Adamawa State University Journal of Scientific Research
Volume 8 Issue 2, 2020; Article no. ADSUJSR 0802004
ISSN: 2705-1900 (Online); ISSN: 2251-0702 (Print)
http://www.adsujsr.com

Dam and its Failure: A Brief Review of some selected Dams around the World

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(Received in June 2020; Accepted in September 2020)

Abstract

This paper critically covers all the aspects of some selected dam failures around the world. The aim of the study is to examine the failures while the objectives are to; investigate the causes of the failures and to give possible recommendations. The materials used are journal articles. The methods involved are Google search with a view of extracting some relevant information on some selected dam failures. The result shows that factors responsible for the failure are due to geological, engineering and human factors. The geological factors are due to; heavy rains, flooding, earthquake, mud and water inundation, overtopping, thunderstorm, landfall, seismic activity, and torrential rainfall. The engineering factors are due to poor foundation, technical breakdown and foundation failure while the human factors are due to poor maintenance. These factors can cause immense damage to loss of life and property when they occur. Prior to the construction of dam, the services of geotechnical engineer and geologist should be sought in other to ensure its safety by carrying out detailed geotechnical and geological site investigations in other to know the surface and subsurface condition of the construction site. It is recommended that adequate geological, geophysical, geotechnical, geographic information technology, use of standard construction material, and regular monitoring should be carried out before and after dam construction.

Keywords: Causes, Dam, Failure, Locations, and uses.

Introduction

Dam failure is a catastrophic phenomenon that results to the destruction of dam and this causes loss of life and property when it occurs. The need to look into the situation through research will help to mitigate the problem of dam failure across the entire world. According to Nimisha (2018) the most common causes of dam failure are overtopping, inadequate spillway capacity, excessive seepage across the body, alkali aggregate reaction, deterioration of concrete, cavitation's in energy dissipaters, stresses due to external and internal forces, and gates of dam not working effectively. Dams can be grouped according to the material which they are constructed Okosun & Amadasu (2016). Dams are generally classified in terms of their hazard potentials, sizes, and operational purposes (Nebraska Department of Natural Resources 2013). The size classification is based on the height of dam and storage capacity while the hazard potential classification is related to the damage that can occur in dam structure and the negative impact it cause on the human society and environment.

Dams are used for water supply, hydropower generation, flood mitigation, irrigation and recreation. Based on the analysis of dam for water supply, hydropower generation, flood mitigation, irrigation and recreation, 40% of dams are failed due to foundation failure, 23% are due to inadequate spillway capacity, 12% are due to poor construction, 10% are due to uneven settlement, and 15% are due to embankment slips of high pore pressure of defective material Nimisha (2018). Over 45,000 large dam had been built in over 140 countries of the world. Today, the top five dam-building countries around the world are; China, United States, India, Spain and Japan and they account for nearly 80% of all large dams worldwide. China alone has built 22,000 large dams, the USA over 6,390 large dams, India with over 4,000 dams and Spain and Japan with between 1000 and 1,200 dams each Ezugwu (2013). In African Country like

Nigeria, the creation of dams and establishment of River Basin Development Authorities to manage the nation's large reservoirs has proved to be effective in the conservation of freshwater environments Akindele & Indabawa (2015). According to Ezugwu (2013) & Daily (2011) the world worst dam disaster happened in Asian country is in China in 1975 when the Banqiao and Shimantan dams failed killing about 171, 000 people while 11 million lost their homes.

The United State of American (USA) has witness a very high cases of dam failures mainly as a result of internal erosion, seismic activity and water leakage. Environmental Agency (2011) & Juliastuti *et al.,* (2019) are of the opinion that factors such as mud, water inundation, overtopping, rain, landfill can results to dam failure and can be control through appropriate reservoir mapping, designed of filters and water tight elements and use of dam failure model to predict inundation hazard map for emergency plan. The use of geophysical survey, hydrochemical and isotopic study will help to mitigate the problem of internal erosion and water leakage in a dam Perparim *et al.,* (2016). Concentrated leak erosion is by far the most dangerous internal erosion mechanism, accounting for the majority of internal erosion incidence in an embankment dams Fry (2016). Internal erosion can be subdivided into four distinct erosion mechanisms: concentrated leak erosion, backward erosion piping, internal instability, and contact erosion (Bonelli 2013; ICOLD 2015). As readily observed from the four mechanism descriptions, the physics involved in each erosion process is quite different. Internal instability and contact erosion depend largely on flow channels and pipes, as well as the surficial erodibility of the soil. Backward erosion piping depends equally on flow through porous media, flow through open channels, and concepts from sediment transport. Despite these significant differences, a single approach can be used to design against all internal erosion mechanisms. Internal erosion in a dam can result to leakage in a dam. In the last few decades, a series of new hydrological techniques have been developed to help in the assessment of leakage and seepage in dams Perparim *et al.,* (2016). A case of dam failures associated with other natural phenomenon have been seen in some parts of Nigeria and has caused a lot of loss of life and damages to properties. According to Lynn, (2011), Eleyele dam in Oyo state located in South Western part of Nigeria which collapsed in 2011 resulting in flooding has claimed 102 lives in downstream communities while properties, agricultural land and historical centres worth billions of naira were devastated. Caleb *et al.,* (2013) have also written on the structurally failed earth dam: A Case Study of Cham Dam, in Gombe State North-Eastern part of Nigeria and finally concluded that the failure has occurs due to geologic factors. Failure of dams in different parts of the world has resulted into considerable socio-economic and environmental losses Dilshod & Art (2017). An adequate assessment of geophysical conditions of the proposed site is necessary for the safety of dam design and construction Oladapo-Adeoye & Oladapo (2011). Most of the dam failures are as a result of poor site investigation carried out by professionals to assess ground quality and this can result to flood propagation Rex *et al.,* (2014), Zongjie *et al.,* (2019), Tayfur & Guney (2013). However physical modelling can be used as an additional supportive way for flood hazard mapping to mitigate dam failure (Bellos 2012, LaRocque *et. al* 2013, Bosa & Petti 2013, Tsakiris & Spiliotis 2013). Construction of dams requires standard engineering investigation of the soil at a chosen site in other to ensure its safety Lukman *et al.,* (2011), Oladapo-Adeoye & Oladapo Ilesanmi (2011). Poor site investigation can also results to poor foundation of a dam, and this can be control by drainage and use of competent material of construction Fell *et al.,* (2014). The use of geophysical and geotechnical method of ground investigation of a site where dam is to be constructed can give proper examination of the subsurface structural geologic condition Caleb *et al.,* (2013), Oladapo-Adeoye & Oladapo (2011). In Northern part of Nigeria dam failures are attributed to poor water management and reservoir operation guidelines Ifabiyi (2011). Poor dam maintenance can reduce the life span of a dam and this can result to dam breakage Luo *et al.,* (2012). To avoid such there is need to improve on maintenance and guidelines for dam operation David (2018). Agnes (2012) observed that Obudu dam in Southern part of Nigeria has reduced downstream water volumes in Obudu town, causing acute scarcity of drinking water in the dry season. In Asian Countries, geologic factors like earthquakes and seismic activity has cause failure and profound damage for dams. Factors contributing to this are; magnitude on the Richter scale, peak horizontal and vertical accelerations, time duration, in addition to

the epicentral distance, nature of foundation rock, criteria of the design, and type of dam materials Nasrat *et al.,* (2020).

To mitigate this factors establishment of seismic codes which govern the design of civil structures must be put into consideration Kenneth & Eloho (2018). Failure of Teton dam in Idaho United State is as a result of seismic activity Debabrata & Tanmaya (2016). Use of substandard construction material has resulted to failure of Laos's dam displacing about 7,000 people, killing 40 people in Attapeu and neighbouring Champassak province Radio Free Asia (2020). In European Country like Italy, in the 20th century there were three cases of dam failures which caused loss of human lives: at Gleno in 1923, Molare in 1935 and Stava in 1985, due to human errors and short comings Fabio *et al* (2014). The possible roles for risk assessment in reaching a conclusion on the safety of dams in the Australian country were given as; an enhancement to the traditional method; an alternative to the traditional approach; and a sole basis for decision making Barker (2011). The aim of the research is to examine the dam failures critically while the objectives are to; investigate the causes of the dam failures and to give possible recommendations.

Materials and Method

The materials used are journal articles written by different Authors related to dam failures published from the year 2011-2020, these are; A brief assessment of a dam and its failure Lukman *et al.,* (2011), A review of dam-break research of earth-rock dam combining with dam safety management Luo *et al.,* (2012), A physical model to study dam failure flood propagation Tayfur & Guney (2013), Structurally Failed Dam: A Case Study of Cham Dam, North-Eastern Nigeria Caleb *et al.,* (2013), Supporting hydropower Rex *et. al* (2014), A review of the effects of dams on the hydrology, water quality and invertebrate fauna of some Nigerian freshwaters Akindele & Indabawa (2015), The influence of dams on the Growth and Development of Nigeria Economy Okosun & Amadasu (2016), Analysis of failed Teton dam Debabrata & Tanmaya (2016), Lessons on internal erosion in embankment dams failures and physical models Fry (2016), The wicked problem of dam Governance in Central Asia: Current Trade-Offs, future challenges, prospects for cooperation Dilshod & Art (2017), Study on dam failure-A Review Nimisha (2018), Dam failure model to predict inundation hazard map for emergency plan Juliastuti *et al.,* (2019), A comprehensive review on reasons for tailings dam failures based on case history Zongjie *et al.,* (2019), Impacts of mainstream hydropower dams on fisheries and agriculture in lower Mekong Basin Yuichiro *et al.,* (2020). The methods involved are Google search with a view of extracting some relevant information on Dam failures around the world.

Results and Discussions

Based on the information that was acquired through Google search the following results presented in table 1 were obtained.

Table 1: The list of some dam failures around the world.

S/N	NAME	LOCATIONS	CAUSES	DATE	USES
1	Eleyele dam	Oyo State (Nigeria)	Torrential rain	2011	Drinking water supply
2	Tiware dam	Ratnagagiri (India)	Heavy rains	2019	Water reserve
3	Banqiao dam	Henan Province (China)	Seismic activity	1975	Water reserve
4	Merriespruit	Virginia (South Africa)	Thunderstorm	1994	Waste tailing reserve
5	Ojirami dam	Edo State (Nigeria**)**	Technical break down	1980	Domestic, agricultural, and industrial.
6	Sanford dam Patricia Lake	Boiling Spring Lakes North Carolina (USA)	Over topping, rainfall, landfall.	2018	Water reserve
7	El Cobre dam	EL Cobre (Chile)	Earthquake	1965	Waste tailing reserve
8	St. Francis dam	San francis quito (USA)	Poor foundation	1928	Water storage
9	Swift dam	Montana (USA)	Heavy rainfall	1964	Waste tailing reserve

10	Cham dam	Gombe State (Nigeria)	Geologic and geotechnical problem	1998	Irrigation purposes
11	Los Frailes	Spain (SW Europe)	Foundation failure	1998	Waste tailing reserve
12	Teton dam	Idaho (USA)	Seismic activity	1976	Water reserve
13	Barahona	Barahona (Chile)	Earthquake	1928	Waste tailing reserve
14	Mina Plakal-nitsa	Bulgaria (SE Europe)	Mud and water inundation	1966	Waste tailing reserve
15	Sempor dam	Central Java province (Indonesia)	Flash floods	1967	Irrigation and Hydroelectric power Generation.
16	Certej dam	Romania (SE part of Central Europe)	Flooding	1971	For holding Cyanide-laced acid tailing
17	Lawn lake dam	Colorado (USA)	Flash flood	1982	Irrigation
18	Wadi Qattara	Benghazi (Libya)	Flooding	1979	Water storage
19	Silver Lake	Michigan (USA)	Heavy rains	2003	Water storage
20	Obudu dam	Cross River State (Nigeria)	Rain storm	2003	Irrigation, fishing, recreation and tourism.
21	Situ Gintung dam	Tangeran (Indonesia)	Poor mainte-nance and heavy monsoon rain	2009	Water retention
22	Patel dam	Solai (Kenya)	Heavy rainfall	2018	Irrigation and fish farming
23	Shihgang dam	Taichung (Taiwan)	Earth quake	1999	Flood control
24	Laos dam	Attapeu province (Asia)	Substandard construction	2018	To store and divert water for electricity
25	Gusau dam	Zamfara State (Nigeria)	Heavy flooding	2006	Water supply

From the results shown above (Table 1), it is clearly shown that dam failures have occurred across the entire world due to different factors. Several Authors has written on the dam failures across the world these includes; Lukman *et al.,* (2011), Luo *et al.*, (2012), Tayfur & Guney (2013), Caleb *et al.*, (2013), Rex *et. al* (2014), Akindele & Indabawa (2015), Okosun & Amadasu (2016), Fry (2016), Debabrata & Tanmaya (2016), Dilshod & Art (2017), Nimisha (2018), Zongjie *et al.,* (2019) & Yuichiro *et al.*, (2020).

Factors responsible for the dam failures based on the results shown above (Table 1) can be classified into three; these are geologic, engineering and human factors. Geologic factors are the most contributing factors that causes the dam failures these are; torrential and heavy rainfall, rainstorm, seismic and earthquake activities, thunderstorm, overtopping, landfall, mud and water inundation, flooding, heavy and flash flood.

The engineering factors are due to foundation failure, poor foundation and technical breaks down, while the human factors are due to poor maintenance. Failure of Banqiao, Teton, El Cobre, Barahona, Shihgang dam are due to seismic and earthquake activities, Debabrata & Tanmaya (2016), Kenneth & Eloho (2018). Failures of Cham dam are due to geologic and geotechnical investigation Caleb *et al.,* (2013).

Failures of Sempor, Lawn Lake, Certej, Wadi Qattara, Gusau, Obudu, Tiware, Swift, Silver Lake, Patel, Eleyele, Merriespruit dam are due to flooding, torrential rain, heavy rainfall; flash flooding, rain and thunderstorm (Bellos 2012, LaRocque *et al.*, 2013, Bosa & Petti 2013, Tsakiris & Spiliotis 2013). Failure of St. Francis and Los Frailes dam are due to

poor foundation and foundation failures Fell *et al.*, (2014).

Failures of Situ Gintung dam are due to poor maintenance and lack of adherence to the use of dam guidelines operation David (2018). Failure of Mina Plakalnitsa, Sanford Patricia Lake and Ojirami dam are due to mud and water inundation, overtopping, rainfall, landfall and technical break down Environmental Agency (2011) & Juliastuti *et al.*, (2019) and failure of Laos dam are due to substandard material of construction Radio Free Asia (2020).

Conclusion

Geology forms the basis for the construction of engineering structures like dam because it gives information about the geotechnical and geological condition of the construction site. Prior to the construction of dam, the consultant should be sought in the area of dam construction in other to ensure safety and sustainability.

Recommendation

The following recommendations are considered necessary in other to prevent dam failures as it could cause destruction of lives and properties.

1. Seismic and earthquake activities can be mitigated by establishment of Seismic Codes which govern the design of dam.
2. Geologic and geotechnical problem can be avoided by carrying out adequate standard and engineering investigation of the soil at the construction site.
3. Heavy rain, thunderstorm and flooding can be mitigated by physical modelling and use of geographic information system technology to predict its occurrence.
4. Foundation problem in a dam can be mitigated by adequate assessment of the geologic conditions of dam site selection, feasibility, and stability.
5. Mud and water inundation, overtopping, landfall, poor maintenance and technical break down can be control by reservoir mapping, and regular monitoring.
6. Substandard construction material should be avoided in other to prevent structural defects of dam after completion.

Acknowledgement

The Authors wish to thank Professor S. J. Mallo of Department of Mining Engineering, Faculty of Engineering, University of Jos for making useful contribution for the research.

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