Long Term Assessment and Mapping of Erosion Hotspots in South East Nigeria

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Keywords: Soil Erosion, Southeast Nigeria, RUSLE, Erosion Hotspots, Land degradation.

Summary

Soil erosion is a serious environmental issue in south east Nigeria. The rate of erosion has continued to increase with devastating impacts, and has led to land degradation (gullies), infrastructural damage as well as loss of lives and properties. Assessment of erosion risk and mapping of erosion hotspots in this region is thus an important step in curbing the increasing menace of erosion in this part of the world. However, erosion hotspots in the region have predominantly been identified through field observations with obvious limitations such as being time consuming, expensive and tedious. More so, current erosion studies in this region have been segmented, focusing on different parts of the region. This study hopes to provide a regional map of erosion hotspots in the region, via, a cost effective and quick method, as a step towards efficient control of increasing erosion impacts in the region. The Revised Universal Soil Loss Equation (RUSLE) was implemented in a GIS, in conjunction with remote sensing techniques as an alternative method of identifying erosion hotspots. The study is aiming at assessing the level of erosion across the entire region and map areas vulnerable to erosion, over an extended period of time. This was done to have a better understanding of the relevant trends and patterns of soil erosion in the region, as well as to identify areas susceptible to erosion for targeted mitigation measures. The research identified five levels of erosion risks in the region ranging from extreme to very low risk areas, and highlighted the spatial distribution of erosion hotspots in the region. The hotspots are mainly located in most parts of Ebonyi State, some parts of Enugu State (Northwest axis), Anambra State (South East and Central axis), and most parts of Abia State. Results from the spatiotemporal variations analysis carried out revealed that there are increasing levels of Erosion risk in Ebonyi State from 1986 to 2011. These results are expected to equip environmental agencies and managers with useful products that will effectively guide erosion control policies and measures in the region.

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1. BACKGROUND

The south east Nigeria has greatly been impacted by soil erosion. This has largely been attributed to extensive use of land for agricultural purposes ('overfarming') due to high population density (Grove, 1951). Erosion is commonly associated with environmental problems such as decreased land productivity, challenges to agricultural sustainability, degradation of soil and water quality, and indirect pollution of the environment through the transport of contaminants such as agricultural and industrial waste attached to sediments to other parts of the environment and the hydrographic network (American Society of Agricultural and Biological Engineers, 2002, Kostadinov, 2002**)**. Most of these problems are currently being experienced in the south east of Nigeria and thus generating a high level of concern among the populace (Ezezika and Adetona, 2011, Obiadi *et al*., 2011, Akpokodje *et al*., 2010, Igbokwe *et al*., 2008, Ofomata, 1965). Erosion is facilitated by numerous factors and processes such as land use, topography, climate, and soil. Thus, the actions of man such as encroachment of agricultural activities on forest areas, deforestation for commercial and industrial purposes, urbanisation and general misuse of land, as well as the effect of climatic changes such as high rainfall regime, drought, and desertification, tend to exacerbate the impact of soil erosion on the environment (UNESCO, 2009).

Various erosion-focused studies have been carried out by researchers in the country (Ofomata, 1965, Ogbukagu, 1976, Egboka and Okpoko, 1984, Okagbue and Uma, 1987, Akpokodje *et al*., 2010, Ezezika and Adetona, 2011, Obiadi *et al*., 2011), however most of these studies have largely been focused at specific parts of the region (Okereke *et al*., 2012, Obiadi *et al*., 2011). None of the research has however explored the power of the Revised Universal Soil Loss Equation in comprehensively modelling erosion processes and mapping areas of high erosion risks in the south east region of Nigeria. Except for a few studies (Igbokwe *et al*., 2008, Okereke *et al*., 2012), most of the erosion hotspots maps for region have largely been produced through ground surveys of the affected sites (Akpokodje *et al*., 2010).

The menace of erosion has not only drawn attention of researchers in the region, but also those of the global research community, and has thus led to the studying of the various effects and aspects of erosion in various parts of the world. Numerous erosion models such as Universal Soil Loss Equation (USLE), Revised Universal Soil Loss Equation (RUSLE), Coordination of Information on the Environment (CORINE), Water Erosion Prediction Project (WEPP), Pan-European Soil Erosion Risk Assessment (PESERA), Kinematic Runoff and Erosion Model (KINEROS), and Erosion Potential Model (EPM) (Wischmeier and Smith, 1978, Kirkby, *et al*., 2003, Blinkov and Kostadinov, 2010, Yuksel *et al*., 2008, Nikolova, *et al*., 2009, Amiri, 2010*)* have been developed and applied in various regions of the world. In addition a wide range of erosion control practices have been developed and adopted in order to contain the various problems caused by erosion. Erosion models utilise the various factors that affect erosion to simulate erosion processes in order to predict the levels of erosion in a region. Thus with these models, insights could be drawn of present and future trends of erosion impacts in a region. Despite the known benefits of this models their use and application in studies carried in developing countries such as Nigeria is significantly minimal.

Mapping of areas of erosion risk is an important stage in the erosion control measures. From the foregoing it has been demonstrated that erosion is a major threat to soil and water resources conservation in south east Nigeria. Various attempts made at controlling erosion in the region have yet to achieve a significant result. Therefore, there is need for the intensification of efforts in this field of study. However, the difficulty and cost involved in carrying out ground surveys of these hotspots limits the extent of implementation of some the erosion control measures. In other to overcome this limitation, the RUSLE was used in this study, in conjunction with GIS and remote sensing techniques to identify areas of high risk of erosion, so they could urgently be targeted for remediation strategies.

2. STUDY AREA

Geopolitical speaking, the south eastern region of Nigeria is comprised of five states namely, Imo, Anambra, Abia, Enugu and Ebonyi States (Figure 1). It is the home of the Igbo speaking people of Nigeria. It is located within latitudes 4° 47’ 35’’N and 7° 7’ 44’’N, and longitudes 7° 54’ 26’E and 8° 27’ 10’E in the tropical rain forest zone of Nigeria, with mean maximum temperature of 27^{o}C, and total annual rainfall exceeding 2500mm (Ezemonye and Emeribe, 2012). The region is largely agrarian and there is thus much dependence on land resources, due to its dense population averaged to about 1000 people/Km^2. This dependence on land has led to the over use of the land resources in the region, leading to the farming of agricultural lands annually.

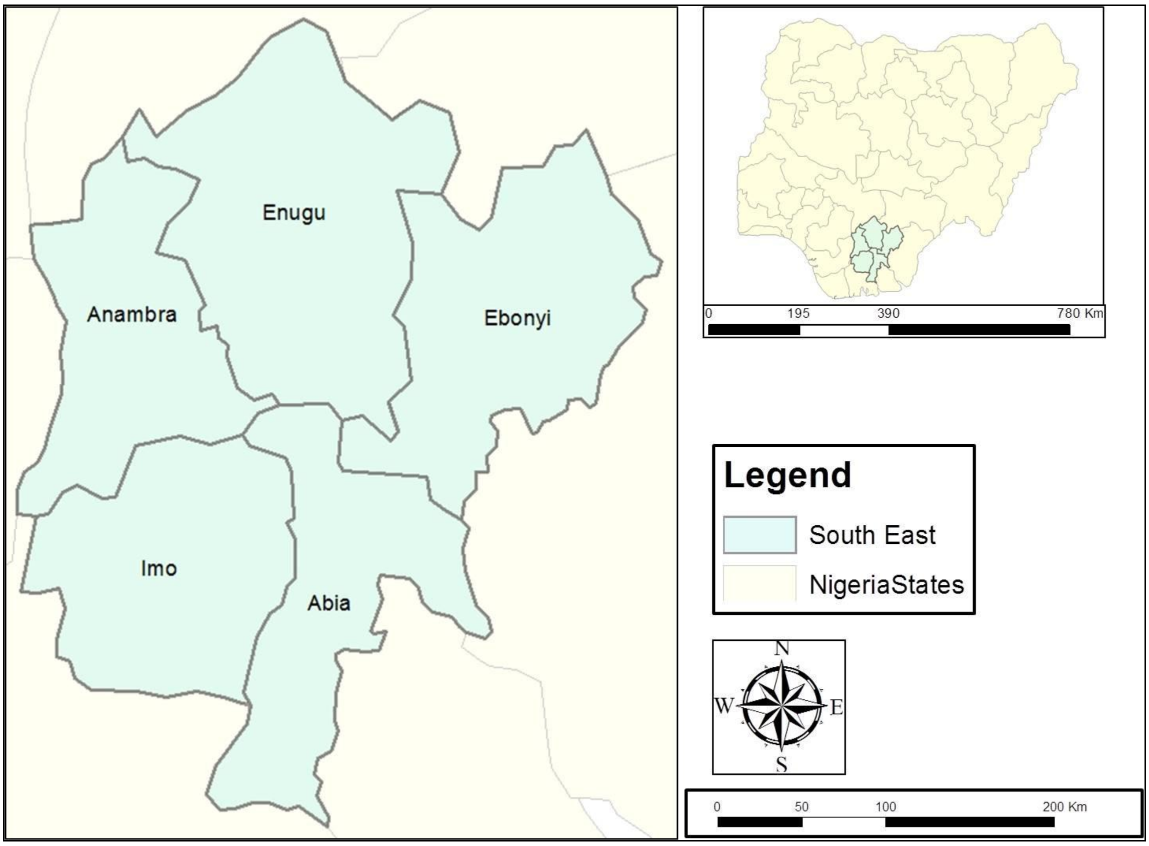

Figure 1: *Map of the south east region of Nigeria showing the five component states. Map of Nigeria is inset.*

3. METHODOLOGY

3.1 Data and preprocessing

The data used in this project include: soil map of the region, political map of Nigeria, monthly mean precipitation data, 3 digital elevation models (DEM) and 15 cloud-free Landsat images from Landsat TM and ETM+, used to obtain the landuse map of the region at various time intervals. The soil map was obtained from the Department of Geoinformatics and Surveying, University of Nigeria Nsukka, and the 30 arc seconds precipitation data, obtained from the WorldClim data centre (http://www.worldclim.org/). In order to have a long-term insight of erosion risk sites in the region, 3 DEM data (ASTER Global DEM V2, SRTM 90m, and GTOPO30 DEM data) spanning three time periods (1996, 2000, and 2011) respectively, obtained from the USGS LPDACC (http://gdex.cr.usgs.gov/gdex/) were used. In order to have a complete coverage of the south eastern region, 5 Landsat scenes were used and thus for the three time periods a total of 15 Landsat scenes were used (Table 1). As there were no available cloud-free Landsat data for most of the period between 1991 and 1999, images from earlier years (1986/1987) were used to derive the landuse map for the period. It is expected that the elevation information contained in the GTOPO data would be a representative of the average elevation condition for these years. The Landsat images were used to obtain the landuse map of each study period.
The vector soil map was reprocessed into a rasterised soil map, delineating six different soil types in the region. Each set of 5 Landsat scenes for the study periods were mosaicked into

one comprehensive image before being cropped with the political map delineating the south eastern region. Based on the acquisition (compilation) dates of the elevation data used, three different time periods were chosen for the study. The first period spans from 1986-1996, the second period spanning1996-2002, and the third period covering 2002-2011. These periods were expected to give a wider insight into the various erosion conditions in the region.

Table 1: *The details of 15 Landsat bands, DEMs and average precipitation used*

			Study Periods			
Scene	**Path**	**Row**	**1987-1996**	**1996-2002**	**2002-2012**	**Sensor**
1	188	56	19/12/1986			TM
	188	56		17/12/2000		ETM+
	188	56			16/12/2011	ETM+
2	188	55	04/01/1987			TM
	188	55		17/12/2000		ETM+
	188	55			14/01/2011	ETM+
3	188	57	17/01/1986			TM
	188	57		17/12/2000		ETM+
	188	57			01/01/2012	ETM+
4	189	56	21/12/1987			TM
	189	56		08/28/2002		ETM+
	189	56			05/01/2011	ETM+
5	189	55	21/12/1987			TM
	189	55		09/01/2001		ETM+
	189	55			05/01/2011	ETM+

DEM Data and Precipitation data

S/N	**Data**	**Spatial Resolution**	**Acquisition Date**
1	GTOPO30	1000km	1996
2	SRTM 90	90m	2000
3	Aster	30m	2011
4	WorldClim	1000	1950-2000

3.2. Assessment of erosion hotspots in the region

The revised universal soil loss equation (RUSLE) was used to assess the areas of erosion risk in the study area. The RUSLE, a modification of the earlier erosion prediction model (USLE) developed by Wischmeier and Smith (1978), is a commonly applied model in erosion prediction studies. It is expressed as (USDA, 2009):

$$A = R * K * LS * C * P \qquad (1)$$

Where:

A = the predicted average annual soil loss from interrill (sheet) and rill erosion from rainfall and associated overland flow (in tons per hectare per year).

R = Rainfall-Runoff Erosivity Factor.
K = Soil Erodibility Factor.
LS = Slope Length and Steepness Factor.
C = Cover-Management Factor.
P = Support Practices Factor.
The model simulates an area with permanent stream networks, where when rain occurs; some of the water is soaked into the soil while the rest flow down the slope towards the permanent streams. The amount of water carried down the slope is determined by the intensity and duration of the rainfall, the moisture content in the soil before the rain, and the soil permeability. As the soil becomes saturated with infiltrated moisture, the amount of water carried as overland flow increases. The raindrops falling on the soil detach soluble sediments and nutrients in the soil, which readily dissolve in the water, and are carried away with the water towards the streams. The land use, soil characteristics, and topographic conditions are the core factors that determine the amount of sediments available for transport by water. This is calculated as (A) through the simulation of the RUSLE factors (see Equation 1) in the model.

The various components of the RUSLE (R, K, LS, C, and P) were integrated in a GIS environment to simulate the action of erosion in the region and the amount of soil annually lost in the area estimated. The RUSLE components were individually computed and the values obtained used to reclassify the corresponding spatial datasets before they were mathematically combined to obtain A.

3.2.1 Rainfall runoff factor (R)

The runoff factor, an index showing how much erosive force a typical storm has on surface soils, was computed using the following equation (Lee and Lee, 2006):

$$R = 38.5 + 0.35 \times Pr \qquad (2)$$

Where, Pr = is the annual average rainfall (mm/yr)
The annual average rainfall was computed from the monthly mean precipitation datasets (Anejionu and Okeke, 2011). The mean monthly precipitation data were compiled using precipitation records from 1950 to 2000 (Hijmans *et al.,*, 2005), thus it is expected that they are representatives of the rainfall regimes in the region. The computed R value with 1000m resolution, was resampled to 30m and 90m resolution to match the corresponding datasets from the Aster and SRTM data respectively used for the computation of (A) for the 2000 and 2011 time periods.

3.2.2 Soil erodibility factor (K)

The soil erodibility factor is an empirically derived index that indicates susceptibility of soil to rainfall and runoff detachment and transport (rates of runoff) based on soil texture, grain size, permeability and organic matter content. It thus represents the combined effects of soil detachment and runoff on a particular soil. It denotes the average soil lost per ton per acre per unit area for a particular type of soil under standard unit plot condition (cultivated, continuous fallow with slope length of 22.13m and percentage slope steepness of 9%) (Institute of Water Research Michigan State University, 2002, Stone and Hilborn, 2000). The higher the value of K, the more susceptible the soil is to erosion. Soils with high clay content have low K values as they are resistant to soil detachment, while soils with coarse texture (sandy soils) that are easily detached equally have low K values due to low runoff (high infiltration rates). Soils with high silt content are the most erodible of all soils as they are easily detached and produce high rates of runoff, thus they usually have high K values up to 0.4 (Institute of Water Research, Michigan State University, 2002).

The values of K for the different soil types within the study area (see Table 2) were used to obtain the soil erodibilty dataset of the study area, through the reclassification of the soil map dataset (Figure 2).

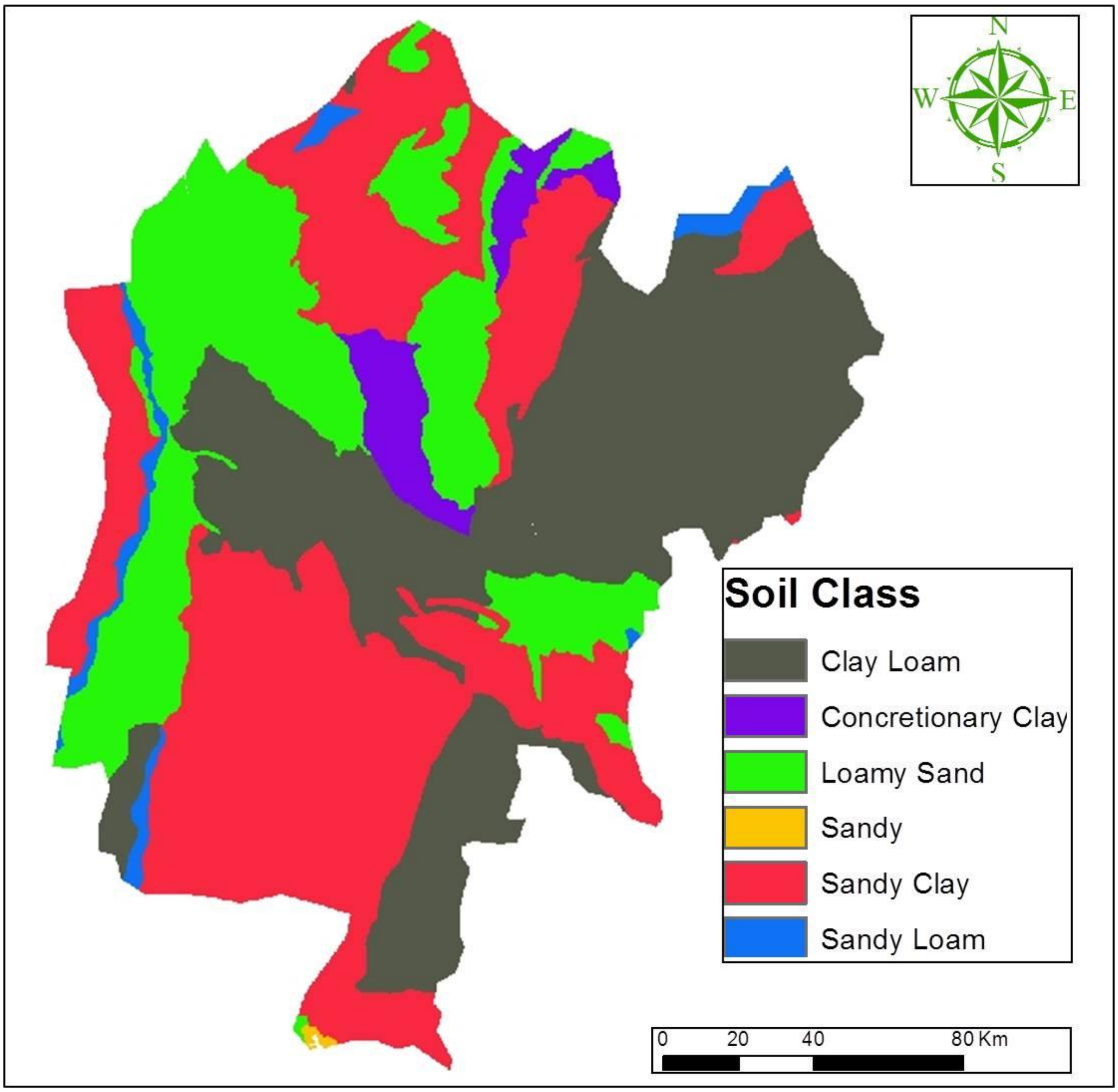

Figure 2: *Soil map delineating 6 different soil types in the study area*

Table 2: Soil erodibilty values (Stone and Hilborn, 2000)

Soil Type	K factor	Soil Type	K factor
Clay Loam	0.30	Sandy Loam	0.13
Concretionary Clay	0.17	Sandy	0.02
Sandy Clay	0.20	Loamy Sand	0.04

3.2.3 Slope length and slope steepness factor (LS)

The LS factor computes the effect of slope length (L) and the slope steepness (S) on erosion. The slope length factor is the ratio of the amount of soil lost from the field slope length to that of 22.13m slope length on the same soil type and gradient; while the slope steepness factor is a measure of the effect of slope steepness on erosion (Institute of Water Research Michigan State University, 2002). The LS factor is expressed as

$$LS = \left(\frac{\lambda}{22.13}\right)^{m}\left(65.41\sin^{2}\theta + 4.56\sin\theta + 0.065\right) \ldots\ldots \quad (3)$$

Where:
λ = slope length in meters; θ = slope in degrees; m = a constant dependent on the value of the slope gradient: 0.5 if the percent slope greater than or equal to 5%, 0.4 on slopes between 3.5% and 4.5%, 0.3 for slopes between 1% and 3%, and 0.2 for uniform gradients with slopes less than 1% (Wischmeier and Smith, 1978, Lu *et al*., 2004).
The DEMS from the Aster, SRTM and GTOPO 30 data were used to derive the slopes in degrees and in percentage for the corresponding study periods. The degree slopes were further converted to radians (I degree = 0.0174532925 radians) before being used in the ArcGIS calculation. The slope length, the distance from the origin of overland flow along its flow path to the location of concentrated flow or start of deposition, was approximated by the flow length computed based on the flow direction derived from the relevant DEMs.

3.2.4 Cover and management factor (C)

The cover and management factor is an index that indicates how crop management and land cover affect soil erodibility. It is used to express the combined effects (reduction of runoff velocity and protection of surface pores) of plants and soil cover as well as those of all other interrelated cover and management variables (Karaburun, 2010). To obtain the C factor dataset, supervised classification were carried out on the 15 Landsat images covering the study periods. The maximum likelihood classifier based on all the Landsat bands was used to map seven major land cover classes (thick forest, light forest, water, swamps, agriculture, bare land and built environment), as shown in Figure 3. The 1986/1987 classification result was resampled to 1000m spatial resolution to match the 1000m resolution of the GTOPO DEM data, while that from the 2000/2002 Landsat data was resampled to 90m to match the 90m SRTM DEM data. Having obtained the land use map of the three study periods, C factor values (Table 3) for the relevant land use types obtained from guidebooks (Lee and Lee, 2006; Shi *et al.*, 2002), were used to reclassify the land use map.

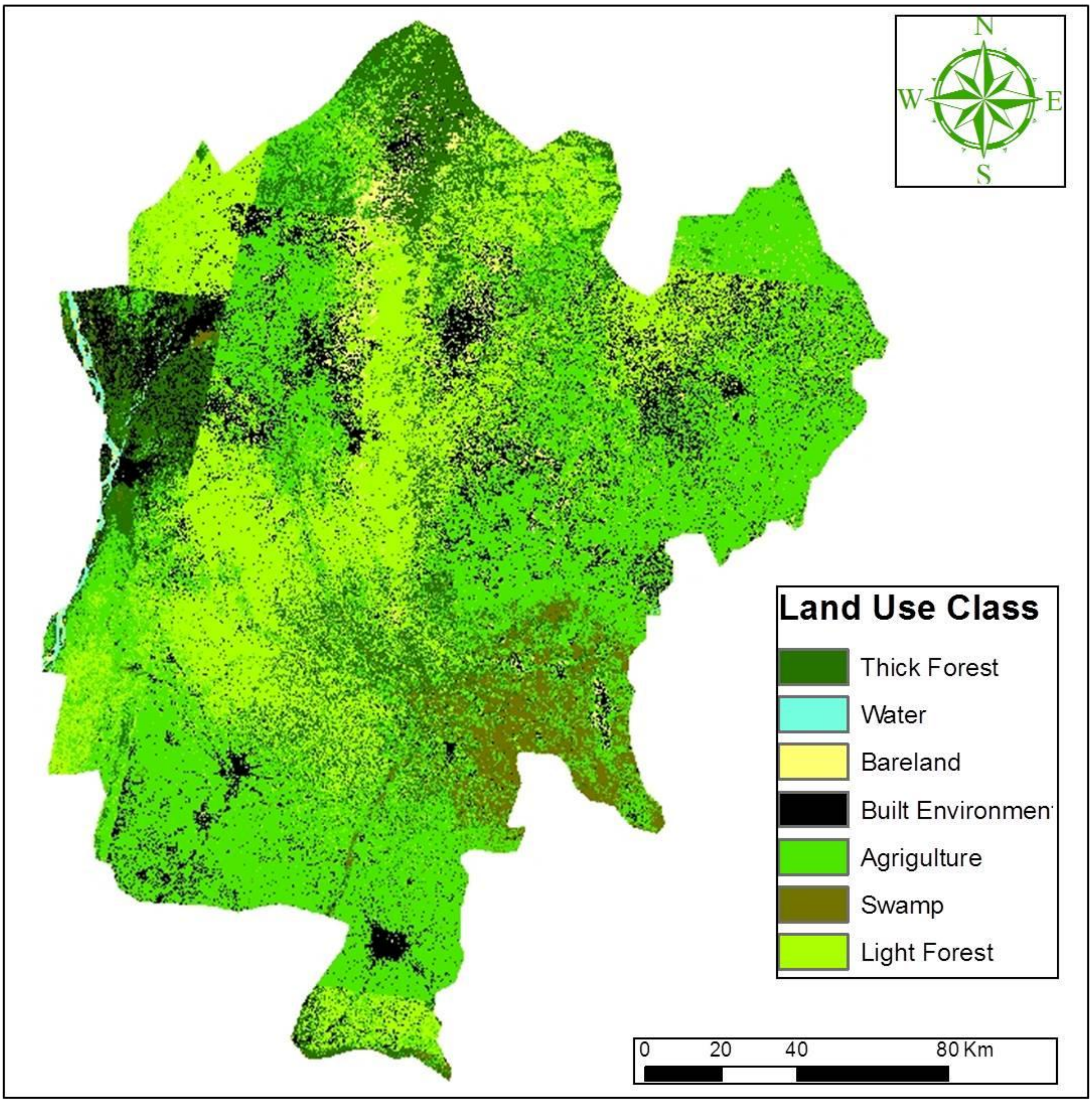

Figure 3: *Land use classification map showing seven major land use classes in the south east Nigeria. Derived from the 2000-2002 ETM+ datasets.*

Table 3: *Cover and management factor values*

*(*Lee and Lee, 2006)

Code	Land Use	C
1	Water	0.000
2	Barren	0.500
3	Developed	0.003

4	Light Vegetation	0.05
5	Agriculture	0.3
6	Thick Forest	0.004
7	Swamp/Muddy	0.002

3.2.5 Support practice factor (P)

The P-factor refers to the level of erosion control practices such as contour planting, terracing and strip cropping, put in place in a watershed, and depends on the average slope steepness within the study area. The values shown in Table 4 were used to reclassify the slope dataset to obtain the P factor for the study area. The predominant practice in the study area is contouring and the values under this column were used for the reclassification.

Table 4: P factor depending on cultivation types and slope

(Korea Institute of Construction Technology, 1992)

Slope	**Contouring**	**Stripping**	**Terracing**
0.0 -7.00	0.55	0.27	0.10
7.00 – 11.3	0.60	0.30	0.12
11.3 – 17.6	0.80	0.40	0.16
17.6 – 26.8	0.90	0.45	0.18
26.8 >	1.00	0.50	0.20

3.2.6 Computation of A

Having computed the various RUSLE factors, the average soil loss in tons per acre per year (A) in the region, for each of the study periods were individually estimated through the multiplication of all the corresponding RUSLE factors. As the soil type and average annual rainfall values for the three time periods were not expected to significantly vary, similar K and R factors were used for the different study periods. Variations in the time periods were expected in the land use, as well as the topography of the regions, thus the need to individually determine the various land use maps and DEMs for the periods. Having obtained the average soil loss from each of the raster cells, these were further reclassified into five different erosion risk level areas (extreme, high, moderate, low, very low). Having obtained the A values for the three study periods, the resulting datasets were individually analysed and subsequently spatiotemporal analysis was carried out to determine hotspots variations across the years.

4. RESULTS AND DISCUSSION

The different erosion risk levels computed in the 2002-2011 time periods are shown in Figure 4. Figure 5 illustrates the erosion risk levels obtained from the 1996-2000 period while that from the 1986-1996 period are shown in Figure 6. The high and extreme erosion areas denote the erosion hotspots (parts of the region seriously affected by erosion) that require urgent remediation measures. Most of this hotspots were noted to be concentrated in most parts of Ebonyi State, Enugu State (Northwest axis), Anambra State (South East and Central axis), and most parts of Abia State. Imo State was the list devastated by erosion, having the least number of erosion hotspots as shown in Figure 7. This corresponds to the spatial distribution of known areas of erosion menace in the region.

From the assessment of the high risk level areas obtained from the three study periods, there was a noticeable increasing erosion risk levels from earlier periods till present. This was clearly demonstrated around the Ebonyi State axis, where most of the areas initially identified as high erosion risk areas gradually turned into the extreme erosion risk areas in the 2002-2011 period. This result is significant as it strongly demonstrates that existing erosion control measures are not adequate to contain the impacts of erosion in the region.

This research clearly demonstrated the seriousness of erosion menace in these parts of the region. Bearing in mind that Ebonyi State is predominantly an agricultural state, with the bulk of the food consumed in the region supplied from this state, the need to take urgent erosion control measures in the state cannot be overemphasised. At the rate of erosion estimated in this research, most parts of Ebonyi State will be severely be impacted by erosion in the next 10 years. The consequences of this on food security in the region would be dire. Thus, this increasing rate of erosion in the region, calls for urgent attention from the relevant government agencies in the country.

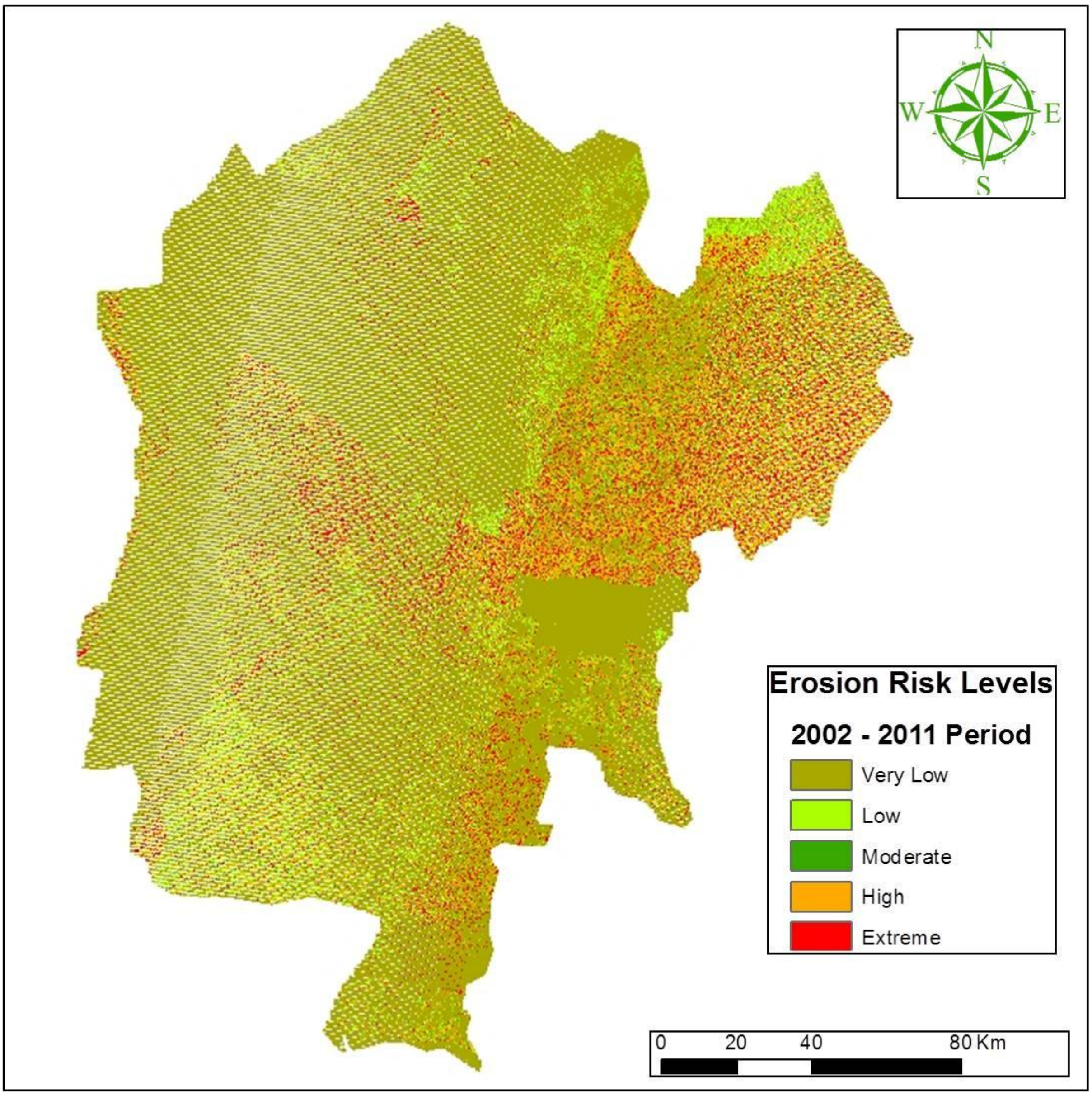

Figure 4: *Spatial distribution of erosion risk levels from the 2002-2011 time period.*

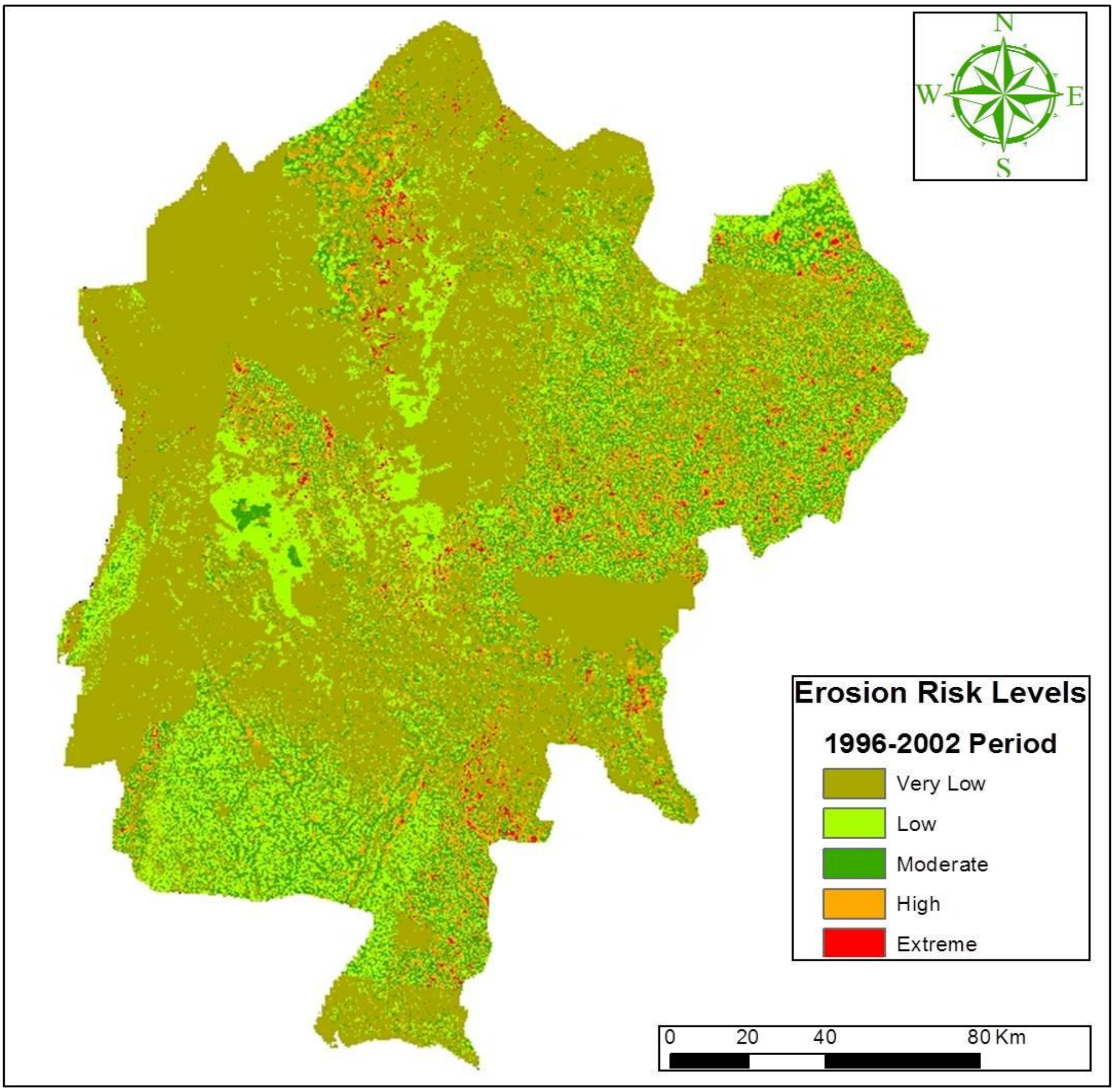

Figure 5: *Spatial distribution of erosion risk levels from the 1996-2002 time period.*

Among the major limitations of the study was the difference in the spatial resolutions and accuracies of the digital elevation models used in this study. As the DEMS came from different satellite and elevation sources, there is a possibility of disparity of the information obtained from each of these sources, due to the differences in their spatial resolutions (spatial accuracies). This may have affected the accuracies of the results obtained for the different time periods. As the topography is expected to change across the years, intercalibration between the DEMs was not considered appropriate. The spatial resolution differences resulted in the presentation of the data in different spatial resolutions for each of the study period. This may have introduced some levels of uncertainties in the results, although the uncertainties are not expected to cause significant errors, as elevation patterns represented by this DEM are expected to give a general representation of the topographic conditions of the region during the particular time periods. Furthermore, environmental managers are usually interested in the spatial distribution of erosion hotspots than the accuracies of the absolute values.

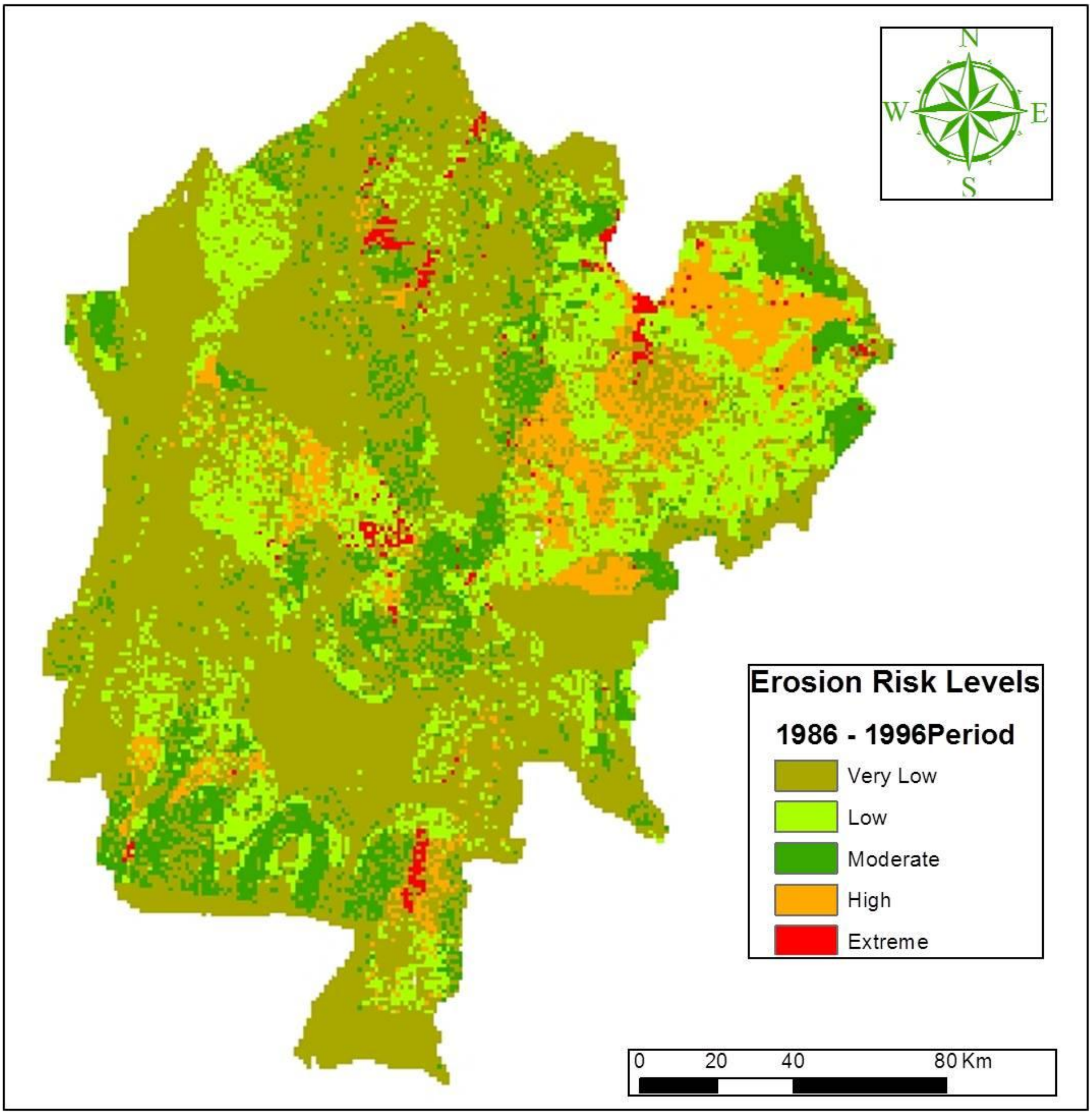

Figure 6: *Spatial distribution of erosion risk levels from the 1986-1996 time period.*

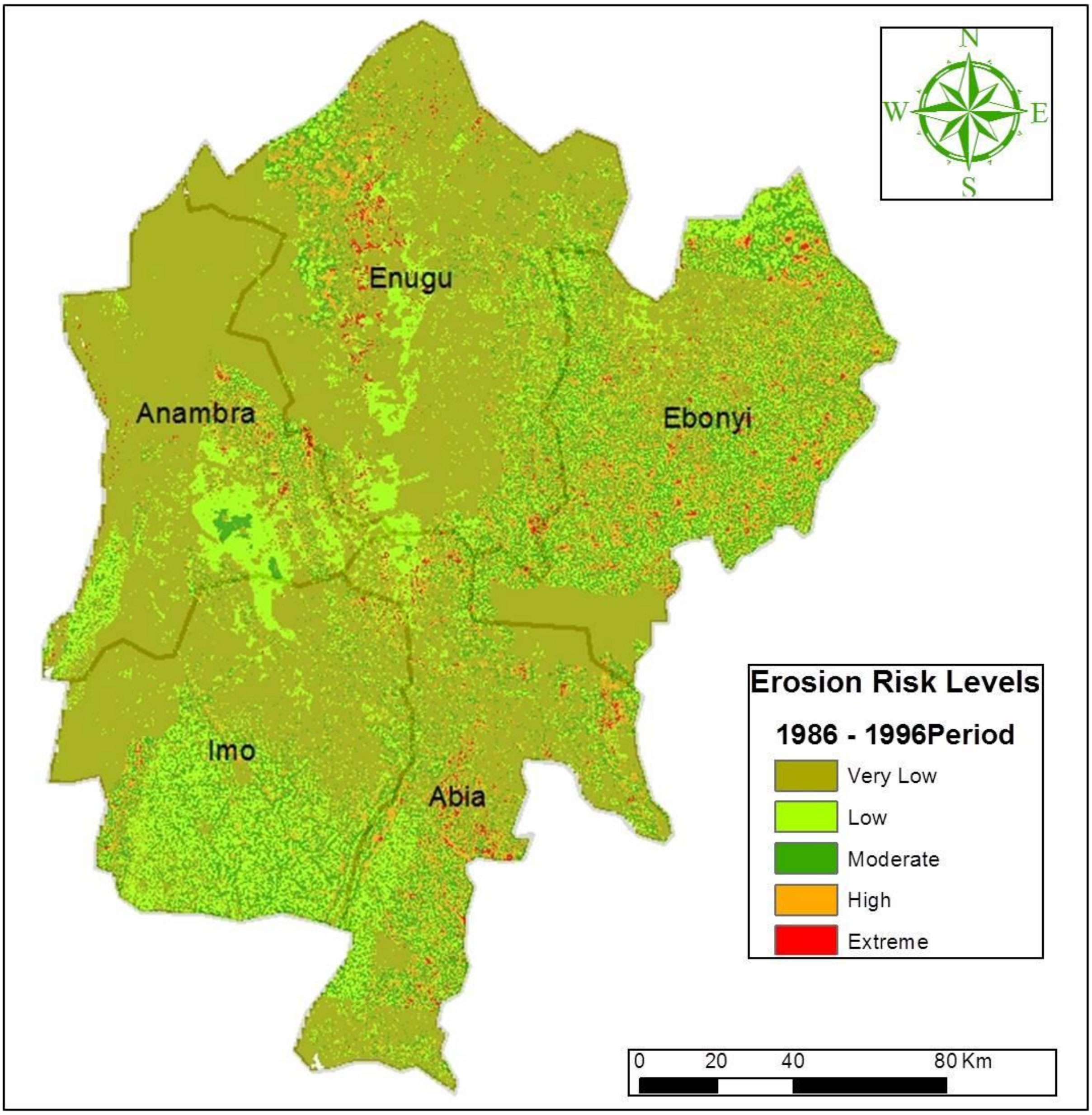

Figure 7: *Demonstration of the levels of erosion impacts across the five south eastern states of Nigeria*

The 2011 Landsat data used in this research was affected by the scan line corrector error (SLC), which affected all Landsat ETM+ data from 2003 to present. The areas affected by the SLC were masked out as nodata, and as a result, may have resulted in the undersampling of the erosion levels in the region for this study period.

An important point to note is that the results obtained from the implementation of RUSLE are estimates of the amount of soil lost from the study area and reflects the general pattern of the erosion processes in the region. The accuracy of the estimation depended heavily on the accurate determination of the various RUSLE parameters. The C factor depends greatly on the details of land-cover classes and classification accuracy, and the determination of a suitable C factor value for each class. There is however uncertainties arising from the assumption that the same land covers have the same C factor and same soil types have the same K factor values irrespective of their spatial location, which is not usually the case in real

world as the same land-cover class may have different C factors due to variations in vegetation density.
This study has however, clearly highlighted the spatial distribution of erosion hotspots in the region over a 26 year period (1986-2011 inclusive), thus providing a great insight of erosion impact trends in the region.

5. CONCLUSION

In this study we carried out a long-time assessment of areas of erosion vulnerability in the south east of Nigeria, in order to assist in the control of erosion. Remote sensing and GIS techniques were used in this research to carry out a long-time assessment of erosion risk areas in the south of Nigeria through the implementation of the Revised Universal Soil Loss Equation. This research pioneers the use of RUSLE in comprehensively mapping erosion hotspots in the region. Five levels of erosion risks ranging from extreme to low were identified based on the amount of soil lost from the areas. Most of the erosion hotspots were located around the north-eastern part of the region covering most parts of Ebonyi State, some parts of Enugu State (Northwest axis), Anambra State (South East and Central axis), and most parts of Abia State. This correlates with known areas of erosion menace in the region. It was noted from this study that there is increasing rate of erosion in the region, which calls for urgent attention from the relevant government agencies in the country. At the rate of erosion estimated in this research virtually every part of Ebonyi (the food basket of the region), will be devastated by erosion within the next 10 years. The implication of this expected devastation of the agricultural lands of Ebonyi State on food security of the region and the nation in general would be severe.

The erosion hotspots maps obtained from this research is expected to serve as a relevant guide to environmental and water resources managers involved in the mitigation of the impact of erosion for urgent intervention. The maps provide a strong basis for urgent establishment of erosion control measures targeted at mitigating the impact of erosion in the south east of Nigeria.

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