INTERNATIONAL JOURNAL OF ENVIRONMENTAL STUDIES
https://doi.org/10.1080/00207233.2022.2081471

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Flooding in Nigeria: a review of its occurrence and impacts and approaches to modelling flood data

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ABSTRACT
This paper surveys flood mapping and modelling in Nigeria in regard to frequency and impact of floods in the last decade. The aim is to understand the frequency and patterns of flooding and approaches to its modelling in relation to current practices globally. The northern part of Nigeria is affected more by flooding than the south, so should be prioritised for flood management. The use of remote sensing data with GIS techniques is the most common approach to flood modelling in Nigeria. Bayesian and machine learning approaches should be used, in preference to process-based models.

KEYWORDS
Extreme events; flood risk management; modelling; Nigeria

Introduction

Many environmental problems threaten the world [1, 2]. Flooding is considered to be the most devastating natural disaster worldwide [3]. Flooding is excess water flowing onto land which is usually dry [4], e.g. when rainfall exceeds absorption capacity of the soil, which in turn causes significant environmental consequences [5]. Peduzzi et al. [6] maintain that 'the rate of flood occurrence in recent times has been unprecedented, with 70 million people globally exposed to flooding every year, and more than 800 million living in flood-prone areas' [6]. Rentschler and Salhab [7] estimate that '1.47 billion people, or 19% of the world population, are directly exposed to substantial risks during 1-in-100 year flood events'.

In developing countries, flooding results from climate change, excessive precipitation, building on waterways, sea-level rise, soil moisture regime, dam operations, especially along borders, uncontrolled rapid population growth, inadequate preparedness, and lack of political will [8–15]. Flooding has both natural and human causes [9]. MacLeod et al. [10] identified excessive levels of precipitation as the main natural cause of flooding, caused by climate change. Tramblay et al. [16] link flood occurrence to maximum level of soil moisture rather than maximum precipitation.

This paper focuses on flooding in Nigeria. Effective flood risk management requires understanding available data, and prediction of extreme weather events. There is still much effort needed. Mashi et al. [17] reviewed Nigeria's emergency management

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Published online 31 May 2022

legislation and found it lacking in terms of development of action plans, empowering resource mobilisation, risk management strategies and in specifying responsibilities of stakeholders.

Komolafe et al. [3] consider only flood mapping and flood vulnerabilities. Nkwunonwo [18] identifies Nigerian limitations in adopting the world's best practices for mitigation. Cirella and Iyalomhe [19] evaluate locations at risk of flood disaster, and suggest ways to mitigate this threat. Nkwunonwo et al. [20] review strengths and weaknesses of some urban flood models for developing countries like Nigeria. Alves et al. [21] review coastal erosion and flood risk management in West Africa. Echendu [22] relates Nigeria's flooding to its food security and its sustainable development goals (SDGs), finding that policy-makers do not recognise the relationship, and so this author makes recommendations for flood mitigation. Dube et al. [23] use the SDG framework and the Sendai Framework for Disaster Risk Reduction 2015–2030 to recommend measures which can manage flood risk to human settlements in South Africa.

The present paper examines work on flood occurrences in Nigeria over the 10-year period from 2011 to 2020 as well as approaches for flood mapping and modelling, some of which have not yet been exploited in Nigeria. The purpose is not statistical analysis, but highlighting possibilities for management and mitigation of the flood risk, through effective data modelling and prediction. The paper also introduces data-driven and Bayesian approaches as alternatives for flood modelling in Nigeria, for mitigating effects of flooding through improved prediction, which is crucial for water resources' management [24]; to the best of our knowledge, these approaches have not been exploited in Nigeria. The next section reviews the occurrence and causes of flooding in Nigeria, including a compilation of flood frequency data. The focus is then on impacts upon Nigerian states, numbers of people affected, value of damage, and a comparison of these between Nigeria and Africa as a whole. The following sections concern flood mapping and modelling in Nigeria, and describe promising approaches used elsewhere which could be exploited in Nigeria. The final sections present discussion and conclusions.

Occurrences and causes of flooding in Nigeria

The Nigeria Hydrological Services Agency in its annual flood outlook [13] defines the major causes of flooding in Nigeria as follows: soil moisture, extreme weather conditions owing to climate change, how dams are functioning, especially those close to the country's borders, and topography. Adegboyega et al. [25] identify changes in land use, such as urbanisation, as a trigger to urban flooding. Abolade et al. [9] find extreme precipitation to be a natural cause. These authors find that human causes include inadequate drainage, dumping of refuse on waterways, building on waterways and river/dam overflow. Aderogba [26] identifies the main causes of flooding in Lagos metropolis, which comprises 16 local government areas (LGAs). These main causes include blockage of canals, inadequate drainage systems, torrential rain, and encroachment. Agbonkhese et al. [27] find excessive or heavy precipitation to be the major cause of flooding; others include climate change and anthropogenic activities. Komolafe et al. [3] find that two natural causes are heavy downpour and river storms. Broken water pipes, inadequate drainage systems, and dam overflow are anthropogenic causes.

There is complete agreement that the occurrence, extent, and intensity of extreme weather-related events, such as extreme rainfall or temperature and storms, among others which cause natural disasters such as floods, will increase because of anthropogenic causes and climate change [28]. Echendu [29] identified anthropogenic causes as the main drivers of flooding in Nigeria and Ghana, worsening the effects of heavy rainfall, but the effects of these can be mitigated by risk-management strategies and infrastructure planning.

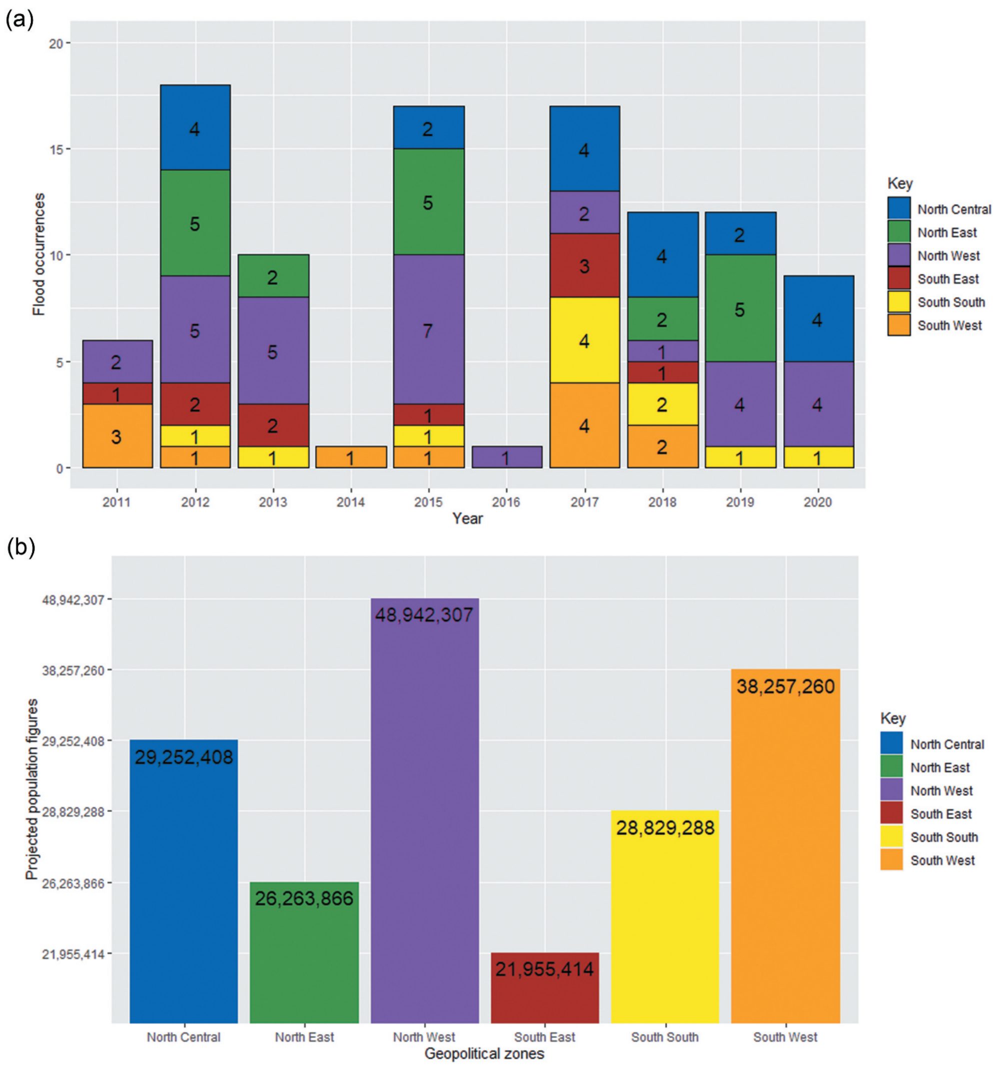

Figure 1. (a) Stacked bar chart showing frequency of major flood occurrences between 2011–2020, by geopolitical zone in Nigeria (Source: Data compiled from Centre for Research on the Epidemiology of Disasters [31]); and (b) bar chart showing projected population figures in 2016 by geopolitical region in Nigeria, from the National Population Commission demographic statistics bulletin [30]). For the purposes of this figure, FCT (Federal Capital Territory) is included in the North Central zone.

Figure 1(a) shows the number of flood occurrences across the six geographical zones of Nigeria within the last decade. It is evident that the North-West zone had the highest frequency of flooding, with 31 instances, followed by the North-Central and North-East zones with 20 and 19 instances, respectively. The South-East zone had the fewest floods, similar to the South-South and South-West zones. The dominance of flooding in the northern regions in most years is clear. The year 2012 had the highest number of flood occurrences in the country in the time period studied, with 18 incidences, closely followed by years 2015 and 2017 with 17 incidences each, and next are 2018 and 2019 with 12 incidences each. The years with fewest flood incidences are 2014 and 2016, each with 1 incidence in the South-West and North-West regions, respectively. Figure 1(b) shows projected population figures for the year 2016 from the National Population Commission (extracted from the demographic statistics bulletin [30]). The North-West zone, where flooding is most frequent, has the highest projected population in the country, with approximately 49 million people, followed by the South-West with 38,257,260 people. The South-East zone, with fewest floods, had the lowest population projection with approximately 22 million people. Accordingly, the North-West zone should be given greater priority for flood mitigation measures, as it has both experienced the highest number of flood incidences within the last decade and has the highest projected population size (as recorded for year 2016).

Table 1 shows a more detailed breakdown of flood occurrence by state and year than seen in Figure 1(a). Niger, Jigawa, Kano, and Yobe (Figure 2) all suffered more than 5 incidences of flooding over the studied 10-year period, with Katsina and Kebbi having five incidences each.

For the past two decades, annual floods in Nigeria have resulted in the loss of 1,763 lives and damage to properties worth close to $1 billion. Most of these disasters were caused by fluvial, flash, and pluvial floods, the deadliest being the fluvial flood [31]. A fluvial (river) flood occurs when the water level of a lake, river, or stream rises and overflows onto the surrounding banks, shores, and neighbouring land. The rise in water level may be caused by extreme precipitation or snow-melt. Flash floods occur through heavy rainfall or sudden release of water within a short period of time. Pluvial (surface water) floods occur when extreme rainfall results in flooding which is independent of an overflowing waterbody [33].

Impact of flooding in Nigeria

The impacts of disasters are generally quantifiable. Drought, flooding, and landslide are natural hazards with devastating impact in Africa [34]. In the last decade, flooding has been the most frequent natural hazard in Africa [35, 36]. In the last 50 years, Nigerians experienced two prominent flood incidences in the years 2012 and 2018 [13]. Flooding in other years was less catastrophic. The impacts of flooding can be direct or indirect. Rentschler et al. [37] investigated effects of floods on businesses in Tanzania, and found that direct effects could be substantial but were less common than indirect effects such as supply chain problems. In Nigeria, where flooding is common, data on the impacts of flooding can be lacking at national and city/state level, or reports on flood events are incomplete, making it difficult to compare impacts across locations and to quantify their magnitude [38].

Table 1. Summary of numbers of flood occurrences by states in Nigeria 2011–2020. Source: Data extracted from [31].

State (Zone)	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	Total
Abia (SE)			1				1				**2**
Adamawa (NE)		1			1						**2**
Akwa Ibom (SS)							1			1	**2**
Anambra (SE)		1			1			1			**3**
Bauchi (NE)		1	1		1			1			**4**
Bayelsa (SS)							2				**2**
Benue (NC)		1			1						**2**
Borno (NE)									2		**2**
Cross River (SS)		1									**1**
Delta (SS)					1			1	1		**3**
Ebonyi (SE)		1	1				1				**3**
Edo (SS)			1				1	1			**3**
Ekiti (SW)							1				**1**
Enugu (SE)							1				**1**
Gombe (NE)		1	1		1						**3**
Imo (SE)	1										**1**
Jigawa (NW)		1	1		1	1			2	1	**7**
Kaduna (NW)		1			1						**2**
Kano (NW)	1	1	1		1				2		**6**
Katsina (NW)	1	1	1		1			1			**5**
Kebbi (NW)		1	1		1		1			1	**5**
Kogi (NC)							1	1	1		**3**
Kwara (NC)							1			2	**3**
Lagos (SW)	2	1					1				**4**
Nasarawa (NC)		1									**1**
Niger (NC)		1			1		1	2	1	1	**8**
Ogun (SW)								1			**1**
Ondo (SW)					1			1			**2**
Osun (SW)							1				**1**
Oyo (SW)	1			1			1				**3**
Plateau (NC)		1					1				**2**
Sokoto (NW)					1		1			1	**3**
Taraba (NE)		1			1				1		**3**
Yobe (NE)		1			1			1	2		**6**
Zamfara (NW)			1		1					1	**3**
FCT								1		1	**2**
Total	**6**	**18**	**10**	**1**	**17**	**1**	**17**	**12**	**12**	**9**	**103**

In 2012, Nigeria experienced its worst flooding in over 40 years, because of heavy rainfall across the country, for many days, and the Lagdo Dam in northern Cameroon east of Nigeria, used for electricity generation, and irrigation, releasing its excess water. The incidence affected 32 states, 24 severely. The floods occurred from July to October that year, affecting more than 7 million people. More than 2 million others were counted as internally displaced persons (IDPs). More than 5,000 people were physically injured. Over 5,900 houses were destroyed [39]. The most severely affected states were Benue and Niger states, because of their riparian communities [40]. The European Commission Joint Research Centre [41] cites the National Emergency Management Agency (NEMA) as having reported that heavy rains across Nigeria caused the rivers Niger and Benue to overflow. The report states that 12 states were affected, with a National Disaster being declared in four states, viz., Anambra, Delta, Kogi and Niger states. The flooding affected 441,251 persons, and more than 100 dead were recorded.

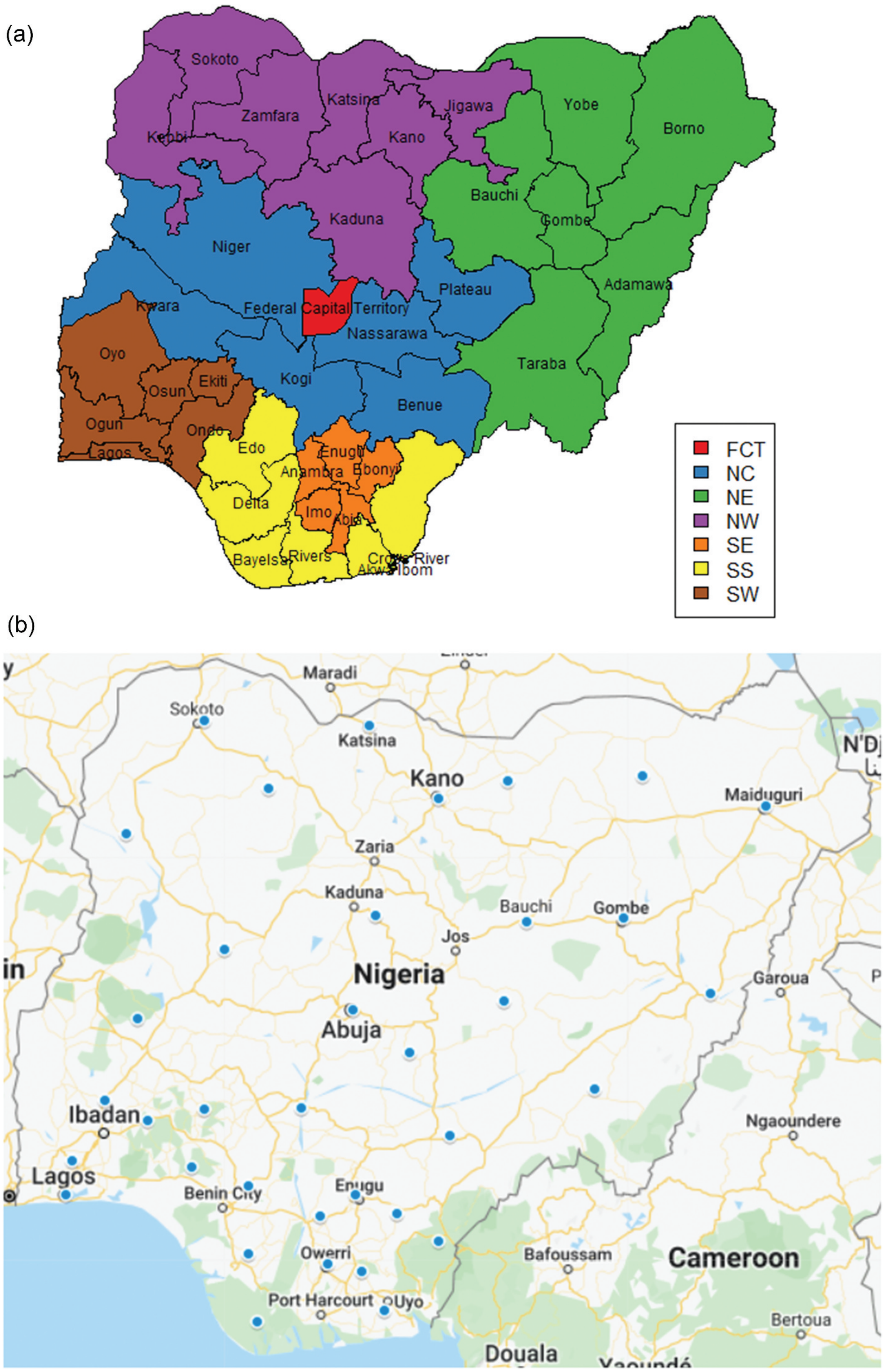

Figure 2. (a) Map of Nigeria showing the 36 states and FCT (Federal Capital Territory) in the 6 geopolitical zones/regions (created using R software package 'naijR' [32]); and b) Map of Nigeria showing the 35 states and FCT affected by flood incidences between 2011–2020 (Source: Google Maps, modified by authors).

Between the years 2011–2020, Nigeria recorded about 1,187 deaths connected to flooding, 15% of Africa's deaths by flooding within the same period. The cost of damage to properties was $904.5 million, which comprised 21% of property damage in Africa from flooding (see Table 2 for details, per year, and Figures 3 (a) and (b)). As well as in 2012 and 2018, flood damage and impact were also high in 2011 and 2020. Figures 3 (a) and (b) show the trends in the numbers of people affected and the numbers of deaths respectively, with two peaks, in the years 2012 and 2018 when severe flooding took place in Nigeria. The general trends are similar to those for Africa as a whole, except in 2015/2016 and in 2019/2020 when there were increased numbers for Africa in both graphs. Figure 2(b) shows the Federal Capital Territory (FCT) and 35 states affected by flooding within the last 10 years [31], showing occurrence of flooding all over Nigeria. From Figure 2(a), it is evident that the north has more land-mass than the south. There are 19 states and the FCT in the north, comprising a bigger area than the 17 states making up the southern part of Nigeria. The National Population Commission's 2016 projections (Figure 1(b), based on the year 2006 population census, show that 54% of Nigeria's population live in the north.

Protection of life and property requires adequate knowledge of the risks associated with natural hazards such as flooding; preparation will strengthen efforts to mitigate the adverse effects of flooding. Risk is a probability of a loss, which depends on three key components, viz., hazards, exposure, and vulnerability, and a change in any of these components will bring about a change in the risk [42]. Eiser et al. [43] maintain that risk in natural hazards always comprises interactions between natural and human factors. Better understanding of the natural hazards can lead to appropriate actions.

Table 2. Summary of flood impact in Nigeria and for Africa as a whole for the years 2011–2020; Source: Centre for Research on the Epidemiology of Disasters [31]. Data on value of damages were not available for Nigeria in some years.

	Numbers of People Affected		Value of Damages ('000 US$)		Numbers of Deaths	
Year	Nigeria (% contribution in Africa)	Africa	Nigeria (% contribution in Africa)	Africa	Nigeria (% contribution in Africa)	Africa
2011	30,915 (2.19)	1,414,579	4,500 (0.45)	1,006,500	174 (25.89)	672
2012	7,000,867 (75.26)	9,302,672	500,000 (49.45)	1,011,115	363 (42.81)	848
2013	81,506 (3.48)	2,345,261	–	147,024	19 (2.59)	735
2014	10,000 (1.05)	948,522	–	126,000	15 (3.02)	496
2015	100,420 (3.99)	2,519,490	25,000 (5.46)	458,000	53 (6.40)	828
2016	12,000 (0.88)	1,369,507	–	295,700	18 (1.91)	943
2017	10,500 (0.66)	1,595,141	–	12,000	20 (5.67)	353
2018	1,938,204 (56.09)	3,455,250	275,000 (35.80)	768,100	300 (40.43)	742
2019	123,640 (2.74)	4,516,338	–	57,100	36 (3.94)	914
2020	193,725 (2.95)	6,575,132	100,000 (22.52)	444,000	189 (14.09)	1,341
Total	**9,501,777** (27.91)	**34,041,892**	**904,500** (20.91)	**4,325,539**	**1,187** (15.08)	**7,872**

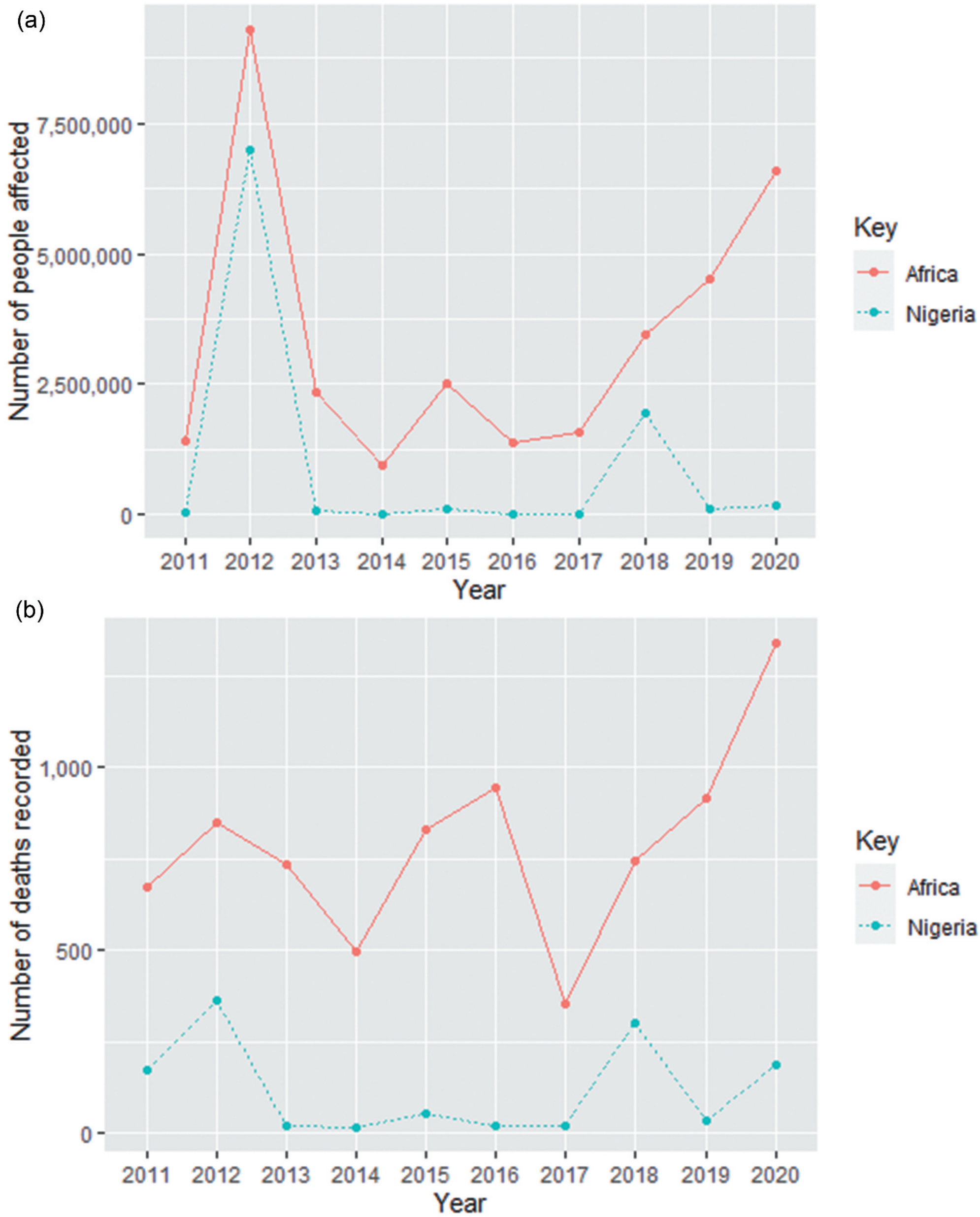

Figure 3. (a) Number of persons affected by flooding in Nigeria and Africa as a whole in the years 2011–2020; and (b) Number of deaths from flooding in Nigeria and Africa as a whole in the years 2011–2020; Source: Centre for Research on the Epidemiology of Disasters [31].

Study of flood impact through results of published statistical surveys

Various studies concerning Nigeria have considered the impact of flooding on people and society, using surveys of the population, to suggest ways of mitigating the effects. For instance, Wizor and Week [44] studied the impact of the 2012 flooding on six communities of Yenagua LGA. The foci of damage were health facilities, school infrastructure, access to roads, drinking water supply, and sanitary conditions. Simple random sampling was used to select the six communities from the 57 communities identified in Yenagua, and 10% of the households in these communities were selected for the study. A total of 465 questionnaires were retrieved for analysis from the 528 administered, and more than 60% of survey respondents agreed that the 2012 flood disaster negatively affected each of these amenities and made it difficult for the population to cope. The two prominent diseases were malaria and diarrhoea.

Dalil et al. [11] studied the impact of flood disasters on health in Ajegunle, a suburban area in Lagos state, Nigeria. These authors had a special interest in flood-related waterborne infectious diseases. Purposive (judgemental) sampling [45] was used to select five neighbourhoods (Aiyetero, Okorogbo, Mba, Wowo, and Alakoto) from the 42 neighbourhoods in Ajegunle, chosen for reasons such as high vulnerability to flooding, especially after heavy rainfall, and waterborne diseases recorded afterwards. The research used questionnaires and personal interviews. Questionnaires were distributed to 56 residents from each of the five neighbourhoods, based on their knowledge of flooding, as well as availability. Key stakeholders were also interviewed, including community heads, traders, nurses, and others. The study found that in the aftermath of a flood waterborne diseases (including diarrhoea, cholera and dysentery, typhoid fever and malaria) kill people, mainly children. Almost half of the disease outbreak in the Ajegunle area after the flooding was diarrhoea.

Oyekale [46] studied the impact of flooding in Epe, Lagos state, on the health of fishermen. This study used both primary and secondary data sources; the latter included books, journals, and the Nigerian Institute of Oceanography and Marine Research (NIOMR), and the former included personal interviews and questionnaires. The Owode and Olowo market communities in Epe were purposively chosen, and simple random sampling was used to select the respondents for interviews. It was observed that the majority of households in that locality used wells as a source of water for daily use, but flooding pollutes the wells, with diseases following. The study identified children and older age groups as the groups most vulnerable. The most frequent diseases were diarrhoea, then typhoid fever and cholera, in that order. Damage and losses of properties and to the economy are the two other most devastating effects from the six effects identified as a flood occurs, from a study of the people of the Epete community of Oyo state [8]. Poverty and increases in prices of commodities are believed to occur as a result of flooding [39]. Floods have an enormous impact both on the individual and society.

Chinwedu et al. [47] studied how worsening climatic conditions impact on the livelihoods of six communities living along the Kaduna River basin, and found that women suffered most because of their role in household management. The authors used purposive sampling to select three LGAs, Shiroro, Gbako, and Lavun, in Niger state; then two communities from each LGA were also chosen purposively. Simple random sampling was used to select 200 households, representing 75% of households from each of these communities. Eze et al. [48] found that flooding affects farmlands in Niger state and that this impacts on the livelihoods of people there.

Agbonkhese et al. [27] highlighted the impact of flooding in August 1980 in Ibadan. That flood was the worst to have hit the city of Ibadan, where over 300 people lost their lives, another 50,000 people were rendered homeless, and floods destroyed over 300 million Naira worth of properties. Otomofa et al. [49] evaluated the impacts of flooding on socio-economic activities in Oleh, Isoko South LGA of Delta state. A systematic random sampling technique was used. Analysis of 400 questionnaires, 100 from each of the four quarters in Oleh, identified critical sectors mostly impacted by flooding in the area, including agriculture, education, transportation and water. Egbinola et al. [50] analysed flood incidences and management in Ibadan, Oyo state, and identified destruction of buildings and loss of livelihood as the most common perceived impacts of flooding within Ibadan city. In that study, 350 questionnaires were administered to respondents in areas that had experienced flooding in Ibadan (Agbowo, Orogun, Apete, Orita Challenge, and Odo Ona-Elewe).

Most of these survey-based studies combined purposive sampling and simple random sampling or systematic sampling. Purposive sampling may be biased as a means of choosing a representative sample from a population [45], but in this context allows choice of areas vulnerable to flooding or communities likely to experience its impacts. Simple random sampling and systematic sampling, used as a second step, both use random selection of people or households to participate, and so have a high chance of giving a representative sample of the population in the selected areas.

An effective flood management scheme requires a clear, robust, and accurate plan [51]. Echendu [52] investigated how flooding affected Nigeria's efforts to achieve its SDGs. Those most impacted were the eradication of poverty, ending hunger, ensuring healthy lives and wellbeing for all, ensuring equitable and inclusive quality education for all, ensuring access to adequate and clean water and sanitation, providing decent work and economic growth, and finally 'making cities and human settlements inclusive, safe, resilient, and sustainable by the year 2030'. Controlling flood disasters is crucial to sustainable development. Prediction of floods and flood mapping are essential for flood mitigation [3].

Approaches to flood mapping and modelling

Flood modelling research includes geography, remote sensing, and statistics. Approaches for flood modelling require multidisciplinary work for obtaining flood risk mitigations [53]. In developed countries like the United Kingdom, United States and the Netherlands, progress in flood risk management has depended on data availability, access to up-to-date data, and fast bureaucratic processes [20]. These conditions are seldom found in developing countries.

Within the last two decades, the most widely used approaches in modelling flooding in Nigeria include geospatial techniques and Geographic Information Systems (GIS), and hydrological modelling and fitting of probability distributions [54–60]. Specific examples of implementing these approaches are described below.

Geospatial techniques and geographic information systems (GIS)

The most popular approach to delineate and map flood-prone areas in Nigeria is the use of remote sensing and GIS techniques.

Jeb and Aggarwal [61] combined GIS, remote sensing, a digital elevation model, and the Gumbel extreme value distribution to investigate flood incidence in Kaduna metropolis. The study indicates that areas close to the River Kaduna are at high risk of flood. Ojigi et al. [62] used satellite imagery, base maps, Shuttle Radar Topography Mission (SRTM), GPS coordinates, and survey data to delineate affected areas during the 2012 flooding for five states connected to the rivers Niger and Benue, in the North-Central zone of Nigeria. The study generated a 2012 flood extent map, identified and classified highly flood-prone locations, and in particular showed that Kogi state held more than half of the IDPs within the study area.

Nkeki et al. [63] used the geospatial approach to analyse flood risk along the Niger-Benue basin for the 2012 flood, using the moderate resolution imaging Spectroradiometre to detect areas vulnerable to flooding. Njoku et al. [64] used GIS techniques in spatial analysis of flood vulnerability in Aba metropolis, finding that areas 35–39 m and 43–48 m above sea-level are prone to flooding as runoff from higher elevations flows through areas of lower elevations. Deforestation, agricultural activities, and rapid increase in barren land result in increased runoff and river discharge [65]. GIS and remote sensing were used to generate a flood vulnerability map of Abakaliki LGA [66], and the flood mapping generated indicates the axis along the River Ebonyi as a very high-risk flood area.

Wizor and Week [67] combine geospatial techniques and statistical analysis for mapping and modelling of the 2012 flood in Yenagoa, Bayelsa state, finding that 7% of the total land area of Yenagoa LGA was affected. The study identified four types of land uses in Yenagoa, viz., built-up areas, waterbodies, forest cover, and farmland, and found that 50.6% of the flooded land was in built-up areas. Akukwe and Ogbodo [68] generate a vulnerability map of Port Harcourt metropolis using ArcGis 10.0 software. The metropolis was clustered into 13 different zones. The spatial pattern of vulnerability to flooding increases towards the north-west, south-west, south, and north-east, and reduces towards the central part. These differences in vulnerability are a result of distances to waterbodies in the metropolis. Ogbonna et al. [69] studied the relationship between topographic information and rainfall trends in Aba metropolis, Abia state. These researchers found from the vulnerability map that about 72% of Aba metropolis is vulnerable to flooding, except for areas around the Ogbor hill axis, whereas the rainfall trend from Mann-Kendall analysis indicates that rainfall did not significantly increase the flood hazard between the years 2000–2010 in the metropolis. Other key parameters increasing flooding in the area include topography, inadequate drainage, and building on waterways.

Okoye and Ojeh [70] identified causal factors pivotal to flooding in Surulere, Lagos. They used GIS to generate a digital elevation map. They concluded from factors such as excessive rainfall and duration, urbanisation, and soil impermeability, that Surulere is prone to flooding. Akinbobola et al. [71] showed the value of GIS in mapping flood risk areas along the Niger-Benue River basin. These authors discovered that 45% of settlements in Nigeria are in the flood risk zones. Dalil et al. [11] used the ArcView GIS package to map the areas vulnerable to flooding in Minna, Niger state, and found that the main cause of flooding there is human activity along the bank of River Suka, including construction on waterways, inadequate and poor drainage systems, and geological relief of the area.

Adewumi et al. (2016) [72] applied GIS and remote sensing techniques to identify flood-prone areas in Igbokoda town in Ondo state, using Landsat 5, 7 and 8 images for the years 1986, 1999, and 2013, respectively. These images showed a high percentage reduction in vegetation and change in land cover over time, making the town susceptible to flooding. Adewumi et al. (2017) [73] used the same techniques but went further to combine the stream network and the area slope to rank the study locations as high, medium, or low flood-risk zones. It was also found that an increase in runoff without adequate increase in drainage contributes to flooding in the area. Adegboyega et al. [25] used geospatial techniques to develop flood vulnerability models for cities in developing countries by combining GIS and the Hydrologic Engineering Centre-River Analysis System (HEC-RAS) model, using Osogbo, the capital of Osun state, as the study location. The resulting flood vulnerability map identified most low-lying areas in the city as vulnerable to flooding.

Wahab and Ojolowo [74] using GPSs and a stratified sampling method found that more than 60% of the 1,025 buildings sampled in Lagos metropolis violated the building codes in flood-prone zones. Komolafe et al. [75] using GIS techniques to describe vulnerable areas prone to flooding close to the Ogun River basin, Nigeria, concluded that the combined mapping of multi-criteria analysis and the Height Above Nearest Drainage (HAND) terrain model generated a better result than the individual models. The vulnerability map indicates that part of Lagos state is extremely vulnerable to flooding, because of its closeness to the Ogun River. Komolafe et al. [76] in related work on the Ogunpa River basin, Ibadan, Oyo state, combined three methods, viz., the HAND model, GIS-based multi-criteria decision analysis and event-based flood simulation using the FLO-2D model, to develop flood hazard maps.

Although this approach is widely accepted in flood modelling, Komolafe et al. [3] and Echendu [52] highlight its disadvantages. For example, the presence of cloud cover at the time of a flood hinders the use of optical remote sensing. There may be insufficient imagery in time and space, and seasonal variations such as cloud cover during the raining season make the use of GIS more difficult than in the dry season.

Hydrological modelling and fitting probability distributions

The combined use of hydrological modelling and extreme value distributions is another approach used to model flooding data [77].

Although it is evident that this approach is not yet widely used to model flooding in Nigeria, Garba et al. [78] studied hydrological modelling using a stochastic weather generator to simulate the impact of climate change on the Kaduna River. From the simulation results, it was observed that monthly runoff of the river basin reaches its peak during June and August, hence providing scope for risk mitigation. In related work, these authors used a calibrated hydrological model to simulate the hydrology of the Kaduna River. A sensitivity analysis of the flow parameters was first carried out on the hydrognomon model prior to calibration, and the authors identified flow recession parameters in the initial soil storage and initial groundwater storage as the most sensitive, and capillary flow as insensitive. As unknown aspects of the physical processes and characteristics on the river-basin scale mean that model parameters cannot be measured directly, the hydrognomon model was calibrated to rainfall data to specify model parameter values. The result from the Nash-Sutcliffe model efficiency indicates that the initial ground storage, the coefficients of inner flow, percolation, surface runoff flow, and base flow are important parameters for hydrological modelling of the Kaduna River basin [79].

Garba and Chukwujama [80] introduced a hydrognomon model for flood-level prediction, using average monthly rainfall data from the River Kaduna for calibration and validation, and concluded that this model predicts flood levels well. Adeogun et al. [81] combined the hydrological modelling approach using a Soil and Water Assessment Tool (SWAT) to simulate and predict the Jebba Lake upstream watershed flow with remote sensing and GIS techniques to delineate the watershed area. To simulate streamflow and sediment discharge yield in the upper Ebonyi watershed, Ndulue et al. [82] used a SWAT model also, which proved to have potential as an effective tool for watershed management, as shown by the R-square, Nash-Sutcliffe model efficiency, and percent bias as indicators of model fit.

To protect roads and bridges from structural damage and other calamities as a result of extreme events such as flooding and drought, accurate estimates of the frequency and magnitude of extreme events are necessary for design and operation of water management plans and technology [83, 84]. Garba et al. [85] used the generalised extreme value (GEV) distribution as a regional flood frequency distribution for the River Kaduna because of its wide acceptability to model sites with little or no stream flow data. The peak annual mean discharge between the years 2000–2010 was used in the study, and four statistical distributions used to fit the discharge variability of the river, viz., the normal, log-normal, log-Pearson type III, and Gumbel distributions. The Kolmogorov–Smirnov test was used to determine whether the annual flood discharge is consistent with the regional GEV flood model for the study location. The results indicate that the annual flood discharges simulated from all four fitted statistical distributions are consistent with the regional GEV flood distribution at three different levels of significance.

Izinyon and Ajumuka [86] consider three probability distributions, viz., the log-normal, extreme value type 1 and log-Pearson type III distributions, in fitting annual series of maximum flow discharges from three gauge stations, Manya, Donga, and Suntai stations, all located within the upper Benue River basin in Nigeria. The study uses 32 years of annual flood peaks for each gauging station, from 1955 to 1986. Four measures of accuracy are applied to select the appropriate model for each station: the root mean square error (RMSE), relative root mean square error (RRMSE), maximum absolute error (MAE), and correlation coefficient. These statistics indicate that the best model for fitting the annual maximum flow discharge for the Manya gauge station is the extreme value type 1; for the Donga gauge station it is the log-Pearson type III; and it is the log-normal distribution for the Suntai gauge station. Therefore, there is no single best approach. Once a suitable model is identified for a given flood data series, the probability quantiles of these distributions can be used to plan the appropriate scale of anti-flood protection infrastructure such as dams, and hence to inform flood management.

In a similar study [87], Izinyon and Ajumuka used three probability distributions to predict floods in the upper Benue River basin. Using datasets from 1955 to 1986, they used log-normal, extreme value type 1 and log-Pearson type III distributions to fit the data series of annual maximum discharge from three gauge stations, viz., River Katsina Ala, River Taraba, and River Mayokam in the upper Benue River basin. The authors used four accuracy measures to select the best model for each gauging station: the RMSE, RRMSE, MAE, and correlation coefficient. It was concluded from these measures that the best distributions to fit the discharge data are the log-normal, log-normal, and log-Pearson type III for the River Katsina Ala, River Taraba, and River Mayokam, respectively, and these could be used to predict the return period of flooding in these stations. This information could therefore be used for forward planning.

There is no scientific agreement as to which distribution model should be used to fit extreme flood discharge for a particular region or area [83] and in the work cited above the best approach found does vary, even within the same study. Ologhadien [83] evaluated five probability distributions – the Gumbel, 2-parameter log-normal, Pearson type III, log-Pearson type III, and GEV distributions – to select the best model to use in four water stations at Ibi, Makurdi, Umaisha and Yola in the Benue River basin. The dataset is a 30-year flood annual maximum data series from 1960 to 1989, and the method of moments was used for estimation of the model parameters. From the five goodness-of-fit measures used, viz., the Modified index of agreement (Dmod), RRMSE, Nash-Sutcliffe model efficiency, Percent bias (PBIAS), and the observation standard deviation ratio (RSR), it was found that for Umaisha, Makurdi, and Yola water stations the best model for the data series is the GEV distribution, whereas the Pearson type III is best for Ibi station. Ologhadien's related work [84] compares the same five probability distributions and six goodness-of-fit measures, including the above plus the probability plot correlation coefficient, to select the best distribution to model flood flow for five water stations: the Aboh, Baro, Idah, Lokoja, and Onitsha stations. It was found that, of the five models, the GEV distribution performs better than the rest, followed by the Pearson type III and log-Pearson type III. Over these two studies, therefore, the GEV distribution was generally the most suitable.

Other approaches to flood modelling

Data-driven models combine the time-series linear statistical models and more recent machine learning techniques. Combining suitable linear and nonlinear models offers the potential for more accurate prediction than an individual linear or nonlinear model does for forecasting time-series data [88]. The data-driven approach is powerful, fast, and easy to build compared to process-based models and has proved to be effective among other competing models [24]. Accordingly, this approach has been followed in studies such as predicting hourly wind speed [89], forecasting natural gas consumption [90], and oil well production forecasting [91]. Recently, data-driven models have been used in modelling water-level discharge, which helps to inform effective water resource management [24, 92].

Bayesian statistical methodology, which relies on probability models, is another approach used in modelling extreme events such as extreme precipitation and sea-level annual maxima. This powerful approach is increasingly used in statistics, and studies in this area are imperative to quantify and forecast precipitation extremes for the purposes of flood planning [91]. Many studies exhibit the advantages of Bayesian statistics for modelling extreme precipitation and related extreme events [93–100].

These approaches can be applied to univariate, bivariate, and multivariate datasets and are good candidates for modelling and understanding extreme events, but to the best of our knowledge they have not yet been used in Nigeria for investigating flooding and managing the risk of flood disasters.

Discussion

This review of the occurrence and impacts of floods in Nigeria has used the world database on natural disasters [31] to extract relevant data. Flooding occurs annually over most of Nigeria, but more frequently and with more impact in the northern states. This is attributed to a number of factors, including the bigger land-mass of the northern region, river paths, and the population of the northern region, which make it both more susceptible to flooding and also more impacted by flooding. The states of Niger, Jigawa, Kano, and Yobe all suffered more than five incidences of flooding over the 10-year study period, and Katsina and Kebbi each had five incidences.

The impacts of flooding are felt by the individual and by society, through loss of property and infrastructure, damage to farmland, displaced water-living wildlife posing threats, contamination of drinking water, spread of waterborne diseases, fatalities and loss of wellbeing, loss of livelihoods, economic depression, and hindrance in achieving social development goals such as safety and eradication of poverty.

Africa's natural hazards include droughts, erosion, landslides, and flooding, because of the continent's diverse climatic conditions. Recent studies have shown that flooding has been the most frequent and worst natural hazard in Africa within the last decade. Nevertheless, 94% of states in Africa fail to remit 1% of their gross domestic product (GDP) for research and development, a figure set by the African Union [35] to promote flood risk management. In Nigeria, flood management measures have been reactive, rather than pro-active and forward-looking [101]. Yet, there is abundant local work to stimulate interdisciplinary risk management appropriate to Nigeria's needs.

Many of the studies reviewed have identified key or main causes of flooding as anthropogenic factors. Building beside rivers leaves settlements vulnerable to flooding, yet town planning could limit further expansion of settlements on vulnerable land. Blockage of waterways, by dumping of refuse, for example, diverts the flow of water. Inadequate drainage and broken water pipes are also problematic, as is dam overflow. Resourcing suitable maintenance programmes could help to prevent these causes of flooding. Trees growing on moderate slopes help to prevent erosion, landslides, water runoff, and flooding, through take-up of water and land stabilisation by tree root systems. Forestry management could mitigate the loss of trees. Impacts of flooding from water-borne diseases must be met with well-resourced health programmes. Therefore, given the political will and prioritising of resources, flood occurrence and impacts could both be reduced.

This paper has reviewed the main available studies in modelling flooding in Nigeria, using geospatial/GIS approaches, hydrological models, and probability models. These studies emphasise the risks and dangers associated with flooding in Nigeria. There appears to be no single best approach for fitting probability distributions to model extreme events such as flooding. It is advisable to be pragmatic in every case by trying a variety of different distributions in order to identify the best one for a given data type, location, and purpose. Using distributions fitted to water discharge time-series data to estimate quantiles for maximum water discharge provides valuable hydrological information for planning suitable water management infrastructure such as dams and embankments. Being able to estimate flood quantiles is an important tool to predict the magnitude of future flood discharge at one or more sites on a river system, hence the widespread use of distribution fitting.

Bayesian and machine learning approaches appear to hold promise for Nigerian forecasting and policy-making.

Conclusions

Flooding in Nigeria is an annual problem, yet the adverse impacts can be mitigated through effective management. Therefore, studies that can lead to better management of the risks associated with flooding are extremely valuable. This requires understanding the information present in the available data and the prediction of extreme events. The northern part of Nigeria has been identified as the region most affected by flooding, and therefore flood risk management should be focused there.

Various approaches have been taken to model flooding in Nigeria, such as the use of geospatial techniques and GIS, hydrological modelling, and distribution fitting. Shortcomings in these approaches have been noted, and so other approaches which have succeeded in other countries should be considered. In particular, there is potential to exploit the data-driven and Bayesian approaches which have been widely used in modelling water-level discharge, extreme precipitation, or river flow gauge data in countries such as the United Kingdom, Australia, China, and Vietnam. These have not so far been used in Nigeria but have the potential to provide valuable additional tools for understanding, predicting, and hence limiting, flood risks in the country, as part of interdisciplinary flood management.

Acknowledgments

The first author is grateful to the Petroleum Technology Development Fund (PTDF), Nigeria, for generously funding his research [reference number NU/1565/19], and Umaru Musa Yar'adua University, Katsina-Nigeria, for their support. The authors thank an anonymous reviewer and the editor for their help.

Disclosure statement

There is no potential conflict of interest, and there are no ethical issues.

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Authors' contributions

The initial research concept was designed by the first author. The literature review, findings, and drafting of the manuscript were jointly done by both authors. Both authors approved the final manuscript.

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