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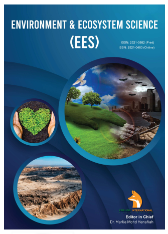

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RESEARCH ARTICLE

LANDSLIDE SUSCEPTIBILITY MODELLING IN SELECTED STATES ACROSS SE. NIGERIA

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ABSTRACT

Identification and mapping of landslide is essential for landslide risk and hazard assessment. This paper gives information on the uses of landsat imagery for mapping landslide areas ranging in size from safe area to highly prone areas. Landslide mitigation largely depends on the understanding of the nature of the factors namely: slope, soil type, lineament, lineament density, elevation, rainfall and vegetation. These factors have direct bearing on the occurrence of landslide. Identification of these factors is of paramount importance in setting out appropriate and strategic landslides control measures. Images for this study was downloaded by using remote sensing with landsat 8 ETM and aerial photos using ArcGIS 10.7 and Surfer 8 software, while Digital Elevation Model (DEM) and Google EarthPro TM were used to produce slope, drainage, lineament and elevation. From the processed landsat 8 imagery, landslide susceptibility map was produced, and landslide was category into various class; low, medium and high. From the study, it was observed that Enugu and Anambra state ranges from high to medium in terms of landslide susceptibility, Imo state ranges from medium to low.

KEYWORDS

Slope, susceptibility, landslide, landuse/landcover and Nigeria.

1. INTRODUCTION

Landslides (LS) is one of the most dangerous geological phenomena that poses danger to modern developed societies, due to their close connection to human and property losses and economic impact on the regional economy. LS is caused by major factors such as; geological, morphological, physical and human factors (Alexoudi, et al., 2010). LS are among the most widespread hazards causing millions of dollars in damages, thousand deaths and injuries around the world. Although Africa does not appear as a LS hotspot at a global scale, nevertheless the limited number of scientific publications and other field experience suggest that LS are responsible for acute problems in Equatorial Africa. During the second half of the 20th century the number of damaging landslides have substantially increased worldwide, as well as the number of studies on LS (Davies et al., 1996; Ayonghe et al., 1999; Ayonghe et al., 2004;Ngecu et al., 2004; Knapen et al., 2006;Zogning et al., 2007;Claessens et al., 2007; Kitutu et al., 2009;Gokceoglu and Sezer, 2009; Van Den Eeckhaut et al., 2009; Gutiérrez et al., 2010;Che et al., 2011; Cheet al., 2011;Broothaerts et al., 2012;Mugagga et al., 2012; Igwe et al., 2014). Like many other developing countries Nigeria has been frequently subjected to a variety of natural hazards.

Although, research on landslides in Southeastern Nigeria is still rather restricted, it is a region where LS is a widespread phenomenon. As steep slopes, high annual rainfall, increasing population pressure, deforestation and extreme rainfall make most areas in Southeast Nigeria very sensitive to LS. This is a region characterized by steep slopes, intense rainfalls, deep soil profiles and population highly vulnerable to geo-hazards. (Okagbue 1988, 1989;Okagbue, 1992a; 1992b;Okagbue, 2010 and Ogbonnaya et al., 2015). In other hand,Okagbue (1992b; 2010) further stated that LS in Southeast Nigeria is influenced by a number of factors such as; moisture, pore pressure, topography and human activities. However, it is clear that landslides have caused damages in several parts of the study area, but their assessment, prediction and management are still not well understood, as available information indicates that erosion is amongst one of the factors that trigger LS in the region (Ogbonnaya et al., 2015). Preliminary studies indicate that while rainfall event is another major triggering factors of LS in these areas, human activities, geologic features and processes also play a part in compounding on the intensity of these events and the possibility of LS with similar magnitudes reoccurring in these areas is high (Ogbonnayaet al., 2015). Though, the Federal Government of Nigeria (FGN) and other non-governmental organization has put in huge amount of resource in reducing the menace, little or no success has been achieved so far. In this paper, we introduce the LS that took place recently in the three states across southeastern Nigeria that is; Anambra, Enugu and Imo as shown in Fig. 1a and b.

1.1 Location and Accessibility

The study area is located in Southeastern Nigeria it covers a total of three states; Anambra, Enugu and Imo State. It lies between latitude $5^0$10'N-$7^0$10'N and longitude $6^0$35'E -$7^0$55' E (Figure 1). The notable rivers and Lakes that were within found within this study area are River Oji, Niger, Imo, Nike Lake, Anambra, Idemili, Njaba and Oguta Lake. The area lies between the Anambra and Niger River basins and has a drainage pattern

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that is dendritic in nature. The major river in the area is River Niger that runs Southeast with the help of tributaries, as other rivers in the area runs from southeast to northwest axis (Igwe, 2014). See (Figure 2) below.

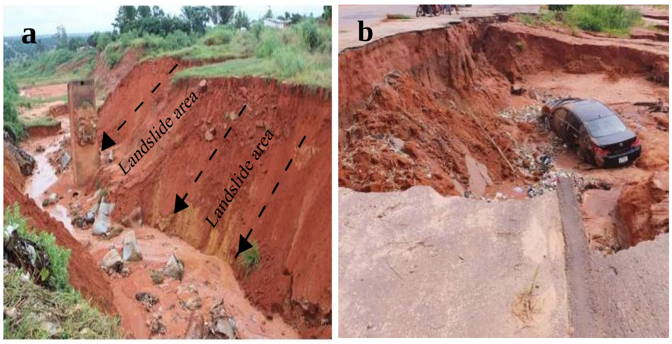

Figure 1: Landslide Points at two different locations Anambra and Imo State Southeastern Nigeria.

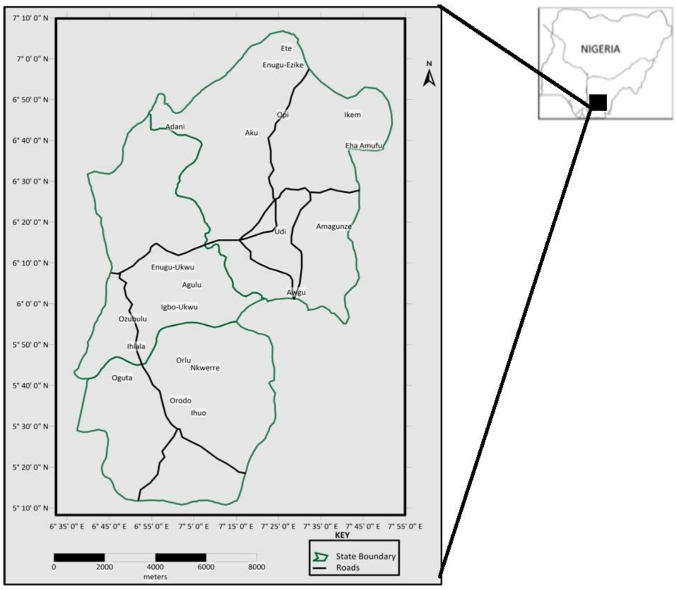

Figure 2: Map of the Study Area.

1.2 Topograhy and Climate of the Study Area

The study area lies within the humid tropical climate. It is characterized by two seasons: the rainy and dry seasons. The rainy season begins toward the end of March or early April and continues until the end of October or early November, while the dry season is between November and March. Between December and February, the northeast trade winds sweep through the region, bringing huge dusts, fog and ultimately reducing visibility. The mean monthly temperatures vary from 22 to 28^{0}C in the wet season and between 28 and 32^{0}C in the dry season. Annual rainfall (based on 2012 precipitation amount) ranges between 1500 and 2100 mm (Igwe, et al., 2013).

The average monthly rainfall for a 30-year period ranges from less than 1 mm in the dry season to about 300 mm in the rainy season (Nwankwor, et al., 1988). The wet periods are characterized by moderate temperatures and high relative humidity, while the dry periods have high temperatures and lower relative humidity (Nwankwor, et al., 1988). The study area falls in the southern Guinea Savannah, where dense forests are few and far apart. Such forests are found in low-land areas particularly where population pressure is less on land. The study area is largely dominated by short grasses at the elevated areas with thick forest of tall trees in the valleys and along drainage channels.

1.3 Geology Setting

The study area lies within the sedimentary area of Nigeria it underlain selected Niger Delta Formation.

1.3.1 Anambra Basin

The Anambra Basin is one of the Nigerian's most important sedimentary basins and comprises an almost triangular shaped embayment covering an area of about 30,000 Km^2 (Offodile,2002). The sequence of depositional events demonstrates a progressively deepening of the Anambra basin, from lower coastal plain shoreline deltas to shoreline and shallow marine deposits. Sedimentation in the Anambra Basin commenced with the Campanian – Maastrichtian marine paralic shales of the Enugu/Nkporo Formations (Obaje, 2009). The fluvio – deltaic sandstones of the Ajali and Owelli Formation which lie on the Mamu Formation constitute its lateral equivalents in most places (Table. 1).

1.3.2 Southern Benue Trough (SBT)

The tectonic history of SBT, Southeastern Nigeria dates back to the Pre Albian times. According to some study see Table 1 (Burke, et al., 1972; Nwachukwu, 1972). The SBT originated as a failed arm of the triple junction rift-ridge system, which led to the separation of Africa from South America during the Aptian/Albian. The opening of these arms started in mid Aptian in the Southern Atlantic by crustal stretching and down warping, accompanied by the development of coastal evaporites basins. It reached the Gulf of Guinea by late Albian and extended north east, to form the Benue-Abakaliki Trough. However the north east-south west (NE-SW) trending Benue– Abakaliki Trough is thought to be the result of the Pre-Albian rifting of the African Shield, prior to the opening of the south Atlantic (Uzuakpunwa, 1974).

Table 1: Lithostratigraphic framework for the Early Cretaceous-Tertiary period in southeastern Nigeria. (after Nwajide, 1990).

MA	TIME		STRATIGRAPHY	
	OLIGOCENE		OGWASHI ASABA FORMATION	
30	EOCENE		AMEKI FORMATION	
54.9	PALEOCENE		IMO FORMATION	
65			NSUKKA FORMATION	
	MAASTRICHTIAN		AJALI SANDSTONE MAMU FORMATION	
74	CAMPANIAN		NKPORO GROUP (OWELLI SANDSTONE / NKPORO SHALE / ENUGU SHALE)	
83.0	SANTONIAN		FOLDING	
86.6	CONIACIAN		AGBANI SANDSTONE	AWGU SHALE GROUP
88.5	TURONIAN	U	NKALAGU FORMATION / AWGU SHALE	
		M	AGU OJO/AMASERI/AGALA SANDSTONES	EZE - AKU SHALE GROUP
		L	NARA SHALES	
90.4	CENOMANIAN	U	EZILLO	
		M		ODUKPANI FM
		L	IBRI AND AGILA SANDSTONES	ASU RIVER GROUP
97	ALBIAN	U	NGBO	
		M	EKEGBELIGWE	
100	PRE ALBIAN - ALBIAN		UN - NAMED UNITS	
	PRECAMBRAIN		BASEMENT COMPLEX	

CRETACEOUS

2. Methods

For the purpose of this study, the research was divided into four stages namely: data capture, database generation and modelling. The Google EarthProTM aerial imagery was employed in obtaining the spatial coordinates of landslides that could not be accessed in the field. In the database generation, the following materials were used; ASTER 30m resolution digital elevation model: an ASTER 30m resolution global DEM was developed for the study area. The slope angle, slope aspect, elevation and curvature thematic maps were generated from the DEM. Landsat 8 imagery: Landsat 8 ETM imagery was acquired from the United States Geologic Survey site (www.earthexplorer.usgs.com). This was used in the extraction of land cover and lineament thematic maps of the study area. Google EarthProTM.: The Google EarthPro TM was used in the extraction of road network and drainage maps of the study area. The modelling and validation stages was carried out with the use of the ArcGIS version 10.7 and Microsoft Excel respectively.

3. Result and Discussion

3.1 Soil and Rock Type

From Figure 3 Ete, Enugu-Ezike, Opi, Aku and part of Udi fell within deep porous red soil derived from sandy deposits, Ikem, part of Eha Amufu and Amagunze fell within red and brown soils derived from sandstone and shale deposits, area such as Awgu and Adani fell within reddish and brown gravely and pale soil, places such as Orodo, Nkwerre, Ihuo, Ogbo-Uwu, Ihaila, Agulu and selected part of Enugu-Ukwu, Oguta, Ozubulu and Nkwerre fell within deep porous red soil derived from sandy deposits. further stated that the contribution of the soil and rock to LS may depends significantly on the similarity of the response of the country rock in their study area and its derivative soil and rock mantle to sliding forces (Okagbue, 1988).

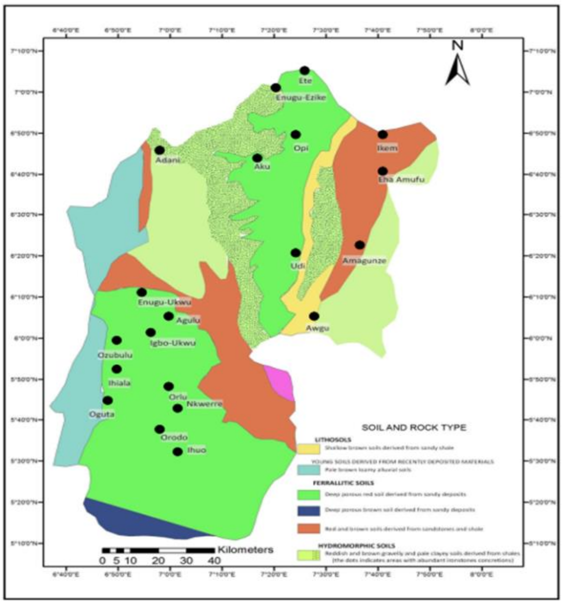

Figure 3: Spatial distribution of Soil and Rock Type across the Study Area.

3.2 The slope angle thematic map

Slope was grouped into six category based on angle range. From (Figure 4) it was observed that the slope angle in the study area ranges from 0^0 to 66.48^0.

Thus, the susceptible level to landslides of the slope ranges from.

i. Fair slope 2.34^0 to 4.95^0 (faciliates the frequency of landslide occurrence)
ii. Moderate slope 4.95^0 to 8.60^0 (has susceptibility level of landslide occurrence).
iii. Fairly moderate 8.60^0 to 14.07^0 (has the highest level of landslide occurrence).
iv. Steep slope 14.07^0 to 25.54^0 (has the second highest susceptibility level of landslide occurrence).
v. Very steep slope 25.54^0 to 66.48^0 (has dangerous susceptibility level of landslide occurrence).
vi.

Van Ranst and Shu stated that slope geometry between the ranges of 2.00 – 68.70^0 contributes to loss of soil and slope failure, as it can trigger landslide (Van Ranst and Shu, 2012). Slope geometry is considered as one of the major factor that trigger landslide, across most part of the world.

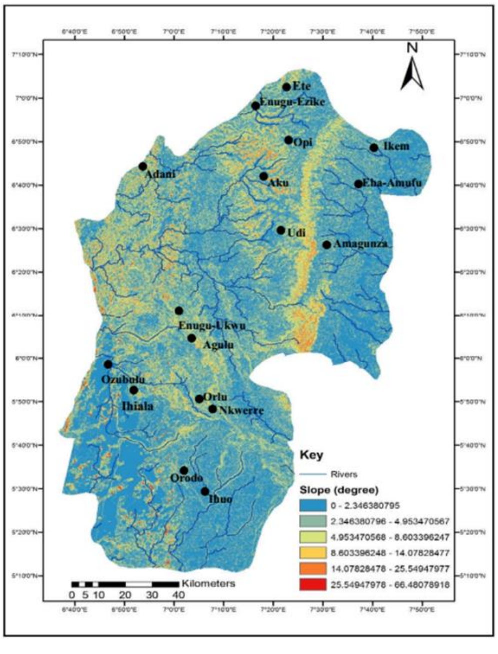

Figure 4: Slope Map of the Study Area.

3.3 Landuse/landcover Thematic Map

The classification and image interpretation indicated that there are five major landcover/landuse patterns in the study area. The five types of landcover/landuse are: rivers, trees, built-up areas, grass/farmland, soils and Rocks (Figure 5). Previous studies has shown that s built-up areas as well as grass and farmland are been encroached upon as a result of human activities the area becomes a major trigger for environmental hazards such as erosion in southeastern Nigeria (Okagbue, 1986; 1988 and 1992).

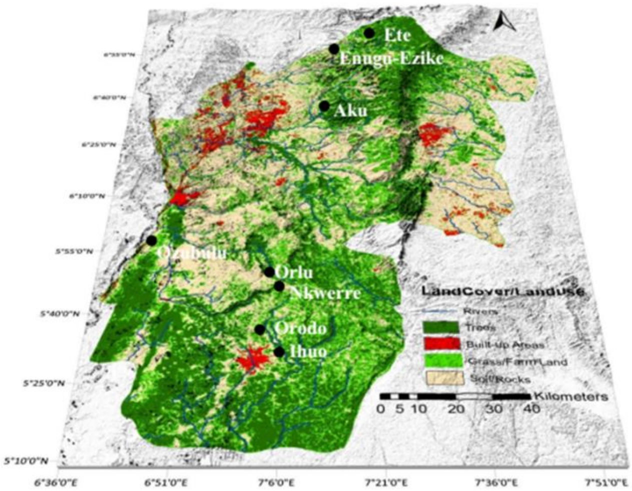

Figure 5: Landuse/landcover Map of the Study Area.

3.4 Lineament Buffer

Lineaments are the linear morpho-tectonic features of the terrain which include faults, fractures, ridges, major discontinuities etc (Sarkar, et al., 1995). Lineament indicates the zone or plane of the weakness of structural feature. Hence, the probability of landslide occurrences increases with increase in the closeness of lineaments (Saranathan and Anabalagan 2013). From Figure 6 shows the spatial distribution of the mapped landslides with respect to distance to drainage. Area that has a highly compacted lineament will be described as area prone to landslide. While area that has with low lineament may not be easily prone to landslide (Figure 6).

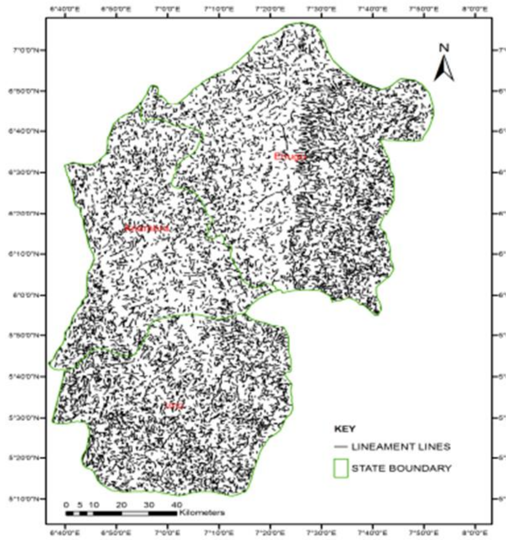

Figure 6: Lineament Buffer Map of the Study Area.

3.5 Lineament Density

Lineaments are the linear morpho-tectonic features of the terrain which include faults, fractures, ridges, major discontinuities (Sakar et al., 1995). Lineament indicates the zone or plane of the weakness of structural feature. As the probability of landslide occurrences increases with increase in the closeness of lineaments (Van et al., 2009). From the lineament density map shown in figure 8 the highest susceptibility level with pale red at 1 to 1.51541 km^2 was found to be areas of low lineament density while the lowest susceptibility level with blue indicates the areas of high lineament density with range at 0.0817201 km^2.Therefore, the sum of susceptibility levels from very low, low to moderate lineament density classes reveal that more than two thirds of total landslide frequencies occurred on these low ranks of lineament density classes (Figure 7).

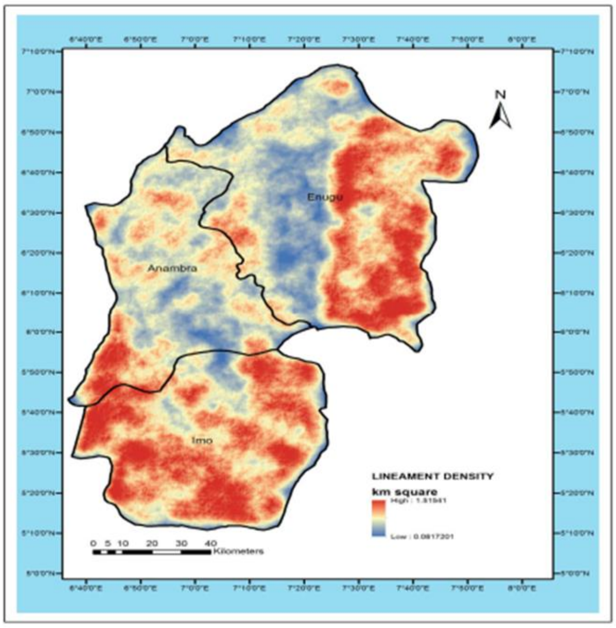

Figure 7: Lineament Density Map of the Study Area.

3.6 Elevation Factor

Studies have shown that landslides tend to occur more often with an increase in elevation (Devkota et al., 2013). Figure 8 shows the spatial distribution of landslides with respect to the altitude in the study area. There is a spatial distribution and relationship between landslides with respect to the elevation in the study area. Some researchers stated that LS hazard evaluation and zonation mapping stated that an elevation ranges of between 196.48m to 735.08m in maps are said to be areas prone to landslides (Anbalagan et al., 2008). Figure 10 shows the different elevation ranges in relation to landslide in the study area.

i. At an elevation range of 350m to 550m within Nsukka, Udi and Oji-River axis the topography is mountainous with high elevation level susceptible to landslide.

ii. At an elevation range of 200m to 350m within Anaocha, Orumba North and Aguata axis the topography is mostly undulating and plain and equally prone to landslide.

At an altitude range of 100 m to 200 m within Ideato North, Ideato South and Orlu axis the topography falls within undulating and plain and also susceptible to landsliding. Where the slope is less than 100m no landslide occur therefore susceptibility level is lowest.

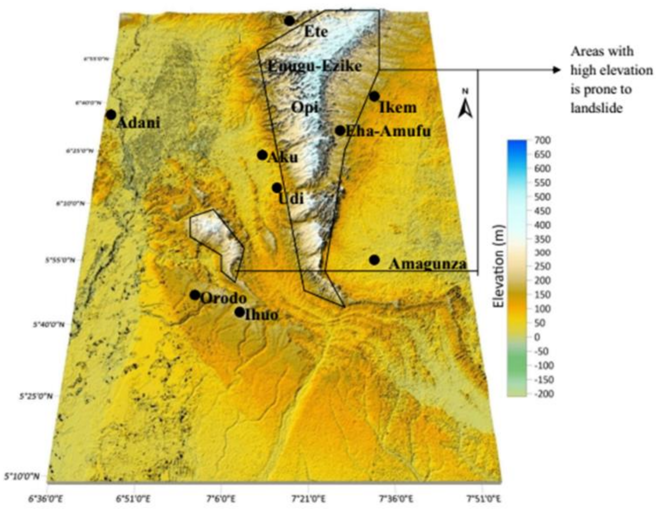

Figure 8: Elevation Map of the Study Area.

The landslide susceptibility was classified into three category: low, medium and high landslide susceptibility zones as shown in Fig. 9. From study it was observed that Nsukka, Udi and Oji- River in Enugu state showed high to medium susceptibility levels. This is followed by Anoacha, Orumba North and Aguata in Anambra state which shows a moderate susceptibility level to landslide occurrence least on the map is Ideato North, Ideato South and Orlu in Imo that falls between medium to low level in susceptibility level.

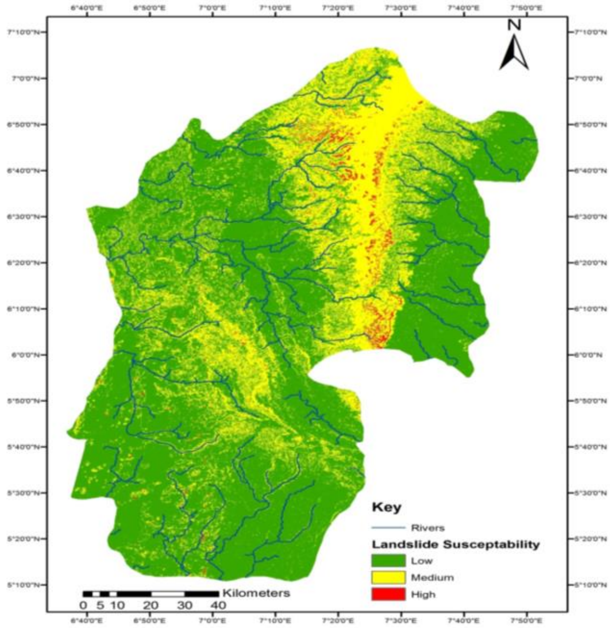

Figure 9: Landslide susceptibility Map of the Study Area.

4. Conclusion

The resultant susceptibility zonation maps were re-classed into three susceptibility zones namely; high, medium and low zones respectively. The landslide density distribution shows an increase in the spatial distribution of landslides from the low to the high susceptibility classes in the landslide susceptibility map produced. The landslide prone areas fall within the high to moderate susceptibility zones in both landslide susceptibilities. In conclusion the research revealed that area where LS occurred is area with soil in high clay content (Enugu and Anambra state) and areas with loosed soil such as sandy soil (Imo state). However, the soil in Imo state is said to be loosed, but loosed soils in the area account for the landslide problems because as water flows through the soil with ease there are movement of soil particles down slope with increase in velocity of motion of the water. While the presence of clay materials presence in soils of (Enugu and Anambra) serve as a gliding plane for landslide within the area.

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