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A Geospatial Expose of Flood-Risk and Vulnerable Areas in Nigeria

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ABSTRACT

Flooding is recurrent in Nigeria, occurring yearly at different scales. This geared the need for a study to reveal local government areas (LGAs) that are at risk and vulnerable to flooding. The multi-criteria approach was adopted, using geospatial techniques and data. Factors considered were elevation, slope, rainfall intensity, and distance to river. The factors were classified, reclassified, rated, and weighed in a systematic process. Nineteen states and 114 LGAs face high risks, especially communities in the Niger Delta, around the lagoons of Lagos, along River Niger, Benue, and the Cross-River. Also, 125 LGAs in 18 states face medium flood-risk vulnerability. Consideration the population density of communities, Lagos State is the most vulnerable because of LGAs with high population densities within high flood-risk zones. Other states with communities exposed to high flood-risk vulnerability include Rivers, Kogi, Cross River, Akwa Ibom, Anambra, and Delta. The study provides information key to proactive policy formulation, mitigation, and adaptation to flood risk in Nigeria.

KEYWORDS

Flooding, Flood-Risk Zones, Geographic Information Systems, Multi-Criteria Analysis, Vulnerability

BACKGROUND TO THE STUDY

The past two decades have seen a significant upsurge in the frequency of flooding on a global scale (Najibi & Devineni, 2017). The Intergovernmental Panel on Climate Change (IPCC) confirmed that flood vulnerability would most likely increase in line with increasing rainfall events (Conix & Bachus, 2007). The occurrence of flooding around the world is fast becoming a normality (Thomalla, Downing, Spanger-Siegfried, Han & Rockström, 2006) with about 70 million people exposed to flood risk and at least 800 million people susceptible (Peduzzi, Dao, Herold & Mouton, 2009). Its impacts are as well immeasurable. For example, in the United States, floods destroy property worth US$6 billion and kill 140 people annually (National Geographic, 2018).

In Nigeria, flooding is a recurrent phenomenon which could be coastal, fluvial or pluvial (Aderogba, 2012). Coastal and fluvial flooding in Nigeria affects coastal and riverine environments and are due to seasonal water upsurge from large rivers such as the Niger, Benue, Cross River, Kaduna,

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and others. On the other hand, pluvial floods are yearly occurrences during the rainy season (from July to October) and are more eminent in the cities (Nkwunonwo, Malcolm & Brian, 2015). Recent flood occurrences in Nigeria have been particularly, among other factors, geared by the release of water from the Lagdo Dam in Cameroon (Udo, Ojinnaka, Baywood & Gift, 2015), the high intensity of rainfall in some regions (Eagle Online, 2018) and the haphazard development of land on flood prone areas (Atufu & Holt, 2018).

Flooding is the most occurring natural hazard in Nigeria and the situation is dire (Aderogba, 2012). An early account of flooding in Nigeria is the Ogunpa River flooding of Ibadan in 1963, 1978, 1980 and 2011, which led to an estimated property loss of at least 30 billion naira and 100 fatalities. In Lagos, there were at least 8 flood events that killed at least 30 people between 2011 and 2012 (Komolafe, Adegboyega & Akinluyi, 2015). Whereas flooding has been a recurrent occurrence in Nigeria, the year 2012 event was a striking one, superseding previous flood events in the last 40 years. The National Emergency Management Agency (NEMA) reported that it affected 7 million people in 30 states, displaced 2.3 million people, killed 363 and cost Nigeria's economy an estimated loss of US$ 9.6 billion (Amangabara & Obenade, 2015).

Earlier studies have examined flooding and flood-risk in Nigeria as a whole (Nkwunonwo, Malcolm & Brian, 2015; Komolafe, Adegboyega & Akinluyi, 2015), while others assessed the problem at a regional or state level (Amangabara & Obenade, 2015; Udo, Ojinnaka, Baywood & Gift, 2015; Udo & Eyoh, 2017, Efiong & Hogan, 2017). The question of "which Local Government Areas (LGAs) in Nigeria are most at risk to flooding and which are more vulnerable?" has however received no empirical attention. Providing answers to these questions are key to flood mitigation and adaptation in Nigeria and elsewhere. The geospatial technologies of remote sensing and geographic information systems (GIS) have proven to be of immense value in this regard.

GIS and remote sensing techniques have become indispensable tools for mapping flood-risk vulnerability (Karmakar, Simonovic, Peck & Black, 2010, Wicht & Osinska-Skotak, 2016; Das, Chattopadhya & Basu, 2017; Gandini, Prieto, Garmendia, San-Jose & Egusquiza, 2018), providing evidence for early warning and emergency response systems.

GIS tools in a multi-criteria approach (MCA) combines causative natural factors to derive flood vulnerability classes that support flood risk mitigation (Daneshbod, 2014; Elsheikh, 2015; Blistanova, Zelenakova, Blistan & Ferencz, 2016). In this vein, Meena & Gupta (2017) integrated multiple parameters such as rainfall, slope, drainage density, land use, building density and so on to make deductions. Similarly, Danumah, *et al.* (2016) integrated parameters such as slope, drainage density, type of soil, isohyet, population density, land use and sewer system density. Njoku, Efiong, Uzoezie, Okeniyi & Alagbe (2018) also combined independent parameters (distance from river, rainfall intensity, elevation, land use, slope and soil- "DRELSS") to evaluate flood-risk vulnerability.

These parameters in the MCA are usually assigned different weights, based on the influence of the variable on flood occurrence. This weighting process, termed the weighted overlay analysis has gained popularity in the spatial flood risk-vulnerability mapping process (Liu, 2013; Mokarram & Hojati, 2017). The selection of appropriate weights and ranks in the MCA process is fundamental in the vulnerability assessment (Hoque, Pradhan & Ahmed, 2019). Some authors have depended on the situation in the field, backed by literature (Udani & Mathur, 2016; Ajjur & Mogheir, 2020), while some others have adopted the Analytical Hierarchy Process (AHP) to compute the priority weights of factors (Umar, Abdullahi & Usman, 2019; Hoque, Pradhan & Ahmed, 2019; Fadhil, Ristya, Oktaviani & Kusratmoko, 2019). Despite these differences, there is a consensus that the MCA is most suitable for decisions on flood mitigation and land use planning (Ogato, Bantider, Abebe & Geneletti, 2020).

Notably, tackling flooding and reducing its associated risks in Nigeria has been an uphill task because of some cardinal gaps highlighted by Nkwunonwo, Malcolm & Brian (2015). Even when flood vulnerability is modeled, a major gap still exists between what the models can provide and what local practitioners need (Liu, *et al.,* 2018). Location-based knowledge which is lacking in Nigeria, is key in informing flood management (Brierley *et al.*, 2013). The current trend of flood occurrences and impacts in Nigeria calls for more studies and accurate spatial information on the potential flood hazards (Umar, Abdullahi & Usman, 2019). The dearth of studies that holistically adopt GIS in planning for flood disaster in Nigeria means there is a crucial need to explore more effectively, the use of recent geospatial methods and data for flood hazard mapping, exposure and vulnerability (Komolafe, Adegboyega & Akinluyi, 2015; Efiong & Ushie, 2019). This highlights the need for flood-risk and vulnerability maps as well as information that would be effectively communicated to decision makers, emergency response units and the public (Yahaya & Abdalla, 2010; Fadhil, Ristya, Oktaviani & Kusratmoko, 2019).

This study attempts to fill these gaps and serves as a baseline for decision making and further studies on flood-risk vulnerability in Nigeria. It focused on revealing through maps, LGAs at risk of flooding in Nigeria and further highlights areas of high and medium vulnerability due to the prevalence of high population densities within high flood-risk zones. It demonstrates the power of GIS and remote sensing in overcoming the dearth of field data needed to model flood-risk vulnerability. The study starts by introducing the flooding problem in Nigeria, presents the data sets used and multi-criteria method employed. It further elaborates on the processes that led to the deduction of flood-risk zones and LGAs that are vulnerable to flood-risk in Nigeria.

The Concept of Risk and Vulnerability

Vulnerability implies the potential for loss, considering the nature of a hazard, who and what are exposed to it (Karmakar, Simonovic, Peck & Black, 2010). Flood vulnerability is thus the degree to which a person, people or place are at risk of flooding and its adverse effects (Conix & Bachus, 2007). Consequently, risk infers the "the probability that a hazard would occur and trigger a disaster or series of events with an undesirable outcome" (Brooks, 2003). It is the probability of a loss that depends on three elements; hazard, vulnerability and exposure (Crichton, 1999). There is a strong relationship between hazard and vulnerability, both of which cannot exist independently (Cardona, 2004). Hazard is "an event with the potential to cause harm" (Brooks, 2003) while vulnerability is examined in this study as the specific sense of an aggregate measure of exposure to the risk of flooding. It is adopted as the risk indicator in this study because of its importance to the risk discourse (Musungu, Motala & Smit, 2012).

Flood-risk vulnerability is a function of natural and anthropogenic factors (Danumah, *et al.*, 2016). While the natural factors, like excessive rainfall (Kim & Kim, 2014), topography and soil type (Rimba, Setawati, Samba & Miura, 2017) may be uncontrollable, the man-made activities such as an intentional sprawl to the riverbanks, deforestation, etc. (Billi, Alemu & Ciampalini, 2015; Forkuo, 2013), aggravate vulnerability levels. In view of this, Wilde's risk homeostasis theory states that "individuals and communities maintain a specific level of risk irrespective of external influences". For instance, the perceptions and defenses that make people reside very close to rivers and in flood plains despite the unpredictable behaviour of the river which increases their vulnerability to risk (Wilde, 1982).

People are becoming more vulnerable to flooding due to a combination of natural and anthropogenic activities resulting from socio-economic necessities (Blistanova, Zelenakova, Blistan & Ferencz, 2016). What may not be possible is man's ability to stop the occurrence of flooding. What is possible however, is man's ability to become less vulnerable and minimize the impacts. This follows from the idea of environmental possibilism which provides that humans are able to use tools and technology to either alter or address environmental concerns.

MATERIALS AND METHODS

Study Area

Nigeria is a West African country, located within latitudes 4° 16′ 13.50″ and 13° 53′ 31.24″, North of the Equator and longitudes 2° 40′ 6.35″ and 14° 40′ 35.09″, East of the Greenwich Meridian. It is bordered by Niger Republic in the North, Benin Republic in the West, the Atlantic Ocean's Gulf of Guinea in the South as well as Chad Republic and the Republic of Cameroon to the East (Figure 1).

Figure 1. Map of Nigeria

Nigeria has 36 States, a Federal capital Territory- FCT (Abuja) and 774 LGAs. It has a total land area of 924,000 km^2 and a population estimate of 173 million in 2015 (Africa Development Bank, 2017).

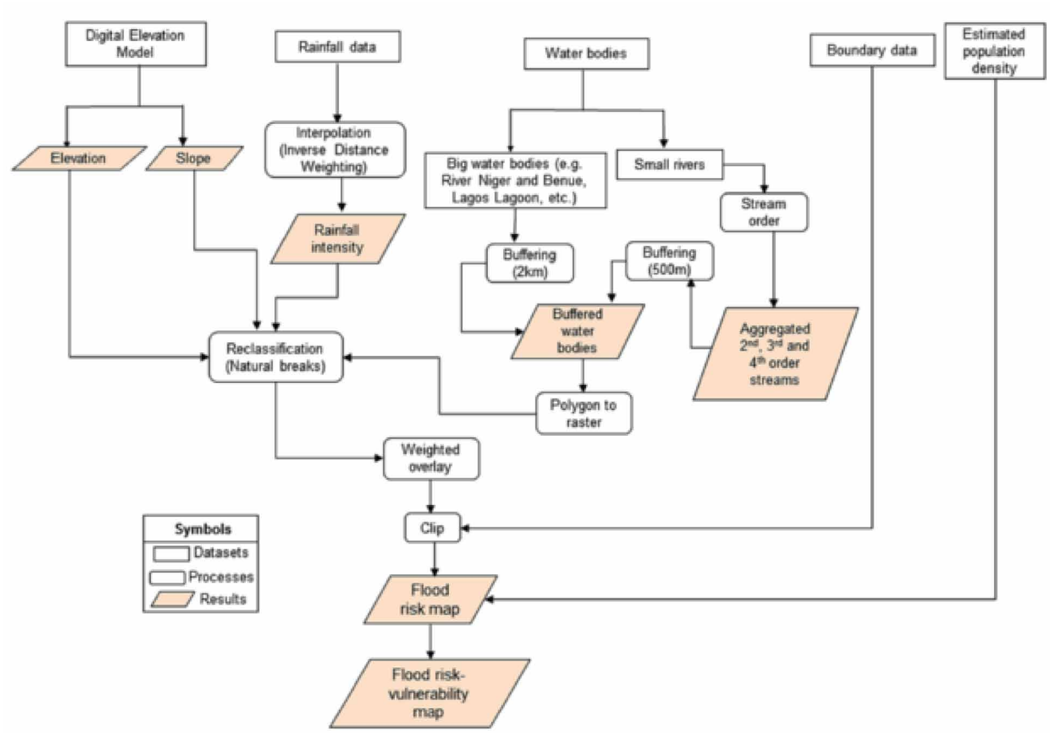
The Country has diverse topography with a variety of relief features, including uplands of 600 to 1,500 m above mean sea level in the North Central and the East highlands, as well as lowlands of less than 20 meters above mean sea level in the coastal areas (Ademiluyi, Okude & Akanni, 2008).

Also, Nigeria is endowed with abundant natural water resources evident in her substantial yearly rainfall, large surface water bodies and abundant reservoirs of underground water (Ojiakor, 2009). The principal rivers in the country are the Niger and its main tributary, the Benue. Both rivers are navigable over most of their courses and together drain the greater part of Nigeria. The country has a tropical climate that varies from south to north and is influenced by elevation. Southern Nigeria faces warm, moist, south-westerly winds from the sea during much of the year and is hot, humid, and oppressive. Temperature averages about 27°C (80°F) with small daily and seasonal variations (Fashae, Olushola & Adedeji, 2017). Annual precipitation is below 500 millimeters in the north, ranges from 1000 to 1500 mm in the central region and exceeds 2000 mm in the south. All these geographical characteristics make flood occurrence possible in the country, with temporal and spatial variations in occurrence and vulnerability.

Analytical Framework

This study employed the MCA approach to develop a flood-risk map to reveal LGAs that are vulnerable to flood-risk in Nigeria. The MCA enables the combination of different geospatial datasets (elevation, slope, rainfall, and distance to water bodies) to derive results. The MCA approach is more suitable for this study because it combines geographical data and a set of preferences to provide the best results for decision making (Malczewski & Rinner 2015; Fadhil, Ristya, Oktaviani & Kusratmoko, 2019). The flow chart (Figure 2) summarizes the step-by-step approach adopted, highlighting data sets, processes and results derived.

Figure 2. Flow chart



Data Types and Sources

The data used in this study include the Digital Elevation Model (DEM), rainfall intensity, population density data and shapefiles of water bodies, state and LGA administrative boundaries. These data were sourced from secondary sources (Table 1) and served as basis to generate other points, lines, polygons and pixel-based data used in the study. Online news platforms and technical reports from renowned organizations also provided statistics related to flood events in Nigeria.

Parameter Inputs

To map flood-risk zones in Nigeria, the selection of effective parameters is vital. Although it is difficult to choose factors unanimously, some important variables have definitive roles (Samanta,

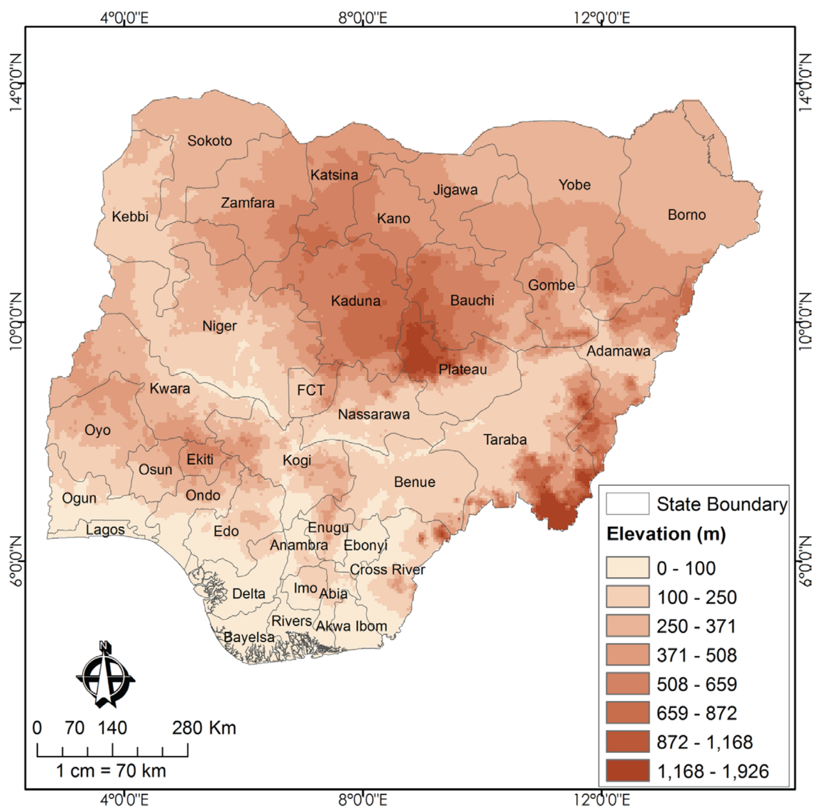
Table 1. Data types and sources

S/n	Data	Data Source	Year
1	DEM	United States Geological Survey (USGS) Google Earth	
2	Rainfall intensity	Nigeria Meteorological Agency (NIMET) Seasonal Rainfall Prediction (2017)	2017
3	Estimated population density	World Bank (2018)	2015
4	Boundary and water body shapefiles	Humanitarian Data Exchange (2018)	2018

Koloa, Pal & Palsamanta, 2016). Different geospatial data sets, such as topography (elevation and slope), rainfall intensity and distance to water bodies were considered as independent parameters in this study. The inability to incorporate other parameters such as soil and land-use characteristics which would have made for a more robust flood-risk modelling and vulnerability assessment presents a gap in this study. This gap is geared by the difficulty in accessing data such as a high-resolution open access satellite imagery or a raster-based soil map for the whole Nigeria.

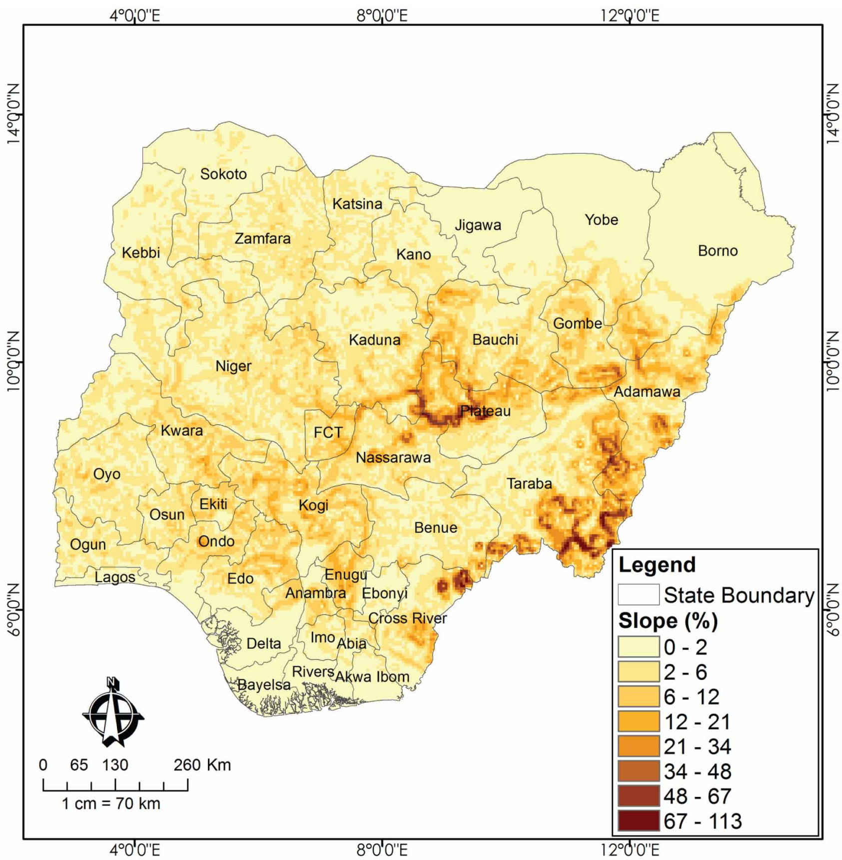
Topography plays a vital role in the spread of flood water and is key to flood extent estimation (Horritt & Bates, 2002). Invariably, places that have low elevations are more liable to flooding (Njoku, Efiong, Uzoezie, Okeniyi & Alagbe, 2018). Topographic parameters of elevation (Figure 3) and slope

Figure 3. Elevation classes in Nigeria



(Figure 4) were derived from the DEM which is a gridded digital representation of terrain which has each pixel value corresponding to a height above a datum (Hawker, Bates, Neal & Rougier, 2018). The DEM was generated using location data (X, Y) obtained from USGS Google Earth platform and elevation values (Z) were extracted using the *TCX Converter* application. Based on the X, Y, Z,

Figure 4. Slope classes in Nigeria

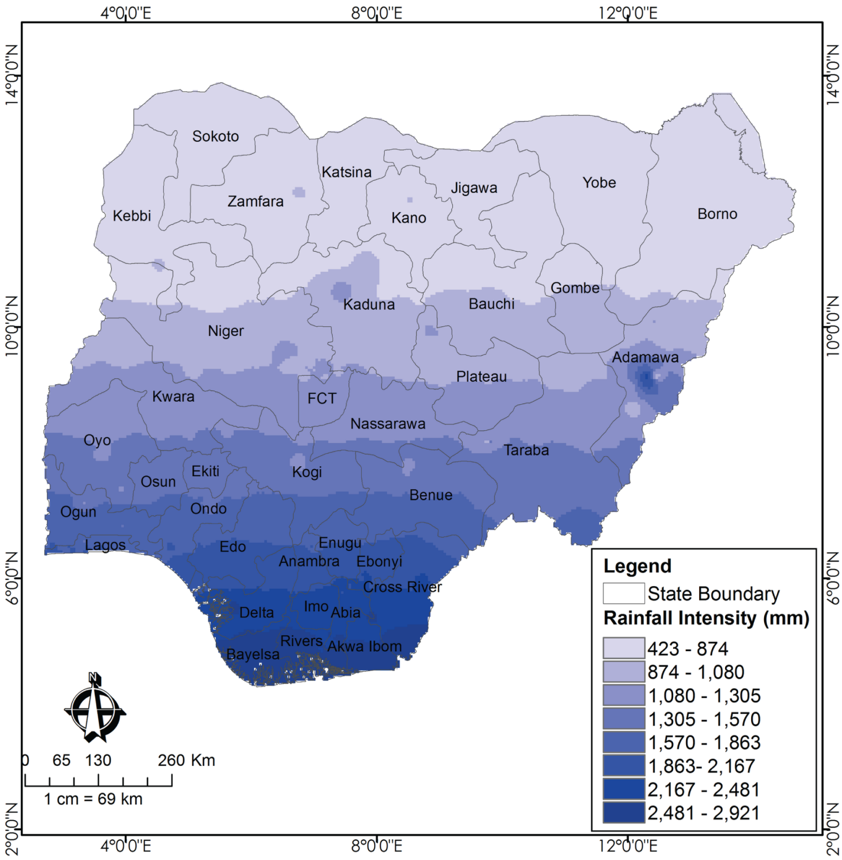


the DEM was generated using the *Inverse Distance Weighting* (*IDW*) interpolation tool. The rainfall intensity zones map (Figure 5) was also generated from the rainfall data using the *IDW*.

Flooding in Nigeria is largely fluvial (Aderogba, 2012) and communities in the vicinity of rivers are more vulnerable to flood risks (Fernandez & Lutz, 2010; Kazakis, Kougias & Patsialis, 2015). Thus, the water body shapefiles which included the large rivers and lakes represented by polygons and the smaller rivers, represented by lines were prepared for analyses. The smaller rivers are numerous; thus, they were ordered from stream one to four (Figure 6) according to the Strahler's (1957) classification. The streams were further reduced and aggregated to the important second, third and fourth order streams (Figure 7) using the *stream order* spatial analyst tool.

The proximity analysis was used to create buffers from the water body data sets using the *single ring buffering tool*. A buffer of 2 km was done for the large water bodies such as River Niger, Benue River, Cross River, Lagos Lagoons, and so on. For the smaller rivers, after reducing them to the important streams, a 500 m buffer was performed. Both buffer outputs were combined into one map (Figure 8). Similar to previous studies (Suleiman, Matazu, Davids & Mozie, 2014; Samanta, Koloa,

Figure 5. Rainfall intensity in Nigeria (2017)



Pal & Palsamanta, 2016; Kazakis, Kougias & Patsialis, 2015), the buffer distance considered from the edge of the river is user-defined based on the history of the extent that is inundated when the river overflows. Since the other parameters (elevation, slope, rainfall intensity) were already in raster format, only the water body layers were converted to raster from their initial vector state. This was to enable the execution of the weighted overlay analysis.

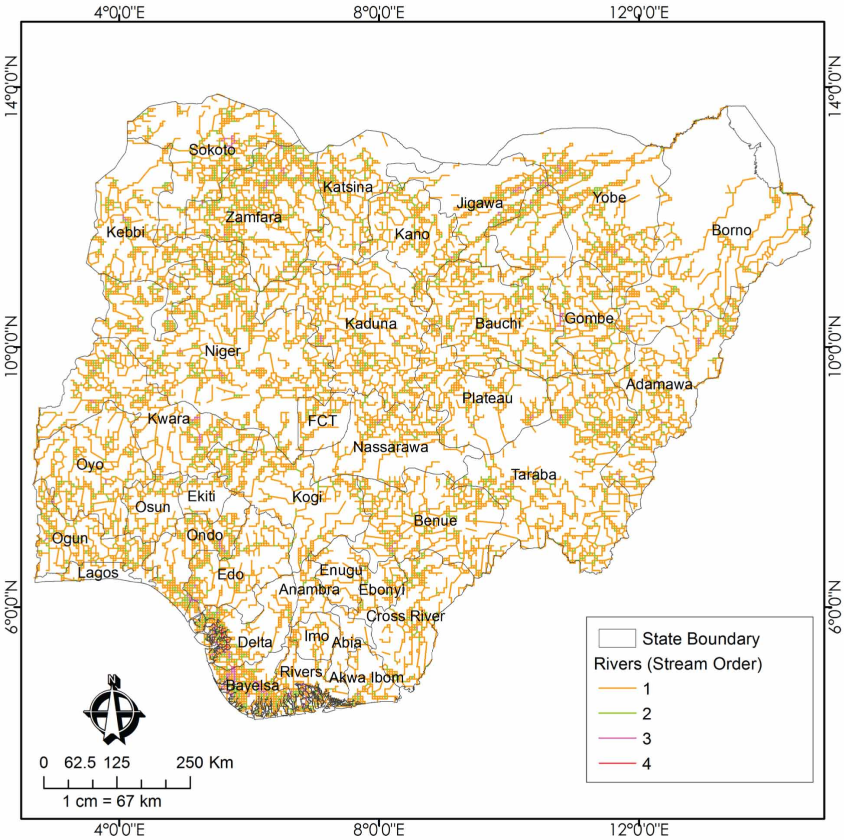
The World Bank raster data also provided estimates of the density of people residing in each 100x100m grid cell in Nigeria. This estimated population density data aided to determine the LGAs that are most vulnerable to flooding considering potential impacts of flooding on more populated communities compared to less populated areas.

Reclassification and Rating Process

The data were reclassified using the *natural breaks* grading method. The DEM was reclassified into 8 classes (Figure 9). Also, the slope map was reclassified into 7 classes (Figure 10); rainfall intensity into 3 classes (Figure 11), and the water bodies into one class.

Furthermore, rates and rating indexes were assigned for all the classes of each parameter based on the reclassification (Table 2). After preparation of all parameters and their individual classes, user-defined rates on a scale of 1 to 8 were assigned for DEM; 1 to 7 for slope; 1 to 3 for rainfall intensity and, 1 for proximity to rivers and water bodies.

Figure 6. Stream order of smaller rivers

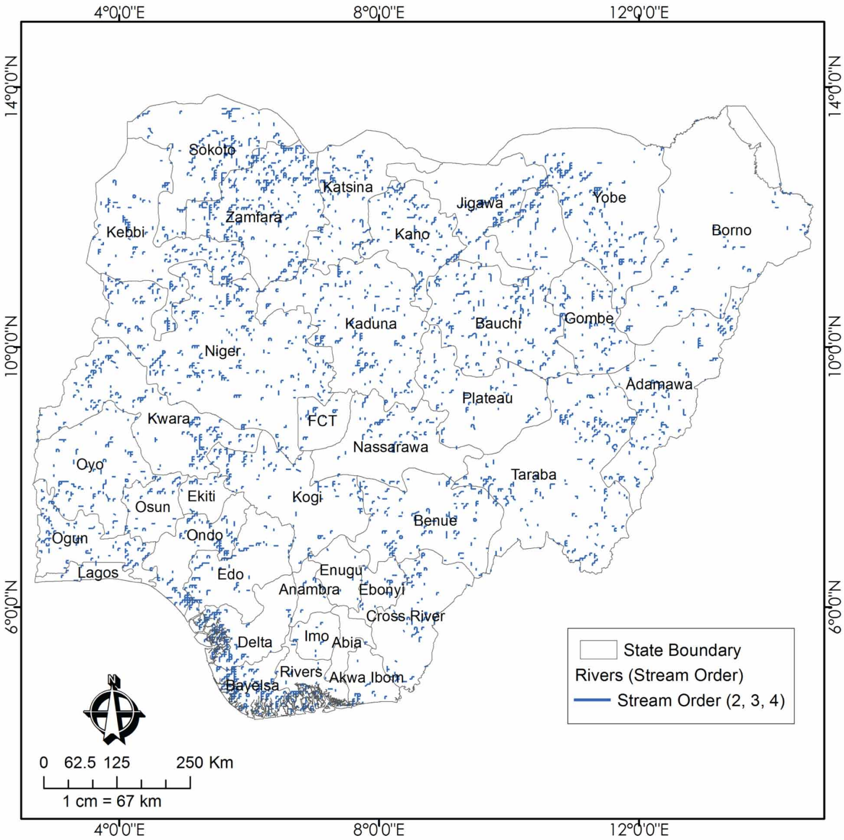


Locations with elevation less than 100 m were rated as high-risk areas and elevations more than 100 m assigned low risk status. Also, areas with slopes less than 10% have higher susceptibility to flooding than those more than 10% (Samanta, Koloa, Pal & Palsamanta, 2016; Orok, 2011). As well, higher rainfall intensity implies higher possibilities of flooding and vice versa (Rimba, Setawati, Samba & Miura, 2017), thus the rating of rainfall intensity area with less than 1000 mm of rainfall as low and areas with more than 1000 mm of rainfall as high-risk zones (Table 2). For DEM and slope, the lowest rating index (1) refers to extreme risk while the higher rates represent low risk zones. For rainfall, 1 alternatively represents low risk, being the rating index for areas with lower rainfall intensity. The rating index of 1 was also assigned as high risk for the areas which are located less than 500m from the smaller rivers and 2000m from the bigger water bodies. These rates and rating indexes are user-defined, based on literature and depending on their influence on flood-risk (Samanto, Koloa, Pal & Palsamanta, 2016, Gigović, Pamučar, Bajić & Drobnjak, 2017, Ajjur & Mogheir, 2020).

Weighting Process

The weighted overlay process was used to integrate the rates and weights (Table 2) and to generate a flood-risk map of Nigeria (Figure 12). Similar to Umar, Abdullahi & Usman (2019), the map was classified into a 3-point rank scale thus: high, medium and low risk zones. The low risk zones refer to areas where the chances of flood occurrences are about zero and high-risk zones refer to the areas where flood can occur at any time due to seasonal as well as sporadic heavy rainfall, overflow of

Figure 7. Aggregated second, third and fourth order streams



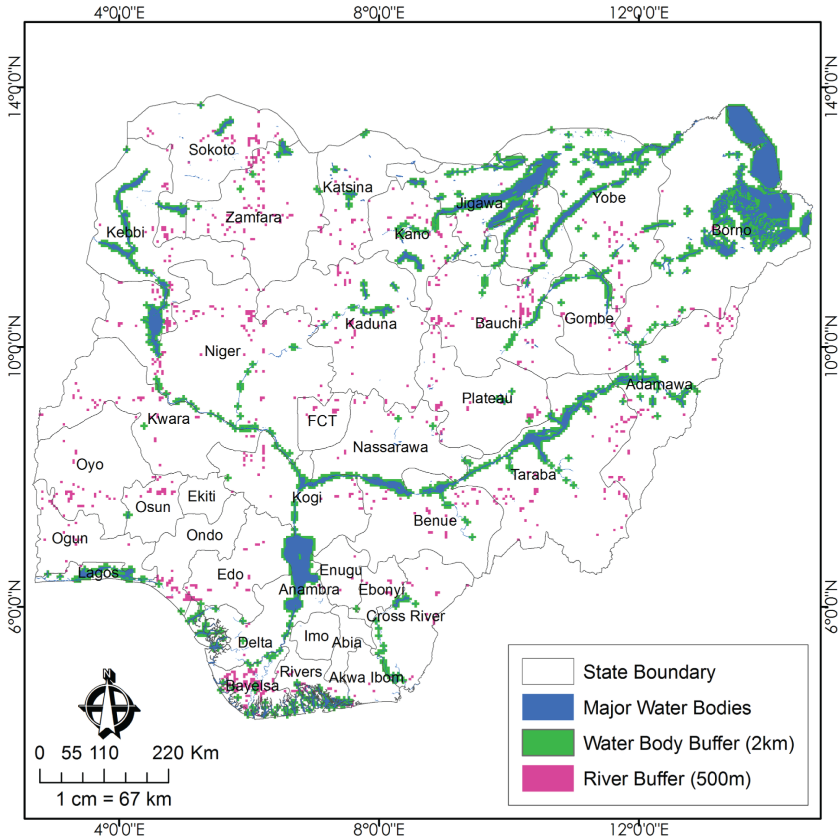
dams, increase in ocean water level and other natural or anthropogenic vagaries. The medium risk are the areas also prone to inundation, but not as severe as the high-risk zone.

Weights were allocated for the parameters to make a final decision on flood risk zones and vulnerable LGAs. The weighted overlay analysis was executed using the *weighted overlay* spatial analyst tool. This tool overlays several raster datasets using a common measurement scale and weighs each according to its importance (ESRI, 2014).

The weight assigned to each parameter determines its role in the final output. This is usually based on the relevance of each factor, backed by the observed behavior of previous flood events in the area and literature. Authors who have adopted the weighted overlay analyses have uniquely selected their weighing preferences. For example, Rimba, Setawati, Samba & Miura (2017) allocated the highest weight to slope. Siddayao, Valdez & Fernandez (2014) and Samanta, Koloa, Pal & Palsamanta (2016) assigned the highest influence to the distance from river, Ouma & Tateshi (2014) assigned the highest weight to soil type, while for Kazakis, Kougias & Patsialis (2015), flow accumulation was assigned the highest influence.

In this study, a total weight of 100 was assigned to all the 4 reclassified parameters (elevation, slope, rainfall intensity and buffer of proximity to water bodies). A weight of 20 was assigned to the distance from large water bodies because the most affected areas during floods are those near rivers, as a consequence of river bank overflow. The slope of the topography also plays an important role in determining surface runoff velocity and rate of vertical percolation; thus, it was assigned a weight of 20. Further, elevation has an important impact on the spread of flooding

Figure 8. Buffer of water bodies



and has a key role in the control of the direction of overflow movement and also in the depth of the flood, thus, the highest weight of 30. Rainfall intensity also plays a significant role as most flood events are triggered by rainfall, thus a weight of 20 was allotted. The other smaller rivers were also assigned a weight of 10 (Table 2).

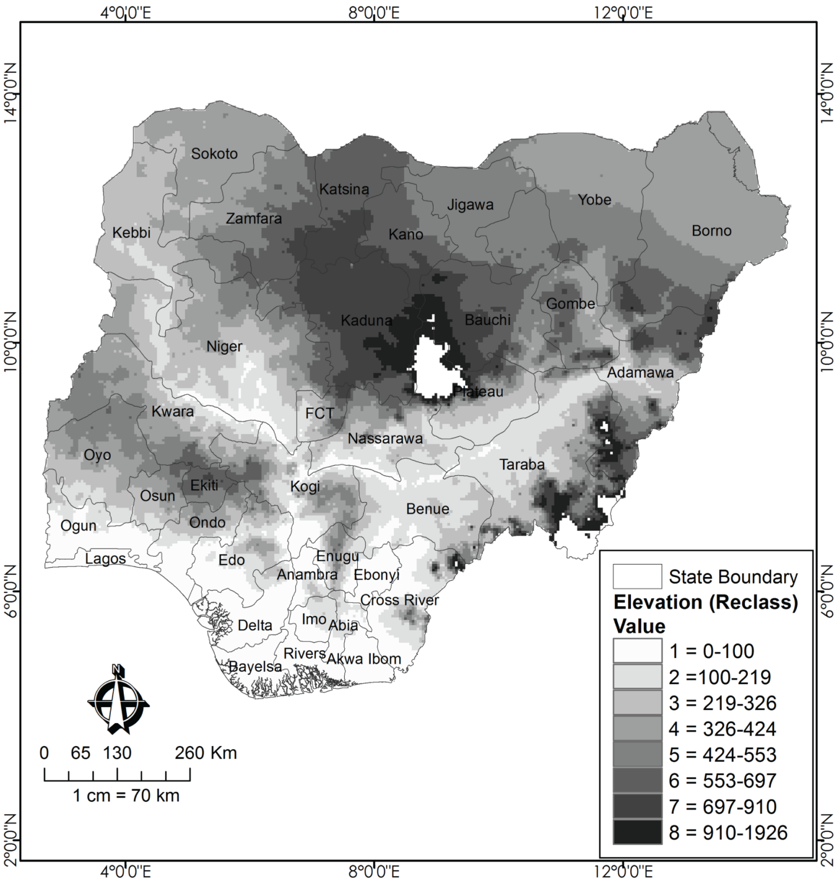
The raster output of the weighted overlay analysis was a flood-risk zones map which was polygonized to enable measurements. Furthermore, to aid deductions of flood-risk vulnerability in Nigeria, the polygonized flood-risk map was overlaid on the population density map which was classified into 3 (<1 = low density, 1-2 = medium and 2-3 = high density). The unit of measurement for the population density map is given as "persons per 200 m^2 grid".

RESULTS AND DISCUSSIONS

Flood-Risk Vulnerable LGAs in Nigeria

A total of 33 out of 36 States and the FCT in Nigeria are faced with high and medium flood-risks. Table 3 shows the LGAs that are at high vulnerability to flooding while Table 4 shows LGAs that are at medium vulnerability to flooding. A total of 12 States in the South of Nigeria have LGAs in high flood-risk zones while in the North, there are seven States with LGAs within high flood-risk zones. In all, 19 States and 114 LGAs (14% of all the LGAs in Nigeria) are exposed to high flood-risks with hotspots majorly at the Niger Delta, the Lagoons of Lagos, along the River Niger, River Benue

Figure 9. Elevation reclassification

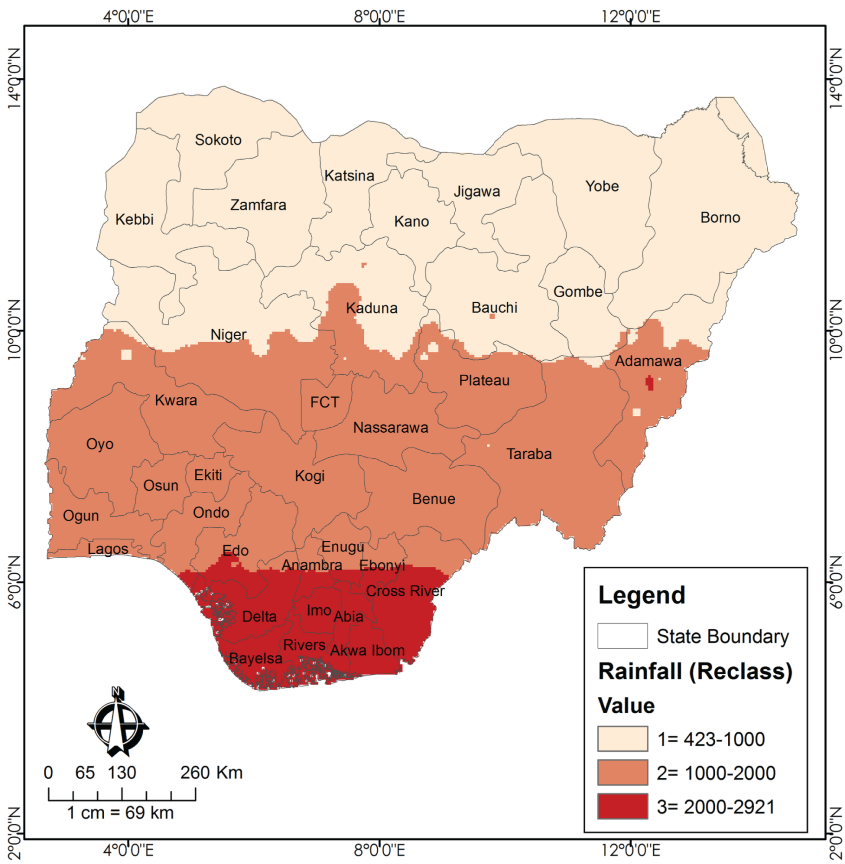


and the Cross River. The Northern part of Nigeria thus has fewer LGAs faced with high flood-risk when compared to the South. This is so because, although there is a fair share of rivers in the North of Nigeria, the elevation is higher (Figure 3) and rainfall is lesser (Figure 5).

There are more LGAs within medium flood-risk zones in the North (120 LGAs in 15 States) with only 5 LGAs within 3 States in the South. This implies that a total of 125 LGAs (16% of all the LGAs in Nigeria) are in medium flood-risk zones (Figure 12). Further, measurements from the flood-risk map revealed that out of a total coverage area of 924,000 km^2, an area of 22,654km^2 is exposed to high risk of flood, 44,923 km^2 to medium risk and 5198 km^2 to low flood-risk.

The flood-risk vulnerability map in Figure 13 is an overlay of the polygonized flood-risk zones on the population density map of Nigeria. The output reveals the LGAs at different levels of flood vulnerability in Nigeria (Table 4). Lagos State is most vulnerable to flooding, being the only State with LGAs of high population densities within high flood-risk zones. There are 4 LGAs (Ajeromi-Ifelodun, Lagos Island, Shomolu and Mushin) with high population densities that are within high flood-risk zones. Other LGAs, such as Ikorodu, Lagos Mainland, Apapa, Surulere, Eti-Osa and Amuwon-Odofin in Lagos have medium population densities and are as well within high flood-risk zones. Seemingly, more than any other State, residents of Lagos have bemoaned from the feedback of flooding on their livelihoods and in recent times it has become a yearly ritual, especially during the rainy season.

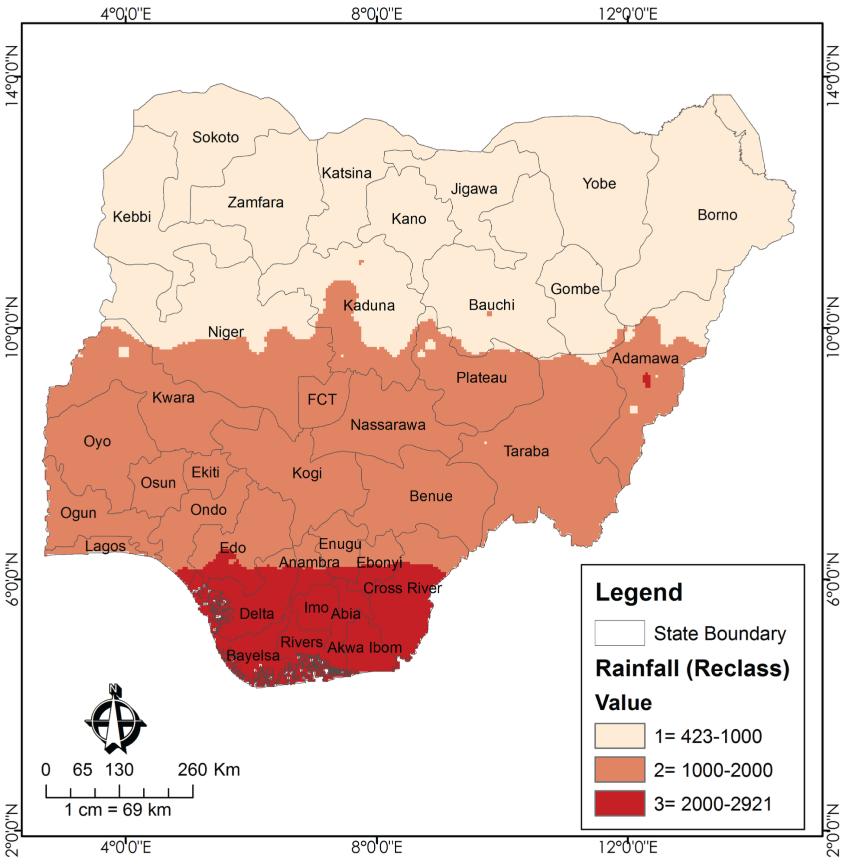
Figure 10. Slope reclassification



In line with this, *The Cable* (2019) reported that, "Lagos is turning into an aquatic habitat" as "the flood is geographically redesigning Lagos". In the same vein, Atufu & Holt (2018) revealed that the flooding in Lagos causes loss of lives and property as well as disruption of movement which hinders socio-economic activities. According to Adelekan & Asiyanbi (2016), a flood event at the Ikorodu area of Lagos in 2010 led to the displacement of 1700 residents. In 2011, floods in Lagos cost the people a loss of more than US$300 million, evidenced from insurance claims (Ajibade, McBean & Bezner-Kerr, 2013). During and after the 2012 deluge which devastated most of the country, it was reported that at least 7.7 million people were affected at different proportions in Lagos alone (Atufu & Holt, 2018). The figures from Lagos are high compared to other states because of the high population density in Lagos LGAs.

Further, as shown in Table 4, a total of six States (Kogi, Cross River, Akwa Ibom, Delta, Anambra and Rivers) have LGAs with medium population densities that fall within high flood-risk zones, thus facing high flood-risk vulnerability. As well, 4 States (Bauchi, Jigawa, Osun and Borno) face medium flood-risk vulnerability with a total of six LGAs having medium population densities within medium flood-risk zones. These findings corroborate with those from other studies and news reports on flooding in Nigeria, some of which expose the flooding challenge, showing its possible reach, impacts and proffering workable solutions in smaller administrative units (Amangabara & Obenade, 2015; Njoku, Efiong, Uzoezie, Okeniyi & Alagbe, 2018; Udo & Eyoh, 2017).

Figure 11. Rainfall intensity zones reclassification



The reports from daily online tabloids go further to support the findings. For instance, *Floodlist* reported on the 19th of September, 2018 that flooding of rivers prompted a state of emergency in Niger, Kogi, Anambra and Delta States of Nigeria, after the disaster agencies stated that it had killed as many as 100 persons and displaced thousands in communities along the major rivers. Similarly, *The Guardian* report of 11th May, 2018 quoted the prediction of the Nigeria Hydrological Services Agency (NiHSA) that 35 States in Nigeria would experience flooding in 2018. The floods were predicted to affect 318 LGAs, 78 of which would have high flood-risks. In a related report, as published by *The Eagle Online* on the 9th of August, 2018, NIMET predicted that cumulative high intensity of rainfall in some parts of the country in June and July of 2018 would trigger floods in which would most likely be intense in Akwa Ibom, Bauchi, Benue, Borno, Lagos, Cross River, Delta, Kaduna, Kwara, Nasarawa, Yobe and Zamfara States.

In October, 2019, the report of the International Federation of Red Cross and Red Crescent Societies (IFRCRCS) affirmed the predictions made in the previous year and substantiated the findings from this study. Following the high-water levels in rivers Niger and Benue, accompanied by heavy rainfall, Cross River, Kogi, Niger and Taraba States experienced flooding in September 2019. A total of 18,640 people (3,104 households) were affected by the floods in 54 communities while some 4,485 people (746 households) are were displaced (IFRCRCS, 2019). Further, since June, 2019, IFRCRCS (2019) reported that in Nigeria as a whole, flooding has affected a total of 210,117 people with 171 casualties recorded in hospital and 130,610 people reported to be displaced. The

Table 2. MCA criteria

Parameters	Class	Reclass (Rates)	Rating Index	Weight (W)
Elevation (m)	0-100	1	High risk	30
	100-219	2	Low risk	
	219-326	3		
	326-424	4		
	424-553	5		
	553-697	6		
	697-910	7		
	910-1926	8		
Slope (%)	0-10	1	High risk	20
	10--15	2	Low risk	
	15-20	3		
	20-30	4		
	30-50	5		
	50-80	6		
	80-113	7		
Rainfall intensity (mm)	0-1000	1	Low risk	20
	1000-2000	2	High risk	
	2000-2921	3		
Distance from rivers (m)	>500	1	High risk	10
Distance from big water bodies (m)	>2000	1	High risk	20

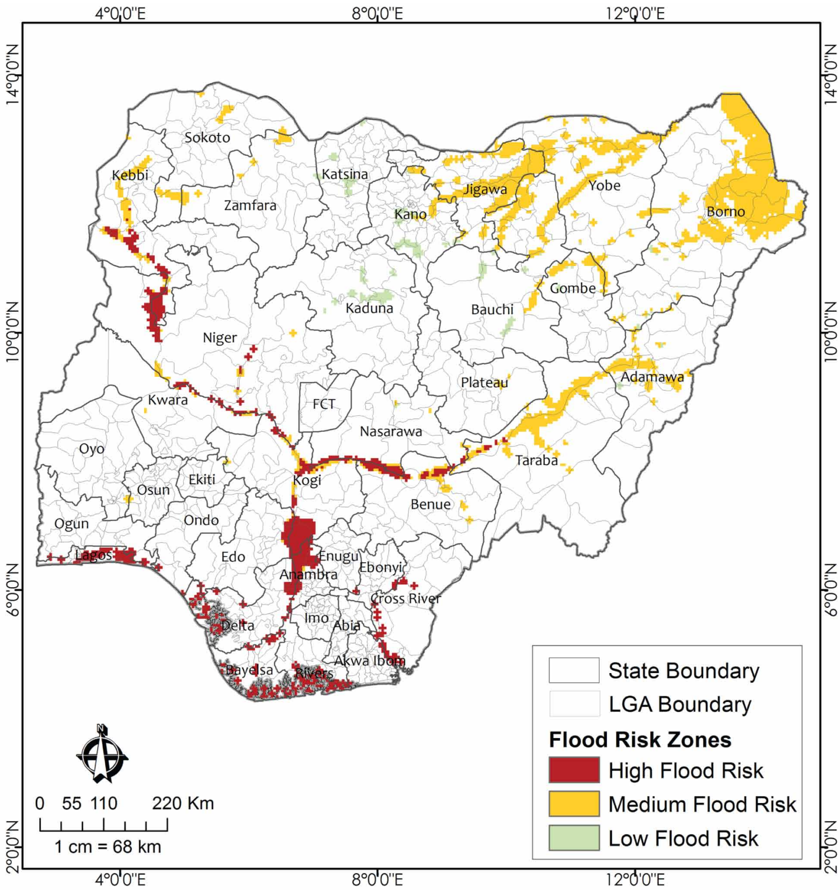
floods are experienced in LGAs that are flood prone as this study has shown. In all, the occurrence of flooding in Nigeria is impending and its multi-dimensional impacts on livelihoods may continue if proper measures are not put in place to tackle the menace (Table 5).

CONCLUSION AND RECOMMENDATIONS

The vulnerability of Nigerians to flood-risk varies across space. The combination of factors such as elevation, slope, rainfall intensity and distance to water bodies resulted to flood-risk and vulnerability maps, revealing LGAs that are in high, medium and low risk zones. Nigeria has 774 LGAs, 30 percent of which are vulnerable to flood-risk at medium and high levels.

This calls for concern and more commitment to flood-risk management, especially in the Southern part of the country where more LGAs are prone to high flood-risks. Lagos showed to be more vulnerable to flooding due to its densely populated LGAs residing within high flood-risk zones. While Lagos stands out, other LGAs like Calabar South in Cross River State, Onitsha North and South in Anambra, and so on are vulnerable too since they have medium population densities and are situated in high flood-risk zones. The prediction of flood-risk zones and vulnerable LGAs in Nigeria as executed in this study is validated by past occurrence of flooding in some of the identified communities from literature and news reports.

Figure 12. Flood-risk map of Nigeria showing vulnerable States and LGAs



This study presents an inventory of LGAs that are vulnerable to different levels of flood risk in Nigeria. At the national scale, this information is novel, thus its relevance for decision making cannot be overemphasized. The information is relevant at all aspects of flood-risk management as it serves as the bases for evaluating the susceptibilities of physical and social systems to the hazard at the LGAs at risk. It would also go a long way to fill the void in the dearth of flood-risk vulnerability studies and models necessary for evidence-based decision making to mitigate the menace and impacts of flooding on the Nigerian populace.

Based on the findings, the following recommendations are suggested:

1. The flood-risk and vulnerability maps derived from this study should be adopted as working documents to support policy formulation and decision making for specific relevant agencies such as the NIMET, NEMA, NiHSA, IFRCRCS, the Federal and State fire departments, city administrators and planners, and so on;
2. The maps and lists of LGAs at different flood-risk zones are useful in all steps of disaster management (prevention, mitigation, preparedness, operations, relief and recovery). Particularly, this information should be used for early warning and evacuation of settlers to higher grounds in a case of an extreme anthropogenic or climatic event such as the recurrent release of excess water from dams or extreme rainfall occurrence;

Figure 13. Flood-risk vulnerability in Nigeria

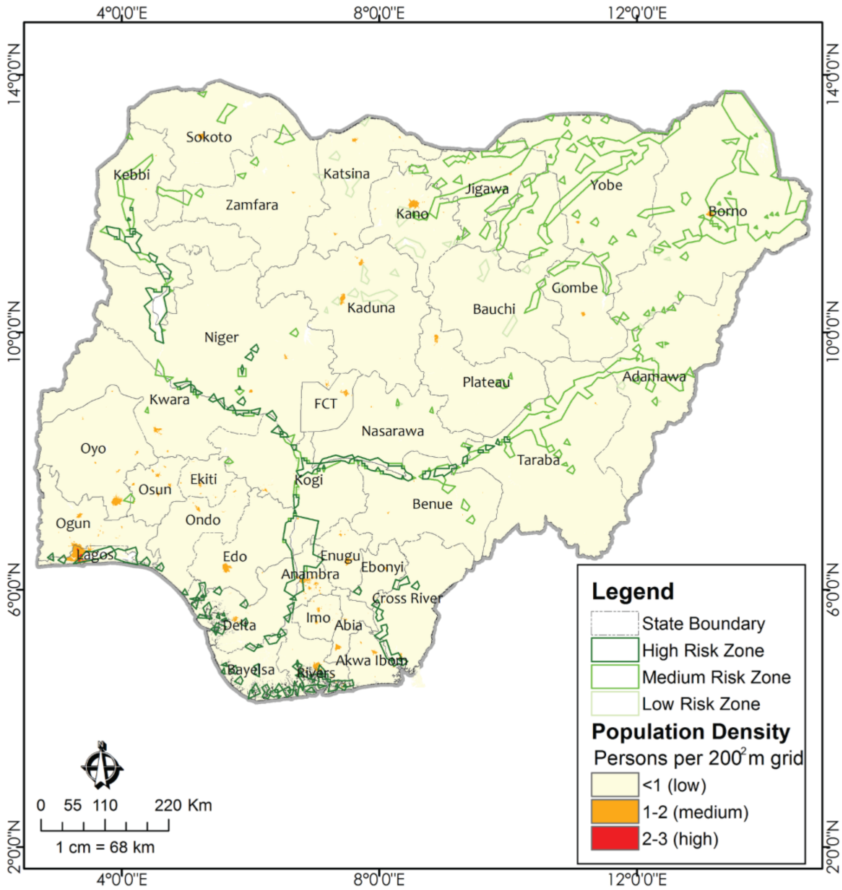


Table 3. LGAs vulnerable to flooding in high flood-risk zones

S/n	State	LGA	Total
1	Kebbi	Suru, Dandi, Bagudo, Koko/Besse, Shanga	5
2	Niger	Yauri, Agwara, Borgu, Magama, Mokwa, Wushishi, Lavun, Edati, Agaie, Lapai	10
3	Kwara	Pategi, Edu	2
4	Kogi	Lokoja, Ajaokuta, Ofu, Omala, Bassa, Kogi, Idah, Ibaji, Igalamela-Odolu	9
5	Nasarawa	Toto, Nasarawa, Doma, Awe	4
6	Taraba	Wukari, Ibi, Gassol	3
7	Benue	Guma, Makurdi, Guer West, Logo, Agatu	5
8	Ogun	Ipokia, Ado-Odo/ Ota, Ogun Waterside, Ijebu East	4
9	Lagos	Badagry, Amuwo Odofin, Ajeromi-Ifelodun, Apapa, Lagos Mainland, Lagos Island, Eti Osa, Kosofe, Surulere, Shomolu, Ikorodu, Ekpe, Ibeju Leki	10
10	Ondo	Ilaje, Ese-Odo	2
11	Bayelsa	Ekeremor, Southern Ijaw, Sagbama, Nembe, Brass	5
12	Imo	Oguta	1

continued on following page

Table 3. Continued

S/n	State	LGA	Total
13	Delta	Warri North, Warri South West, Burutu, Warri South, Ethiope West, Ethiope East, Udu, Ughelli North, Patami, Oshimili North, Oshimili South, Ndokwa East, Isoko South	14
14	Rivers	Ogba/Egbema/Ndoni, Akuku Toru, Degbema, Bonny, Okrika, Port-Harcourt, Ogu/Bolo, Andoni, Emohua, Opobo/ Nkoro, Khana.	12
15	Anambra	Ogbaru, Ekwusigo, Onitsha South, Onitsha North, Idemili North, Idemili South, Anambra West, Anambra East, Ayamelum, Akwa North	10
16	Enugu	Uzo-Uwani, Ezeagu, Aninri	3
17	Ebonyi	Ohaozara, Ivo, Ikwo, Afikpo North	4
18	Akwa Ibom	Ikot Abasi, Uruan, Okobo, Oron, Itu	4
19	Cross River	Calabar South, Calabar Municipality, Odukpani, Biase, Abi, Obubra, Ikom	7
20	Total		114

Table 4. LGAs vulnerable to flooding in medium flood-risk zones

S/n	State	LGA	Total
1	Oyo	Egbeda, Lagelu	2
2	Osun	Irewole, Isokan	2
3	Kwara	Moro	1
4	Kogi	Yagba East	1
5	Ekiti	Ikole	1
6	Benue	Tarka, Buruku, Katsina-Ala, Kwande	4
7	Taraba	Wukari, Gassol, Bali, Karim-Lamido, Jalingo, Ardo-Kola	6
8	Plateau	Wase, Kannam, Langtang	3
9	Nasarawa	Akwanga, Lafia	2
10	Adamawa	Lamurde, Numan, Guyuk, Shelleng, Demsa, Mayo-Belwa, Yola South, Yola North, Fufore, Girei, Song, Mayo-Belwa	12
11	Gombe	Dukku, Nafada, Funakaye	3
12	Kebbi	Bunza, kalgo, Birnin-Kebbi, Argungu	4
13	Sokoto	Tambuwal, Kebbe, Wurno, Illela, Guronyo, Gada	6
14	Zamfara	Gummi, Bakura, Shinkafi, Talata-Mafara, Maradun	5
15	Kano	Dambatta, Dawakin Kudu, Warawa, Gabasawa, Wudil, Ajingi, Takai	7
16	Jigawa	Garki, Ringim, Taura, Sule-Tankarkar, Babura, Birni-Kudu, Buji, Gwaram, Kiyawa, Miga, Jahum, Kafin Hausa, Auyo, Kaugama, Hadejia, Kiri Kasamma, Guri, Biriniwa, Maigatari, Gumel	20
17	Bauchi	Kirfi, Ganjuwa, Shira, Jama'are, Itas/Gadua, Zaki, Gamawa, Damban, Misau, Darazo	10
18	Yobe	Bade, Karasuwa, Yusufari, Jakusko. Bursari, Yunusari, Geidam, Tarmua, Damaturu, Nangere, Fune, Gujba, Galani, Fika	14
19	Borno	Shani, Bayo, Itawul, Askira/Uba, Bamboa, Kaga, Konduga, Maiduguri, Jere, Magumeri, Gwoza, Mafa, Bama, Dikwa, Nganzai, Mobbar, Abadam, Kukawa, Mongumo, Marte, Ngala, Kala/Balge	22
20	Total		103

Table 5. LGAs within high and medium flood vulnerability levels

Vulnerability Level	State	LGA
High vulnerability	Lagos	Ajeromi-Ifelodun, Lagos Island, Shomolu and Mushin
	Kogi	Idah
	Cross River	Calabar South
	Akwa Ibom	Oron
	Delta	Oshimili South
	Anambra	Onitsha South, Onitsha North, Idemili South
	Rivers	Port-Harcourt, Eleme, Okrika, Ogu/Bolo, Opobo/Nkoro
Medium vulnerability	Lagos	Ikorodu, Lagos Mainland, Apapa, Surulere, Eti-Osa Amuwon-Odofin
	Bauchi	Jama'are
	Jigawa	Hadeja
	Osun	Irewole, Isokan
	Borno	Maiduguri, Jere

3. To build sustainable rural and urban communities, the findings here should support monitoring or restriction of anthropogenic activities around flood-risk zones. Areas with existing human activities, especially landuses within flood-risk zones should be re-modeled and re-engineered to cater for flood events. Alternatively, residents should be evicted, resettled or advised to relocate, as the case may be. Only these proactive measures would reduce the socio-economic impacts of flooding on livelihoods of residents in Nigeria;
4. Proactive and workable mitigation and adaptation policies must be implemented by the Nigerian government and other stakeholders at local, state or national levels. This would help the LGAs and other players adjust their systems in response to expected effects, thereby moderating possible risks.

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