Developing Appropriate Techniques to Alleviate the Ogun River Network Annual Flooding Problems

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Abstract - The perennial annual flooding problems occurring in Lagos and Ogun States during the rainy season due largely to release of excess water from the multi-purpose Oyan Dam reservoir built across Oyan River, a tributary of Ogun River, located in Abeokuta North Local Government of Ogun State, has reached unacceptable level. Annually, the flooding hazard causes severe economic, social, ecological and environmental impacts such as displacement of no less than 1,280 residents, interruption of major roads which inevitably leads to loss of valuable man-hours, infection of surface and ground water leading to increased incidences of water-borne diseases, disruption of commercial and educational activities and recession of shoreline. This paper reviews the genesis and root causes of the flooding problems with a view to proffer the best approach to alleviate and solve this problem on a permanent basis combining hydraulic and hydrological best practices.

Keywords: flood, dam, reservoir, management, hydraulic, hydrology.

1.0 INTRODUCTION

Worldwide, dams have contributed significantly to socio-economic development of countless developed and developing nations. Often, they are usually designed for one or more of the following purposes: power production, water supply, irrigation, navigation and flood control (Tucci, 1994). However, the preponderances of dams for socio-economic development since the middle of the last century and the associated impacts have created conflicting interests. These have been exercabated by the various dam failures and catastrophic floods associated with the operation and management of dams in various nations of the world. This scenario have reiterated the urgent need for a paradigm shift in the design, construction, operation, management and monitoring of dams. In addition, it also calls for a need to take into consideration the upstream and downstream constraints and their protection in the planning and operational phases to avert avoidable colossal losses. Even more challenging is the contribution of climate variability and dynamic forces to the sustainability of these dams. While developing nations such as Nigeria is still grappling with the above challenges, countries such as USA, Brazil amongst others, have taken conscious and pragmatic efforts to improve the efficient operation and management of their dams with reduced impacts on the environment while the protection of the surrounding floodplains have been brought to the front burner (Knapp and Ortel, 1992; Carter, et al 2006; Obeysekera, et al 1986; Tucci, 1994). A case in point is the Foz do Areia dam built in the 1980's, located 100km downstream of Iguacu River, State of Parana, Brazil. Despite the fact that the operational level was reduced from 744m to 741.5m, the 1983 flood with a return period of 170 years and duration of 62 days produced an estimated loss of US$78.1 Million while in 1992, a flood with a return period of 30 years and duration of 65 days produced an estimated loss of US$54.6Million.Meanwhile, for about fifty (50) years from 1930 to 1982, only a low to medium floods occurred (Tucci, 1994). Integration of flood forecasting model with a lead time of 24 hours, updated every four hours, using a known rainfall, helped to improve the operation of the dam, by keeping the level of water in the dam within operational level taking into consideration upstream and downstream constraints(Mine ,1998)(Figure 1).

Figure 1: Levels at Foz do Areia dam actual operation, with flood forecasting and operation management model (Mine, 1998)

From the study of Tucci and Villanueva (1997), it was recommended that the use of a combination of both structural and non-structural protective measures were necessary to enhance the protection of the surrounding floodplains considering the huge intervention costs. On the other hand, in USA, reduction of flood risks necessitated a nationwide re-evaluation of existing infrastructure for flood protection following Hurricane Katrina which involved levees and flood control dams among which is Folson Dam. Located in Sacramento, a confluence of Sacramento and American rivers, one of the US cities most vulnerable to significant flooding, efforts have been made to improve the reliability, capacity, and operations of the existing infrastructure as well as construction activities to modify and build flood damage reduction infrastructure (Carter, et al, 2006).Although largely, the use of both structural and nonstructural measures were still debatable. The need to inculcate such proactive and preventive measures in the management of our dams and in the protection of our floodplains was brought to the fore by the incessant flooding caused by the release of water from Oyan Dam resulting in catastrophic losses. Oyan Dam, with coordinates 7015' 30''N, 30 15' 20''E commissioned by Shehu Shagari administration in 1983 and operated by

Ogun-Oshun River Basin Development Authority, has been a mixed blessing. Being a storage dam, Oyan dam was originally designed to supply raw water to Lagos and Ogun States for municipal water production and support the 3,000ha Lower Ogun Irrigation Project with power generation potentials. Sadly, the dam has largely remained dysfunctional having failed to serve these purposes. Established in 1984, structurally, the dam has an embankment crest length of 1044m, a height of 30.4m, four spillway gates(each 15 m wide and 7m high), and three outlet valves (each 1.8m in diameter). The reservoir has a surface area of 4,000ha, a catchment area of 9,000km2, a gross storage capacity of 270 million m3, and a dead storage capacity of 16 million m3. Owing to the perennial flooding of the affected floodplains in the Ogun River network and the resultant adverse effects, attention has been drawn to the poor management of the dam and the associated reservoir and the need for effective reservoir and dam management in line with modern best practices (Ofoezie & Asaolu, 1997) and likewise for enhanced protection for the floodplains in the region along the river network downstream. Hence, the essence of this paper.

1.1 EFFECTS OF THE FLOODING

The flooding caused as a result of the poorly planned release of excess water from the multi-purpose Oyan Dam located in Abeokuta North Local Government of Ogun State portends grave economic, social, ecological and environmental impacts on the surrounding floodplains (Ofoezie & Asaolu, 1997). The two states largely affected are Lagos and Ogun States. The communities ravaged by the flood include Isheri, Ojodu-Berger, Majidun, Ikosi-Ketu, Mile 12, Agileti, Thomas Laniyan Estate, Owode Elede, Owode Onirin, Agboyi, Arepo, Odogun, Maidan, Epe and Ijebu-Ode.Likewise, parts of Abeokuta, Ewekoro and Obafemi/Owode Local Government Areas in Ogun State. The most recent flooding occurred in October 2010 while the flooding which took place in May 2009 after a heavy rainfall caused flooding over an area of 2,800ha. The unprecedented flooding incidence of October 2010 led to displacement of no fewer than 1,280 residents, loss of valuable man-hours owing to deadlock traffic, erosion of bridges and road surfaces, disruption of commercial and educational activities, endangered lives and properties, disruption of wildlife and spawning and recession of shoreline(Figure 2).

Figure 2. Flooding in Ajegunle, Ketu area of Lagos State (Source: The News, Oct 11, 2010)

Infection of surface water and ground water leading to increased incidences of water-borne diseases such as Schistosomiasis (Ofoezie & Asaolu, 1997) is also prevalent. Flooding also exposes residents to an impending cholera, diarrhea, malaria, skin infections and other water-borne diseases epidemic
(Etuonovbe, A.K.,2011)(Figure 3).

Figure 3. Ajegunle-Ikorodu Flood in Lagos (Source: Etuonovbe, A.K., 2011)

Encroachment of residential and commercial developments into the floodplain of the dam as a result of false security has not help matters. Based on the Federal Guidelines for Dam Safety, it is classified as Class 1 dam taking into consideration the height of dam, storage volume and potential downstream hazard (Federal Guidelines for Dam Safety, 1979).

2.0 HYDROGEOLOGY OF THE STUDY REGION

The location of a dam and the type of dam constructed is based on factors such as local geology, shape of the valley, local hydrology, climate, availability of materials, manpower and plant. For a river in any catchment, the flow is determined by climatic factors (particularly precipitation) and the physical characteristics of the drainage basin such as land use, type of soil, type of vegetation, area, slope, elevation, orientation, type of drainage network, extent of indirect drainage and artificial drainage (Wisler and Bater, 1959; Ward, 1967; Fetter, 1988). Geologically, the Ogun-Osun River Basin to which the drainage basin of Oyan Dam belongs is predominantly a basement complex in the north and coastal plain sand in the south but interspersed by Abeokuta, Ilaro and Ewekoro Formations with some measure of Alluvium(Aketoyon, et al, 2010) (Figure 4). Located in the southwest region of Nigeria, it discharges through a chain of dendritic system (Idowu and Martins, 2007) into the Atlantic Coast via the coastal sedimentary plains in Lagos State. The dam impounds Oyan River, a tributary of Ogun River creating Oyan Lake. Owing to the topography of the region which makes the upstream rivers and tributaries discharge into it, the Ogun River receives water from Iseyin, Lanlate and other towns. The tributaries flowing into Ogun River include Rivers Oyan, Ewekoro, Opeji, Eredu, Iwopin, Sokori, Owiwi, Ajire amongst others. The Ogun and Oshun Rivers in the basin discharge into Lagos Lagoon which flows into the Atlantic Ocean.

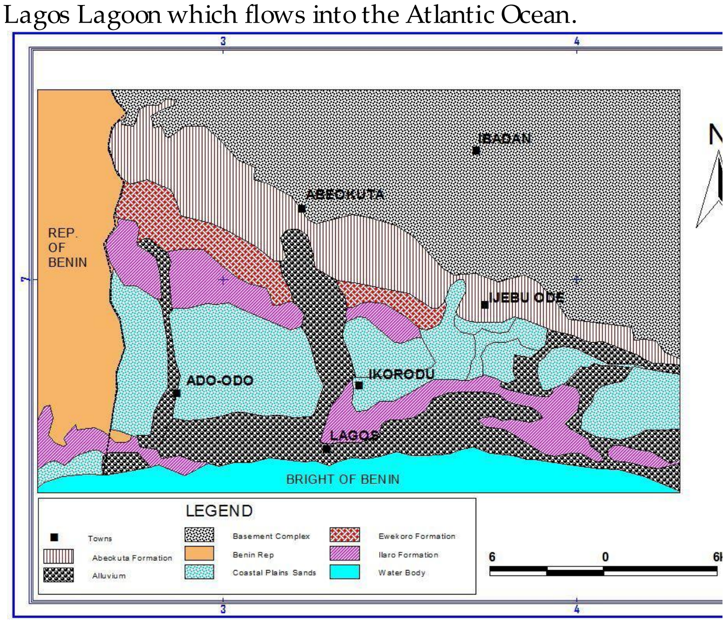

Figure 4. Geology of the Ogun-Osun River Basin (Source: Aketoyon et al, 2010).

Hydrologically, Oyan Dam is located at a confluence of Oyan and Ofiki rivers at an elevation of 43.3m above mean sea level. Short duration rainfalls of less than two or three hours are common occurrence, contributing immensely to flooding in this tropical region of the world (Oyegoke and Oyebande, 2008).

The mean annual rainfall of the catchment is 1015.09m, out of which rainy season accounts for 96.1% and the dry season 3.9 %(Ufoegbune, et al, 2011). With eight(8) rainy months, the highest rainfall occur in June, July and September which accounts for 47% of the total mean annual rainfall. The mean annual runoff generated from the catchment is 822.2million cubic metres. . The highest wind speed are found in the rainy seasons, April (0.44m/s) while the highest relative humidity occurs in July (89.5%).The mean monthly maximum and minimum temperature are observed in April and December which are 35.20c and 26.10c while the minimum and maximum air temperature occur in August(29.70c) and May and June(31.20c) respectively(Ufoegbune, et al, 2011). Furthermore, the variability of rainfall within the basin is within the range of 7%-13 %(Adeaga, 2006). The study of precipitation data from synoptic stations in the basin covering 1944-2003 showed that station at Osogbo had the highest rainfall stability(1.17) and the lowest instability of hydrological regime(1.10) compared to the coastal stations which recorded the lowest rainfall stability (0.71) and the second highest instability of hydrological regime(1.65)(Adeaga, 2006). The ecological zone varies from savanna to predominantly mangrove and freshwater rainforest (Idowu and Martins, 2007; Odumosu et al, 1999). The floodplains are fragile wetlands. The flow of the Ogun River network is influenced by rainfall in upstream region, rainfall in the study region and downstream, water release from the various dams located upstream and high tide of Lagos Lagoon. The southern end of the basin, which is Lagos State is drained by River Ogun in the centre, Ona and Osun Rivers in the east and Yewa in the west (Aketoyon, et al, 2010).

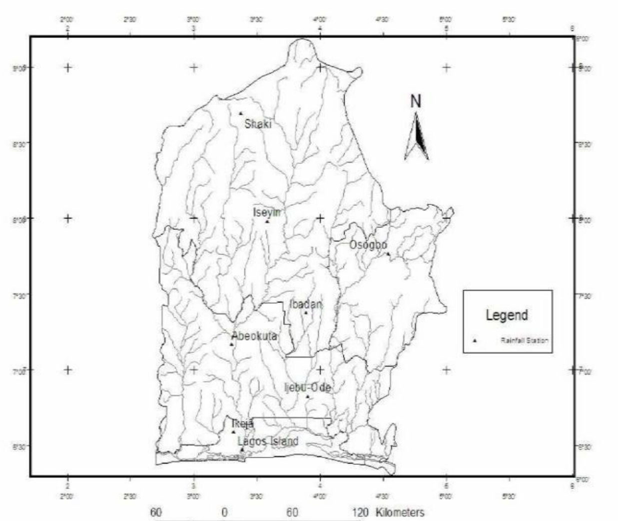

Figure 5. Ogun-Oshun River Basin Drainge Network, Southwestern Nigeria (Source: Adeaga, 2006)

3.0 CURRENT MANAGEMENT PRACTICE AND FLOOD PROTECTION MEASURES

During heavy precipitation in the region which are usually intensive, short-duration rainfall and apparently with contribution from upstream dams, the reservoir of the Oyan dam quickly fills up. When the reservoir level approaches 63m which seems to be the maximum design operational level, the gates of the dam are forced open to release excess water until the reservoir level falls to between 58-62m. Owing to the sudden and rapid discharge of water from the Dam, the channels of the downstream rivers reach flood levels which overflow their banks. Coupled with the sense of false security which has encouraged infrastructural development in the floodplains along the downstream channels and disregard for flood warnings, the impact of the flood assumes a catastrophic dimension. Added to this fact is the lack of structural protective measures for the entire floodplain (Figure 6). It is worrisome though that the Master Plan for Metropolitan Lagos (1980-2000) and Ogun State Regional Plan (2005-2025), which have zoned the floodplains and adjoining areas as forest reserves, conservation areas and buffer zones, have been jettisoned by both private and public developers.

Furthermore, emergency measures taken by the governments of the affected states to evacuate and relocate affected residents leaves so much to be desired. The conveyance channels downstream of the

Oyan Dam are not lined let alone built up for flood protection purposes. Also, majority of the communities in the floodplain have poor drainages which makes matters worse. Without gainsaying, it is apparent that the current operational management of the dam is far below the minimum best practice required for a dam of such magnitude. The non-structural measures for flood protection in form of flood warnings and temporary evacuation is far from being adequate, let alone being effective.

4.0 HYDROLOGICAL MODEL FOR DAM MANAGEMENT

The use of modelling to enhance dam operation and management and mitigate flooding of downstream has been in use within the last two to three decades. For Foz do Areia dam, flow forecasting model has been applied (Mine, 1998) in combination with a rainfall-runoff model and a hydrodynamic model which stimulates the flow in the river reach (Tucci, 1978; Wark et al, 1991; Villanueva, 1997). With the use of the models, the operational level was not exceeded using a flow forecast with a lead time of 24 hours. Hence, downstream flooding was drastically reduced. Likewise for Stratton Dam, a hydrologic model which serves dual purpose of simulating rainfall-runoff process in the watershed and flow-forecast was used along with a flow routing FEQ model which simulates flow hydraulics of Stratton Dam, Fox Chain Lakes and Fox River (Knapp et al, 1991; Knapp and Ortel, 1992). There results showed that the early release from the dam prior to the arrival of flood upstream through the use of flow forecast helped to reduce downstream flooding. The accuracy of the flow forecast model depends largely in part on the number of rain gauges used to develop the model.

For the development of a hydrological model for Oyan Dam, precipitation data from raingauge stations within its catchment area spanning considerable number of years would be used. Preferably, extreme, high-risk precipitation and some moderate-risk precipitation data which span some days would be valuable. Now that short-duration rainfall is a common phenomenon nationwide, data on this would be included. The eight synoptic rainguage stations within the catchment area which would be used include Ikeja, Lagos Island, Abeokuta, Ijebu-Ode, Ibadan, Osogbo, Shaki and Isheyin.(Adeaga, 2006)

The Oyan Dam/River hydrological model performs two basic functions:

(1.) Estimates flow hydrographs for ungauged tributaries/rivers of the Ogun/Oyan Rivers upstream which serve as input into the Flood Routing Model, which is in line with Corps of Engineer Study (USACOE, 1984) and

(2.) When modified into a flow forecast model, it produces flow forecasts using near real-time data but first using past historical data to estimate a "pseudo-forecast" for each historical flood that would be analysed. To make an operating decision for any day during these historical floods, it is necessary to have :

I. knowledge of the antecedent streamflow and oyan lake conditions occurring that day
II. an estimate of the flow forecast that would have been available on that day
III. establish a relationship between the flow forecasts and associated observed or recorded flows
IV. the probability of underestimating or overestimating the flows of actual floods that occur
V. Recommended policy for operating the dams for each alternative , based on antecedent conditions and forecast data.

The model would be used for implementation of the early release of storage in the Oyan Dam in anticipation of flood event before arrival at the Dam.

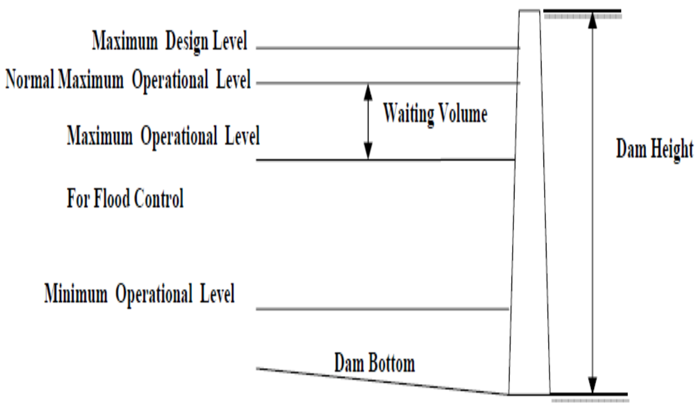

Figure 7.Dam schematic operational levels for Flood Control.

Likewise, it would allow for some lag time for safe water release from the dam within acceptable level of risk to downstream floodplain and provide waiting volume to contain the flood event (Figure 7).

4.1 FLOOD ROUTING MODEL FOR DAM WATER RELEASE

Routing has been in use to predict temporal and spatial variation of a flood wave as it traverses a river reach and outflow hydrograph from a watershed (Viessman, 1989). The flood routing model stimulates the hydraulics of the Oyan Dam, and associated rivers, and Oyan downstream channels and rivers using momentum equations utilizing partial differential equations for unsteady flow. The flood routing hydraulic model will take into consideration a wide range of historical and simulated flood conditions and potential operating schemes and would be utilised in producing the outflow hydrograph from Oyan Dam taking into consideration different precipitation and dam operation conditions. For the flood routing model, two types of data are required namely physical and temporal data. The physical data includes channels and rivers cross sections upstream and downstream of Oyan Dam. The temporal data include: inflow hydrographs, Oyan Dam gate operations and initial water levels. Past rainfall model could be used and updated with new data. Using various floods with different return periods would be useful in determining potential flood risk of downstream floodplains depending on the various dimensions of protective structures considered. The behaviour of a flood wave has been described by Muskingum in his method called Muskingum method(Viessman, 1989).It is states that the storage in a river reach depend primarily on the discharge into and out of a reach and on the hydraulic characteristics of the channel section expressed as:

$S = b/a\,[XI^{m/n} + (1-X)O^{m/n}]$ assuming $m/n = 1$ and $b/k = K$

This becomes: $S = K\,[XI + (1-X)\,O]$

Where K = the storage time constant for the reach

X = a weighting factor that varies between 0 and 0.5.

Constants a and n reflect the stage discharge characteristics of control sections

b and m = stage-volume characteristics of the section.

X = the relative weights given to inflow and outflow for the reach.

Assigning a routine incremental time time interval Δt which varies between K/3 and K, the resulting equation becomes

$O2 = C0I2 + C1I1 + C2O1$

Where $C_0 = \frac{-KX+0.5\Delta t}{K-KX+0.5\Delta t}$; $C_1 = \frac{KX+0.5\Delta t}{K-KX+0.5\Delta t}$; $C_2 = \frac{K-KX-0.5\Delta t}{K-KX+0.5\Delta t}$

Where subscripts 1 and 2 denote the beginning and ending times for Δt and $C0 + C1 + C2 = 1$

The limitations of the muskingum method was overcome by Cunge(1967) yielding results comparable with hydraulic methods.

5.0 DAM OPERATION ALTERNATIVES AND STRUCTURAL PROTECTION FOR FLOOD MANAGEMENT

In order to enhance protection of the affected floodplains, both structural and non-structural measures need to be implemented. The dam operation alternatives are one of the several non-structural protection measures that would be considered since it plays a significant, critical role in the flooding of the downstream floodplain. Other non-structural measures include flood zoning and emergency flood alert and evacuation.

5.1 DAM OPERATION ALTERNATIVES FOR FLOOD MANAGEMENT

The dam operation alternatives include:

I. Open gates below maximum gate opening during intra-storm periods whenever stages in the dam exceed the normal pool level

II. Open gates below maximally during intra-storm periods whenever stages in the dam exceed the normal pool level

III. Open the existing gates below maximum gate opening prior to the flood using the flood forecast model to estimate inflow using various scenarios of one to two days lead time

IV. Open the existing gates maximally prior to the flood using the flood forecast model to estimate inflow using various scenarios of one to two days lead time

IV. Follow alternative I but with normal pool level reduced.

V. Follow alternative II but with normal pool level reduced.

VI. Follow alternative III but with normal pool level reduced.

VIII. Follow alternative IV but with normal pool level reduced.

Calibration and validation of the model would be done to ascertain its effectiveness and applicability using two or more flood events using stage/discharge data.

5.2 STRUCTURAL PROTECTION FOR FLOOD MANAGEMENT

Structural protection for flood management includes dams, levees, dykes, canals, levees, retention ponds, etc (Tucci, 1994). For Sacramento in United States, a combination of Folson dam and levees spanning several miles have been in use to confine floodwaters to the river network and out of the floodplain where the city is located(Carter, et al, 2006). For the floodplains downstream of Oyan River Dam, feasibility studies into the best form of structural protection to provide is necessary considering the huge capital expenditures that would be involved which would have to take into consideration the level of protection to be provided and the socio-environmental impacts as well. In the interim, relocation of affected citizens to safer areas may prove a temporary measure, but a permanent solution is inevitable owing to the attractiveness of the floodplains for infrastructural development.

6.0CONCLUSION AND RECOMMENDATIONS

Climate change and variability coupled with the traditional operational method in use at Oyan River dam and the poor protective measures have led to incessant flooding of the floodplains downstream of the dam. The urgent need for a robust protection system for the affected floodplain is revealed by the enormous losses and impacts of the annual flooding. A combination of both structural and non-structural protection measures is required to alleviate the impacts of such flooding. The provision of a proactive and preventive system in the use of hydrologic model for flood-warning and hydraulic model for flow forecasting is required to enhance the operation of the dam and mitigate flooding downstream of the dam.

Failure to provide such pragmatic protection system for the floodplains and improve operation of the dam could prove disastrous in the near future. The hydrologic model would take into consideration the various operational alternatives mentioned while feasibility studies is required ascertain the best form of structural protection measure to be put in place for affected floodplain. On the whole, dam planning and operation involves responsibility for the effects which may be produced upstream and downstream of the dam and as such a robust protection system for the surrounding floodplains should be taken into consideration.

This should apply to Federal- and state-owned infrastructures such as dams across the country henceforth. Furthermore, there is need to increase the density of observation/monitoring stations and rain gauge stations along our rivers networks and in each river basin especially along flood plain areas across the nation with facilities for telemetering hydrologic data. This will enhance the accuracy of model developed for hydraulic and hydrologic purposes and provide lead time to avert flooding disasters. In conclusion, there is need to put structures in place to enhance the usage of Oyan Dam for irrigation, water supply and hydro-power generation purposes which will enhance the socio-economic development of the flood plain and likewise help reduce flooding of the affected wetlands in general.

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