Erosion Hazard Model Mapping for Orlu Zone, Imo State, Nigeria Using GIS

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Abstract
Soil erosion is a significant environmental issue of common concern in the world today. For the past five decades, the study area (Orlu Zone) in Imo State, Nigeria has been experiencing environmental degradation and loss of properties due to soil erosion. Impact of soil erosion on man and his environment is natural and as old as the time of Earth’s creation. It has been supported that a number of factors combined in contributing to soil erosion and its negative environmental consequences ranging from social, economic and property losses of which serious runoff and soil loss has become one of the main factors restraining local economic developments. The aim of this study is therefore, to produce an erosion hazard model map that identifies areas of high and low risks for erosion. Study identified seven susceptibilities factors (soil characteristics, variation in elevation, slope, land use, geology, population density and drainage density) of soil erosion, converted them to grid format and reclassified each factor into five potential after assigning erosion risk values based on acceptable hazard potential of each factor. Thereafter, weighed on Arc GIS version 10.2 software weighted overlay toolbox to produce erosion risk map showing Orlu Zone lands classified into various hazard potentials. Result showed that highest vulnerable land areas to soil erosion occurred in the Northern part of the study area while the lowest vulnerable areas occurred on the Southern counterpart.

Keywords: Erosion, susceptibility factors, Arc GIS weighted overlay

1. Introduction
Soil is essentially a non-renewable resource and a very dynamic system which performs many functions and delivers service vital to human activities and ecosystems survival (European Commission, 2006). However, this importance relating directly to soil status and availability has created a severe struggle among environmental, social, and economic benefits (Viglizzo, Parure, Latera and Jobbagy; 2012) even as humans have attempted to more effectively understand the complex relationships between variables explaining soil degradation. Abegunde, Adeyinka, Olawumi and Ohuodo (2006) defined soil erosion as the gradual washing away of soil through the agents of denudation which include, man, wind and water These denuding agents’ loose, wear away and transport soil particles from one location to another as deposit. This occurs primarily when the velocity of the water is able to create shear strength great enough to overcome the cohesion between the soil particles, and is commonly worsened when the level of water flow cannot be adequately infiltrated into the surface. This buildup of unabsorbed water can occur due to multiple factors but is initially driven by causes such as rainfall and runoff accumulation.

Multiple biotic and abiotic factors can be related to the amount of soil erosion likely to occur in a given location. For example, various soil types and textures are more prone to erosion. Soils with a high level of clay have been typically thought to erode less due to the strong bond present between each individual particle. On the other hand, soil with more fine sand will erode more easily (Dvořák & Novák, 1994) and therefore makes that zone more susceptible to water erosion. Erosion is also more likely to occur on sloped areas rather than in flat valley floors as water erosion from runoff is driven by a gravitational force.

Additionally, studies have found that soil erosion speeds are reduced exponentially with regards to vegetative cover (Gyssels, Poessen, Bochet and Li; 2005) and that an inverse exponential relationship is apparent amongst mean sediment production and vegetation at the watershed level (Vanacker, Blanckenburg, Govers, Malina, Poessen, Deckers and Kubík; 2007; Molina, Govers, Cisneros and Vanacker; 2008). Weighting of these erosive variables will not only identify areas more vulnerable to soil erosion, but various levels or severity of erosion can also be determined. Soil loss has been identified by Bazzoffi, (2009), as the utmost important consideration to distinguish between these levels of erosion and understand their environmental impacts. Thus, with careful monitoring and limited human impact, however, some soils can withstand some degree of erosion by naturally replenishing the amount of soil lost (Bazzoffi, 2009).
The aim of this study is to produce erosion hazard model map that identifies the study areas at varying degrees of erosion risks.

2. Materials and Method

2.1. Study Area

The study area (Orlu Zone) is a senatorial district of 12 LGAs in Imo State, geographically located at Longitude 6.662E -7.121E and Latitude 5.274N -5.949N (fig 1). It is bordered by Okigwe and Owerri on the East, River Niger and Delta State to the West, Anambra on the North and Rivers State to the South. The main water bodies draining the study area are; Njaba River, Nwangale River and Urashi River. The areas that charge these water bodies constitute four subbasins within the Anambra-Imo River Basin as shown in fig2.

Study area falls within the sub-equatorial region that is characterized by high annual rainfall (over 2000mm/yr), high relative humidity (90%) and temperatures (24 - 270C). The area experiences two main seasons - rainy season and dry season NIMET, (2015).

2.2. Erosion Susceptibility Factors Processing

Hard paper base map of the State Local Government Areas was acquired from the Imo State Ministry of Lands, Survey and Urban Planning was scanned to convert to grid format, called up in ArcGIS10.2 software and georeferenced to UTM Zone 32N using the ArcGIS version10.2 software. The resultant referenced map was digitized and delineated to the study area as dissolved map (fig1).

Considerations in gully erosion susceptibility factors were; soil characteristics, geology, DEM (elevation, slope and drainage density), population density and landuse landcover. Randomly collected soil samples (0-20cm and 20-45cm) in the study area based on existing Anambra-Imo River basin was analysed for various soil characteristics such as; atterberg limit, gradation, permeability, structure, organic matter content and bulk density. Results obtained are keyed into; wischmeier and smith (1978) formula for erodibility estimation (equation 2.14), USDA soil texture and organic matter content table for K estimation and USDA (2001) soil quality K factor permeability code. Average K obtained from each unit soil sample location was added to other soil parameters sampled, interpolation by krigging and reclassified into five classes of soil characteristic map (fig 3) of the entire study area in ArcGIS version 10.2 software environment.

SRTM data procured from the Regional Centre for Training in Aerospace Survey (RECTAS) Ile Ife, Osun State was integrated with recently downloaded SRTM data from Global Mapper software and analysed using ARCGIS surface analyst tool for elevation and slope. Resultant maps were reclassified into five classes of elevation and slope maps (fig 4 and 5) respectively. With Arc Hydrological engineering extension tool of ArcGIS, version 10.2, the drainage lines and basins were generated from the SRTM data. Thus, the drainage density was estimated through the ratio of drainage length to its basin and reclassified into five classes of drainage density map of the study area (fig6).

Landsat imagery downloaded from the global land use land cover facility website containing the land use land cover of Orlu Zone was classified into various regions of interests such as; paved surface, bared/cultivated land, wetland, water body, forested land and vegetated land, in ENVI remote sensing software and the resultant classification exported to ArcGIS environment where erodibility values were assigned and reclassified into five classes (fig7).

Population data collected from Nigerian Population Census (NPC) office, Federal Secretariat, Owerri was projected to recent population figure and exported to ArcGIS software as a point map with the (x,y) coordinates of their LGAs against its projected population figure as attribute. Thus, the ratio of the projected population figure to its LGA area (population density) was calculated using geo calculator in ArcGIS environment and reclassified into various five classes (fig 8).

Procured geologic map of Imo State from the National Geohazard Office, Akwa, Anambra State was scanned, georeferenced and digitized into various geo-forms. The output map (geologic map) was delineated to the study area and converted to raster format and assigned erosion risk values through reviewed literature on erosion hazard potentials of various geo-forms on the state and reclassified into five classes (fig 9).

2.3. Weighted Overlay

The weighted overlay tool of ArcGIS version 10.2 software combines the weight and ratio of each susceptibility factor (table1). This is achieved by multiplying the calculated ratio of each factor to determine its total weight. The five different hazard levels were assessed as; very high-10, high-8, moderate-5, low-2 and very low-1. The ratio of the gully susceptibility factors according to their weight on hazard formation were assessed for soil characteristics 15%, Drainage density 10%, slope 20%, elevation 15%, geology 15%, land use 15% and population density 10%. The gross weight of the total weight was determined and each of the reclassified maps of erosion susceptibility factors were weighed on the weighted overlay tables (table1) to produce erosion hazard map of the study area (fig10).

3 Results and Discussion

Table 1 and figure 3-9 are reclassified erosion hazard potentials factors for the study that produced the Erosion hazard map of the study area (fig 10). The area in square kilometer of each potential (table2) was generated through vectorization of the map via extract using geometric calculation tool in ArcGIS Software environment. It was observed that high and highest potential areas were found in the northern part of the study area at 964.28km² and 173.31km² areas, representing about 7.52% and 42.07 % respectively of total area. Moderate potential cut across slightly extreme Northeast and dominated Southern part of the study area at 1014.23km², occupying about 44.25% of total area. Low and lowest
hazardous potential areas were found on the Southwest part of the study at an area of 123.01km\(^2\) and 18.3km\(^2\) maintaining about 5.37% and 0.79% respectively of total area land. Thus, the ratio of various hazard potential classes showed that for every 13.05km\(^2\) of land found in the study area, there are 1km\(^2\) of highly vulnerable place, 5.6km\(^2\) of land posed at risk though not highly vulnerable and 6.75 km\(^2\) of less vulnerable.

4. Conclusions

This study explored the classifications of gully erosion susceptibility factors into five different potentials that were weighted in the ArcGIS10.2 weighted overlay dialogue box of spatial analyst toolbox to produce erosion hazard map for the study area. It was observed that highest potential occurred in the Northern part of the study area, moderate potential southern part while the lowest potential wee on the Southwest part of the study area. Thus, the area occupied by various hazard potentials showed that out of every 13.05km\(^2\) of land in the study area, there are 1km\(^2\) of highly vulnerable area, 5.6km\(^2\) of moderate vulnerability and 6.75 km\(^2\) of less vulnerable.

| Factor              | Domain           | Descriptive Level | Proposed weight (a) | Ratio (b) | Weighted ratio (a*b) | Total weight | Percentage (%) |
|---------------------|------------------|-------------------|---------------------|-----------|----------------------|--------------|----------------|
| Soil Characteristics| 1.8-1.94         | Lowest            | 1                   | 1.5       | 1.5                  | 39           | 15             |
|                     | 1.94-2.08        | Low               | 2                   | 3         |                      |              |                |
|                     | 2.08-2.22        | Moderate          | 5                   | 7.5       |                      |              |                |
|                     | 2.22-2.36        | High              | 8                   | 12        |                      |              |                |
|                     | 2.36-2.50        | Highest           | 10                  | 15        |                      |              |                |
| Slope               | 0-5.5            | Lowest            | 1                   | 2         |                      | 52           | 20             |
|                     | 5.5-14.7         | Low               | 2                   | 4         |                      |              |                |
|                     | 14.7-27.4        | Moderate          | 5                   | 10        |                      |              |                |
|                     | 27.4-42.6        | High              | 8                   | 16        |                      |              |                |
|                     | 42.6-70.5        | Highest           | 10                  | 20        |                      |              |                |
| Elevation           | 1-41             | Lowest            | 1                   | 1.5       | 1.5                  | 39           | 15             |
|                     | 41-95            | Low               | 2                   | 3         |                      |              |                |
|                     | 95-153           | Moderate          | 5                   | 7.5       |                      |              |                |
|                     | 153-210          | High              | 8                   | 12        |                      |              |                |
|                     | 210-350          | Highest           | 10                  | 15        |                      |              |                |
| Drainage density    | 0.10-0.18        | Lowest            | 1                   | 1.0       | 1                    | 26           | 10             |
|                     | 0.18-0.21        | Low               | 2                   | 2         |                      |              |                |
|                     | 0.21-0.24        | Moderate          | 5                   | 5         |                      |              |                |
|                     | 0.24-0.27        | High              | 8                   | 8         |                      |              |                |
|                     | 0.27-0.28        | Highest           | 10                  | 10        |                      |              |                |
| Population density  | 833-1377         | Lowest            | 1                   | 1.0       | 1                    | 26           | 10             |
|                     | 1377-1922        | Low               | 2                   | 2         |                      |              |                |
|                     | 1922-2467        | Moderate          | 5                   | 5         |                      |              |                |
|                     | 2467-3011        | High              | 8                   | 8         |                      |              |                |
|                     | 3011-3556        | Highest           | 10                  | 10        |                      |              |                |
| Lithology           | Alluvium         | Lowest            | 1                   | 1.5       | 1.5                  | 39           | 15             |
|                     | Imo shale        | Low               | 2                   | 3         |                      |              |                |
|                     | Benin formation  | Moderate          | 5                   | 7.5       |                      |              |                |
|                     | Ogwashi-asaba    | High              | 8                   | 12        |                      |              |                |
|                     | Ameki            | Highest           | 10                  | 15        |                      |              |                |
| Land use            | Water body       | Restricted        | 0                   | 1.5       | 1.5                  | 39           | 15             |
|                     | Wetland          | Lowest            | 1                   | 3         |                      |              |                |
|                     | Paved surface    | Low               | 2                   | 7.5       |                      |              |                |
|                     | Forested         | Moderate          | 5                   | 12        |                      |              |                |
|                     | Vegetated        | High              | 8                   | 15        |                      |              |                |
|                     | Bare/cultivated  | Highest           | 10                  | 15        |                      |              |                |
| Total               |                   |                   |                     |           |                      | 260          | 100            |

Table 1: Classifications and Weighting Factors for Erosion Hazard Map
Source: ESRI 2002; Selvim and Cigdem 2015
Figure 1: Study Area Map

Figure 2: Sub Drainage Basin of the Study Area
Figure 3: Soil Characteristics

Figure 4: Elevation Map
Figure 5: Slope

Figure 6: Drainage Density
Figure 7: Land Use

Figure 8: Population Density Map
Figure 9: Geology

Figure 10: Erosion Hazard
Erosion Hazard Class | Area (km²) | Percentage Occurrence | Cumulative Ratio |
---------------------|-----------|------------------------|-----------------|
Highest             | 172.31    | 7.52                   | 7.52            |
High                | 964.28    | 42.07                  | 49.59           |
Moderate            | 1014.23   | 44.25                  | 93.84           |
Low                 | 123.01    | 5.37                   | 99.21           |
Lowest              | 18.3      | 0.79                   | 100             |
Total               | 2292.13   | 100                    | 13.35           |

Table 2: Class Statistics for Erosion Hazard Map
Source: Author's Generated

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