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A Wholistic Assessment of Causes, Impacts and Modelling Techniques in Flood Risk Management in Nigeria

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Abstract **Review Article**

Flooding is one of the most devastating natural disasters in the world. Nigeria has recorded several incidences of flood lately in which uncountable lives and properties were lost. Several factors factor have been identified as the major causes of flooding. The main types of flood categorized by their causes are: Fluvial, pluvial and flash floods. These may be natural or anthropogenic. Fluvial floods occur when rivers overflow their banks into neighboring lands as a result of excessive rainfall or release of water from dams. Pluvial occur when heavy rain overwhelm hydraulic structures and artificial catchments causing overflows to the surrounding and this is mainly due to urbanisation while Flash flood are triggered by heavy rainfall or failure of hydraulic structure in short duration. Nigeria has suffered the worst flooding lately because of lack of hydraulic structures and climate change aggravated by uncontrolled anthropogenic activities because of poor land use and waste management practices. The major dams in Nigeria are easily overwhelmed by rainfall and this is worsened by lack of buffer dam (Dasin Hausa Dam) to the Lagdo dam which Nigeria has not built. Flood mitigation can be structural or non-structural with former being the provision of hydraulic infrastructures like dam, canals etc. while the latter is efficient land use management practices such as good urban planning. Flood risk management can be achieved through mapping and modeling and this can be performed with water Resources models, geospatial and GIS or machine learning techniques. These techniques are still facing challenges bordering on complexities and erroneous model outputs. However, collaboration, coupling/integration and data update can be applied for enhancing flood risk management.

Keywords: Fluvial, Pluvial, Anthropogenic, Rainfall, Dams, Drainage. Flood risk, climate change.

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1.0 INTRODUCTION

Flooding is one of the most devastating natural disasters in the world. It is the overflow of natural water body (Ocean, River, Stream, lake) overland or the overflow of excess runoff overland from canals, drainages or ditches causing human and material loses and damage to the environment (Nkwunonwo, 2016). Peduzzi et al. (2009) maintain that on global scene, the rate of flood incidence today is becoming unprecedented. They noted that over 70m people in the world today are suffering from flooding and more than 800m people living in areas susceptible to flood. The rise in sea-level, extreme weather condition such as heavy and prolonged rainfall or snowmelt has made flooding worse in exposed areas where uncountable human and material loss is inestimable (Agbonkhese, et al. 2014). Urbanization, industrialization and developmental goals are the major pursuits of human survival. However, these goals have not been achieved without environmental backlash evident by the counter-response from the environment in form of flooding, climate change, heat waves, desertification or other negative reactions (Abolade et al. 2013). In this sense, human activities cannot cease as survival of man is tied to anthropogenic activities which culminate to urbanization, industrialization and developmental goals. Thus, human activities are premised on this and as such efforts should be geared towards ameliorating its impact for sustainable development.

Therefore, flood risk management measures involve a combination of; flood infrastructure, emergency planning, flood early warning alerts, forecasting and disaster insurance and enhanced public enlightenment campaign (Odufuwa et al. 2012) to reduce the impact. In Nigeria, flooding has remained a perennial problem bedeviling the nation (Komolafe et al. 2015). Mfon et al., (2022) reports that flooding occur most frequently with devastating effects in most developing countries like Nigeria due to weak mitigation strategies including; poor enforcement of relevant environmental laws that has become an albatross to flood mitigation aggravated by poor funding, corruption and negligence by government and relevant agencies.

Recorded flood incidence in Nigeria occurred in 1963 when Ogunpa River overflowed and flooded Ibadan resulting in loss of lives and material resources. Eze (2023) and Komolafe et al (2015) noted that this reoccurred in 1978, 1980 and 2011 because, no proactive measure was taken. Umar and Gray (2023) documented the events of flooding in Nigeria for 10years (2011-2020) and discovered that Nigeria has suffered over 104 incidences of flood from 2010-2020. However, the most devastating was that of July-October; 2012 which cost over 363 lives, 2.1m IDPs and over 7.7m people being affected. Over 600,000 houses were destroyed and 32 out of 36 states were affected (OCHA, 2012). (FGN, 2013) reports that out of the 12 most affected states, Bayelsa and Rivers lost ₦596 and ₦507billion respectively while Anambra came third with ₦484billion. Despite these worrisome events, there is still no robust literature to analyse the causes, impact and approaches to mitigate flooding in Nigeria. Therefore, this paper attempts to highlight the causes, impacts and modeling techniques in flood risk management to mitigate flooding in Nigeria.

2.0 INCIDENCES OF FLOOD IN NIGERIA

Recorded flood incidence in Nigeria occurred in 1963 when River Ogunpa overflowed its bank. From that time to this recent time, Nigeria has recorded flood disasters of catastrophic proportions which were poorly managed (Odufuwa et al. 2012). In the nine (9) Local Government Areas (LGAs) of Rivers State that were assessed, DTM identified 337,393 individuals in 60,963 households that were affected by the floods.

These affected individuals included Internally Displaced Persons (IDPs) (123,233 individuals), residents (132,324 individuals) and returnees (81,836 individuals) who were displaced by the floods but have since returned to their communities.

The flood in subsequent years of 2022 in Nigeria became severe and more devastating in terms of the human and material losses since 2012 whereby it was reported by FGN through her agencies that over 603 lives were lost, 1.4 million people displaced, 2,400 were severely injured, 82,035 houses were destroyed and 332,327ha were affected (Oguntola, 2022).

Table 2.1: Reported Flood Incidences in Nigeria **(**Updated from Oluwaseyi, 2017, IOM, 2022, Oguntola, 2022, UNOCHA, 2017-2025, Naku, 2024, Umoru, Vanguard News 24th June, 2025, Davies, FloodList, 2017**)**

S/No	**Year / States**	1963-2001	2012	2017-18	2022	2024-2025
		Human and Material losses	Human and Material losses	Human and Material losses	Human and Material losses	Human and Material losses
1	Adamawa	Houses, farmlands, destroyed, 500 affected	41 fatalities, 46,030 in IDPs camps. Houses and properties, destroyed=₦135billion	10 fatalities, 500 affected and properties destroyed	Houses and properties destroyed. 388,791 affected, 25 fatalities, 131,638 IDPs	House and properties destroyed. 49,005 affected, 13,693 IDPs, 110 Cholera cases, 28 deaths
2	Akwa-Ibom	367 houses destroyed, 4000 affected	70 Houses destroyed, 847 IDPs			Few houses touched, 1,571 affected
3	Anambra	Houses destroyed, 500 affected	9,964 Houses, farmlands destroyed, destroyed = ₦484billion		Over ½ a million affected, 76 people drowned 28 IDP camps	
4	Bayelsa	Houses, markets, farmlands destroyed, 273,266	Houses, schools, markets and farmlands submerged, 382,000 affected		160 cholera cases, houses, property destroyed, 1.2million IDPs 96 deaths	Some Houses, properties submerged, 21,549 affected, 5,328 displaced

		affected				
5	Bauchi					House and properties destroyed , 94,000 affected and 36,000 IDPs and 29 fatalities
6	Benue		Many Houses and properties destroyed. 55,000 affected, 4,543 IDPs 23 fatalities =₦38billion	4,000 homes damaged, 100,000 affected	House and properties destroyed. 10,012 affected and 2,239 IDPs	
7	Borno		Properties worth ₦50million		4,980 shelters, House and properties destroyed. 1735 affected	419,482, affected and 390,736 IDPs + 586, cholera cases, 38 deaths
8	Cross River	25,000 affected	178 house lost, 2656 IDPs, 3 fatalities and 12 injured		718 cholera outbreaks, houses and property destroyed	
9	Delta		100 Houses, properties, submerged, ₦171billion, 5,000 affected	25,000 affected in 2017	425,839 affected in all 3 incidences, 78,640 people affected	
10	Edo	560 houses destroyed, 820 affected	3.8 million in State-wide, devastation with up t to ₦38billion	Houses, farmland destroyed, 30,000 affected		Over 100, houses touched.15,146 affected and 11,445 IDPs
11	Imo	1000 houses,150 electric poles, 40,000 oil palms destroyed				House and properties damaged, 28,663 affected and 11,656 IDPs
12	Jigawa	450,150 affected, 35,500 displaced	House, properties, farmland and livestock lost = ₦38billion 15,718 IDPs, 23 fatalities	Houses, farmlands and animals destroyed	92 fatalities	Houses and properties damaged. 71,297 affected and 19,030 IDPs, 54 deaths
13	Kaduna		1,394 Houses, 79 farmlands destroyed, 570 affected and 4,397 IDPs,			Houses and properties touched, 7,419 affected 200 IDPs
14	Kano	Houses, farmland, livestock destroyed20,445 affected	House destroyed, 5,466 IDPs, 18 fatalities, 53 injured		289,655 persons affected	Houses and properties destroyed. 48,854 persons affected and 1831 IDPs 45 deaths
15	Katsina		House destroyed, 2,730 IDPs			Houses and properties touched. 20952 affected and 3,073 IDPs
16	Kebbi		25,950 people were affected , 37,610ha of farmland, 5,495 houses, Losses was ₦167billion	14 LGAs sacked		Houses and properties damaged. 68,678 affected and 21,384 IDPs.

17	Kogi		143,446 homes, 2,500ha farmlands, 12 bridges 24 access roads were destroyed = ₦158billion lost, 910,000 affected, 10,000 IDPs, 8 fatalities	Houses and farmlands destroyed, 11,500 IDPs, 8 fatalities	over 1million affected and 623,900 IDPs displaced	Properties damaged.1,659 affected and 517 IDPs
18	Lagos,	Houses destroyed, 300,000 affected	430 persons affected, 5 missing		405,599 persons affected	Properties destroyed. 9,324 persons affected
19	Nasarawa		House, schools, 2000ha farmland destroyed 489 affected, 220 IDPs, 12 fatalities ₦100billion lost			Properties damaged. 6,495 affected and 2,597 IDPs
20	Niger		Over 200,000 IDPs,		1,500 corpses, 478,515 affected, 94 cholera cases	265 Houses, 2 bridges, rail lines farmland destroyed. 161 dead, 11 injured, 46,730 affected, 3,611 IDPs
21	Oyo, Ogunpa	500 houses, 2 bridges destroyed, 50,000 IDPs	Houses destroyed, 7 bridges, 5 lives lost	>300 houses, markets destroyed	10,046 persons affected	Houses destroyed 5,300 affected & 300 IDPs
22	Plateau		>500 House, farmlands and properties lost, 4,583 affected, 13,000 IDPs, 78 fatalities, 35 injured			Some houses touched.823 affected
23	Rivers		1,007 Houses, farmlands and properties, schools worth ₦507billion destroyed, > 146,000 IDPs, 5 fatalities	> 200 IDPs in 1 LGA	337,393 affected, 123,233 in IDPs	11,682 affected and 287 IDPs in Rumuagholu-Nkpolu
24	Sokoto	Houses and properties destroyed, 16,000 affected				Houses and properties destroyed, 102,155 affected and 55,865 IDPs
25	Taraba	Houses and properties destroyed Over 50,000 IDPs	15,011 IDPs,10 injured, 11,178 houses, schools, 83,511ha of farmland = ₦140billion		111,255 people affected, 28, 511 IDPs,	598,858 affected and 32,793 IDPs plus house and properties destroyed
26	Zamfara	Houses and properties destroyed. 12,398 IDPs			78,081 persons affected	78,840 affected and 32,910 IDPs plus houses and properties damaged
27	Yobe	Houses and properties destroyed. Over 100,000 affected	House destroyed, 959,503 affected, 159,322 IDPs, 207 fatalities, 71 injured, 40 missing		479,676 affected, 320 cholera outbreak	Houses and properties damaged 14,742 affected and 3,656 IDPs

NIHSA noted that from July –September, 2018 constant heavy rain resulted in the overflow of River Niger and Benue and the consequent flooding of the frontal states and local communities where 1.9 million people were affected and 82,000 houses destroyed while 210,000 people were displaced. Livestock was destroyed and farmland completely submerged (UNOCHA, 2018). The 2022 flood may be regarded as the worst flood that has ravaged the country in terms of loss of lives compared to 2012. In 2024, about 1.15 million people were affected, 655, 011 were displaced while 297 lost their lives and 2,653 were severely injured with over 10,603 houses destroyed across in 31 states (NEOC, 2024). From the foregoing, the impact is devastating and this calls for urgent attention from the federal Government to mitigate flooding in Nigeria.

Fig 2.1: 2022 Flood: Ahoada West LGA, Rivers

2025 flood: Mokwa city after the flood (Satellite)

3.0 CAUSES OF FLOODING IN NIGERIA

The causes of flood incidences in Nigeria cannot be far-fetched and this study has dealt with the incidences extensively. However, mitigation strategies can only be offered when the causes has been fully identified. The causes of flood may be broadly categorized as natural or anthropogenic, thus, the three main types of flood categorized by their causes are: Fluvial, pluvial and flash floods.

3.1 Types of Floods

Fluvial Floods

Fluvial floods occur when rivers, streams or lakes overflow their banks into surrounding shores and neighbouring land as a result of excessive precipitation, snowmelt or release of water from dams into the rivers, streams or lakes which causes them to overflow their banks. This type of flood is the most devastating and represents the substantial flooding incidences in Nigeria (Centre for Research on the Epidemiology of Disasters, 2021). The fluvial flood may be caused by natural event such as heavy rainfall or snowmelt (Agbonkhese et al. 2014) or anthropogenic activities which are driven by human activities. Fig 3.1 shows the areas affected by the 2022 flood incidence in Nigeria. Human activities led to climate change which has altered the atmospheric gas balance resulting in heavy precipitation, heat waves and snowmelt. So, these natural and anthropogenic factors are somewhat interrelated. However, fluvial floods are directly caused by natural causes (rainfall, snowmelt, etc) but the frequency and intensity such as prolonged rain and incessant downpour may be orchestrated by the effect of climate change.

Causes of major flooding incidences in Nigeria

A major flood incidence in Nigeria was recorded in 1963 when Ogunpa River overflowed its banks and flooded Ibadan resulting in loss of lives and material resources.

Eze (2023) and Agbonkhese et al. (2014) noted that this reoccurred in 1978, 1980 and 2011 with more devastating effect in Ibadan and tensions rose questioning the role of government in mitigating flooding in the city.

According to NEMA (2012) and UNOCHA (2012), the 2012 flood came as a result of heavy down pour between July-October, 2012 which led to the fluvial overflow of River Niger, coupled with rising water level from heavy run off and causing large scale flooding of overland human settlement downstream of Kainji, Shiroro and Jebba dams on the Niger river wing and the Lagdo dam in Cameroon on the Benue River wing, the Kiri dam in Gongola River and some other irrigation dams.

The flood destroyed part of these dams when they could not hold the level of water rise. As a result unprecedented flooding hit the frontline states of Adamawa, Taraba, Kogi, Benue and Anambra. Other southern states of Edo, Delta, Rivers and Bayelsa were also heavily hit.

Fig 3.1: 2022 flood in Nigeria – States affected (Nigeria Floods, 2022)

According to NIHSA (2018) the 2018 flooding of the riparian states were as a result of the overflow of the River Niger and Benue causing the spilling of water by Shiroro, Kainji and Jebba dams. The resultant effect was the rising of water levels downstream of Lokoja up to 9.89m and discharge of 21,326m^3/s as at 6th Sept; 2018 at the NIHSA hydrological monitoring Stations which NIHSA stated was similar to the disastrous event of 2012. However, NiMet, (2018) in their Seasonal Rainfall Prediction earlier in the year had predicted that the earliest cessation of date of rainfall in Sokoto and Katsina will be 28th Sept; 2018 while that of southern coastal states will be Dec; 2018. Thus, there was panic from the North because more rain is expected for about 3 week. However, at this point, the Lagdo dam was still impounding water. Thus the high discharge into the Northern catchment precipitated the overflow from the Shiroro, Kainji and Jebba dams which hit the riparian states. Ogbonna et al. (2017) had earlier attributed the flooding of parts of Rivers state to the overflow of the Orashi River which sacked many LGAs such as Ahoada East and West, Ogba-Egbema/Ndoni and parts of Akuku Toru and Obio-Akpor LGAs

UNOCHA, (2022) reported that the main cause of the 2022 flood in Nigeria was climate change which triggered heavy and prolong rains. World Weather Attribution project carried out a climate modeling work on Lake Chad and lower Niger catchment which confirmed that the 2022 flood was more likely to have been triggered by climate change. So, flood was exacerbated by the perennial release of water from the Lagdo Dam in neighbouring Cameroon which cascaded down the River Benue and its tributaries, flooding the frontline states of Kogi, Benue, Anambra, Adamawa, etc.

Poor Hydraulic infrastructures and Management

An important aspect of this is lack of the political will to initiate hydraulic infrastructures like dam and canals and their proper management by various levels of government in Nigeria. A classic example is insensitivity of Nigerian government over the years to complete the Dasin Hausa dam Project to protect her people from incessant perennial flood problems. When Lagdo dam was constructed in Cameroon in 1982, there was an agreement to construct a second, twin dam in Dasin village, Fufore LGA of Adamawa known as The Dasin Hausa Dam project to act as buffer to contain overflows from the Lagdo dam, but this important dam was never built by Nigerian government (Wahab, 2022). The Lagdo dam was built for hydro power generation and irrigation and its operation requires that water is released from time to time to stabilize at full capacity especially during rainy season. So when this occurs, the buffer dam in Dasin Hausa will contain this released water preventing excess water discharge into the River Benue and its tributaries thus mitigating flood overflows downstream.

Consequently, the lack of synergy between the two countries in the management of water release from the Lagdo dam is a failure that will always leave a sour taste in the mouth of citizens of Nigeria when flood comes knocking. Once there is high water level in Niger, Benue and Gongola Rivers as a result of high rainfall and the Lagdo dam is stopped from impounding water or water is released, all the riparian states like; Niger, Benue, Kogi, Adamawa, Enugu, Anambra, Delta downstream of Niger and Benue Rivers suffer heavy flooding, (NIHSA, 2018). It appears Nigeria is living at the mercy of the Lagdo dam (Wahab, 2022).

Poor or non-existent Canals and channelization of water is a major contributor to flooding in Nigeria urban cities (Ubani and Obi, 2014, Adekola and Ogundipe, 2017). Canalisation is very important in urbanization to protect the cities from flooding. The poor execution or failure of canalization of the Ogunpa River in Ibadan caused the Ogunpa River flooding in 1963, 1978 and 1980 (Agbonkhese, et al. 2014, Eze, 2023)

The influence of Climate change through natural variability

Climate change refers to the long term shifts in the elements of weather patterns due to natural variability or anthropogenic activity. When elements of weather such as rain, sunshine, temperature, pressure and wind change their pattern over a long period of time, the result is climate change. So, changes in rainfall intensity, duration and runoff (discharge) over a catchment and its distribution overtime influences river morphology (erosion of banks and river bed sedimentation). Therefore, Ogbonna et al. (2017) in their work posited that these changes introduce augmented dynamic flow and flood shift patterns.

Changes due to natural variability involve gradual change in the weather pattern due to effect of rise and fall of ocean tide, volcanic eruption, wind and ocean currents or eclipse (Martel et al. 2018) Natural causes of climate change introduces a shift in the pattern of weather due to interferences in the existing weather pattern overtime (IPCC, 2014).

Pluvial Flood

Pluvial floods are surface water floods which occur when heavy rain overwhelm drainage and artificial water catchments resulting in high run offs which overflows to surrounding surfaces. The result is the formation of a large pool of water especially in urban areas where there is limited infiltration capacity. This is a major cause of urban flooding where a large area of vegetative land has been covered by impervious pavements thus reducing the land area for run off infiltration into the ground (Nkwunonwo et al, 2016). This land cover modification has considerably reduced the water percolation into the ground causing surface water settlement. The major cause of urban flooding is anthropogenic activities (Seto and Kaufmann, 2009, Sangodoyin and Essein, 1996) arising from poor urban planning namely; poor drainage facilities, poor land use policy culminating to indiscriminate erection of buildings on any available space including flood plains and poor design criteria (Cirela and Iyalohme, 2018).

The influence of Climate change Through Anthropogenic Activities

Anthropogenic activities climate change which indirectly causes flooding (IPCC Climate Change, 2014). Anthropogenic activities could manifest as:

i. Burning of fossil fuel: This releases a lot of Greenhouse Gas (GHG) such as CO_2, NO_2, SO_2 etc into the atmosphere which alter the atmospheric air balance by depleting the ozone layer causing a shift in the weather pattern which in return changes the natural climate sequence.

ii. Deforestation: Deforestation is the act of cutting down trees and removal of the natural vegetation of a place exposing the soil to the direct rays of the sunlight which results in erosion and decomposition of soil organic matters and consequent emission of excess CO_2 in the atmosphere. Thus, photosynthesis (autotrophic activity) involving the use of CO_2 and release of O_2 by plants enhancing atmospheric gas balance as well as transpiration are all cut off from the natural ecosystem encouraging heterotrophic activity which releases excess CO_2 into the atmosphere causing climate change (IPCC, 2014)

iii. Commercial agricultural practices such as fertilizer applications exposes the land to erosion coupled with industrial activities which releases gas that pollutes the atmosphere

iv. Poor waste management practices: poor disposal of waste in open dump exposes dangerous wastes like lead, nuclear, medical and toxic wastes to the open environment causing the emission of toxic gases and GHG to the atmosphere resulting in climate change.

The direct effect of climate change is the increase in humidity of the air over a long time which ultimately alters the rainfall intensity, discharge and duration and temperature of the area (O'Hare, 2002). Climate change is the cause of the recent heat waves and high temperature in the world today due to the depletion of the ozone layer of the atmosphere and this imparts high rainfall intensity (O'Hare, 2002).

Direct influence of anthropogenic activities of flooding

Anthropogenic activities can also alter natural drainage capacity and patterns, increase runoff and reduce excess water absorption into the soil – erosion, which causes flooding (Owoeye et al. 2020, Agbonkhese et al. 2014). Such anthropogenic activities are:

i. Poor land use practices: This involves the conversion of natural wetlands and floodplains to land for agriculture and urbanisation. This includes poor urban planning whereby buildings are indiscriminately erected on wetland and floodplains. This alters the drainage pattern and reduces its capacity exacerbating flooding

ii. Poor waste management practices: The indiscriminate disposal of waste into drainages cause blockade of drainage systems exacerbating flooding.

iii. Land use changes: Land cover modification such as the conversion of natural wetland and floodplains to impervious paved surfaces reduces the water percolation into the ground, increasing the risk of surface water flooding. Ayotamuno and Enu-Obari, (2017) discovered that the built-up area in Port Harcourt, Rivers State has increased from 16.50% in 1984 to 51.38% in 2014 and paved surfaces has taken over gallery forest vegetation and wetlands. Therefore, this has reduced the forest vegetation and wetland and warning that property development in Port Harcourt should be controlled to mitigate the perennial surface flooding

Surprisingly, these anthropogenic lapses are continuously perpetrated by individuals, and government lack proper policy implementation plan to control it (Ayotamuno and Enu-Obari, (2017)

Flash Flood

These are rapid floods triggered by heavy rainfall with associated thunderstorm occurring in a short duration. Flash floods can also be caused by levee failures or shore protection failure and they are common in urban areas or coastal area. In coastal areas, sudden heavy downpour can trigger flash flooding especially when there is poor drainage infrastructure to contain it. This type of flooding is common in coastal areas where unpredictable heavy down pour occur in a short period or hydraulic structure fails and water released suddenly (Zurich Insurance Group Limited, 2017). For example the Mokwa City flooding in Niger State (UNOCHA, 2025)

4.0 FLOOD RISK MANAGEMENT – MITIGATION STRATEGIES/MEASURES

Flood Risk management is a combined and coordinated strategy that identifies, investigates and minimizes the risk of flooding on human settlement, property, infrastructure and environment. These actions involve a collection of preventive, protective and mitigation approaches such as emergency planning, early warning alerts, forecasting and land-use planning to manage and control flood (Cirela and Iyalohme, 2018). The ultimate goal is to reduce the impact of flood by increasing the level of preparedness, speed up recovery after flood, and palliative provision. The main idea is to manage flood risk than eliminating it completely because flood cannot be eliminated as long as it is a natural disaster. However, in managing flood, a mix of Structural and non-structural approaches are applied. This study highlights structural and non-structural measures to mitigate flood.

STRUCTURAL MEASURES

This involves the building of hydraulic structures like dams, levees, dykes, diversion of spillways, gabion etc. to check flood and rising sea level. The EU Floods Directive 2007/60/EC and the United Nations and Economic Commission for Europe (UN/ECE) Guidelines on Sustainable Flood Prevention prescribed an *integrated River basin approach* to check the overflow of rivers. This highlights the building of hydraulic infrastructures to prevent flooding in major catchments.

These measures include:

i. Dams and Reservoirs

A dam is a hydraulic structure comprising a concrete, earth or rock-fill barrier built across a river to retain or impound water and prevent it from flowing to the downstream, thus acting as a reservoir for future use, flood prevention and hydro-electric power generation. The dams can hold water to a very high level till the water begins to recede to a safe level. The construction of the Dasin Hausa Dam Project in Fufore LGA of Adamawa state will go a long way to protect the riparian states downstream of the Niger, Benue and Gongola Rivers. Coastlines should be protected with embankments and leeves built along the banks of these rivers to check river overflows.

ii. Embankments

Embankments are walls built along the banks of a river but higher than the river bank above the ground surface to prevent the overflow of water thereby protecting the shoreline against flooding (Agbonkhese et al. 2014). These embankments include; leeves, dykes, flood walls etc. mostly built in low-lying coastline areas.

iii. Canalisation and drainage system

Canals are hydraulic structures lined with concrete to prevent seepage and designed to convey water from one point to the other for irrigation, navigation or water supply. The Ogunpa River in Ibadan which overflowed several times and wreaked havoc on the city was to be canalized to control the city's perennial flood but this was plagued by contractor abandonment (Agbonkhese et al. 2014)

iv. Dredging

Dredging is the process by which sediments such as silt, sand, pebbles, debris and mud is removed from river bed to deepen the river channel, improve navigation and potentially reduce the risk of flood. Dredging has a lot of advantage which includes; Navigation, flood control and land reclamation. For the purpose of this study, flood control will be the focus. The Nigerian government under former President Goodluck Jonathan awarded the dredging of lower River Niger from Warri in Delta State to Baro in Niger State at a whooping cost of ₦47billion. However, the project was either not or poorly executed (Oladeinde Olawoyin, 2017).

NON STRUCTURAL MEASURES

These are management techniques or strategies to check flood.

i. Proper Land use Plan

This includes proper urban planning whereby buildings are properly erected outside on free land as against on floodplains. All such effective land planning practices such as zoning ordinances and Government Reserved Areas (GRAs) should be adopted to manage property development in urban or semi-urban areas. Floodplains should be free of any obstruction to allow water flow

ii. Afforestation and Restoration of Wetland

Afforestation is the planting of trees or the act of regenerating the vegetative forest in a given place. Afforestation restores the natural environment with transpiration and photosynthesis which restore the atmospheric gas balance and controls climate change

iii. Proper Waste Management Practices

Banning of open dump system as waste disposal method is key as this will control climate change and pollution. Apply effective waste management practice such as integrated waste management system whereby, landfill and controlled incineration is adopted. Drains must not be covered with wastes to avoid blockage, hence adequate cleaning of the drains must be ensured.

iv. Public Awareness Campaign

There should be early warning signals and flood alerts through proper hydrologic monitoring of river levels and weather patterns to sensitize the people at all times Adekola and Ogundipe (2017). NIHSA (2018) uses their hydrological monitoring stations at strategic points along the river to determine the water level.

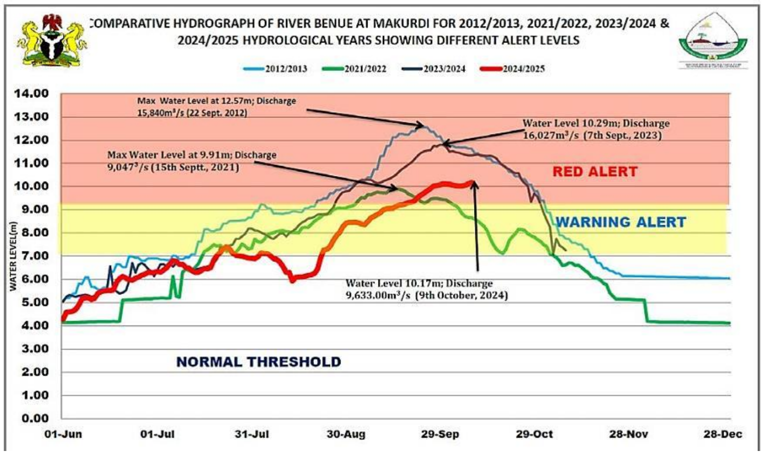

Fig 4.1: The hydrograph of River Benue

Fig 4.1 shows the hydrograph of River Benue which is used to monitor stream-flow patterns through water level and discharge at a given time.

5.0 FLOOD MAPPING AND MODELING

Flood mapping and modeling is a multidisciplinary approach used to identify flood risk areas, flood depth and the extent to which flood occurred at a given location for a return period. The return period indicate the frequency of event. Thus, they can be used to predict flood extent, depth and velocity in risk assessment and mitigation strategies. Flood risk is a probabilistic approach based on hazard, exposure and vulnerability (Eiser et al. 2012, Jha, and Gundimeda 2019). In Nigeria the common Flood mapping and modeling applications uses approaches such as;

WATER RESOURCES MODELING

These are models developed by simulating flow parameters; flow distribution and water quality to predict flow dynamics, flood vulnerability, sediment transport and water balance. Water Resources modeling tools incorporate essential parameters such as discharge, flow velocity, water depth, rainfall runoff to perform this function.

In predicting the flood risk of a watershed, an established process must be followed to arrive at a reliable result. However, the objective of the assessment must be defined. Most times the focus may be: To design a suitable hydraulic infrastructure, establish early warning alert, zoning for land use or flood risk mitigation. However, the established process includes:

i. Delineation of watershed:

This involves the marking or delineation of the boundaries of the watershed which gives an approximate area of the watershed

ii. Data collection:

This step involves the collection of data for the assessment which includes;

a. Topography or levels using various surveying instruments (Digita Elevation models, DEM)

b. Land use or land cover of the watershed

c. Rainfall data such as; rainfall intensity which is obtained using intensity-duration curve. However, this is obtained only when the duration T_t and the storm return period (T) are known. Then estimate these using the *weibull or Gumbel* frequency distribution or estimated based on the potential damage expected at flooding. An often time, a return period of 5 years is selected if the potential risk (damage) is small and 50-100years if damage is huge. The historic flood data too is important to further guide the process to precision. The run-off coefficient which determines the rate of infiltration is determined using the land use/land vegetative cover data and slopes.

d. Stream flow data: velocity, discharge etc.

e. Determine the capacity of the hydraulic structures such as dams, drainages, culverts, leeves

f. Historical flood data

iii. Hydrological modeling – Estimation of run-off volume and rainfall peak discharge:

According to Aguwamba, (2001) for Hydrological modeling approach, the following methods can be used:

a. The unit hydrograph approach

b. The Rational method if the delineated boundaries of the watershed are small or

c. Simulation using software simulation tools e.g Hydrologic Modeling Center-Hydrologic modeling System (HEC-HMS) which simulates surface runoff of the watershed, water flow velocity by analysing rainfall infiltration to estimate runoff. They are used to for predicting the amount and duration of run-off in a watershed

d. Soil Conservation Service Curve Number (SCS-CN) method: This runoff empirical model too that also can be used to estimate the runoff (Mishra, S.K. and Singh, 2004)

iv. Hydraulic Modeling:

Simulate flood water movement in open channel flows such as in rivers, hydraulic structure such as; drainages, culverts, dams, floodplains etc. This tool analyses input parameters like: geometry, dimensions and manning's roughness coefficient, flow resistance, hydraulic radius, bed slope, Reynolds number to estimate discharge, flood depth, velocity distribution based on physical principles of fluid mechanics and hydraulics. Therefore, the following tools may be used:

Hydrologic Engineering Centre-River Analysis System (HEC-RAS) for either 1D or 2D (river flow or flow over a flood plain)

a. MIKE HYDRO River/MIKE SHE (Jaber and Shukla, 2012)

This tool is best for integrated River basin modeling advocated by United Nations and Economic Commission for Europe (UN/ECE) Guidelines on Sustainable Flood Prevention. The tool is used manage river basins by River Basin Authorities and to monitor climate change monitoring. It can simulate both surface and subsurface water dynamics.

b. Storm Water Management Model (SWMM): This software is used for simulating and analyzing stormwater runoff and flood risk in urban area (EPA, 2025)

c. TUFLOW: Hydraulic modeling tool to model 1D, 2D and 3D flow patterns for wide range of applications; urban drainage, coastal flooding and river systems (Fahad, et al. 2020)

d. Soil and Water Assessment Tool (SWAT) (Mohamed et al. 2016)

The other leg of this is when the quality of water is to be assessed for agriculture to determine nutrient loading and waste disposal. Soil and Water Assessment Tool (SWAT) is a hydrological tool used to simulate water quantity and quality in watershed to understand agricultural run-off and nutrient availability land use impacts.

e. TELEMAC-2D: This tool is used to simulate shallow waters like small lakes, streams and pools. Wave propagation and tidal actions and gravitational forces which interact with atmospheric conditions are analysed and simulated in 2-dimensions and interpretations are made using this software. As earlier mentioned, the software can be used for turbulent modeling.

The hydrologic and hydraulic models can help during the examination of water flow during a flood to identify high flood risk locations and the potential hazard associated with it such as sweeping away the foundations of building, road, electric poles, drowning of persons exposed to flood, etc. (Duchan et al. 2022)

v. Geospatial and Geographic Information System, GIS

This technique involves delineating and mapping the flood-prone areas using GIS after collecting the information using remote sensing. These tools are vital in delineation and mapping.

Remote sensing is a geospatial process of acquiring data (satellite imagery, aerial photograph hyperspectral imagery, Infrared imagery and Light Detection and Ranging LiDAR) of land use, land cover, flood exposed areas etc by using sensors on satellites, aircraft or drone. Therefore, GIS integrates topography, land cover and hydrological data layers already collected using geospatial remote sensing to create flood hazard maps. Therefore, these tools are processing tools for delineation and mapping functions (Favorskaya, 2017). Inundation maps may be: Flood inundation mapping which deals with stream, River or Lake Overflow, Storm Surge inundation mapping for storm surge flooding or Dam failure of hydraulic failure inundation mapping for the impact of dam or hydraulic failure flooding (Dasallas et al. 2019)

In predicting flood risk, the following methods are applies:

a. The remote sensing and GIS technology is used to analyse the hydraulic model output to generate flood inundation maps which highlights the flood extent, depth and velocity which describes the hazard posed by the flood

b. In the inundation map, the flood prone areas are then identified based on the expected severity as already noted when estimating rainfall duration and return period for rainfall intensity which may be 5, 20, 50 or 100years scenario depending on the severity of the flood.

vi. Flood Risk Assessment

This involves the combination of flood hazard parameters such as flood depth, extent and velocity to determine the severity or level of risk posed by the flood on population, infrastructure, urban settlement etc. exposed to flooding. This answers the question what is the population, infrastructure etc. that will be affected by flood? The assessment will also cover the vulnerability of the persons, infrastructure or other elements exposed to flood. The analysis of this method is done with multi-criteria analysis or GIS-based flood models. Some popular GIS processing tools used for Water Resources Modeling are:

a. ***ArcGIS***: This is a powerful tool used to process hydrologic information or data such as topography, land use and hydrological data to produce flood inundation, hazard and vulnerability maps. In their work to delineate and generate flood vulnerability map of Port Harcourt metropolis, Akukwe and Ogbodo, (2015) used ArcGIS 10.0 software cluster to divide the City into 13 zones. The flood vulnerability pattern increased towards the outskirts; NW, SW, S and NE leaving the centre. ArcView GIS too has been used to map areas vulnerable to flooding in Minna, Niger State in Nigeria where they found out that anthropogenic activities such as blockage of flooplains along the bank of River Suka were responsible for flooding (Dalil et al. 2015)

b. ***QGIS***: This tool performs similar function in delineating and mapping flood exposed areas to produce flood vulnerability or inundation maps.

c. ***Google Earth***: This is a geospatial processing tool that visualizes data from different sources like; the GPS or remote sensing, then manipulate, analyze and present geographic information.

DATA-DRIVEN PROCESSING TECHNIQUES (TOOLS)

Statistical and Machine learning modeling

This modeling approach deals with historical flood data to predict future events within a watershed. It employs the artificial neural networks and support vector machines to predict flooding based on historical data. More recently, combining machine learning with time-series linear statistical models gives an improved accuracy, efficiency and management of complex non-linear models (Babu and Reddy, 2014, Bui et al. 2015 and Phan and Nguyen, 2020). The striking thing about machine learning is that the algorithms can handle large and complex datasets and most importantly, the non-linear models very difficult for the classical models (Refadah, 2025, Agha Kouchak, et al. 2020). The training of machine learning tends to produce a more reliable outcome than the statistical models and it is quicker than the traditional models

Interestingly, studies carried out by Fatima et al. (2018) in the assessment of Flood hazard in El Maleh River basin in south East of Morocco compared the result of using the surface hydrologic model, HEC-RAS approach which can determine the depth and flood velocity to predict the probability of flooding and the FHI multi-criteria index method which allows for larger area of the watershed at regional level. However, the WMS had been used to map the watershed for flood risk prediction using the terrain model data in combination with the HEC-RAS. The Relative Importance of each parameter was weighted and the values determined using an Analytical Hierarchy Process AHP. After superimposition to produce flood risk map, The WMS/HEC-RAS predicted accurate flood heights but only covered a small area of the basin while the FHI approach covered a much larger area but with inaccurate flood depth prediction. This result further validated the position that the combination of different hydrologic/hydraulic approaches and the statistical models is a promising approach to accurate flood risk modeling and water resource management (Bui et al. 2015 and Phan and Nguyen, 2020)

CHALLENGES AND PROSPECTS

The major challenges confronting flood modeling are:

i. Availability of quality data:

The quality, accuracy and authenticity of a data used for modeling is a measure of the accuracy and reliability of that model. If the data is obsolete, the model output may not reflect the true situation in the local environment presently. Other challenges such as inaccessibility and poor hydrological data pose serious challenges in flood modeling of such an environment

ii. Process of validation and calibration:

In this case sourcing a complete alternative data to validate and calibrate the model is herculean and most times might end up distorting the result.

iii. Computational Complexity

The complexity of a model requires more data to satisfy the conditions required for accurate modeling, thus inadequate data may provide an erroneous model output

iv. Unpredictability of the accuracy and authenticity of a model

The unpredictability of the data which is linked to the physical processes may be tasking. Nothing correlates some of the physical processes and yet they are assumed to be dependent while applying it. Such situation may raise doubt on the accuracy of the model.

STRATEGIES TO IMPROVE MODEL OUTPUT

Coupling and Integration

Researcher have advocated the coupling and integration of linear and non-linear models or more hydrologic/hydraulic/hydrodynamic models and machine learning model to obtain a higher degree of accuracy (Refadah, 2025, Agha Kouchak, et al. 2020, Babu and Reddy, 2014). The successful comparison of the prediction carried out by Bui et al. (2015) is a pointer that combination by coupling and integration is more effective, timely and accurate in flood risk prediction.

i. The coupling and integration of WMS/HEC-RA, FHI and GIS technology is a worthwhile approach for flood depth, flow velocity, from WMS/HEC–RAS, then discharge, slope, distance from drainage network, land use, drainage network density and bed and side materials of the basin from FHI while the topography and land cover from GIS

ii. Coupling and integration of HEC-HMS, HEC-RAS and GIS: Topography input from GIS, precipitation runoff from HMS and RAS for hydraulic modeling will be an ideal combination.

iii. SWAT, MODFLOW and GIS to model surface and groundwater interaction

Coupling and integration of models is a better approach for accurate prediction, however, most of these modeling approaches have not been explored in Nigeria as at today.

Statistical and Machine learning modeling deal with historical flood data to predict future events within a watershed. It employs the artificial neural networks and support vector machines to predict flooding based on historical data. More recently, combining machine learning algorithm like artificial neural networks (ANN) with time-series linear statistical models like Autoregressive Integrated Moving Average (ARIMA) gives an improved accuracy, efficiency and management of complex non-linear models (Umar and Gray, (2023 and Bui et al. 2015).

Collaboration

This involves the collaboration of professionals from different discipline to achieve a common goal. For examples, Water Resources Engineers who design hydrological and hydraulic models can collaborate with surveyors who use geospatial and GIS tools for data collection to efficiently develop a model, software engineers who are experts in software engineering and risk practitioners to advance modeling approach to enhance flood risk management

Update of data

Data must be updated especially as climate change has altered the weather elements over the years and as such the previous data has been rendered obsolete because of new trend arising from climate change. For example, change in the intensity of precipitation due to climate change

6.0 CONCLUSIONS AND RECOMMENDATIONS

Flooding is one of the most devastating natural disasters in the world. Nigeria has recorded several incidences of flood lately in which uncountable lives and properties were lost.

Several factors factor have been identified as the major causes of flooding. The types of flooding has been categorized by their causes as: Fluvial, pluvial and flash floods. These may be natural or anthropogenic. Fluvial floods occur when rivers overflow their banks into surrounding shores while Pluvial occur when heavy rain overwhelm hydraulic structures and artificial catchments. Flash floods are triggered by heavy rainfall or failure of hydraulic structure in short duration. This study concludes that Nigeria had suffered the worst flooding lately because of lack of hydraulic structures and with no appropriate measure taken the country will still suffer worse flood disaster. Flood frequency in Nigeria is aggravated by the failure of Nigerian government to complete the Dasin Hausa Dam project which would have served as a buffer to the Lagdo dam and Climate change aggravated by anthropogenic activities not controlled because of poor land use/land cover policy implementations. Flood mitigation can be structural or non-structural with former being the building of hydraulic infrastructures like dams, canals etc. while the latter is efficient and management practices. Flood risk management can be achieved through mapping and modeling and this can be performed with water Resources models, geospatial and GIS or machine learning techniques. These techniques are still facing challenges bordering on complexities and erroneous model outputs. However, collaboration, coupling/integration and data update can be applied for enhancing flood risk management.

RECOMMENDATION

The following recommendations are made:

The Federal Government should ensure the building of hydraulic infrastructure such as the Dasin Hausa Dam project and other dams for buffer. Proper and effective land use and waste management practices should be ensure through effective policy implementation and enforcement of physical planning laws. Flood risk management approaches should be enhanced by coupling and integration, professional collaboration and data update to achieve accurate model output.

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