consequence of a rainfall shortage and the siltation of the dam in 2017, which together resulted in significant socioeconomic impact on the beneficiaries of these water infrastructures. This has, in turn, resulted in inadequate water supply to state water agencies that depend on the dam to supply water for drinking, irrigation and other uses. The water shortage due to this climate change variability has compelled the dislocation of the socioeconomic life of people, families and livestock, forcing migration of human and animal life, thereby igniting social tension and poor personal and communal hygiene, resulting in epidemics including cholera and dysentery. This study proposes immediate remedial solutions, including the construction of tubewells and effective integrated water management of the entire water resource in order to improve and mediate these multiple and widely varying impacts on the settlements of Goronyo infrastructures, including on their dependents and beneficiaries.

Keywords Climate change · Goronyo dam · Precipitation water resources · Conflict and tube wells

M. O. Eduvie (✉) · I. F. Oseke
National Water Resources Institute, Kaduna Nigeria, Nigeria
e-mail: martineduvie@gmail.com

S. Diop et al. (eds.), *Climate Change and Water Resources in Africa*,
https://doi.org/10.1007/978-3-030-61225-2_8

1 Introduction

A dam is a man-made structure built across sections of a river or stream to retain water, which is generally used for agricultural purposes such as farmland and garden irrigation and the watering of livestock (Lodha 2007). It also can serve as a constructed barrier across a stream or river to impound water and raise its level for various purposes, such as drinking water supply and irrigation systems, and also increase river depth for navigation, generating electricity, control of water flow during times of floods and droughts, and the creation of artificial lakes for fisheries and recreational use. Many dams serve multiple of these purposes (Uyigue 2006). However, in the past twenty (20) years especially in 2017/2018, there has been upsurge in extreme events which negatively impacted the dams as a result of changes in climate (NASRDA 2012). In this particular event of 2017/2018, the rainfall period was not as long as anticipated. On the average, rainfall period always occurs between March/April to September/October but in the 2017/2018, the rains only occurred between April to early August. Climate and water resource systems have a special relationship insofar as water resources depend on the hydrological cycle which itself is part of the climate system (Stainforth et al. 2005). The impact of climate change on the function and operation of existing water resource systems and infrastructures, including hydropower, structural flood defenses, drainage and irrigation systems, as well as water management practices (Alvarez et al. 2014) are critical. As effects of climate change on water resource systems accumulate, there is corresponding impact of other stresses, such as population growth, changing economic activity, land-use change and urbanization (Thornton et al. 2008).

The concept of climate change revolves around the atmospheric concentrations of greenhouse gases (GHG) which have increased since the pre-industrial era due to human activities, primarily the combustion of fossil fuels and changes in land use and land cover (Gwary 2008). These, together with natural forces, have contributed to changes in the Earth's climate over the twentieth century. Land and ocean surface temperatures have warmed, the spatial and temporal patterns of precipitation have changed, sea level has risen and the frequency and intensity of cumulative pressure from climate change events have increased. These changes have affected dams and reservoirs and other water infrastructures (Gwary 2008).

The importance of water resources to man cannot be overemphasized. These include provision of water for domestic use, agricultural production, fishing, transportation, industrial use, hydro-electric power, recreation, tourism and mining. Furthermore, according to the World Bank (2014), every development challenge of the twenty-first century, such as food security, management of rapid urbanization, energy, security, environmental protection and adaptation to climate change requires urgent attention to the infrastructure management of water resources. Available information and statistics indicate that in recent times, climate variation or change is becoming more extreme in certain areas. This dynamic is not specific to Nigeria of course, but rather is represented by a rapidly growing global catalogue of storms, floods and drought in all parts of the world, which together make climate variability headline news.

Flood and drought as consequences of climate change cause tremendous losses to infrastructure and industry, including reducing the quality of personal and communal hygiene, with the consequence of epidemics like cholera and dysentery. In addition, losses to agriculture caused both by floods and droughts are staggering and affect a vast majority of the population directly dependent on water resources for their livelihood (Azman 2007). A recent example of this is the horrendous hardship inflicted in 2017 on the people of the town of Goronyo in the Sokoto state, located in north central Nigeria, caused by drought as a result of the shortage of rainfall in 2017 and the related siltation of the Goronyo Dam. This devastated socioeconomic activities and cost lives.

Cumulative climate change, water resources and socioeconomic systems are interconnected in complex ways (Alex et al. 2005), so a change in any one of these variables causes change in one or more others. Persistent drought and flooding, off-season rains and dry spells have interrupted the growing season of areas dependent on rain-fed agriculture. Plants that require low or high temperature at some stage of their life cycle may adapt and survive in the short term, but could become extinct in the long term.

As available water resources decrease and concern rise over the influence of climate change, the reliability of estimates of current and future water resources in reservoirs are becoming increasingly important to water managers. We, therefore, consider the cumulative pressure from climate change that encompasses all pressures from human activities, specifically examining impacts on the Goronyo Dam of the Iullemmeden basin in northwest Nigeria.

1.1 Aim and Objectives

The aim of this study is to consider climate variability in the context of global change that encompasses all pressures from human activities on water resource systems and infrastructures. Specific objectives are to analyse and review the impacts of climate change variability on the Goronyo Dam and to evaluate possible response options (or adaptation options) through an integrative approach covering

i. Climate variability and change, and its impact on dams;
ii. Observed changes in the spatial distribution of water resource systems and infrastructure in response to climate variability, especially change in temperature and rainfall and
iii. Development of responses that address the impacts of cumulative pressures, including climate change on dams.

2 Literature

2.1 Climate Change and the Impact on Dams

Climate change and its impact of dams are characterized by

i. Observed changes in the hydrological circle (atmosphere, oceans) and the role of human activity in those changes;
ii. Observed impacts of these changes on water resource systems, especially dams and reservoirs and
iii. The role that adaptation can play in responding to these changes.

2.2 Projected Changes in the Climate System

Future emission of greenhouse gases and aerosols are driven by forces such as changes in human population, socioeconomic development, technological and policy with necessary action plans by Governments as well as other stakeholder interventions. In 2014, the Inter-Governmental Panel on Climate Change (IPCC) presented in its special report on emissions six groups of scenarios or plausible futures which are based on narrative storylines and account for a wide range of driving forces. The scenarios project future emissions of the greenhouse gases, carbon dioxide, methane and nitrous oxide, and the aerosol sulphur dioxide. For gases that stay in the atmosphere for a long period, such as carbon dioxide, the atmospheric concentration responds to changes in emissions relatively slowly, whereas for short-lived gases and aerosols, such as sulphate aerosols, the atmospheric concentration responds much more quickly.

This is due to the length of the half-life of carbon dioxide in the atmosphere as well as inertia in the system. Even if emissions were to halt today, the Earth's surface temperature could continue to rise for a few centuries, and sea level could continue to increase for several millennia, due to thermal expansion and melting of ice. According to the IPCC, the following effects are likely to occur to surface temperatures, precipitation and climate-related extreme events:

2.2.1 Projected Changes for Surface Temperatures, Precipitation

i. The globally averaged surface temperature is projected to increase by 1.4 to 5.8 °C between 1990–2100 and
ii. Some areas are projected to become wetter and others drier, with a net increase in precipitation projected.

2.2.2 Projections for Climate-Related Extreme Events (E.G. Floods, Heat Waves). Include

i. Higher maximum temperatures: more hot days and heatwaves over nearly all land areas;
ii. Higher minimum temperatures: fewer cold days, frost days and cold spells over nearly all land areas;
iii. More intense precipitation events over many areas;
iv. Increased summer drying over most mid-latitude continental interiors and associated risk of drought and
v. Increase in peak wind intensity and mean and peak precipitation intensities in tropical cyclones.

2.3 Current Concern

2.3.1 Cumulative Impact of Climate Change on the Goronyo Dam

Climate change is likely to affect dams directly (e.g. through changes in temperature) and indirectly (e.g. through impacts on hydrology). Dams have typically been designed using historic periods of streamflow record to determine storage capacity and related dam infrastructure features, including spillways and hydroelectric turbine capacities. Understanding climate change will likely impact the quantity and timing of water availability. Specific impacts are projected to include

i. *Decreased water availability in the Sokoto River Rima Basin (Goronyo Dam catchment).*

The decrease of water availability is attributed to poor watershed management, deforestation, irrigation systems, waste and poor management of hydrology in the catchment area and shortage of rainfall as well as siltation of the dam (Plates 1 and 2).

Developing countries are projected to be the most vulnerable to climate change: many are already more prone to water shortages. In the area under study, indigenous communities that depend on dam water resources are already vulnerable and will become more vulnerable as a result of these projected impacts; current conditions are the worst seen in the dam in over 25 years. Compounding the chronic problems is the shortage of rainfall in 2017 and siltation of the dam, which is directly related to climate change. In addition, increasing sea surface temperatures were recorded in most of the region during the last three (3) decades 1980–2019 (Plate 3, 4 and 5).

Plate 1 Section of Goronyo Dam from the northern side before 2017

Plate 2 Goronyo Dam Showing Upstream (A–B) and Downstream (C–D)

2.4 Study Area

2.4.1 Characteristics of Goronyo Dam

The Goronyo Dam in Sokoto is located in the Sokoto Rima basin, situated within the Niger north hydrological area (HA-1) in the semi-arid region of the Northwestern

Plate 3 Goronyo Dam water shrinkage from spillway in 2017

Plate 4 Sand Dome presence in Goronyo Dam

part of Nigeria (Fig. 1), between latitude 11°N to 16°N and longitude 3.3°E to 10°E. The entire basin covers a total catchment area of 131,600 km^2 and is drained by many rivers, including the Tarka (upstream of Goronyo Dam), Kaba, Tagwai, Maradun, Bunsuru, Gagare, Sokoto, Zamfara and Ka rivers. The Sokoto-Rima extends from parts of Katsina and the entirety of Sokoto, Kebbi and Zamfara, and covers a small portion of Kaduna and Niger States. Major dams in the basin are the Bakolori and Goronyo dams. The capacities of the dams are 942 and 450 million m^3 with planned irrigation area of 69,000 ha and 30,000 ha, respectively. The actual developed irrigation area is just 40,000 ha.

Plate 5 Goronyo Dam showing water resource shrinkage

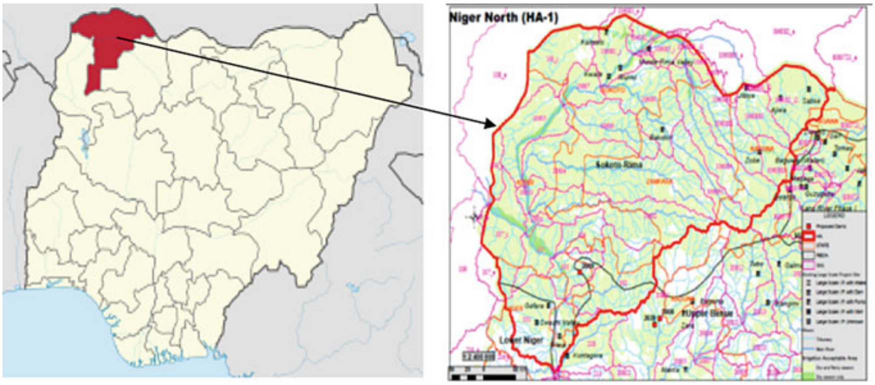

Fig. 1 The Study Area Showing Goronyo Dam; *Source* NASRDA 2012

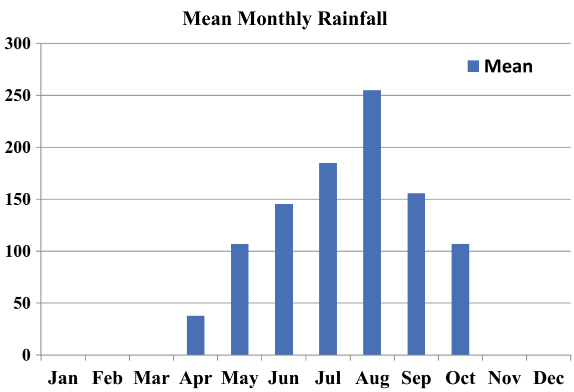

Fig. 2 Average Rainfall Amount (mm) in Sokoto from 2007 to 2017

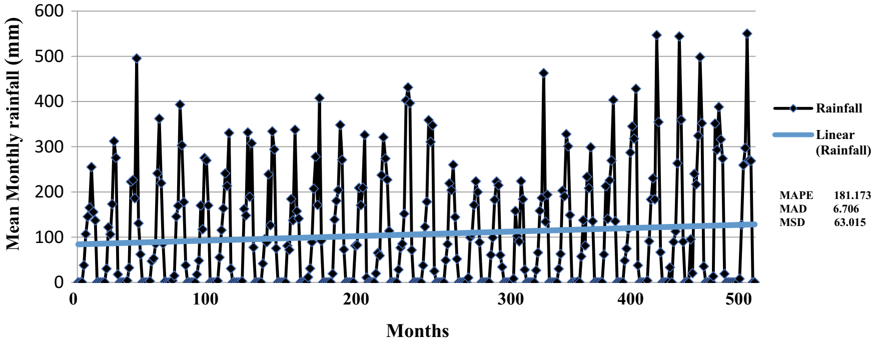

Fig. 3 Time series of total rainfall; 1920–2007 at Gusau Aerodrome

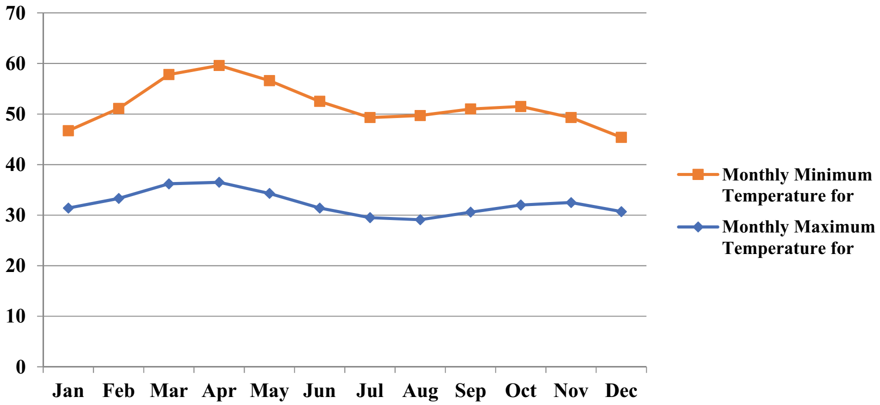

Fig. 4 Maximum, Minimum and Average Temperature (°C) in Sokoto

The Goronyo dam is classified as large dam in Nigeria and it is multipurpose in nature. The Goronyo dam was completed in 1984 but commissioned in 1992 and is to store 942 millioncubic meters for irrigation and development of downstream areas from Goronyo to Argungu, covering an area of about 200 km^2. The dam, which is earth-filled and built across the Rima River on the Sokoto Rima basin, is located near Keta Village, about 25 km east of the town of Goronyo and 90 km northeast of Sokoto City; it is the largest dam under the jurisdiction of the Sokoto Rima River Basin Authority (SRRBDA) (Figs. 2, 3, 4 and 5).

2.4.2 Hydrology of the Goronyo Dam

The Goronyo Dam is located within the Sokoto Rima River Basin, which is essentially drained by the Sokoto River, a prominent part of the Niger River drainage system.

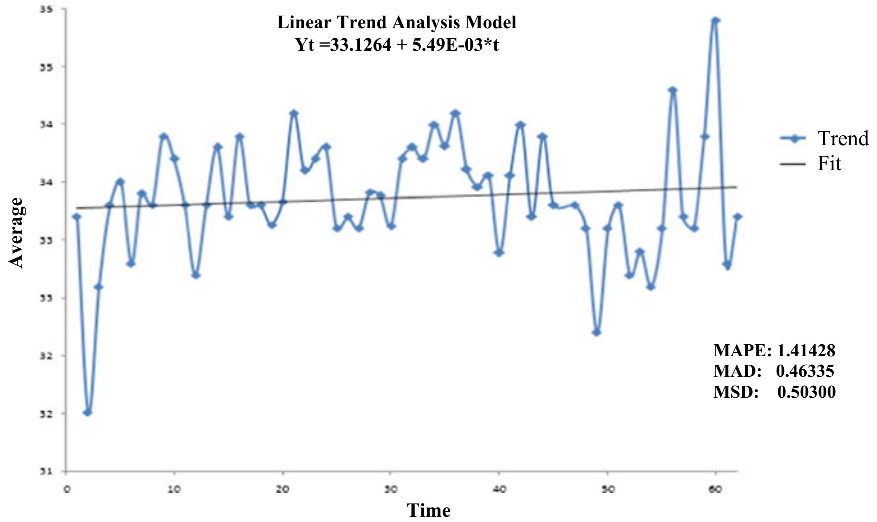

Fig. 5 The trend analysis for temperature 1949–2009 (*Source* Sokoto New Airport)

The Sokoto River rises with its main tributaries, the Ka, Zamfara and Rima, from the 600 to 900 meter-high Mashika and Dunia highland areas bordering the eastern part of the basin, and flows sluggishly down a gentle slope towards the northwest around Sokoto town. It is joined by the Rima in the north, making a southward swing, collecting the rivers Zamfara and Ka before entering into the Niger River. The river systems thus effectively drain the whole basin. At the source areas in the east, the Sokoto River System is only seasonal, but in the western parts of the basin, the river becomes perennial as substantial groundwater contributes to its flow.

The dam comprises three earth-filled dams; the main, secondary and saddle dyke with a total length of 12 km, a concrete intake and outlet structure including a spillway of 1,540 cubic meters and other infrastructure.

2.4.3 Goronyo Dam Capacity

The dam is designed to provide water for irrigation and development of downstream areas including the middle Rima Valley and the Zauro Polder Project, covering a total of 17,000 hectares. It provides an annual regulated flow of 425 million cubic meters to double the present rice cultivated fadamas from 40,000 to 80,000 hectares, and supplies 80 million cubic meters of water annually to the Sokoto, Argungu and Birin Kebbi water supply scheme, while the 200 km^2 lake formed by the dam is expected to boost the fishing industry in the area.

2.4.4 Climate Around Goronyo Dam

Like the rest of West Africa, the climate of the region is controlled largely by the two dominant air masses affecting the sub-region. The regions are also associated with the movement of air masses of the Inter Tropical Convergence Zone north and south of the equator.

3 Methodology

3.1 Data Collection and Analysis

Data for this study was generated through field visits to the dam site on 30 November 2018, and geographical review of the Goronyo Dam by comparing historical data from imagery, field observations and assessment of the dam and water shortage evidence, and field assessment of the effects of climate variability on settlements and farmlands. Using a digital camera, pictures were taken of the dam and of the farmland that was once irrigated using the dam water. Farms using dam water for irrigation were also investigated. The historical climate records up to 2018 were compared to determine the trends in various climate parameters, including temperature and precipitation in the hydrological area. The catchment for analysis, chosen as a basis for the general climate conditions of the area, was Sokoto New Airport and Katsina and Gusau aerodromes. Secondary sources of data were collected through desk research from subject-matter Internet sources, including published journal articles, discussion papers, environmental reports and presented conference papers (National Water Conference and National Water Resources Council) (Plate 6).

3.2 Climate Change Variability Analysis

Stream flows are generally affected by the cumulative effect of climate change. Hence, study of stream flow over time is essential, especially to determine the sustainability of water resource systems. The most significant observed impacts include changes in temperature and precipitation, which in turn have varying consequences for water availability. For this reason, trend analysis was used to define climate change with respect to rainfall, evaporation, temperature and humidity in the hydrological area, using Microsoft Excel (Plate 7).

Plate 6 Goronyo residents queuing for water from alternative sources due to water shortage from Goronyo dam to the water treatment plant

Plate 7 Stream drying up and fishermen abandoning fishing net as a result of impact of climate change on the dam

4 Results and Discussion

Results have established the impacts of climate variability around the Goronyo Dam located in Hydrological Area I. However, all the stations considered in the analysis for stream data, i.e. Wamakko on the River Rima, Jega on the River Sokoto and Gidan Doka on the River Zamfara, have demonstrated the impact of climate variability on their discharges over the duration under study. Moreover, the stations, i.e. Sokoto New Airport and the Katsina and Gusau aerodromes, were selected for the analysis of temperature and precipitation and have also shown the impacts of climate variability.

4.1 Trend in Climate Variability Analysis

The intensity, frequency and seasonal distribution of rainfall have particular impact on the amount of water available for various uses in the study area. The dry season, from early November until March, has no trace of rainfall at all. The mean monthly rainfall for the study area is depicted in Fig. 2, with the historical data in Fig. 2. This shows a reduced rainfall of 1.2% in the period 1949–1976 compared to 1976–2008. In addition, the historical trend shown in Fig. 3 at Katsina and Gusau aerodromes also shows an increase in annual rainfall in 1936 and 1965, reaching a maximum of 1,025 mm and 1039.4 mm, respectively, an increase of 1.4%. The average annual rainfall in Sokoto from the end of the 1970s through the 1980s was 632 mm, a decreasing trend, with the lowest recorded year at 325 mm in 1987.

The mean monthly maximum temperature of the study area is between 30.6 and 36.5 °C, with the hottest period in the months of March and April. The highest mean monthly temperature is observed in April with 36.5 °C, while the lowest mean monthly temperature is in December with 14.7 °C. Seasonal and latitudinal variations affect the extremes and the diurnal and seasonal ranges of the temperature in all areas. In addition, the daily minimum temperature by monthly average is lowest in August at 30.5 °C. From Fig. 4, it is evident that there was a significant rise in temperature at Sokoto New Airport between 1989 and 2009. A decrease of 1.8% was observed between the periods 1949–1976 and 1976–2008 (see Fig. 5).

4.2 Cumulative Effect on Water Supply

The communities of Goronyo that consist mostly of farmers depend largely on dam water for domestic purposes, especially during the dry season. The importance of dam management is most evident during times of drought. The 2017 drought in the Goronyo dam affected the lives and livelihoods of almost two million people as a result of the shortage of water. Levels in the Goronyo dam basin, which provides water for farmers, fishermen and families, have dropped dramatically in the 2017/2018 to about 10% of its capacity, forcing authorities to ration water to homes and seek alternative water sources (Plate 6).

The impacts of climate change are being felt by both developed and developing countries. To the extent that they are felt more by developing countries, it is not necessarily because they are the highest contributors of climate variation, but rather because these countries lack economic, social and political infrastructures to respond adequately to the effects of climate change. The Sokoto state of Northern Nigeria, where Goronyo dam is located, contains a significant portion of the Sudan-Sahel ecological zone of West Africa. Since the early 1970s, climate anomalies in the form of recurrent droughts and numerous dust storms have threatened access to clean drinking water.

4.3 Loss of Fishing Grounds

Fishermen set traps in dam water bodies for home consumption and sale. Shortage of water from the dam has resulted in the disappearance of fish on the dried neighbouring streams. According to Tambuwal (2010), fishermen were negatively affected by the extreme event of fish stocks being carried away with the escape of the water, which devastated fishing activity.

4.4 Effect on Agricultural Farmlands

Climate change compounds the linkage of agricultural farmlands to poverty; the adverse impacts of climate change on farmland exacerbate the incidence of rural poverty. This is likely to be most severe in Nigeria, where agriculture is a major livelihood for the majority of the rural population. If nothing proactive is done to replenish the shrinking water supply, water resources in the Goronyo dam will become insufficient to support its communities.

In communities surrounding the dam, over 80% of the population depends on the dam for most of its survival, including from livelihoods from agriculture and fishing. The severe drought in 2017 brought into dramatic relief the adverse effects of variability in timing and amount of rainfall, and lack of water for the irrigated farmlands (Plate 8).

4.5 Migration and Conflict

Nigeria is home to more than 15% of the entire African population, with a median age of just 19 years. Its total population is projected to double to roughly 320 million by 2040 (Red Cross 2013). Climate change is already affecting Nigeria in significant ways. The most noticeable is in the 1,350 square miles of Nigerian land that turns to desert each year, driving farmers and herders south from the Sahel and into cities. Lake Chad, which marks Nigeria's northeast border, was reduced to one-twentieth of its size during the 1960s due to a drier climate and changing water management. These effects have exacerbated additional destabilization. More recently, in 2017, the Goronyo dam saw its water level depleted to about 10% of its installed capacity due to the cumulative pressure of climate change. This has devastated the livelihood

Plate 8 Farmlands showing symptoms of stress downstream of the dam

of many farmers in Goronyo and its surrounding communities, and resulted in some farmers migrating to other areas, in particular the Bakolori Dam in neighboring Zamfara state.

The Bakalori Dam was the source of water for cattle farmers living within Goronyo, as well as for nomadic herdsmen who brought their cattle to drink at the dam. Herdsmen also graze their cattle, because grasses grow along the banks of the dam. During the study visit to Goronyo dam in 2017 and 2018, only a few small herds of cattle were observed to be moving on the plain of the dam, compared to the thousand observed previously in the 1980–2000 (Plate 9).

Plate 9 Few cattle with herdsmen and a fisherman behind them (showing decline in cattle numbers)

It is critical to consider the resulting effect with regard to migration and conflict associated with the 2017/2018 drought due to shortage of water in the Goronyo Dam, because it includes migration, leading to tension, violence, conflict and loss of livelihood in the affected communities or areas of new settlement. The majority of those affected by the migration lost their farm land, the source of pasture and water for their livestock, compelling them to leave their familiar rural environments to reside in an unfamiliar urban setting.

4.6 The Role of Adaptation (Interventions)

Adapatation to climate change has the potential to mitigate its adverse effects, but cannot prevent all impacts. Numerous projects and processes designed to reduce the impact of climate change have been identified that can reduce adverse and enhance beneficial impacts of climate change, but all come at a cost (Gwary 2008). Adaptation is necessary to complement efforts to take deliberate action to reduce the sources of and/or enhance the sinks of greenhouse gases. Together, adaptation and mitigation contribute to sustainable development objectives for dams and reservoirs.

Adaptation activities can promote conservation and sustainable use of man-made and natural solutions to reduce the impact of changes in and extremes of climate on cumulative pressures on dams and reservoirs. These activities include the establishment of interconnected, multiple-use reserves designed to take into account projected changes in climate, and integrated land and water management activities that reduce non-climate pressures on dams and reservoirs and hence reduce structural and human vulnerability to changes in climate. The effectiveness of adaptation and mitigation activities are enhanced when they are integrated within broader strategies for sustainable development.

4.7 Management Approaches for Addressing the Impacts of Climate Change on Dams (the Goronyo Experience)

The Nigerian government should as a matter of urgency facilitate a sustainable program to mitigate the upsurge and cumulative effects of climate change. Within such a strategy, the following approaches for the case of Goronyo Dam are suggested.

4.7.1 Use of Wetlands as Improved Watershed Infrastructures

Wetlands can be used to trap sediment, retain water during high flow periods and attenuate nutrient loads. Strategically placed constructed or restored wetlands in watershed headwaters or near dams have the potential to ameliorate the impacts of large precipitation events (World Commission on Dams 2015). The upstream debris dams and sediment basins can help trap coarse-grained sediment before it reaches the dam. River basins can be dredged periodically at less cost than large reservoir dredging.

4.7.2 Integrated Watershed Management (Sokoto River Rima Basin Development Authority-SRRBDA)

Sokoto Rima River Basin Development Authority should be encouraged to develop and implement a sophisticated Watershed-based Management Program for Restoration and Protection Strategy (WRAPS), based on the dams within its jurisdiction, involving collaboration among several state agencies. The program should be built on a planning and management framework with stakeholder involvement, which is essential because it is the stakeholders who are responsible for developing watershed assessment, establishing goals, identifying necessary actions and costs, preparing a watershed plan, and securing resources needed to execute on it. This process must be closely monitored by the SRRBDA, under the authority of the Federal Ministry of Water Resources in the capital of Abuja, Nigeria. Relevant stakeholders for the Goronyo Dam include

Bilateral and Multilateral Organizations

i. Niger Basin Authority (NBA)
ii. IAEA-UNESCO-GEF Regional Project on Development of Water Resources of the trans-boundary Iullemeden Aquifer System
iii. UNICEF: Water Supply and Sanitation Projects
iv. World Bank: Water Supply and Irrigation Projects
v. African Development Bank (AfDB)

Nigeria Federal Level:

i. Federal Ministry of Agriculture
ii. Federal Ministry of Environment
iii. Federal Ministry of Water Resources—Implementing and Coordinating Capacity.

State Level:

State Water Boards (SWBs)/Corporations or Utility Boards for water supply schemes, including the development and Operation & Maintenance (O & M) of the schemes.

Areas of Collaboration:

i. Various stakeholders should provide relief material and supports (which include seedlings for agricultural purposes, technological support with information from extreme weather events, water pumps and credit facility, etc.) to the farmers affected by the shortage of water from Goronyo Dam who have suffered loss of farmlands and food crops with a view towards rehabilitating their shattered lives;

Table 1 Dam services and possible impacts due to climate change

Reservoir-Derived Ecosystem Services	Possible Effects due to Climate Change
Flood Control	Overwhelm flood control capacity
Water Supply: Municipal	Sedimentation diminishes water supply capacity; uncertainty in drought adds water supply stress; increased nutrient loading will increase eutrophication
Water Supply: Industrial	Sedimentation diminishes water supply capacity; uncertainty in drought adds water supply stress and decrease in water quality
Water Supply: Agriculture	Sedimentation diminishes water supply capacity; uncertainty in drought adds water supply stress
Power Generation	Decreased inflow may bring water levels below turbines and decrease power generating potential

ii. Every stakeholder should work towards ensuring that water resources, especially small and large-scale dams, are properly managed: mismanagement leads to the loss of water resources as well as the destruction of live sand properties and
iii. Technical personnel should be hired to supervise the dam and its condition during the rainy season so that excess water is released in a timely manner.

4.7.3 The Need for Flexible Financial Mechanisms to Cope with Climate Change

Another strategic management approach to address the impacts of climate change on dams is the consideration and development of flexible financial mechanisms to manage climate change adaptation. The most obvious option is to provide agricultural subsidies to farmers and herders during floods and drought. This measure has the potential to create a highly enabling macroeconomic environment in which approaches for addressing climate change adaptation becomes the responsibility of individuals. The challenge is to secure equitable wealth distribution to affected individuals and to target support to those most likely to be affected by climate change (Table 1).

4.7.4 Innovative Technology Through Use of Tubewells

Tubewells (also known as sand point wells) are an important adaptation technology measure for providing a domestic water supply during times of water shortage and drought. They extract freshwater from subsurface or deeper groundwater aquifers. The approach includes both creating new tubewells as a response to drought, and/or deepening and rehabilitating existing ones. Construction is relatively easy, and tubewells are most often installed using a hand auger. However, for a tubewell to serve as a source of potable water, precautions must be taken to ensure that water quality

Table 2 Major factors in tubewell management

Consideration	Description
Environmental benefits	Relieves pressures on surface water sources, reducing risks of pollution and degradation
Socioeconomic benefits	i.Provides freshwater for domestic and other uses in times of drought ii.Produces high-quality water, reducing health risks that may occur from use of surface water sources iii.Helps avoid interruption of significant socioeconomic activities during dry periods
Opportunities	Increased diversification of water sources provides for more water but also increases water supply resiliency
Major Barriers	i.Requires pumping and associated energy supply (and costs) for larger volumes, ii.Requires knowledge of local geological conditions and assessments of chosen drilling sites iii.Poorly coordinated well development can cause a groundwater table decrease and create risk of over-abstraction iv.In areas with high climate variability (floods and droughts), tubewells and boreholes are at risk of contamination during flood events

is acceptable. This is done through groundwater surveys. Major factors in the choice of tubewells include Table 2.

4.7.5 Improvement of Disaster Preparedness and Management Skills

Given the general lack of disaster preparedness in the region, community-created emergency structures, including procedures and training for potential disaster scenarios, must be created, institutionalized and expanded to include stabilization or livelihood programs, to build a systematic structure for redeploying labour after drought or other extreme events of climate change (Plate 10).

4.8 Integrated Approach to Reservoir Management with Climate Change

The sustainability of dams is critical, but long-term sustainability efforts are complicated by the uncertainties of climate change. Even if past climate data can be used as a proxy for possible future droughts and floods, it may not be sufficient for planning into the future (Uyiguie, 2006). In an era of uncertainty, water resource managers must employ flexible methods to adapt to a changing climate. Adaptive policies and strategies can be informed and developed through simulation modelling. The most common approach is to combine a series of climate, hydrologic, reservoir and/or

Plate 10 Tubewells for Agriculture and water supply during drought

ecological models. A variety of mathematical and statistical models used to study the impacts of climate change on reservoirs is presented in Table 2.

Hydrologic tools (Table 3) are currently used to conduct climate change impact analyses for dams, and are ideal for examining a variety of climate simulations to inform management decisions.

Table 3 Mathematical and statistical tools used to study impacts of climate change on reservoirs

Tool	Description	Developer
Soil and Water Assessment Tool (SWAT)	Simulates water quality and quantity of surface water and can test scenarios related to land use, land management practices and climate change	USDA-ARS and Texas A&M Agri-Life Research
Hydrologic Engineering Center—Reservoir System Simulation (HEC-ResSim)	Uses rule-based approach to mimic decision-making process	Army Corp of Engineers
Integrated Adaptive Optimization Model (IAOM)	Contains three modules: weather generator, hydrological simulator and multipurpose reservoir optimization to develop optimal operating rule curves under climate change	Y. Zhou and S. Guo
Dynamic Hydroclimatological Assessment Model(DYHAM)	Utilizes system dynamics theories and feedback causal loops to simulate dynamic processes within watershed and reservoir	SP Simonovic and LH Li
Phytoplankton Responses to Environmental Change: PROTECH	Simulates the daily change in Chl-a concentration for up to 10 algal species in response to environmental variability in lakes and reservoirs	Alex Elliott, Colin Reynolds, Tony Irish

5 Conclusion

Reservoirs are established to provide critical services; they represent a large financial legacy from previous generations. With often limited locations appropriate to site new reservoirs, it is imperative that current reservoirs are analyzed and studied to improve and enhance their overall sustainable management.

In Nigeria, there are many dams that have been built and utilized for various purposes, particularly in semi-arid northern Nigeria. These dams are vital resources because they enhance the socioeconomic life of the people in areas where they are established.

The purpose of Goronyo Dam is to regulate flood from watershed areas in Kastina and Zamfara, including parts of the Niger Republic. However, in exceptionally dry years such as 2017 and 2018, there was an unanticipatedly low flow, siltation problems and little volume of rainwater, coupled with over-abstraction for irrigation agriculture from the upstream area of the dam.

Climate change in Nigeria is now devastating and destructive: the promotion of concerted effort and action is necessary to decelerate its impact on society.

Maintenance, including de-silting which has not been undertaken in over twenty years, is essential in order for Goronyo residents in Sokoto State to reduce the risk of even more water shortage challenges. To achieve this, collaboration among reservoir managers and climate scientists in Nigeria must result in the development of simulation modeling platforms to explore and test adaptive management strategies for altered climate patterns through careful review of available tools and thorough consultation with resource managers.

References

Alex Elliott SJ, Thackeray J, Huntingford RG Jones (2005) Combining a regional climate model with a phytoplankton community model to predict future changes in phytoplankton in lakes. Freshwater Biol. 50:1404–1411

Alverez M, UFH R, Trudel L, Leconte (2014). Impacts and adaptation to climate change using a reservoir management tool to a northern watershed: application to Lievre River watershed, Quebec, Canada. Water Resource Manage. 28:3667–3680

Azman B (2007) Impact of Climate Change on Water Resources Availability in the Komati River Basin Using WEAP21 Model. At the UNESCO-IHE Institute for Water Education, Delft, the Netherlands

Calebwura (2014) Impact of Climate Change That Causes Dryness on Water-Coast in Kware Stream, Sokoto State, Nigeria. https://calebwura.wordpress.com/2014/02/19/impact-of-climate-change-that-causes-dryness-on-water-coast-in-kware-stream-sokoto-state-nigeria/. (Date Accessed 9 September 2018)

Inter-Governmental Panel on Climate Change (2014) Synthesis Report. A Contribution of Working Groups I, II, and III to the Third Assessment Report of the Intergovernmental Panel on Climate Change. R.T. Watson and Core Writing Team. Cambridge University Press, Cambridge, U.K. and New York, USA

World Commission on Dams (WCD) (2015) Dams and Development, www.dams.org

International Federation of Red Cross and Red Crescent Societies (2013) Information Bulletin Nigeria; floods. www.frc.org/docs/Appeals/13/IBNG
Gwary D (2008) Climate change, food security and Nigerian agriculture. In Challenges of climate change for Nigeria; a multi-disciplinary perspective pp 179–202. Ibadan: Nigerian Institute of Social And Economic Research (NISER)
JICA (2013) The project for review and update of Nigeria national water resources master plan. Japan International cooperation Agency Yachiyo Engineering Co., Ltd. CTI Engineering International Co., Ltd. Sanyu Consultants Inc
Stainforth DA, Aina T, Christensen C, M., Collins, N., Faull, D., Frame, J. A., Kettleborough, S., Knight, A., Martin, J, M., Murphy., Piani, D., Sexton., Smith, R.A., Spicer, A, J., Thorpe M. R., Allen (2005) Uncertainty in predictions of the climate response to rising levels of greenhouse gases. Nature, 433, 403–406
Tambuwal UA (2010). Climate change: Threat to food security and livelihoods in selected states of Northern Nigeria. Paper presented at the 51st annual conference of the association of Nigerian Geographers at Department of Geography and Planning, Kogi State University, Anyigba
Thornton PK, Jones PG, Owiyo T, Kruska RL, M, Herrero, V., Orindi., S., Bhadwal, P., Kristjanson, A, Notenbaert, N, Bekele, A et al (2008) Climate change and poverty in Africa: Mapping hotsports of vulnerability. AFJARE, 2(1), 24–44 (Department for International Development, ILRI, Nairobi, Kenya)
Uyiguie E (2006). Dams are Un-renewable: A Discussion Paper. www.credcentre.org/publications/dams
World Weather Report (2018). https://www.worldweatheronline.com/kanoweather/kano/ng.aspx/wwo_r=srch (Date Accessed 5th August 2018)