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Application of Remote Sensing (RS) and Geographic Information System (GIS) in Erosion Risk Mapping: Case Study of Oluyole Catchment Area, Ibadan, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author OIO designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors TPA and MOL managed the analyses of the study. Author MOL managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Soil erosion is one of the major unresolved problems of rural agriculture. The causes of soil erosion in the study area are heavy precipitation, persistent drought, farming activities, deforestation and indiscriminate bush burning that expose soil to impact of rain drop. This study is aimed at applying Remote Sensing (RS) and Geographic Information System (GIS) in erosion risk mapping in Oluyole Catchment Area. Remote Sensing (RS) and Geographic Information System (GIS) techniques were used to map out the erosion risk areas. Google Earth and LANDSAT ETM+ were used to acquire the satellite imageries of Oluyole catchment area. Using high resolution imageries, a Digital Elevation Model (DEM) was developed with Surfer 8 and ArcGIS 10.0 to identify erosion

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risk areas. The Triangulated Irregular Network (TIN), flow length, flow accumulation and slope maps of the study area were generated with the use of Digital Elevation Model. The slope, flow accumulation and flow length maps were combined with land use map to produce erosion risk map with the use of map algebra in ArcGIS 10.0 software. The erosion risk map showed that the high, medium and low erosion risk areas covered 165 (26%), 269 (43%) and 195 km^2 (31%) respectively while the land use map revealed that the areas occupied by vegetation, settlement and mixed are 221 (35%), 124 (20%) and 284 km^2 (45%). Also, the Triangulated Irregular Network (TIN) indicated that the areas of high elevation are low in vulnerability to erosion, areas of medium elevation are moderately vulnerable to erosion as well as areas of low elevation are highly vulnerable to erosion accordingly. The results indicated that the used of remotely sensed data and GIS provide an effective approach to develop accurate in erosion risk mapping with a minimum amount of time, effort, and cost. This approach creates easily read and accessible charts and maps that facilitate the identification of erosion risk areas and also can be used effectively in public enlightenment, disaster response planning and erosion risk management.

Keywords: Geographic information system; remote sensing; erosion risk and mapping.

1. INTRODUCTION

The major natural disasters in the world which have adverse socio-economic consequences on the people are drought, desertification, deforestation, fire hazards, floods and erosion. Erosion stands out to be one of the most frequent and devastating natural disasters around the world [1]. Soil erosion is a serious global land degradation phenomenon affecting human beings since humanity's basic sources of livelihood is from the land [2]. Soil erosion has enormous negative impact on agriculture. It does not only involve the removal of valuable topsoil but also affects crop emergence, growth and yield through the loss of natural nutrients [3]. However, changes in land use across the world have been identified as one of the factors responsible for accelerating soil erosion [4]. Marsh and Grossa [5] revealed that degraded soil is unproductive, which is also estimated by the degree of severity to land damage. Erosion does not only reduce the soil fertility and endanger the lives of humans and animals, but have other negative effects on the environment and aquatic life [6]. This also includes sediment deposition downstream and destruction of spawning grounds for fish and other wildlife habitat. The pronounced effects of erosion in the developing countries as a result of low incomes, poor waste management, inadequate drainage systems, inadequate warning systems have been reported almost everywhere in the world [7]. The major effects of erosion are outbreak of diseases and loss of soil fertility [8]. The occurrence of erosion has been on the increase all over the world especially in developing countries like Nigeria, where deforestation, climate change, conscription of river channels and poor drainage systems as well as maintenance have rendered most of our preventive and mitigating measures ineffective.

However, various control measures have come up over the years, but most of these have not focused on the identification of areas that are prone to high, moderate and low risk potentials of erosion in Oluyole catchment area which had led to loss of resources worth billions of naira [9]. The historical update shows that erosion management has become the major issues to contend with in this catchment area, especially whenever there is a serious or intense rainfall. This underscores the need for this research work because it will facilitate a good management of the situation. The application of GIS and RS in erosion risk mapping approach will therefore reduce the persistent occurrence of erosion in Oluyole catchment area.

Erosion risk mapping is a vital component for appropriate land use in erosion areas. It creates easily read and accessible maps which facilitate the identification of risk areas and prioritize their mitigation effects [10]. Erosion risk mapping is not new in the developed countries of the world. This research aimed at applying remote sensing and Geographic Information System (GIS) in erosion risk mapping in Oluyole Local Government Area, Nigeria. Erosion management strategies in these regions have been geared towards 'compensating' the people of the affected areas after occurrence. Very little attention is paid on formulating rational land use planning to reduce erosion induced disasters. Preparation of erosion risk map for this catchment area would be one of the most crucial steps for implementing non-structural remedial measures.

2. MATERIALS AND METHODS

2.1 Description of the Study Area

Fig. 1 represents the Oluyole catchment area, Ibadan, Nigeria. Its capital is Idi- Ayunre and it is located between latitude $7° 30^{1} 00^{11}$ N, longitude $3°43^{1}00^{11}$ E, and latitude $7° 20^{1} 00^{11}$ N, longitude $4°28^{1} 00^{11}$ E, in the south western political zone of Nigeria. It has a tropical wet and dry climate, with a lengthy wet season and relatively constant temperatures throughout the course of the year. It has total area coverage of 629 km^2 and a population of 202,725. River Ogunpa, River Ogbeere, River Omi and River Apasan are some of the prominent rivers in the catchment area. On account of extensive fertile soil which is suitable for agriculture, the basic occupation of the people is farming. There are pockets of grass land which are suitable for animal rearing, vast forest reserves and rivers.

2.2 Data Collection

For the research, satellite images of LANDSAT 7 sensor of 2006 ETM+, path 191 and row 55 of VHS with Latitude $7° 30^{1} 00^{11}$ N, Longitude $3°43^{1}00^{11}$ E and Latitude $7° 20^{1} 00^{11}$ N, Longitude $4°28^{1} 00^{11}$ E was obtained from Global Land Cover Facility (GLCF) an Earth Science Data Interface hosted by University of Maryland, USA and was acquired in November, 2015. A topographic map (scale: 1:200,000) of Oluyle catchment area was obtained from the office of the Surveyor General, Oyo State was used. The map was scanned and geo-referenced before it was imported into ArcGIS 10.0 [11].

2.3 Data Processing

Pre-processing of the data was done to eliminate any discrepancies of mismatching during overlaying of the images because geo-referencing image was needed. This was done with the aid of topographic map and images. Image enhancement was done in order to increase the details of the image by assigning maximum and minimum brightness values to maximum and minimum display values, and it was done on pixels values. This makes visual interpretation easier and assists in data analysis. Image classification was not only done to convert image data into thematic data but also to improve the visual quality and to classify the image into different land use type. This was done by assigning a group of pixels to a specific class. The band combination was done through the

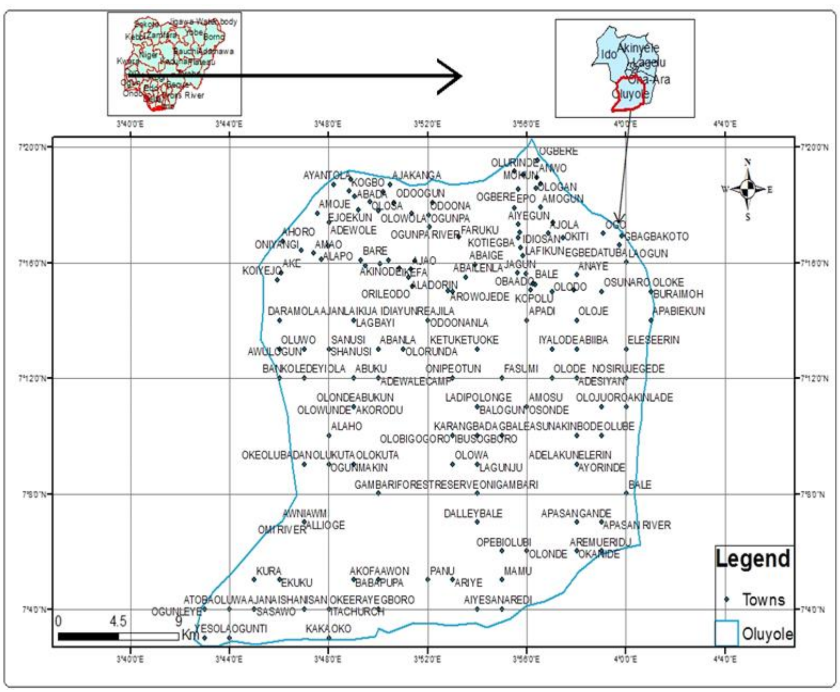

Fig. 1. Map of the study area

analyses of reflectance properties of features, correlation matrix of the bands and spectral reflectance curve of known features in all bands. Spectral profile was generated from the image and the different band combinations were made for the analysis. By using different ETM+ bands for (Red, Green and Blue), different colour composite were created for the catchment, each with its own characteristics. By comparing the different colour composites, a selection was made, which was used for vegetation, mixed and settlement differentiation.

2.4 Data Analysis

Data were analysed in Surfer 8 and ArcGIS to generate Digital Elevation Model, Triangulated Irregular Network, slope map, land use map, flow accumulation, flow length, and flood risk map for this research.

2.5 Digital Elevation Model (DEM)

The Oluyole catchment area was delineated in Google Earth and several points within the study area were marked within Google Earth and their coordinates and elevations were recorded in a Microsoft Excel spreadsheet. The X, Y and Z point data was exported to Surfer 8 software where the data were re-sampled to a grid interval of 10 m. The re-sampled data was blanked from the blank file and then the digital elevation model of the study area was generated. High resolution imagery was required for a clear depiction of the extent of vulnerability [12].

2.6 Triangulated Irregular Network (TIN)

The TIN is a vector based representation of the physical land surface and it shows the variation in the elevation of the study area in colour graduation which corresponds to the elevation of the study area. According to Olaniyan and Akolade [13], a triangulated irregular network (TIN) is a digital data structure used in a geographic information system (GIS) for the representation of the physical land surface or sea bottom, made up of irregularly distributed nodes and lines with three dimensional coordinates (X, Y, and Z) that are arranged in a network of non overlapping triangles. The adjustment of a regular grid was made to the roughness terrain in the ArcGIS software and was highly redundant in smooth terrain. Triangulated irregular network is used to determine the points that are most necessary to an accurate representation of the terrain. This was generated by using the TIN function in 3D analyst tool box.

2.7 Land Use Map

Unsupervised classification was performed to extract the land use spectral pattern from the imagery. A total of three classes were selected for the unsupervised classification upon field investigation and the following classes were obtained; vegetation, mixed and settlement [14]. Unsupervised classification was performed on Landsat ETM+ data for 2006 to generate three classes. This was carried out by assigning the number of classes according to the pixels represented by each feature in the study area. The features represented by classes were areas covered by vegetation, settlements and mixed [15].

2.8 Filling of Sinks

This function fills the sinks in a grid. If cells with higher elevation surround a cell, the water is obstructed in that cell and cannot flow. The fill sinks function regulates the elevation or depression value to solve these problems [13]. The hydrology analysis was carried out on DEM by using the fill function in the spatial tool box.

2.9 Slope Map, Flow Accumulation and Flow Length

The slope map which is the degree of steepness of a surface was generated by using the slope function in the 3D analyst tool box. The flow accumulation which represents the cell within the study area where water accumulates as it flows downwards was developed by using the flow accumulation function in the spatial analyst tool box and flow length which represents the distance at which water flows in the study area was generated by using the flow length function in the spatial analyst tool box [15].

2.10 Erosion Risk Map

Goel et al. [16] revealed that the slope, flow length and flow accumulation were combined with the land use or classified (unsupervised) using map algebra function in ArcGIS to produce the erosion risk map of the study area. The erosion risk areas were classified into low risk potential, moderate risk potential and high risk potential areas. Based on the outcome of the analysis, erosion risk map was generated for erosion management to address current problems in order to proffer measure against future occurrence and spread in Oluyole catchment area.

3. RESULTS AND DISCUSSION

3.1 Digital Elevation Model (DEM)

The Digital Elevation Model in Fig. 2 revealed that Oluyole catchment area consists of areas with high, medium and low elevation within the terrain. Fig. 2 represents the DEM of the study area which ranges between 105 – 195 m. The values within 105 m indicate the lowest point on the map while the areas with values within 195 m represent the peak of the study area. Values from 195 – 170 m, 165 – 140 m and 135 – 105 m show areas of high, medium and low elevation which are less, moderately and highly vulnerable.

3.2 Triangulated Irregular Networks (TIN)

Fig. 3 shows the TIN of the study area ranges between 58 – 300 m. The values between 58 – 84.8 m represent the lowest point on the map while the areas with values between 58 – 84.8 m represent the lowest point on the map while the areas with values between 273.1 – 300 m represent the peak of the study area. Values from 273.111 – 300 m to 219.4 – 246.2 m shows areas of high terrain which was classified as having low susceptibility or vulnerability to erosion; values from 192.5- 219.3 to 138.7-165.5 shows areas of moderate terrain which was classified as moderately vulnerable to erosion while values ranging from 111.8 – 138.6 to 58 – 84.8 shows areas of very low terrain which was classified as highly vulnerable to erosion.

3.3 Slope of the Study Area

The slope map characterizes the percent of terrain slope, classified by 0° – 2.78°, 2.79° – 6.15°, 6.16° – 24.51°. It shows the steepness and direction of slope of study area in the descending order of the percent, indicating the directing of flow of water. In Fig. 4, the first level with yellow colour indicates the low degree of hazard or instability while the second level with brown colour indicates the high degree of hazard or instability which may lead to loss of arable land and soils and the third level with red colour indicates the higher degree of hazard or instability which may endanger human life and property. This type of hazard is indicated on the map by corresponding erosion. Generally, the study of the slope of the area measured in degree shows values range between 0° – 24.51°, where 0° represents areas with the lowest slope and 24.51° represents areas with the highest slope. However, the areas with low slope (0° - 2.78°) show the lowland region while the areas with medium slope (2.79° - 6.15°) represent the

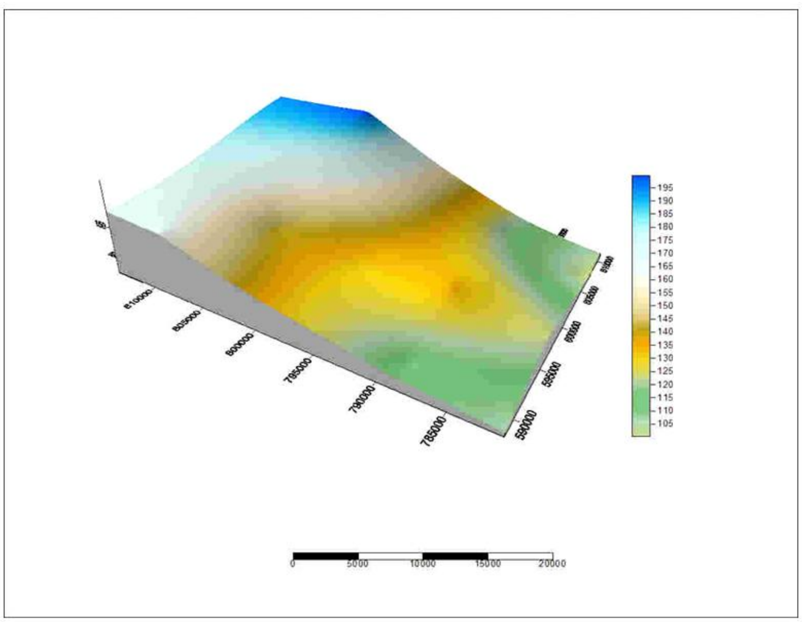

Fig. 2. DEM showing a 3D view developed from Surfer 8

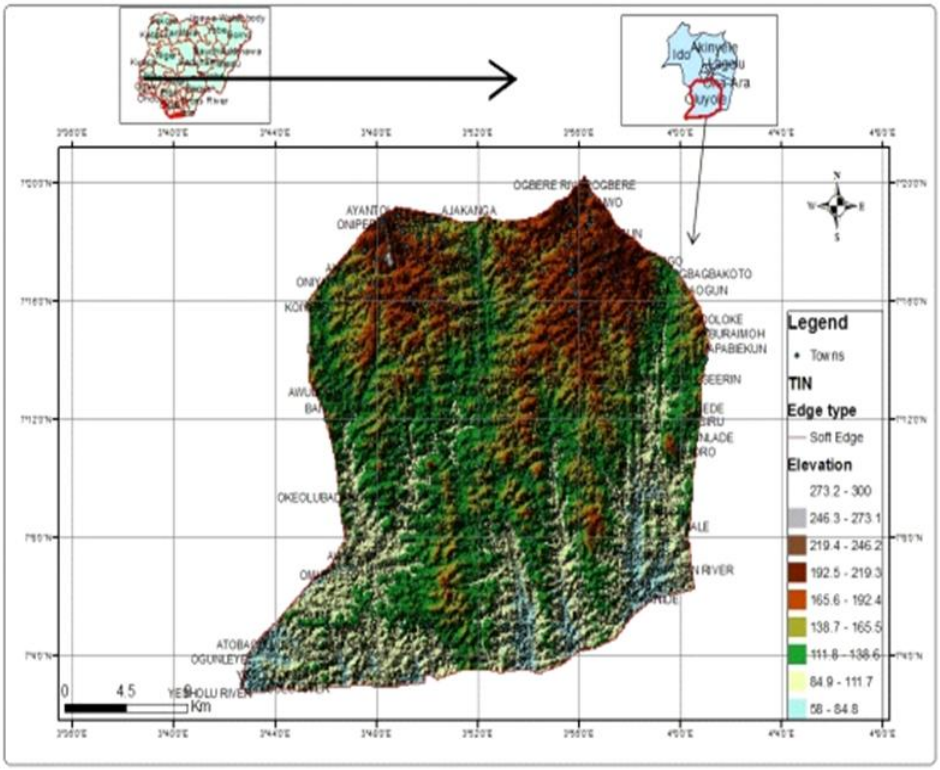

Fig. 3. TIN of the study area

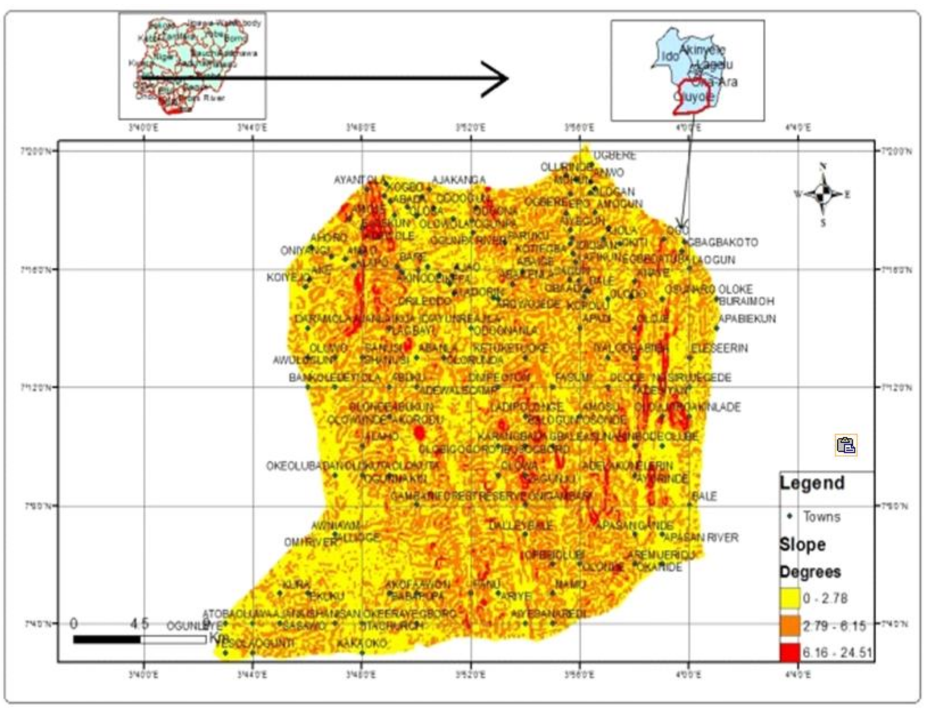

Fig. 4. Slope map of the study area

plain region and the areas with high slope (6.16° - 24.51°) indicate the highland region. The areas with low, medium and high slope are less, moderately and highly vulnerable to erosion.

3.4 Flow Length of the Study Area

Fig. 5 shows that the flow length varies between 0 – 43309.3 m. The lowest flow distance is between 0 – 13247.5 m while 13247.6 – 27174.4 m is the average flow length and the highest flow distance is between 27174.5 – 43309.3 m. However, the area in olive lighter green colour represents the area with the shortest flow distance while the area in olive light green colour represents the area with the moderate flow distance and the area in olive dark green colour represents the area with the longest flow distance. The areas with long flow length (27174.5 - 43309.3 m) are more vulnerable to flooding while the areas with medium flow length (13247.6 - 27174.4 m) are moderately vulnerable to flooding and areas with low flow length (0 - 13247.5 m) are less susceptible to flooding.

3.5 Flow Accumulation of the Study Area

Fig. 6 shows the flow accumulation of the study areas which vary between 0 – 136782 m with the areas with low values representing areas that are ridges and areas with high values representing areas that are stream channels or concentrated flow. The area with the values range between 55785.7 – 136782 m represents the areas with the highest flow or accumulation of water while the areas with 12873.6 – 55785.6 m represents the areas of average concentration of river or stream channels and areas with 0 – 12873.6 m represents areas that are ridges or colour represent the areas with low flow accumulation while the areas in yellow colour show the areas with medium flow accumulation and areas in red colour indicate the areas with high flow accumulation. The areas with high flow accumulation are more vulnerable to flooding while the areas with medium accumulation are moderately susceptible to flooding and areas with low flow accumulation are less susceptible to flooding.

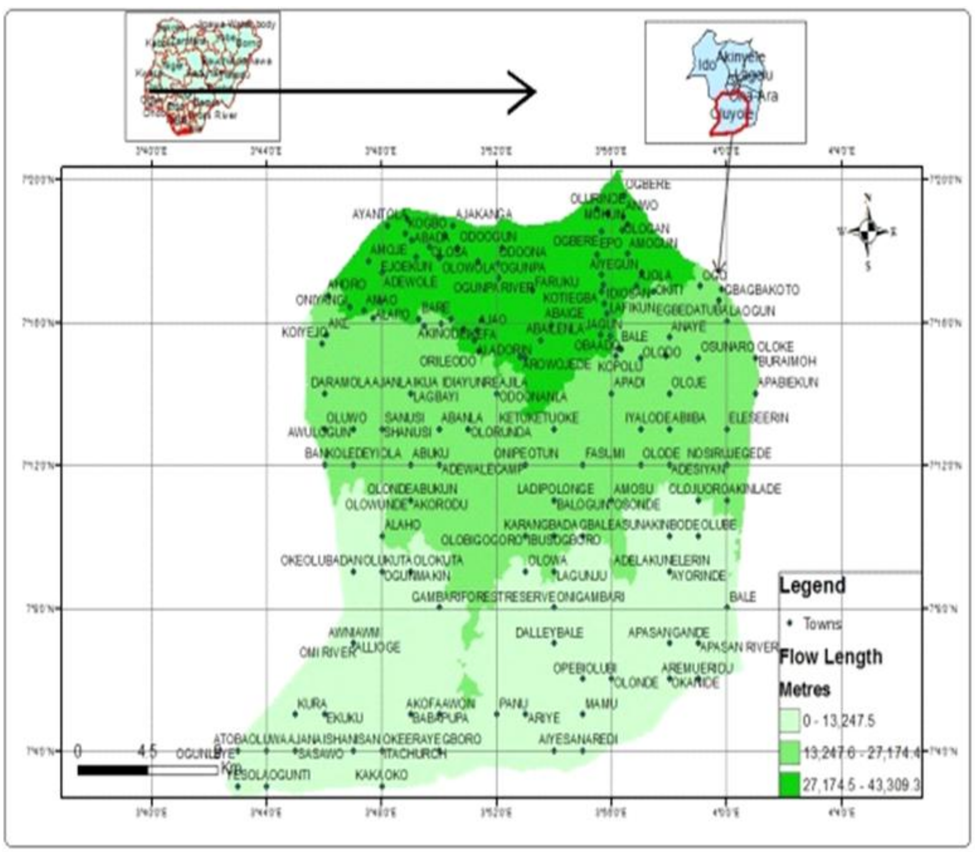

Fig. 5. Flow length of the study area

3.6 Land Use Map of the Study Area

The green colour represents the areas with vegetation while the yellow colour represents the areas with vegetation and human activities and the red colour represents the areas with settlement. Fig. 7 also revealed that 221 km^2 (35%) areas are covered by vegetation, 274 km^2 (45%) covered by mixed (vegetation and human activities) and 124 km^2 (20%) covered by settlement. The areas covered by vegetation are: Gambari Forest Reserve, Bale, Iyalode Abiba, Obaado, Akinlade, Apasan river, Olonde, Okanlade, Panu, Ologan, Okanlade, Amosu and Jegede while areas covered by mixed are: Dalley Bale, Omin river, Oniyangi, Ariye and the areas covered by settlement are: Ogbere, Ogunpa river, Oke Olubadan, Mohun, Ogunleye, Idi- Ayunre, Idiosan and Egbeda. The areas covered by vegetation, mixed and settlement are less, moderately and highly vulnerable to flooding respectively.

3.7 Erosion Risk Map of the Study Area

The erosion risk map was classified into three: The high erosion risk, medium erosion risk and low erosion risk areas. Fig. 8 shows that the green colour represent the areas with low erosion risk while yellow colour represent the areas with medium erosion risk and the red colour represent the areas with high erosion risk. The high erosion risk areas occupied 165 km^2 (26%) while the medium erosion risk areas covered 269 km^2 (43%) and low erosion risk areas occupied 195 km^2 (31%).

High erosion risk areas include the following: Olodo, Apadi, Akinlade, River Apasan, Aiyesan , Panu, Bale, Gambari, River Omin while medium erosion risk areas are: Ogunti, Ekutu, Iyalode, Olode, Ogunleye, Atoba and low erosion risk areas are: Ajila, Ogbeere river, Odo- Ona, Idi-Ayunre, Oke Olubadan, Orile Odo, Onile Odo, Alapo, Olaoye, Idiosan, Arapaja, Olaoye, Amogun, Aiyegun, Epo, River Ogunpa, Onipepeye, Mohun, Ogbere, Olurinde.

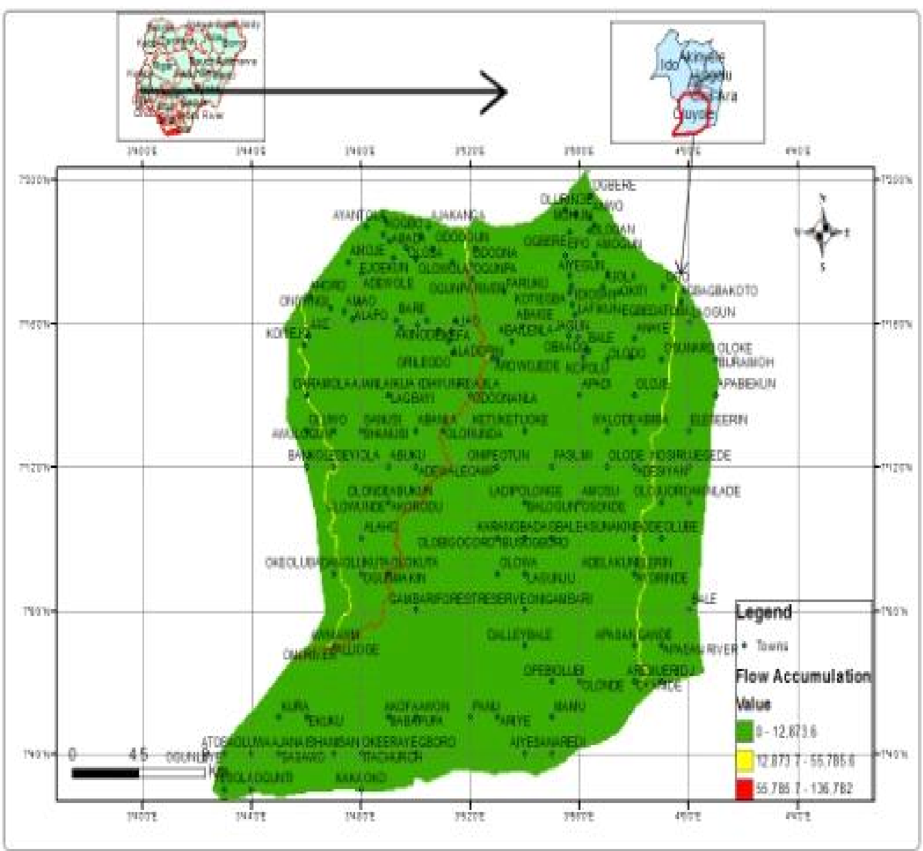

Fig. 6. Flow accumulation of the study area

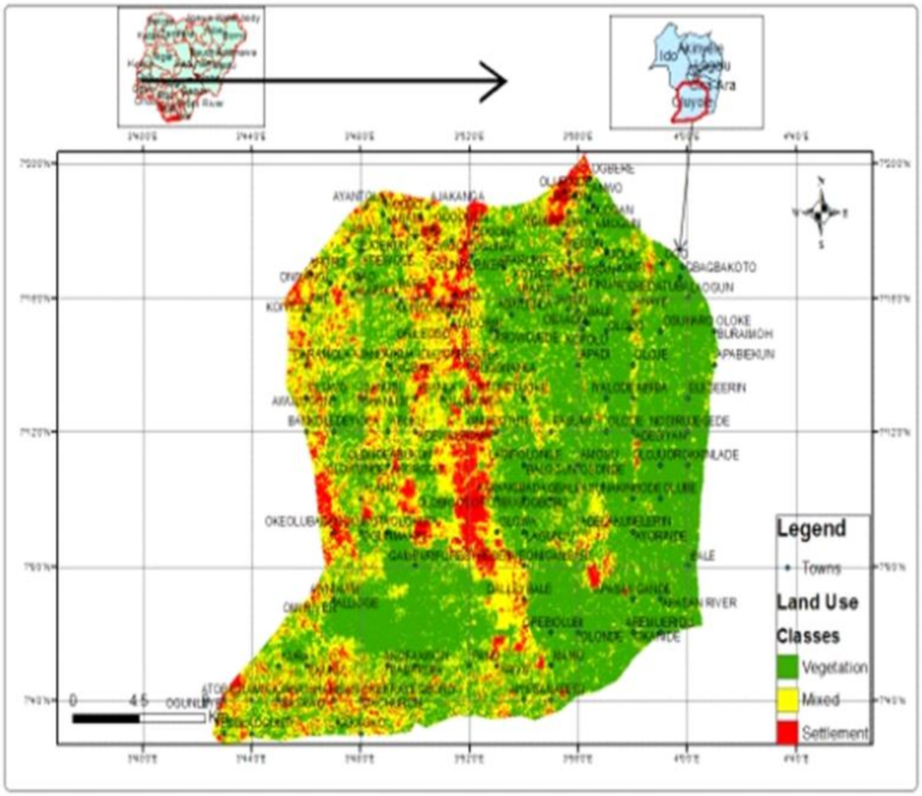

Fig. 7. Land use map of study area

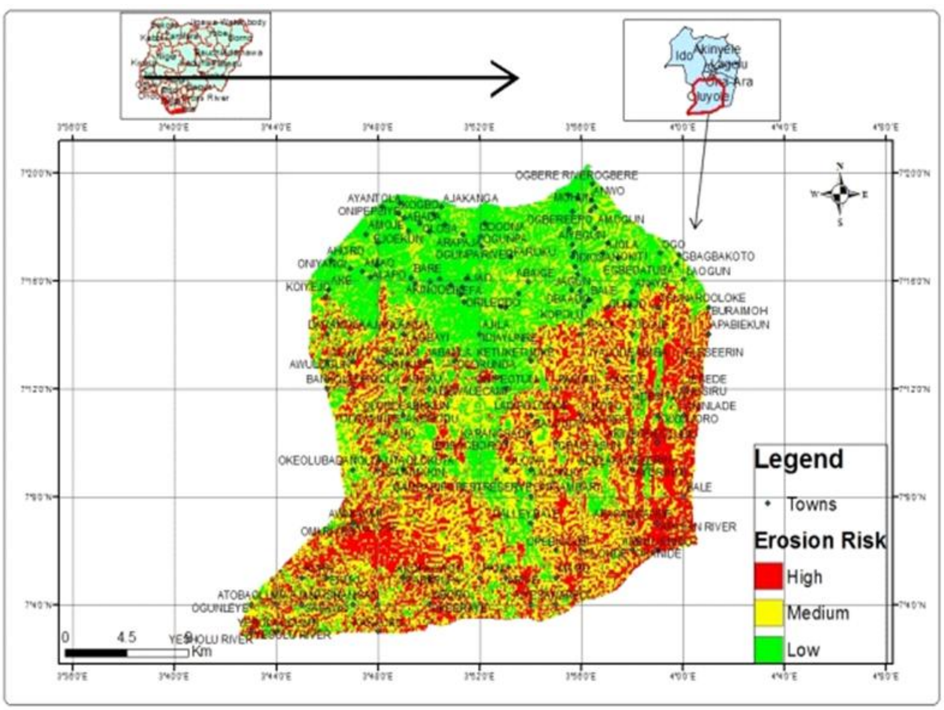

Fig. 8. Erosion risk map of the study area

4. CONCLUSION AND RECOMMENDATIONS

The erosion prone areas were identified by using erosion risk map of Oluyole catchment area. The erosion prone areas were classified into three categories: High, medium and low risk. The erosion risk map showed that the high, medium and low flood risk areas occupied 26%, 43% and 31%. The land use map was used to determine the land use pattern of the study area. The land use pattern of the study area was classified into three main categories: Vegetation, mixed and settlements. Areas covered by vegetation, mixed and settlement are less vulnerable, moderately and highly vulnerable to erosion respectively. The Triangulated Irregular Network (TIN) was used to analyze the elevation of the study area. The slope map revealed that the areas with low, medium and high slope are less, moderately and highly vulnerable to erosion. The map showed that the areas of high, medium and low elevation are low in vulnerability, moderately vulnerable and highly vulnerable to erosion. The results showed that the used of remote sensing and ArcGIS 10.0 software provide an effective approach to develop erosion risk map with a minimum amount of time, effort, and cost. This approach creates easily read charts and maps that facilitate the identification of erosion risk areas and also can be used effectively in public enlightenment, disaster response planning and erosion risk management. Finally, farming activities should not be carried out in the high risk zones and riparian vegetation should be planted to act as flood breaks, reducing the velocity of flow.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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