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GIS MULTI–CRITERIA ANALYSIS FOR FLOOD SUITABILITY WITHIN LOKOJA, AJAOKUTA, IBAJI AND IGALAMELA-ODOLU LOCAL GOVERNMENT AREAS OF KOGI STATE, NIGERIA.

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ABSTRACT

Floods are common natural disasters that affect many parts of the world. It has caused deaths and destruction of properties that are worth a lot of money. Floods have put natural biodiversity at risk and rendered millions of people homeless. With regard to the effects, this study aims to apply a GIS multi-criteria approach in determining the suitable sites for safety in the flood zones within the Lokoja, Ajaokuta, Bage, and Kuje areas of Kogi State. Identification of areas that can be prevented from being flooded is very important for effective flood management. The weighted overlay analysis approach with the input parameters including proximity to road, soil suitability, distance to major road and distance to minor road, slope suitability, TWI suitability, and elevation for flood modeling was applied in this study. For the purpose of analysis of these parameters, ArcGIS 10.5 software was used. The study's findings in relation to flooding indicate areas that are very highly, highly, moderately, lowly, and very lowly suitable for settlement. Following the study, it is recommended as a crucial measure that drainage systems and artificial levees be constructed along flood-prone areas to mitigate the effect of flooding in the study area. Additionally, dredging can be adopted as another preventive and corrective measure to prevent flooding in the study area.

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1. Introduction:

Floods represent one of the most frequent and widespread environmental hazards of different kinds and magnitudes (Gleeson et al. 2012; Betts et al. 2017). They have caused severe damage and disruption to economic activities, businesses, infrastructure, services, and public health (Messager et al. 2016; Omondi et al. 2014), floods are considered natural hazards that occur in extreme hydrological (runoff) events. Floods are regarded as natural phenomena causing the temporary submerging with water of a land that does not occur in normal circumstances (Omondi et al. 2014; Abdi, 2020). One of the most common and widespread environmental hazards in the world, floods come in many different forms and sizes (Sanyal, 2004). They have caused serious harm and disruption to businesses, infrastructure, services, public health, and economic activities (Omondi et al. 2014; Abdi, 2020). Floods are defined as natural hazards occurring as extreme hydrological (runoff) events. They are defined as natural events that cause the temporary submerging with water of a land that does not occur under normal conditions (Omondi et al. 2014; Abdi, 2020).

Flooding is the accumulation of excess water that rises and overflows the land that is not normally submerged (Betts et al. 2017). This includes overflow from water bodies such as rivers, lakes, and seas as well as overflow from heavy rainfall, snowmelt, and dam breaks, in which water escapes out of its natural boundaries (Betts et al. 2017; Cretaux et al. 2016). Flooding is rated as one of the most devastating natural hazards, which leads to significant economic and social damages compared to any other natural phenomenon (Gleeson et al. 2012; Betts et al. 2017) A flood is a hazard that results from extreme meteorological events, including heavy rainfall, causing rivers and oceans to overflow their banks and can have far-reaching effects on the people and the environment (Ma et al. 2014; UN 2018).. It can also be caused by convectional or frontal storms whereby a lot of rainfall is experienced in a short duration of time. Ajaykumar et al. (2021)`stated that intensity and duration of rainfall are the most influencing factors for flood hazard. Globally, several flood cases have been documented. Disasters caused by flooding have also been experienced in many developing countries, such as Nigeria, Bangladesh, Pakistan, and Nepal. According to Zhou et al. 2013;), over 125 deaths have been reported, and millions of people displaced as a result of recent flooding incidents in developing countries, especially those that occurred in places like Bihar, Uttar Pradesh, and Assam. According to Ichangi and Makokha (2017), flooding is an event whose impacts could be minimized or avoided through construction of dams and flood defenses or using advanced technology.

Flooding has brought about destruction in livelihoods and properties that have been estimated to cost millions of naira in Nigeria. This has occurred after heavy rainfall, drainage obstructions, and breakdowns in the dam structure (UN 2015; Rokini et al. 2104). Flooding is a frequent phenomenon in Nigeria, particularly urban flooding, which takes place in towns, flat, and low lands where there is minimal or no arrangement for surface drainage or where there are obstructions in the drainage from refuse and soil erosion materials (;Adiat and Abdullah (2012); Milles et al. (2017); Okeke and Nwokolo (2008). Flooding in Nigeria traces its first incidence to 1963 in the city of Ibadan when the Ogunpa River overflowed, leading to huge damages to both life and property (Beshir et al. 2023; Kar et al. 2015). Since then, there has been an increase in the incidences of flooding throughout the country. According to a report issued by the National Emergency Management Agency in 2012, more than 1.3 million people in Nigeria were displaced due to floods, while 431 people died from floods in different states. In the same year, almost 30 Nigerian states were affected by floods (Pradhan et al. 2014). Some of the states that were badly affected by floods include Kano, Niger, Jigawa, Kaduna, Adamawa, Benue, Kogi, and some parts of southern Nigeria (Rejani et al. 2017; Rizeei et al. 2016). Kogi State has been identified as one of the most affected states in Nigeria because of its situation at the junction of the nation's main rivers (River Niger and Benue). The state experienced a flood disaster in 2012 and 2018 that destroyed many hectares of farmland, caused loss of livestock, and also affected aquatic life. Flooding in Kogi State was due to the release of water from Ladgo Dam into River Benue, while Shiroro and Kanji Dams release water into River Niger as well as climate change (Singh et al. 2015; Stefanidis and Stathis (2013). It has been found by various scientists that there are possibilities that climate change will be the reason for changing the pattern of floods globally, increasing the risk of populations to severe flooding, and the effect of climate extreme changes will affect more in the future (Tehrany et al. 2013; Egboka et al. 2006)

Remote sensing and GIS are two technologies that have been noted to be efficient in providing flood maps, models, and management due to the provision of data concerning the geographic location, pattern, and dynamics

of floods (Enoh et al. 2021; Sun et al. 2023). The technology of remote sensing provides current and credible data on environmental changes, spread of water surfaces, effect of rainfall, terrain features, and the extent of the floods over vast geographic locations, thus making it helpful in the detection and impact assessment of floods (Enoh et al. 2023). Similarly, GIS is a tool through which spatial data such as elevation, drainage, land cover, soil features, and climate are integrated and analyzed to create flood vulnerability and risk maps (Kadam et al. 2018; Pelorosso et al. 2021). Nevertheless, there has been a lag on the part of Nigeria in adopting remote sensing and GIS technology in assessing floods and managing them. The problem of pinpointing flood-prone areas, setting up early warning systems, and managing flood problems has faced challenges (Tariq et al. 2022). Several severe floods that have occurred recently and have affected more than 23 states have led to death, destruction of property, displacement of people, and environmental disturbances. Hence, it is necessary to integrate remote sensing, GIS, and modeling technologies to solve flood problems in Nigeria (Cook (2016); Ghorbanzadeh et al. 2013)

2. The study area

The study location encompasses Lokoja–Ajaokuta–Ibaji–Idah in Kogi State, Nigeria, within the Lower Niger River Basin. The area lies between latitudes 6°30′N–8°00′N and longitudes 5°50′E–7°30′E in the Niger–Benue confluence area and is found to play a great role in defining its hydrology and environment (Figure 1) (Ghorbanzadeh et al. 2013; Thapa et al. 2017). This is made up of varied landforms like river courses, floodplains, wetlands, alluvial plains, agriculture areas, and industrial lands, with varied elevations from uplands in Lokoja and Ajaokuta to lowlands in Ibaji and Idah. The study location experiences a tropical wet and dry climate with rainfall occurring from April to October, where there is usually flooding due to heavy rainfall, river inundation, and surface runoff, mainly in areas that are low-lying and poorly drained. This is brought about by various factors like rainfall intensity, altitude, slope, drainage density, soil characteristics, and human activity. Due to its varied nature of being both urban and fluvial, this location is ideal for studying flood susceptibility using GIS, remote sensing, the analytical hierarchy process (AHP), and machine learning approaches (Teferi et al. 2013; Toure et al. 2018)

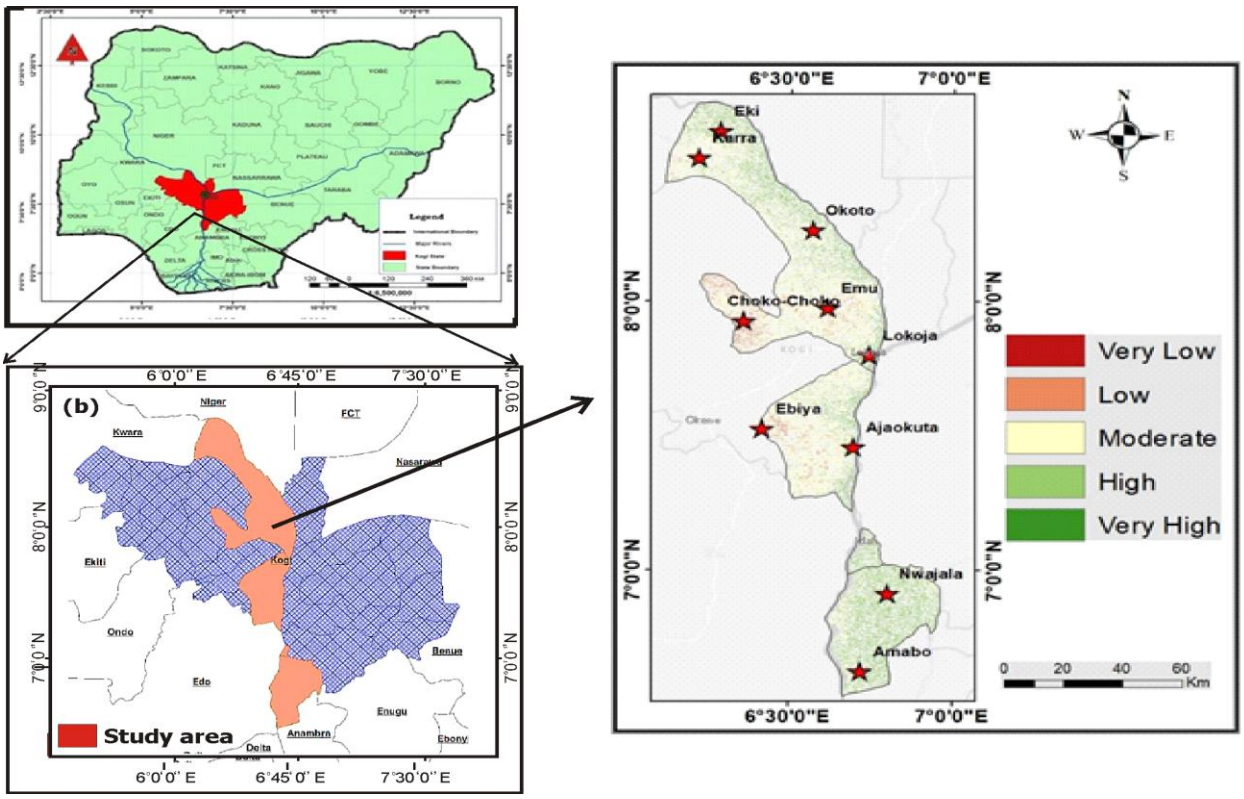


Figure 1; Map of: (a) Nigeria; (b) Kogi state; (c) the study area

3. Materials and Methods

This section discusses data gathering, its sources, method of gathering, process of analyzing, and instruments utilized in the gathering of data.

3.1: Data acquisition and their sources

i. Data collected for this study were both primary and secondary sources (see Table 1). The primary data sources made use of the GPS receiver to collect coordinates of the flood-prone areas in the study area. A digital camera was used to take photographs of the flood-prone areas. Besides the primary data sources, the following data from secondary sources were collected:
ii. Landsat 9 OTI/LIRS was collected from the United States Geological Survey (USGS) at paths and rows of 189/55. These data with a spatial resolution of 30 m were used for generating a land use and land cover map of the study area.
iii. ASTER DEM was collected from USGS for generating a slope map, elevation map, and drainage map of the study area;
iv. The soil map was collected from the Kogi State Ministry of Agriculture. This map provided soil information in the study area.
v. Rainfall data was collected from the Nigeria Meteorological Agency (NIMET), Kogi State. These data were collected to provide information on the rainfall pattern in the study area.
vi. A Google Earth image of flood-prone areas was collected from Google Earth, 2024.

Table 1: Data Source and Data Acquisition

Data	Data Source	Data Source types	Year acquired
Landsat 9 OTI/LIRS	USGS	Secondary	2024
ASTER DEM	GLCF	Secondary	2024
Soil Map	Ministry of Agriculture, Kogi State.	Secondary	2024
Photographs	Field Work	Primary	2024
GPS - coordinates	Field Work	Primary	2024
Rainfall data	NIMET	Secondary	2024
Google Earth Image	Google Earth	Secondary	2024

3.2: Ground trothing information and Field studies

For this study, field observation was undertaken to confirm the extent of flooding that is detected through satellite images of the study area. The devices used in the field observations included a digital camera, GPS device, hard copies of satellite images and the base map for delineation of flooded areas. The road was the mode of transport. Pictures from the flooded areas and the GPS coordinates of the floods were obtained and mapped for emergency purposes.

3.3: Terrain analysis of the study area

Information about the terrain enables us to have an accurate understanding of the flow direction of the water because of gravity. In the Digital Elevation Model (DEM) technique, all sinks were filled for the development of the flow direction grid model. The flow direction grid model of the study area was developed through the Digital Elevation Model (DEM), while the flow accumulation grid of surface water was developed through the flow direction grid model in ArcGIS 10.5 software.

3.4 Processing of the Data

This research was based on a multi-criteria evaluation approach. The zonation process was done with parameter inputs such as proximity to the river, elevation, land use/land cover, slope, and soil.

3.4.1 Flood-Related Factors for Settlement Suitability

These factors are essential for evaluating the flood risks in a particular area and, hence, the suitability of such an area for human habitation. Areas with higher chances of flooding are less suitable for habitation as compared to areas with low chances of flooding (Gleeson et al. 2012; Omondi et al. 2014).

3.4.1.1 Elevation: Elevation is one important factor since areas at lower elevations are likely to suffer from flooding, considering that water always moves from a higher to a lower elevation. Areas with a higher elevation will be less vulnerable to floods and therefore ideal for settlement Abdi (2020); Betts et al. 2017.

3.4.1.2 TWI (Topographic Wetness Index): TWI is an indication of the moisture content in a catchment area, as well as places where water will accumulate. High values of TWI imply high vulnerability to floods/water logging and will therefore not be suitable for settlement (Cretaux et al. 2016; Ma et al. 2014).

3.4.1.3 Distance from major and minor rivers: One of the main criteria of flood risk is the distance from a river. Closer locations to a river will be more vulnerable to flooding, particularly when there is heavy discharge in the river. With increasing distance from a river, the risk of flooding decreases (Cretaux et al. 2016).

3.4.1.4 Proximity of road: Roadways play an important role in determining water flow and runoff. Improperly built or poorly situated roads can serve as an obstacle to water flow or water channels, leading to increased chances of flooding in certain areas. In addition, current settlements are frequently located within vicinities of major roads due to ease of transportation and connectivity. Areas without access to roads are usually avoided for any developmental purpose (Cretaux et al. 2016).

3.4.1.5 Slope: The slope affects the speed of water flow. Areas having steeper slopes have faster runoff, thus, chances of water accumulation or flooding decrease. Areas with flatter slopes will have chances of flooding since the water flows at a slower pace in them and also gets accumulated.

3.4.1.6 Proximity to existing settlement areas: Proximity to current settlement areas is usually taken into consideration in case of planning for easy access to resources etc. But in case of floods, it can mean that the new area chosen also has the same vulnerabilities unless certain preventive actions are taken (UN, 2018 Ajaykumar et al. 2021).

3.4.1.7 Soil suitability: The type of soil determines how much water can be infiltrated into the ground. The highly permeable soils, like sandy soils, will facilitate fast infiltration, thereby reducing surface runoff, while poorly permeable soils, such as clay soils, will encourage surface runoff (Ajaykumar et al. 2021)

3.5 Weighted Overlay Analysis

Flood Susceptibility Mapping Using Weighted Overlay Analysis refers to the GIS-based methodology that involves the utilization of various spatial factors in order to determine areas at risk of flooding. In this methodology, various factors such as elevation, Topographic Wetness Index (TWI), slope, distance to rivers and roads, land use/land cover, and soil properties are initially created as separate thematic maps in the GIS software (Teferi et al. 2013; Toure et al. 2018). The factors are normalized, and each of them is given a weight based on their significance in causing floods. Afterward, the weighted thematic maps are combined in order to generate a final flood susceptibility map. The final map categorizes the study area into various susceptibility zones, usually from highly susceptible to least susceptible (Congalton and Green, 2017)

4. Results

Tables (a-g) show the spatial distribution of suitability classes for various factors that affect settlement formation within the study area. The five suitability levels assigned to each factor (Very Low to Very High) were determined according to the level of contribution of each factor to safety or danger to settlements due to floods and accessibility.

4.1 Road Proximity

The road factor reveals a high level of clustering in the medium (29.50%) and high (33.58%) suitability categories, implying that most of the region is adequately connected through road networks. This implies that accessibility is favorable, leading to favorable conditions for settlements and economic activities. Very low suitability levels (5.66%) reveal few regions that are poorly connected through roads.

4.2 Soil Suitability

The suitability of the soil is very favorable, with high (49.95%) and very high (32.89%) classes occupying the greater proportion of the land. It implies that the soil is well suited for construction in most of the area under study. A very small percentage (0.18%) of the area is highly unsuitable for construction.

4.3 Distance to Major Roads

The distance from the main road criterion shows that a considerable share of the study area is assigned as very low (42.44%) and low (22.60%) suitability. Accordingly, many places are at distances from the network of main roads, which makes their accessibility lower. Consequently, the settlements there are not very suitable for development. Places with very high (7.06%) and high (10.01%) suitability constitute a smaller share of the study area, meaning that places with good access to main roads are few.

4.4 Distance to Minor Roads

As in the case of major roads, the accessibility of minor roads is also inconsistent. Very low (33.32%) and low (27.24%) suitability classes are predominant. This means that there is a large extent of area which is poorly accessible from minor road networks. Nevertheless, there are moderate to very high suitability classes as well.

4.5 Slope Suitability

The slope criteria appear to be conducive for the development of the study area, where the medium class accounts for the maximum share (54.24%), followed by highly suitable criteria (32.68%). This means that the study area consists of mostly gentle and moderate slopes that are good for construction purposes, while very steep slopes form just 2.06% of the total area.

4.6 Suitability of Topographic Wetness Index (TWI)

TWI suitability output is evenly distributed with high suitability classes (32.31%) and very high suitability classes (29.05%), showing that most of the locations are moderately drained. But it is also complemented by moderate suitability (23.66%) and low suitability (11.37%), indicating variable moisture storage capacity of the surface and susceptibility to floods.

4.7 Suitability of Elevation

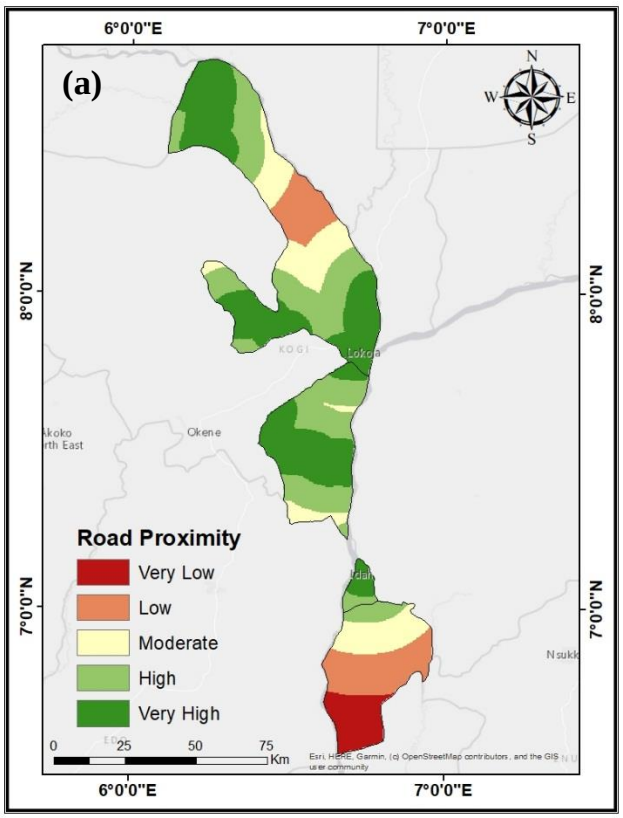
Suitability of elevation is quite restrictive with very low suitability class (45.93%) as the major suitability class, followed by low suitability class (21.99%). It indicates that the study area consists of mostly low elevations, which are generally vulnerable to floods. There are only a few locations with high suitability class (6.80%) and very high suitability class (7.83%).

Figure 2(a)-(g) highlight the flood settlement suitability maps

Table 2: Area and percentage for final settlement suitability

(a) Road proximity			
S/N	**Suitability**	**Area (km2)**	**Percentage (%)**
1	Very low	342.981	5.6611
2	Low	874.204	14.429
3	Moderate	1019.95	16.835
4	High	1786.98	29.495
5	Very High	2034.39	33.579
	Total	**6058.505**	**100**
(b) Soil suitability			
S/N	**Suitability**	**Area (km2)**	**Percentage (%)**
1	Very Low	10.8845	0.180
2	Low	763.7658	12.607
3	Moderate	265.1027	4.376
4	High	3026.411	49.953
5	Very High	1992.341	32.885
	Total	**6058.505**	**100**
(c) Distance to major road			

S/N	**Suitability**	**Area (km2)**	**Percentage (%)**
1	Very low	2571.482	42.444
2	Low	1368.939	22.595
3	Moderate	1084.165	17.895
4	High	606.2618	10.007
5	Very High	427.6572	7.059
	Total	**6058.505**	**100**
(d) Distance to minor road			
S/N	Suitability	Area (km2)	Percentage (%)
1	Very low	2018.387	33.315
2	Low	1650.415	27.241
3	Moderate	1203.895	19.871
4	High	768.708	12.688
5	Very High	417.100	6.885
	Total	**6058.505**	**100**
(e) Slope suitability			
S/N	Suitability	Area (km2)	Percentage (%)
1	Very low	124.7820	2.060
2	Low	213.5085	3.524
3	Moderate	3286.182	54.241
4	High	1979.661	32.676
5	Very High	454.3715	7.500
	Total	**6058.505**	**100**
(f) TWI suitability			
S/N	Suitability	Area (km2)	Percentage (%)
1	Very low	219. 956	3.631
2	Low	688.549	11.365
3	Moderate	1433.381	23.659
4	High	1957.684	32.313
5	Very High	1758.935	29.049
	Total	**6058.505**	**100**
(g) Elevation			
S/N	**Suitability**	**Area (km2)**	**Percentage (%)**
1	Very low	2782.900	45.934
2	Low	1332.480	21.994
3	Moderate	1056.620	17.440
4	High	412.193	6.804
5	Very High	474.312	7.829
	Total	**6058.505**	**100**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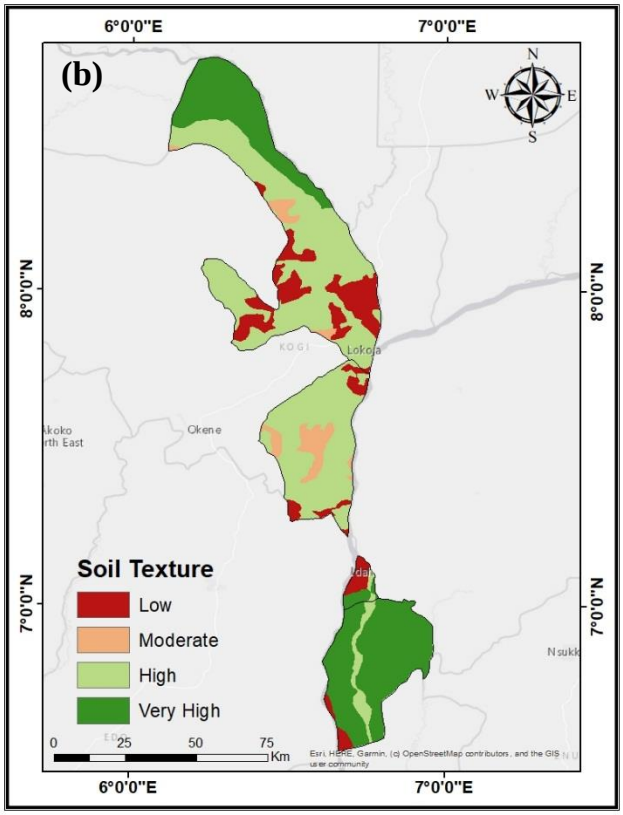
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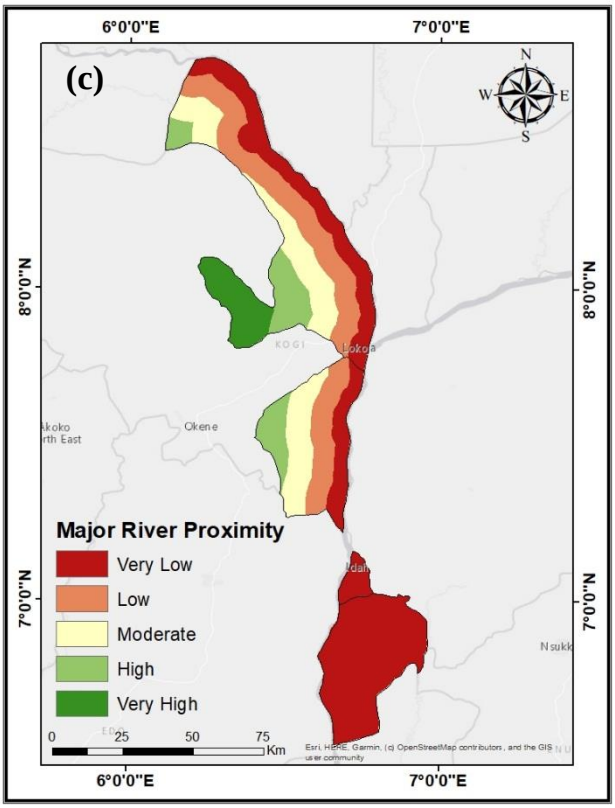
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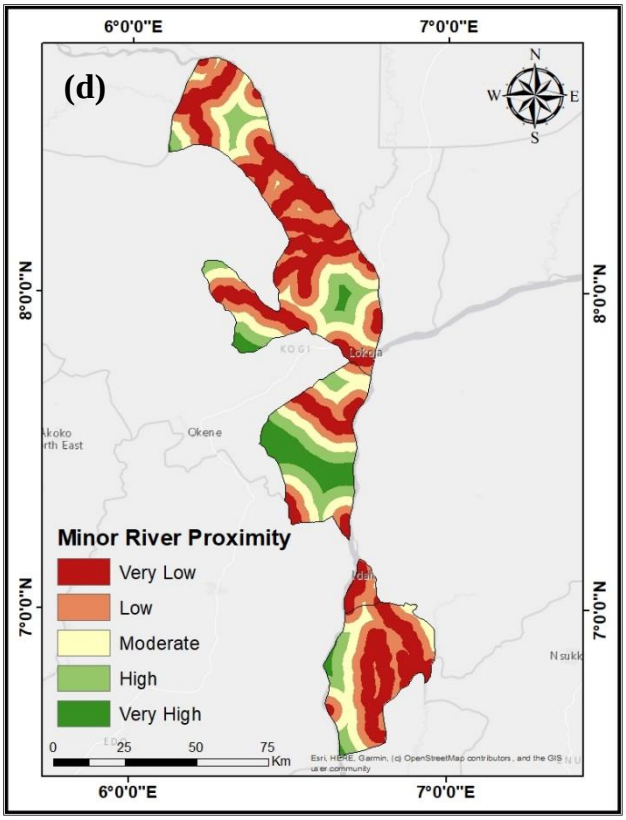
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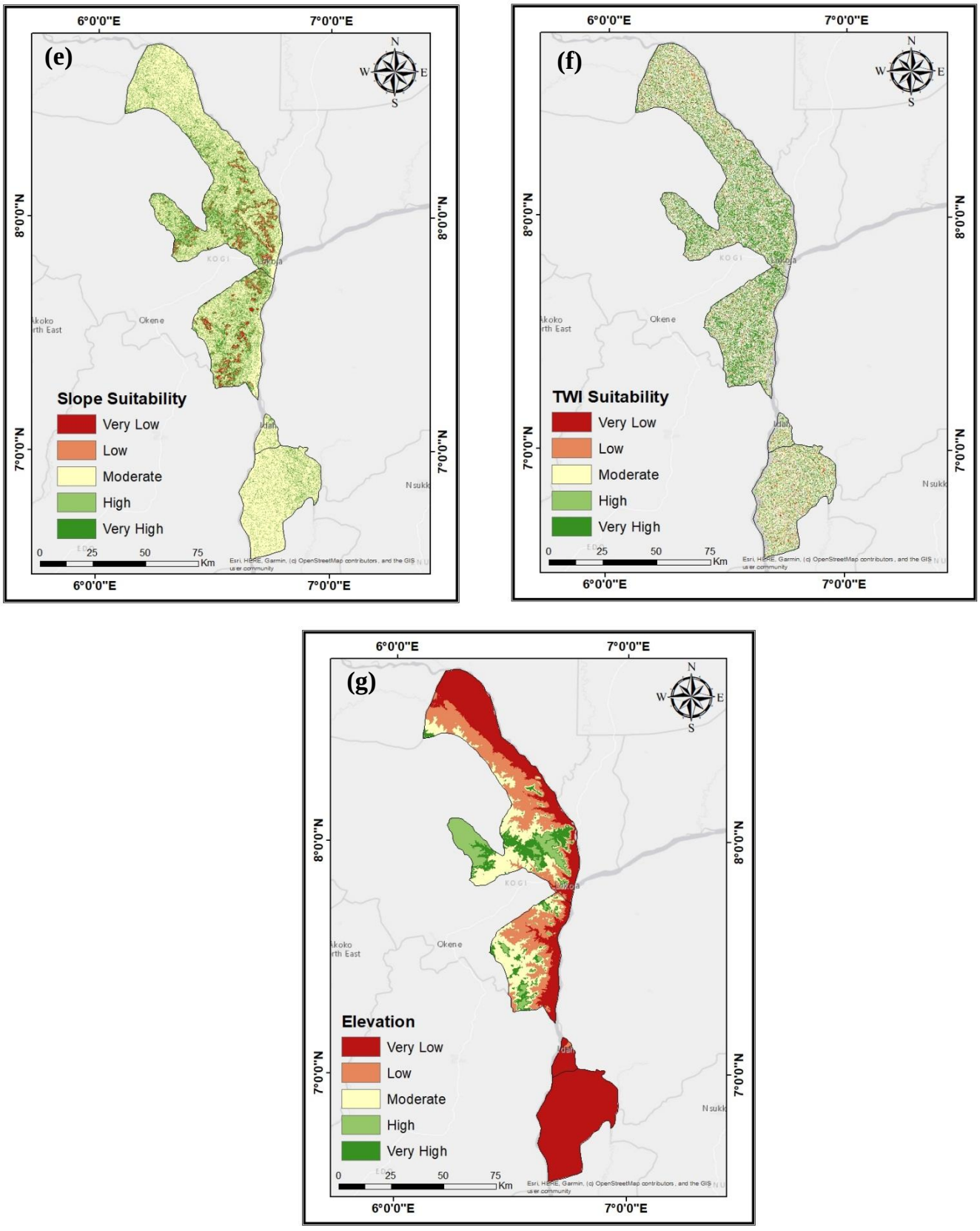

Figure 2(a)-(g): Flood settlement suitability maps

4.8 Final Suitability analysis

Table 3 depicts the spatial distribution of settlement suitability categories in the study area. This table provides information on the spatial distribution of the suitability categories in terms of area (km2) and percent coverage. The results clearly indicate the dominance of moderately suitable to less suitable areas, suggesting that much of the area is poorly suited to settlement development. The very low suitability class occupies an area that is very insignificant at 0.248 km² (0.004%), indicating that highly unsuitable settlement sites exist, but their location is limited in space. Figure 3 shows the last settlement suitability map, the low suitability class had covers of 1,941.042 km² (32.04%). It means that there is a considerable area of the study location that is restricted due to unfavorable factors such as increased flood hazard, inadequate drainage, or closeness to flooding locations. Settlements located in such places should be under strict control. The moderate suitability class has the largest share of the total study area, which is 2,741.292 km² (45.25%). It means that almost half of the whole area has average conditions for settlements due to the environment. The areas do not have much vulnerability to floods, but some planning and mitigating actions should be taken prior to further development. The high suitability class accounted for 1,321.875 km² (21.82%), which reflects those locations that are reasonably secure for establishing human settlements. These lands are rarely exposed to flood risks and have more favorable physical features, including elevation, drainage, and access. In contrast, the very highly suitable classification has an area of only 54.048 km² (0.89%). This is an extremely small proportion of the study area. Such areas have the highest level of suitability for habitation because of their environmental stability and absence of floods, thus making them highly suited for urbanization. Figure 3 depicts the final settlement suitability map

Table 3: Area and percentage for final settlement suitability

S/N	Suitability	Area (km2)	Percentage (%)
1	Very Low	0.248	0.0041
2	Low	1941.042	32.0383
3	Moderate	2741.292	45.2470
4	High	1321.875	21.8185
5	Very High	54.048	0.8921
	TOTAL	6058.505	100

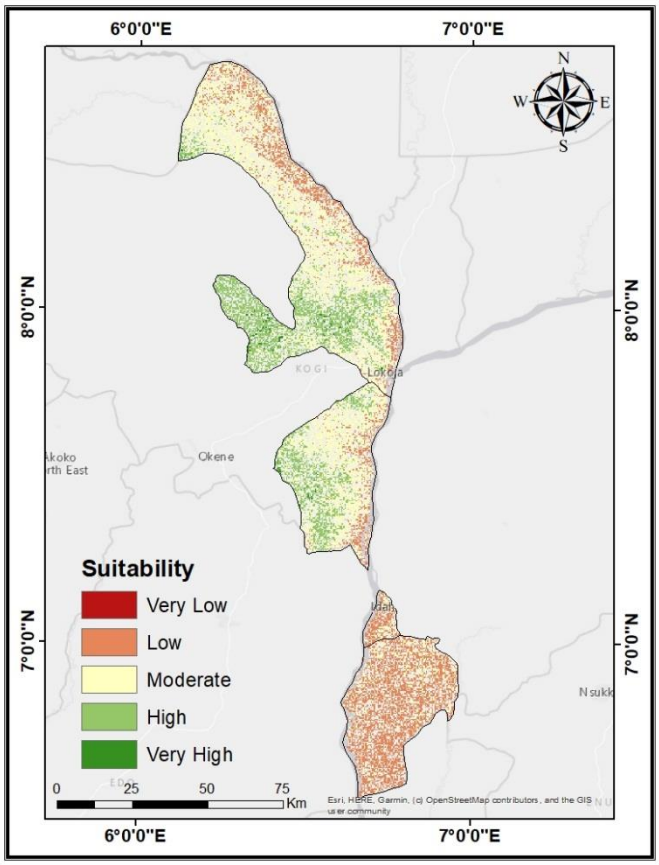

Figure 3: Final settlement suitability map

5. Conclusion and Recommendation

5.1: Conclusion

In the current research, geospatial techniques have been employed to emphasize areas that are prone to flooding in Lokoja, Ajaokuta, Ibaji, and Igalamela-Odolu Local Government Areas of Kogi State. Various thematic parameters that consist of road proximity, soil suitability, distance from major road, distance from minor road, slope suitability, TWI suitability, and elevation have been considered for settlement suitability in the current study area. Final overall weight analysis was done through overlaying the nine parameters to prepare a flood-prone map. The prepared map is further classified into five categories: very low, low, moderate, high, and very high settlement suitability areas. Their values are, respectively, 0.248 km² (0.0041%), 1941.042 km² (32.038%), 2741.292 km² (45.247%), 1321.875 km² (21.819%), and 54.048 km² (0.892%).

5.2: Recommendation

Recommendations that arise as a result of the research findings include the following:

i. The area needs proper land utilization practices.
ii. Residents are warned against randomly dumping waste materials in flood areas since it may result in a flood disaster;
iii. Levees need to be constructed within the flood-prone areas.
iv. In some flood-prone areas, drainage systems need to be either installed or expanded.
v. Structures should not be built in flood-plain areas.
vi. Dredging operations should be carried out to ensure that there is increased depth in the nearby water bodies.

vii. In order to prevent people from dumping waste in the existing drainage systems, the Kogi State Waste Management Board needs to ensure that there is frequent collection of waste materials;
viii. In flood-prone areas, afforestation practices should be encouraged.

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