# On the Causes and Effects of Earth Dams Failures in North-Eastern Nigeria

Umaru A. B,[1*] Sangodoyin, A. Y[2] , Oke, I. A[3]
[1]Department of Agricultural and Environmental Engineering,
Modibbo Adama University of Technology, Yola, Nigeria
[2]Department of Agricultural and Environmental Engineering,
University of Ibadan, Nigeria
[3]Department of Civil Engineering, Obafemi Awolowo University,
Ile- Ife, Nigeria

***Abstract*** **- An investigation of earth dam's failure in accordance with Association of States Dam Safety Officials (ADSO) 2011 guidelines was carried out in 3 northeastern states of Nigeria. A total of 42 earth dams were investigated comprising of 25 in Adamawa, 10 in Gombe and 7 in Bauchi States. Of this number, eleven (27%) were found to have failed, five (12%) were distressed, five (12%) were under construction and twenty one (49%) were functional. The failure modes exhibited include Hydraulic, Seepage, Structural and Piping. Sometimes, a combination of one or more of the failure modes with interaction in a complex manner was noticed in some dams. Lack of proper maintenance, embankment erosion, reservoir siltation and inadequate spillways are the major reasons responsible for failures of dams in the study area. To minimise incidence of failures, embankments should be maintained, reservoirs are to be desilted and spillways should be adequately designed and placed. Similarly, appropriate land use activities should be encouraged upstream. Slope protection in form of turfing (grasses) surd or rock rip rap is suggested at both the upstream and downstream slopes of embankments. Ant's and termite's infestation which are rampant in the embankment should be treated and removed. In addition, fence should be placed around the whole length of the embankment to avoid trampling.**

***Keywords: Earth Dam, Embankment, Reservoir, Failure Mode, North Eastern Nigeria***

## INTRODUCTION

A dam is a barrier that blocks the flow of water and produces a reservoir. The water stored in the reservoir is used for various purposes, such as irrigation, municipal and industrial supply, hydropower and recreation. Dams may also be constructed for flood control, retention of debris, navigation and various other purposes. A dam and a reservoir are complements of each other (Arora, 2001). Archeological evidences help in estimating that the very first man-made dam is at least 3000 to 5000 years old (Garg, 2008).

In Nigeria, there has been an upsurge in dam construction in the past three decades (Ofoezie, 2002). A total of 325 dams were identified in literature out of which 246 or 77% were constructed between 1970 and 1995. Following the Sahelian drought of 1972 to 1975, the impoundment of river basins was seen as inevitable to provide sufficient water for year-round irrigation and thus led to the construction of over 246 dams (Imevbore et al, 1986). Earth dams were made even popular since the creation of River Basin Development Authorities (R.B.D.A) under the Federal Ministry of Water Resources and Rural Development (Umaru et al., 2010).

The performance of water dams in Nigeria is still largely below expectation. Evidence abound in their frequent failures especially in northern Nigeria. There are evidences that the water resources of these dams are largely underutilized. The water has not been properly managed probably due to poor reservoir operation guidelines. Inefficient reservoir management has also partially intensified flood problems (Ifabiyi, 2011).

Earth dam's failures can be catastrophic involving lives and properties. The magnitude of recorded damages to earth dams range from complete catastrophic failure, resulting in large property damage and loss of life, to relatively minor deterioration which may or may not necessitate remedial work (ICOLD, 1983). The worst type of complete failure occurs when the reservoir water suddenly breaks through the embankment and surges downstream in one devastating flood wave. Lesser damages may in the long run lead to complete failure if left unattended and some of which require only maintenance work even under most extreme conditions (Gopal and Rao, 2007).

Dam's failures and incidences have been taking place all over the world over a long period of time in history. Reports on failure of dams are common things nowadays. Effects of dam's failure on man and environment are well known. These require both preventive and mitigation measures. Dam failures may occur due to a variety of causes. The most common causes of dam failure are leakage and piping (35%), overtopping

(25%), spillway erosion (14%), excessive deformation (11%), sliding (10%), gate failure (2%), faulty construction (2%), and earthquake instability (2%) (Lukman *et al*, 2011). Investigations carried out by Arora (2001) also showed that about 35% of failures of earth dams are due to hydraulic failures, while about 30% and 20% are attributed to seepage and structural failures respectively, the remaining 7% of the failures are due to other miscellaneous causes such as accidents and natural disasters.

There have been several cases of dam-related disasters in Nigeria with displacement of thousands of people, loss of livelihood and massive destruction of properties. These include the failures of Shiroro dam in 1999, Ojirami dam in August, 1980, Tiga dam in August 2001, Challawa dam in August, 2001, Shiroro second dam failure in September, 2003, Obudu dam in July, 2003, Igabi dam failure on river Kaduna and Cham dam in Gombe, September 1998. (Ezugwu, 2013, Lukman et al, 2011, Etiosa, 2006, Hope, 2003, and Umaru, 2001).

Ezugwu (2013), Daily Triumphs, (2011) and Wikipedia (2007) documented dam failures around the world. The world worst dam disaster happened in China in 1975 when the Banqiao and Shimantan dams failed killing about 171,000 people while 11 million lost their homes (Wikipedia, 2012 and Yi Si, 1975).

On a worldwide scale, it is clear that the objective of constructing stable dams is not always achieved. During the 1900–1965 periods, for example, about 1% of the 9000 large dams in service throughout the world have failed, and another 2% have suffered serious accidents (Wrechein and Mambretti, 2009).

Knowledge of the principal lessons learned from failures and damages in the past is an essential part of the training of the earth dam designer (Punmia and Lal, 1992). The information on dam's failure and causes of failure are important in environmental protection, safety of design and construction as well as operation and maintenance for overall national development. The main focus of this study is to identify failed earth dams in North eastern part of Nigeria, determine the causes, examine the modes of failure and suggest appropriate engineering measures to improve their functionality.

## MATERIALS AND METHOD

The method adopted for carrying out this study follows the Association of State Dam Safety Officials (ADSO) guideline, (2011). Dam sites were visited to locate and inspect dams in the region (Fig. 1), failed dams were identified, observations were made and necessary information on the dams were sought. Field work in form of site visits to 42 dams was conducted. This comprises of 25 dams in Adamawa, 10 in Gombe and 7 in Bauchi States. To get more information on the construction and maintenance of the dam, personal interviews were conducted with some officers and staff of the organization who were directly involved in the dam projects.

## RESULTS AND DISCUSSIONS

Of the 42 earth dams investigated, 11 have failed, 5 are damaged, 5 are under construction and 21 are functional (Fig. 1)

Nzuzu dam failed as a result of poor construction of the spillway coupled with general lack of maintenance. The stone pitched spillway gave way after a heavy storm; the flood breached the embankment below original ground level, retracing the original stream downstream. Animals also stampede the embankment further weakening it and aggravating erosion problems. There is no slope protection of any kind for the dam. The impounded water in the reservoir escaped through the eroded spillway flooding some parts of Garkida town (Figs. 2 & 3)

The reservoir of Nasarawo Gongoshi Grazing Reserve Dam1 (Dalehi) is silted up. Erosion has destroyed the embankment due to lack of spillway and maintenance. The dam is generally poorly maintained. There is no slope protection in place. The dam has completely failed with a gully cutting the right abutment below foundation level (Figs. 4 & 5).

Bambam dam design height was not achieved when the contractor left the site and was paid off. Compaction was achieved using a dozer which usually does not give good results. The dam failed hydraulically when the reservoir water overtopped the otherwise short and settled embankment forming a complete breach of the dam with the stream water passing through freely (Figs. 6 & 7).

At Sarau Belel Grazung Reserve Dam2, the runoff from the surrounding hills and mountains charges the reservoir through a stream. As at the time of the site visit the seasonal stream that recharges the reservoir does not flow into the reservoir; it is diverted over time to

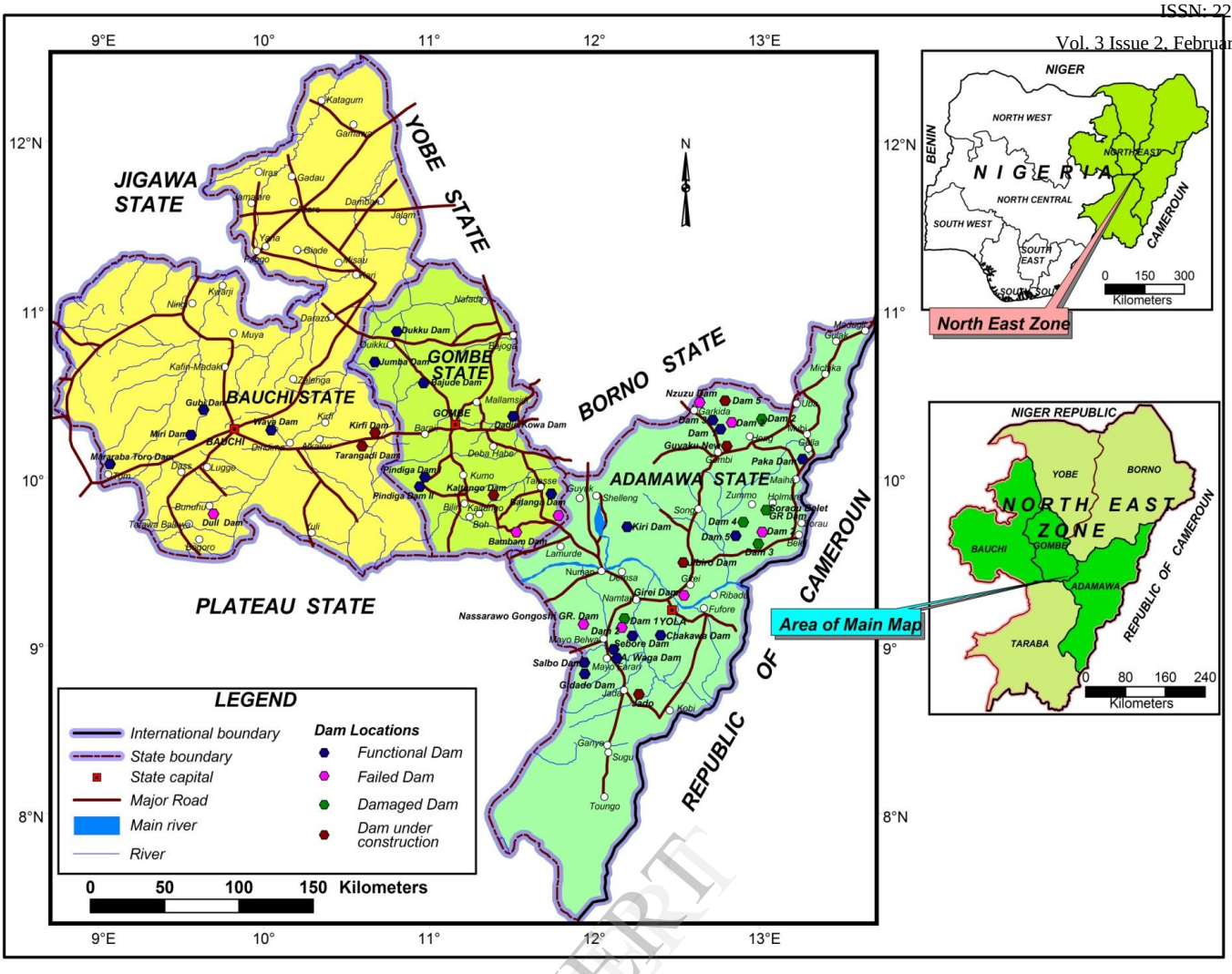


Figure 1; Map of North Eastern Nigeria Showing Dams Locations and Status

flow behind the dam due to lack of maintenance. The reservoir is completely empty. The dam has failed hydraulically. There is no slope protection, nor an appropriate spillway at site. There is virtually no access road to the dam site to facilitate maintenance (Fig. 8).

Dull dam failed as a result of a poorly constructed spillway which gave way during the first filling of the reservoir. The stone pitched spillway was fixed without a good foundation. These explain why the spillway failed and the embankment remained intact, allowing all the reservoir water to drain completely through the broken spillway. The appearance of ant's infestation on the crest shows a sign of danger from seepage and probably piping (Fig. 9).

At Girei dam, weak clayey soils were noticed around the spillway area which manifested in ultimate spillway failure. Excessive wetness along the embankment and at the toe of the dam was also observed. Loose silty sands were observed as predominant soil in the reservoir area, hence the low water retention capacity of the reservoir. The reservoir was completely dry during the second site visit just after two months from the first visit when the reservoir was almost full and water was about to spill. There is termite infestation on the crest along the embankment, thus posing additional danger to the dam. Girei dam failed essentially as a result of excessive seepage, siltation and spillway failure. This explains the unique failure of Girei dam where the embankment remains intact while the reservoir remains empty for greater part of the year (Figs. 10 & 11).

At Waya Dam in Bauchi, cracks were noticed on the crest at several positions as well as slope failures at different points on the embankment. The spillway was incapacitated and the flood wall failed subsequently. Seepage was noticed on the downstream shell of the embankment which resulted to piping and subsequently led to complete breach of the embankment. It appears that the design crest level was not achieved and coupled with a narrow spillway, the reservoir water overtopped the embankment. Both the spillway and the embankment suffered serious damages. The spillway was washed away by impounded water and the water tracks back and washed most of the downstream shell. Seepage resulted to piping and complete failure of the embankment as water from the reservoir escaped through the embankment. It was gathered that loose stockpiled materials were left on the embankment between successive layers during compaction after which the contractor left site. Later, the work was continued as direct labor under the Upper Benue River Basin Development Authority (UBRBDA). The loose materials does not compact to desired level due to difficulty with terrain as the roller cannot be maneuvered to achieve that. Another view has it that, after the contractor left the site, vehicles, human and animals traffic created a loose dusty layer on the embankment. Loose materials (dust) in between the contractors work and that of UBRBDA staff (direct labor) was created. The loose material that was left on the embankment which could not compact very well gave way to seepage and resulted into piping which led to the failure of Waya dam in Bauchi (Figs. 12 & 13)

The Guyaku Grazing Reserve Dam2 failed as a result of general lack of maintenance. An eye witness account indicated that the dam was in serious threat of failure for a long time but no action was taken. The dam finally gave way when part of the embankment was washed away as a result of serious erosion and ultimate overtopping. There was no definite spillway in place to cope with the reservoir water that led to the ultimate failure of the dam. This resulted in the formation of a gully that cut the dam axis at the right abutment below original ground level (Figs. 14 & 15).

The spillway of the Cham dam was not completed signifying danger to the dam during high inflow regimes. Again, the design height of the dam was not achieved when the dam was hurriedly commissioned in 1992. The dam was constructed without following design specifications. Two different designs were found for the dam crossection; one shows a zoned embankment with clearly delineated zones of central impervious core flanked with zones of pervious shells while the other one does not contain such zonings. The physical examination of the dam cross-section along the breach shows a homogeneous embankment with a mismatch of clayey to gravel size particles with no clear zoning. These are the major reasons for the dam failure. A similar phenomenon was observed on world population of dams by Foster et al, (2000a) and Foster et al, (2000b). The dam failed hydraulically and structurally when it was overtopped by a flashflood which undermines the height of the shortened embankment with uncompleted spillway and a very small outlet which could not drain the reservoir fast enough. With the absence of zoning, a complete breach of the embankment resulted in the cutting the dam up to foundation level, allowing the river to pass across the dam freely (Figs. 16 & 17).

Figure 2; Spillway Failure at Nzuzu Dam Garkida

Figure 3; Failure as viewed from Dam crest

Figure 4; N/G G Reserve Dam 1 Dalehi Silted up

Figure 5; Water overtops and cuts the dam forming a gully

Figure 6; Complete Failure of Bambam Dam in Gombe

Figure 7; Bambam Dam Spillway

Figure 8; The reservoir of SB/GR Dam 2 remains empty

Figure 9; Dull Dam Spilway Failure in Tafawabalewa Bauchi

Figure 10; Girei Dam reservoir about to spill and rehabilitated Spillway

Figure 11; Girei Dam reservoir empty after barely two months from first visit

Figure 12; Cracks on the embankment crest at Waya Dam Bauchi

Figure 13; Rehabilitation work in progress at Waya Dam in Bauchi after failure

Figure 14; Guyaku Dam2 Poorly Maintained Embankment

Figure 15; A Gully cut the Embankment at the right Abutment

Figure 16; Complete Failure of Cham Dam in Gombe

Figure 17; Crossection through the Embankment of Cham Dam in Gombe at the point of failure



## CONCLUSIONS

Generally there is lack of information and data on failures of earth dams in North Eastern Nigeria. The dams are poorly maintained with trees and shrubs growing on them while ant's and termites infestations were rampant on some embankments. Sometimes, spillways were not properly designed and placed. Cracks, slope failures and excessive erosion aggravated by animals trampling are common sights. Some embankments were not compacted to the desired level while the design height of some was not reached. High seepage and siltation rates were noticed in some dams and these are precursors to failure.

To minimise the incidence of dam failures trees and shrubs should be removed, reservoirs be desilted and spillways be adequately and properly designed. Appropriate land use activities should be encouraged upstream to minimise siltation. The embankment heights should be increased to compensate for erosion and siltation of the embankment and reservoir respectively. Slope protection in form of turfing surd or rock rip rap should be provided on both the upstream and downstream slopes. Ant's and termite's infestation should be treated and removed from the embankments. Animal fence should be placed around the whole length of the embankment to avoid trampling. The application of impervious blanket in the reservoir area is also suggested to minimise seepage and deep percolation. Access roads to the dams should be provided to facilitate maintenance.

## REFERENCES

1. ASDO (2011); Association of State Dam Safety Officials. *Dam Failure Investigation Guideline.* Dam Failure Investigation Committee.
2. Arora, K.R (2001). *Irrigation water power and water resources engineering*. Naisarak India:Standard publishers .
3. Daily Triumph (2011); Enhancing Dams Operation in Nigeria. Daily Triumph News Paper of March 4th 2011. Nigerian Newspers.com. Retrieved 4th Dec, 2011.
4. Etiosa, U. (2006) : Dams are Unrenewable. *A Discussion Paper. Community Research and Development Centre, Nigeria* ; A Paper Submitted to Federal Ministry of Water Resources, Abuja, Nigeria.

5. Ezugwu C. N. (2013). Dam Development and Disasters in Nigeria. International Journal of Engineering Research and Technology 21(9): 960 - 977)
6. Foster M., Robin F. and Matt S. (2000a). A method for assessing the relative likelihood of failure of embankment dams by piping. *Canadian Geotechnical Journal*. 37: 1025-1061
7. Foster M., Robin F. and Matt S. (2000b). The statistics of embankment dam failures and accidents. *Canadian Geotechnical Journal*. 37: 1000-1024
8. Garg K. S. (2008). Irrigation Engineering and Hydraulic Structures.21st rev. ed. New Delhi, India. Khanna Publishers Delhi.
9. Gopal R. and Rao A.S.R (2007). Basic and Applied Soil Mechanics (Rev. 2nd Edtn). *New Age International (P) Ltd; Publishers* 4835/24 Ansari Road, Daraganji, New Delhi-110002, India
10. Hope, E.O (2003): Damned to be Dammed? A Case Study of Ojirami Dam in Southern Nigeria. *Society for Water and Public HealthProtection*. www.swaphep.virtualactivism.net (2003)
11. ICOLD (1983). Deteriration of dams and reservoirs. International Commission on Large Dams (ICOLD), Paris.
12. Imevbore A. M. A., Ofoezie I. E., and Obot E. A. (1986). Report on the study on snail and cyclopoid borne disease problems of small scale water resources development projects in Nigeria. *Submitted to the World Health Organization by the* Institute of Ecology, Obafemi Awolowo University, Ile-Ife, Nigeria.
13. Ifabiyi, I. P (2011). Contributions of Reservoir Elements to Monthly Electricity Generation in the Jebba Hydropower Reservoir, Nigeria. Ozean Journal of Applied Sciences 4(3): 251- 265
14. Lukman S, Otun J. A, Adie D. B, Ismail A and Oke I. A (2011). A Brief Assesment of a Dam and its Failure Prevention. *Journal of Failure Analysis and Prevention*. 11;97-109
15. Ofoezie I. E. (2002). Human Health and Water Resources Development in Nigeria: Schistosomiasis in Artificial Lakes. Natural Resources Forum. 26: 150-159
16. Punmia B. C. and Lal P. B. B. (1992) . *Irrigation and Water Power Engineering. 12th ed*. Laxmi Pupblications (P) Ltd., India.
17. Umaru, A (2001). A Study on Earth Dams Failures in Nigeria, Cham dam in Gombe state as a case study. M.Sc project report. Agric. Engineering. Technology. University of Ibadan.
18. Umaru A., Ogedengbe K. and Omobowale M. O. (2010), Structural Failures of Earth Dams in Nigeria: A Case Study of Cham Dam in Gombe State. ARPN Journal of Engineering and Applied Sciences, 5, (11): 48 -52
19. Wikipedia Free Encyclopedia (2007). *Main Causes of Dam Filures*. Retrieved Dec. 10th, 2007 from http://en.wikipedia.org/wiki/List_of_dam_failures.
20. Wikipedia Free Encyclopedia (2012). *Banqiao Dam*. Retrieved Apr. 21st, 2013 from http://en.wikipedia.org/wiki/Banqiao Dam History.
21. Wrechien D. and Mambretti (2009). Dam-break Problems, Solutions and Case Studies. *WIT eLibrary*. WITpress Southampton, Boston USA.
22. Yi Si (1975) The World's Most Catastrophic Dam Failures; The August 1975 Collapse of Banqiao and Shimantan Dams. Online PDF Material retrieved 2nd May, 2012.