

Original Research Article

**A GIS APPROACH TO EROSION VULNERABILITY ASSESSMENT OF A
DEVELOPING CITY**

ABSTRACT

The problem of erosion has over time been exacerbated by the development and constructions of buildings, roads, poor drainage system and other urban characters on areas transiting from rural to urban setting. This study set out to evaluate the vulnerability of Orlu L.G.A., Nigeria, to erosion in the face of increased anthropogenic activities using topography as criteria. Satellite images were analyzed for changes in land use and land cover, while GPS coordinates of different points in the area were obtained and interpolated into a map to create digital elevation model (DEM). With the aid of the Geographic Information System (GIS), slope pattern was established, and the final erosion vulnerability map was produced. Urbanization has triggered some erosion problems in the study area. Gully formation was seen to have been induced mainly by poorly designed construction works. The study also established that though erosion problems have been triggered by certain urban characteristics, other erosion problems were also due to the inherent geologic formations of the study area. Erosion problems appearing not to be incited by urbanization were such as seen in the very prone areas on the vulnerability map (which is towards north of the study area); however, other areas prone to erosion with very little trace of urban influence could be as an indirect impact of the *built-up* area.

Keywords: Erosion, Vulnerability, Geographic Information System, Digital
Elevation Model, Urbanization

25 1.0 INTRODUCTION

26 Soil erosion is one of the most serious land degradation problems all over the world, causing
 27 irreversible land quality reduction. (Jianping, et al., 2012). It has been defined as the removal
 28 of the soil surface material by wind or water (Wischmeier & Smith, 1978). Water is
 29 the most dominant agent of erosion where the process includes detachment, transportation and
 30 deposition of sediments by rain drop impact and flowing water. Erosion is one of the major
 31 problems in agriculture and natural resources management. It reduces soil productivity,
 32 pollutes streams and fills reservoirs (Fangmeier, *et. al.*, 2006). Human activities such as
 33 construction of roads, highways, and dams, control works on streams and rivers, mining, and
 34 urbanization usually accelerate the process of erosion, transport, and sedimentation (Julien,
 35 2010).

36 An important factor contributing significantly to soil erosion problems in southern Nigeria is
 37 anthropogenic influence arising from misuse of land. Poor farming systems have contributed
 38 to collapse of soil structure and thus encouraging accelerated runoff and soil loss due to
 39 erosion. The event of uncontrolled grazing caused by nomads has resulted in deforestation of
 40 the landscape while indiscriminate foot paths created on the landscape has helped the
 41 incipient channels on the landscape to form. These channels eventually metamorphose to
 42 gullies especially when they are not checked at inception. Road constructions including
 43 uncontrolled infrastructural developments have contributed significantly in gully
 44 developments. Some road networks under construction have been abandoned in the region
 45 due to gully formation (Igwe, 2006).

46 According to (Landscape Planet, 2015) human activities, mainly agriculture and construction
 47 on the earth's surface are known to exacerbate erosion 10 times more than naturally occurring
 48 processes. Construction when unnecessarily conducted can be quite damaging to soil and dirt,
 49 while deforestation and agriculture remove the top soil and makes it prone to erosion
 50 The need for comfort and satisfaction of human desires, majorly as a result of human
 51 population increase and migration activities, has led to the transformation of rural landscapes
 52 into urban. As a result, structures are developed and virgin areas and agricultural lands
 53 restructured to follow suit. This act of urbanization results in changes unusual to the natural
 54 environment, as it creates transformation in the land cover, slope and even the watershed of
 55 the area (Living Certificate Geography. 2015).

56 In the context of environmental protection, most concerns about erosion are related to accelerated
 57 erosion, where the natural rate has been significantly increased mostly by human activity. (Ionuș,
 58 O. et. al., 2013). Erosion vulnerability has been mapped using GIS models (Lufafa., et. al.,
 59 2003; Maidment, & Djokic, 2005).

60 This paper focuses on assessing the erosion tendencies of an area transiting from the rural
 61 settings to urban. Parameters of urbanization include the proliferation of structures, clearance
 62 of vegetative cover for urban purposes, road constructions in lieu of foot tracks, and other
 63 significant changes on the land use and cover.

2.0 STUDY AREA

This study was carried out inOrlu L.G.A. in Imo state Southeast Nigeria. It has a total land area of 7.34km², and lies within latitude 5°43'45" to 5°53'00" and longitude 7°0'00" to 7°7'30". The population of the area is 142,717 (NBS, 2006). It is the third largest city in Imo state located in a sedimentary rock formation and lies within the Awka-Orlu uplands in a zone of sandy lateritic soil (FIG.1). The climate is typically humid, the same as is obtainable in the Southeastern region of Nigeria. Two distinct seasons are familiar with the climate of the area. The rainy season, that begins in April and ends in October, with higher intensity in June and late September, and the dry season, which begins in November and ends in March. The annual rainfall varies between 1,990mm and 2,200mm.

Temperature is generally high with little variation during the year. The mean annual temperature is about 27⁰C with an average annual relative humidity of 75 percent which is high during the rainy season.

The vegetation of Orlu is rain forest and the topography is undulating. Inhabitants produce agricultural products such as palm produce, cocoa and rubber. The main staple crops are yam, cassava, cocoyam and maize. The economy of the area depends largely on agriculture and commerce and the chief occupation of the people is farming. Sample communities were Amaifeke, Mgbidi and Ehiri.

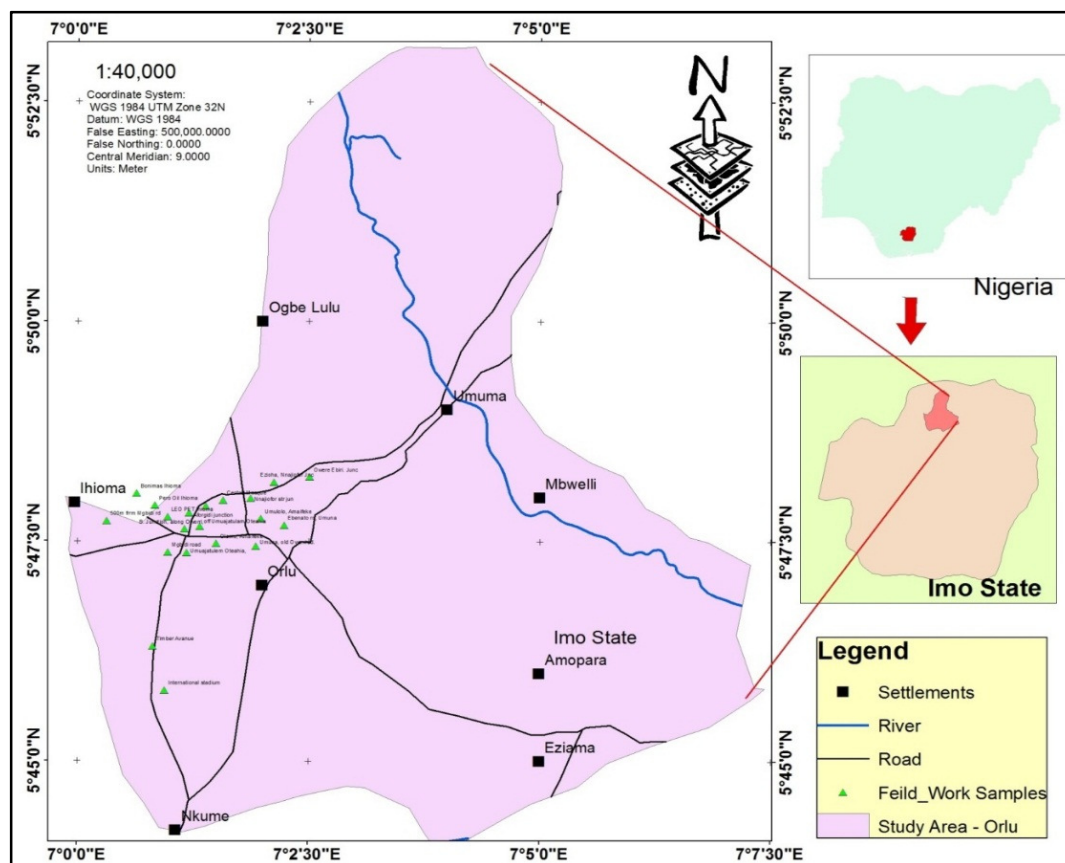


Figure1: Map of the Study Area

(Arabinda, 2010), asserts natural as well as human-induced land use land cover change (LULC) has significant impacts on regional soil degradation, including soil erosion, soil acidification, nutrient leaching, and organic matter depletion. Since the last century, soil erosion accelerated by human activities has become a serious environmental problem. It has a manifold environmental impact by negatively affecting water supply, reservoir storage capacity, agricultural productivity, and freshwater ecology of the region.

3.0 MATERIALS AND METHODS

3.1 TYPES OF DATA

Data for this study were obtained from both primary and secondary sources.

The primary data was obtained from direct field observations and a GPS (Extrex Garmin Version 16.0) instrument. The GPS was used to acquire the coordinates of specific areas used in assessing the terrain of the study area. While secondary data include the following satellite data: the NigeriaSat-X image of 2nd December 2013, acquired from GeoApps Plus with band combination 123 and 22 metre spatial resolution and the Shuttle Radar Topographic Mission (SRTM) data, acquired from U.S Geological Survey (USGS) University of Maryland, as well as publications from textbooks, journals, articles and the World Wide Web (www)

Softwares used to execute this study include;

a. Arc-GIS 10.0: Arc-Map was used for the vectorization and digitizing of the images to generate the map of the study area. ArcCatalogue was used in creating a personal geo-database and shape-file used to generate the study area map.

b. Arc-Scene™ 10.1: This was used to generate the 3D Digital Elevation Model of the area in order to assess the nature of the terrain.

c. ERDAS IMAGING 9.2: Erdas Imagine 9.2 was used for spatial, spectral and radiometric enhancement. Spatial enhancement was carried out using a resolution merge model. It was also used to generate the land use land cover map revealing the current land use in the area

d. Other ancillary software used were:

Microsoft office word 2013, Microsoft office excel 2013 etc.

The mapped out area for the analysis was subjected to a supervised classification analysis and at this stage the domain of the spatial parameters mentioned above were adopted and further subjected to maximum likelihood classifier of the ERDAS software.

Land-use and land cover classification was done using the Anderson,*et. al.*, (1976), USGS classification scheme. Results describing the various disparities in vegetation, settlements, and the nature of the terrain are presented in maps, tables and histogram. The results in a table form showing disparities in spatial parameters using the number of pixels classified and the corresponding area in hectare. Furthermore, the tables will also be displayed in pie charts, histogram etc., for enhanced visual interpretation of the results.

4.0 RESULT PRESENTATION AND DISCUSSION

4.1 LAND USE LAND COVER DISTRIBUTION OF THE STUDY AREA

The land use land cover classification results are presented in maps, as shown in Fig. 2

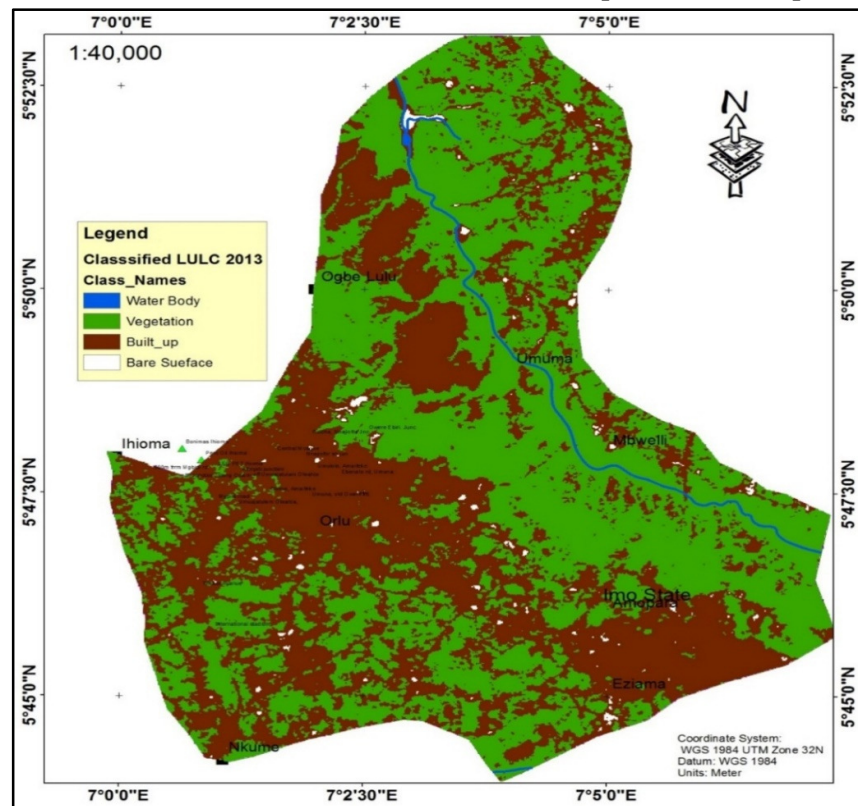


Figure 2: Land use land cover map of the study area 2013

In this study, three colour composite with RGB, R=Red, G=Green, B=Blue bands of Nigériasat-X multispectral image was adopted for the Landuse Landcover classification. The mid infrared portion of the spectrum is sensitive to active vegetation, blue represented the areas occupied by water bodies, white was used to represent areas covered by bare soil and brown was used to indicate areas with built-up surfaces. The composite image provides a naturalistic and earth view of the study area. The composite images revealed the drainage pattern of the study area to be linear. The raster attributes of the classification is shown in table 4.1

Table 4.1 The Raster Attributes for 2013 (Land Use Land Cover Distribution) Results

Class Name	Red	Green	Blue	Histogram	Opacity	Area(H)	Area (%)
Unclassified	0	0	0	0	0	0	0
Bare Surface	1	1	1	1805	1	87.362	0.672762
Water Body	0	0.33	0.48	80	1	3.872	0.029818
Vegetation	0.65	0.29	0.31	142440	1	6894.096	53.09044
Built-up	0	0.87	0.83	123972	1	6000.245	46.20702
Total				268297	4	12985.57	100

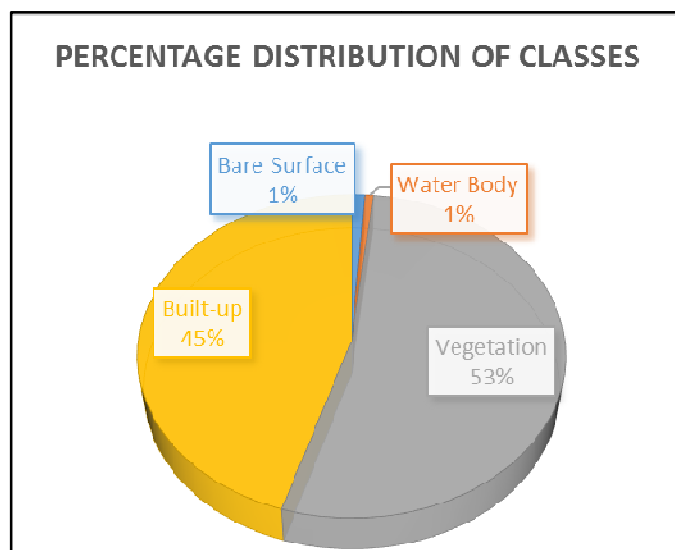


Figure 3: Percentage distributions of classes from the LULC map.

According to the assessment of the LULC from the satellite imagery, it was revealed that vegetation occupied the highest percentage of the total area with an estimated land cover of about 53% of the total land cover classes, taking up more than half of the total classes. Whereas Built-up cover was the second largest with total of 45% of the entire study area, bare surface land with only 1% and water body occupying a very little space of the entire area as seen from the LULC map this was because the major watershed in the area was surrounded by a very high riparian vegetation making the water body 1%. This is further depicted in figure 3

The area is thus urbanizing as it appears not to be more built-up than vegetative; it therefore becomes a clear basis for the considerations for an Emerging urban center as is the aim of the study.

4.2 EROSION VULNERABILITY MAPPING RESULTS

Geostatistical model (GM) and the Geographic Information System (GIS) are used as the Decision Support System (DSS) for the examination of the vulnerability rate of gully erosion (Lu., *et. al.*, 2004). In this study, the slope of the area was generated in order to develop the vulnerability map of the area. The terrain of the study area was also assessed in order to visualize the undulation of the terrain.

4.2.1 SLOPE PATTERN OF THE AREA

See figure 4 for the map of slope pattern of the study area.

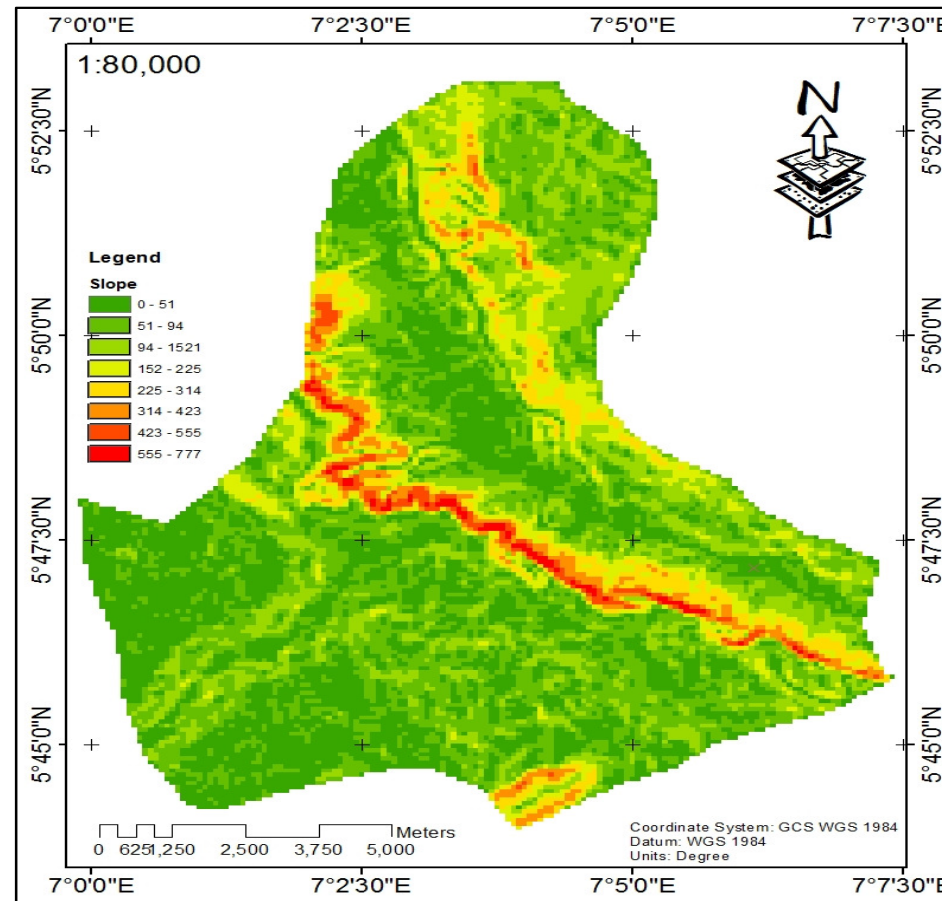


Figure 4: Slope Map of the Area

The legend shows slope of eight (8) categories. The slope here is the gradient of the particular zone as indicated in the classified map. Areas of higher slope values shows the direction of erosion occurrence and the possible movements of run-off. This implies that areas with increasing slope values shows run-off /moving water runs into the gullies or flows in the direction of the eroded areas. Essentially water runs off from the areas of higher value to the areas of lower value. This is in agreement with the result of the generated erosion vulnerability map of the study.

The areas under 555-777 metres are highly steep and those between 0-51 metres are the less steep places, relatively. It is of necessity to mention the region under 225-314 metres as well represented in the area. The image shows a lesser distribution of the very steep places and a larger distribution of the slope regions below the “yellow” mark places. This indicates that higher slope areas will trigger higher water runoff. As a consequence, the “red” places though fewer are highly vulnerable to erosion. This slope cut across through the north-east and through the centre of the whole area, which falls within the communities of Amaifeke, Ogberuru, Eziam, Amopara and Umuna. Such areas of high gradient are anticipated to have several gully erosion sites.

In relation to the LULC distribution, the areas with greater slope gradient had more vegetation than built-up areas. This indicates that gully formation would not have been a function of urbanization only. Urbanization impacts on erosion in these high slope gradient areas can only result indirectly. On the other hand, the study concludes that as the watershed runs down to the receptive water body, built-up areas would have created barriers such that runoff becomes too high at the slightest incidence of rainfall leading to massive erosion and formation of gullies.

The perch of high slope in the south part of Ezizama indicates the same event as we see the much built-up community close to the water body.

4.2.2 ELEVATION MODEL

FIG. 5 is a display of the elevation pattern evident in the study area.

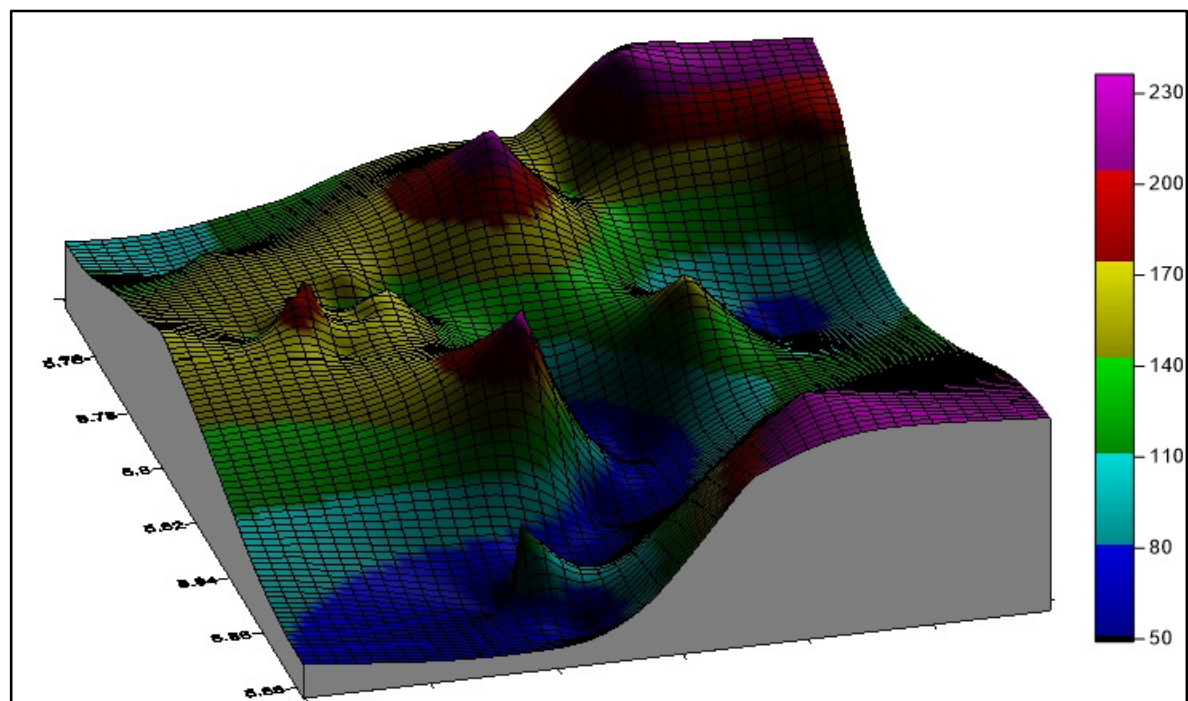


Figure 5: Digital Elevation Model Showing the Area Vulnerable to Erosion.

The elevation patterns revealed by this DEM gives a general representation of the topographic conditions of the study area.

As a result of the spatial resolution of the Shuttle Radar Topographic Mission data used to generate the digital elevation model, the results display the geomorphologic characteristics that facilitate the development and formation of gullies inherent in the area.

From the results of the area, it was concluded that: Areas within the elevation of 230m-170m are regarded as highly safe from erosion and flood. While areas within the elevation of 170m-140m are regarded as moderately safe from erosion and flood.

Thus, areas within the elevation of 140m- below were classified as highly prone to flood and erosion. This is due to the increased steepness and length of the slope which invariably increases the velocity and volume of surface runoff (Ahmad, 2013)

4.2.3 EROSION VULNERABILITY MAPPING OF THE AREA

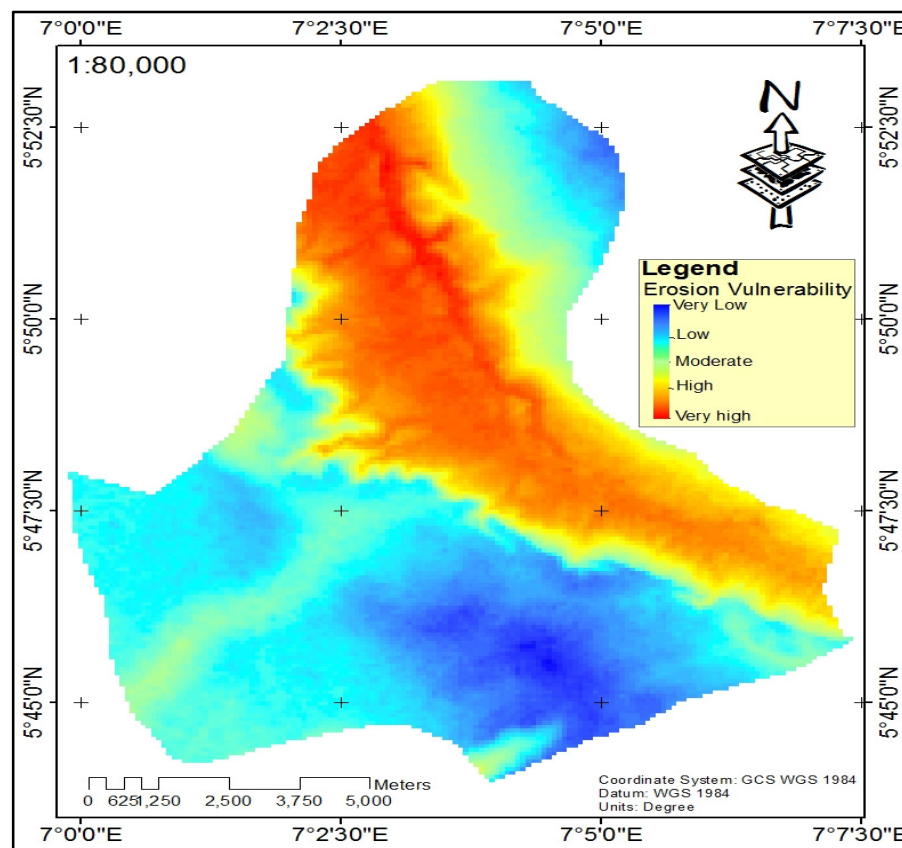


Figure 6: Vulnerability map of the area.

Figure 6 corresponds to the spatial distribution of known areas of erosion menace in the region.

From figure 4, the slope map of the area, it was observed that the steep areas in the study areas are more vulnerable to erosion risk. According to Figure 6 the category of erosion risk in the study area were classified as low, very low, moderate, high and very high. Comparing the LULC map generated during the study, it was deduced that there were major built-up areas in the study area that are located within high to very high erosion risk zone. Thus, areas within High to very high are critical areas vulnerable to erosion.

5.0 CONCLUSION

According to the result, certain areas vulnerable to erosion was due to urbanization resulting from constructions of buildings/roads and especially the ongoing construction Eastern Palm University and Stadium, which required land excavation etc that results in alteration of landforms at particular times. Though urbanization played a role in the erosion vulnerability of the urban center, it was also seen that certain other erosion problems emerged not as a result of construction of buildings. The instances for these are the very prone areas close to the water body which naturally will be a collection point for runoff in the watershed system.

5.1 RECOMMENDATION

Based on the level of vulnerability of erosion in the study area, this study recommends that the urban planning unit of the government should engineer the runoff channels in the area such that it will properly be channeled to the nearby streams.

The residents of the area should manage properly drainage systems in the areas to enhance flow of runoff after rainfall as this will reduce the effect on the soil structure of the area.

It is worthy to also recommend, as a consequence of this study, that careful considerations be given to the drainage flow and pattern in the area, as this will reduce the risk of erosion and also flooding.

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