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Exploring Geographical Information Systems (GIS) and Analytical Hierarchy Process (AHP) for the Mapping of Flood Prone Areas in Ikpoba-Okha Local Government Area, Edo State, Nigeria

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Abstract: Flood susceptibility mapping is an important element of flood mitigation and prevention since it aids in the identification of the most vulnerable areas. The target is to develop a flood susceptibility/inundation map for the identification of flood risk zones in Ikpoba-Okha LGA, Edo State, Nigeria. Ten (10) thematic maps namely; Topographic wetness index (TWI), Elevation, Slope, Precipitation, Land use land cover (LULC), Normalized difference vegetation index (NDVI), Distance from river, Distance from road, Drainage density, and soil were employed for the study. The thematic maps were reclassified in order to obtain a uniform scale using the reclassification tool in Arcmap. To obtain the percentage weight of influence for each of the data, analytical hierarchy process (AHP) was employed to generate a pairwise comparison matrix which was validated using the index of consistency (IC). Thereafter weighted overlay method was employed to stack the reclassify maps in order to generate the final flood susceptibility map for the study area. The outcome of the study was the delineation of the study area through the generation of a flood prone map that helped to identify the specific areas that are prone to flooding. Overall, areas within the red spot are very highly susceptible to flooding while the green and yellow spot signifies areas with low and high susceptibility to flooding

Keywords: Flooding, Flood Susceptibility, Flood Mapping, Topographic wetness index (TWI), Normalized difference vegetation index (NDVI).

I. INTRODUCTION

Nigerian Meteorological Agency (NiMet), has warned Nigerians to expect more flooding in the coming days, following the information obtained from the Nigeria Hydrological Services Agency (NIHSA). A significant increase in floods around the world has been observed in recent years. Not only have the frequency of flood increased, there is also an unusual increase in the severity of floods (Alho et al., 2008, Klijn, 2009). Floods are a natural phenomenon which always and which will continue to occur. Though floods cannot be entirely prevented, appropriate planning and protection measures helps in the reduction of the severity of floods and the damages they cause (Izinyon, 2018, Ehiorobo et al., 2012). Based on information from the United Nations Office for Disaster Risk Reduction (UNISDR) around 150,061 flood events occurred in the world from 1996 to 2015 accounting for 11.1% of the global disaster fatalities (Wei et al., 2019; Hong et al., 2018a. The increasing trend in the occurrence of flood events in recent time can be trace to the issues of ongoing climate change which is the consequence of Greenhouse Gas Emission resulting to Global Warming and further compounded by land use changes driven by human activities (Sofia et al., 2017, Fohrer et al., 2001). The long term secondary effect of flood disaster is however, more rigorous where affected communities are hampered by impacts such as disease and starvation including economic losses (Cao et al., 2016; Pilon, 2004; Wisner et al. 2004).
On account of the danger pose by flood and other water related disaster, researchers all over have clamor for early warning signals that will help for flood preparedness and prevention (Dalil et al., 2015; Hirabayashi et al., 2013; Oyekale, 2013). Mapping and analysis of flood susceptibility is one of the most important elements of early warning systems or strategies for prevention and mitigation of future flood situations since it identifies the most vulnerable areas based on physical conditions that determine the propensity for flooding (ISDR, 2004; ISDR, 2007; Matej and Jana, 2019). Therefore, the term susceptibility can also be perceived as one of the dimensions of vulnerability assessment (Jacinto et al., 2015). Informing the public about flood risks is an initial step to encourage public participation in flood risk management. Maps are useful tools for informing communities about their flood risk as they can be used for prioritizing local mitigation efforts, such as regulating build-up in flood-prone areas, and identifying which properties should adopt flood-proofing measures (e.g., installing a backwater valve).

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Several factors can influence the development of a flood susceptibility map for a specific location. Depending on the physical characteristics of the area to be investigated, flood susceptibility mapping techniques rely on various conditioning factors such as; geology or lithology, morphometric properties (e.g., elevation, slope), river network density, soil types or hydrological soil groups, land use/land cover, and the like. In selecting the conditioning factors for flood susceptibility analysis, it is important to consider the spatial scale (investigated area) of the analysis. For large spatial scale (national and regional scale analysis), using less factors seems to be rational since it is more difficult to gain the same data (same scale or resolution) for the whole territory. For local scale studies (e.g., catchment scale), a wider range of location-specific data and factors are required, thus allowing for more accurate characterization of the flooding characteristics (Matej and Vojteková, 2019). In this study ten (10) conditioning factors which include; slope, elevation, land use/land cover, precipitation, river distance, road distance, drainage density, soil, topographic wetness index (TWI) and normalized vegetation difference index (NDVI) were selected to prepare a flood susceptibility map for the study area.

II. RESEARCH METHODOLOGY

A. Description of Study Area

The study area is Ikpoba-Okha LGA which is one of the LGAs in Edo State. Edo State lies roughly between longitude 06^{o} 04'E and 06^{o} 43'E and latitude 05^{o}44' N and 07^{o}34' N. Edo State has a tropical climate characterized by two distinct seasons: the wet and dry seasons. The wet season occurs between April and October with a break in August, and an average rainfall ranging from 150 cm in the extreme North of the State to 250 cm in the South. The dry season lasts from November to April with a cold harmattan spell between December and January. The temperature averages about 25 °C (77 °F) in the rainy season and about 28 °C (82 °F) in the dry season. The climate is humid tropical in the Southern part and sub-humid in the Northern part (Ahuchaogu, and Aniekan, 2017)**.**
Figure 1 is 3D map of the study area

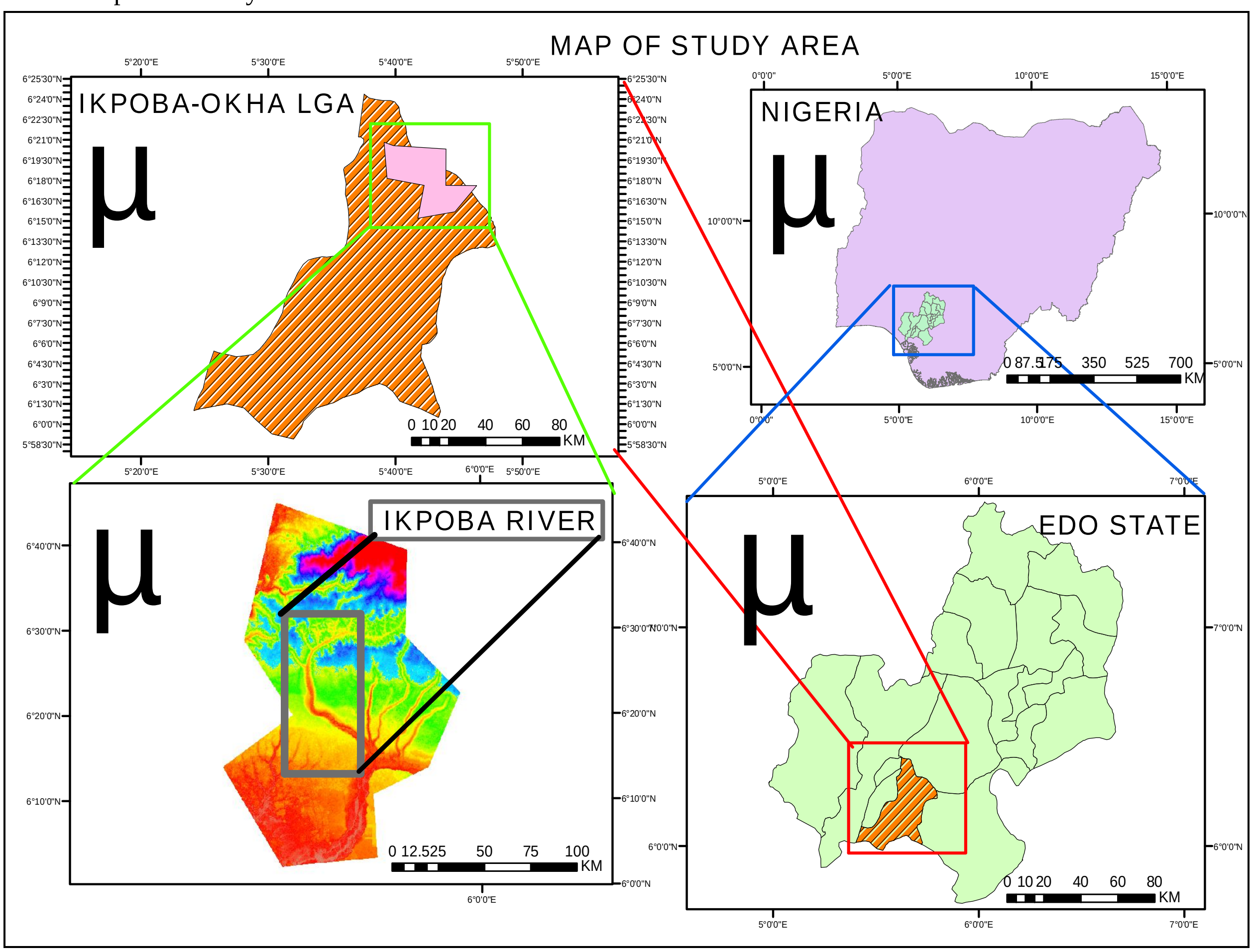

Figure 1:Map of suggested study area

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B. Data Requirement

Since floods are multi-dimensional phenomena with spatial and temporal aspects, geographical information systems (GIS) represent useful tools for the synthesis of different input data and variables using specific logical and mathematical relations to produce flood susceptibility maps (Eastman et al., 1995). The flood causative criterion (input data) needed in this study include; soil data, slope data, land use/land cover data, precipitation data, flow length data, river distance data, drainage density data, topographic wetness index (TWI) data, normalized difference vegetation index (NDVI) data, road distance data, and elevation data.

C. Generation Of Flood Susceptibility Map Using Ahp And Weighted Overlay

In order to arrive at the final flood susceptibility map, the thematic maps (TWI, Precipitation, LULC, Slope, Elevation, drainage density, soil, NDVI, distance from road, and distance from river) were overlayed using weighted overlay analysis. Weighted overlay analysis is a simple and straightforward method for a combined analysis of multi class maps. The weight of influence for each factor was computed statistically using analytical hierarchy process (AHP). The first step in obtaining the AHP design was to define the criteria and the sub-criteria. Table 1 presents the selected criteria and their respective sub-criteria's.

Table 1: Definition of criteria and sub-criteria for AHP analysis

Criteria	Sub-Criteria TWI	Sub-Criteria Elevation	Sub-Criteria Slope	Sub-Criteria Precipitation	Sub-Criteria LULC	Sub-Criteria NDVI	Sub-Criteria DfRiv	Sub-Criteria DfRoad	Sub-Criteria Drain Den
TWI	Elevation	Slope	Precipitation	LULC	NDVI	Distance from River	Distance from Road	Drainage Density	Soil Type
Elevation	Slope	Precipitation	LULC	NDVI	Distance from River	Distance from Road	Drainage Density	Soil Type	LULC
Slope	Precipitation	LULC	NDVI	Distance from River	Distance from Road	Drainage Density	Soil Type		
Precipitation	LULC	NDVI	Distance from River	Distance from Road	Drainage Density	Soil Type			
LULC	NDVI	Distance from River	Distance from Road	Drainage Density	Soil Type				
NDVI	Distance from River	Distance from Road	Drainage Density	Soil Type					
Distance from River	Distance from Road	Drainage Density	Soil Type						
Distance from Road	Drainage Density	Soil Type							
Drainage Density	Soil Type								
Soil Type									

To define the one to nine scale of parameter significance, the scheme proposed by Saaty, reported in Table 2 was employed to translate linguistic judgments into numbers.

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Table 2: Saaty summary table

Sig. Strength	Explanation	Comments
1	Equal significance	Two elements contribute equally to the objective
3	Moderate significance	Judgment slightly favour one element over another
5	Strong significance	Judgment strongly favour one element over another
7	Very strong significance	Judgment strongly favour one element over another, its dominance is demonstrated by experience
9	Maximum significance	The dominance of one element over another is demonstrated and absolute
2, 4, 6, 8	Can be used to express intermediate values	

The AHP matrix employed to compute the percentage weight of influence for each of the flood causative variable is presented in Table 3.

Table 3: Generation of AHP matrix

Criteria	TWI	Elevation	Slope	Precipt.	LULC	NDVI	DfRiver	DfRoad	Drain Den	Soil Type
TWI	1	1	1	1	3	5	1	3	1	3
Elevation	1	1	1	1	2	3	1	3	1	3
Slope	1	1	1	1	3	3	½	1	1	1
Precipitation	1	1	1	1	3	2	2	3	3	7
LULC	1/3	½	1/3	1/3	1	1	½	5	1	3
NDVI	1/5	1/3	1	½	1	1	½	1	½	1
Distance from River	1	1	2	½	2	2	1	5	1	3
Distance from Road	1/3	1/3	1	1/3	1/5	1	1/5	1	½	½
Drainage Density	1	1	1	1/3	1	2	1	2	1	3
Soil Type	1/3	1/3	1	1/7	1/3	1	1/3	2	1/3	1

To validate the AHP results, the index of consistency was employed. The principal eigenvalue ($\lambda_{\max}$) is a function of the matrix divergence from consistency. In other words, a pairwise matrix is considered consistent only when $\lambda_{\max}$ is equal or more than the number of the layers examined. The index of consistency was estimated using the mass balance equation of the form

$$\text{CI} = \frac{\lambda_{\max} - n}{n - 1} \tag{1}$$

Where; $\lambda_{\max}$ denotes the principal eigenvalue, and n represent the number of parameters. For a 3 by 3 matrix, the consistency index is less than 0.05. For a 4 by 4 matrix, it is 0.09 while for large matrices, it is 0.1. If it matches, then the pairwise comparison is said to be consistent and the calculated weight of influence is said to be valid. The overall flowchart for the generation of flood susceptibility map of the study area is presented in Figure 2

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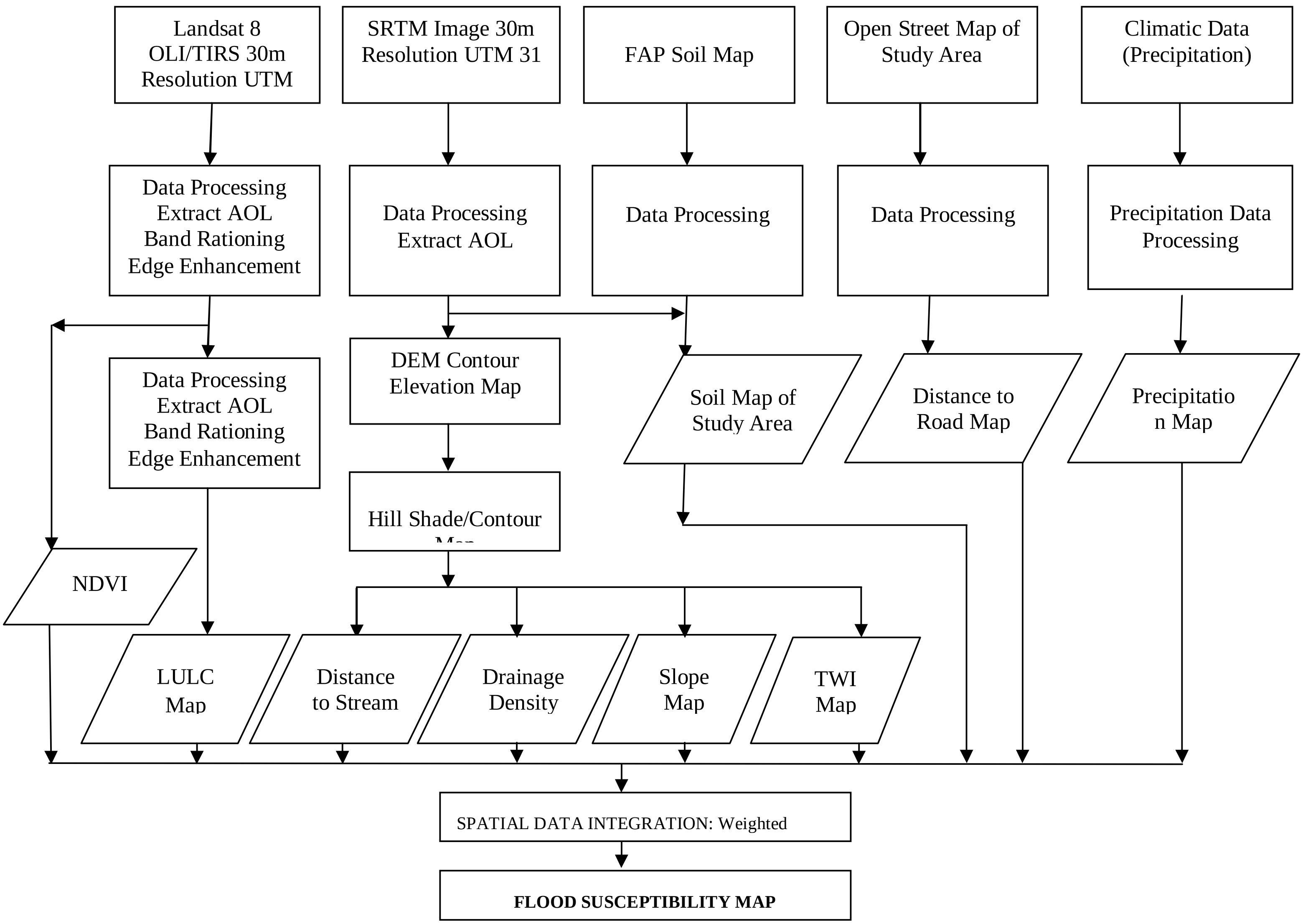

Figure 2: Layout for the preparation of flood susceptibility map

III. RESULTS AND DISCUSSION

The Food and Agriculture Organization (FAO) usersoil table was used to determine the different soil types in the study region, including the hydrological soil group, in order to construct the curve number map. Table 4 shows the results of the soil type, soil code, and associated hydrological soil group around the study area

Table 4: Curve number value around the study area

S/N	Soil Codes	FAO Soil Code	Soil Type	HYDGRP	CN
1	Lf60-2b	1484	Sandy_Clay_Loam	C	86
2	Lf61-2a	1485	Sandy_Clay_Loam	C	86
3	Nd15-1a	1552	Sandy_Loam	C	86
4	Nd20-1a	1558	Sandy_Loam	B	79
5	Nd17-1a	1554	Sandy_Loam	B	79
6	Nd18	1555	Loam	C	86
7	Nd21	1559	Sandy_Clay_Loam	C	86
8	Ge-2/3a	1193	Clay_Loam	C	86
9	Nd18-1a	1556	Sandy_Loam	B	79

With the help of the HEC-HMS technical reference manual, the runoff curve number for an urban area in poor condition (grass cover 50%) was utilized to determine the curve number corresponding to the hydrological soil group. From the result of Table 4, it was observed that the area under study has an average curve number of 83, which is considered to be high. High Curve Numbers, often associated with urban environments characterized by extensive impervious surfaces like roads and buildings, hinder the natural process of rainfall infiltration into the soil. This results in rapid runoff during heavy rainfall events, as the water is unable to permeate the impermeable surfaces and instead flows over them. Consequently, stormwater drainage systems in these areas can become overwhelmed, leading to localized flooding in streets, basements, and low-lying areas. Moreover, the increased runoff from high CN areas can exacerbate flash flooding, as the water accumulates quickly and is unable to be absorbed by the ground. The digital elevation model (DEM) and the shapefile of the study area is presented in Figures 3 and 4 respectively.

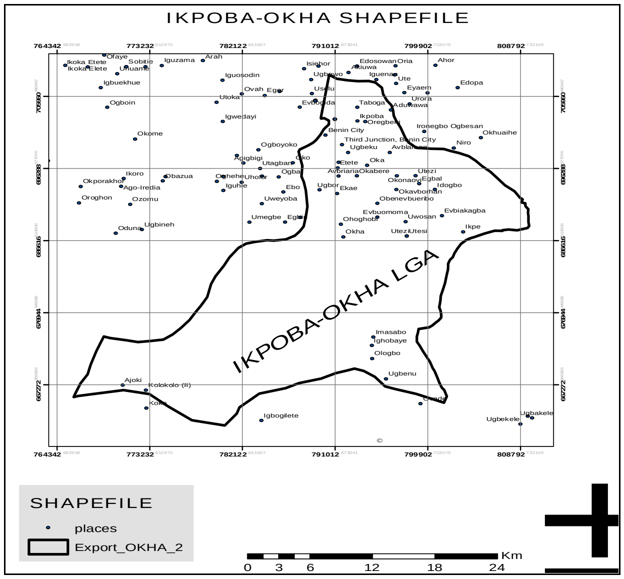

Figure: 3: Shapefile of the study area

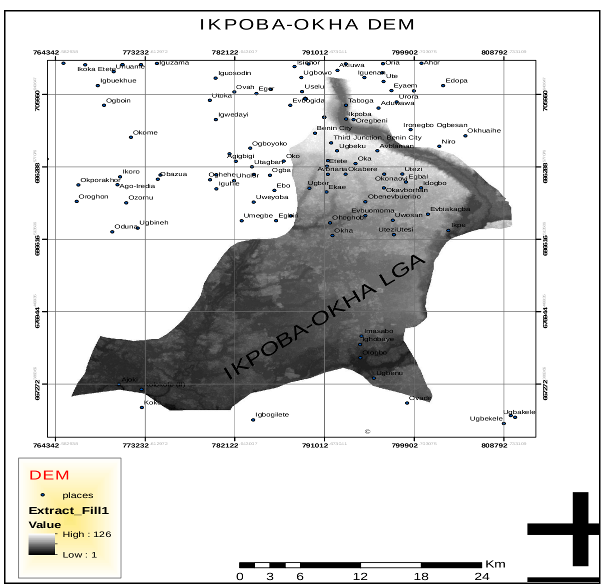

Figure: 4: DEM of the study area

Digital Elevation Models (DEMs) are integral to flood mapping due to their provision of detailed elevation and terrain data, facilitating the analysis of water flow paths during flood events, delineation of watersheds and drainage networks, and hydraulic modeling for predicting flood extents, depths, and velocities. By utilizing DEMs, hydrologists and engineers can accurately assess flood vulnerability, identify at-risk areas, and develop effective flood hazard maps for informed decision-making and risk mitigation strategies. The slope map of the study area is presented in Figure 5a while the reclassified slope map is presented in Figure 5b

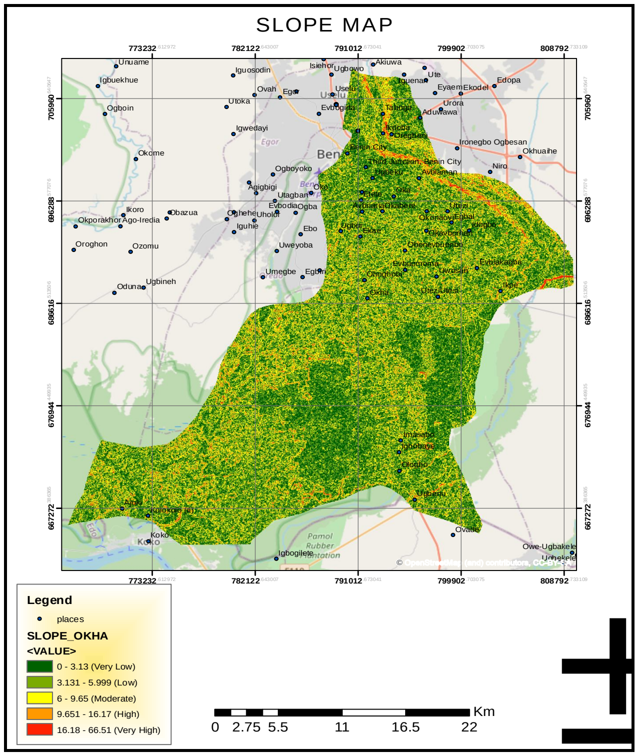

Figure 5a: Slope map of the study area

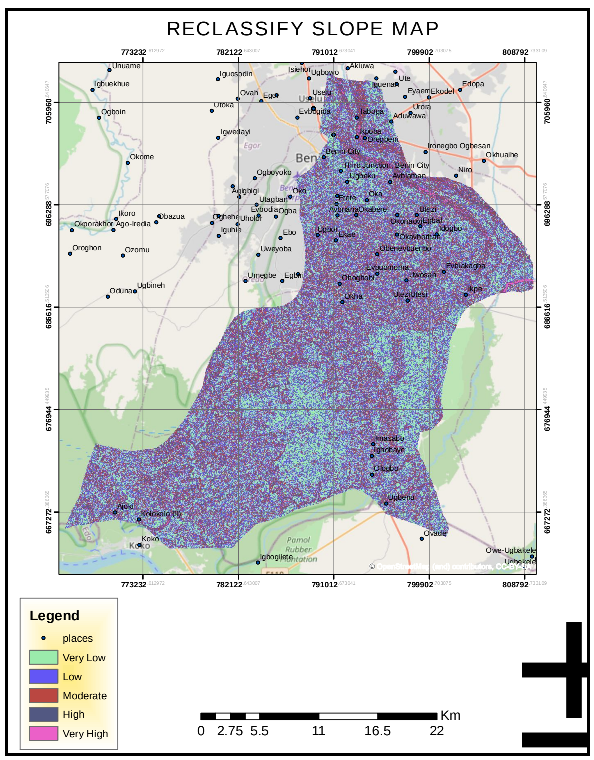

Figure 5b: Reclassified slope map

The slope affects the amount of surface runoff or subsurface drainage that reaches a location as well as its direction. Flooding can occur on a smooth or flat surface because it allows water to move fast, while a rougher surface can lessen the flood response.

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The slope of the terrain is a fundamental factor influencing the occurrence and severity of flooding in a given area, with significant implications for hydrological processes and landscape dynamics. Areas with steeper slopes are more prone to rapid surface runoff during heavy rainfall events, as water flows downhill with greater velocity, increasing the risk of flash flooding and erosion. In contrast, areas with gentler slopes tend to facilitate slower water movement and better infiltration into the soil, reducing the likelihood of flooding. The elevation map of the study area is presented in Figure 6a while the reclassified elevation map is presented in Figure 6b

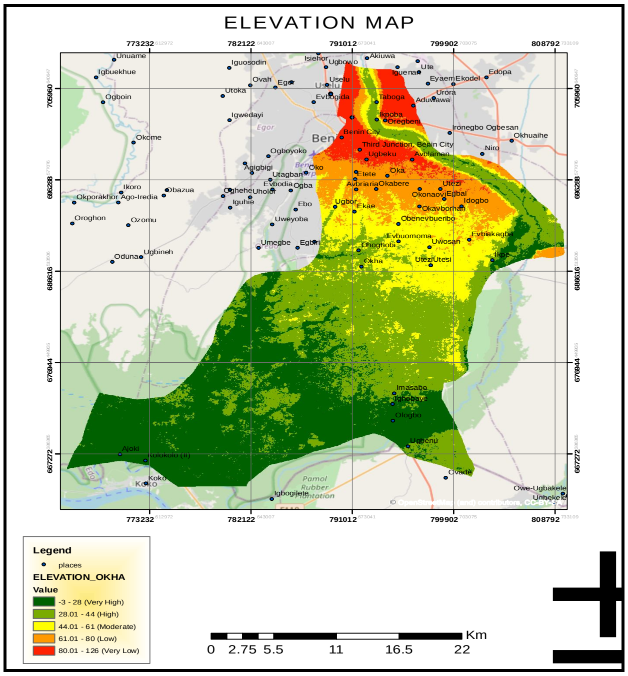

Figure 6a: Elevation map of the study area

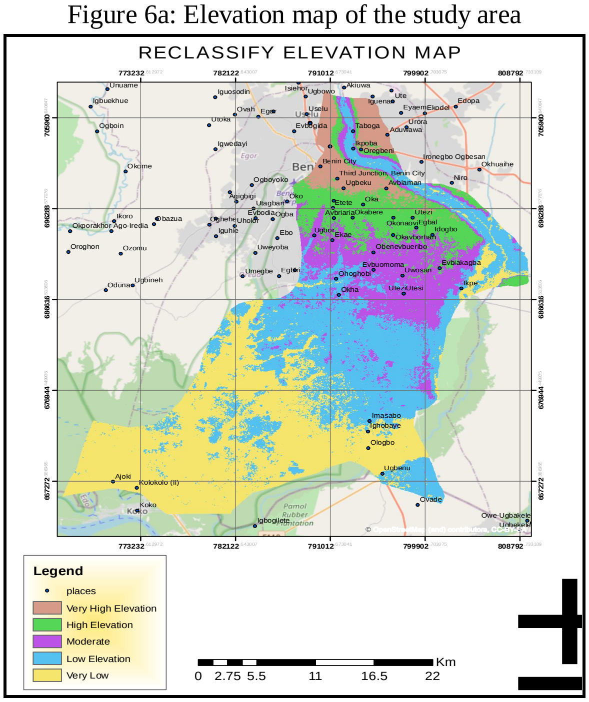

Figure 6b: Reclassified elevation map

Understanding the relationship between elevation and flooding is crucial for effective flood risk assessment and management. It informs decisions regarding land use planning, infrastructure development, and the implementation of flood protection measures such as levees, floodwalls, and zoning regulations.

By incorporating elevation data into flood hazard mapping and modeling efforts, authorities can identify high-risk areas, prioritize mitigation strategies, and enhance community resilience to flooding events. The topographic wetness index (TWI) map of the study area is presented in Figure 7a while the reclassified TWI map is presented in Figure 7b

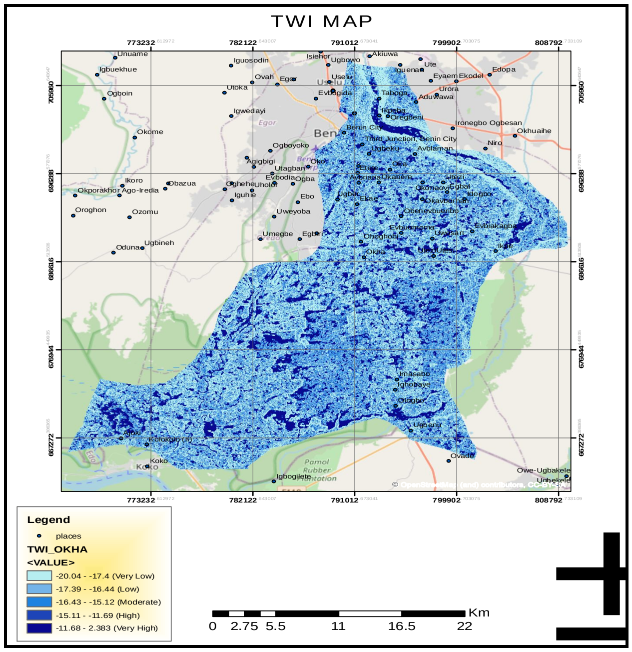

Figure 7a: TWI map of the study area

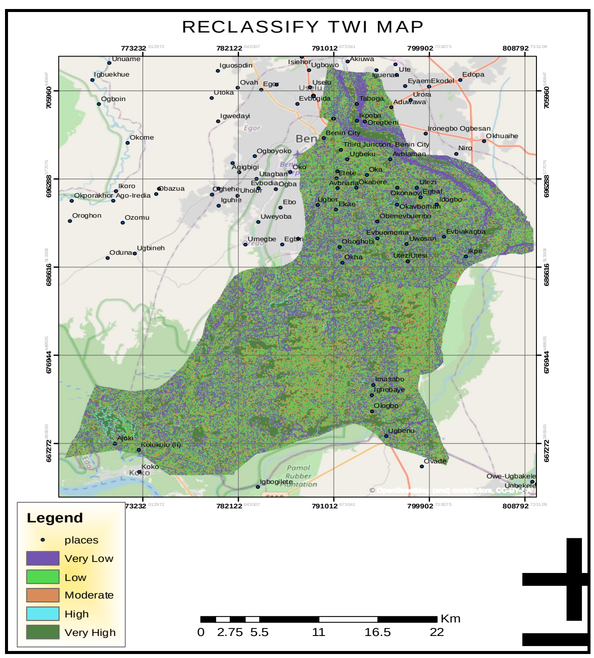

Figure 7b: Reclassified TWI map

The Topographic Wetness Index (TWI) serves as a critical tool in assessing flood susceptibility by identifying areas prone to water accumulation based on slope and upslope contributing area. Utilized in hydrological modeling, TWI aids in predicting water movement, delineating flow paths, and mapping flood hazard zones by integrating with factors like land cover and rainfall intensity. Furthermore, it facilitates the monitoring of landscape changes over time, offering insights into long-term flood risk trends and guiding effective land use planning and risk mitigation strategies. The normalized difference vegetation index (NDVI) map of the study area is presented in Figure 8a while the reclassified version is presented in Figure 8b

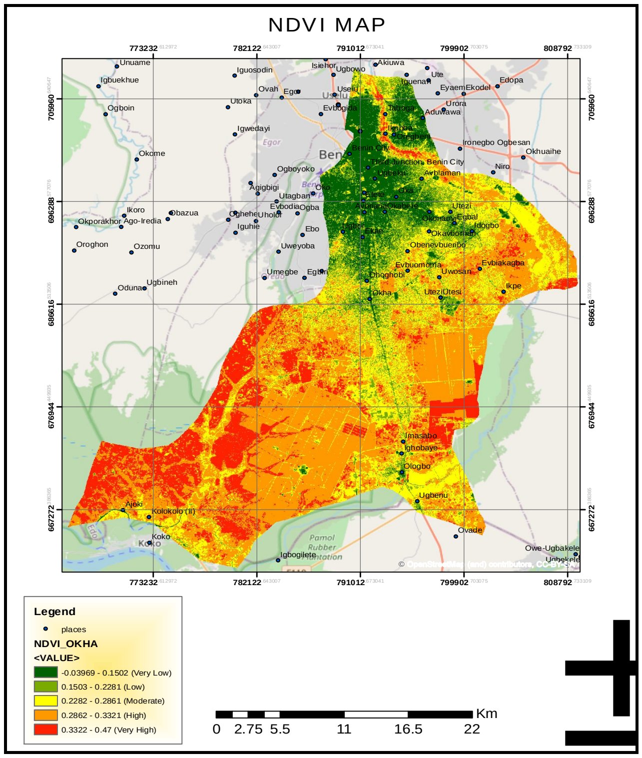

Figure 8a: NDVI map of the study area

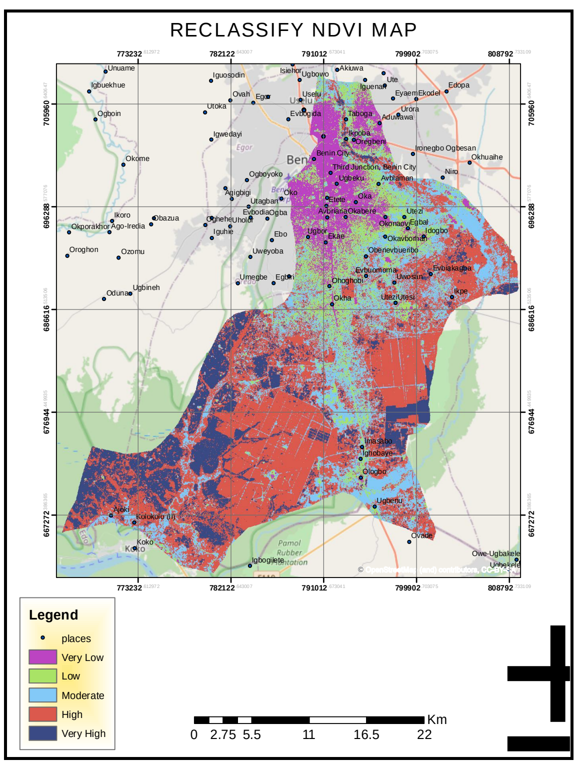

Figure 8b: Reclassified NDVI map

The Normalized Difference Vegetation Index (NDVI) provides valuable insights into vegetation health and density, offering indirect but crucial contributions to understanding flooding dynamics. High NDVI values indicate dense vegetation cover, which plays a vital role in mitigating flooding by intercepting rainfall, reducing surface runoff, and enhancing soil infiltration capacity.

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Vegetation acts as a natural sponge, absorbing excess water and stabilizing soil, thereby reducing the risk of erosion and surface water runoff. Conversely, low NDVI values suggest sparse vegetation or barren land, which can exacerbate flooding susceptibility by increasing surface runoff, soil erosion, and sediment transport. The distance to road map of the study area is presented in Figure 9a while the reclassified version is presented in Figure 9b

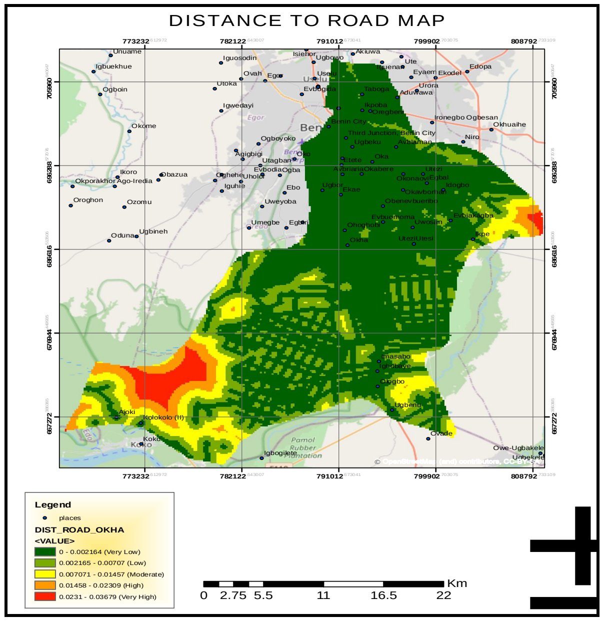

Figure 9a: Distance to road map

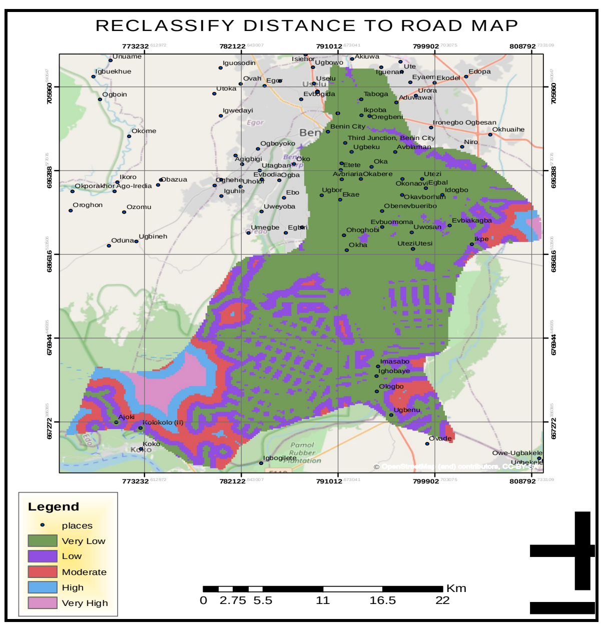

Figure 9b: Reclassified distance to road map

The distance from roads is a significant factor in assessing and mitigating flood risk, influencing the vulnerability of an area to inundation. Areas located closer to roads often face higher flood risk due to the potential for impeded drainage caused by road infrastructure such as embankments, culverts, and stormwater drains. These structures can alter natural drainage patterns, leading to increased surface runoff and potential flooding during heavy rainfall events. Additionally, roadways can act as barriers to the natural flow of water, causing water to accumulate and inundate nearby areas. Conversely, areas situated farther away from roads typically experience lower flood risk, as they are less likely to be affected by these alterations in drainage dynamics. The distance to river map of the study area is presented in Figure 10a while the reclassified version is presented in Figure 10b

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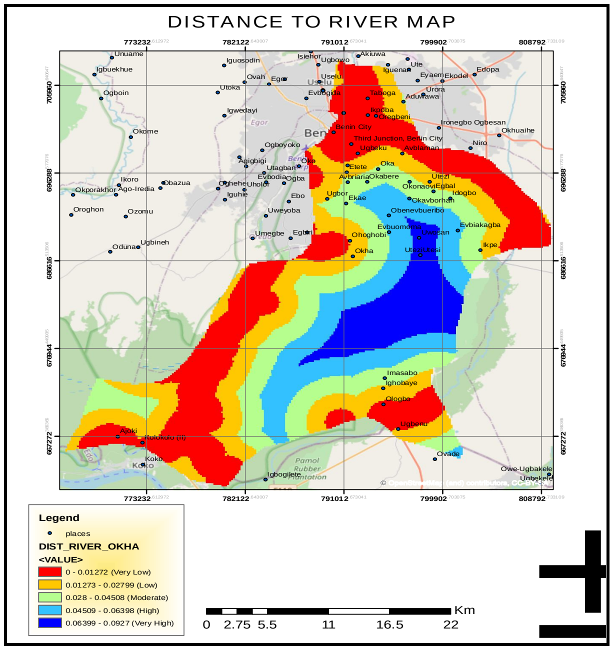

Figure 10a: Distance to river map

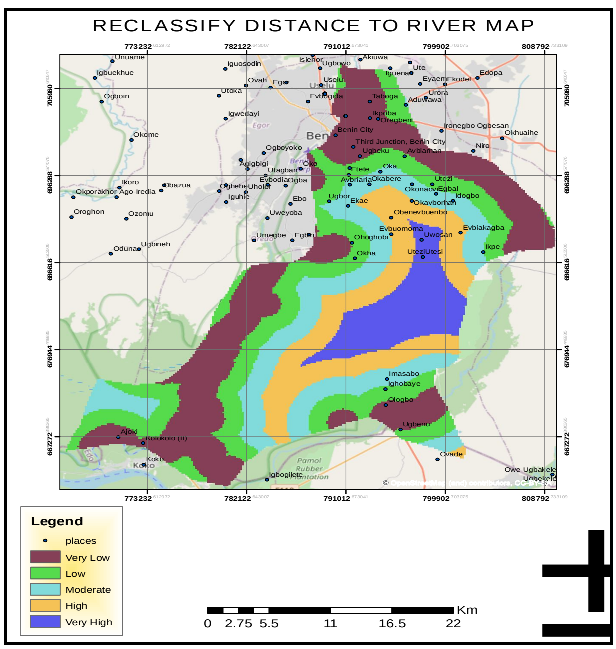

Figure 10b: Reclassified distance to river

The distance from a river is a crucial factor in understanding and predicting flooding dynamics, as it directly influences the vulnerability of an area to inundation. Areas located in close proximity to rivers are inherently at higher risk of flooding due to their susceptibility to overflow during periods of heavy rainfall or snowmelt. These areas, often referred to as floodplains, serve as natural channels for water flow, and their low-lying nature makes them prone to inundation. Conversely, areas located farther away from rivers typically experience lower flood risk, as they are less likely to be directly affected by riverine flooding events. The precipitation map of the study area is presented in Figure 11a while the reclassified version is presented in Figure 11b

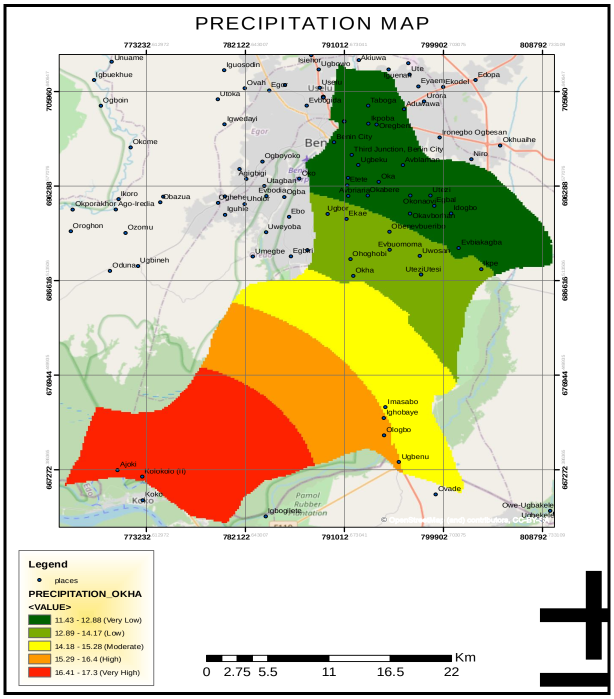

Figure 11a: Precipitation map

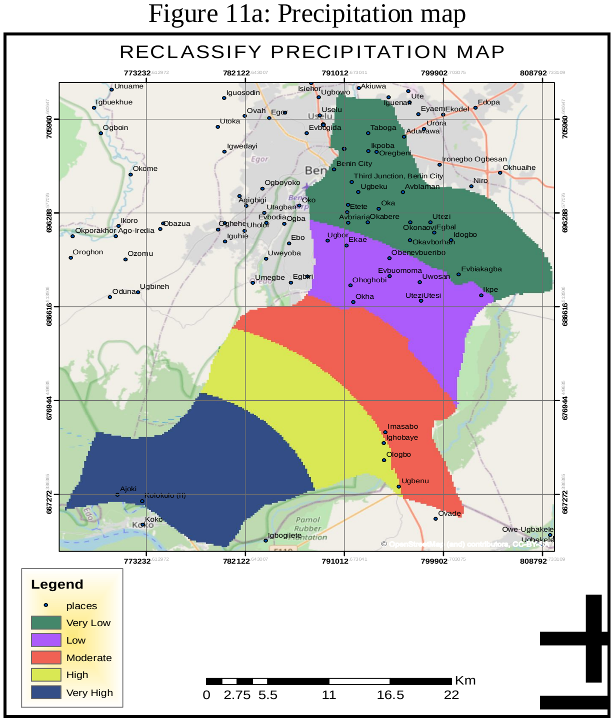

Figure 11b: Reclassified precipitation map

Precipitation, whether in the form of rainfall, snowmelt, or intense storms, is a primary driver of flooding, influencing the frequency, intensity, and extent of inundation events. Heavy rainfall over a short period or prolonged precipitation can saturate the soil, increase surface runoff, and overwhelm drainage systems, leading to riverine, urban, or flash flooding. Similarly, rapid snowmelt due to warm temperatures or rain can contribute to sudden rises in river levels and subsequent flooding. The spatial and temporal distribution of precipitation patterns determines the vulnerability of an area to flooding, with regions experiencing high-intensity rainfall or persistent precipitation facing heightened flood risk. The drainage density map of the study area is presented in Figure 12a while the reclassified version is presented in Figure 12b

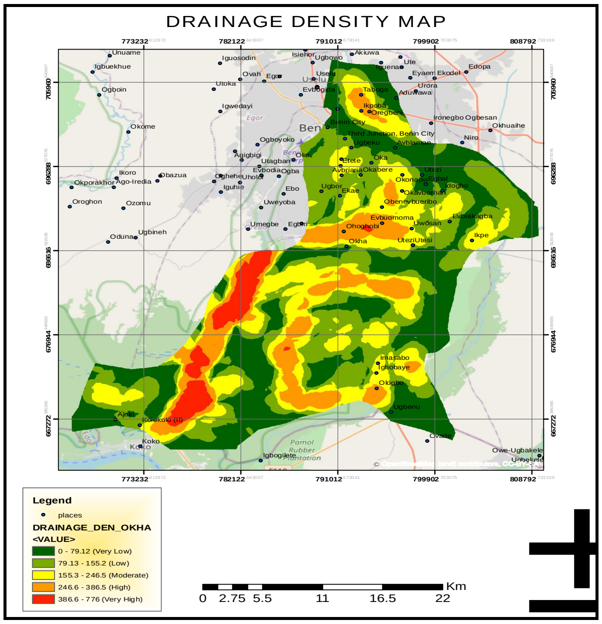

Figure 12a: Drainage density map

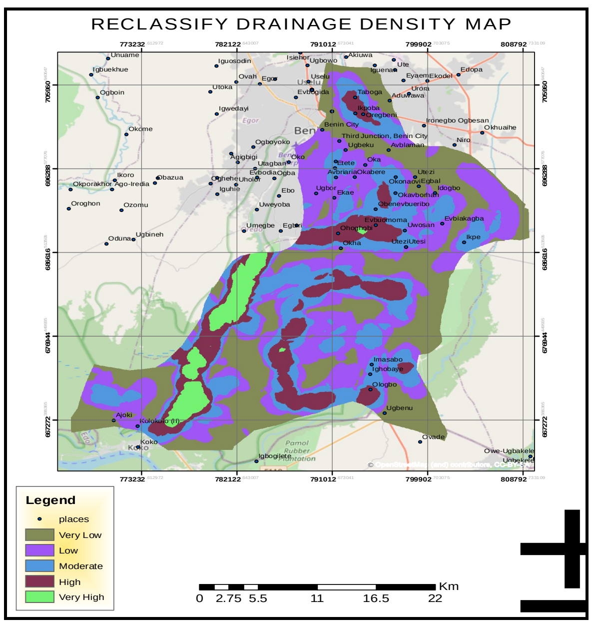

Figure 12b: Reclassified drainage density

The balance between the erosive strength of overland flow and the resistance of surface soil and rocks to runoff is shown by drainage density, which is regarded as an important index (Jacinto et al., 2015). The construction of channels and the contribution of streams are both hindered by vegetation, which also intercepts and stores water. Sparsely vegetated areas have comparatively high drainage densities, which causes increased runoff. The balance between the erosive strength of overland flow and the resistance of surface soil and rocks to runoff is shown by drainage density, which is regarded as an important index (Jacinto et al., 2015). The construction of channels and the contribution of streams are both hindered by vegetation, which also intercepts and stores water. Sparsely vegetated areas have comparatively high drainage densities, which causes increased runoff. The LULC map of the study area is presented in Figure 13a while the reclassified version is presented in Figure 13b

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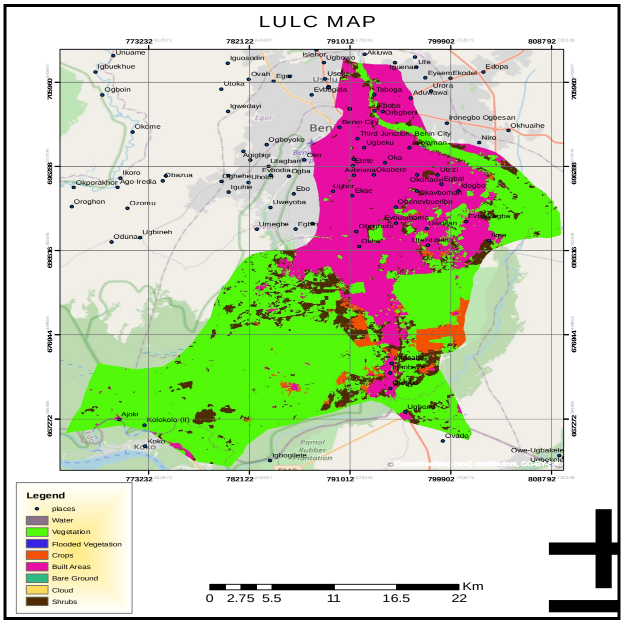

Figure 13a: LULC map of the study area

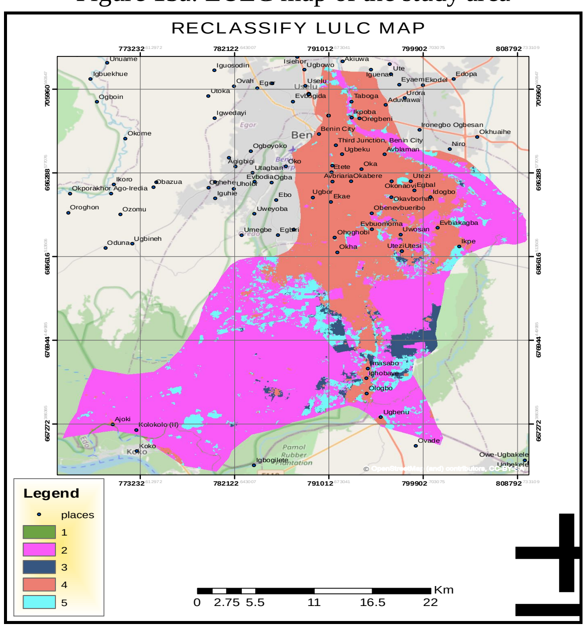

Figure 13b: Reclassified LULC map

Land use and land-cover management is one of the influential variables affecting flooding since it is one of the components that reflects the current use of the land, its pattern and the value of its use in terms of soil stability and infiltration. Land cover, including vegetation cover of soils, whether permanent grassland or cover of other crops, has an impact on the soil's capacity to function as a water store. On bare fields compared to fields with a thick crop cover, rainwater runoff occurs much more frequently. Land Use and Land Cover (LULC) significantly influence the occurrence and severity of flooding, serving as a critical determinant of the landscape's ability to absorb, retain, or convey water. Urban areas characterized by impervious surfaces such as roads, buildings, and pavements hinder infiltration and increase surface runoff, exacerbating flood risk by directing water rapidly into drainage systems and waterways. Similarly, deforestation and conversion of natural habitats to agriculture or urban development reduce vegetation cover, which diminishes the capacity of the land to intercept rainfall, stabilize soil, and mitigate runoff. Conversely, areas with extensive vegetative cover, such as forests, wetlands, and grasslands, play a vital role in flood attenuation by enhancing infiltration, reducing runoff, and providing natural floodplain storage. The soil map of the study area is presented in Figure 14a while the reclassified version is presented in Figure 14b

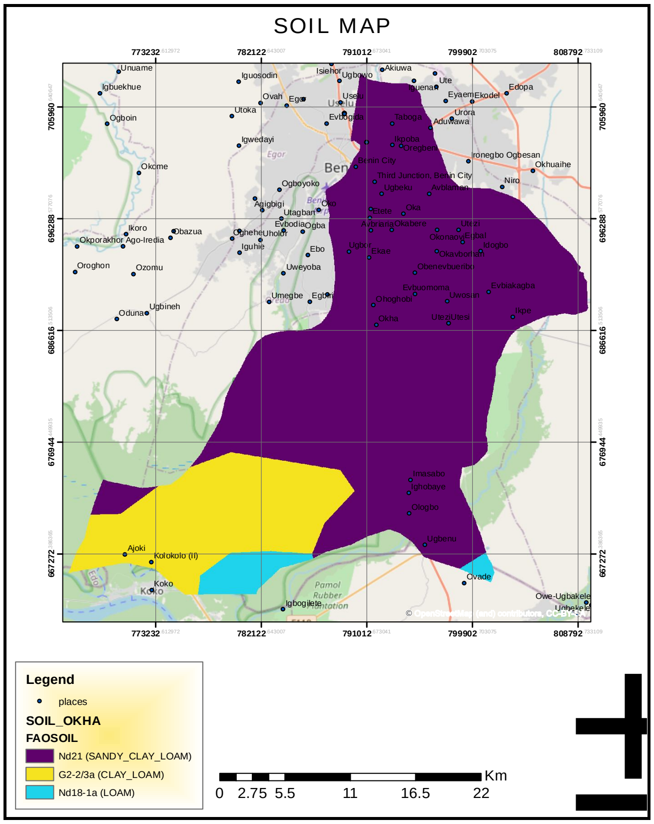

Figure 14a: Soil map of the study area

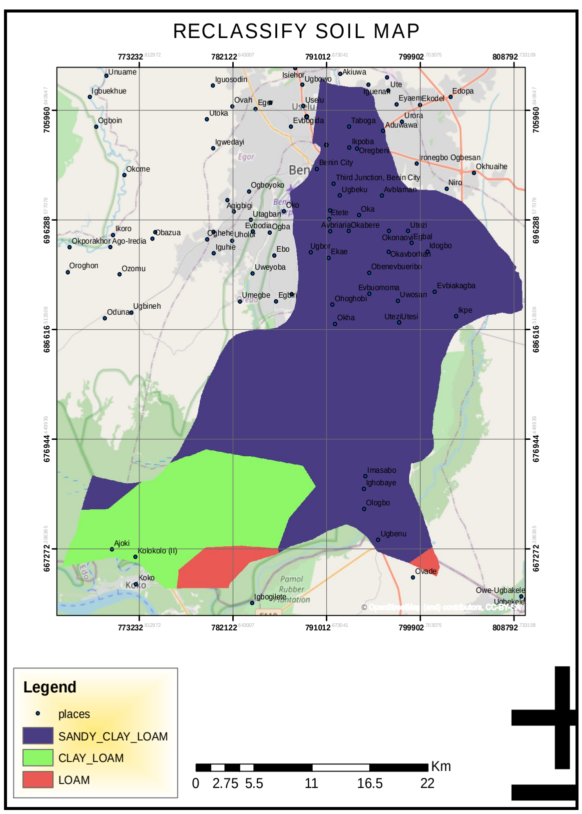

Figure 14b: Reclassified soil map

The texture and wetness of soils are its two most important characteristics. Sandy soil has a huge impact on flooding because it absorbs water quickly and creates little drainage. Conversely, clay soils are less porous and retain water for a longer period of time than sandy soils.

As a result, areas with clay soils are more prone to flooding. Soil characteristics are integral to the dynamics of flooding, exerting significant influence on the infiltration, retention, and transmission of water within the landscape. The infiltration capacity of soil, determined by its porosity, texture, and structure, dictates its ability to absorb and store precipitation. Soils with high infiltration rates can effectively capture and retain water, reducing surface runoff and mitigating flood risk. Conversely, soils with low infiltration rates, such as compacted or saturated soils, contribute to increased runoff and surface water accumulation, amplifying the likelihood and severity of flooding.

Furthermore, soil moisture content influences the partitioning of rainfall into infiltration, surface runoff, and groundwater recharge, thereby modulating flood dynamics. Understanding the role of soil in flooding is crucial for flood risk assessment, land use planning, and the implementation of effective flood management strategies.

To generate the final flood map, a weighted overlay analysis was done. To carry out a weighted overlay analysis, each factor considered was assigned weights and ranks. The weights of each factor was computed statistically using analytical hierarchy process (AHP) in order to determine the weight of influence of each parameter. In establishing the level of desirability of each attribute, measurements ranges were used to rank each factor, a scale of 1- 5 was assigned for ranks while weighting was assigned in percentage. Result of the percentage weight estimation using AHP is presented in Table 5

Table 5: Estimated percentage of Influence for flood causative criterion using AHP

Criteria	%
TWI	14.02
ELEVATION	12.47
SLOPE	10.11
PRECIPITATION	17.77
LULC	7.83
NDVI	5.45
DISTANCE FROM RIVER	13.14
DISTANCE FROM ROAD	4.47
DRAINAGE DENSITY	9.87
SOIL TYPE	4.87

IC = 0.043; RC = 5.67%

The validation parameters of the AHP analysis, with an inconsistency index (IC) of 0.043 and a random consistency ratio (RC) of 5.67%, indicate a reasonable level of consistency in the pairwise comparisons made during the analysis. The IC value falling below the threshold of 0.1 suggests that the judgments provided for the relative importance of flood variables are sufficiently consistent. Additionally, the RC value below 10% indicates that the level of inconsistency in the pairwise comparisons is within an acceptable range. This implies that the AHP results are reliable and can be confidently used to prioritize flood variables based on their relative influence.

Using the estimated percentage weight base on AHP, the weighted overlay tool in ArcGIS 10.6.1 was then employed to stack the reclassify raster data in order to generate the final flood map presented in Figure 15

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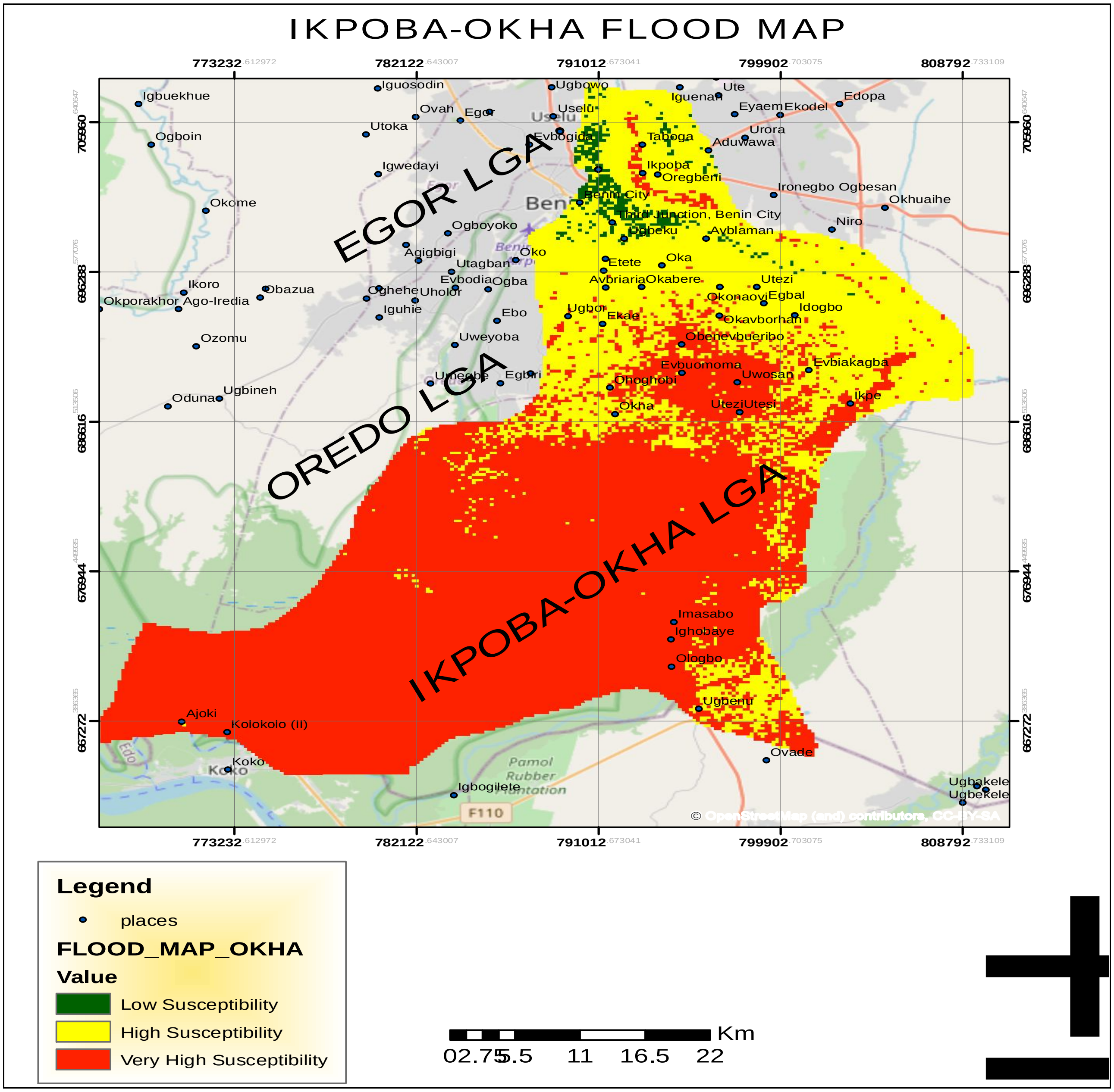

Figure 15: Flood susceptibility map of Ikpoba-Okha LGA

Areas within the red spot are very highly susceptible to flooding while the green and yellow spot signifies areas with low and high susceptibility to flooding

IV. CONCLUSION

The findings of this study underscore the intricate interplay between environmental factors and flooding dynamics. Precipitation emerges as the primary driver of flooding, with its intensity, duration, and spatial distribution significantly impacting the likelihood and severity of inundation events. Soil characteristics, particularly infiltration capacity and moisture content, exert considerable influence on flood susceptibility by modulating surface runoff and groundwater recharge. Additionally, topographical features such as elevation and slope play crucial roles in determining flood risk, with low-lying areas and steep slopes often exhibiting heightened vulnerability to inundation. Land use and land cover patterns further shape flood dynamics, with urbanization and deforestation exacerbating runoff and reducing natural floodplain storage capacity. These findings underscore the complexity of flooding processes and emphasize the importance of adopting holistic, multi-disciplinary approaches to flood risk management that integrate knowledge from hydrology, climatology, soil science, and land use planning.

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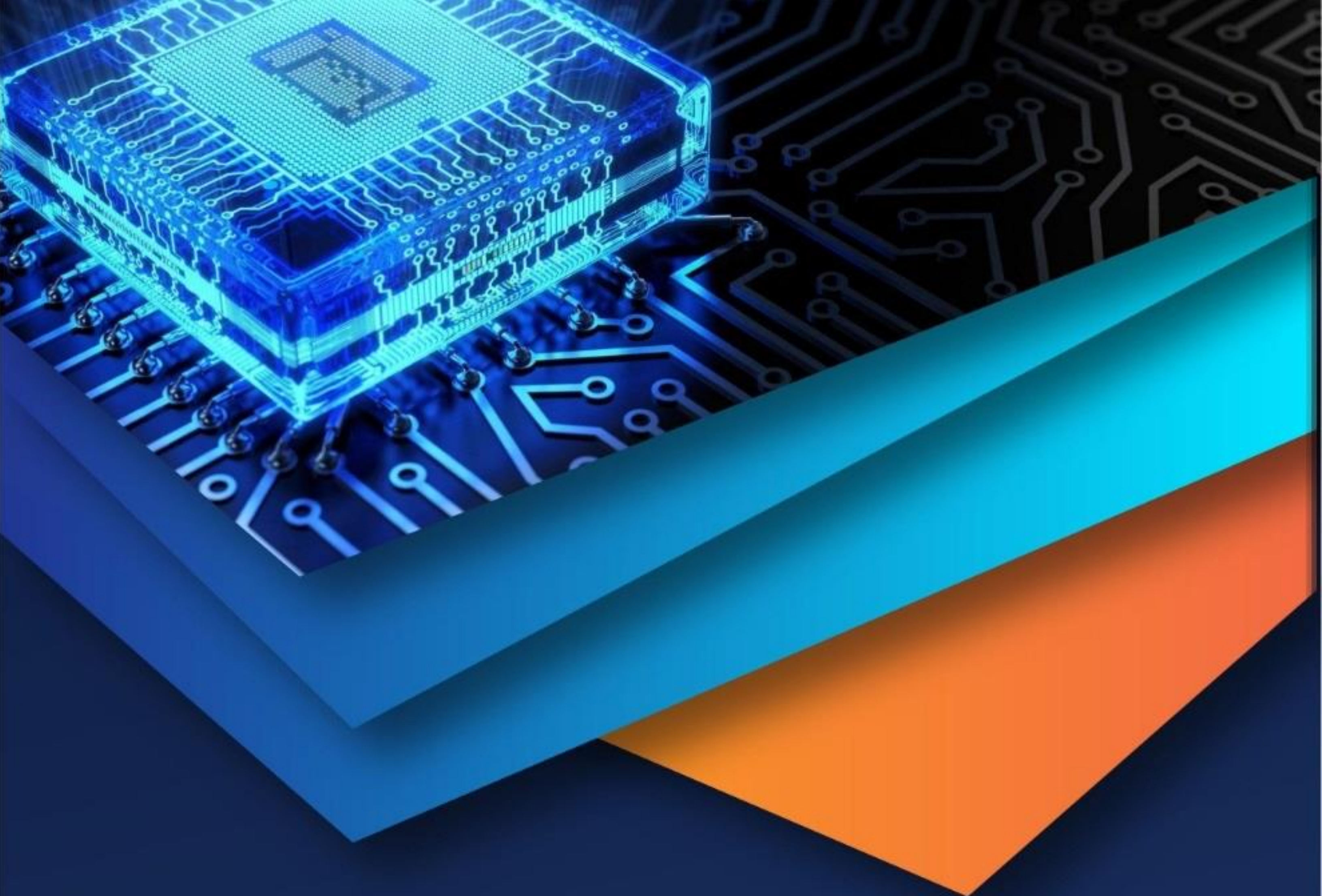

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