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Temporal Assessment of Soil Loss using the Revised Universal Soil Loss Equation (Rusle) Model and Geospatial Techniques

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Abstract This is a GIS-based time series study of annual soil loss value and soil erosion trends linked with precipitation and land use in Okigwe. The Revised Universal Soil Loss Equation (RUSLE) model was used to calculate annual soil loss. In applying the model, flow length was used instead of flow accumulation to estimate the slope length and steepness (LS) factor. The modeling is carried out for the years 1985, 2000, and 2015, and is based on LANDSA Tremotely sensed data, digital elevation models, rainfall data from the study area, as well as existing soil maps. The study shows that the average annual soil loss for Okigwe was estimated to be 462 t h^{-1} yr^{-1} for the year 1985, decreased to 119 t h^{-1} yr^{-1} in 2000 and increased to 378 t h^{-1} yr^{-1}in 2015. The Northeastern part of the study area where the topography is hilly appears to have high risk of soil loss compared to the western part of the study area in Onuimo that is not hilly and also have a good NDVI analysis. Over exploitation of land is probably compensated by improved agricultural management and no significant increase in precipitation. Even if there are reports of more intense and increasing amounts of rainfall in the area, this could not be verified, neither through analysis of climate data, nor by trends in estimated soil loss. The study concludes that there are no significant soil erosion trends or patterns, as well as significant trends in precipitation and land cover changes during the last decade in Okigwe.

Keywords GIS, Remote Sensing, erosion, RUSLE, Okigwe, precipitation, landcover, soil loss

Introduction

Soil erosion is a major geomorphological process in South Eastern Nigeria, the gradual but constant dissection of the landscape by soil erosion caused by surface runoff results in the formation of massive gullies dotting the entire landscape causing serious financial losses in regions where the economy is dependent on the efficiency and workability of soils [1]. 1.6% of the entire land area of the Eastern Nigeria is occupied by gullies. This is very significant for an area that has a high population density per square km in Nigeria.

Geomorphological mapping has tremendously evolved over the past decades from classic field based approaches and interpretation of stereoscopic aerial photos, contemporary approaches focus increasingly on the use of digital elevation models. RUSLE model with the help of remote sensing and GIS can help in developing such erosion map showing the rate of erosion over a 30-year period of 15 years' intervals between 1985 – 2015 with areas least, marginally, moderately and severely eroded. These results can then be compared with the erosion causing factors (overlaid maps) to analyze how they have affected the area.

Erosion models are used to predict soil erosion. Soil erosion modeling is able to consider many of the complex interactions that influence rates of erosion by simulating erosion processes in the watershed. Soil erosion model is a necessary tool to predict excessive soil loss and to help in implementation of erosion control strategy [2]. These models are comparatively over-parameterized. Most of these models need information related with soil type, landuse, landform, climate and topography to estimate soil loss. They are designed for specific set of conditions of particular area for example The Universal Soil Loss Equation (USLE) [3] was designed to predict soil loss from sheet and rill erosion in specific conditions from agriculture fields. The Revised Universal Soil Loss Equation (RUSLE) [4] a modified version of USLE is applicable to other conditions by introducing hydrological runoff factor for sediment yield estimation, different factors affecting erosion such as rainfall erosivity, soil erodibility, slope length, steepness, soil cover and farm practices are incorporated to estimate the average annual soil loss and sediment delivery rate of an area or watershed.

With the advent of remote sensing technology, deriving the spatial information on input parameters has become more handy and cost-effective. Besides with the powerful spatial processing capabilities of GIS and its compatibility with remote sensing data, the soil erosion modeling approaches have become more comprehensive and robust. Remote Sensing can facilitate studying the factors enhancing the process, such as soil type, slope gradient, drainage, geology and land cover. Multi-temporal satellite images provide valuable information related to seasonal land use dynamics. Satellite data can be used for studying erosional features, such as gullies, rainfall interception by vegetation and vegetation cover factor. DEM (Digital Elevation Model) one of the vital inputs required for soil erosion modeling can be created by analysis of stereoscopic optical and microwave (SAR) remote sensing data. Hence, by integrating RUSLE and GIS, the spatial distribution of erosion location and intensity can be obtained. This technique makes potential soil loss estimation and its spatial distribution reasonably cost effective and better accuracy for larger areas [5-6].

Aim and Objectives

The aim of the study is to produce a reliable and accurate soil erosion estimates and soil erosion intensity trends from 1985 to 2015 for Okigwe Local Government Area in Imo State of Nigeria and this is achieved through the following objectives:

i. The preparation of a Normalized Difference Vegetation Index (NDVI) map of the study area using high resolution satellite data.
ii. The generation of a Digital Elevation Model (DEM) of the study area.
iii. Calculating the average soil loss rate using the rainfall, DEM, soil type map and NDVI data
iv. To perform the model calculations for the years 1985, 2000 and 2015 in order to estimate soil erosion and create soil erosion intensity maps to analyze and discuss the results of possible soil erosion intensity trend from the year 1985 to 2015, affected by precipitation and land cover situation in the study area.

Current huge investment in civil engineering and geotechnical works aiming to renovate the results of erosion is comparatively higher than investments in soil conservation effort [6]. Therefore, the need is not merely quantifying the erosion rate but such results of erosion assessment can be core of any decision making and supportive in policy formulation for sustaining the environment as a whole coupled with the land productivity

Materials and Methods

The Study Area

Okigwe metropolis lies between latitude 5˚ 40’ 54” and 5˚ 43’ 34” and longitude 7˚ 15’ 07” and 7˚ 23’ 03”. Okigwe Metropolis consists of Okigwe and Onuimo Local Government Areas. The study area is bisected by the Port Harcourt – Enugu – Maiduguri rail line as well as the Port Harcourt – Enugu Expressway. The area has grown into major transit town for the southeastsub regions. The area lies in the rain forest belt of South eastern Nigeria characterized by hills and lowlands.

The rains begin in April and lasts until October with annual rainfall varying from 1500mm to 2200mm. An average annual temperature above 20˚C (68.0˚F) creates an annual relative humidity of 75%. With humidity reaching 90% in the rainy season. The dry season experiences two months of Harmattan from late December to late February. The hottest months are between January and March.

The geomorphology of the Okigwe is dominated by hills. Due to mountainous characteristics around the Northern and eastern part of Okigwe, the variation of the slope is large. The area is underlain by a complex geological setting. Stratigraphically, its underlain by the Benin formation, the Ogwashi-Asaba formation, the Bende-Ameki formation, Imo shale formation, Nsukka formation and Ajali formation. The Benin formation is overlain by lateritic overburden and underlain by Ogwashi-Asaba formation of Eocene to Oligocene age [8]. The Ogwashi-Asaba formation is made up of variable succession of clays, sands and grits with seams of lignite. The Ameki formation consists of greenish-grey clayey sand stones, shales and mudstones with interbedded limestones. The formation in turn overlies the impervious Imo Shale group characterized by lateral and vertical variations in lithology. The Imo shale of Paleocene age is laid down during the transgressive period that followed the cretaceous. It is overlain in succession by Nsukka formation, Ajali sand stones and Nkporo shales.

The soil texture varies with topographic spread of the study area. The river basin belt stretches from eastern Umuduru through eastern Nkwe and Umuna areas. There is a large clay soil accounting to a very high utility vegetation. At the south west of Okwelle, Okwe, and far north of Umuduru, the variety of red mud texture account for the low vegetation belt.

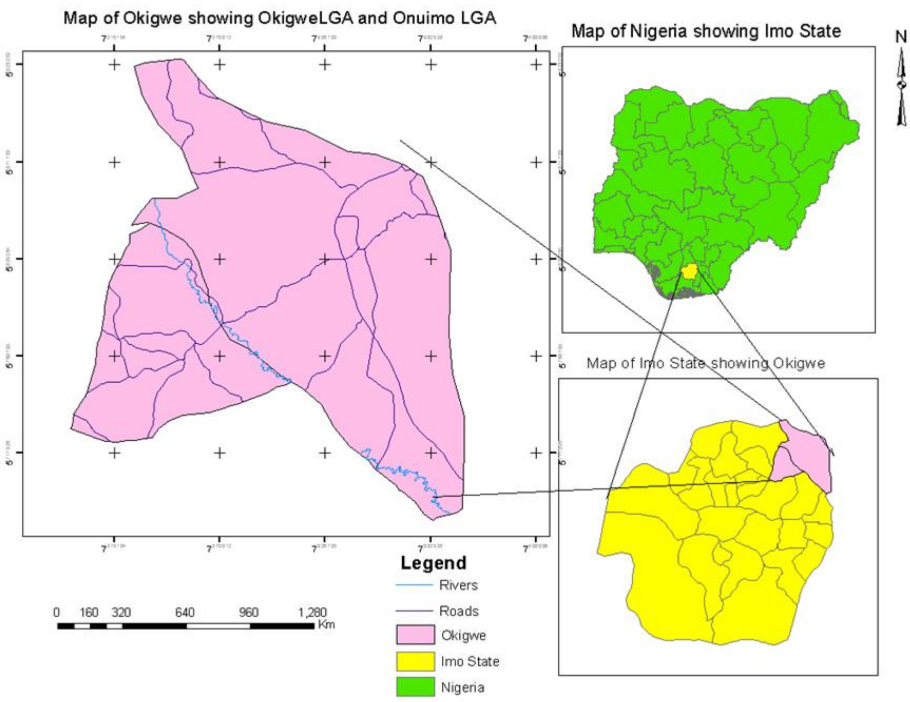


Figure 1: Map of study Area

Types of Data and Sources

Two categories of data were collected. They are primary and secondary data.

The primary data were collected as a study on the farm and management practices to prevent soil erosion

The secondary data are;

1. Satellite imageries of LandSat 4 (21st November 1986), LandSat 7 (17th December 2003) and LandSat 8 (3rd January 2015) for path 188 and row 56. Multiple bands were acquired from the website of United States Geographical Survey (USGS) – earthexplorer.usgs.gov
2. Shuttle Radar Topographic Mission (SRTM) of Nigeria from the National Space Research and development Agency (NASRDA)
3. Rainfall data from the Nigeria Meteorological Agency (NIMET) from 1985-2015
4. Geological and Mineral map of Nigeria from the Nigeria Geological Survey.

Method of Data Collection and Analysis

The following dataset were used to predict the rate of soil loss using the RUSLE model in the Okigwe between 1985-2015

i. Digital Elevation Model
ii. Average annual rainfall data

iii. Satellite images
iv. Soil type Map

Digital Elevation Model

The purpose of this data set is to provide a single consistent elevation model for national scale mapping, GIS and Remote Sensing applications and Natural Resource Assessment. The Topographic map was imported into ArcGIS 10.1, it was georeferenced, then digitized with a scale of 1:100 000 to extract the contour lines and it was masked to extract the study area. The DEM will be used to calculate the slope length and steepness factors in the RUSLE model for the purpose of the study.

Rainfall Data

The mean rainfall depth in millimeters for a 15-year period for the target years 1985, 2000 and 2015 were extracted from a large data set. The rainfall erosivity factor was estimated by importing the values from the weather station. Wischmeier and Smith (1978) recommended that at least a 20 years of rainfall data is required to capture the natural climatic variation [9]. All the data can be read as tables by ArcGIS or Excel.

Soil Classification Map

The primary source of Soil map for the study area is from the Nigeria Geological Survey. The geological and mineral map was imported into ArcGIS 10.1. it was geo-referenced under the WGS84 Coordinate System to give it a spatial attribute and the study area was masked from it.
Based on the digitized map Okigwe is divided into 4 soil regions which includes;

1. Clay and Shales (Ebenebe and Umunna sandstones) – Paleocene
2. Clayey sands and shales (Bende, Ameki and Nanka stones) – Eocene
3. Sand stones (Imo formation) – Palaocene
4. Sand stones, Limestone and coal (Upper coal measures) – Maestriclitian- Danian

Satellite Remote Sensing Images

The Landsat images were from the summer periods of the years 1986, 2000 and 2015. The spatial resolution of the satellite images are 30metres. All images were georeferenced under the WGS84 Coordinate System (Table 1). However, due to heavy cloud coverage in the Southeast region during Summer time, this requirement is difficult to fulfill. The data used in the study area are the best combination which can be found.

Table 1: Information about LandSat satellite images

Time	Path/Row	Cloud Coverage	Band
21st November 1986	188/56	<10%	4,3,2
17th December 2010	188/56	<10%	4,3,2
3rd January 2015	188/56	<10%	5,4,3

In the downloaded data, the digital values for red, green and near infrared bands were interpreted following the spectral reflectance characteristics. That means that the satellite image can be used for Normalized Difference Vegetative Index (NDVI) calculation directly in the further processing stage. The NDVI maps indicate the land cover environment. NDVI was thus used to estimate the cover management factor which is one of the components in RUSLE model.

The RUSLE Model

The RUSLE soil erosion model is used to estimate annual soil loss value and estimate soil erosion intensity in catchment. The RUSLE model is based on the USLE erosion model structure which was developed by Wischmeier & Smith (1978), and improved and modified by Reynard *et al*. (1997). Five parameters are used in the RUSLE model to estimate soil loss. They are rainfall erosivity (R), soil erodibility (K), slope length and steepness factor (LS), cover management factor (C) and conservation practice factor (P). RUSLE model

relationship is expressed as:
A=R ×K ×LS×C ×P
where

A(t $ha^{-1}y^{-1}$) is the computed spatial average of total soil loss per year;

R (MJmm $ha^{-1}h^{-1}y^{-1}$) is the rainfall erosivity factor;

K(t ha h $ha^{-1}MJ^{-1}mm^{-1}$) is the soil erodibility factor

LS is the slope length and steepness factor (dimensionless);
C is the land surface cover management factor (dimensionless); and
P is the erosion control or called conservation practice factor (dimensionless).

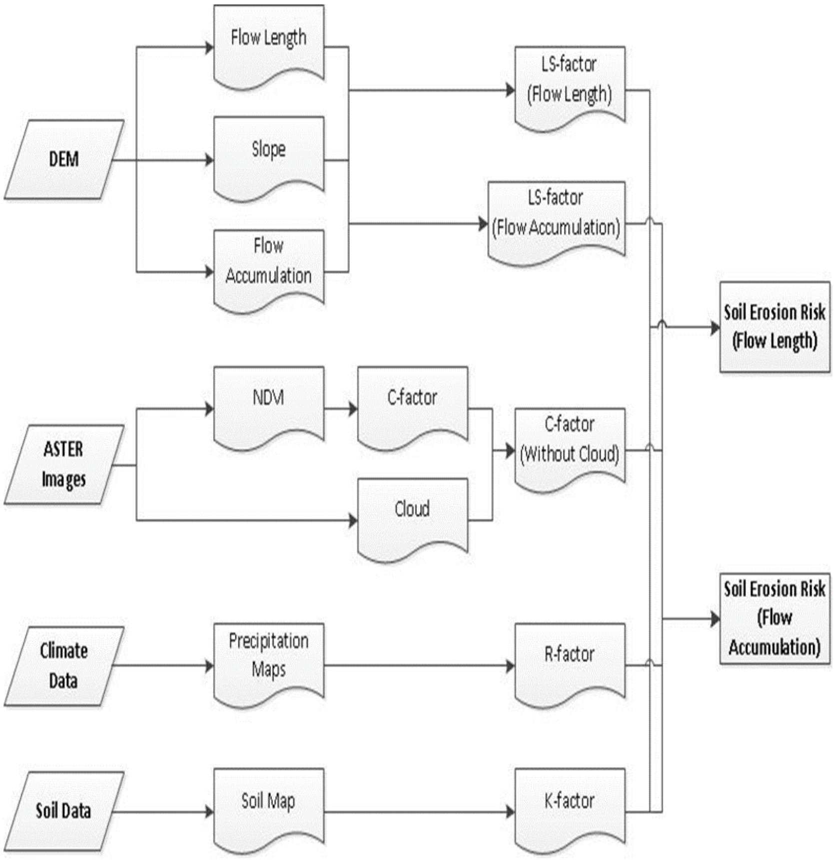


Figure2: Flow chart of RUSLE modeling

The methods and formulas for estimating each of the parameters in the RUSLE model are mainly based on three previous studies [10-12]. The work flow is shown below in Figure 2.

The rainfall erosivity factor indicates the erosive force of a specific rainfall [12]. The relationship between rainfall erosivity and rainfall depth developed by Wischmeier & Smith (1978) was used to translate the rainfall depth to rainfall erosivity. The calculation formula is expressed as

$$R = \sum_{i=1}^{12} 1.735 * 10^{\left(1.5 * log\,10\left(\frac{Pi\,2}{P}\right) - 0.08188\right)}$$

where R is rainfall erosivity value in MJ mm ha−1 h−1 y−1 , Pi is the monthly rainfall in mm; and P is the annual rainfall in mm.

In order to apply the relationship above, the monthly and annual rainfall depth are required to be prepared in raster format. Thus, the original rainfall data which distributed in daily form from four climate stations was extracted and summed up to monthly rainfall and annual rainfall depth for the three target year 1985, 2000 and 2015. The position of the stations and the corresponding rainfall depth values were imported to ArcGIS as point vector data. Afterwards, Inverse Distance Weighting (IDW) interpolation with second power calculation was applied to create totally 13 rainfall depth maps, 12 monthly and an annual rainfall depth maps, for each of the target years. The relationship developed by Wischmeier & Smith (1978) [9] was used to construct rainfall erosivity maps.

Results and Discussion

Rainfall Erosivity Factor (R)

From the above analysis, the rainfall erosivity of the study area for the year 1985, 2000 and 2015 varies from 0 to 1105.7 MJ mm ha^{-1} h^{-1} y^{-1}. Three rainfall erosivity maps are using the same stretch method and stretch scale to help comparison.

In Figure 3, the spatial distribution of the computed rainfall erosivity for the year 1985 is given. The range of the rainfall erosivity varied from 1.6 to 1032 MJ mm ha^{-1} h^{-1} y^{-1} with the average value 271.7 MJ mm ha^{-1} h^{-1} y^{-1}.

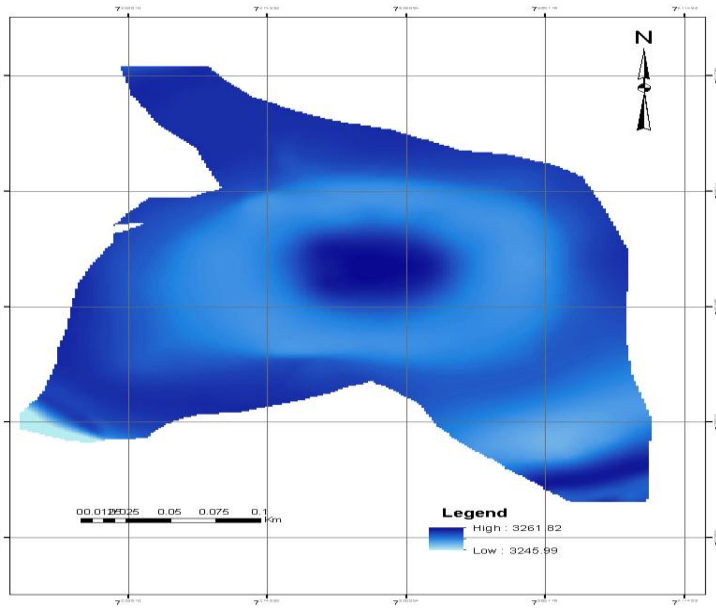


Figure 3: Rainfall erosivity map for the year 1985

While for the year 2000, the rainfall erosivity factor was found to be 0 to 764.8MJ mm ha^{-1} h^{-1} y^{-1} with the average value 279 MJ mm ha^{-1} h^{-1} y^{-1} for the entire study area (Fig 4). From the rainfall erosivity map for 2015 (Fig 4b), the largest amount of rainfall was observed. The map shows the range of the factor values changed from 4.2 to 1105.7MJ mm ha^{-1} h^{-1} y^{-1} with the highest average value 298 MJ mm ha^{-1} h^{-1} y^{-1} in the three target years.

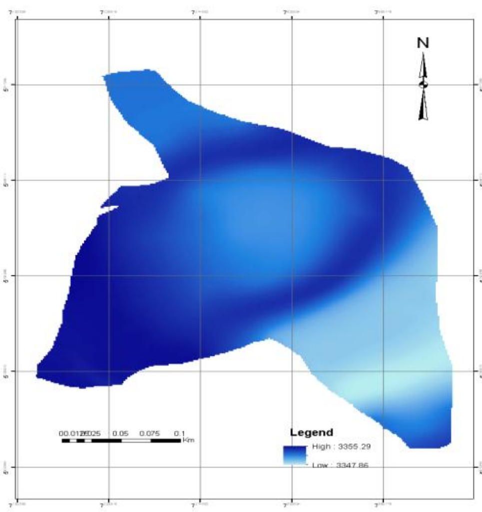


Figure 4a: Rainfall erosivity for year 2000

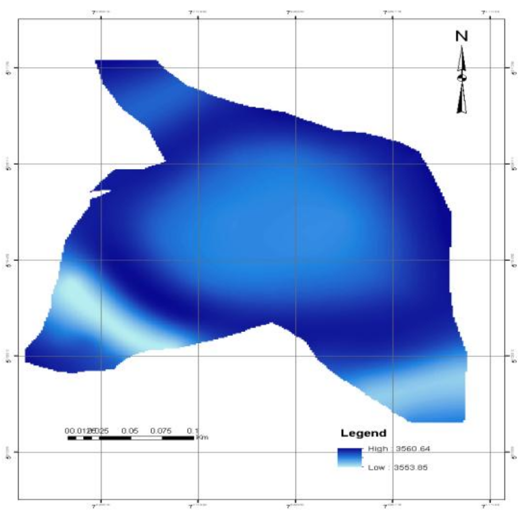


Figure 4b: Rainfall erosivity for year 2015

Soil Erodibility Factor (K)

Soil erodibility values were estimated based on the soil map, which contains the soil classification according to soil composition in Soil erodibility factor classification and fig 5 was generated which classified four types of soil in the study area.

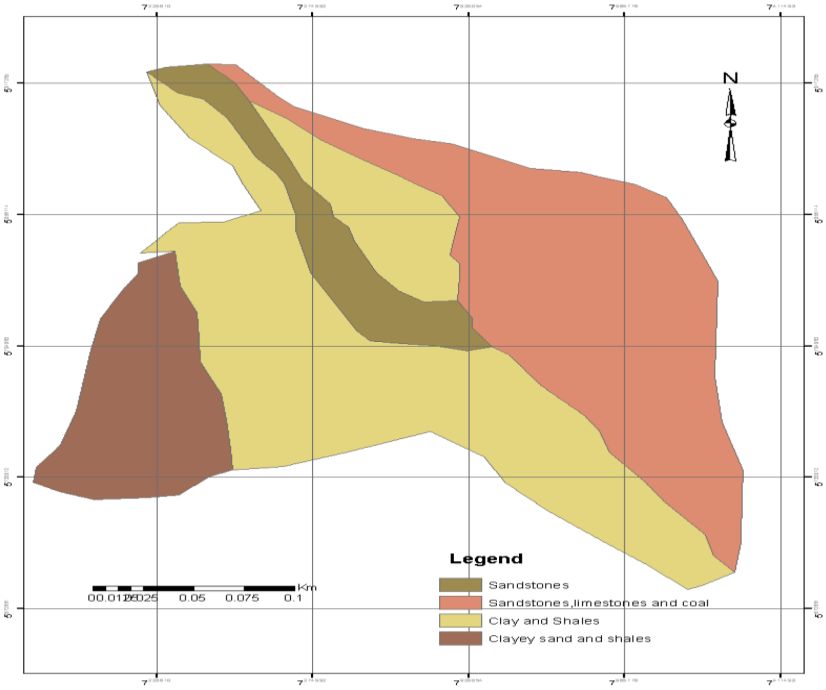


Figure 5: Soil map showing four different soil types in the study area

Table 2: Percentage of area taken by each soil type

Soil type	Percentage coverage (%)
Clay and Shales	43.1
Clayey Sands and Shales	13.8
Sandstones	7.92
Sandstones, Limestones and Coal	35.2

Different soil types normally have different structure, which influence the intensity of the soil erosion. The soil erodibility K-value indicates the vulnerability and susceptibility of the certain type of soil to detachment by erosion. The higher erodibility value the soil has, the more erosion will be suffered when the soils are exposed to the same intensity of rainfall, splash or surface flow. Table 3 shows the K-value for different soil composition in the study area.

Table 3: The K-value for different soil compositions

Composition	K-value
Clay and Shales	0.13
Clayey sands and Shales	0.14
Sandstones	0.05
Sandstones, Limestones and Coal	0.12

The four different soil types were assigned K-values according to the composition of the soils. With the help of interpolation tool in ArcGIS, the cell values which indicated the soil types were replaced by using the K-values shown above and which produced the map of soil erodibility factor (Fig 6).

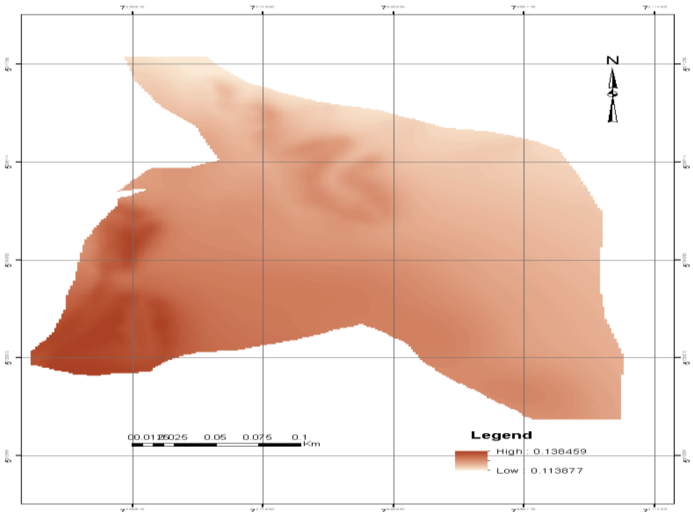
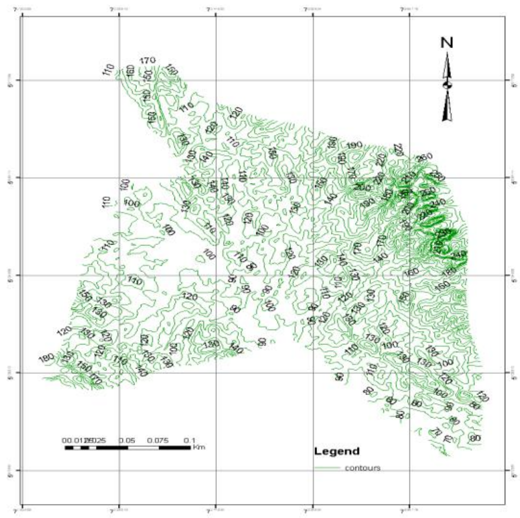


Figure 6: The translated soil erodibility (K-value) factor map of the study area

Slope Length and Steepness Factor (LS)

With the help of ArcGIS, the contour map shown in figure 7a was digitized from a topographic sheet and converted to DEM in figure 7b, the original DEM with 20m resolution was firstly converted to slope map in degree and flow direction map. Afterwards, the flow direction map was used to create map of flow length.



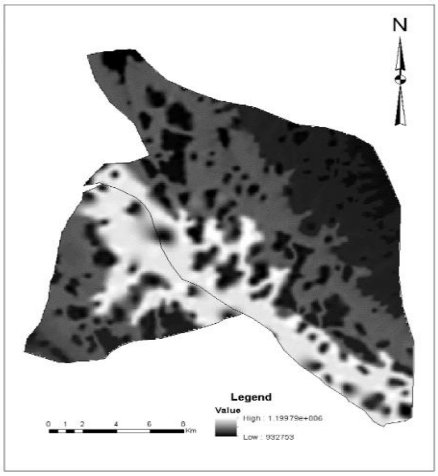


Figure 7a: Digitized Contour map of Okigwe *Figure 7b: Digital Elevation Model of Okigwe*

According to the smallest pixel size from satellite images, maps of flow length were re-sampled to 20m resolution. Both flow length and flow accumulation can be used to estimate the contribution of upstream cells in a DEM to the downstream cells. Flow length, also called slope length, estimates the water flow along lines while flow accumulation is based on drainage area. For a specific cell, the flow accumulation is estimated based on the upslope area and not just along flow lines. For the purpose of this study, the flow length was used. The LS factors were estimated applying the equation proposed by Moore *et al.*, (1991) [12]. In the equation, the flow length of upslope cells which contribute to a given cell. In addition, in ArcGIS calculation, flow length is the number of upslope cells which contribute to a particular cell, so they can be replaced by each other in the equation. The relationship is as follows:

$$LS = (\text{Flow Length} * \text{Cellsize}/22.13)^{0.4} * ((\text{Sin Slope})/0.0896)^{1.3}$$

where LS is the combination of slope length and steepness; Flow length is the accumulated upslope contribution to a cell; Cell size is the resolution of the raster image, and Sin slope is the sin value of the slope in degrees. The estimated LS values based on flow length, varying between 0 and 1, are presented in Fig 8.

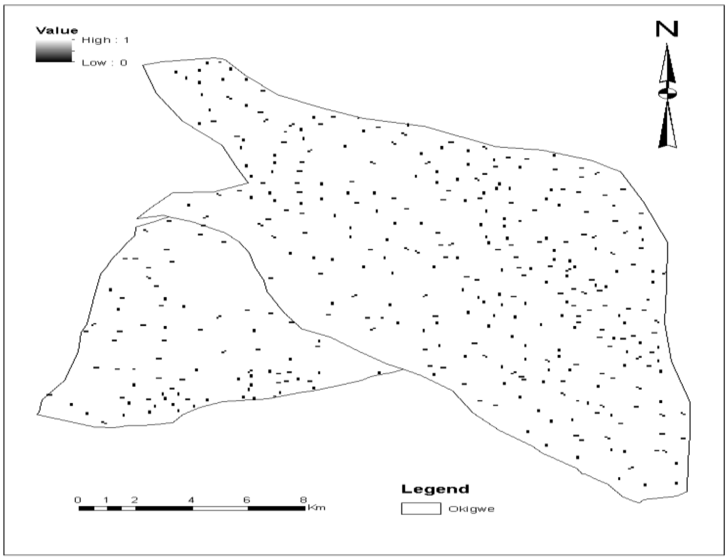


Figure 8: LS-factor map obtained by using flow length

Cover management factor (C)

The cover management factor represents the effect of plants, crop sequence and other cover surface on soil erosion. The value of C-factor is defined as the ratio of soil loss from a certain kinds of land surface cover conditions [9]. According to Prasanna kumar *et al.* (2012) [13], the Normalized Difference Vegetation Index (NDVI) can be used as an indicator of the land vegetation vigor and health. In this study, the original satellite images from the year 1985, 2000 and 2015 with the reflectance values in bands green, red and near-infrared, were converted to NDVI for the corresponding years. The NDVI expressed as:

$$NDVI = \frac{rNIR - rRed}{rRed - rNIR}$$

where rNIR is the reflectance value in near-infrared band; rRed is the reflectance value in visible red band.After calculated NDVI, the C-factor was estimated by applying the following relationship

$$C = \exp(-\alpha * (NDVI/\beta - NDVI)$$

where C is the calculated cover management factor; NDVI is the vegetation index, and α and β are two scaling factors. Van der Knijff *et al*. (2000) [14] suggested that by applying this relationship, better results than using a linear relationship can be obtained. They suggest the values for the two scaling factors α and β to be 2 and 1, respectively. For the year 1985, the C-factor map is shown in Fig 9. The C-factor varies from 0.34 to 1.32. By running the formula with the raster calculator tool in ArcGIS, the C-factor maps were obtained.

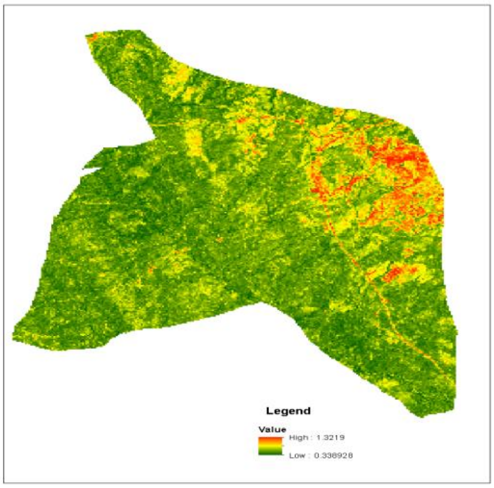


Figure 9a: C-factor maps (1985) of Okigwe

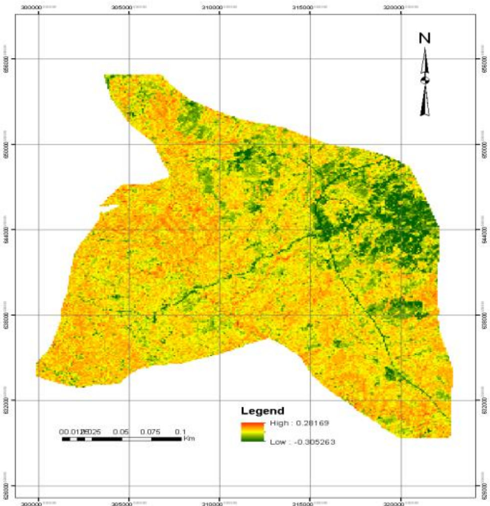


Fig 9b C-Factor Map 2000 of Okigwe.

For the year 2000, (fig 9b) The C-factor varies from 0.42 to 2.46. For the year 2015,(fig 9c) The C-factor varies from 0.3 to 0.8

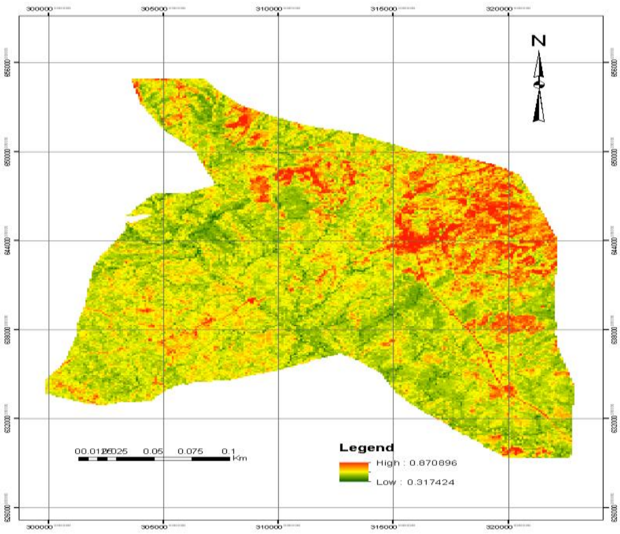


Figure 9c: C-factor map of the study area in the year 2015.

Conservation Practice Factor (P)

The conservation practice factor (P) represents the soil-loss ratio after performing a specific support practice to the corresponding soil loss, which can be treated as the factor to represent the effect of soil and water conservation practices [15-16]. The range of P factor varies from 0 to 1. The lower the value is the more effective the conservation practices are. In this study, this conservation practice factor was assigned to the maximum value of one (1) for the entire study area for running the RUSLE model. It is because there are no significant conservation practices detected. In Okigwe, most of the conservation practices are tree planting, and can thus be considered to influence the cover management factor (C) [10].

Annual Soil Loss Estimation (A)

In order to estimate annual soil loss, the five factors were multiplied according to the relationship in RUSLE model. In total three layers with annual soil loss were computed for each year. The soil loss was classified into soil erosion risk maps with five different soil erosion risk levels according to Bamutaze (2010) [10]. The threshold for each of the risk level is presented in Table 4.

Table 4: Categorization of soil erosion risk

Erosion Risk	Threshold (- -)
Very Low	Soil Loss ≤ 2
Low	2 < Soil Loss ≤ 10
Moderate	10 < Soil Loss ≤ 50
High	50 < Soil Loss ≤ 100
Very High	Soil Loss ≥ 100

In general, the soil erosion risk maps obtained by flow length method have relatively high annual soil loss values. Exploring the maps (see Figure 10), it can be concluded that about 30% of the area is exposed for high erosion risk.

For the year 1985, Figure 10 below illustrates the estimated erosion risk. The soil loss estimated by flow length method in this year varies between 0 and 4614 t $ha^{-1}y^{-1}$, with the average value 385 t $ha^{-1}y^{-1}$. The following histogram Figure 11 shows the land coverage percentage of each soil erosion risk level.62.24% of the area has a very high erosion risk, 12.42% a high risk, 16.91% a moderate risk, 6.02% a low risk, and only 2.42% a very low risk of soil erosion.

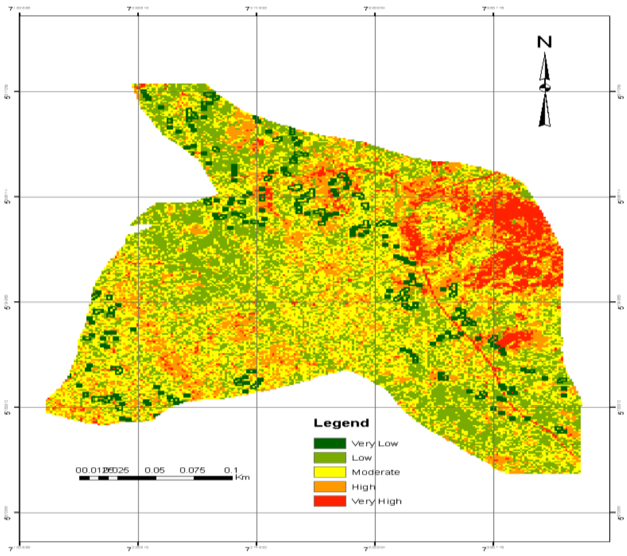


Figure 10: Soil erosion risk map for the year 1985

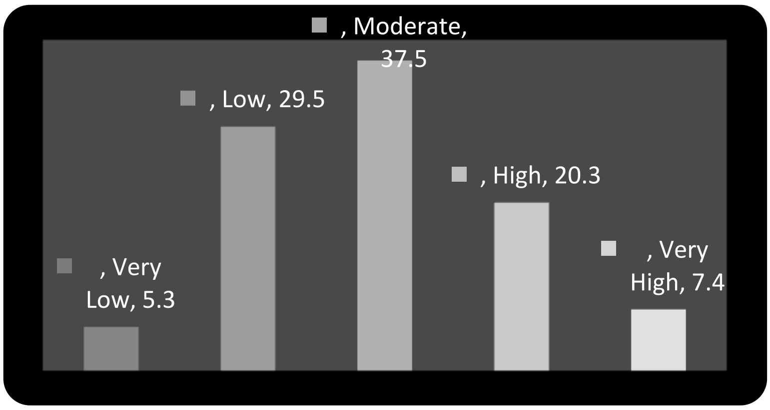


Figure 11: The percentage of coverage for the erosion risk map 1985

For the year 2000, the erosion risk map is shown in Figure 12. The estimated annual soil loss varies between -1239 and 1189 t ha^{-1} y^{-1}, which is similar to the result of year 1985. However, the mean value is 202 t ha^{-1} y^{-1}, which is much lower than 2000. Fig 11 shows that, 7.4 of the area has a very high erosion risk,20.3% a high risk, 37.5% a moderate risk, 29.5% a low risk, and only 5.3% a very low risk of soil erosion.

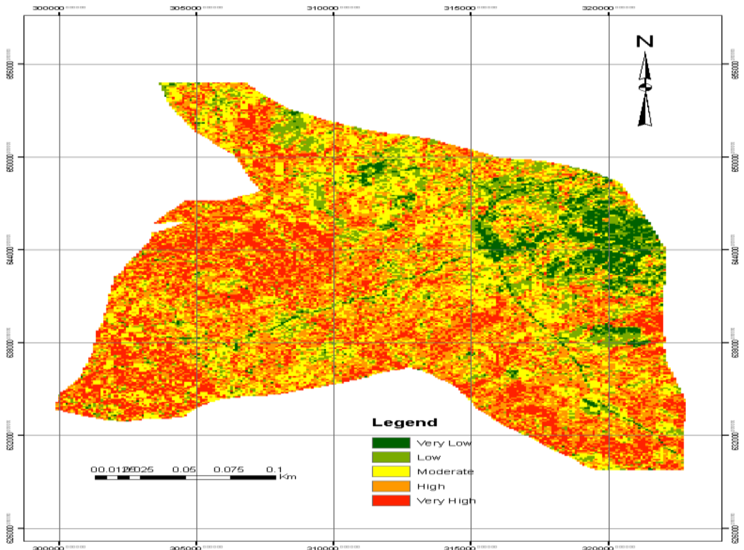


Figure 12: Soil erosion risk map for the year 2000

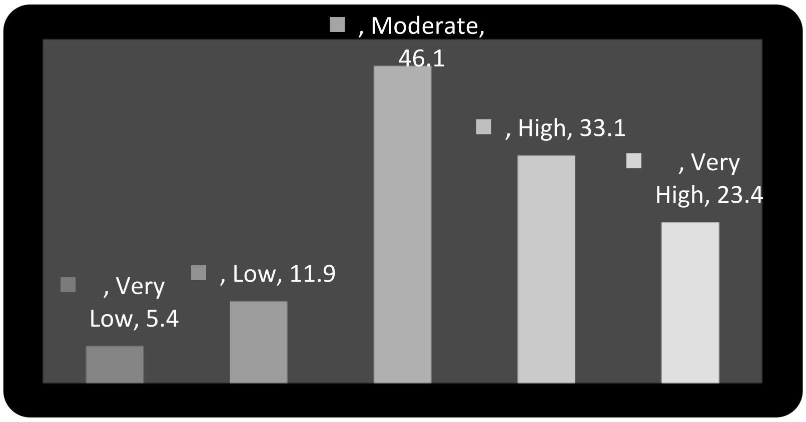


Figure 13: The percentage of coverage for the erosion risk map 2000

The result for 2015 (Fig 14), the estimated soil loss values vary between 0 and 3784 t ha^{-1} y^{-1}. The mean soil loss value is 315 t ha^{-1} y^{-1}, which is higher than the one for year 2000. From the histogram (Fig15), 34.1% area is under very high erosion risk, which is less than the year 2000. 11.2% of the area has a very high erosion risk, 22.9% a high risk, 29.1% a moderate risk, 30.8% a low risk, and only 5.9% a very low risk of soil erosion. There is an increase for the area of low and moderate erosion risk compared with year 2000. The coverage percentage of year 2015 is very similar to the situation in 2000.

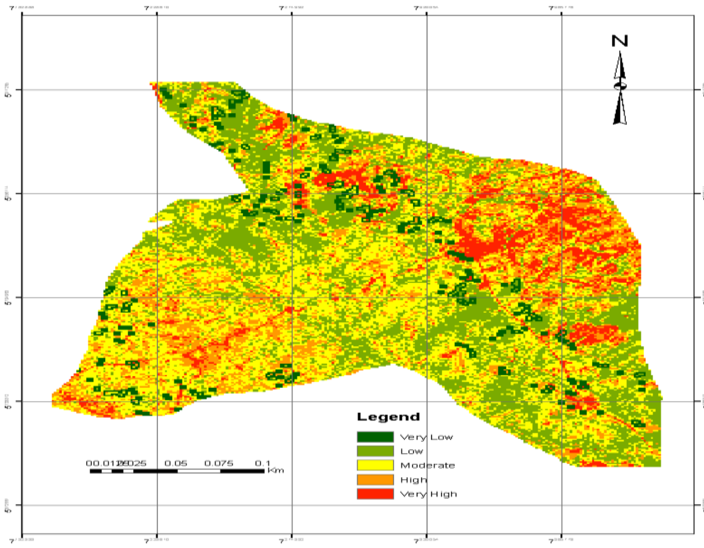


Figure 14: Soil erosion risk map for the year 2015

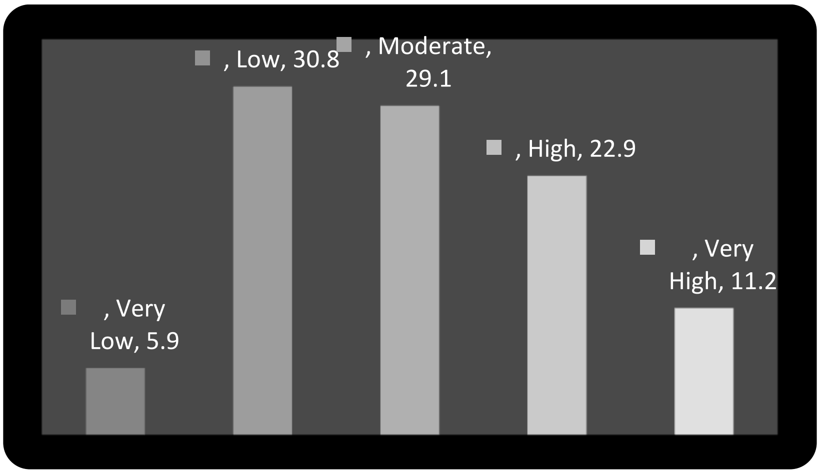


Figure 15: The percentage of coverage for the erosion risk map 2015

Soil Erosion Trends Related to Precipitation and Land cover Changes

From 1985 to 2000, the mean annual precipitation decreases from 195mm to 194 mm. Afterwards, there was increase from 194 mm to 248 mm from the year 2000 to 2015. The mean annual precipitation for 1985 is approximately the same as for the year 2000. The R-factor shows similar trend. However, the mean R-factor value in the year 2015 is higher and shows the highest rainfall erosivity for the three target years. Regarding land cover, mean NDVI was used as the detector for land cover changes. Mean NDVI values increase from 0.79 to 2.0 during the years 1985 to 2015. The increasing of NDVI indicates better ground cover vegetation condition. From the year 1985 to 2015, the land area has an increasing NDVI. This area is mainly located in the western part of the study area. The area with decreasing NDVI appears mainly in the south and east. From 1985 to 2015, an increasing trend is kept with the increasing coverage. The increasing NDVI is still located in the western part of the study area. The decreasing NDVI is mainly in the northeast. Comparing the year 1985 and 2015, Large portion of the land has an increasing NDVI. Even if the analysis is influenced by cloud cover and not significant, one can see clear indications that most of the western part of the study area has got more vegetation cover during the last decade. However, a regular polygon located in the southwest corner has a large decrease in vegetation cover, may be caused by artificial activities such as urban construction, or agriculture land conversion.Soil erosion changes and trends can be explored. The estimated soil erosion decreases between 1985 and 2000, and increases between 2000 and 2015. This “trend” is similar to the precipitation trend discussed earlier. The R-factor in the year1985 is much lower than the year 2000 and 2015. It seems that soil erosion is more sensitive to precipitation

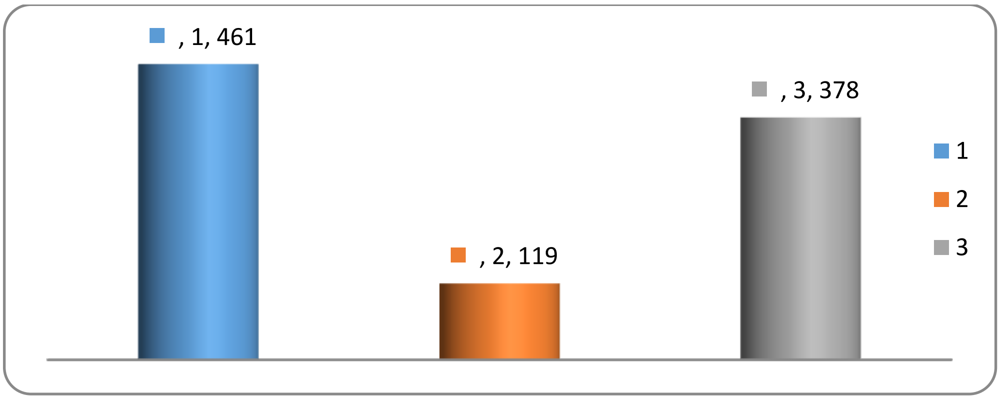


Figure 16: Mean annual soil loss for entire study area from year 1985 to 2015

Summary and Conclusion

From year 1985 to 2000, 65.57% of the study area has a deceasing trend of annual soil loss. Most of the area with large decrease is located in the northeastern part of the study area. From 2000 to 2015, there is a general increase in soil erosion risk (52.17% of the study area). The areas with higher risk for soil erosion are generally located in the southwestern part of the study area. When comparing the two years 1985 and 2015, one can conclude that 60.51% of the land has a decreasing trend in soil erosion risk. The 39.49% of the land with an increasing risk is mainly located in northeastern corner, southeastern corner, and some of the western part of the study area. The relatively high decrease in soil erosion risk can be seen as contradictory in comparison with the high maximum soil loss (378) detected in the year of 2012. One explanation can however be that the erosion area decreases but the intensity of the erosion at some particular place increases.

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