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Vulnerability, Resilience and Adaptation of Lagos Coastal Communities to Flooding

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Lagos has been identified as one of the 50 cities most vulnerable to extreme sea levels. The state also ranked 30th among 136 port cities in terms of population exposure to flooding under a past climate scenario (2005) and 15th under a future climate scenario (2070s). The state faces significant environmental strains as a result of its geo-economic status. Some of the problems are wetland loss, pollution, population pressure, restricted access to drinkable water, and flooding. All these factors have contributed to the instability of Lagos ecosystems, but the impact of flooding is particularly significant because Lagos is surrounded by aquatic ecosystems and its low elevation and topography increase its susceptibility to flooding. The method adopted in this review involved the use of PICO (Population, Intervention, Control, and Outcomes) criteria to synthesize the research questions and objectives. Thereafter, PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines was employed for the study selection criteria, search strategies and data extraction methods. A broad search strategy involving databases (Google scholar, Science Direct), pertinent keywords and search filters was used to identify relevant articles and minimize selection bias. After the search, PICO criteria was again used to select the studies to be considered in the review. The selected text were downloaded and the essential scientific information were extracted and analyzed in the study. The impacts of flooding are numerous. Flooding is a key factors that has prevented Africa's growing urban population from escaping poverty, and it also impedes the achievement of some SDGs. This is because many African cities lack the resources and infrastructures needed to withstand extreme weather conditions. Surviving in flood-prone cities like Lagos is a daunting task because flood affects livelihood, human health, and can even cause death. Specifically, the 2020 flood incidence in Nigeria affected about 40% of the local government areas, and 97% of the states, displacing over 120,000 persons and killing 68 persons aside from properties and farmlands destroyed. Women and children are the most vulnerable. The adoption of advanced flood risk management strategies could help in flood containment and management in the state.

Keywords: flood, sea level rise, vulnerability, resilience strategies, Lagos State

INTRODUCTION

Flooding is a major challenge to coastal states all-over the world. The global incidences of flooding has witness an upsurge in recent times due to a combination of factors: climatic, anthropogenic, demographic, socio-economic and political. Specifically, some of these variables are: awareness of the risk of flooding, the lack of progress made in many areas to reduce the risk of flood disasters, increased urbanisation and population expansion, industrialization, the exposure and vulnerability of a vast human population to flooding and sea level rise (Raaijmakers et al., 2008). Flooding in Nigeria can be classified as either fluvial (arising from rivers surpassing man-made or natural barriers), coastal (primarily affecting coastal areas), or pluvial (flash, occurring suddenly after a strong storm) (Bashir et al., 2012). In addition to the above categories, flooding in Lagos State is caused by poor waste disposal practices and improper urban planning. These floods have been a major source of concern for Nigeria's cities and rural areas particularly Lagos State (Nkwunonwo et al., 2016). These anthropo-climatic factors are the prime causes of the current flood incidences. Although, climate change has been linked to other extreme weather events like desertification, wildfire, heat waves, tornadoes and tropical cyclones (IPCC, 2019b), flooding caused by a rise in sea level constitutes a significant threat to the human population.

Sea levels rose at the rate of 1–2 mm per year in the last century (IPCC, 2019a). The current rate is about 3.7 mm annually (IPCC, 2021). The primary cause is climate change brought on by humans, which constantly warms (and thereby expands) the ocean and melts glaciers and land-based ice sheets (Mengel et al., 2016). Sea level rise between 1993 and 2018 stood at about 42% and was primarily caused by the thermal expansion of water. Other significant contributions came from melting temperate glaciers (21%), Greenland (15%), and Antarctica (8%) [World Climate Research Programme (WCRP) Global Sea Level Budget Group, 2018]. Since sea level rise follows variations in Earth's temperature, it will continue to rise between now and 2050 predominantly as a result of current warming; whether it rises thereafter depends on human greenhouse gas emissions (National Academies of Sciences, Engineering, and Medicine, 2011; IPCC, 2013). In the next 2000 years, sea level rise would still be 2–3 m (7–10 ft) if global warming is kept at 1.5˚C (2.7˚F) (IPCC, 2018), while it would be 19–22 m (62–72 ft) if it reaches a maximum of 5˚C (9.0˚F) (IPCC, 2021). Increasing sea levels put unprotected areas at risk of flooding directly, as well as indirectly through increased storm surges, king tides, and tsunamis. Additionally, they are linked to secondary effects like the destruction of coastal ecosystems such as mangroves, decreased crop yields caused by the salinization of irrigation water, and the cessation of maritime trade as a result of damaged ports (Pramanik, 2014; Ward et al., 2016). Tens of millions of people will be forced to live in areas that are prone to yearly flooding due to the projected sea level rise by 2050. If greenhouse gas emissions are not significantly reduced, this could rise to hundreds of millions in the later decades of this century (Kulp and Strauss, 2019). While gradual rises in sea level may give time for adaptations like sea walls, time can also accelerate the number of people at risk because many coastal communities have experienced rapid population growth because of the human quest to enjoy the services provided by the aquatic ecosystems. Under warming of 3˚C (5.4˚F), which aligns with the current trajectory, million of people would be impacted in cities like Miami, Rio de Janeiro, Osaka, Shanghai, and Lagos later in the century (Holder et al., 2017).

Lagos is one of the major urban agglomerations in the world with an estimated population of over 28 million people (Mogaji, 2020). The state is the industrial hub of Nigeria with over 50% of the country's industrial capacity. Lagos State is described as the "State of Aquatic Splendour" because of its enormous aquatic resources. Water bodies and wetlands cover over 40% of the total land area of the state with lagoons and creeks consisting 22% of its area (Olajuyigbe et al., 2012; Obiefuna et al., 2013a). The above geographical and socio-economic variables contribute to the vulnerability of Lagos to flooding as she has been identified as one of the 50 cities most vulnerable to extreme sea levels (IPCC, 2022). Climate-induced flooding is almost becoming an annual event in Nigeria in the last 10 years and Lagos State has not been spared in any of these episodes (**Figure 1**). In 2020, flood incidence in Nigeria affected about 40% of the local government areas, and 97% of the states, displacing over 120,000 persons and killing 68 persons aside from the properties and farmlands destroyed. The 2022 record showed that 92% of the states in Nigeria were affected and over two million persons were displaced (Aguiyi, 2022). The projection for 2023 predicts severe impacts on the population, infrastructure, livestock, and livelihood. About 89% of the states would be affected, 36% of the local government areas in Nigeria would experience high flood incidents while another 40% would be impacted by moderate flood (Thisday, 2023). The Lagos figure is not

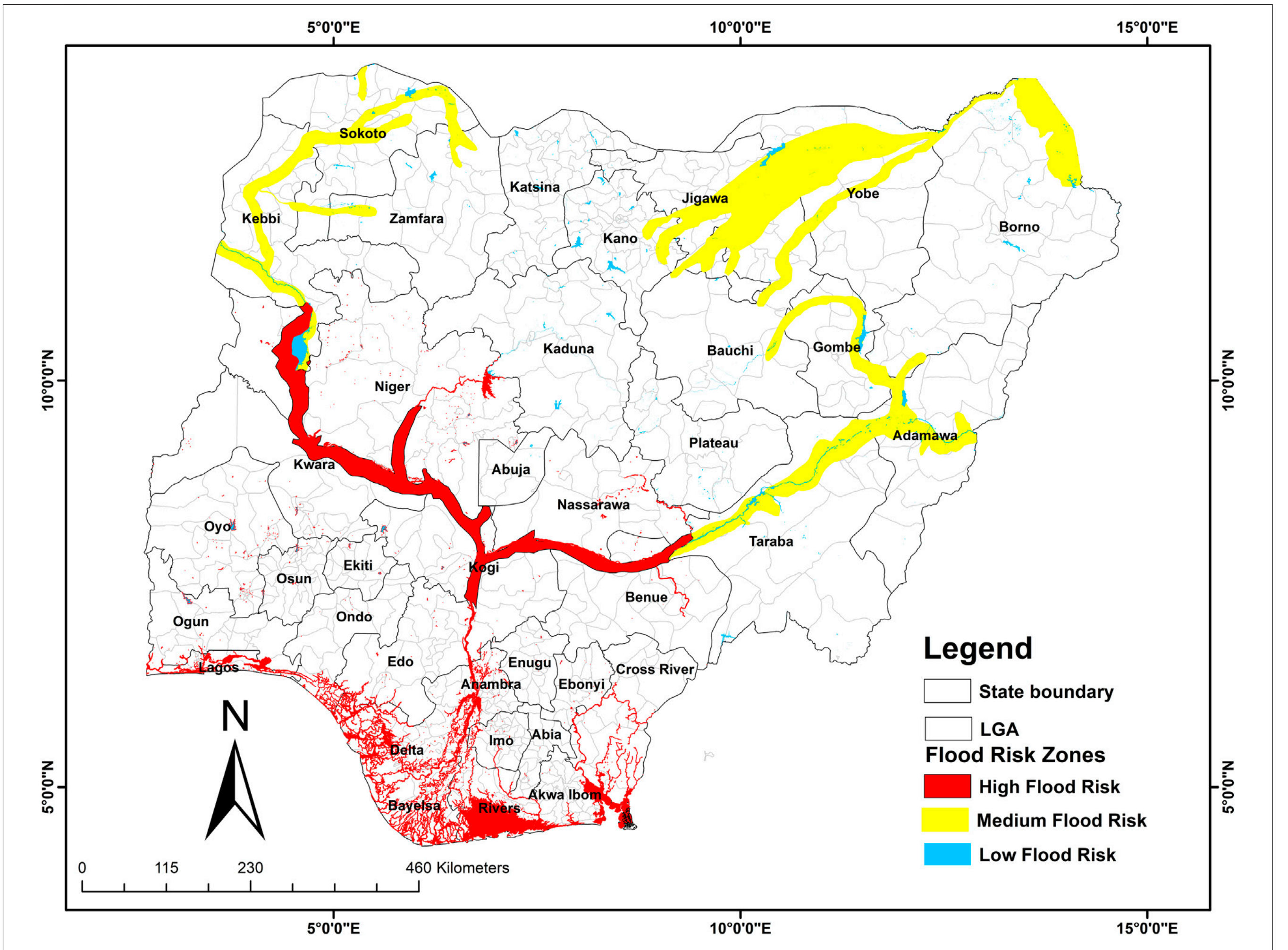

FIGURE 1 | Flood-risk map of Nigeria showing the intensity of flooding in the 36 states and FCT. Source: Njoku et al (2020).

different from the national outlook. According to the InsuResilience Solutions Fund (2021), flooding affects about 90,000 Lagos residents each year, and in 2021 it caused 4,000 people to be evacuated from their homes (Usigbe, 2021). In the last few decades, floods have caused many thousands more to be displaced.

Much of what is known about flooding in Nigeria appears to be lacking in terms of proffered solutions, as seen by the rising number of flood victims and its negative consequences on sustainable development. The topic at hand is particularly important because Nigeria is one of the most populous nations in the world, with an estimated population of about 202 million people and annual growth rate of approximately 2%, with Lagos State accounting for 8% of her population (National Bureau of Statistics, 2023). The issue is further compounded by high poverty rate, which stands at about 37% and insecurity of lives and properties. Given the postulation that future flood risk would be propelled by expected population expansion, this anticipated demographic change and socio-economic challenges would stimulate interest in increasing the capacity of humans to withstand flooding. This laudable goal is achievable if appropriate steps are taken beyond the current practices, which are largely reactive. Some of the suggested proactive measures include infrastructural development, enhanced public enlightenment campaign, policy initiatives, physical and socio-economic interventions (Agbola et al., 2012), deployment of community-based early warning systems (Agbonkhese et al., 2014), capacity building for risk management and reduction (Adedeji et al., 2012) and humanitarian gestures from the private and public sectors (Adeoye et al., 2009).

Furthermore, it will also be good to introduce scientific approaches to flood risk management as the practice is in the advanced world by the use of models to predict flood scenarios, and satellite technology for concurrent floods detection at different scales. The main challenge in executing the above propositions is the paucity of flood data in Nigeria. This study, which adopted the PICO (Population, Intervention, Control, and Outcomes) criteria for research questions and objectives synthesis, and PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines for study selection criteria, search strategies and data extraction methods is propelled by four key issues—1) to understand the current flood risk management practices in Lagos State, Nigeria and their short-comings, 2) to identify the factors contributing to flooding in Lagos State and the segments of the Lagos coastal population vulnerable to flooding, 3) to encourage the adoption of advanced flood risk management strategies like the use of models and remote sensing techniques deployed in industrialized nations, and 4) to advocate flood risk awareness programmes among the populace so that they can leverage on socio-economic interventions, improve their resilience and build capacity to cope with flooding. Therefore, the aim of this study was to examine the impacts of climate-induced flooding on Lagos coastal ecosystem, indicators of vulnerability by different segments of the coastal population, the use of advance technology to predict and manage flood as well as the adaptation and resilient strategies employed to combat the consequences of flooding in the state.

Conceptual Framework of the Study

According to Parnell et al. (2007), cities in developing nations are more susceptible to the effects of flooding. Also, with rising climate change, Lagos has been predicted to rank fifth of the most exposed cities to climate change (Nicholls et al., 2008). This has undoubtedly been reflected in the increased frequency of floods in many of Lagos's inland areas and the constant flooding in the coastal communities arising from the Atlantic Ocean. Gandy (2006) reported that when there is heavy rainfall in Lagos, over half of the city's residences become flooded, while about a third of homes deal with knee-deep water inside their houses.

Many urban and coastal communities, including Lagos State, are severely impacted by floods in several ways. Some of the impacts of flood reported in different studies include the effect on human health, increased exposure to disease, especially waterborne diseases, caused by temporary restrictions on access to medical services, worsened condition of the cities' sanitation, and food spoilage resulting in economic devastation (Action Aid, 2006). The report of the July 2011 Lagos Flood Incident by the Nigerian Insurance industry showed that the flood resulted in the displacement of over 5,000 residents and the death of about 100 persons. Serious economic loss of goods and properties estimated at 380 billion Naira (US$320 million) were also reported during this period (Ajibola et al., 2012; Adelekan and Asiyanbi, 2016). In a similar report by IPCC (2007), more than 40% of people living in coastal cities in West Africa are also considered to be at risk from flooding.

Along Nigeria's coastline, erosion is a common natural occurrence that has been attributed to contributing significantly to flooding in many of the surrounding coastal communities. The coastal erosion many of which are observed to exceed 10s of m/y in some areas (Ibe and Antia, 1983), often results from severe sea wave conditions, poorly developed coastal plains, delicate sedimentation processes, the existence of underwater gullies and canyons, and the rapid rise in sea level (Ibe, 1990).

Coastlines have also been altered by a variety of human activities, both locally and globally. These include backshore vegetation clearance, port construction, drilling and mining exploration, building barrages, and breakwater infrastructures (Pandian et al., 2004). Similarly, depending on the prevailing processes affecting the coastline, flood vulnerability of the coastal areas also results from coastline exposure to tidal activities which are frequently caused by erosion or sediment accumulation. In addition, rapid population, and infrastructure growth along the Lagos coast (Kundzewicz et al., 2008), slum expansion, inadequate urban planning, and increased urban migration all contribute a great deal to an increased flood vulnerability in Lagos inland and coastal communities and hence demand the formulation of an effective coastal zone management strategy (Wang et al., 2013; Bevacqua et al., 2018).

Due to the increasing flood incidents and the associated hazards in Lagos State, and other coastal cities, there is a need to develop a flood risk management programme that is focused on the growing population, the critical human and government infrastructures and assets (McGranahan et al., 2007; Hallegatte et al., 2013). According to Miceli et al. (2008), the formulation of an appropriate flood risk mitigation and adaptation strategy requires providing an accurate depiction of flood risks on the social and physical lives of the people, as well as improving public knowledge on flood vulnerabilities. These will assist in the identification of areas at risk from sea level rise (Wang et al., 2013; Bevacqua et al., 2018).

To reduce the danger of flooding in Lagos inland and coastal communities, Lagos has focused on structural measures including building waterways and drainage systems, providing assistance after natural disasters, and improving public awareness to the point that it can deter people from disposing of rubbish in drainage channels. Other efforts involve more public participation in formerly state-led flood protection initiatives, as well as global civic partnerships like membership in the International Council for Local Environmental Initiatives (ICLEI) (Breitmeier et al., 2009; Adelekan, 2010). However, more scientific approaches like flood modelling, flood hazard mapping and the use of remote sensing techniques in flood risk prediction and management should be adopted by Lagos State to drastically reduce the impacts of flooding on the people of the state.

MATERIALS AND METHODS

Description of Lagos State

This study focused on the vulnerability, resilience, and adaptation of Lagos coastal communities to Flooding. Lagos State is one of the coastal cities in Nigeria which has coastal boundaries with the Atlantic Ocean. The state is located within latitudes 6°23′N and 6°41′N and longitudes 2°42′E and 3°42′E. Lagos is also one of the most populous cities in Nigeria and Africa with a population currently estimated to be approximately 28 million people (Mogaji, 2020). Surrounded by the Atlantic Ocean and inland waters, more than 100 informal communities and slums are located within the city and along the Lagos coastal stretch. The state is exposed to frequent heavy rains, storm surges, and coastal floods caused by sea level rise. Based on predictions of the 2070 climate scenario, Lagos is ranked the 15th most exposed city to flooding in the world (Nicholls et al., 2008). This poses a big risk to the over 28 million people of Lagos, the economy, housing, and infrastructure in the state.

Literature Search

In this review we conducted a comprehensive analysis of existing literatures to examine the dynamics of vulnerability, resilience, and adaption of Lagos coastal communities to flooding. We followed the PICO (Population, Intervention, control, and outcomes) criteria in developing research questions and objectives for the study. The objective of the study is to examine the effects of climate-induced flooding on Lagos coastal ecosystem, the indicators of vulnerability by the different segments of the Lagos coastal communities, the use of advance technology in predicting and managing floods, as well as the adaptation and resilient strategies employed in combating the consequences of flooding in Lagos coastal communities.

After identifying the research questions/objectives, we followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines for the study selection criteria, search strategies, data extraction methods to ensure a transparent review process. A comprehensive search strategy which involved the use of multiple databases; Google scholar,[1] and Science Direct,[2] relevant keywords, and search filters was used to identify all relevant studies on the topic, in order to minimize the risk of missing relevant evidence and reduce selection bias. During the search, keywords such as “Flood in Lagos State,” “Flood episodes in Nigeria,” “Impacts of flooding on Livelihood in Lagos State and Nigeria,” “Flood Adaptation in coastal communities,” “Adaptive measures to flooding,” “Resilience of Lagos coastal communities to flooding,” and “Flood vulnerability in Lagos and Nigeria” were used.

When the search was concluded, the PICO criteria used for developing the study objectives was employed in selecting studies that will be included in the review. To remove discrepancies and further minimize bias, two independent authors were engaged in the screening of search results and extracting data from the selected studies. In order to ensure consistency and reliability of our findings, the quality of included studies were assessed by considering factors such as study design, the robustness and quality of the study, peer-review status, and study objectives. After the screening and selection was completed, full text of the selected articles were downloaded. Thereafter, a critical appraisal of the included studies was done by synthesizing the relevant scientific information contained in those studies and discussing their strengths, limitations, and potential biases in our review. The flow diagram of the selection process in shown in **Figure 2**.

[1]http://scholar.google.com/

[2]http://www.sciencedirect.com/

RESULTS AND DISCUSSION

Flood Incidences in Lagos State, Nigeria

Flooding is a general condition of partial or complete inundation of normally dry areas from overflow of inland or tidal waters or from unusual and rapid accumulation of runoff (Seenu et al., 2020). According to Louw et al. (2019), Lagos State has a long history of natural and human-induced flooding incidents that have led to the displacement of people, loss of properties, and deaths. The natural factors contributing to flooding in Lagos State include the city’s location in a coastal area, which is prone to sea-level rise and storms. The topography and low-lying condition of the city also make it prone to flooding during heavy rainfall (Obiefuna et al., 2021; Dube et al., 2022). Moreover, human-induced factors, such as poor drainage systems, improper disposal of waste, and the destruction of wetlands due to urbanization and human activities also contribute to flooding in Lagos State (Auwalu et al., 2021). According to documented records by the Federal Ministry of Environment (FME, 2012), Lagos State is one of the few states in the country with high flood incidents (**Figure 1**). The record of flood disasters in Lagos State retrieved from the database of Centre for Research on the Epidemiology of Disasters alludes to this assertion (Centre for Research on the Epidemiology of Disasters, 2023). While the population of Lagos State increased progressively from 2004 to 2023 (National Bureau of Statistics, 2023), the number of people affected by flood was within a narrow range except in 2012/2013 and 2022/2023 where there were upsurges of about 3,900% and 1,700%, respectively (**Figure 3**). With the exception of 1973, flooding in Lagos has been an annual occurrence since 1968 till date. The most affected areas include Lagos Island, Ikorodu, Ikeja, Apapa, Surulere and few other parts of the state as shown in **Table 1** below. It can be deduced from **Table 1** that Lagos Island has the highest intensity and severity of flooding in Lagos State with a yearly occurrence from June 1968 to June 2020. This is closely followed by Victoria Island, which was struck by flooding about three times within a year (Year 2000). Other severely affected areas are: Ikorodu, Surulere and Ikoyi that had incessant occurrence of flooding from June 1969 to June 2020. It also showed that every part of the Lagos metropolis is prone to flooding as no single area of the state is left out. The only difference is that the intensity, severity and the occurrence of flooding differ from one area of the state to the other. **Table 2** shows the effects of flooding on the people and properties of Lagos State with reference to the national averages between 2004 and 2023. Flood damages to properties in Lagos State was low within this period except in the years 2012/2013 and 2022/2023 where significant destruction of properties were recorded. Even during these years, the values were below 7.0%

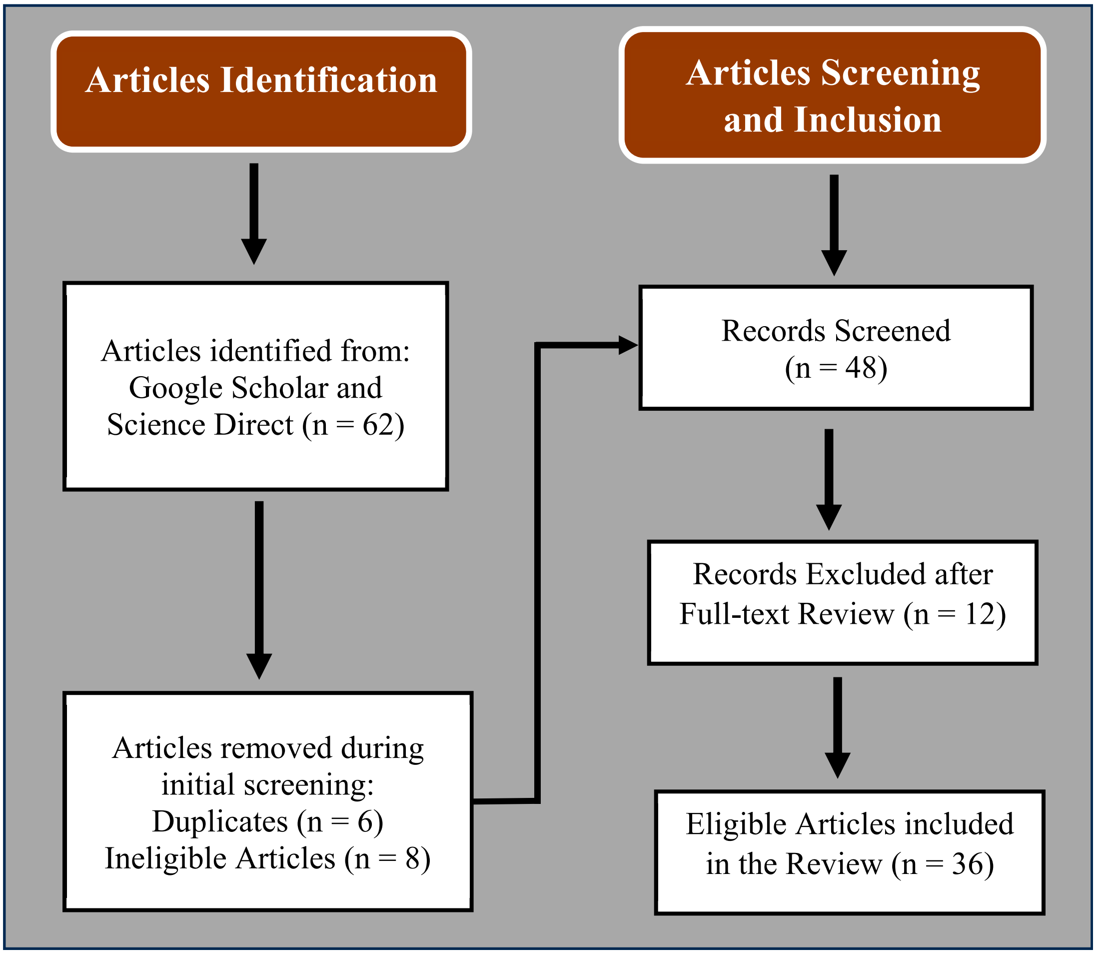

FIGURE 2 | Flow chart for article identification and studies included in the review.

of the total damages recorded nationally. The percentage of flood victims in Lagos State with reference to the national average was relatively low during the period (2004–2023) except in 2006/2007 where 14.04% was recorded. The death toll was also low except in 2008/2009 where 100% was recorded implying that Lagos State accounted for all the deaths caused by flood in Nigeria in the 2 years.

On 10th July 2021, major floods hit the city of Lagos, submerging cars and houses and bringing many parts of the metropolis to a standstill (Higuera Roa et al., 2022). The flood was caused by a mixture of high tides and heavy rainfall that occurred during a low-pressure storm system. The tidal water and sea levels were raised by more than 122 cm by the high tides, which submerged drainage channels and coastal defences near Lagos Lagoon and the Atlantic Ocean. Throughout this time, the government of Lagos State declared a catastrophe and urged people to remain calm. An estimated 100 people were killed, many were rendered homeless, and properties valued at over 380 billion Naira (US$320 million) had been destroyed by the time the storm subsided (Oladunjoye, 2011). Houses were submerged in low-lying communities which included Ketu, Alapere, Agric, Owode Onirin, Ajegunle, Alagbole, Kara, Isheri Olowora, Araromi Otun Agiliti, Maidan, Mile 12, Odo Ogun, Owode Elede, Agboyi I, Agboyi II, all located in Ikorodu which is high flood risk local government area in Lagos State (**Figure 4**). More recently, THISDAY Newspaper of 19th February 2023 predicted that local government areas in Lagos State, which are part of the 178 LGAs in 32 states that are located in high-risk flood zones in Nigeria, would experience coastal flooding due to rising sea level and tidal surge which will have serious negative effects on fishing, wildlife habitation, and river navigation. It is also tagged as one of the cities across the country that will experience flash and urban flooding (Adelekan, 2015).

A good number of the studies mostly highlighted the immediate post-disaster management strategies ranging from provision of foods, clothes and relocation of affected persons to internally displaced persons (IDP) camps (Adeoye et al., 2009; Agbola et al., 2012; Nkwunonwo et al., 2016). There has been an enormous humanitarian reaction to flood incidents in Nigeria. In nearly every instance of this extreme weather event in Nigeria, victims have benefited from humanitarian aid from non-governmental organisations

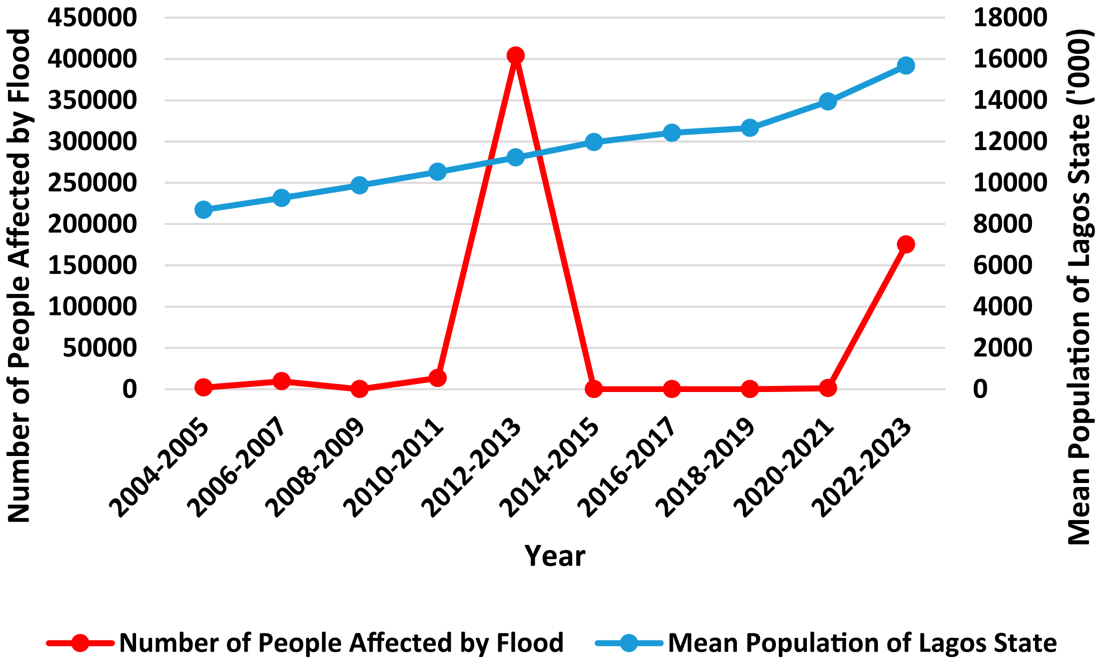

FIGURE 3 | The population of Lagos State and the number of flood victims (The 2023 Lagos State population figure was an estimate). Sources: Centre for Research on the Epidemiology of Disasters, 2023, EM-DAT emergency events database. Available online at: www.emdat.be (accessed 5th February 2024).

TABLE 1 | Occurrence of flood events in Lagos State (June 1968–June 2020).

Location	Dates	Number of Flood events
Lagos Island	June 1968–June 2020	14
Victoria Island	June 2000–October 2019	6
Idiaraba Mushin	July 1974–June 2020	6
Ikoyi	August 2007–June 2015	5
Lekki Phase 1	June 2015–June 2020	4
Surulere	June 1969–June 2020	4
Ebute Ero	October 2010–June 2020	4
Ogba	July 2011–October 2019	4
Ikorodu	August 1974–June 2020	3
Ikeja	July 2011–October 2019	3
Agege	June 2011–October 2019	3
Maryland	May 2018–October 2019	2
Ojota	May2018–June 2020	2
Yaba	June 1969–July1974	2
Kosofe	August 2007–July 2017	2
Apapa	October 2010–June 2015	2
Agbede	June 2015–June 2020	2
Oshodi	October 2019	1
Ketu	June 2015	1
Shomolu	May 2018	1
Ijora	June 1968	1
Lagos Mainland	June 2015	1
Badagry	June 2015	1
Bariga	May 2018	1
Oworonshoki	May 2018	1

Sources: Nkwunonwo et al. (2016) and Idowu and Zhou (2021).

(NGOs) such as the International Federation of Red Cross (IFRC), the World Bank, the United Nations, foreign nations like the United Kingdom, Japan, the United States, France, and China, as well as religious groups. Over US$70 million was spent on humanitarian relief in response to the 2012 flood disaster [UN Office for the Coordination of Humanitarian Affairs (OCHA, 2012)]. However, there has not been much emphasis on permanent solutions to the socio-economic and health problems arising from the flood incidents. This is an area requiring urgent attention. There must be political will by the government to permanently resettle flood victims to flood-free areas and provide them adequate funds to continue their former businesses or start a new one. National health insurance could be helpful to tackle post-flood health crises. Some of the socio-economic crises caused by flood are loss of farmland, destruction of social amenities like schools, hospitals, etc. The health effects include the transmission of water-borne diseases like cholera and diarrhea especially among children below the age of five and people with underlying illnesses. This could lead to disease outbreak as has been reported in some states in Nigeria (Olanrewaju et al., 2019; Gao et al., 2016). Flood waters are home to more than 100 pathogens, including bacteria, viruses, and parasites (Sharifi and Bokaie, 2019). Flood victims who come in touch with these vectors and contaminated water through drinking or food preparation will likely become infected as a result of the favourable conditions created by the floodwater for pathogens and their vectors (Komolafe et al., 2015). The relocation of flood victims to IDP camps has its peculiar problems if not properly managed. More often than not, IDP camps have poor sanitary conditions, inadequate safe drinking water, over-population as well as shortage of shelter, which could lead to water-, insect- and air-borne diseases. Sexual assaults and

TABLE 2 | Summary of flood impact in Lagos State and for Nigeria as a whole for the years 2004–2023.

Year	Number of people affected	Value of damages ('000 US$)	Number of deaths
	Lagos State (% contribution in Nigeria)	Lagos State (% contribution in Nigeria)	Lagos State (% contribution in Nigeria)
2004–2005	2,000 (5.90)	–(0.00)	–(0.00)
2006–2007	9,545 (14.04)	–	12 (9.16)
2008–2009	–(0.00)	–	31 (100)
2010–2011	13,483 (0.88)	–	10 (4.44)
2012–2013	403,937 (5.69)	28,778 (5.74)	35 (8.82)
2014–2015	–(0.00)	–(0.00)	–(0.00)
2016–2017	28 (0.12)	–	2 (3.03)
2018–2019	–(0.00)	–(0.00)	–(0.00)
2020–2021	1,250 (0.62)	–(0.00)	–(0.00)
2022–2023	175,156 (6.24)	262,500 (6.25)	38 (6.23)

Source: Centre for Research on the Epidemiology of Disasters, 2023, EM-DAT emergency events database. Available online at: www.emdat.be (accessed 5th February 2024).

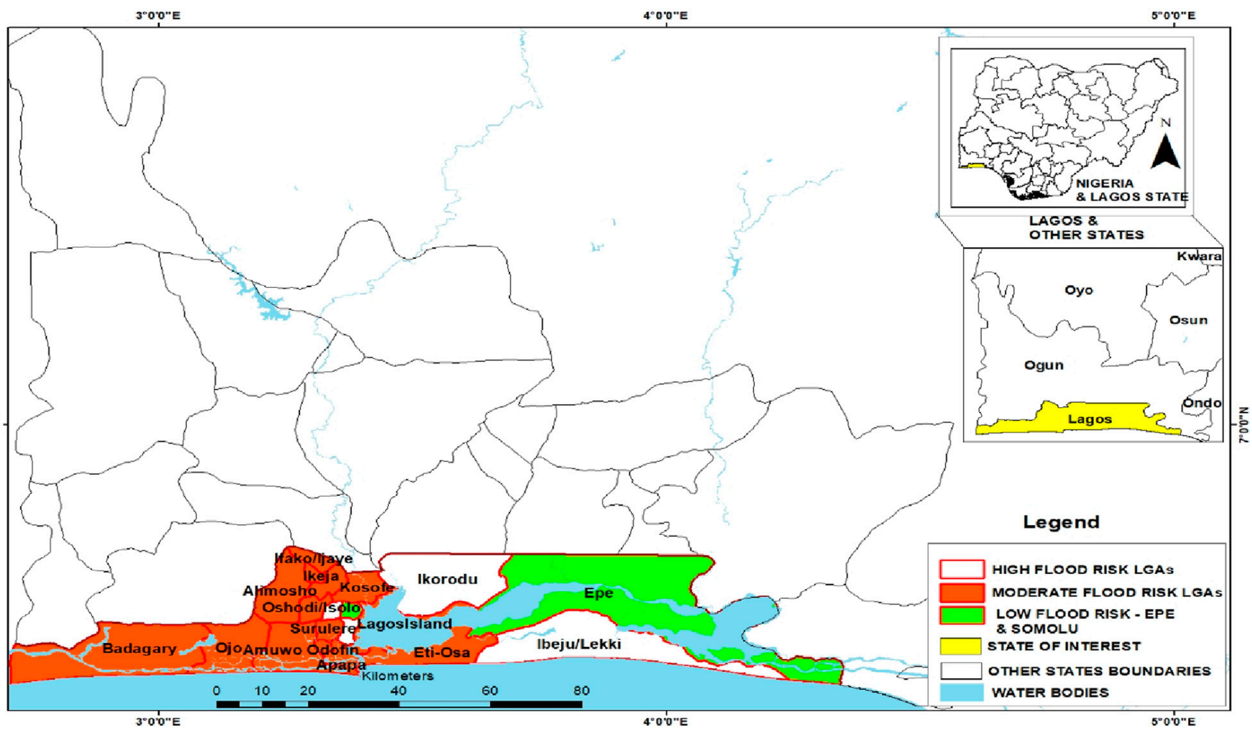

FIGURE 4 | Map of Lagos State showing high, moderate, and low flood-risk Local Government Areas.

their consequences like sexually transmitted infections (HIV, *chlamydia*, and gonorrhea) are common in IDP camps. There are also non-communicable diseases attributable to flooding particularly mental health disorders caused by flood-induced trauma (Olanrewaju et al., 2019).

Environmental Factors Contributing to Flooding in Lagos State, Nigeria

Land Use Change

Due to its geographical location, and low-lying terrain, Lagos State is highly vulnerable to flooding. Land use change, which involves the conversion of natural land covers such as forests, wetlands, and grasslands to urban or agricultural land uses, has been identified to significantly contribute to exacerbating flooding in the region (Israel, 2017) (**Figure 5**). Land use change can alter the natural drainage patterns of the land, resulting in the diversion of water from its natural channels and causing increased flooding in adjacent areas (Sugianto et al., 2022). For example, deforestation and the conversion of wetlands for agricultural use can reduce the capacity of the land to absorb and retain water, leading to increased surface runoff and soil erosion (Adebayo, 2014).

Additionally, urban development through land reclamation, lagoon dredging, conversion of coastal wetlands into urbanized communities, and the construction of buildings,

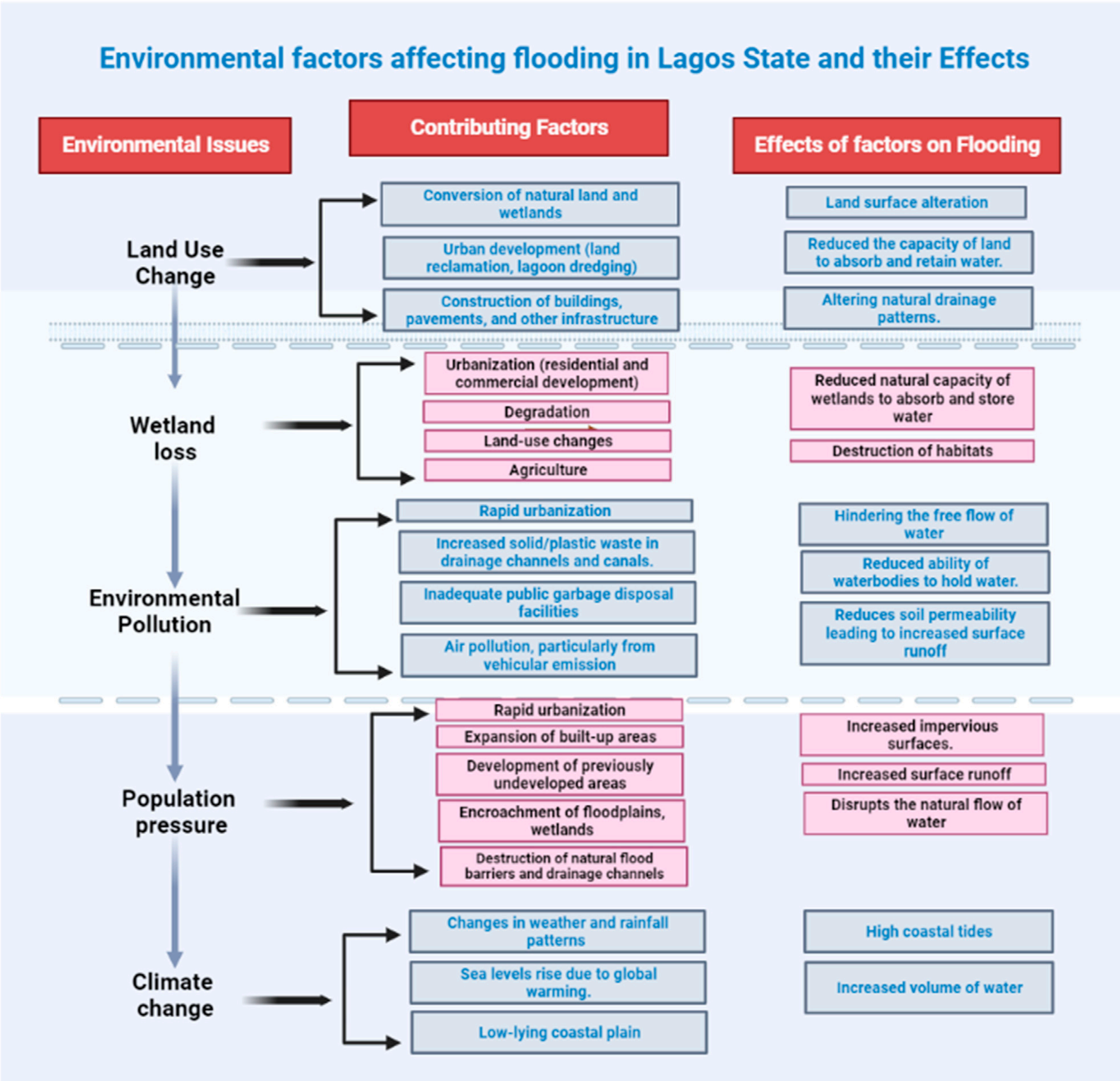

FIGURE 5 | Environmental factors contributing to flooding in Lagos State and their effects.

pavements, and other infrastructure can alter the surface of the land, leading to increased runoff and decreased infiltration of water into the ground (Kandissounon et al., 2018). This can further exacerbate flooding, and flash floods in low-lying areas, as more water is directed towards existing drainage systems, which may already be overwhelmed during heavy rainfall events. Identifying flood-prone areas, implementing appropriate land use change, and sustainable land management practices such as agroforestry and conservation agriculture, will help to reduce the impact of land use change on flooding and promote sustainable development in Lagos State (Otokiti et al., 2019).

Wetland Loss

Wetlands are important natural ecosystems that provide a wide range of benefits, including flood regulation, water purification, biodiversity conservation, and carbon sequestration (**Figure 5**). Generally, wetlands act as natural sponges, absorbing and storing large amounts of water during heavy rainfall and releasing it slowly over time. This process helps to reduce the intensity and frequency of flooding in nearby areas (Jisha and Puthur, 2021). Unfortunately, wetland loss has been identified as a significant factor contributing to the increased flooding in Lagos State, Nigeria (Uluocha and Okeke, 2004). Lagos State is home to several wetlands, including the Ogun River Basin, Lekki Conservation Center, and the Lagos Lagoon (Oyebande et al., 2003). However, wetland loss is occurring primarily due to urbanization, degradation, and land-use changes (Adegboyega et al., 2019). As the population of the state is increasing, more and more wetlands are being converted to residential and commercial areas, agriculture, and other land uses. This has led to a reduction in the natural capacity of wetlands to absorb and store water, which in turn has increased the risk of flooding (Adebayo, 2014).

Aside from flooding, wetland loss has led to the destruction of the habitats of many important aquatic plant and animal species (Kingsford et al., 2016). To lessen the effects of floods and other environmental issues, policymakers and stakeholders need to emphasize wetlands' protection and restoration by regulating land-use changes, establishing protected areas, and encouraging green infrastructure that can help control stormwater runoff (Ndimele et al., 2024).

Pollution

Pollution is among the pressing environmental challenges facing Nigeria and has a significant impact on flooding in Lagos State (Evelyn and Tyav, 2012). In Lagos, rapid urbanization has resulted in increased pollution, especially from industrial activities, transportation, and waste disposal. In most Nigerian cities and communities, waste disposal is at its lowest point. The majority of city centers lack public garbage disposal facilities, so residents bury, burn, or carelessly dispose of their waste without thinking about its effects on the environment. With the increase in solid waste pollution, the accumulation of solid waste, especially plastic waste in drainage channels and canals hinders the free flow of water, causing flooding during heavy rainfall (Adelekan, 2010). Furthermore, the pollution of water bodies, such as rivers and lagoons, reduces their ability to hold water, leading to increased surface runoff and flooding (Ndimele et al., 2022).

In several studies assessing the impact of environmental flooding in Lagos State, it was observed that poor waste management practices, such as littering, dumping of waste in unauthorized places, and open defecation, contribute significantly to flooding (Ike et al., 2018; Samson and Oluwatoyin, 2012). Similar to solid waste pollution, air pollution has also been identified as a significant contributor to flooding. It was found that air pollution, particularly from vehicular emissions, reduces the permeability of the soil, leading to increased surface runoff during rainfall and, consequently, flooding (Akanwa et al., 2023). From the foregoing, it is apparent that solid wastes particularly plastics contribute significantly to flood incidents in Lagos State because they clog drainages and prevent the free flow of water after rainfall. This problem can be addressed in several ways. Decrease the usage of single-use plastic products, implement legislative measures to discourage the use plastics, provide incentives to users of alternatives to plastics, raise public awareness on the consequences of plastic pollution, invest in waste management infrastructure, and foster eco-friendly innovations like bio-plastics.

Population Pressure

Population pressure has a significant impact on flooding in Lagos State, Nigeria. The state is one of the most populous in Nigeria and the world, with an estimated population of over 20 million people (Mogaji, 2020). This population growth has led to rapid urbanization, expansion of built-up areas, and the development of previously undeveloped areas.

In Lagos State, the combination of a rapidly growing population and poor urban planning has contributed to frequent and severe flooding in the state (Obiefuna et al., 2013b). As the population grows, the demand for housing, infrastructure, and other facilities increases, leading to the encroachment of floodplains, wetlands, and the destruction of natural flood barriers and drainage channels (Kasim et al., 2022). This intrusion disrupts the natural flow of water, leading to increased surface runoff and flood risk, particularly during heavy rainfall events. According to a 2016 poll by the Lagos State Government, 19% of respondents had experienced floods in the previous year (Lagos Bureau of Statistics, 2016). After crime, flooding is considered by locals to be the second-most significant threat to the city (Adelekan and Asiyanbi, 2016).

Additionally, rising population density can lead to increased impervious surfaces, such as roads, buildings, and parking lots, which prevent rainwater from being absorbed into the ground, leading to overwhelming drainage systems, and causing flood incidents (Echendu, 2020). Also, the improper disposal of waste and debris in drainage channels and water bodies is known to further worsen the flood situation, as it hinders the flow of water and causes blockages.

Climate Change

Climate change is a global phenomenon that has far-reaching effects on the environment and people's livelihoods. In recent years, flooding has been identified as one of the most visible and devastating effects of climate change, particularly in low-lying coastal areas like Lagos State, Nigeria. The city is situated by the Atlantic Ocean and has a long coastline. As sea levels rise due to global warming, the risk of flooding and coastal erosion increases (Erlandson, 2012). Many areas of the state's coastline now experience coastal flooding at a very alarming rate during high tides.

Climate change is causing alterations in weather and rainfall patterns, which can lead to prolonged periods of drought, followed by intense rainfall events (NASEM, 2016). In Lagos State, heavy rainfall events have become more frequent and intense, leading to flooding in many areas. This flooding is exacerbated by the fact that Lagos State is situated on a low-lying coastal plain, and this makes it especially susceptible to storm surges and sea level rise. In addition, the city's drainage systems are ill-equipped to handle the increased volume of water, leading to widespread flooding in both urban and rural areas.

The impacts of flooding in Lagos State are widespread and devastating. Floods can damage homes, infrastructure, and agricultural land, leading to human displacement, loss of livelihoods, economic hardship, and death. Flood also increases the risk of waterborne diseases such as cholera and typhoid fever, which can spread rapidly in crowded urban areas like Lagos State (Adelekan and Asiyanbi, 2016).

Adverse Effects of Flooding on Animal and Human Ecology in Lagos State

Effects of Flooding on Artisanal Fisheries

Jiboye et al. (2019) reported that floods at Ibereko, Iyafin Isalu, Aradagun, Badagry Town, Ropoji, Toga, and Topo negatively affected artisanal fishermen as their catches dwindled whenever the creek is flooded. Furthermore, lakes and ponds in the neighborhood that serve as breeding sites for several species of freshwater fish and other aquatic animals which provides the majority of the population with a means of livelihood are overflowed with salt water due to floods in the neighborhood (Jiboye et al., 2019). This sort of saltwater intrusion causes the mortality of freshwater fish species. Makela (2008) examined the effects of flooding on Lagos fishermen and reported that floods affected at least 20% of the coastal population with consequences ranging from the depletion of the fish population, change in fish species composition, and loss of livelihood by fishers (Ndimele et al., 2021). Adeoti et al. (2010) investigated how flooding affects the welfare of fishermen households in Epe, Badagry, Eti-Osa, and Ikorodu and discovered that 82% of the fishermen from these local governments in Lagos State experienced the loss of income from fishing, destruction of gears and nets, especially between May and August, when the rainy season is most intense. The decrease in the amount of fish caught was said to have caused the loss. The respondents, however, experienced different levels of income loss.

Impacts of Flooding on Crop Farming

Agricultural produce in Lagos State and Nigeria at large is mostly rain-fed. As a result, decreased agricultural productivity will result from increasing coastal rainfall intensity, floods, and farmland degradation (Ogbuabor and Egwuchukwu, 2017). Nigeria produces a variety of food crops, such as rice, corn (maize), yams, cocoyams, beans, sorghum (guinea corn), melons, and soybeans (Shiru et al., 2018). The livelihoods of the populace, the nation's economy, and the security of its food supply would all be significantly impacted by a decrease in agricultural output (Onwutuebe, 2019). Flooding due to rising sea levels makes soils too salted for growing, thus eroding soils and resulting in lower yields (Sayne, 2011; Amobi and Onyishi, 2015).

Impacts of Flooding on Social Infrastructure

Flooding and its effects are becoming important topics on the agenda of Lagos State. Studies have shown that the frequency, intensity, and severity of flooding incidents across the majority of the city have made Lagos to be listed as one of the most vulnerable cities to flooding (Marcott et al., 2013; NOAA, 2016). Lagos has been impacted by ocean swells and deterioration of coastal beaches including Alpha, Kuramo, and Lekki, where homes were damaged, and people died. An ocean surge in early August 2012 was reported to have displaced the inhabitants of Lekki from their homes and submerged Lekki Beach for some days (Fabiyi and Yesuf, 2013). The report of Riise and Adeyemi (2015) on the social and economic variables affecting housing types among the low-income group in Makoko, Lagos State revealed that a significant section of the population lives in homes constructed of bamboo and planks. These homes are inexpensive and accessible but the major cause of flooding in Makoko was inadequate or nonexistent drainage (Louw et al., 2019). Also, the infrastructural deficits make Makoko susceptible to flooding, which happens at least three times a year on average (Lawanson et al., 2022). However, in the Makoko neighborhood, flooding typically takes two different forms, namely, storm-related coastal flooding that escalates waves and tides, and pluvial flooding which occurs during intense rainfall resulting when river levels around the slum rise over the banks (Ajibade, 2019; Ajibade and McBean, 2014).

Flooding could impedes development in at least four ways: displacing human populations, collapsing buildings, damaging plants, and disrupting livestock (Oladokun and Proverbs, 2016). Abolade et al. (2013) explained that the reasons for and consequences of floods in Agege Local Government Area (LGA) emanated from the non-functional or/and non-existent drainage systems, high rainfall, and direct dumping of waste into the drainage systems. This ultimately contributed to spoilt roads and buildings within Agege LGA. Adelekan (2015) evaluated the dangers and vulnerabilities of four specifically chosen poor urban areas close to the ocean in Lagos State, Nigeria, and concluded that flooding is exacerbated by urban development. The assessment of the impact of Lagos' coastal population's exposure to coastline deterioration showed that between the months of April and August when the water rises, flooding of Victoria Island and other low-lying parts in Lagos State is frequent (NOAA, 2016). This impact causes destructive pounding of the coastline. According to the vulnerability assessment database, there were 6,983 features in total that were climate-vulnerable, and the impacted features, buildings, and infrastructures have exposure levels that change depending on distance, concurrency, and severity (NOAA, 2016). For instance, the rate of the ocean surge was made worse by the Eko Atlantic City project; thus, several communities such as Epe, Ibeju Lekki, Eti-Osa, and Kosofe, and other infrastructures (cultural, religious, academic, and the primary access point to the community) have been swept away by the Atlantic (NOAA, 2016). The wide range of infrastructures across the state that are vulnerable to flooding hazards according to the vulnerability mapping of the CRA project was huge and had a range of impacts, varying from least to mildly and most severely impacted (NOAA, 2016).

Consequences of Flooding on Human Health

The impacts of flooding on humans include skin infections, diarrhea, communicable and acute respiratory infections, vector-borne illnesses, and non-communicable disorders (Aderogba, 2014). In coastal eco-zones in Nigeria including Lagos State, windstorms, extreme rainfall, and flood can result in drowning, death, and severe physical and psychological harm, especially for residents who live along major rivers, on islands, and in low-lying coastal areas (Abdulkadir et al., 2017). Intense rainfall, floods, and contaminated groundwater all contribute to a rise in the spread of water-borne illnesses as well as other conditions including hepatitis and malaria (Ebele and Emodi, 2016). In addition to contaminating drinking water with sewage, industrial waste, and chemical wastes, heavy rainfall events may also create disease epidemics and force people to spend their limited resources on emergency medical treatment (Ebele and Emodi, 2016; Louw et al., 2019).

Effects of Flooding on Food Security and National Economy

In Nigeria, food insecurity is a significant and evolving issue. According to reports, over 40% of Nigerians are classified as food insecure (Thomas and Turk, 2023) and 70% did not have enough food to eat in 2021 (World Food Programme, 2022). Flooding, which is becoming a yearly occurrence in Nigeria, exacerbates the problem. As Nigeria is expected to become the third most populous country in the world by 2050 (United Nations, 2022), it is imperative that food security concerns be addressed. The national agricultural plans, which do not even address the influence of catastrophes on food security, demonstrate that politicians/policymakers do not recognise flooding as a danger despite its impact on food security. Flooding could affect all the four pillars of food security, which are; availability, accessibility, utilisation, and stability of food.

Food production determines the amount of food that is accessible. Nigeria is currently producing less food than is needed, and imports play a major role in filling the gap. The problem is exacerbated by flooding. In addition to destroying livestock, crops, farm settlements, and seedling storage, flood destroys the ecosystem. This lowers yield and has an impact on the following planting season, which leads to a crisis of food scarcity. Flooding affects food access in a number of ways, including making food more expensive, harder to physically obtain, and scarcer. About 88% of Nigerian farmers are small-holder farmers, who are the most susceptible and most affected sector of the agricultural industry (Sabo et al., 2017). Floods have the power to severely destroy infrastructure, as seen by the collapse of roads and bridges in Nigeria, which prevents physical access to inputs (such as fertiliser or seeds) and markets for the products produced there. A crucial component of food security is food utilisation. If soil and nutrient loss from flooding has resulted in inadequate nutrition from food, then access to and availability of food do not ensure appropriate food utilisation. Food produced on degraded soil has lower nutritional value and quality (Akpoveta et al., 2014). Flooding can cause damage to plant tissue, which can lead to the emergence of bacterial and fungal diseases that compromise crop quality (Jaffar et al., 2023). Changes in the nutritional makeup of food have an impact on the consumption of micronutrients (Reddy et al., 1984). The agricultural farmlands of Nigeria have shown evidence of this following flood episodes (Osakwe et al., 2014). Food stability—the guarantee that food is consistently available, palatable, and healthy—is also impacted by flooding.

Agriculture is a significant area of life in the Nigerian economy. Therefore, floods can negatively impact the gross domestic product by reducing agricultural yields and productivity (Solomon and Edet, 2018; Anabaraonye et al., 2019). Flood can also undermine economic growth through loss of produces/products and destruction of infrastructure, which could result in extra-budgetary spending (Federal Government of Nigeria, 2013). Nigeria's agriculture industry is heavily affected by climate change because the system relies enormously on rain-fed techniques. For instance, numerous economic sectors in Nigeria were impacted by the 2012 floods and it also resulted in reducing the GDP by 1.4% (Federal Government of Nigeria, 2013). According to the results of flood impact assessments, there have been significant losses in terms of human lives and means of subsistence, as well as disruptions to vital services and commercial activity. Food security and revenue streams were jeopardised, and both the agricultural and non-agricultural sectors suffered significant losses in revenue. A recovery and long-term flood risk reduction plan are therefore necessary, as the evaluation also reveals low recovery rates of impacted households and towns following the 2022 floods. Compared to roughly 40% in urban areas, the effects of the flood were substantially greater in rural areas (74%). The effect of the floods varies by gender as well; 57 percent of families headed by women and 66% of those headed by men were affected.

Effects of Flooding on the Achievements of SDG

The Sustainable Development Goals (SDGs) aim at achieving global environmental and human development by the year 2030 (Bebbington and Unerman, 2017). However, frequent flooding events observed in Nigeria and in particular Lagos State now serve as a major hindrance towards achieving the SDGs (Echendu, 2020). Some specific sustainable development goals already known to be impacted by the flood that will be discussed include SGD-1: No Poverty, SDG-2: Zero Hunger, SDG-3: Good Health and Wellbeing, SDG-6: Clean Water and Sanitation, SDG-11: Sustainable Cities and Communities, and SDG-13: Climate Action.

Globally, poverty has been identified as the biggest challenge to achieving the SDGs. Unfortunately, several environmental issues such as flooding are exacerbating the living condition of people in Nigeria and Lagos State in particular. Lagos State is characterized by a low-income population, many of whom are living below the global poverty line (Wahab, 2017). These people reside in poorly built houses which are prone to the risk of flooding. In addition, flooding results in the destruction of businesses, properties, physical terrains, social capital, and investments of already poor households (Echendu, 2020). The effect of this results in more hunger, increased disease occurrence, low *per capita* income, and reduced life expectancy (Samans et al., 2017).

Ensuring food security through improved agricultural production is key to achieving the zero-hunger goal of sustainable development. However, the food production and agricultural supply sector of Nigeria and Lagos State is greatly impacted by annual flooding (Osabohien et al., 2018). In many parts, floods destroy crops and livestock, cause reduced yield and harvest, affect the seedling and farm storage houses, and more importantly, flood negatively impacts the planting seasons (Conforti et al., 2018). In addition, flooding results in the destruction of cultivable lands, thereby causing scarcity of food, and an increase in food prices (Azubuike and Nnubia, 2015; Matemilola and Elegbede, 2017). The direct effects of this are felt mostly by the poorer rural farming communities who suffer the loss of income and lack of money to buy other commodities.

Ensuring healthy lives (SDG-3) has a strong relationship with access to clean water and sanitation (SDG-6). Flooding has a direct and indirect impact on the health of people. For example, flooding causes hunger and poverty, which increases the vulnerability of people to disease, injury, and even death (Echendu, 2020). When homes become flooded, they provide suitable habitats for breeding mosquitoes and molds, causing a trigger in the outbreak of malaria, allergies, and other epidemics diseases like typhoid, dysentery, and cholera, which affects the health of children, women, and other people (Rieckmann et al., 2018). According to Oriji (2015), flood results in the transportation of environmental pollutants such as fertilizers, pesticides, sewers, insecticides, plastics, other contaminants, and microorganisms most of which cause detrimental impacts on the environment and human health. This also contaminates water bodies, thereby reducing access to portable water (Louw et al., 2019).

SDG 11 strives to create inclusive, secure, resilient, sustainable cities and human settlements while SDG 13 is concerned with immediate action to mitigate the effects of climate change. Flooding in Lagos State induced by climate change, poor solid waste management, inadequate maintenance of wastewater infrastructures, and rapid urbanization are hindering the achievement of these goals. For example, climate change causes sea level rise and more heavy rainfall, both of which can make flooding more likely and severe. Also, the poor urban planning observed in many parts of Lagos State is contributing to the deterioration of the physical environment and livability in many residential areas (Nnaemeka-Okeke, 2016). Similarly, the integrity and security of vulnerable human settlements are also threatened by climate-induced flooding. With flooding causing damage to infrastructure, interference with transportation systems, and displacing residents from their houses, achieving the 2030 goal of a sustainable city in Lagos State is difficult. Achieving SDG-13 is hinged on dealing with the underlying factors contributing to climate change, such as reducing greenhouse gas emissions, encouraging the use of sustainable energy, and safeguarding forests and other ecosystems.

Vulnerability to Flooding

Lagos State has been identified as one of the states most susceptible to flooding in Nigeria (Nkwunonwo et al., 2016). Between 1985 and 2014, the fluvial and coastal floods in the state impacted negatively on the economic activities of the people and their properties. The experience of flood in the urban context as well as gender interaction, environmental conditions and socio-economic status has been documented (Ajibade et al., 2013). Although, work by Adelekan (2010) and Etuonovbe (2011) suggested that floods disproportionately affect women. However, they failed to provide explicit reasons for such assertion. Ajibade et al. (2013) opined that if mediating factors of vulnerability and resilience are identified, then it became easy for policymakers to pinpoint empirical basis to select the most vulnerable women and children, and therefore can channel the adaptation efforts to where it is most crucial and needed.

Adelekan and Asiyanbi (2016) investigated the perception of residents from some flood-affected communities in Lagos State, by using different vulnerability and psychometric approach. On the other hand, sustainable approach was used by Olajide and Lawanson (2014) to investigate the livelihood and environmental vulnerabilities of low-income coastal communities in Lagos, Nigeria. Olajide and Lawanson (2014) further submitted that vulnerability of the city of Lagos to flood does not have a single factor. This suggests that tackling flooding in Lagos would involve a multi-dimensional approach with all stakeholders participating. For fisheries sector in the state, one of the notable reports on the effect of flood on fishing was made by Adeoti et al. (2010). Their findings revealed that flood had adverse effect on the fishing communities and cause them to lose 81% of their income. However, fisherfolks often employ coping strategies such as relocating temporarily to another fishing site or outrightly moving permanently to another site in order to safeguard their income (Adeoti et al., 2010). The effectiveness, short- and long term effects of this relocation has not been properly elucidated.

Resilience and Adaptation Strategies to Combat Flooding in Lagos State

Lagos State has made significant and continuous progress in combating flooding. The approach can be resilient or adaptive in orientation. Some of the adaptation techniques are enhancing water systems, stream clearing, de-clogging drainage channels, safeguarding shorelines, and preventing erosion. In addition, the state hosts the International Climate Change Summit each year since 2009 through the Ministry of the Environment and Water Resources to address climate change issues that pose a threat to human existence. Lagos State's resilient strategies include 1) the establishment of Lagos State Emergency Management Agencies (LASEMA) by LASEMA Law 16 of 2008 for emergency and disaster management in the State, 2) capacity building in government ministries by employing more qualified professionals, 3) enhanced and continuous data collection and warehousing for prediction of extreme events, 4) infrastructural development such as building 69 km of concrete secondary storm water drainage to manage coastal flooding; construction of the "Great Wall of Lagos," multiple shoreline protection projects; drainage of 100,000 ha of land, 5) discontinuation of physical development of areas prone to flooding and 6) partnership with organizations like the Rockefeller Foundation via programs like the 100 Resilient Cities (100RC).

Advanced Flood Risk Management Strategies

Effective flood risk management must involve the use of robust and scientific methods such as modelling, satellite technology and machine learning tools. Flood modelling is important for the development of flood risk management policies. Though at the moment, there is no perfect singular technique or model that has been adjudged capable of single-handedly capturing all the aspects of the hydrodynamics of flood at all locations. It is clear that the peculiarity of location affects flood and the nature of flood hazard usually inform the model to be used. The reviewed paper by Nura and Alison (2023) also opined that there is no single best approach for fitting probability distributions to model extreme flooding. Till date, different models have been used to predict the occurrence of flood and its intensity in Nigeria. While the map of vulnerability for Port Harcourt metropolis was generated via ArcGis 10.0 software (Akukwe and Ogbodo, 2015), the use of GIS techniques, remote sensing, satellite imagery, and shuttle radar topography mission have been used to identify flood-prone areas and flood vulnerability analysis in Nigeria (Njoku et al., 2013; Ojigi et al., 2013; Adewumi et al., 2016). Wizor and Week (2014) combined statistical analysis and geospatial techniques for modeling and mapping of flood that took place in Yenagoa, Bayelsa State, while simple mathematical flood models, e. g., reduced complexity models (RCM), and Cellular Automata (CA) etc., was used by Nkwunonwo et al. (2020) to simulate the historical event of flooding in Lagos. Adegboyega et al. (2018) combined GIS and the Hydrologic Engineering Centre-River Analysis System model to investigate flood vulnerability in Osogbo town of Osun State. On the other hand, Komolafe et al. (2020) developed flood hazard maps by combining three methods, namely; event-based flood simulation using the FLO-2D model, the HAND model, and GIS-based multi-criteria decision analysis.

Adeogun et al. (2014) used remote sensing and GIS techniques to define the catchment area of the Jebba Lake and employed Soil and Water Assessment Tool (SWAT) to model and predict the Lake's upstream watershed flow. The upper Benue River basin floods were predicted by Izinyon and Ajumuka (2013) using three probability distributions, while Garba et al. (2013) utilised the generalised extreme value (GEV) for River Kaduna. Ologhadien (2021) also affirmed that GEV distribution was the best models for data series among the five distribution models that was used in the study. Studies have shown that across most nations of the world, flood monitoring in the last few decades has relied heavily on remote sensing technologies combined with geographic information systems (GIS). However, some of its drawbacks have been identified by Komolafe et al. (2015) and Echendu (2020). These include the occurrence of cloud cover during floods, which could impede the use of optical remote sensing; inadequate spatio-temporal imagery; and seasonal variations of weather properties, such as cloud cover in the rainy season, which makes the application of GIS more challenging than during the dry season. Additionally, while technological advancements in geospatial mapping and remote sensing have made it possible to effectively tackle this data dilemma, there are still significant financial obstacles to overcome due to the need for software, data processing skills, and the cost of airborne or space-borne data collection systems (Nkwunonwo et al., 2020). High resolution topographic data has frequently been replaced by widely accessible topographic data, such as the Shuttle Radar Topographic Mission (SRTM) and the Advanced Space-borne Thermal Emission and Reflection Radiometers Global Digital Elevation Models (ASTERGDEM) (DEFRA, 2013).

It is evinced that despite all the adopted models in Nigeria, the menace of flooding is yet to be properly curtailed. Therefore, the way forward to having effective prediction, proactive mitigation measures as well reliable flood vulnerability analysis in Nigeria, is to begin to embrace the combined use of hydrological modeling, extreme value distributions, remote sensing, CDT-based ensembles, and other approaches which have succeeded in other countries. Furthermore, multiple machine learning developed by Khosravi et al. (2018) and Pham et al. (2020), deep learning and MCDM techniques (Pradhan, 2010; Rahmati et al., 2020), CDT-based ensemble algorithms and Bayesian statistical methodology (Yang et al., 2023) should be used in synergy by all environmentalist and policymarkers in Nigeria as new approaches for investigating flooding and its consequences.

The following are suggested to control urban flooding in Lagos State:

Urban Planning and Design

i) Formulating and implementing policies and regulations for the development and management of wetlands, water plains, flood programs, and climate change activities within the State.
ii) Reviewing of the existing drainage master plans and flood control measures. Preparation of new plans, in conjunction with other relevant stakeholders, which will reflect the development orientation and growth in the city especially the flood-prone areas of the mainland and Island. The establishment of new and developing estates should follow due procedures.
iii) Liaising with local and international agencies and stakeholders in developing an appropriate and sustainable flood management framework for the city of Lagos.
iv) Exerting pressure on the Federal Government to pass into law the National Climate Change Commission Bill and take necessary steps to domesticate the same, when passed into law, in Lagos and Ogun States, where there is much inflow of water into Lagos.
v) Coordinating all drainage functions and developments across the state, especially within non-government scheme settlements.

vi) Review of developments along water channels and develop appropriate strategies to correct the anomaly with minimal loss to the settlers.
vii) Flood-proof structures. For areas with greater flood risk, some quick and relatively inexpensive things can be done to protect homes or businesses from flooding. These include elevating utilities, installation of "check valves" in sewer traps to prevent flood water back-ups, and constructing interior barriers to stop low-level floodwater from entering basements. Others include sealing walls in basements with waterproofing compounds to avoid seepage.

Urban Drainage System

i) Developing flood database and funding research on flood and climate change-related programs.
ii) Exploring all relevant technologies in tracking climate change, monitoring water levels, and developing reliable warning systems for the city. Though these technologies might not be enforceable in the already established part of the city, however, it can be fully incorporated into the new emerging plush neighborhoods. Coordinating dam operation with upstream and downstream dam owners. There should be confirmation if there is a contingency plan (back operations and emergency operations) procedure in place.
iii) Dams should be operated in a timely manner to reduce the risk of gate failure and/or damage.

Hydro-Metrological Risk Assessment

i) Management of the ecological fund, subventions, grants, and any other resources for the purpose of preventing and alleviating flood disasters.
ii) Following health and safety advice. Learning about the emergency supplies the state will need in case of flooding, enlightening the homeowners and the populace on identifying potential home hazards to avoid, and the flood evacuation route, as well as other steps they will need to take to protect themselves if flooding occurs.

CONCLUSION

Flooding in Lagos State is caused mostly by anthropogenic activities. Climate-induced sea level rise results in flooding especially in coastal states like Lagos. The impacts of flooding in Lagos State are displacement of persons, destruction of lives and properties, loss of livelihood, outbreak of disease and loss of lives. Environmental factors such as land-use change, wetland loss, population pressure, pollution and climate change worsens flooding in Lagos State. Flooding affects all forms of agricultural activities like fisheries and crop production, as well as the socio-economic lives of the coastal communities that depend on these livelihood options. Further implications include threat to food security and health of flood victims as flooding provides conducive environment for disease-causing organisms. The achievement of some of the sustainable development goals by 2030 is threatened by flooding even as the most vulnerable segment of the population to flooding are women and children. Lagos State has implemented resilient and adaptive strategies that have mitigated the impacts of flooding on Lagosians but more still needs to be done. Some of the areas that need to be addressed include mainstreaming effective management of extreme weather events in the planning and development of Lagos urban areas, proper drainage management, deployment of advanced weather forecasting equipment for prediction of hazardous weather conditions and prompt response by government agencies when such situation arises.

AUTHOR CONTRIBUTIONS

PN: Concept development, Introduction, editing of whole manuscript. AO: Environmental factors contributing to flooding. GM: Adverse Effects of Flooding on Animal and Human Ecology in Lagos State. LB: History of Flooding in Lagos State, Nigeria. CA: Adverse Effects of Flooding on Animal and Human Ecology in Lagos State. EO: Climate Change and Sea Level Rise. OL: Resilience and Adaptation Strategies to Combat Flooding in Lagos state. JS: Climate Change and Sea Level Rise. OJ: Resilience and Adaptation Strategies to Combat Flooding in Lagos state. KO: Resilience and Adaptation Strategies to Combat Flooding in Lagos state. FN: Effects of Flooding on the Achievements of SDG. CO: Effects of Flooding on the Achievements of SDG. IA: Climate Change and Sea Level Rise. OA: Advanced Flood Risk Management Strategies. All authors contributed to the article and approved the submitted version.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

REFERENCES

Abdulkadir, A., Maryam Lawal, A., and Muhammad, T. (2017). Climate Change and its Implications on Human Existence in Nigeria: A Review. *Bayero J. Pure Appl. Sci.* 10 (2), 152–158. doi:10.4314/bajopas.v10i2.26
Abolade, O., Muili, A. B., and Ikotun, S. A. (2013). Impacts of Flood Disaster in Agege Local Government Area Lagos, Nigeria. *Int. J. Dev. Sustain.* 2 (4), 2354–2367. Available at: www.isdsnet.com/ijds (Online ISSN: 2168-8662).
Action Aid (2006). *Climate Change, Urban Flooding and the Rights of the Urban Poor in Africa: Key Findings From Six African Cities*. London: Action Aid International.
Adebayo, W. A. (2014). Environmental Law and Flood Disaster in Nigeria: The Imperative of Legal Control. *Int. J. Educ. Res.* 2 (7), 447–468.

Adedeji, O. H., Odufuwa, B. O., and Adebayo, O. H. (2012). Building Capabilities for Flood Disaster and Hazard Preparedness and Risk Reduction in Nigeria: Need for Spatial Planning and Land Management. *J. Sustain. Dev. Afr.* 14 (1), 45–58.

Adegboyega, S. A., Oloukoi, J., Olajuyigbe, A. E., and Ajibade, O. E. (2019). Evaluation of Unsustainable Land Use/Land Cover Change on Ecosystem Services in Coastal Area of Lagos State, Nigeria. *Appl. Geomatics* 11, 97–110. doi:10.1007/s12518-018-0242-2

Adegboyega, S. A., Onuoha, O. C., Adesuji, K. A., Olajuyigbe, A. E., Olufemi, A. A., and Ibitoye, M. O. (2018). An Integrated Approach to Modelling of Flood Hazards in the Rapidly Growing City of Osogbo, Osun State, Nigeria. *Am. J. Space Sci.* 4, 1–15. doi:10.3844/ajssp.2018.1.15

Adelekan, I. O. (2010). Vulnerability of Poor Urban Coastal Communities to Flooding in Lagos, Nigeria. *Environ. urbanization* 22 (2), 433–450. doi:10.1177/0956247810380141

Adelekan, I. O. (2015). Flood Risk Management in the Coastal City of Lagos, Nigeria. *J. Flood Risk Manag.* 9, 255–264. doi:10.1111/jfr3.12179

Adelekan, I. O., and Asiyanbi, A. P. (2016). Flood Risk Perception in Flood-Affected Communities in Lagos, Nigeria. *Nat. Hazards* 80, 445–469. doi:10.1007/s11069-015-1977-2

Adeogun, A. G., Sule, B. F., Salami, A. W., and Daramola, M. O. (2014). Validation of SWAT Model for Prediction of Water Yield and Water Balance: Case Study of Upstream Catchment of Jebba Dam in Nigeria. *Int. J. Civ. Environ. Eng.* 8 (2), 264–270.

Adeoti, A. I., Olayide, O. E., and Coster, A. S. (2010). Flooding and Welfare of Fishers' Households in Lagos State, Nigeria. *J. Hum. Ecol.* 32 (3), 161–167. doi:10.1080/09709274.2010.11906335

Adeoye, N. O., Ayanlade, A., and Babatimehin, O. (2009). Climate Change and Menace of Floods in Nigerian Cities: Socio-Economic Implications. *Adv. Nat. Appl. Sci.* 3 (3), 369–378.

Aderogba, K. A. (2014). Polymer Wastes and Management in Cities and Towns of Africa and Sustainable Environment: Nigeria and European Experiences. *Soc. Sci.* 3 (4–1), 79–88. doi:10.11648/j.ss.s.2014030401.19

Adewumi, J. R., Akomolafe, J. K., Ajibade, F. O., and Fabeku, B. B. (2016). Application of GIS and Remote Sensing Technique to Change Detection in Land Use/land Cover Mapping of Igbokoda, Ondo State, Nigeria. *J. Appl. Sci. Process Eng.* 3 (1). doi:10.33736/jaspe.173.2016

Agbola, B. S., Ajayi, O., Taiwo, O. J., and Wahab, B. W. (2012). The August 2011 Flood in Ibadan, Nigeria: Anthropogenic Causes and Consequences. *Int. J. Disaster Risk Sci.* 3, 207–217. doi:10.1007/s13753-012-0021-3

Agbonkhese, O., Agbonkhese, E. G., Aka, E. O., Joe-Abaya, J., Ocholi, M., and Adekunle, A. (2014). Flood Menace in Nigeria: Impacts, Remedial and Management Strategies. *Civ. Environ. Res.* 6 (4), 32–40.

Aguiyi, G. (2022). *Tackling the Problem of Flooding in Nigeria*. Lagos State, Nigeria: THISDAY Newspapers Ltd. Published 25th October, 2022. Available at: https://www.thisdaylive.com/index.php/2022/10/25/tackling-the-problem-of-flooding-in-nigeria/ (Accessed April 28, 2023).

Ajibade, I. (2019). Planned Retreat in Global South Megacities: Disentangling Policy, Practice, and Environmental Justice. *Clim. Change* 157 (2), 299–317. doi:10.1007/s10584-019-02535-1

Ajibade, I., and McBean, G. (2014). Climate Extremes and Housing Rights: A Political Ecology of Impacts, Early Warning and Adaptation Constraints in Lagos Slum Communities. *Geoforum* 55, 76–86. doi:10.1016/j.geoforum.2014.05.005

Ajibade, I., McBean, G., and Bezner-Kerr, R. (2013). Urban Flooding in Lagos, Nigeria: Patterns of Vulnerability and Resilience Among Women. *Glob. Environ. change* 23 (6), 1714–1725. doi:10.1016/j.gloenvcha.2013.08.009

Ajibola, M. O., Izunwanne, E. M., and Ogungbemi, A. O. (2012). Assessing the Effects of Flooding on Residential Property Values in Lekki Phase I, Lagos, Nigeria. *Int. J. Asian Soc. Sci.* 2 (3), 271–282.

Akanwa, A. O., Joe-Ikechebelu, N., Enweruzor, A. C., Okafor, K. J., Omoruyi, F. A., Oranu, C. B., et al. (2023). "Changing Climate, Flood Footprints, and Climate-Related Actions: Effects on Ecosocial and Health Risks Along Ugbowo-Benin Road, Edo State, Nigeria," in *Ecological Footprints of Climate Change: Adaptive Approaches and Sustainability* (Cham: Springer International Publishing), 749–771.

Akpoveta, V. O., Osakwe, S. A., Ize-Iyamu, O. K., Medjor, W. O., and Egharevba, F. (2014). Post-Flooding Effect on Soil Quality in Nigeria: The Asaba, Onitsha Experience. *Open J. Soil Sci.* 4, 72–80. doi:10.4236/ojss.2014.42010

Akukwe, T. I., and Ogbodo, C. (2015). Spatial Analysis of Vulnerability to Flooding in Port Harcourt Metropolis, Nigeria. *Sage Open* 5 (1), 215824401557555. doi:10.1177/2158244015575558

Amobi, D., and Onyishi, T. (2015). Governance and Climate Change in Nigeria: A Public Policy Perspective. *J. Policy Dev. Stud.* 9 (2), 199–210. doi:10.12816/0011217

Anabaraonye, B., Okafor, C., and Hope, J. (2019). Educating Farmers and Fishermen in Rural Areas in Nigeria on Climate Change Mitigation and Adaptation for Global Sustainability. *Int. J. Sci. Eng. Res.* 10 (4), 1391–1398. doi:10.1007/978-3-319-93336-8_184

Auwalu, F. K., Wu, Y., Ghali, A. A., Roknisadeh, H., and Akram, A. N. A. (2021). Analyzing Urban Growth and Land Cover Change Scenario in Lagos, Nigeria Using Multi-Temporal Remote Sensing Data and GIS to Mitigate Flooding. *Geomatics, Nat. Hazards Risk* 12 (1), 631–652. doi:10.1080/19475705.2021.1887940

Azubuike, O. C., and Nnubia, U. E. (2015). Challenges of Food Insecurity Due to Climate Change (Flood Disaster) in the South Eastern Region of Nigeria: Need for Home Economics Extension Workers. *World Sci. News* 2 (15), 40–48.

Bashir, O. O., Oludare, A. H., Johnson, O. O., and Aloysius, B. (2012). Floods of Fury in Nigerian Cities. *J. Sustain. Dev.* 5 (7), 69. doi:10.5539/jsd.v5n7p69

Bebbington, J., and Unerman, J. (2017). Achieving the United Nations SDGs: An Enabling Role for Accounting Research. *Acc. Audit. Acc. J.* 31 (1). doi:10.1108/AAAJ-05-2017-2929

Bevacqua, A., Yu, D., and Zhang, Y. (2018). Coastal Vulnerability: Evolving Concepts in Understanding Vulnerable People and Places. *Environ. Sci. Policy* 82, 19–29. doi:10.1016/j.envsci.2018.01.006

Breitmeier, H., Kuhn, J., and Schwindenhammer, S. (2009). "Analyzing Urban Adaptation Strategies to Climate Change: A Comparison of the Coastal Cities of Dhaka, Lagos and Hamburg," in *Contribution to the Panel, Regieren im Klimawandel Section, Regierungssystem und Regieren in der Bundesrepublik Deutschland* (Berlin, Germany: DVPW-Kongress), 21, 25.

Centre for Research on the Epidemiology of Disasters (2023). EM-DAT Emergency Events Database. Available at: www.emdat.be (Accessed February 5, 2024).

Conforti, P., Ahmed, S., and Markova, G. (2018). *Impact of Disasters and Crises on Agriculture and Food Security, 2017*.

DEFRA (Department for Environment Food and Rural Affairs) (2013). *Desktop Review of 2D Hydraulic Modeling Packages*. Bristol: Environmental Agency.

Dube, K., Nhamo, G., and Chikodzi, s D. (2022). Flooding Trends and Their Impacts on Coastal Communities of Western Cape Province, South Africa. *GeoJournal* 87 (Suppl. 4), 453–468. doi:10.1007/s10708-021-10460-z

Ebele, N. E., and Emodi, N. V. (2016). Climate Change and its Impact in Nig Erian Economy. *J. Sci. Res. Rep.* 10 (6), 1–13. doi:10.9734/jsrr/2016/25162

Echendu, A. J. (2020). The Impact of Flooding on Nigeria's Sustainable Development Goals (SDGs). *Ecosyst. Health Sustain.* 6 (1), 1791735. doi:10.1080/20964129.2020.1791735

Erlandson, J. M. (2012). As the World Warms: Rising Seas, Coastal Archaeology, and the Erosion of Maritime History. *J. Coast. Conservation* 16, 137–142. doi:10.1007/s11852-010-0104-5

Etuonovbe, A. K. (2011). "The Devastating Effect of Flooding in Nigeria," in *FIG Working Week* (Marrakech, Morocco: Bridging the Gap between Cultures), 201.

Evelyn, M. I., and Tyav, T. T. (2012). Environmental Pollution in Nigeria: The Need for Awareness Creation for Sustainable Development. *J. Res. For. Wildl. Environ.* 4 (2), 92–105.

Fabiyi, O. O., and Yesuf, G. (2013). Dynamics and Characterization of Coastal Flooding in Nigeria: Implication for Local Community Management Strategies. *Ife Res. Publ. Geogr.* 12, 45–61.
Federal Government of Nigeria (2013). Nigeria Post-Disaster Needs Assessment – 2012 Floods. Available at: https://www.gfdrr.org/sites/gfdrr/files/NIGERIA_PDNA_PRINT_05_29_2013_WEB.pdf.
Federal Ministry of Environment (FME) (2012). *Bulletin on Ecological Disasters*, 25. Abuja, Nigeria: FME.
Gandy, M. (2006). Planning, Anti-Planning and the Infrastructure Crisis Facing Metropolitan Lagos. *Urban Stud.* 43 (2), 371–396. doi:10.1080/00420980500406751
Gao, L., Zhang, Y., Ding, G., Liu, Q., Wang, C., and Jiang, B. (2016). Projections of Hepatitis A Virus Infection Associated With Flood Events by 2020 and 2030 in Anhui Province, China. *Int. J. Biometeorol.* 60 (12), 1873–1884.
Garba, H., Ismail, A., and Tsoho, U. (2013). Fitting Probability Distribution Functions to Discharge Variability of Kaduna River. *Int. J. Mod. Eng. Res.* 3 (5), 2848–2852.
Hallegatte, S., Green, C., Nicholls, R. J., and Corfee-Morlot, J. (2013). Future Flood Losses in Major Coastal Cities. *Nat. Clim. Change* 3 (9), 802–806. doi:10.1038/nclimate1979
Higuera Roa, O., O'Connor, J., Ogunwumi, T. S., Ihinegbu, C., Reimer Lynggaard, J., Sebesvari, Z., et al. (2022). *Technical Report: Lagos Floods*.
HolderKommenda, J. N., and Watts, J. (2017). The Three-Degree World: Cities That Will Be Drowned by Global Warming. *Guard*. Available at: https://www.sciencedirect.com/ https://www.scholar.google.com/ (Accessed April 28, 2023).
Ibe, A. C. (1990). *Global Climate Change and the Vulnerability of the Nigerian Coastal Zone to Accelerated Sea Level Rise: Impacts and Responds*.
Ibe, A. C., and Antia, E. E. (1983). *Preliminary Assessment of the Impact of Erosion along the Nigerian Shoreline*.
Idowu, D., and Zhou, W. (2021). Land Use and Land Cover Change Assessment in the Context of Flood Hazard in Lagos State, Nigeria. *Water* 13, 1105. doi:10.3390/w13081105
Ike, C. C., Ezeibe, C. C., Anijiofor, S. C., and Daud, N. N. (2018). Solid Waste Management in Nigeria: Problems, Prospects, and Policies. *J. Solid Waste Technol. Manag.* 44 (2), 163–172. doi:10.5276/jswtm.2018.163
InsuResilience Solutions Fund (2021). CLIMADA Climate Risk Analysis: Urban Flood Resilience Against Riverine Floods in Uganda and Nigeria. Available at: https://www.insuresilience-solutions-fund.org/content/1-our-work/1-climate-riskanalysis/climate-risk-analysis_uga-nga_5-pager_final.pdf.
Intergovernmental Panel on Climate Change, IPCC (2007). "Climate Change 2007, Impacts, Adaptation, and Vulnerability," in *Working Group II Contribution to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*. Editor M. L. Parry (Cambridge (UK): Cambridge University Press).
IPCC (2013). *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press. doi:10.1017/CBO9781107415324
IPCC (2018). "Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C Above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways," in *The Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*. Editors V. Masson-Delmotte, P. Zhai, H.-O. Pörtner, D. Roberts, J. Skea, P. R. Shukla, et al. (Cambridge, UK and New York, NY, USA: Cambridge University Press), 616. doi:10.1017/9781009157940
IPCC (2019a). "Summary for Policymakers," in *IPCC Special Report on the Ocean and Cryosphere in a Changing Climate* Editors H.-O. Pörtner, D. C. Roberts, V. Masson-Delmotte, P. Zhai, M. Tignor, E. Poloczanska, et al. (Cambridge, UK and New York, NY, USA: Cambridge University Press). doi:10.1017/9781009157964.001
IPCC (2019b). "Climate Change and Land," in *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems*. Editors P. R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, et al. (In press).
IPCC (2021). "Summary for Policymakers," in *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Editors V. Masson-Delmotte, P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, et al. (Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press), 3–32. doi:10.1017/9781009157896.001
IPCC (2022). in *Climate Change 2022: Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. Editors H.-O. Pörtner, D. C. Roberts, M. Tignor, E. S. Poloczanska, K. Mintenbeck, A. Alegría, et al. (Cambridge, UK and New York, NY, USA: Cambridge University Press. Cambridge University Press), 3056. doi:10.1017/9781009325844
Israel, A. O. (2017). Nature, the Built Environment and Perennial Flooding in Lagos, Nigeria: The 2012 Flood as a Case Study. *Urban Clim.* 21, 218–231. doi:10.1016/j.uclim.2017.06.009
Izinyon, O. C., and Ajumuka, H. N. (2013). Probability Distribution Models for Flood Prediction in Upper Benue River Basin-Part II. *Civ. Environ. Res.* 3 (2), 62–74.
Jaffar, N. S., Jawan, S., and Chong, K. P. (2023). The Potential of Lactic Acid Bacteria in Mediating the Control of Plant Diseases and Plant Growth Stimulation in Crop Production - A Mini Review. *Front. Plant Sci.* 13, 1047945. doi:10.3389/fpls.2022.1047945
Jiboye, J. O., Ikporukpo, C. O., and Olatubara, C. O. (2019). Impact of Environmental Degradation on Livelihoods in the Coastal Areas of South West, Nigeria. *J. Aquac. Res. Dev.* 10 (4), 1–11.
Jisha, K. C., and Puthur, J. T. (2021). Ecological Importance of Wetland Systems. *Wetl. Conservation Curr. Challenges Future Strategies*, 40–54. doi:10.1002/9781119692621.ch3
Kandissounon, G. A., Karla, A., and Ahmad, S. (2018). Integrating System Dynamics and Remote Sensing to Estimate Future Water Usage and Average Surface Runoff in Lagos, Nigeria. *Civ. Eng. J.* 4 (2), 378. doi:10.28991/cej-030998
Kasim, O. F., Wahab, B., and Oweniwe, M. F. (2022). Urban Expansion and Enhanced Flood Risk in Africa: The Example of Lagos. *Environ. Hazards* 21 (2), 137–158. doi:10.1080/17477891.2021.1932404
Khosravi, K., Pham, B. T., Chapi, K., Shirzadi, A., Shahabi, H., Revhaug, I., et al. (2018). A Comparative Assessment of Decision Trees Algorithms for Flash Flood Susceptibility Modeling at Haraz Watershed, Northern Iran. *Sci. Total Environ.* 627, 744–755. doi:10.1016/j.scitotenv.2018.01.266
Kingsford, R. T., Basset, A., and Jackson, L. (2016). Wetlands: Conservation's Poor Cousins. *Aquatic Conservation Mar. Freshw. Ecosyst.* 26 (5), 892–916. doi:10.1002/aqc.2709
Komolafe, A. A., Adegboyega, S. A. A., and Akinluyi, F. O. (2015). A Review of Flood Risk Analysis in Nigeria. *Am. J. Environ. Sci.* 11 (3), 157–166. doi:10.3844/ajessp.2015.157.166
Komolafe, A. A., Awe, B. S., Olorunfemi, I. E., and Oguntunde, P. G. (2020). Modelling Flood-Prone Area and Vulnerability Using Integration of Multi-Criteria Analysis and HAND Model in the Ogun River Basin, Nigeria. *Hydrological Sci. J.* 65 (10), 1766–1783. doi:10.1080/02626667.2020.1764960
Kulp, S. A., and Strauss, B. H. (2019). New Elevation Data Triple Estimates of Global Vulnerability to Sea-Level Rise and Coastal Flooding. *Nat. Commun.* 10 (1), 4844. doi:10.1038/s41467-019-12808-z
Kundzewicz, Z. W., Mata, L. J., Arnell, N. W., Döll, P., Jimenez, B., Miller, K., et al. (2008). The Implications of Projected Climate Change for Freshwater Resources and Their Management. *Hydrological Sci. J.* 53 (1), 3–10. doi:10.1623/hysj.53.1.3
Lagos Bureau of Statistics (2016). Household Survey 2016. Lagos State Government. Available at: http://mepb.lagosstate.gov.ng/wp-content/uploads/sites/29/2020/08/House-Hold-REPORTY2016.pdf.

Lawanson, O. I., Proverbs, D., and Ibrahim, R. L. (2022). The Impact of Flooding on Poor Communities in Lagos State, Nigeria: The Case of the Makoko Urban Settlement. *J. Flood Risk Manag.* 16 (1), 1–16. doi:10.1111/jfr3.12838

Louw, E., Olanrewaju, C. C., Olanrewaju, O. A., and Chitakira, M. (2019). Impacts of Flood Disasters in Nigeria: A Critical Evaluation of Health Implications and Management. *Jàmbá J. Disaster Risk Stud.* 11 (1), 557–559. doi:10.4102/jamba.v11i1.557

Makela, F. (2008). *Socio-Economic Study of the Impact and Adaptation to Flooding of Fishermen in Epe, Lagos State*. Unpublished Thesis. Oyo State, Nigeria: Department of Agricltural Economics, University of Ibadan.

Marcott, S. A., Shakun, J. D., Clark, P. U., and Mix, A. C. (2013). A Reconstruction of Regional and Global Temperature for the Past 11,300 Years. *Science* 339 (6124), 1198–1201. doi:10.1126/science.1228026

Matemilola, S., and Elegbede, I. (2017). The Challenges of Food Security in Nigeria. *Open Access Libr. J.* 4 (12), 1–22. doi:10.4236/oalib.1104185

McGranahan, G., Balk, D., and Anderson, B. (2007). The Rising Tide: Assessing the Risks of Climate Change and Human Settlements in Low Elevation Coastal Zones. *Environ. urbanization* 19 (1), 17–37. doi:10.1177/0956247807076960

Mengel, M., Levermann, A., Frieler, K., Robinson, A., Marzeion, B., and Winkelmann, R. (2016). Future Sea Level Rise Constrained by Observations and Long-Term Commitment. *Proc. Natl. Acad. Sci.* 113 (10), 2597–2602. doi:10.1073/pnas.1500515113

Miceli, R., Sotgiu, I., and Settanni, M. (2008). Disaster Preparedness and Perception of Flood Risk: A Study in an Alpine Valley in Italy. *J. Environ. Psychol.* 28 (2), 164–173. doi:10.1016/j.jenvp.2007.10.006

Mogaji, E. (2020). Impact of COVID-19 on Transportation in Lagos, Nigeria. *Transp. Res. Interdiscip. Perspect.* 6, 100154. doi:10.1016/j.trip.2020.100154

National Academies of Sciences, Engineering, and Medicine (2011). *Climate Stabilization Targets: Emissions, Concentrations, and Impacts over Decades to Millennia*. Washington, DC: The National Academies Press, 5. ISBN 978-0-309-15176-4. doi:10.17226/12877

National Academies of Sciences, Engineering, and Medicine (2016). *Attribution of Extreme Weather Events in the Context of Climate Change*. Washington, DC: The National Academies Press

National Bureau of Statistics (2023). Demographic Statistics Bulletin 2022. Available at: https://www.nigerianstat.gov.ng/pdfuploads/DEMOGRAPHIC_BULLETIN_2022_FINAL.pdf (Accessed February 5, 2024).

National Oceanic and Atmospheric Administration (NOAA) (2016). State of the Climate: Global Climate Report for Annual 2015. National Oceanic and Atmospheric Administration (NOAA) National Centers for Environmental Information (NCEI). Available at: http://www.ncdc.noaa.gov/sotc/global/201513.

Ndimele, P. E., Akanni, A., Ositimehin, K. M., Shittu, J. A., Ojewole, A. E., and Ayeni, Y. Z. (2024). Fostering International and Trans-Boundary Cooperation in the Management of Lake Chad Fisheries, Wildlife and Flora: The Role of a Trans-Boundary Ramsar Conservation Area. *Aquat. Living Resour.* 37, 6. doi:10.1051/alr/2024004

Ndimele, P. E., Owodeinde, F. G., Clarke, E. O., Whenu, O. O., and Joseph, O. O. (2021). Population Parameters, Exploitation Rate and Diet of Black-Chinned Tilapia, Sarotherodon Melanotheron Rüppell, 1852 (Pisces: Cichlidae), From Badagry Creek, Lagos, Nigeria. *Afr. Zool.* 56 (4), 279–291. doi:10.1080/15627020.2021.2006779

Ndimele, P. E., Owodeinde, F. G., Giwa-Ajeniya, A. O., Moronkola, B. A., Adaramoye, O. R., Ewenla, L. O., et al. (2022). Multi-Metric Ecosystem Health Assessment of Three Inland Water Bodies in South-West, Nigeria, With Varying Levels of Sand Mining Activities and Heavy Metal Pollution. *Biol. Trace Elem. Res.* 200, 3355–3376. doi:10.1007/s12011-021-02907-8

Nicholls, R. J., Hanson, S., Herweijer, C., Patmore, N., Hallegatte, S., Corfee-Morlot, J., et al. (2008). *Ranking Port Cities With High Exposure and Vulnerability to Climate Extremes: Exposure Estimates*.

Njoku, C. G., Efiong, J., and Ayara, N. N. (2020). A Geospatial Expose of Flood-Risk and Vulnerable Areas in Nigeria. *Int. J. Appl. Geospatial Res.* 11 (3), 1–24. doi:10.4018/IJAGR.20200701.oa1

Njoku, J. D., Amangabara, G. T., and Duru, P. N. (2013). Spatial Assessment of Urban Flood Risks in Aba Metropolis, Using Geographical Information Systems Techniques. *Glob. Adv. Res. J. Environ. Sci. Toxicol.* 2 (3), 086–092.

Nkwunonwo, U. C., Whitworth, M., and Baily, B. (2016). Review Article: A Review and Critical Analysis of the Efforts Towards Urban Flood Risk Management in the Lagos Region of Nigeria. *Nat. Hazards Earth Syst. Sci.* 16, 349–369. doi:10.5194/nhess-16-349-2016

Nkwunonwo, U. C., Whitworth, M., and Baily, B. (2020). A Review of the Current Status of Flood Modelling for Urban Flood Risk Management in the Developing Countries. *Sci. Afr.* 7, e00269. doi:10.1016/j.sciaf.2020.e00269

Nnaemeka-Okeke, R. (2016). Urban Sprawl and Sustainable City Development in Nigeria. *J. Ecol. Eng.* 17 (2), 1–11. doi:10.12911/22998993/62277

Nura, U., and Alison, G. (2023). Flooding in Nigeria: A Review of Its Occurrence and Impacts and Approaches to Modelling Flood Data. *Int. J. Environ. Stud.* 80 (3), 540–561. doi:10.1080/00207233.2022.2081471

Obiefuna, J. N., Adeaga, O., Omojola, A., Atagbaza, A. O., and Okolie, C. J. (2021). Flood Risks to Urban Development on a Coastal Barrier Landscape of Lekki Peninsula in Lagos, Nigeria. *Sci. Afr.* 12, e00787. doi:10.1016/j.sciaf.2021.e00787

Obiefuna, J. N., Nwilo, P. C., Atagbaza, A. O., and Okolie, C. J. (2013a). Land Cover Dynamics Associated With the Spatial Changes in the Wetlands of Lagos/Lekki Lagoon System of Lagos, Nigeria. *J. Coast. Res.* 29 (3), 671–679. doi:10.2307/23486349

Obiefuna, J. N., Nwilo, P. C., Atagbaza, A. O., and Okolie, C. J. (2013b). Spatial Changes in the Wetlands of Lagos/Lekki Lagoons of Lagos, Nigeria. *J. Sustain. Dev.* 6 (7), 123. doi:10.5539/jsd.v6n7p123

OCHA (UN Office for the Coordination of Humanitarian Affairs) (2012). Nigeria: Floods, Emergency Situation Report No 2. Available at: www.ochaonline.un.org/rowca.

Olanrewaju, C. C., Chitakira, M., Olanrewaju, O. A., and Louw, E. (2019). Impacts of Flood Disasters in Nigeria: A Critical Evaluation of Health Implications and Management. *Jàmbà: J. Disaster Risk Sci.* 11 (1), 1–9.

Ogbuabor, J. E., and Egwuchukwu, E. I. (2017). The Impact of Climate Change on the Nigerian Economy. *Int. J. Energy Econ. Policy* 7 (2), 217–223. Available at: https://dergipark.org.tr/en/download/article-file/361739.

Ojigi, M. L., Abdulkadir, F. I., and Aderoju, M. O. (2013). "Geospatial Mapping and Analysis of the 2012 Flood Disaster in Central Parts of Nigeria," in *8th National GIS Symposium* (Dammam, Saudi Arabia: NASRDA), 1067–1077.

Oladokun, V. O., and Proverbs, D. (2016). Flood Risk Management in Nigeria: A Review of the Challenges and Opportunities. *Flood Risk Manag. Response* 6, 485–497. doi:10.2495/safe-v6-n3-485-497

Oladunjoye, M. (2011). *Nigeria: July 10 Flooding–Lagos Gives Relief Materials to Victims*. Lagos State, Nigeria: Daily Champion Newspaper. Accessed January 30, 2024.

Olajide, O., and Lawanson, T. (2014). Climate Change and Livelihood Vulnerabilities of Low-Income Coastal Communities in Lagos, Nigeria. *Int. J. Urban Sustain. Dev.* 6 (1), 42–51. doi:10.1080/19463138.2013.878348

Olajuyigbe, A. E., Rotowa, O. O., and Durojaye, E. (2012). An Assessment of Flood Hazard in Nigeria: The Case of Mile 12, Lagos. *Mediterr. J. Soc. Sci.* 3 (2), 367–377.

Ologhadien, I. (2021). Comparative Evaluation of Probability Distribution Models of Flood Flow in Lower Niger Basin. *Eur. J. Eng. Technol. Res.* 6 (2), 107–117. doi:10.24018/ejeng.2021.6.2.2352

Onwutuebe, C. J. (2019). *Patriarchy and Women Vulnerability to Adverse Climate Change in Nigeria*. doi:10.1177/2158244019825914SAGE

Oriji, C. C. (2015). What to Do About Climate Change-Caused Flooding and the Associated Diseases in Rivers State of Nigeria. *Glob. J. Human-Social Sci. Res.* 15 (4), 29–33. doi:10.17406/GJHSSBVOL15IS4PG29
Osabohien, R., Osabuohien, E., and Urhie, E. (2018). Food Security, Institutional Framework and Technology: Examining the Nexus in Nigeria Using ARDL Approach. *Curr. Nutr. Food Sci.* 14 (2), 154–163. doi:10.2174/1573401313666170525133853
Osakwe, S. A., Akpoveta, V. O., and Osakwe, J. O. (2014). The Impact of Nigerian Flood Disaster on the Soil Quality of Farmlands in Oshimili South Local Government Area of Delta State, Nigeria. *Chem. Mater. Res.* 6 (3), 68–77.
Otokiti, K. V., Akinola, O., and Adeniji, K. N. (2019). Geospatial Mapping of Flood Risk in the Coastal Megacity of Nigeria. *Am. J. Geophys. Geochem. Geosystems* 5 (4), 129–138.
Oyebande, L., Obot, E. O., Bdiliya, H. H., and Oshunsanya, C. O. (2003). *An Inventory of Wetlands in Nigeria*. Burkina Faso: World Conservation Union–IUCN, West African Regional Office Ouagadougou.
Pandian, P. K., Ramesh, S., Murthy, M. V. R., Ramachandran, S., and Thayumanavan, S. (2004). Shoreline Changes and Near Shore Processes Along Ennore Coast, East Coast of South India. *J. Coast. Res.* 20 (3), 828–845. doi:10.2112/1551-5036(2004)20[828:scansp]2.0.co;2
Parnell, S., Simon, D., and Vogel, C. (2007). Global Environmental Change: Conceptualising the Growing Challenge for Cities in Poor Countries. *Area* 39 (3), 357–369. doi:10.1111/j.1475-4762.2007.00760.x
Pham, B. T., Avand, M., Janizadeh, S., Phong, T. V., Al-Ansari, N., Ho, L. S., et al. (2020). GIS Based Hybrid Computational Approaches for Flash Flood Susceptibility Assessment. *Water* 12 (3), 683. doi:10.3390/w12030683
Pradhan, B. (2010). Flood Susceptible Mapping and Risk Area Delineation Using Logistic Regression, GIS and Remote Sensing. *J. Spatial Hydrology* 9 (2).
Pramanik, M. K. (2014). Assessment the Impact of Sea Level Rise on Mangrove Dynamics of Ganges Delta in India Using Remote Sensing and GIS. *J. Environ. Earth Sci.* 4 (21), 117–127.
Raaijmakers, R., Krywkow, J., and van der Veen, A. (2008). Flood Risk Perceptions and Spatial Multi-Criteria Analysis: An Exploratory Research for Hazard Mitigation. *Nat. hazards* 46, 307–322. doi:10.1007/s11069-007-9189-z
Rahmati, O., Darabi, H., Panahi, M., Kalantari, Z., Naghibi, S. A., Ferreira, C. S. S., et al. (2020). Development of Novel Hybridized Models for Urban Flood Susceptibility Mapping. *Sci. Rep.* 10 (1), 12937. doi:10.1038/s41598-020-69703-7
Reddy, K. R., Patrick, W. H., and Broadbent, F. E. (1984). Nitrogen Transformations and Loss in Flooded Soils and Sediments. *CRCCritical Rev. Environ. Control* 13 (4), 273–309. doi:10.1080/10643388409381709
Rieckmann, A., Tamason, C. C., Gurley, E. S., Rod, N. H., and Jensen, P. K. M. (2018). Exploring Droughts and Floods and Their Association With Cholera Outbreaks in Sub-Saharan Africa: A Register-Based Ecological Study from 1990 to 2010. *Am. J. Trop. Med. Hyg.* 98 (5), 1269–1274. doi:10.4269/ajtmh.17-0778
Riise, J., and Adeyemi, K. (2015). Case Study: Makoko Floating School. *Curr. Opin. Environ. Sustain.* 13, 58–60. doi:10.1016/j.cosust.2015.02.002
Sabo, B. B., Isah, S. D., Chamo, A. M., and Rabiu, M. A. (2017). Role of Smallholder Farmers in Nigeria's Food Security. *Sch. J. Agric. Sci.* 7 (1), 1–5.
Samans, R., Blanke, J., Corrigan, G., and Drzeniek-Hanouz, M. (2017). *Rising to the Challenge of Inclusive Growth and Development*. Geneva: World Economic Forum, 1–132.
Samson, A. O., and Oluwatoyin, O. R. (2012). Challenges of Waste Management and Climate Change in Nigeria: Lagos State Metropolis Experience. *Afr. J. Sci. Res.* 7 (1).
Sayne, A. (2011). *Climate Change Adaptation and Conflict in Nigeria*. Washington, DC: USIP. Available at: https://www.usip.org/sites/default/files/Climate_Change_Nigeria.pdf.
Seenu, P. Z., Venkata, R. E., and Jayakumar, K. V. (2020). Visualisation of Urban Flood Inundation Using SWMM and 4D GIS. *Spatial Inf. Res.* 28, 459–467. doi:10.1007/s41324-019-00306-9
Sharifi, L., and Bokaie, S. (2019). Priorities in Prevention and Control of Flood Hazards in Iran 2019 Massive Flood. *Iran. J. Microbiol.* 11 (2), 80–84. doi:10.18502/ijm.v11i2.1065
Shiru, M. S., Shahid, S., Alias, N., and Chung, E. S. (2018). Trend Analysis of Droughts During Crop Growing Seasons of Nigeria. *Sustainability* 10 (3), 871. doi:10.3390/su10030871
Solomon, E., and Edet, O. G. (2018). Determinants of Climate Change Adaptation Strategies Among Farm Households in Delta State, Nigeria. *Curr. Investigations Agric. Curr. Res.* 5 (3). doi:10.32474/ciacr.2018.05.000213
Sugianto, S., Deli, A., Miswar, E., Rusdi, M., and Irham, M. (2022). The Effect of Land Use and Land Cover Changes on Flood Occurrence in Teunom Watershed, Aceh Jaya. *Land* 11 (8), 1271. doi:10.3390/land11081271
THISDAY (2023). *Lagos, FCT, 30 States Risk Looming Flood Disasters*. Lagos State, Nigeria: THISDAY Newspapers Ltd. Published 19th February, 2023. Available at: https://www.thisdaylive.com/index.php/2023/02/19/lagos-fct-30-states-risk-looming-flooddisasters/#:~:text=The%20high%20flood%20risk%20areas,Yobe%2C%20Zamfara%2C%20and%20the%20Federal (Accessed April 28, 2023).
Thomas, A. H., and Turk, R. A. (2023). Food Insecurity in Nigeria: Food Supply Matters Nigeria: Nigeria. USA. *Int. Monet. Fund.* 2023 (018). doi:10.5089/9798400236921.018
Uluocha, N. O., and Okeke, I. C. (2004). Implications of Wetlands Degradation for Water Resources Management: Lessons From Nigeria. *GeoJournal* 61, 151–154. doi:10.1007/s10708-004-2868-3
United Nations (2022). World Population Prospects 2022. Available at: http://esa.un.org/unpd/wpp.
Usigbe, L. (2021). Dogged by Massive Floods, Nigeria Ramps up Actions to Tackle Climate Crisis. Available at: https://www.un.org/africarenewal/magazine/november-2021/dogged-massive-floods-nigeria-rampsactions-tackle-climate-crisis.
Wahab, B. (2017). "Transforming Nigerian Informal Settlements Into Liveable Communities: Strategies and Challenges," in *The 2017 Edition of Mandatory Continuing Professional Development Programme (MCPDP) of the Nigerian Institute of Town Planners*.
Wang, S., Wang, W., Ji, M., Chen, W., and Xu, S. (2013). "Assessment of Vulnerability to Sea-Level Rise for China's Coast," in *2013 21st International Conference on Geoinformatics* (IEEE), 1–6.
Ward, R. D., Friess, D. A., Day, R. H., and MacKenzie, R. A. (2016). Impacts of Climate Change on Mangrove Ecosystems: A Region by Region Overview. *Ecosyst. Health Sustain.* 2 (4), e01211. doi:10.1002/ehs2.1211
Wizor, C. H., and Week, D. A. (2014). Impact of the 2012 Nigeria Flood on Emergent Cities of Nigeria: The Case of Yenagoa, Bayelsa State, Nigeria. *J. Civil. Environ. Res.* 6 (5), 31–34.
World Climate Research Programme (WCRP) Global Sea Level Budget Group (2018). Global Sea-Level Budget 1993–Present. *Earth Syst. Sci. Data* 10 (3), 1551–1590. Bibcode:2018ESSD, 10.1551W. doi:10.5194/essd-10-1551-2018
World Food Program (2022). *Hunger Hotspots*. Rome.
Yang, D., Zhang, T., Arabameri, A., Santosh, M., Saha, U. D., and Islam, A. (2023). Flash-Flood Susceptibility Mapping: A Novel Credal Decision Tree-Based Ensemble Approaches. *Earth Sci. Inf.* 16 (4), 3143–3161. doi:10.1007/s12145-023-01057-w