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Geospatial Mapping of Flood Risk in the Coastal Megacity of Nigeria

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Abstract

Flood risk in coastal megacities of developing nations is higher than those in developed nations due to inadequate fiscal resources, urbanization, and poor flood maintenance infrastructure, amongst other factors. Lagos is one of the coastal megacities of the developing nations characterized by increasing urbanization and population growth. This study presents geospatial mapping of flood risk areas in the coastal megacity of Nigeria. The flood prone areas were derived by overlaying seven flood factors in ArcGIS environment, which include: elevation, curvature, slope, flow accumulation, normalized difference water index (NDWI), land cover and drainage density. Results showed that of the 2507.2 km^2 land area covered by this study area, 0.006% (0.15km^2) falls in very high risk, 30.9% (774.7 km^2) falls in high risk, 68.8% (1725km^2) falls in moderate risk and only 0.31% (7.8km^2) falls in low risk areas. Furthermore, highly urbanized Local Governments in relatively low elevations with low slope angles such as Eti-Osa, Apapa, Lagos Island, Lagos Mainland and Ojo have high risk of getting flooded while most Local Governments with low level of urbanization and high elevations have moderate to low risk of getting flooded. These findings have implications on sustainable decision making and planning for flood risk prevention and management, prioritizing flood risk control mechanisms where necessary, and the development and implementation of potent flood control policies with appropriate infrastructure in areas that fall in both very high risk and high risk.

Keywords

Coastal Megacity, Flood Risk, Geospatial, Nigeria, Ikeja, Lagos State

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1. Introduction

For many cities in both the developed and developing nations, urban flooding has been, and continues to be, a major environmental problem [1]. Between 1950 and 2017, the record of flood events registered showed that about 2% occurred in 1950s and increased rapidly to 52.2% by the end of 2017 [2], endangering lives and causing property damage in the process [3-6]. In the last decade, flood has affected more than 1.4 billion people and accounted for the death of about 100,000 people [7]. Also, between 1998 and 2018, more than 3,136 flood disasters have occurred around the world, with an estimated total damage of US$556 billion [8].

By and large, floods account for 47% of all weather-related disasters and 43% of the total natural disasters. More than 70 million out of 800 million people currently residing in flood-prone areas, are exposed to floods each year [9]. However, coastal megacities of developing nations concentrate a large proportion of those most at risk due to their weak capacity to manage flood risks and high vulnerability to extreme weather events [10, 11].

A variety of factors influence flood occurrence in cities.

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Urbanization without corresponding upgrade of drainage infrastructure [3], limited capacity of river channels [12], settlements in low areas [13], and flood plain encroachment [14] are common phenomena attributed to the increasing flood impacts. The manifestation of climate change which is evident in extreme rainfalls has equally contributed to the frequency, severity and intensity of the problem [15].

With the increasing concern over flood, flood risk mapping and risk analysis using remote sensing (RS) and GIS technologies have been increasing [14-22]. Thus, maintaining both the social and physical environment, advancing economic development [23], minimizing flood impacts and the corresponding costs, strengthening community resilience [24], helping in efficient flood risk modelling, enabling proper flood risk management planning, and proffering potent solutions towards addressing the problem.

This study builds on a growing number of flood risk mapping, using a well-established methodology. Consequently, it adopts the use of digital elevation model, curvature, slope, flow accumulation, normalized difference water index (NDWI), land cover and drainage density to detect areas prone to flood in Lagos State, Nigeria. The identification of areas prone to flood can contribute significantly to flood risk management and land use planning such that, potent flood management policies could be put in place, flood defense infrastructure could be constructed [25, 26] and urban development in flood prone areas could be duly monitored [27].

2. Materials and Methods

2.1. Research Locale

In this study, Lagos State, the erstwhile Federal Capital Territory of Nigeria is selected as the study area (see Figure 1). It is by far one of the most heavily populated cities in the country. Worldwide, Lagos is one of the 14 Coastal megacities of developing nations [28]. The study area comprises of 16 Local Government Areas (LGAs).

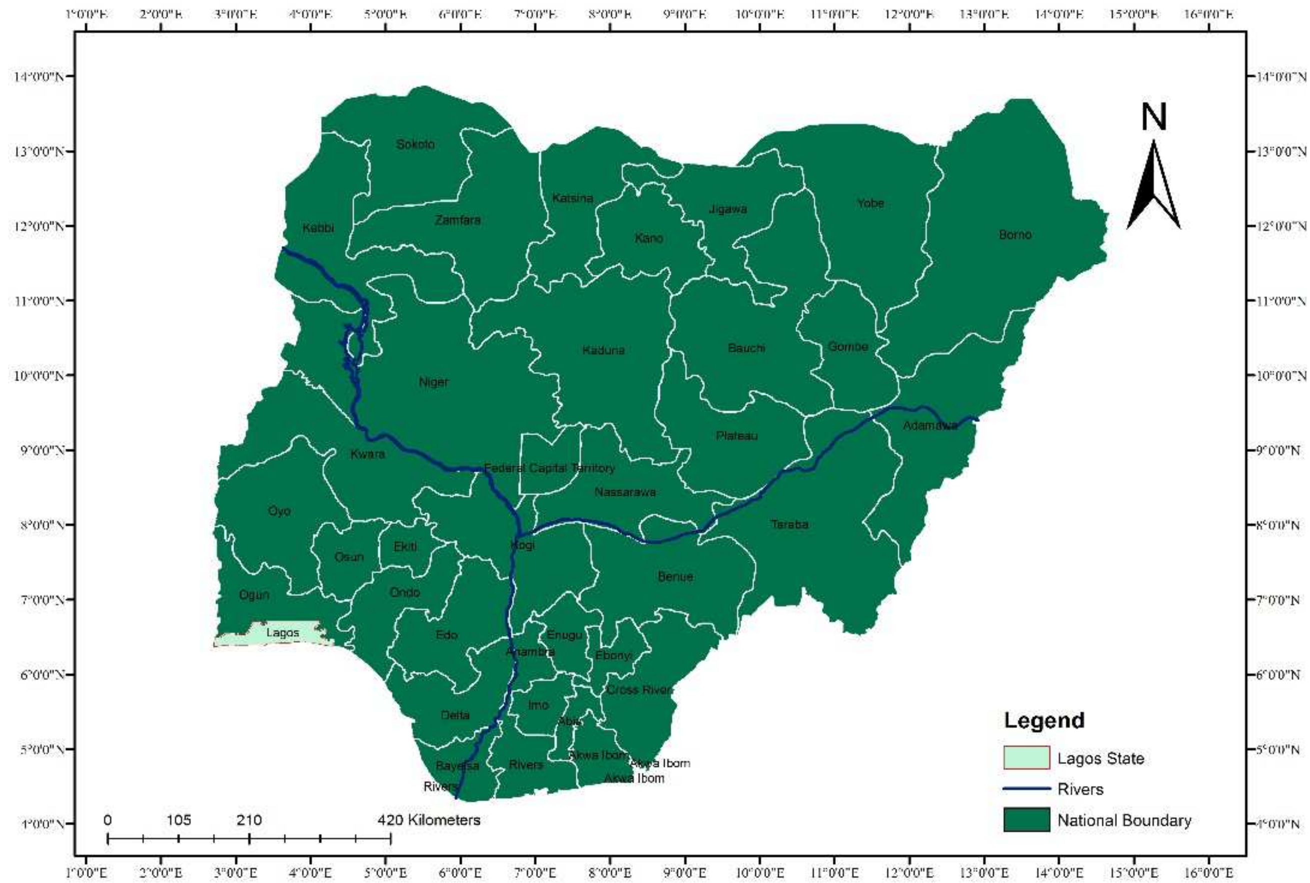

Figure 1. Lagos State in the context of Nigeria.

Source: Ministry of Surveys, Abuja (Digitized by Authors).

The position of the coastal city of Lagos as the nation's hub of commercial and industrial activities is evident in the fact that the city is the foremost contributor (62%) to the country's non-oil sector gross domestic product [29]. Similarly, it also accounts for about 80% of international air traffic in the nation and more than 70% of the nation's maritime cargo freight and seaport activities [30].

Lagos has been experiencing galloping urbanisation and increasing population. The population density of Lagos given at 20,000 persons/km^2 [31] is more than the global average population density of 112 persons/km^2 for coastal zones [32]. Consequently, there is an overwhelming pressure on the environment.

In the context of climate change, Lagos ranks among the top 10 global cities and only city in Africa with 'high risk' from climate change [33]. Evidently, there has been increasing severity and impact of both inland and coastal floods [34, 35].

2.2. Methods

A flood risk map can be defined as a map that shows a community's flood prone zones. It is an essential tool for land use planning in flood prone areas [36]. The flood risk map was generated by overlaying various reclassified thematic layers as no single environmental variable can be used to evaluate flood risk in isolation. Parameters used to generate the flood risk map include land cover type, Digital Elevation Model (DEM), drainage density, curvature, slope, Normalised Difference Water Index, and flow accumulation as carried out in several studies [37-41].

The datasets used to generate the parameters were obtained from the archive of the United States Geological survey (USGS). Sentinel-2 imagery of the study area was used to derive the landcover and NDWI map while, Shuttle Radar Topography Mission (SRTM) data was used to derive the elevation and other parameters which were overlaid to obtain the flood risk map.

The green (band 3), red (band 4) and near infrared (band 8) bands of the sentinel-2 data were stacked together in ArcGIS environment using the 'Composite Bands' tool to derive the false colour composite which was then classified using the supervised classification algorithm. The Normalised Difference Water Index (NDWI) was used to delineate surface waterbodies in the study area. It was derived using the formula given below [42]:

$$\text{NDWI}=\frac{GREEN-NIR}{GREEN+NIR}$$

The Digital Elevation Model (DEM) of the study area was extracted from the SRTM data and was subsequently filled using the 'Fill tool' in ArcGIS to correct missing data. The DEM was used to generate the slope and curvature of the study area using the 'Slope' and 'Curvature' tools respectively in the ArcMap environment. The DEM was also used to generate the flow direction raster of the study area using the 'Flow Direction' tool. The flow direction raster was then used to generate the flow accumulation raster using the 'Flow Accumulation' tool. The flow accumulation raster was used to derive the stream order raster which was converted to a line shapefile using the 'Stream to Feature' tool. The line shapefile was further analysed to generate the drainage density of the area using the 'Line Density' tool.

Each thematic layer was reclassified using the 'Reclassify' Tool and different values were assigned to different classes within each layer with a rating scale of 1 to 5 depending on how they influence vulnerability of humans, flow of surface water and water permeability [43]. The range of values within each layer was divided into five classes using the equal interval option in ArcMap 10.3. [41].

In the ranking (Table 1), classes within each dataset that highly encourages flood formation were assigned value "5", classes which do not encourage flood occurrence at all were assigned value "1" while intermediate classes were ranked between "2" and "4". All the layers from the various datasets were then assigned weights based on how critical they are to flooding in the study area after rainfall events, and overlaid in ArcMap environment to generate the flood susceptibility map using the weighted overlay tool.

Table 1. Flood influencing factors and ranking.

Thematic layer	Class	Rank	Risk vulnerability	Weight (%)
Elevation	-3 – 12	5	Very high risk	20
	13 – 27	4	High risk	
	28 – 43	3	Moderate risk	
	44 – 58	2	Low risk	
	59 - 73	1	Very low risk	
Landcover	Waterbody	5	Very high risk	17
	Builtup	4	High risk	
	Disturbed forest	3	Moderate risk	
	Undisturbed forest	2	Low risk	
Slope (Degree)	0 – 6.8	5	Very high risk	15
	6.9 – 13.5	4	High risk	
	13.6 – 20.3	3	Moderate risk	
	20.4 – 27.1	2	Low risk	
	27.2 – 33.8	1	Very low risk	

Thematic layer	Class	Rank	Risk vulnerability	Weight (%)
	342,960.9 – 428,701	5	Very high risk	
	257,220.7 – 342,960.8	4	High risk	
Flow Accumulation	171,480.5 – 257,220.6	3	Moderate risk	10
	85,740.3 – 171,480.4	2	Low risk	
	0 – 85, 740.2	1	Very low risk	
	7.8 – 20.1	5	Very high risk	
	20.2 – 32.5	4	High risk	
Drainage Density (km/km^2)	32.6 – 44.9	3	Moderate risk	15
	45 – 57.2	2	Low risk	
	57.3 – 69.6	1	Very low risk	
	0.11 – 0.24	5	Very high risk	
	-0.03 – 0.1	4	High risk	
NDWI	-0.17 - -0.04	3	Moderate risk	13
	-0.31 - -0.18	2	Low risk	
	-0.46 – 0.32	1	Very low risk	
	8.6 – 12.3	5	Very high risk	
	4.8 – 8.5	4	High risk	
Curvature	1.1 – 4.7	3	Moderate risk	10
	-2.7 – 1	2	Low risk	
	-6.6 - -2.6	1	Very low risk	

3. Results and Discussion

3.1. Thematic Layer Generated and Their Description

3.1.1. Land Cover

Land use map identifies the present use to which land is put. It is an integral factor in flood risk mapping because of its importance in relation to soil stability and infiltration [44, 43]. Impermeable surfaces such as buildings, roads, and parking lots reduce infiltration capacity and increase runoff while vegetated surfaces enhance the percolation and infiltration of raindrops into the soil which prevents runoff [45]. From the false colour composite of the study area, four landcover classes namely Built up, waterbody, disturbed forest and undisturbed forest were identified (Figure 2).

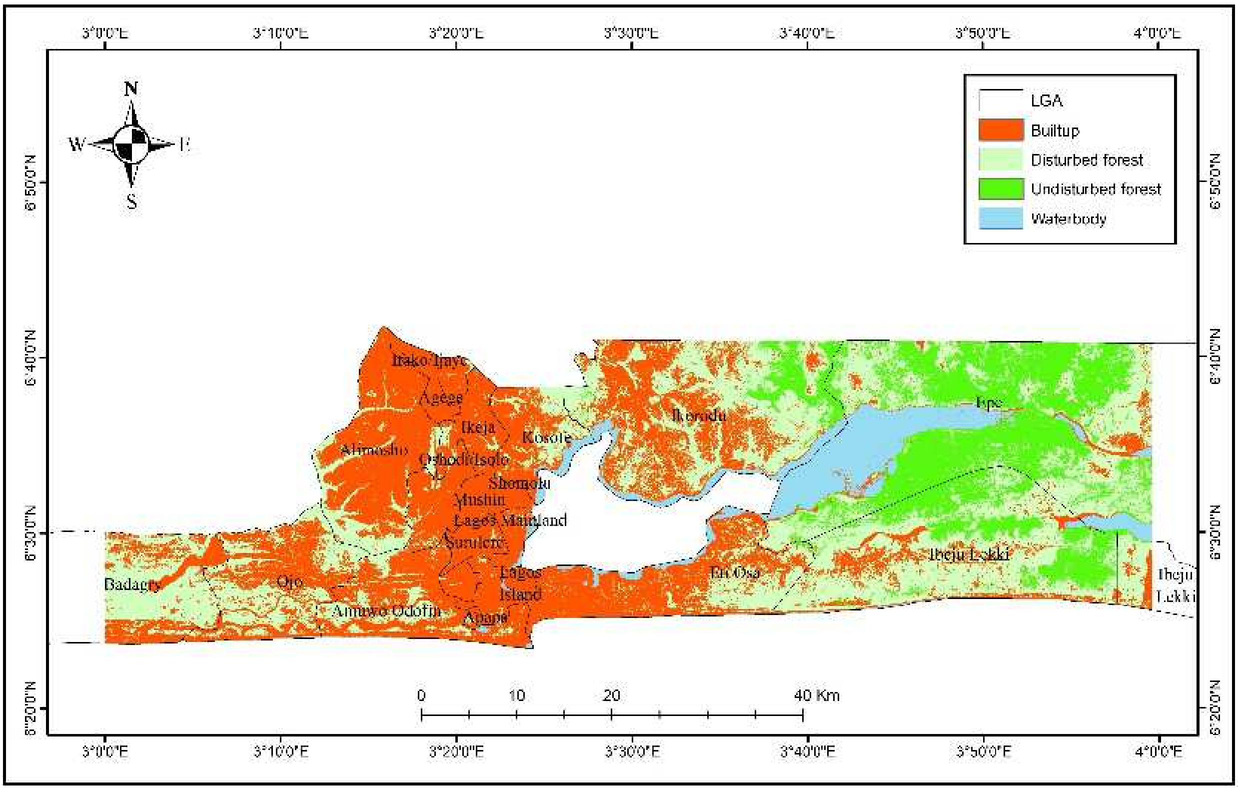

Figure 2. Land cover map.

3.1.2. Elevation

Elevation is the height of a place above sea level. Based on expert's knowledge, elevation is the primary factor that controls flood occurrence in an area. This is because water flows from highlands to lowland areas and therefore, areas of lower elevations have higher probability of getting flooded than areas of higher elevations [46, 41, 40]. The result showed that elevation in the study area ranged from -3 metres around the Lagos Lagoon to about 73 metres around the northernmost parts of the state (Figure 3).

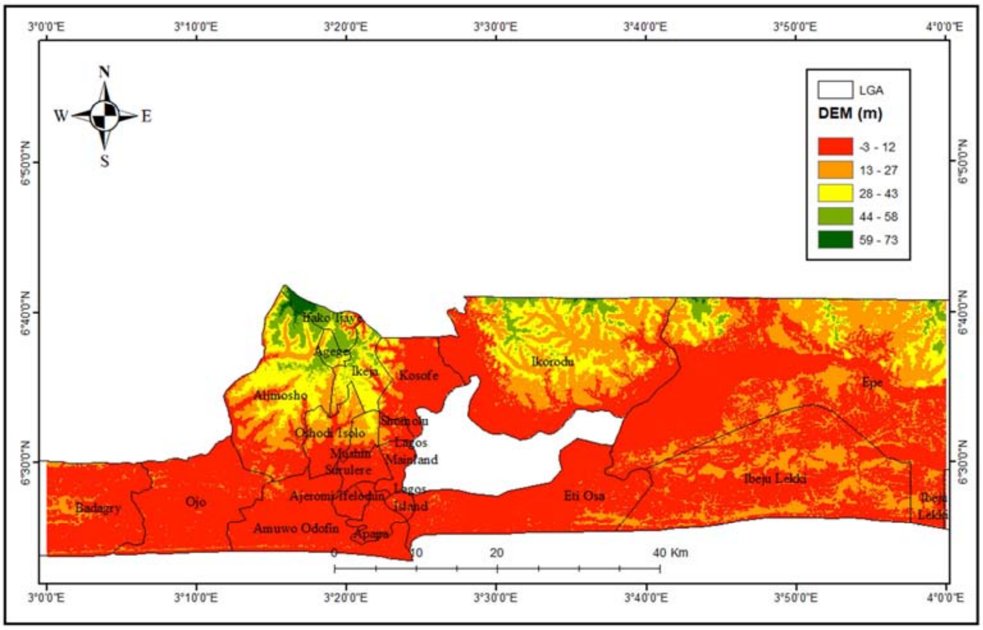

Figure 3. Elevation Map.

3.1.3. Slope Angles

Slope is the rate of steepness or the degree of inclination of a feature in relation to the horizontal surface [47]. Gently sloped areas (areas with low slope angles) have higher probability of being flooded than areas with steep slopes (high slope angles) [38]. This is because, on gentle slopes, surface runoff is usually slow and encourages ponding, whereas on steep slopes, the rate of runoff is usually very high [44]. Slope in the study area ranged between 0 and 33.6 degrees (Figure 4). Areas with low slope angles have high flood risk while areas with high slope angles have low flood risk.

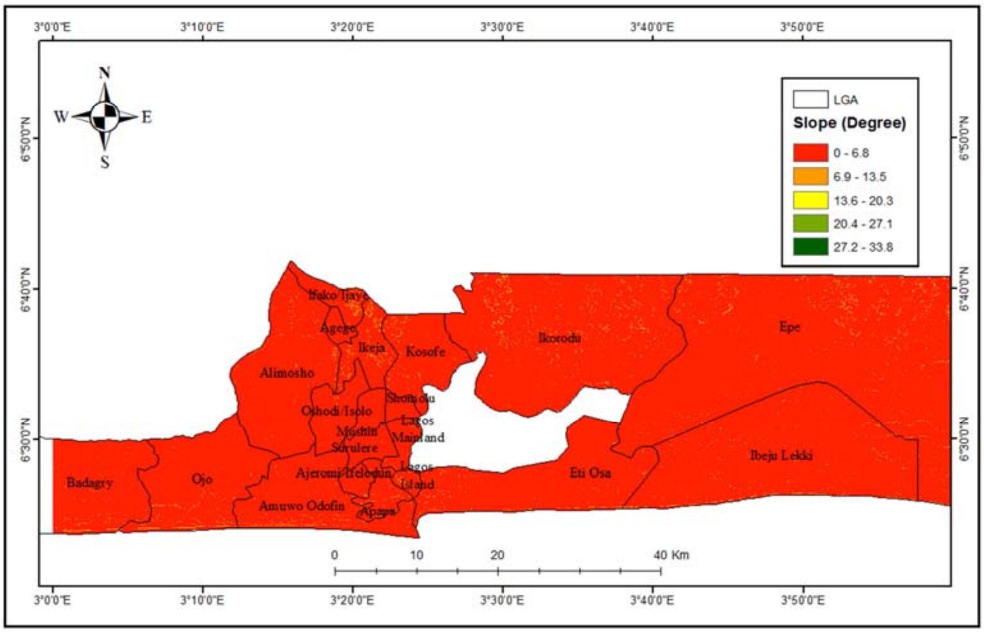

Figure 4. Slope Map.

3.1.4. Flow Accumulation

The flow accumulation shows the possible drainage channels in the area in an event of water runoff [48]. Flow accumulation is an important parameter to be considered during flood risk mapping because high flow accumulation indicates high vulnerability to flood and vice versa [41]. Flow accumulation in the study area ranged from 0 to 428,701 (Figure 5).

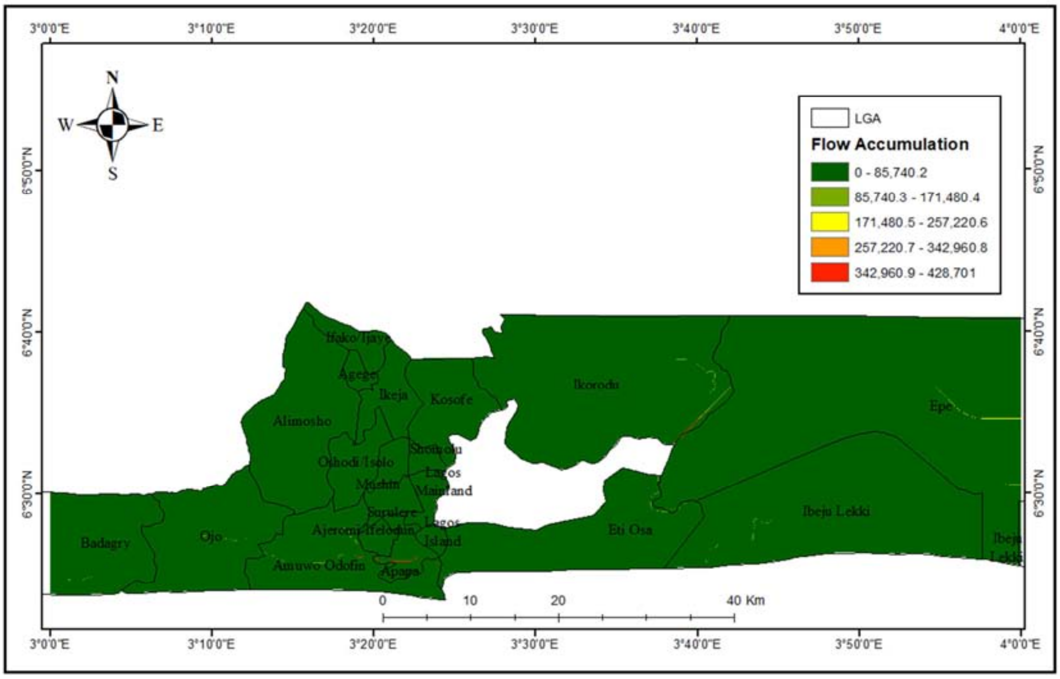

Figure 5. Flow Accumulation Map.

3.1.5. Drainage Density

Drainage density can be defined as the total length of stream channels per unit area [49]. Drainage density is vital in determining flood vulnerability because it denotes the nature of the soil and its geotechnical properties such as infiltration capacity and permeability [41]. Areas of higher drainage density have high tendencies of been flooded because high drainage density indicates greater surface runoff and vice versa. Drainage density in the study area ranged from 7.8 km/km^2 to 69.6 km/km^2 (Figure 6).

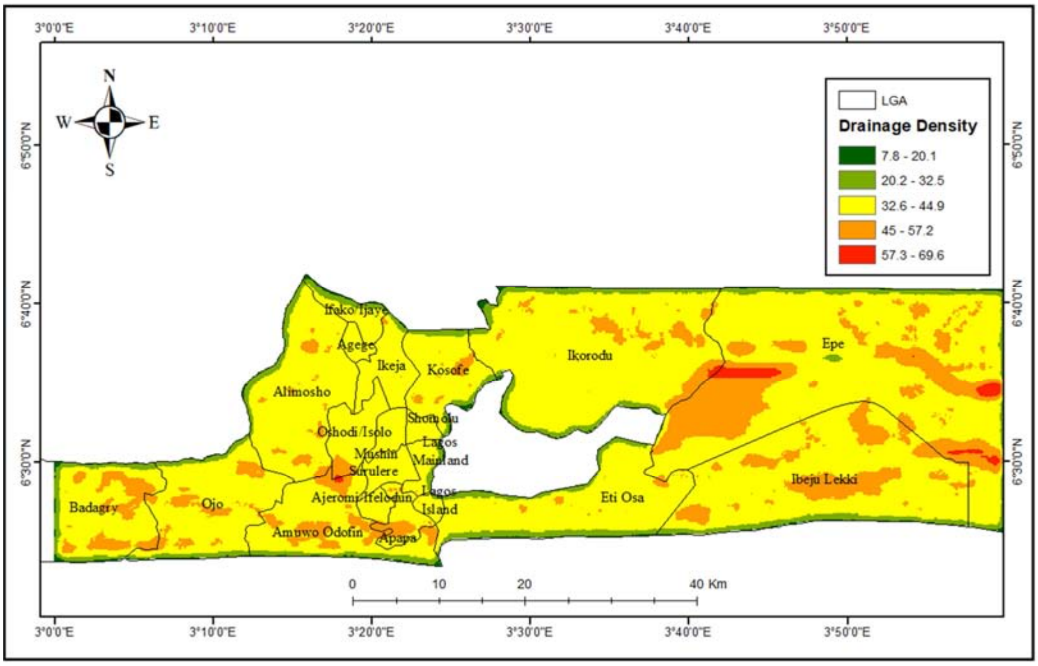

Figure 6. Drainage Density Map.

3.1.6. Normalized Difference Water Index (NDWI)

NDWI is a tool that can be used to distinguish water-bearing features from non-water bearing features which will help to identify open/permanent waterbody, moist soil/vegetation, areas liable to flood, as well as areas without any proportion of water that could lead to flooding [38]. The formula is mathematically given as:

$$NDWI = \frac{GREEN - NIR}{GREEN + NIR}$$

The result showed (Figure 7) that NDWI ranged from -0.46 (relatively waterless and therefore has low flood risk) to 0.24 (presence of surface water and relatively high flood risk).

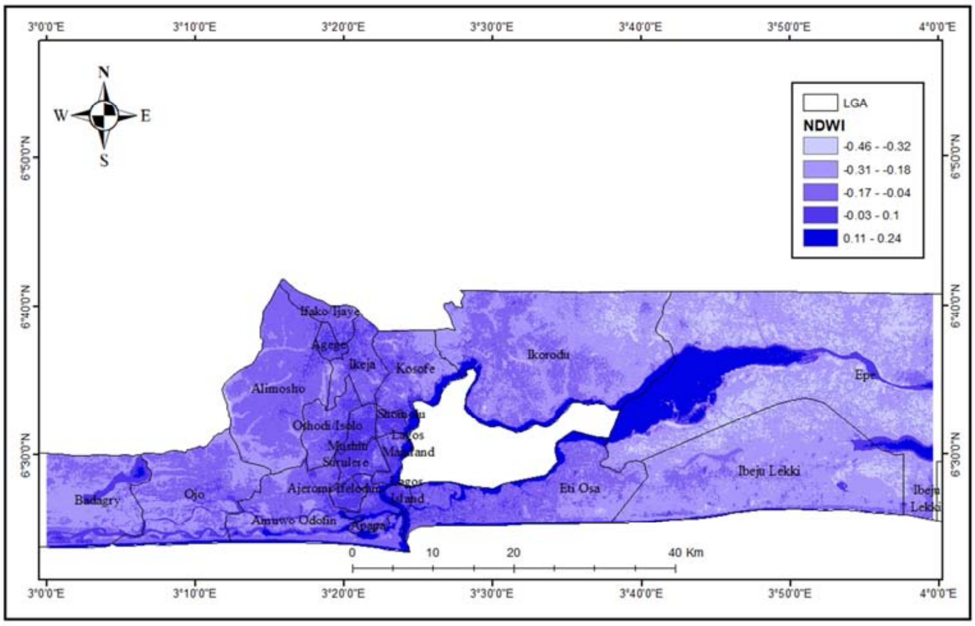

Figure 7. NDWI Map.

3.1.7. Curvature

Topographic curvature plays a crucial part in determining the runoff and infiltration process of an area [40]. It is found that the curvature between 1 and 2 have higher propensity of getting flooded. Topographic curvature as shown in Figure 8 ranged from -6.6 (low flood risk) to 12.3 (high flood risk).

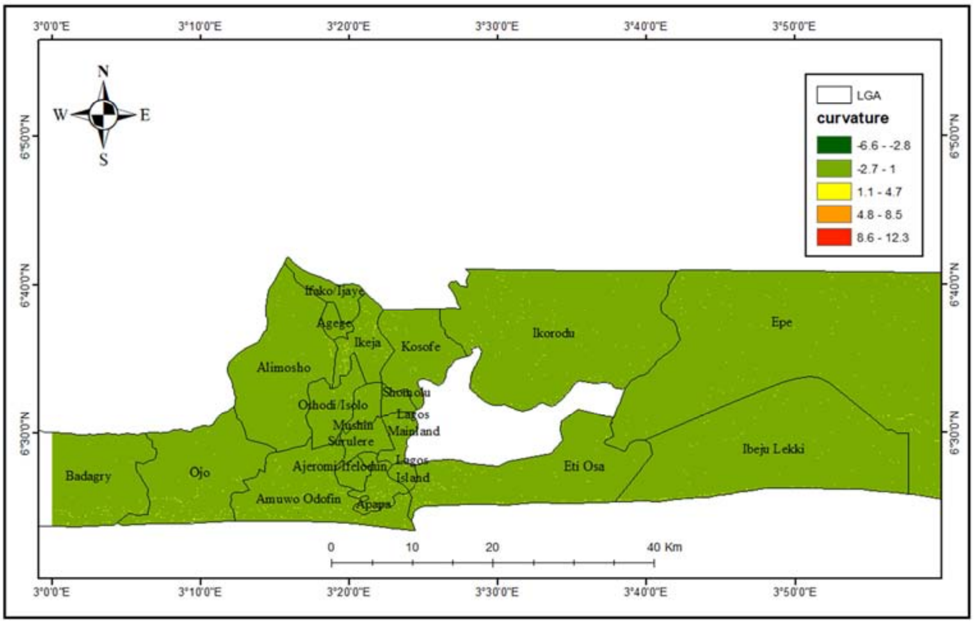

Figure 8. Curvature Map.

3.2. Flood Risk Result

The flood risk map (Figure 9) shows that 0.006% of the study area have very high risk of getting flooded, 30.9% have high risk, 68.8% have moderate risk, 0.3% have low risk while no area has very low risk of getting flooded as the process didn't generate any. This means that of the 2,507.2 km^2 area covered by this study, 0.15 km^2 have very high risk of getting flooded, 774.7 km^2 have high risk of getting flooded, 1725 km^2 have moderate risk and 7.8 km^2 have low risk of getting flooded. It can be observed that local governments with very high to moderate flood risk such as Eti-Osa, Kosofe, Lagos Mainland, Lagos Island, Mushin, Surulere and Ikeja, show a combined characteristic of being highly urbanized with low slope angle (0 - 4.2 degrees), and low to average elevation (-3m – 41m). However, it can be observed that some areas with relatively high elevation still have high flood risk.

The low risk zones are the locations where the probability of flood event is very low either due to high elevation, forest cover or other factors which discourage accumulation of water. The moderate risk zones are locations where the chances of flood occurring are slightly high and can be triggered by torrential rainfall which lasts for a relatively long period of time, coupled with inadequate drainage channels or blockage of culverts and gutters. The high and very high-risk zones are areas where flood occurrences can be easily triggered by rainfall event even over a short period of time.

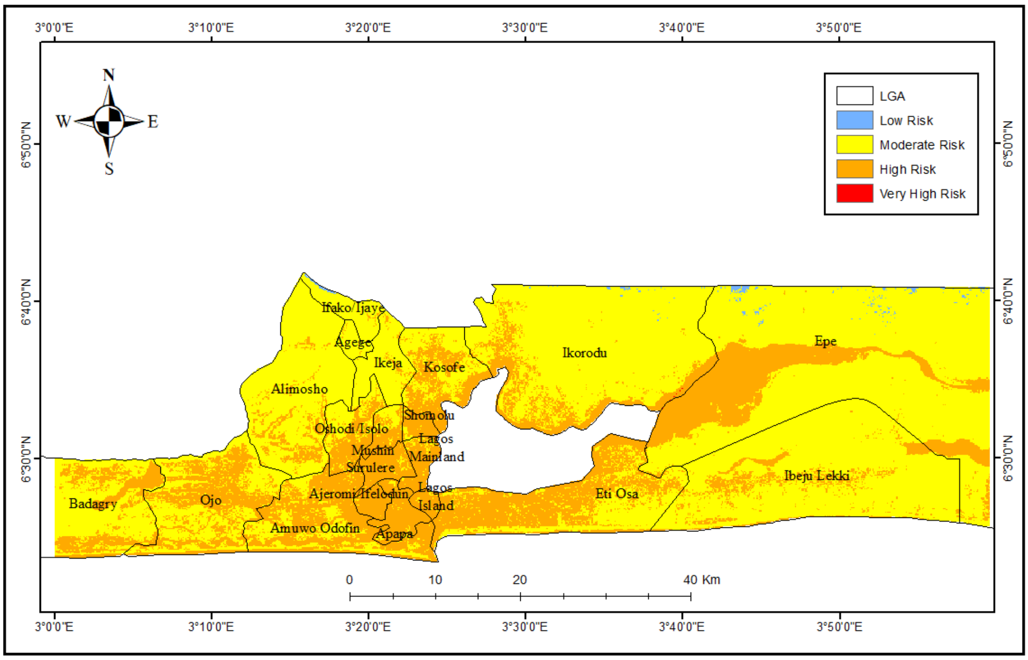

Figure 9. The Flood Risk Map.

4. Conclusion

In the context of flood hazard and risk, a step in the right direction is the promotion of flood risk mapping. The study findings have implications on sustainable decision making and planning for flood risk prevention and management; prioritizing flood risk control mechanisms where necessary; and the development and implementation of potent flood control policies with appropriate infrastructure in areas that fall in both very high risk and high risk. This will promote sustainable development, and reduce the impact of flooding in the coastal megacity of Nigeria.

The method adopted in this study is a cost-effective option for the academic and non-profit sectors. However, higher resolution imageries would improve the assessment of flood risk.

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