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MULTI-CRITERIA DECISION ANALYSIS AND GIS MAPPING OF FLOOD VULNERABILITY IN THE CORE OF LAGOS STATE NIGERIA

OTOKITI, K.V.,[1] AKINOLA, O.[2] *ORIRI, O.G.[1]
[1]Department of Urban and Regional Planning, University of Ibadan, Ibadan, Nigeria
[2]Institute of Ecology and Environmental Studies, Obafemi Awolowo University, Ile-Ife, Nigeria
*Corresponding author: oririoluwabukolami@gmail.com

Abstract
Cities have recently experienced more frequent and intense flooding that poses far-reaching implications on humans in terms of its negative effect on the quality of urban life, urban efficiency, economy, infrastructure, and sustainability. Flood vulnerability mapping based on multiple factors that influence flooding is considered a widely used approach to understand and analyse the extent of risk. With this background, the study examined flood vulnerability in Lagos core using multicriteria decision approach (MCDA) on ArcMap 10.5. Evidence from the current study indicates that the Lagos core is acutely vulnerable to flood threats as 95.62% of the total area is highly vulnerable to flooding. The study suggests the need for proactive flood vulnerability management actions rather than reactive measures to minimise the impact.

Key Words: *Flood, Lagos, Multi-Criteria Decision Analysis, GIS*

Introduction

Globally, floods represent the most common natural catastrophic event today, affecting millions of people and wreaking havoc on property, infrastructure, institutions, businesses, and lives (Youssef *et al*., 2011). Alongside urbanisation and deforestation, complicated geological, geomorphological, and hydrological factors are leading causes of flooding (Mukherjee and Singh, 2019). Similarly, flooding occurrences are also influenced by different climatic scenarios, especially precipitation characteristics (distribution, magnitude, intensity, and duration) and temperature patterns (Bates *et al*., 2008). Flooding may thus be attributed to the characteristics of the climatic system and increasing urban-oriented developmental activities.

Floods are known to be the most frequently encountered natural disaster with severe impacts on the lives and properties of the people (Aderogba, 2012). Between 1945 and 1986, the study of Glickman *et al*. (1992) revealed that flooding accounted for about 30% of all global disasters, while a much more recent study by Komolafe *et al*. (2018) reported that flood constitutes more than 40% of all natural disasters between 1985 and 2009, causing severe harm in terms of economic loss and disaster victims. Furthermore, its catastrophes are the third deadliest geophysical or hydrological disaster, based on the number of fatalities recorded (Komolafe *et al*., 2019). For instance, between 1980 and 2013, over 220,000 lives were lost, and the global economic damages caused by floods exceeded US$1 trillion (Winsemius *et al*., 2016). In 2013 alone, floods cost the world more than US$50 billion (Wasko and Sharma, 2017), and the damages increased to approximately US$60 billion in 2016 (Aerts *et al*., 2018). In Nigeria, floods affected about 9.7 million Nigerians in 2012 alone, displacing 2 million people and negatively impacting the lives of others. More specifically, 363 lives were lost, over 5000 people were injured, and over 5900 houses were destroyed. The losses incurred as a result of the flood events in 2012 were estimated to be around US$16.9 billion (Nkwunonwo *et al*., 2015), making the 2012 flooding the most severe on record (Komolafe *et al*., 2020).

Damages resulting from flood events are engendered by the persistence, speed, and depth of floodwater and the amount of dissolved and suspended load carried by the floodwater. In addition, liquid and solid materials (raw sewage and other pollutants) travelling with floodwaters can negatively affect the flood-impacted area, often causing severe health risks (Kundezewicz, 2019). Different studies widely acknowledge that climate change impact, especially sea-level rise and shifting rainfall patterns, in combination with poor land use planning and increased urbanisation, will increase flood frequency and intensity in the future. Thereby causing more unfavourable impacts on the economy, environment, and human life (Birkmann *et al*., 2012, Asian Development Bank, 2015, Abdullah *et al*., 2021), especially in many low-lying cities (Kulp and Strauss, 2019).

Amidst these challenges, GIS, in conjunction with remote sensing and multicriteria decision analysis (MCDA), provides a platform for flood disaster assessment and management at all stages, from planning to response and recovery. According to Voogd (1983), multicriteria decision-making is a decision support tool that describes a set of strategies for constructing and assessing alternatives based on numerous criteria and objectives. The weights of the criteria are significant, and their meaning varies depending on the context of decision-making and the multicriteria analysis methodologies used (Kafle and Shakya, 2018). MCDA has been effectively used to identify optimal solutions to mitigate flood vulnerability s, thus helping efficient and effective allocation of available resources (Malekian and Azarnivand, 2015; Ghanbarpour *et al*., 2013) and building community resilience (Otokiti *et al*., 2019).

As one of the 14 coastal megacities in the world, Lagos ranks among the top 20 regions of the world with the greatest exposure to flood vulnerability (Sojobi *et al*., 2016). It is marked by explosive population growth, unplanned urbanisation, unregulated wetland reclamation, drainage channel encroachment, sand filling of lagoon shores, and uncontrolled deforestation (Abegunde, 1988). Furthermore, more than 54% of its developed area has no drainage networks, while the existing ones lack adequate maintenance (Ede *et al*., 2016). Again, about 68% (2,432km^2) of the total land area (3,577km^2) is either covered with swamp and water body or is a floodplain (Fashae and Onafeso, 2011). These characteristics contribute to the increasing flood occurrences in Lagos. In agreement, the Federal Ministry of Environment (2012) asserts that Lagos experiences more frequent destructive flooding events than other regions in Nigeria (Federal Ministry of Environment, 2012). Within this context, the present study attempts to map out probable flood vulnerable areas in the core area of Lagos using geospatial methods and MCDA to support current and future urban planning policies, the development of preparedness plans, and the provision of flood control infrastructure.

Study Area

Lagos, the most densely populated region in Nigeria, is located approximately between latitude 6° 22′ N to 6° 52′ N and longitudes 2° 42' E and 3° 42' E. It occupies 0.4% (3,577km^2) of Nigeria's total landmass of 923,773km^2. On the north and east, it is bordered by Ogun State in Nigeria, the Republic of Benin in the west, and the Guinea Coast of Bight of Benin in the south, where it stretches over a distance of more than 180 kilometres. Lagos is characterised by two climatic seasons: dry (November-March) and wet (April-October). The study area is vulnerable to flooding and other climate-related risks due to its physical, topographical, and locational characteristics (Adeniran *et al*., 2020).

The primary focus of this study is the core of Lagos State, a highly developed region, crisscrossed by water bodies and comprising of five Local Government Areas namely; Lagos Island, Lagos Mainland, Surulere, Apapa, and Eti-Osa (Figure 1). The study area's elevation ranges from 0 to 52 metres above mean sea level. The Lagos core was selected due to the events of flood and losses that have occurred there in time past.

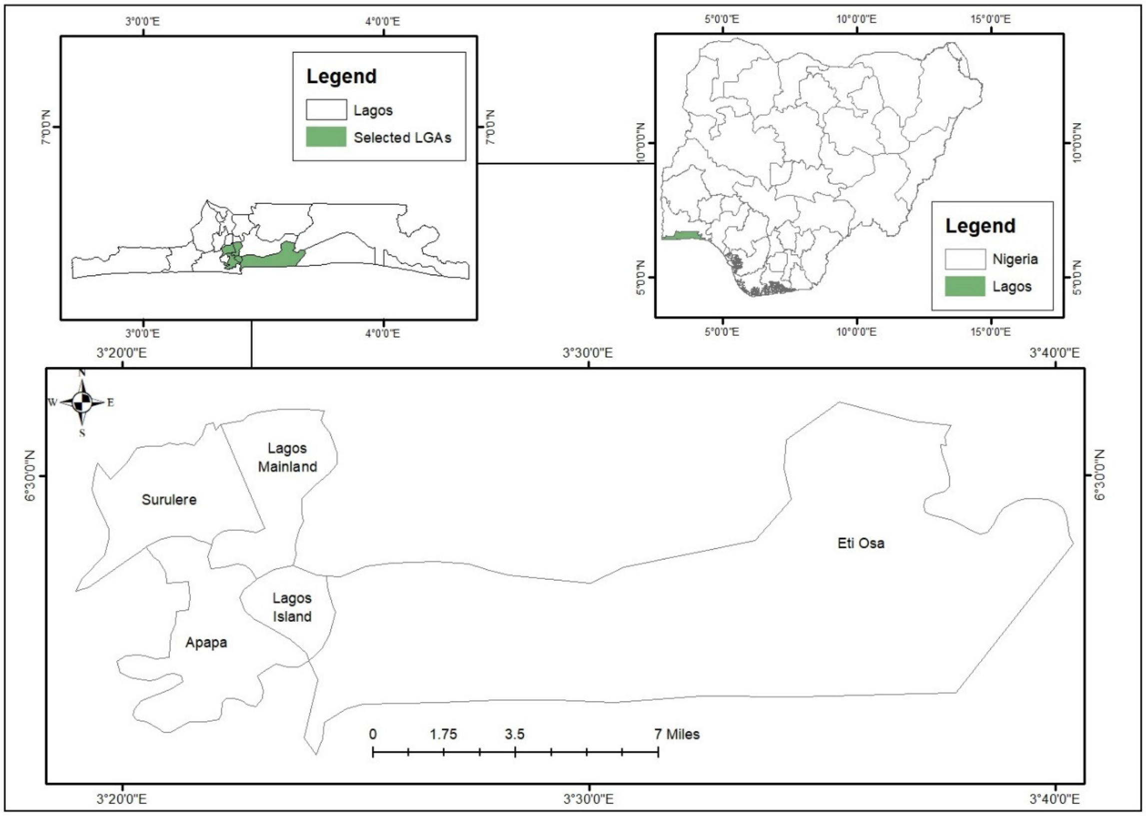

Fig. 1: Study Area Map

Methodology

The use of MCDA and weighted overlay for flood zonation mapping involves integrating several parameters to derive an optimal result (Ghanbarpour *et al*., 2013). The use of multiple parameters is based on the premise that the occurrence of a flood event is not caused by a single factor or two (Otokiti *et al*., 2019). Hence, drawing on existing studies (Krouska and Parcharidis, 2014; Raji *et al*., 2014; Mmom and Ayakpo, 2014; Cao *et al*., 2016; Das, 2019), a total of seven thematic layers (parameters) were selected for this study including, land cover, Normalized Difference Water Index (NDWI), flow accumulation, elevation, drainage density, slope, and curvature. On the one hand, slope, flow accumulation, drainage density, and curvature thematic layers were generated from the Shuttle Radar Topographic Mission (SRTM) data using Spatial Analyst tools. On the other hand, the land cover thematic layer was generated from Sentinel-2 images. The Sentinel-2 images and SRTM data were downloaded from the United States Geological Survey (USGS) portal and processed in ArcMap 10.5.

In effect, a simple rating scale ranging from 1 (very low) to 5 (very high) and weights (Table 1) were assigned to each parameter based on how they influence water permeability, surface water flow, and human vulnerability (Mwangi, 2016). Finally, the parameters' weighted and rating values were aggregated to delineate probable flood vulnerable areas in the

Lagos core. The equal interval classification method was used to classify the vulnerable zones of the flood vulnerability map.

Table 1: Flood influencing factors and ranking

Thematic layer	Class	Rank	Flood vulnerability	Weight (%)
Elevation	0 – 10.4	5	Very high	20
	10.5 – 20.8	4	High	
	20.9 – 31.2	3	Moderate	
	31.3 – 41.6	2	Low	
	41.7 - 52	1	Very low	
Land cover	Waterbody	5	Very high	25
	Built-up	4	High	
	Disturbed forest	3	Moderate	
	Undisturbed forest	2	Low	
Slope (Degree)	0 – 6.8	5	Very high	20
	6.9 – 13.5	4	High	
	13.6 – 20.3	3	Moderate	
	20.4 – 27.1	2	Low	
	27.2 – 33.8	1	Very low	
Flow Accumulation	333,813.7– 417,267	5	Very high	5
	250,360.3– 333,813.6	4	High	
	166,906.9– 250,360.2	3	Moderate	
	83,453.5– 166,906.8	2	Low	
	0 – 83,453.4	1	Very low	
Drainage Density (km/km^2)	16.2 – 22.8	5	Very high	15
	20.9 – 29.5	4	High	
	29.6 – 36.1	3	Moderate	
	36.2 – 42.7	2	Low	
	42.8 – 49.4	1	Very low	
Normalised Difference Water Index (NDWI)	0.13 – 0.24	5	Very high	10
	0.01 – 0.12	4	High	
	-0.12 - -0	3	Moderate	
	-0.24 - -0.13	2	Low	
	-0.37 – -0.25	1	Very low	
Curvature	7.2 – 10.5	5	Very high	5
	3.8 – 7.1	4	High	
	0.4 – 3.7	3	Moderate	
	-3.1 – 0.3	2	Low	
	-6.6 – -3.2	1	Very low	

Result and Discussion

Flood Inducing Factors

Due to the lack of a consensus on which factors to be considered in flood vulnerability mapping (Tehrany *et al.*, 2014), the selection of flood causative factors for this study is based mainly on recent studies and experts' opinions. To that effect, curvature, land cover type, elevation, drainage density, slope, NDWI, and flow accumulation were selected based on their contribution in flood occurrences at different locations as indicated by several studies (Shivaprasad *et al*., 2018; Ugoyibo *et al*., 2017; Njoku *et al*., 2020). It is, however, of critical importance to understand their respective roles in flood vulnerability.

Slope (S)

As a significant terrain feature, slope affects flood vulnerability due to its role in determining vertical surface percolation and runoff velocity (Omid *et al*., 2016). In a typical flood event, floodwater flowing from hilly areas accumulates in low-lying areas with gentle slopes. In effect, low-lying areas become more susceptible to flooding. Therefore, the slope of the research locale was grouped into five risk categories, namely, Very high (0 - 6.8°), High (6.9 - 13.5°), Moderate (13.6 - 20.3°), Low (20.4 - 27.1°), and Very low (27.2 - 33.8°), respectively (Table 1). However, it could be observed from Figure 2 that the study area is primarily a low slope region (0 - 6.8°), and such areas were depicted as very high flood susceptible areas.

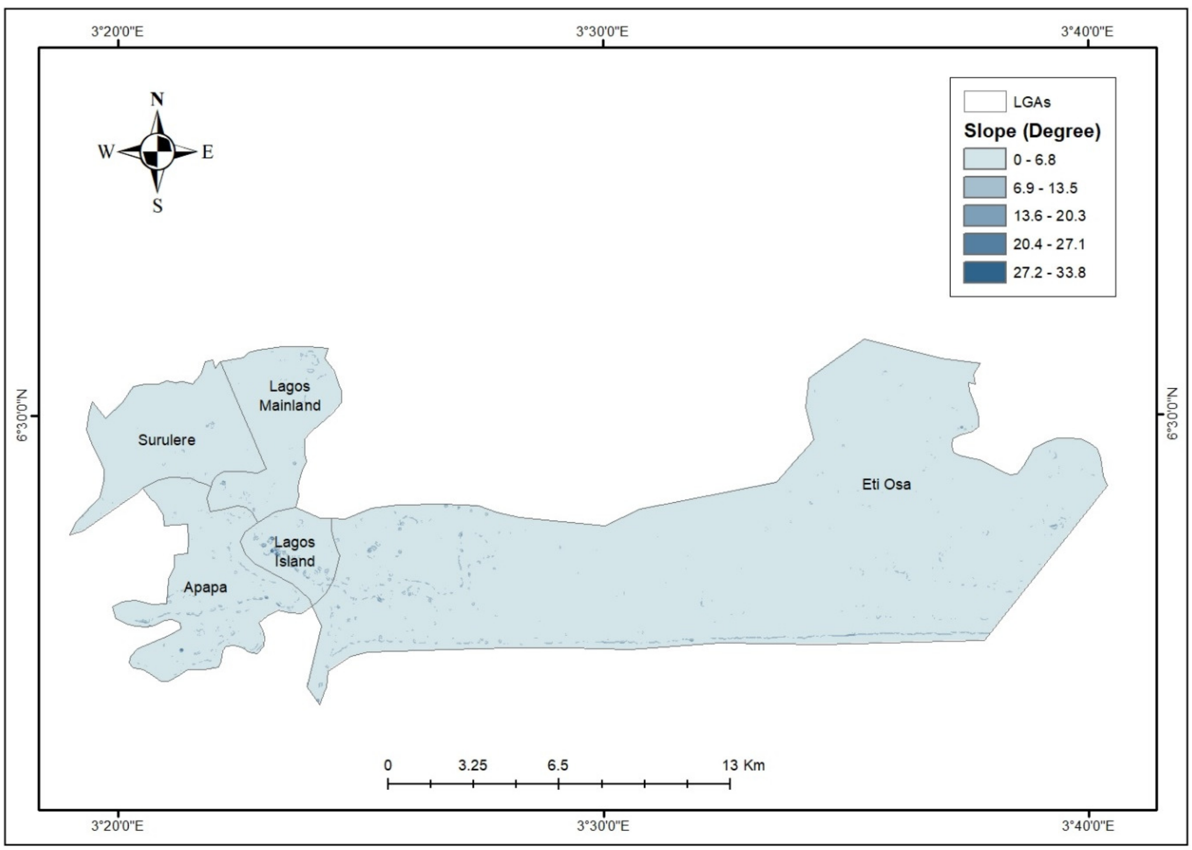

Fig. 2: Slope Map

Elevation

The elevation is one of the topographical factors that influence the occurrences of a flood event. Therefore, areas with low elevation are usually at higher risk of flooding compared to areas with higher elevation. Elevation of the study area is categorised into five classes as 0 – 10.4m, 10.5 – 20.8m, 20.8 – 31.2m, 31.3 – 41.6m, and 41.7 – 52m (Figure 3). The elevation map (Figure 3) indicates that the most extensive portion of the study area belongs to the low elevation class (0 – 10.4m). Accordingly, the low elevation class implies very high flood vulnerability since they are more likely to be inundated by floodwaters than areas at higher elevations.

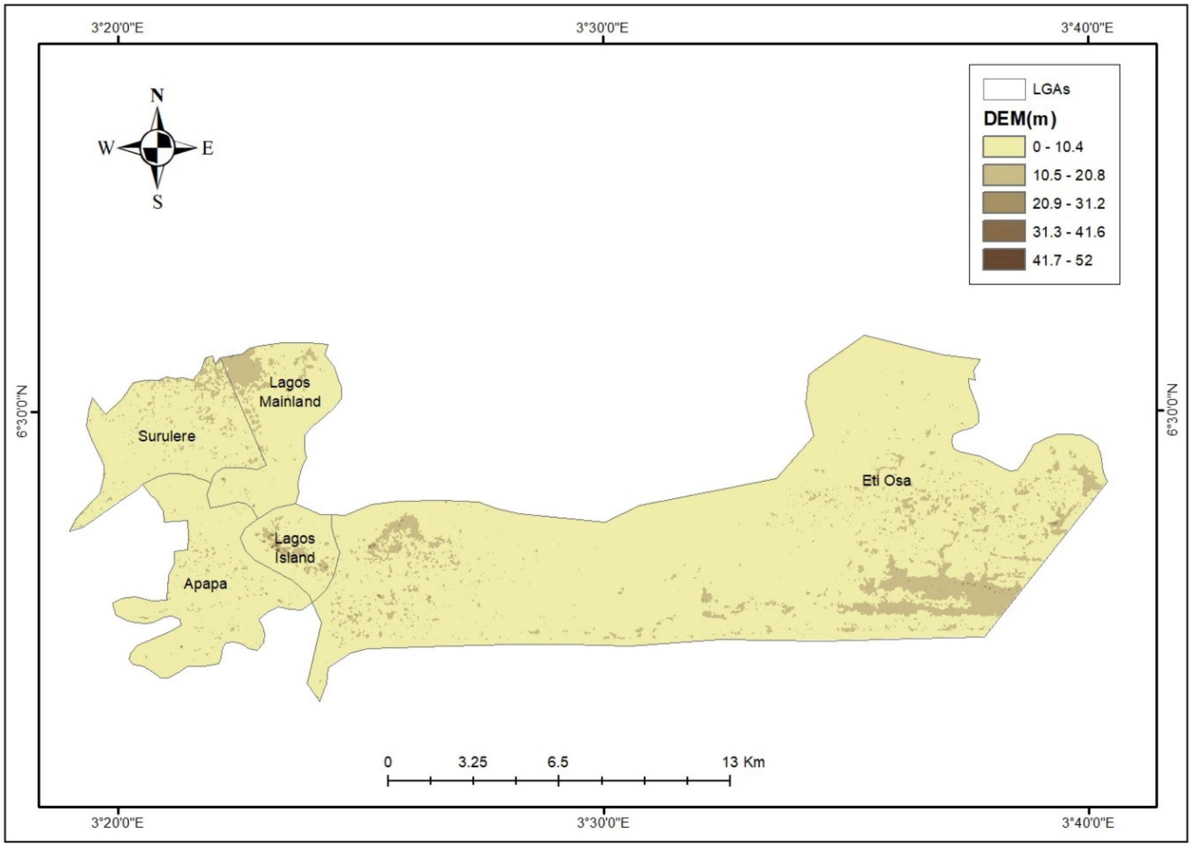

Fig. 3: Elevation Map

Land Cover

Amongst the flood-inducing factors examined in this study, the land cover was assigned the highest weight (Table 1) due to its dominant role in controlling the hydrological process. The resulting map identified four land cover categories, including waterbody, built-up, disturbed forest, and undisturbed forest, and determined (Figure 4). Built-up comprises 197.64km^2, and disturbed forest covers about 53.4km^2, while waterbody and undisturbed forest constitute 16.3km^2 and 0.63km^2, respectively. Based on the flood vulnerability ranking, the study depicted waterbody as very high, while the undisturbed forest is considered low-risk.

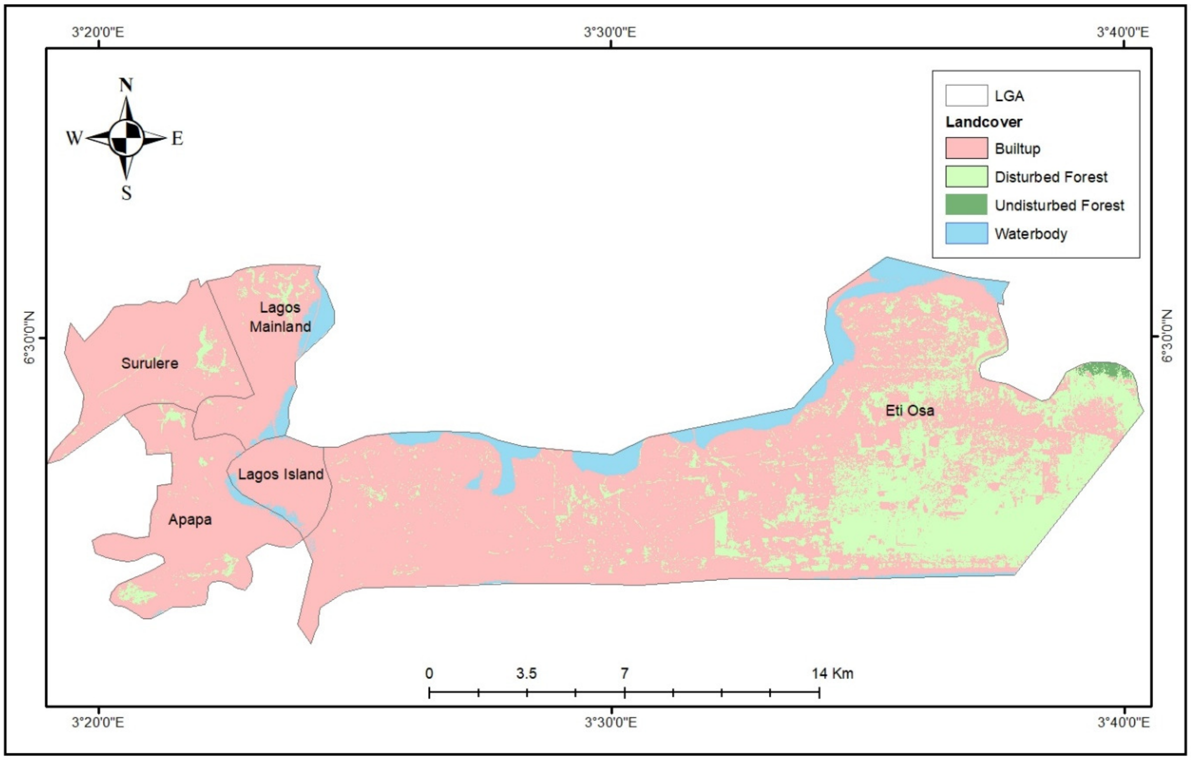

Fig. 4: Land Cover Map

Flow Accumulation

The flow accumulation determines the level of land surface flow concentration. Increased flow accumulation usually coincides with increased flood vulnerability (Lehner *et al*., 2006). Resultantly, flood vulnerability of urban infrastructure and housing situated in areas marked by high flow accumulation is high. The flow accumulation map values were categorised into five risk classes: very high (0 – 83,453.4 pixels) and very low (333,813.7 – 417,267 pixels).

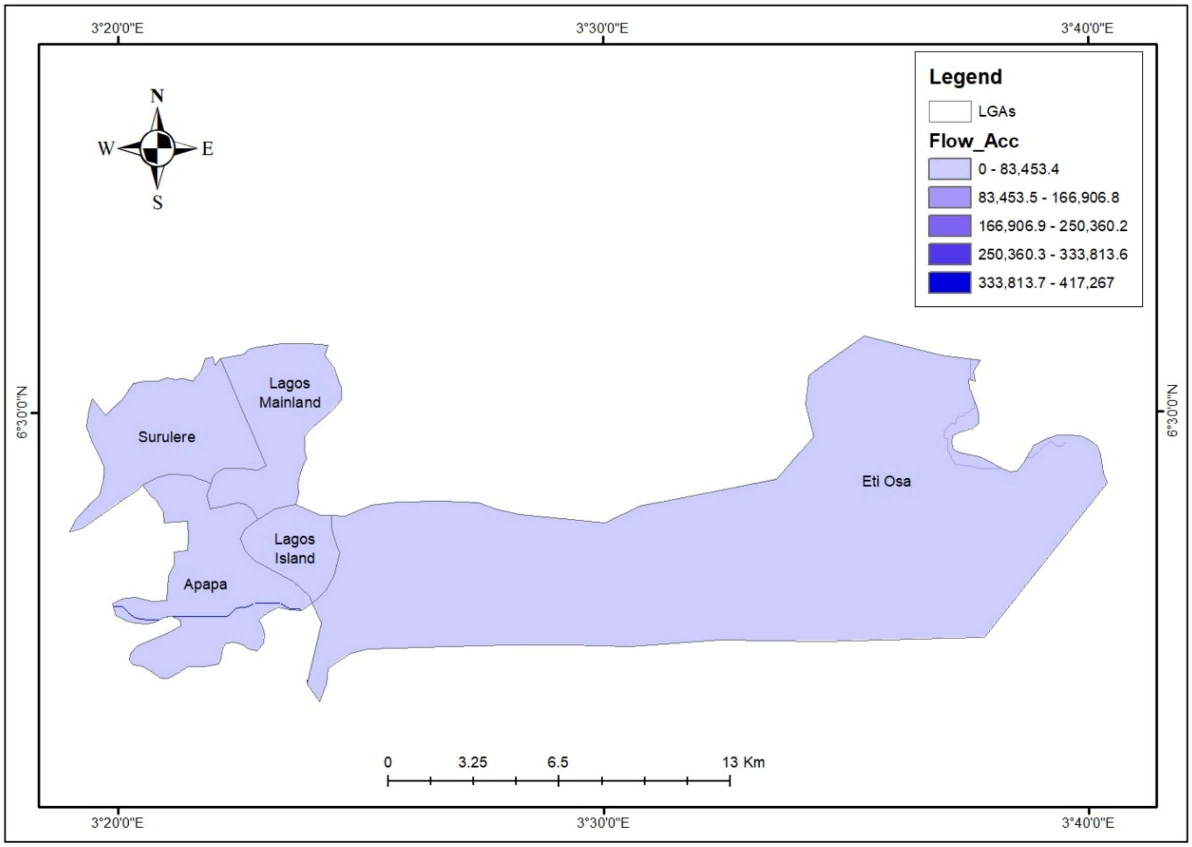

Fig. 5: Flow Accumulation Map

NDWI

The NDWI map was used to understand water-bearing and non-water bearing features in the study area. This, in turn, helps identify areas susceptible to flooding (Raji et al., 2014). Thus, NDWI is a key to flood vulnerability mapping. The NDWI map (Figure 6) was extracted using McFeeters's (1996) equation, which was given as:

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

The classification of the NDWI for the study area ranged between -0.37 and 0.24 and was divided into five distinctive categories, where areas between 0.11 – 0.24 class are very high zones (Table 1).

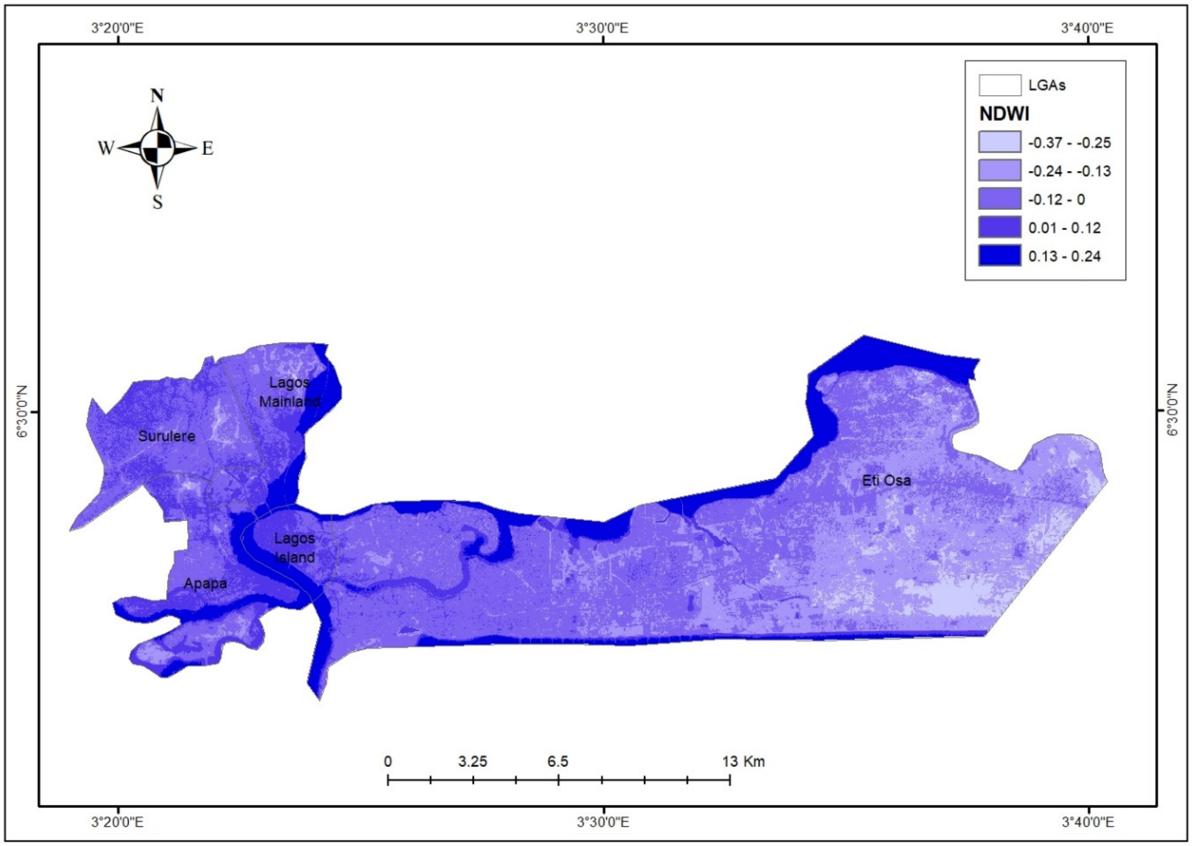

Fig. 6: NDWI Map

Curvature

The topographic curvature of an area significantly influences the infiltration process and land surface runoff (Cao *et al*., 2016). Hence, the curvature of a place is a critical factor in flood vulnerability mapping. The curvature of the Lagos core was classified as very low (-6.6 - -3.2), low (-3.1 - 0.3), moderate (0.4 – 3.7), high (3.8 – 7.1), and very high (7.2 – 10.5).

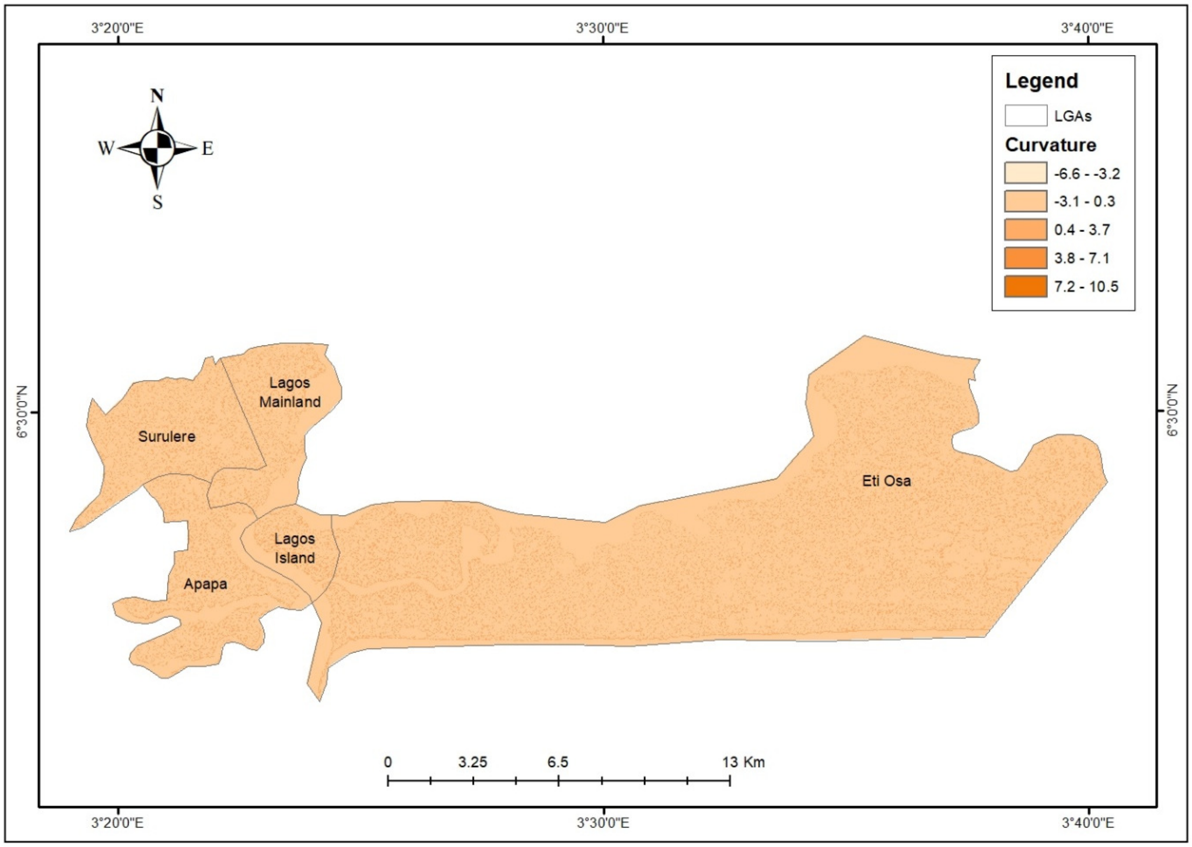

Fig. 7: Curvature Map

Drainage Density

Drainage density is included as part of the thematic layers used to determine areas probable to flooding because of its ability to describe the nature of the soil and its geotechnical properties such as permeability and infiltration capacity (Das, 2019). High drainage density contributes to greater surface runoff and thus increases flood vulnerability (Otokiti *et al*., 2019). The map revealed that the drainage density of the study area is between 16.2km to 49.4km (Figure 8).

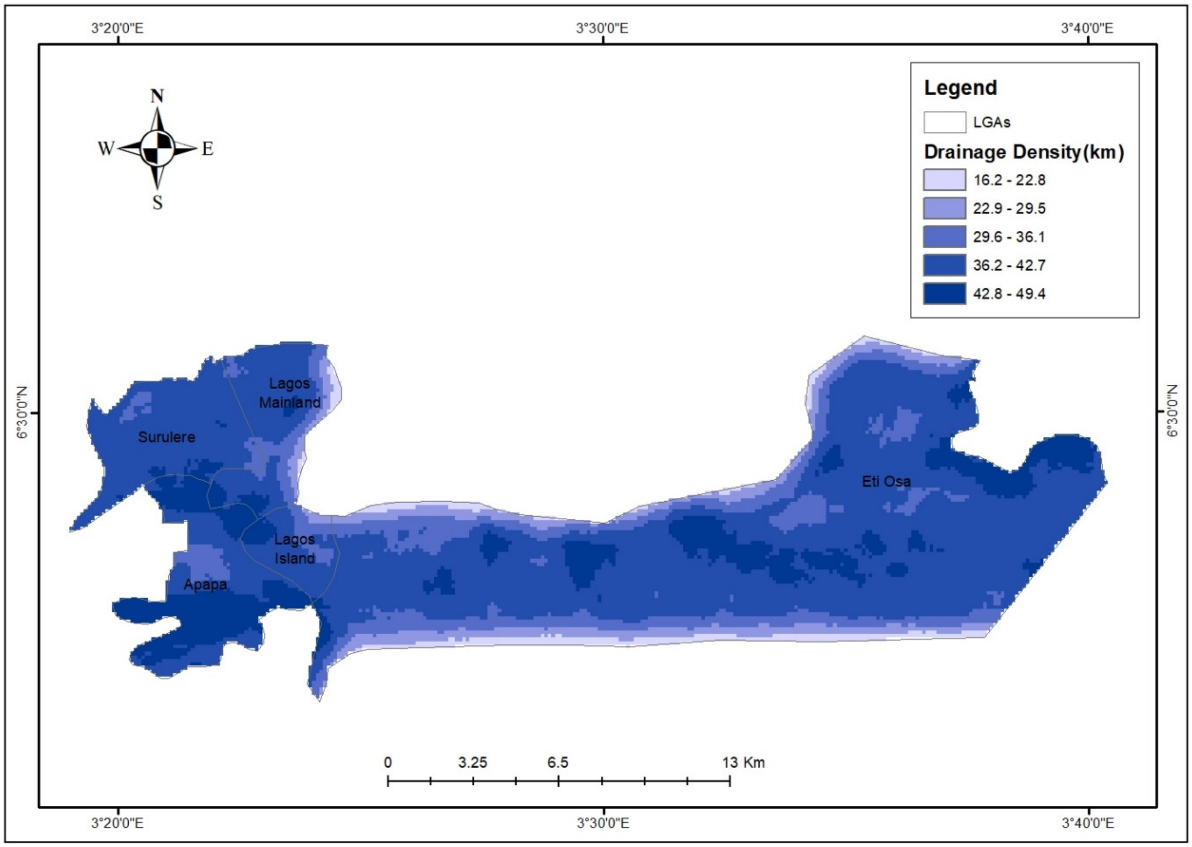

Fig. 8: Drainage Density Map

The flood vulnerability map was obtained by aggregating a broad set of flood-inducing factors, including curvature, land cover type, elevation, drainage density, slope, NDWI, and flow accumulation. The output is shown in Figure 9, and the calculated area of flood vulnerability zones and percentage share are presented in Table 2. Our findings revealed that the highest percentage share was recorded in the high class, occupying about 95.62% of the total area. The moderate class accounts for 2.75% of the Lagos core, while the very high class covers about 1.63%. These (High, Very High, and Moderate) equate to the total land area. By implication, flood vulnerability ranges from Moderate to Very High (Table 2). As such, no part of the study belongs to the low-risk and very low-risk classes.

The flood vulnerability map shows that Lagos core – a highly developed low-lying part of Lagos, Nigeria is acutely vulnerable to flood threats. Human lives, ecosystem services, economic activities, housing, public facilities, and infrastructure are particularly at risk in this context. This could be as attributed to adjacency to the Lagos lagoon in the south and Guinea Coast of Bight of Benin in the north. Other contributing factors are changing climate, frenetic urbanisation, dwindled proportion of undisturbed forest cover, and topographic features such as gentle slope and low elevation. These characteristics have been identified by Vignesh (2021) as critical factors contributing to and also acting as flood triggers in Tamil Nadu, India. A similar conclusion was also reported by Komolafe *et al*. (2020), who revealed that the proximity to water bodies, deforestation, and urbanisation are intimately linked with an increase in vulnerability to severe flooding in Eti-Osa and Lagos Island, which are situated in the Lagos core.

This study further confirms the reliability of MCDA in flood vulnerability mapping. However, it is essential to note that MCDA based on expert opinion and weighted overlay approach may be subjected to the researchers' bias, especially with respect to selecting and assigning weights to the flood-inducing factors. Hence, special attention should be given to selecting the best-fitting criteria for MCDA and the weighted overlay method.

Table 2: Distribution of Flood vulnerability classes

Rank	Flood Vulnerability	Land Area (Sq.km)	Percentage
3	Moderate	7.14	2.75
4	High	248.6	95.62
5	Very High	4.25	1.63
	Total	259.99	100

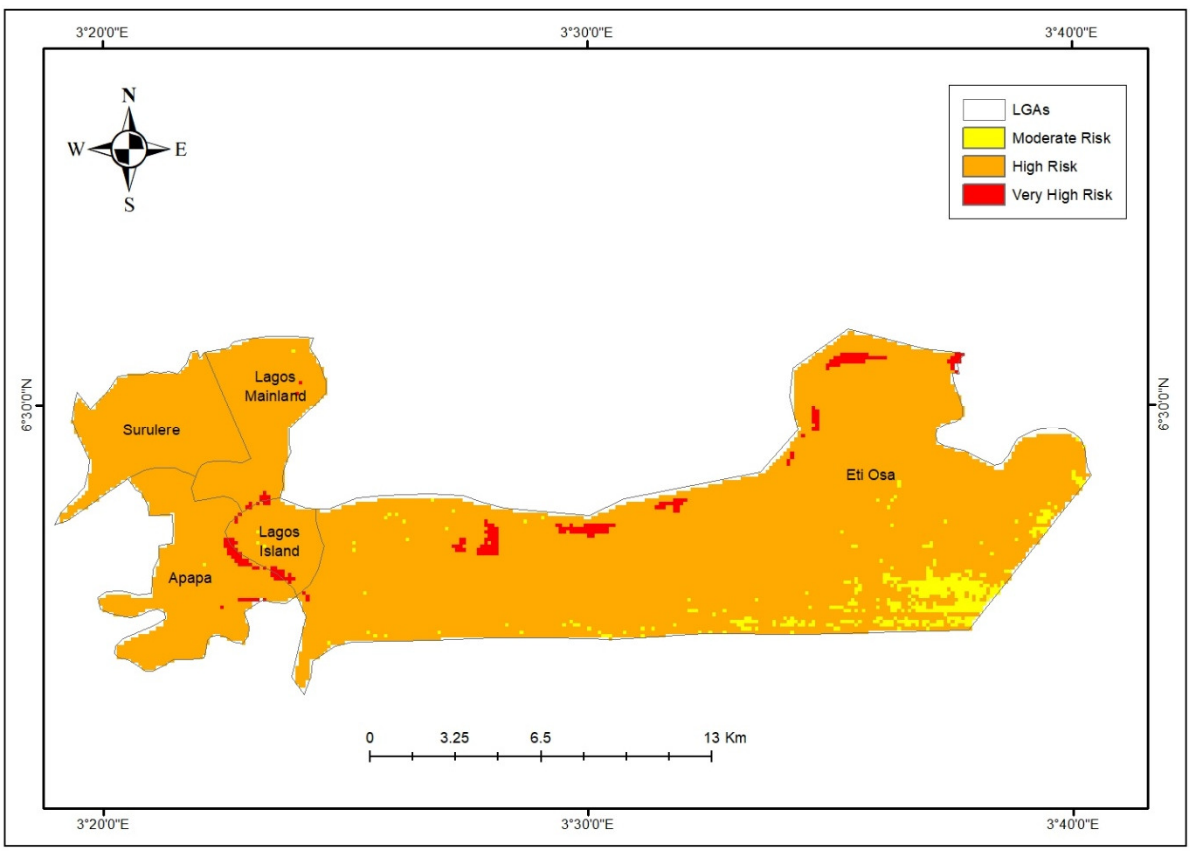

Fig. 9: Flood vulnerability Map

Conclusion

Flood vulnerability mapping is of critical relevance to policymaking, infrastructure planning and improvement, Urban planning practice, and public awareness and risk communication. In this study, the MCDA approach, which relies on several flood-inducing factors, was selected to investigate flood vulnerability in the Lagos core, highlighting the urgent need for the development of sustainable flood vulnerability management measures in the study area. Hence, the use of flood vulnerability maps must be encouraged to develop sustainable flood vulnerability management measures.

Considering the high class (95.62%) share in the study area, a flood event in the region may have severe implications for sustainable urban development. Hence, the study suggests the need for proactive flood vulnerability management actions rather than reactive measures to minimise the impact. Furthermore, further research should be encouraged in the study area, where more extensive flood vulnerability factors will be considered. Such studies could provide additional insights into flood vulnerability in the study area.

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