Cumulative Pressure from Climate Change: Case Study of the Goronyo Dam, Iullemmeden Basin, Northwest Nigeria

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Abstract

Goronyo Dam is located across the Rima River at Goronyo (Latitude 13° 25' 56"E) in the Iullemmeden basin of Sokoto state, Northwest Nigeria. It has a storage capacity of 942 million cubic metres, mainly for water supply and irrigation to Sokoto and Birnin Kebbi states with population of over 8.5 million people. Recently, the water level in the dam has been reported to have depleted by 90% of its installed capacity, the worst since the construction of the dam over 30 years ago. Climate change with the shortage of rainfall in 2017 and the siltation of the dam has been attributed to this serious water level depletion. This has resulted to inadequate water supply to the Water Board that depends on water from the dam for water supply, irrigation, and other uses. The impact of the water shortage due to this climate change include dislocation of the socio-economic life of the people, families and livestock will be compelled to migrate thereby igniting socio tension and poor personal and communal hygiene with consequences of epidemics like cholera and dysentery etc. Construction of tube wells and effective management of water has been recommended to provide water supply to these communities until the rainfall situation improves.

Keywords: *Climate Change, Goronyo Dam. Precipitation, Water Resources, Conflict and Tube-wells.*

INTRODUCTION

A dam is a man-made structure built across sections of a river or stream to retain water and the water is generally used for agricultural purposes such as irrigating farmlands, garden, and watering of livestock (Lodha, 2007). It is as well a barrier constructed across a stream or river to impound water and raise its level for various purposes such as water supply and irrigation systems, and in addition increase river depth for navigation, generating electricity, control water flow during times of floods and droughts, create artificial lakes for fisheries and recreational use. However, many dams are multi-purpose and fulfil several of these reasons outlined (Uyigue, 2006). But very recently there has been upsurge in extreme events negatively impacting dams as result of changes in climate.

Climate and water resources systems have a special relationship in so far as water resources depends on the hydrological cycle which itself is part of the climate system

(Stainforth, et al 2005). Climate change has been observed to impacts on the function, operation and management of existing water resources systems and infrastructures, which include hydropower, structural flood defences, drainage, and irrigation systems as well as water management practices (Alvarez, et al. 2014). As effects of climate change on water resources systems aggravate, 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 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 uses, hydro-electric power, recreation and tourism, minerals etc. Furthermore, according to the World Bank, 2014, every development challenge of the 21st century such as food security, managing rapid urbanization, energy security, environmental protection, adapting to climate change require urgent attention to water resources infrastructural management.

Available information and statistics indicate that in recent times, climate variation or change is becoming more extreme in different areas. Various news media, print and electronic, all points to this obvious fact in their press release from time to time. This is not only peculiar to Nigeria but a global wide rapidly growing catalogue of storms, floods, and drought from all parts of the world, readily make climate variability headlines news.

Flood and drought as consequences of climate change causes tremendous losses on infrastructure and industry including poor personal and communal hygiene with consequences of epidemics like cholera and dysentery. In addition, the losses to agriculture caused both by floods and droughts are staggering and affect a vast majority of the population directly dependent for their livelihood (Azman, B. 2007)). A recent example of this was the horrendous hardship inflicted on the people of the Goronyo town of Sokoto State located in north central Nigeria in 2017 by drought due to shrinkage in water resources as result of shortage of rainfall in 2017 and the siltation of the Goronyo dam. This affected the socio-economic 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 induces a change in another. Persistent drought and flooding, off-season rains and

dry spells have interrupted the growing season of areas dependent on a rain-fed agriculture. Plants that require low or high temperature at some stages of their life cycle may adapt and survive in the short term, but in the long term, could become extinct.

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

AIM AND OBJECTIVES

The aims and objectives of this study is to consider climate variability and change in the context of global change that encompasses all pressures from human activities on water resources systems and infrastructures. We specifically look at some of the impacts on the Goronyo dam and then look at possible response options (or adaptation options) through integrative approach. The paper therefore covers:

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

METHODOLOGY

The data for the research study was generated through field visit to the dam site on 30th November 2017. Observation on the dam and the water shortages evidence, the effects on settlement, farmlands were assessed. Using a digital camera, pictures of the dam and the farmland that used to be irrigated using the dam water were snapped, farmers that used the dam water for irrigation were interviewed as they are the target population.

The interview question is on what time the dam water is used, the type of crops cultivated and the implication of the shortage of the dam water resources is having due to the impact of climate change, and their general knowledge on climatic variability

Secondary sources of data were collected through desk research from internet web sites related to the subject. Other sources include published journal articles, discussion papers, environmental reports and presented conference papers (National Water Conference and National Water Council). The data collected was then edited to suit the guidelines of Springer/Nature Book on Water Resources Management in the Climate Change Context in Africa. Descriptive analysis was employed to analyse the data with the aid of maps and pictures.

Climate Change and the Impact on Dams

We summarize the following:

i. Changes that have been observed in the hydrological circle (atmosphere, oceans) and the role of human activities in those changes.

ii. The (observed) impacts of these changes on water resources systems and especially dams and reservoirs.
iii. The role that adaptation can play in responding to these changes.

Table 1: Dams 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

Projected changes in the Climate System

Future emissions of greenhouse gases and aerosols are determined by driving forces such as changes in human population, socio-economic development, and technological change. The Inter-Governmental Panel on Climate Change (IPCC) in 2007 presents in its special report on emission scenarios six groups of scenarios or plausible futures which are based on narrative storylines and span a wide range of driving forces. The scenarios are used to project the 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 the emissions were to be stopped today, the Earth’s surface temperature could continue to rise for a few centuries, and sea level, due to thermal expansion and melting of ice, could continue to increase for several millennia. According to the inter-governmental panel on climate change, the following is likely to occur on Surface Temperatures, Precipitation, and the

projections for climate-related extreme events

Projected Changes for Surface Temperatures, Precipitation:

i. The globally averaged surface temperature is projected to increase by 1.4 to 5.8˚C over the period 1990-2100.
ii. Some areas are projected to become wetter and others drier, with an overall increase in precipitation projected.

Projections for Climate-related Extreme Events (e.g., floods, heat waves etc.) include:

i. Higher maximum temperatures; more hot days and heat waves 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.

CHARACTERISTICS OF GORONYO DAM IN NORTHWEST NIGERIA

Goronyo dam in Sokoto State is rated the second largest dam in Nigeria after Kainji dam. It is a multipurpose dam, designed to store 942 million cubic metres for irrigation and development of downstream areas from Goronyo to Argungu covering an area of about 200km^2. The dam is as well the largest dam under the jurisdiction of Sokoto Rima River Basin Development Authority (SRRBDA). It is located near Keta village about 25km east of Goronyo town and 90km northeast of Sokoto city. The earth fill dam is built across River Rima in the Sokoto Rima basin.

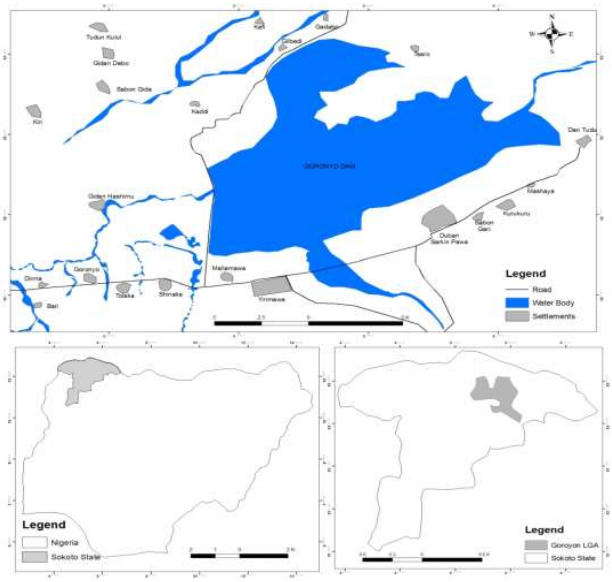

Figure 1: The Study Area Showing Goronyo Dam; Source: NASRDA, 2012

Hydrology of the Goronyo Dam

The Goronyo dam is located within the Sokoto Rima river basin. The basin is essentially drained by the River Sokoto a prominent part of Niger River drainage system. The Sokoto river rises with its main tributaries, the Ka, Zamfara, and Rima from the 600 to 900 meters high Mashika and Dunia highland areas bordering the eastern part of the basin, and flows down, rather sluggishly down a gentle slope toward the northwest around Sokoto town. It is joined by the Rima in the north, making a southward swing, collecting the river Zamfara and Ka before entering the river Niger. The river systems, thus effectively drains the whole basin. At the source areas in the east, the Sokoto river system is only seasonal. However, in the western parts of the basin, the river becomes perennial as it begins to receive substantial ground water contribution to its flow.

The dam comprises three (3) earth filled dams (main, secondary and saddle dyke of total length of 12km, a concrete intake and outlet structure including spillway of 1,540 cubic meters as well as other infrastructure.

Goronyo Dam Capacity

The dam is designed to provide water for irrigation and development of downstream areas that is, the middle Rima valley and Zauro polder project covering 17,000:00 hectares

The dam is design to provide an annual regulated flow of 425 million cubic metres to double the present rice cultivated Fadamas from 40,000 to 80,000 hectares

The dam also supplies 80 million cubic of water annually to Sokoto, Argungu and Birnin Kebbi water supply scheme while the 200km^2 lake formed by the dam is expected to boost fishing industry in the area.

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 region is also associated with the movement of air masses of the Inter tropical Convergence Zone north and south of the equator. During the raining season (March to October), it receives rainfall averaging 1200 mm annually. Under the influence of a Saharan high-pressure zone, the north-eastward harmattan wind brings hot, dry air and high temperatures onto the basin during the dry season (November to February). March is the warmest month of the year with an average air temperature of 35.3°C and the month of December is the coldest month, with temperatures averaging 18.2°C as shown in Tables 4.20 and 4.21.

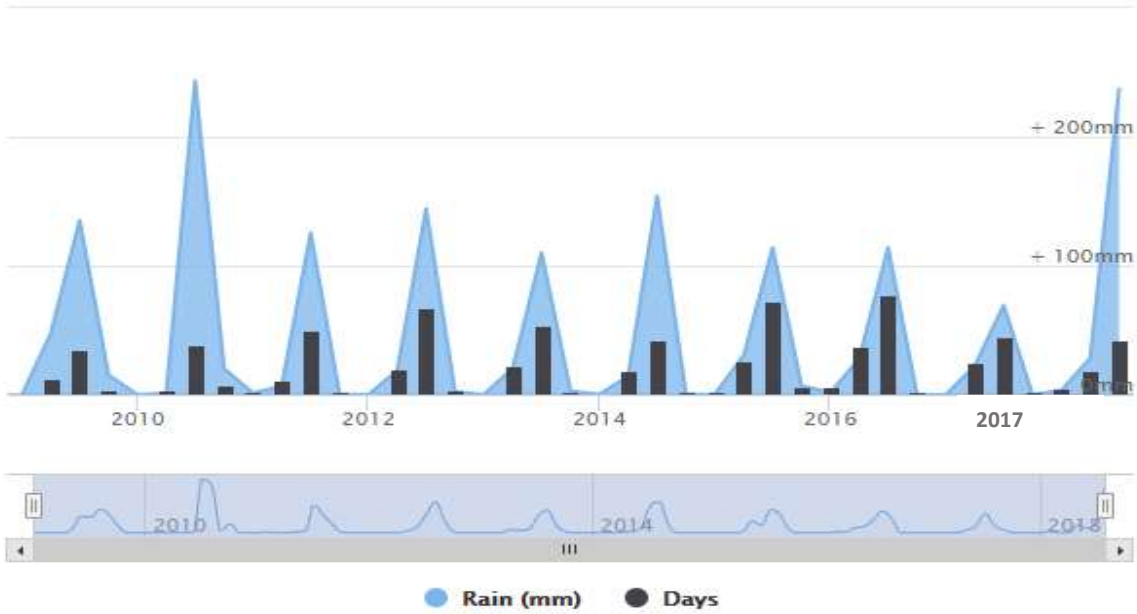

Figure 2: Average Rainfall Amount (mm) and raining Days in Sokoto
(Source: worldweatheronline.com)

In terms of climatic statistics, the annual rainfall for Sokoto ranges between 300 mm and 800 mm. The mean annual temperature is 34.5℃, although dry season temperatures in the region often exceed 40°C. (Ekpoh and Ekponyong, 2011). The temperature of Sokoto is given in (Figure 2.)

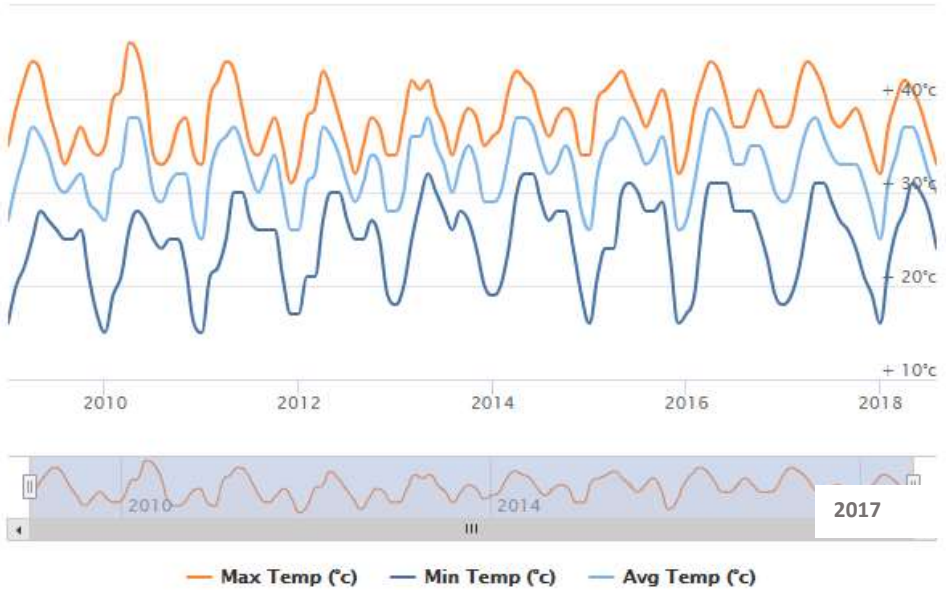

Figure.3. Maximum, Minimum and Average Temperature (°C) in Sokoto
(Source: worldweatheronline.com)

CLIMATE CHANGE IMPACTS ON GORONYO DAM

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

i. Decreased water availability in Sokoto river Rima basin (Goronyo dam catchment).

This in many spheres is attributed to poor watershed management, deforestation, irrigation system, waste, and poor management of Hydrology in the catchment area and shortage of rainfall as well as siltation of the dam as some of the factors affecting the dam.

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

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

Plate 3. Goronyo Dam water shrinkage from spillway in 2017

Plate 4. Sand Dome presence in Goronyo Dam

Developing countries are projected to be the most vulnerable to climate change; many are already more prone to water shortages. In area under this study, the indigenous communities that depend on dam for water resources needs are already vulnerable and would become more vulnerable because of these projected impacts. This is worst seen in the dam in over 25 years. However, there was also the problem of shortage of rainfall in 2017 and siltation of the dam which directly related to climate change. In addition, increasing sea surface temperatures were recorded in much of the region during the last several decades of the decades (Plate.3).

Plate 5. Goronyo Dam showing rate of water resource shrinkage.

GORONYO DAM DROUGHT IMPACTS (THE 2017 EXPERIENCE)

Effect on Water Supply

The communities of Goronyo who farmers are predominantly largely dependent on the dam for supply of water for domestic purposes especially during the dry season. The importance of dam management is brought into focus during times of drought. The 2017 experience of drought in Goronyo dam affected the lives and livelihoods of almost two million people as 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 past year, the water levels have dropped to just 10 percent of its capacity, forcing authorities to ration water to homes and seek alternatives elsewhere.

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

The impacts of climate change are being felt by both developed country and developing countries. These impacts are likely to be felt more by developing countries not necessarily because they are the highest contributors of climate variation but because they lack economic, social, and political infrastructures to respond adequately to the effects of climate change. In Sokoto State of Northern Nigeria, where Goronyo dam is located, contains significant portion of Sudan-Sahel ecological zone of West Africa, since the early 1970s, climate anomalies in the form of recurrent droughts and numerous dust storms with its adverse effects.

Loss of Fishing Grounds

The dam serves as fishing ground to fishermen that set traps in the dam water bodies to catch fish for home consumption and for economic purposes. The shortage of water from the dam has resulted in the decline of the dam water and no fish can be found on the dried neighbouring streams. According to Tambuwal, (2010), fishermen were negatively affected by the extreme event of the dam as fish stocks were carried away with

the escape of the water. All fishing activities were put off by the dry streams.

Plate 7. Stream drying up and fishermen abandoning fishing net because of impact of climate change on the dam.

Effect on Agricultural Farmlands

The concern with climate change is heightened given the linkage of agricultural farmlands to poverty. It is anticipated that adverse impacts on the farmland will exacerbate the incidence of rural poverty. Impacts on poverty are likely to be especially severe in Nigeria where the agriculture is an important source of livelihood for much of the rural population if nothing proactive is done to replenish the shrinkage situation of water resources in Goronyo dam.

In surrounding communities around the dam, over 80% of the population depends on the dam for large part of their daily survival including agriculture and fishing as their primary occupation. The 2017 experience however brought scenario leading to high risk of food production system being adversely affected by the variability in timing and amount of rainfall, and lack of water for their irrigated farmlands.

Plate 8: Farmlands showing symptoms of stress downstream of the dam.

MIGRATION AND CONFLICT

Nigeria is home to more than 15 percent of the entire African population and the median age is just 19 years. Its total population is projected to double to roughly 320 million by 2040 (Red Cross, 2013). In addition, climate change is already affecting Nigeria in significant ways. More noticeably is that roughly 1,350 square miles of Nigerian land turns to desert each year, driving farmers and herders south from the Sahel and into cities. Lake Chad, which marks Nigeria's northeast border, has been reduced to one twentieth its size during the 1960s due to a drier climate and changing water managements. Changing weather patterns have additional destabilizing effects.

More recently in 2017, Goronyo dam in north-western Nigeria have seen its water level in the dam been reported to have depleted by 90% of its installed capacity due to cumulative pressure of climate change. This has devastated the source of livelihood of many farmers in Goronyo and its surrounding communities. This has resulted in some of these farmers migrating to other areas especially the Bakolori dam in neighbouring Zamfara State.

This is because prior to the event of 2017, the dam use to be source of water supply to farmers who rear cattle that live within Goronyo and herdsmen who are nomadic in nature do come to the dam site with their cattle to drink water. The herdsmen also graze their cattle as grasses do grow along the banks of the dam. During the visit to the dam site, few groups of herds of cattle numbering a few numbers were observed to be moving on the plain of the dam as against the thousand previously observed.

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

The resultant effect is migration, which will lead to loss of livelihood, tension, violence and conflict in the affected communities or areas of new settlement. The view here is to consider the resulted effect with regards to migration and conflict associated with the 2017 drought due to shortage of water in the Goronyo dam located in Sokoto State, northwest Nigeria. Majority of those affected by the migration lost their farmlands, source of pasture and water for their livestock and compelling them to reside in an unfamiliar environment reflecting more of an urban setting different from their convectional rural environment.

THE ROLE OF ADAPTATION

The role of adaptation in climate change context has the potential to reduce the adverse effects of climate change but cannot prevent all impacts. Numerous adaptation options (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 will incur costs (Gwary, 2008). Adaptation is a necessary strategy to complement efforts to mitigate climate change (deliberate actions to reduce the sources or enhance the sinks of greenhouse gases). Adaptation and mitigation can contribute to sustainable development objectives for dams and reservoirs.

Adaptation activities can promote conservation and sustainable use of man-made and nature-based solutions to reduce the impact of changes in climate and climatic extremes on cumulative pressure on dams and reservoirs. These activities include the establishment of a mosaic of interconnected multiple use reserves designed to consider projected changes in climate, and integrated land and water management activities that

reduce non-climate pressures on dams and reservoirs and hence make the systems less vulnerable to changes in climate. Some of these adaptation activities can also make people less vulnerable to climatic extremes. The effectiveness of adaptation and mitigation activities can be enhanced when they are integrated within broader strategies designed to make development paths more sustainable.

MANAGEMENT APPROACHES FOR ADDRESSING THE IMPACTS OF CLIMATE CHANGE ON DAMS (THE GORONYO EXPERIENCE)

The Nigerian government should a matter of urgency facilitate sustainable climate change programme that will mitigate the upsurge and cumulative effect of climate change. However, for the case of Goronyo dam, the following measures are suggested.

In-Lake Sediment Management

In many areas, dams are rapidly filling with sediment, and action is needed to preserve these water resource investments (Gwary, 2008). Reducing incoming sediment and removing excess stored sediment are both options to preserve water storage capacity and increase the usable lifetime of reservoirs (Calebwura 2014). Basically, methods for drastic solution towards removing sediments include hydraulic flushing and hydraulic dredging.

In hydraulic flushing sediment is carried by water through a low-level outlet. However, reservoir levels must be low and reservoir inflow must be high for this method to be successful (Gwary, 2008). One major concern is in environmental protection, since the flushed sediments through the dam could be detrimental to downstream ecosystems, depending on the amount of sediment released (Alex, et al. 2005). This can be application the Goronyo dam as a measure to restore the dam.

The hydraulic dredging process employs an underwater cutter head to loosen consolidated sediments and then pumps the sediment-rich slurry through a pipeline to the storage location. It is important to note that dredging can be expensive and requires a large area for sediment disposal or storage and can decrease water quality (Stainforth et al 2005). It can also be challenging to dispose of dredged material without causing further environmental degradation (IPCC, 2007).

Use of Wetlands as Improved Watershed infrastructures

The uses of wetlands are also effective at trapping sediment, retaining water during high flow periods, and attenuating nutrient loads. Strategically placed constructed or restored wetlands in watershed headwaters or near dams could possibly ameliorate the impacts of large precipitation events (IPCC, 2007). This is because upstream debris dams and sediment basins can help trap coarse-grained sediment before it reaches the dam. River basins can be periodically dredged of material at a greater convenience and reduced cost compared to large reservoir dredging.

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

Sokoto Rima River Basin Development Authority should be encouraged to have a

highly developed watershed-based management program in the form of watershed restoration and protection strategy (WRAPS), program based in the dams within its jurisdiction which involves collaboration among several State agencies. The program should involve a planning and management framework based on stakeholder involvement. This is because the stakeholders are responsible for developing a watershed assessment, establishing goals, and identifying necessary actions and costs, preparing a watershed plan, and securing resources needed to execute that plan. This should closely be monitored by the department of river basins development authority under the Federal Ministry of Water Resources, Abuja Nigeria. The relevant stakeholder within the jurisdiction of the Goronyo dam includes:

Bilateral and Multilateral Organizations

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

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 development, Operation and Maintenance (O & M) of the schemes.

Thing to Collaborate on:

i. The various stakeholders should provide relief materials to the farmers affected by the shortage of water from Goronyo dam who suffered loss of farmlands and food crops with a view towards rehabilitating their shattered lives.
ii. Every stakeholder should work towards ensuring that water resources especially small- and large-scale dams are properly managed, as their mismanagement may not only leads to the loss of water resources but also causes destruction of lives and properties.
iii. Employment should be given to technical personnel that will be engaged in the supervision of the dam and its condition during the rainy season so that excess water is timely released.

The need for Flexible Financial Mechanisms to Cope with Climate Change

Another management approaches for addressing the impacts of climate change on dams is strategic approach that looks at 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 could create a highly enabling macroeconomic environment in which approaches for addressing climate change adaptation is the responsibility of individuals. The challenge will be to secure equal wealth distribution to each affected individual and target relevant support for

those most likely to be affected by climate change

Innovative Technology through use of Boreholes/Tubewells

Tubewells are important adaptation technology measures for providing a domestic water supply during times of water shortages and drought. They extract freshwater from subsurface or deeper groundwater aquifers. The approach can include both creating new tubewells as a drought response measure or deepening and rehabilitating existing ones. Its implementation is relatively easy to construct and most often installed using a hand auger. However, for tubewell to use as a drinking water source, precautions should be taken to ensure that water quality is acceptable. This is done through effective groundwater surveys. Major factors to consider in the choice of tubewells include:

Table: 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 socio-economic 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 being contaminated during flood events.

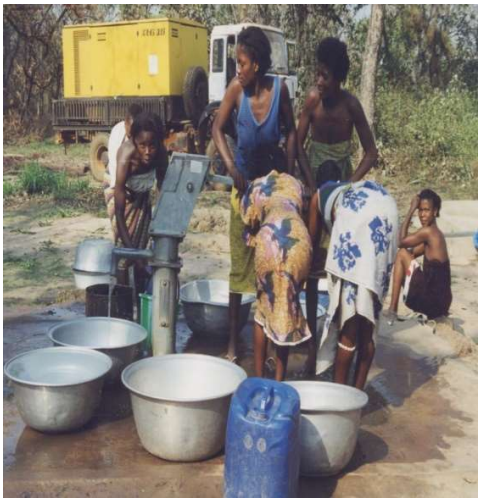

Plate10. Borehole for domestic water supply during drought

Improvement on Disaster Preparedness and Management Skills

Given the lack of disaster preparedness, community-created emergency structures, including procedures and training for possible scenarios must be built. If these structures could be institutionalized and expanded to include stabilization or livelihood programs, there would be a systematic and structured means of redeploying labour after occurrence of drought or other extreme events of climate change.

The Present Condition of the Goronyo Dam

Field visit to the dam site for data collection was held in November 2017. In May 2018, the dam was gradually refilling with the rainy season beginning in June, the water starts to recollect in the dam.

IDENTIFIED INFORMATION NEEDS AND GAPS

As noted above, it is widely accepted that human activities as evident through climate change are adversely affecting ecosystems and their ability to provide ecosystem services that support humans and life on earth more generally. As climate change and other environmental pressures are inter-linked, we need to assess the effects of these multiple pressures if we are to develop programmes and actions that support sustainable development and human well-being. This assessment includes:

i. Obtaining knowledge of the extent of many water infrastructures (dams) their condition and their hydrology.
ii. Improved understanding of the response of dams to changes in climatic factors and other cumulative pressures.
iii. Development of data and models for the geographical distribution of river networks and their response to climate change at local level.
iv. Development of models that include patterns of human land use and water use to provide a realistic projection of the future state of dams; and
v. Indicators to measure the effect of adaptation and mitigation options for climate change.

CLIMATE ADAPTATION IN RESERVOIR MANAGEMENT

Dams' sustainability is a critical issue, but long-term sustainability efforts are challenged by the uncertainty of climate change. In the past climate data can be used as a proxy for possible future droughts and floods, but this past data may not be sufficient for future planning (Uyiguie, 2006). In an era of uncertainty, water resources managers will need to use 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, and reservoir and/or ecological models. A variety of mathematical and statistical models used to study the impacts of climate change on reservoirs is presented in (Table 2).

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 Centre – Reservoir System Simulation (HEC-ResSim)	Uses rule-based approach to mimic decision-making process	Army Corp of Engineers
Integrated Adaptive Optimization Model (IAOM)	Contains 3 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

The hydrologic tools (Table 3) are currently used to conduct climate change impact analyses for dams. This tool is ideal for examining a variety of climate simulations to improve management decisions.

CONCLUSION

Reservoirs provide critical services and represent large fiscal investments from previous generations. With often limited locations to develop new reservoirs, it is imperative that current reservoirs are maintained and managed sustainably.

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

The purpose of Goronyo dam is to regulate flood from watershed area covering Katsina, Zamfara including parts of Niger Republic in addition to other purposes. However, in exceptional dry year as we experience in 2017, there was an unexpected/unpredicted low flow, siltation problem, water leakages from the dam and little volume of rainwater coupled with over abstraction for irrigation agriculture from the upstream area of the dam.

Slowly but surely, climate change is now in Nigeria and is manifesting in a manner devastating and destructive that promoted and concerted effort and action must be taken to overcome its impact on the society.

If the dam which is in dire need of maintenance including de-silting which had not been done in over twenty years is allowed to continue, Goronyo residents in Sokoto State are at risk of facing more water shortages challenges.

It is therefore in the best interest of all stakeholders to have collaborations between reservoir Managers and climate scientists in Nigeria to develop simulation modelling platforms that can explore and virtually test adaptive management strategies in the context of altered climate patterns This should be through careful review of available tools before selecting one and should consult with other resource managers to determine if a model has already been developed for their area of interest.

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