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Vulnerability Assessment of Soil Erosion Based on Topography and Vegetation Cover in a Developing City of Orlu L.G.A, South East Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Authors MCI and KOEU designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Authors GTA and OLI managed the analyses of the study. Authors JDN and SOA managed the literature searches. All authors read and approved the final manuscript.

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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 a combination of Geographic Information System (GIS) and soil characteristics. Soil samples were collected and analysed for geotechnical/physical properties, slope was also measured. Satellite images where 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 GIS, slope pattern was established. Urbanization has triggered some erosion problems in the study area. Gully formation

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was seen to have been induced mainly by poorly designed construction works. The study also established the degree and length of slope, the soil and inherent geologic formations of the study area are the primary factors of the gully erosion in the study area. From the GIS generated images, the northern and western section of the study area are prone to erosion hazards and this was confirmed by a field reconnaissance survey.

Keywords: Erosion; vulnerability; Geographic Information System; Digital Elevation Model; urbanization.

1. INTRODUCTION

Soil erosion is one of the most serious land degradation problems all over the world, causing irreversible land quality reduction [1]. It has been defined as the removal of the soil surface material by wind or water [2]. Water is the most dominant agent of erosion where the process includes detachment, transportation and deposition of sediments by raindrop impact and flowing water. Erosion is one of the major problems in agriculture and natural resources management. It reduces soil productivity, pollutes streams and fills reservoirs [3]. Human activities such as construction of roads, highways, and dams, control works on streams and rivers, mining, and urbanization usually accelerate the process of erosion, transport, and sedimentation [4].

An important factor contributing significantly to soil erosion problems in southern Nigeria is anthropogenic influence arising from misuse of land. Poor farming systems have contributed to collapse of soil structure thus encouraging accelerated runoff and soil loss due to erosion. The event of uncontrolled grazing caused by nomads has resulted in deforestation of the landscape while indiscriminate foot paths created on the landscape has helped the incipient channels on the landscape to form. These channels eventually metamorphose to gullies especially when they are not checked at inception. Road constructions including uncontrolled infrastructural developments have contributed significantly in gully developments. Some road networks under construction have been abandoned in the region due to gully formation [5].

According to [6] human activities, mainly agriculture and construction on the earth's surface are known to exacerbate erosion ten times more than naturally occurring processes. Construction when unnecessarily conducted can be quite damaging to soil and dirt, while deforestation and agriculture remove the top soil and makes it prone to erosion.

The need for comfort and satisfaction of human desires, majorly because of increase in human population and migration activities, has led to the transformation of rural landscapes into urban landscapes. Thus, structures are developed and virgin areas and agricultural lands restructured to follow suit. This act of urbanization results in changes unusual to the natural environment, as it creates transformation in the land cover, slope and even the watershed of the area [7].

In the context of environmental protection, most concerns about erosion are related to accelerated erosion, where the natural rate has been significantly increased mostly by human activity [8]. Erosion vulnerability has been mapped using GIS models [9,10].

It has been noted that natural as well as human-induced land use land cover change (LULC) have had significant impacts on regional soil degradation, including soil erosion, soil acidification, nutrient leaching, and organic matter depletion [11]. 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 Study area.

Geo-spatial modelling also known as digital terrain modelling is the study of ground surface relief and pattern by numerical methods [12; 13]. It has become integral to hydrology, tectonics, oceanography, climatology, and geo-hazards assessment and involves a combination of Remote Sensing and Geographic Information System (GIS) as tools in landscape analysis. The importance of GIS in landscape analysis stems from its ability to combine through overlay different layers of data such as land cover conditions and human pressure indices such as population density, and urban expansion.

This paper assessed the vulnerability to soil erosion of an area transiting from the rural setting to urban landscape. Prominent factors that necessitated this research were the poor soil quality and terrain of the area. Parameters of urbanization include the proliferation of structures, clearance of vegetative cover for urban purposes, road constructions in lieu of foot tracks, and other significant changes on the land use and cover.

2. STUDY AREA

This study was carried out in Orlu Local Government Area of Imo State, Southeast Nigeria. It has a total land area of 7.34km^2, and lies within latitude 5^{o}43'45" to 5^{o}53'00" and longitude 7^{o}0'00" to 7^{o}7'30". The study area was chosen because there are several gullies in the area and it lies on an undulating highland. Equally there has been unprecedented urbanization efforts by two successive civilian regimes in Imo State, Nigeria whose executive governors have come from this area, since the inception of democratic governance in 1999. The population of the study area was 142,717 [14]. It is the third largest urban centre in Imo State located on a sedimentary rock formation within the Awka-Orlu uplands in a zone of sandy lateritic soil [15] (Fig. 1). The climate is typically humid, the same as is obtainable in the Southeastern region of Nigeria. There are two distinct seasons; the rainy and dry season. The rainy season begins in April and ends in October, with higher intensity in June and late September, while the dry season, begins in November and ends in March. The annual rainfall varies between 1,990 mm and

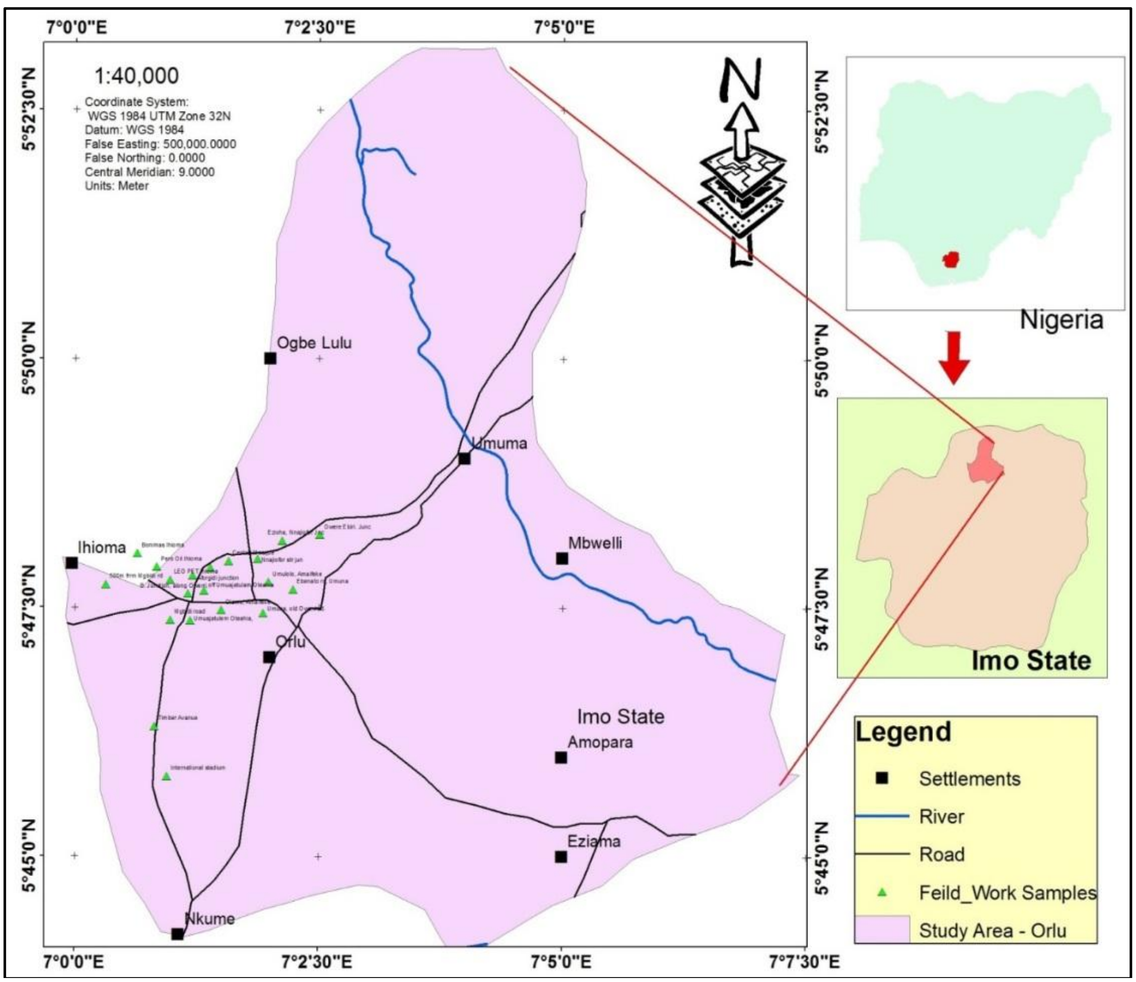

Fig. 1. Map of the study area

2,200 mm. Temperature is generally high with little variation during the year. The mean annual temperature is about 27°C with an average annual relative humidity of 75 percent. The vegetation of Orlu is rain forest and the topography is undulating. Inhabitants of the area are farmers producing 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.

3. 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 included 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 used for assessment of the topography of the area which was used to generate the slope map of the study area, acquired from U.S Geological Survey (USGS) Earth Explorer data archive, as well as publications from textbooks, journals, articles and the World Wide Web (www).

Software used 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. **Surfer 10:** This was used to generate the 3D Digital Elevation Model of the area in order to assess the nature of the terrain. The data used was based on the Longitude, Latitude and Altitude GPS data collected during the field survey.
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 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 [16], 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.

Soil analysis for bulk density, dry density, moisture content, shear strength and atterberg limits was carried out in the laboratory using the [17] soil survey laboratory methods.

4. RESULTS 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.

In this study, three colour composite with RGB, R=Red, G=Green, B=Blue bands of Nigeriasat-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 are shown in Table 1.

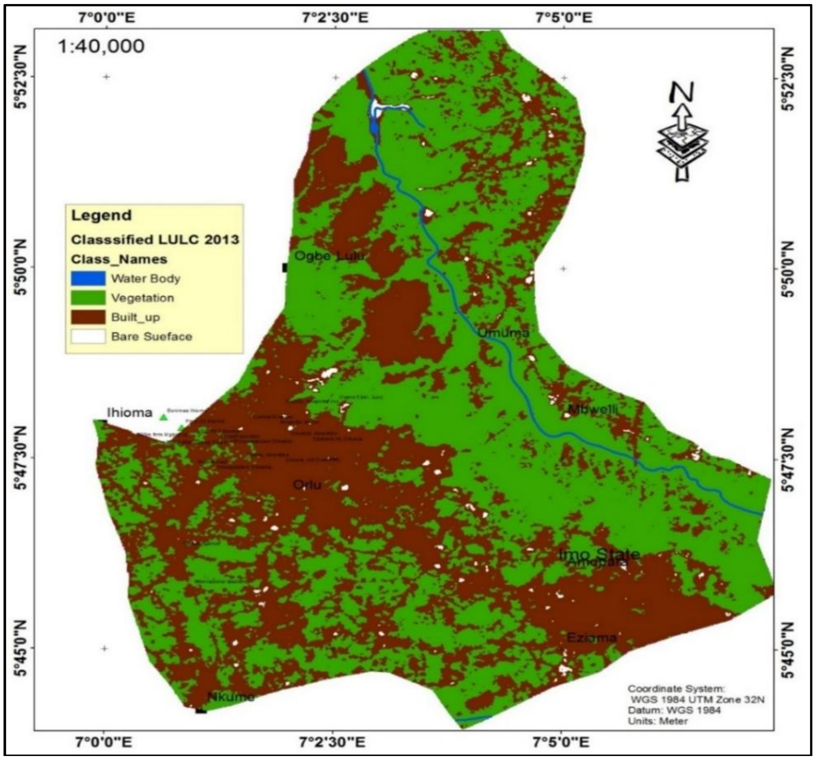

Fig. 2. Land use land cover map of the study area 2013

Table 1. The raster attributes for 2013 (land use land cover distribution) results

Class name	Histogram	Opacity	Area(H)	Area (%)
Bare Surface	1805	1	87.362	0.672762
Water Body	80	1	3.872	0.029818
Vegetation	142440	1	6894.096	53.09044
Built-up	123972	1	6000.245	46.20702
Total	268297	4	12985.57	100

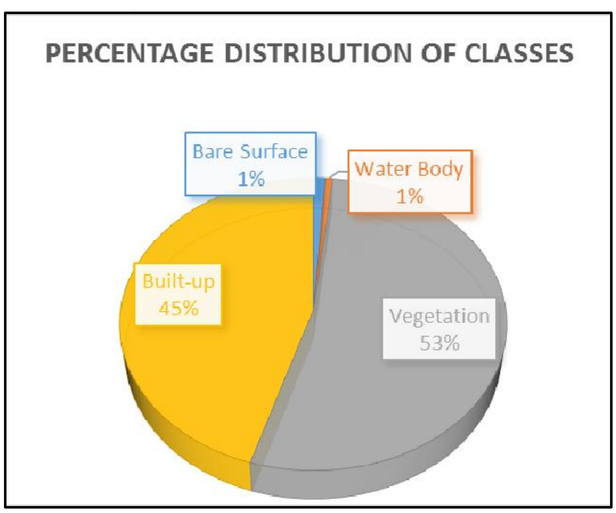

Fig. 3. Percentage distributions of classes from the LULC map

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. 45% occupied by built-up area is huge indicating that the area is under intense urbanization which will ultimately lead to excessive surface water runoff from the impervious surfaces associated with urban landscape.

4.2 Soil Characteristics of the Area

The LULC show 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. While Built-up cover is 45% of the entire study area, the area occupied by built-up area is huge indicating that the area is under intense urbanization which will ultimately lead to excessive surface water runoff from the impervious surfaces associated with urban landscape. Table 2 shows that Slope is between 3.49% to 12.28%, permeability 1.7×10^{-2} while the Atterberg limit of the soil showed that the soil in the area is non-plastic.: A non-plastic do not bind and are easily eroded, once the top layer or cover is removed.

4.2 Erosion Vulnerability Mapping Results

Geostatistical model (GM) and Geographic Information System (GIS) are used as the Decision Support System (DSS) for the examination of the vulnerability rate of gully erosion [18]. In this study, the slope of the area was generated and 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 Fig. 4 for the map of slope pattern of the study area.

The legend shows slope of six (6) categories. The slope here is the gradient of the particular zone as indicated in the classified map. Areas of higher slope values show the areas vulnerable to erosion as a result of steep slopes and the possible movement of runoff. This implies that areas with increasing slope values shows runoff /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.

The areas under 33-63 percent are valleys (part of the tributary of Orashi river (Ezize Asa Stream and the boundary between Orlu and Ideato) and areas between 0-20 percent are well represented in the area, it is from this zone that runoff are generated, is a gentle slope (2- 7° i.e between 3.49% to 12.28%). 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. Consequently, the areas where runoff is generated with poor erodibility characteristics are highly vulnerable to soil erosion while the "red" places serves as sink receiving sediments from the gully erosion. This vulnerable area are in the North and Northwest section of the study area, communities within this boundary are Amaifeke, Ogberuru, Eziama, Amopara and Umuna. And these places are known as the erosion precinct of Orlu.

Table 2. Topography/Characteristics of soil in the study area

Locations	Elevation (m)	Slope	Texture	Bulk Density	Dry Density	Moisture content	Shear Strength	Atterberg Limits
Mgbidi	146	2°		1.58	1.64	14.67%	-9 kpa/σ31°	NP
Amaifeke	155	4°		1.51	1.63	16.79%	-8kpa/σ30°	NP
Ndiokwe	148	6°		1.65	1.31	13.31%	-15kpa/σ31°	NP
Okporo Rd	130.1	4°		1.48	1.71	14.08%	6 kpa/σ30°	NP
Ogberuru	155	7°		1.49	1.59	15.68%	5 kpa/σ29°	NP

- *Shear strength Cohesion (kpa)/angle of internal friction (σ°)*
  NP – Non Plastic

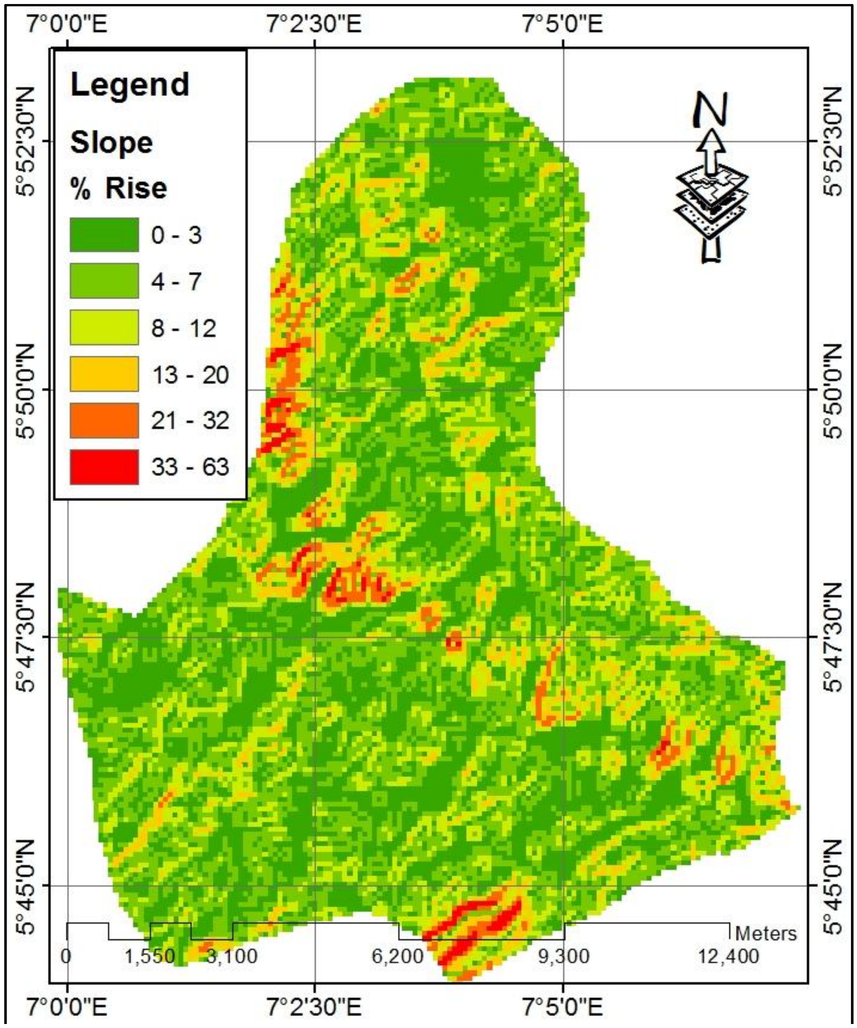

Fig. 4. Slope map of the area

Fig. 5 is an erosion vulnerability map generated from an overlay of landuse Landcover map and the slope map of the study area, while Table 3 shows the vulnerability distribution of built-up areas.

Table 3. Vulnerability distribution

Total Built-up Area	100
Low Vulnerability	21
Moderate Vulnerability	12
High Vulnerability	8

From Fig. 5, it is evident that a total of 41% of the entire Built-up area are vulnerable to erosion in the study area. This is due to massive urban expansion within the watershed region and areas of low elevation. This vulnerability map revealed that a total of 8% of the entire Built-up area are highly vulnerable to erosion. And 12% of the built-up settlements are moderately vulnerable while a greater estimate of 21% was discovered to be settlements under low erosion vulnerable areas (see Table 3).

Superimposing the LULC distribution, the areas associated with poor soil conditions and slope are also highly built-up. The observation drawn here is that, large runoff is generated from impervious surface and because the area has a gentle slope of about 12.28% with poor soil cohesive quality (soil being non-plastic) and lateritic sands, runoff quickly generate knick-points which ultimately develop into rills and gullies, these gullies due to the unstable nature of their banks heave in in the form of landslides and cause secondary environmental problems.

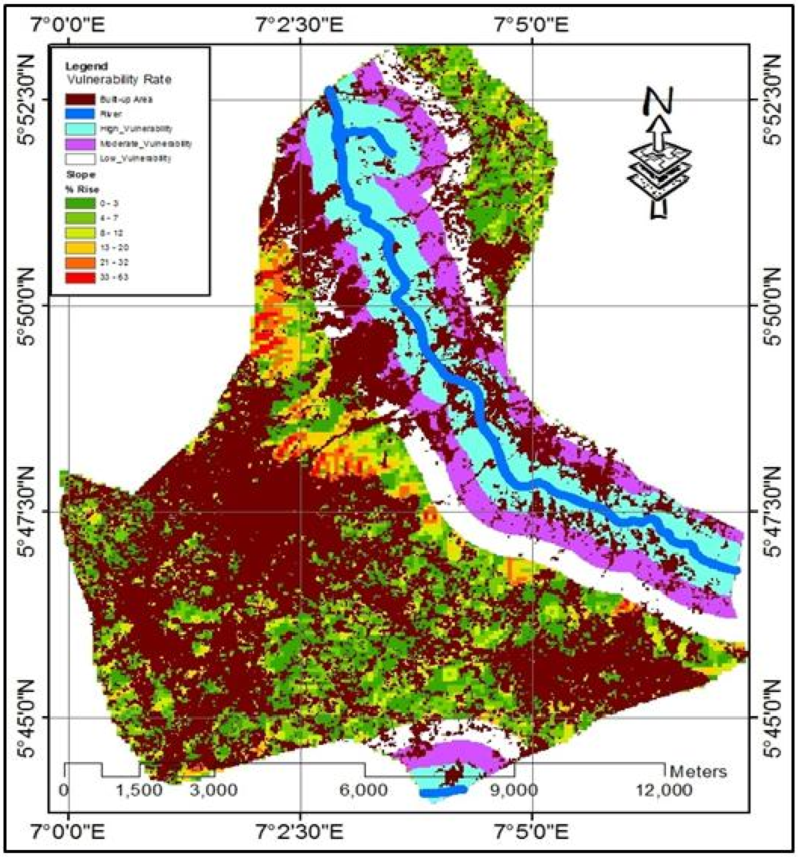

Fig. 5. Erosion vulnerability map

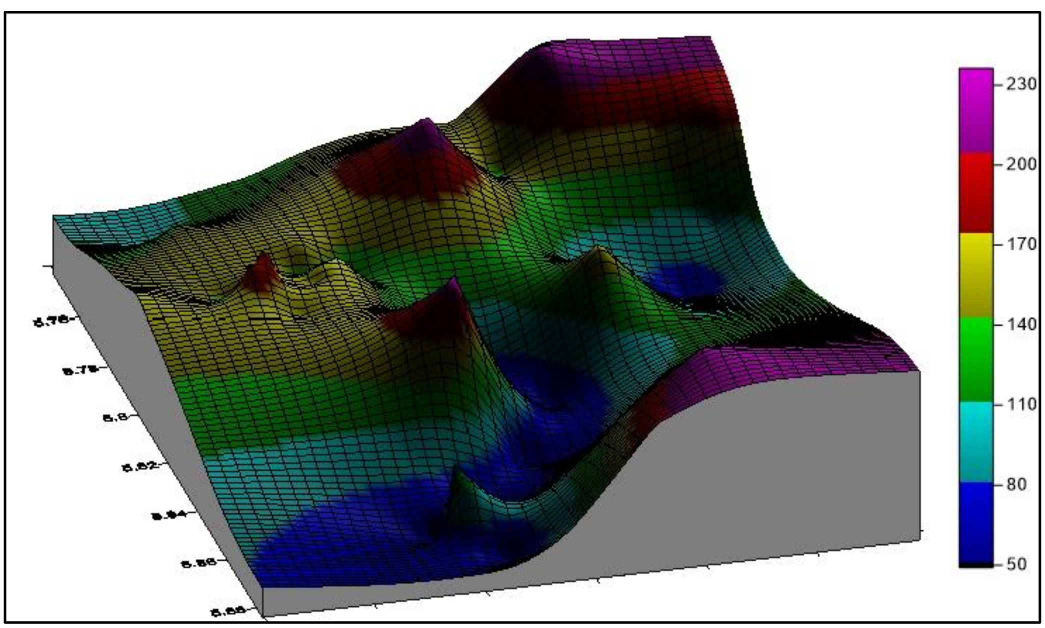

Fig. 6. Digital elevation model showing the area vulnerable to erosion

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

4.2.2 Elevation model

Fig. 6 is a display of the elevation pattern evident in the study area.

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 230 m-170 m are regarded as highly vulnerable to erosion. The areas within the elevation of 170 m-140 m are regarded as moderately vulnerable to erosion and landslide, this is due to the increased steepness and length of the slope which invariably increases the velocity and volume of surface runoff.

While the areas within the elevation of 140 m-below were classified are prone to flood and sedimentation.

5. CONCLUSION

The conclusion reached in this work is that the communities in the North and Northwest of the study area (e.g. Amaifeke, Ogberuru, Eziama, Amoparaetc.) are highly vulnerable to erosion principally because they are on a gentle and long topography with a slope of between 3 – 13%, the soil condition is also contributory as the area is underlain by the Bende-Ameki formation which is characteristically composed of fractured sandstones inter-bedded with siltstones and shales which are generally permeable. The sandstones are coarse, cross bedded, fine gray and sandy clay, weak, feeble sedimentary geologic condition thus making them have weak cohesion, poor angle of internal friction, poor bulk and dry density. This scenario is compounded by the processes and activities of urbanization which generally leads to increased surface runoff from impervious surfaces and weakening of soil colloids by construction of buildings/roads and especially the ongoing construction at Eastern Palm University and Stadium, which required land excavation.

6. 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 and properly channel runoffs in the area efficiently to nearby streams armoring them as they empty into the streams. The residents of the area should manage the drainage systems by ensuring that the drainage systems are free of debris and clogs to enhance flow of runoff after rainfall as this will reduce the effect on the soil structure of the area. Development on slopes should only be carried out after careful environmental impact assessment.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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