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Soil Erosion Assessment and Estimation of Soil Erodibility Factors Influencing Gullies in Anambra and Imo States, Nigeria

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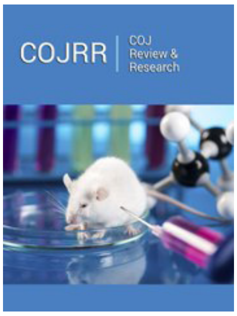

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Abstract

This research aims at assessing and estimating soil erodibility factors influencing gullies in Anambra and Imo States, southeastern Nigeria. The Revised Universal Soil Loss Equation (RUSLE) parameters were determined using a separate equation, whose input was obtained from satellite imagery and Digital Elevation Model (DEM). Equations for calculating the variables were iteratively reviewed and the best equations were selected based on their suitability for use with the available data and their ability to provide estimates comparable to the reported field-based erosion measurements. Results revealed that, for Anambra State, the numerical range for areas classified as low erosion classes was between 11.23 and 47.71 and it indicated a total of 2216.93 tons of soil loss per year (46.57%). The areas classified as high erosion recorded a numerical range of between 97.32 (t/ha/year) and 157.12 (t/ha/year) which indicated an annual loss of 756.48 (t/year) (15.89%). The very high and severe erosion classes have numerical range values between 157.13 (t/ha/year) and 244.65 (t/ha/year) and between 244.66 (t/ha/year) and 383.24 (t/ha/year) respectively. These two classes recorded annual loss of 378.86 (t/year) and 171.67 (t/year) respectively. The results of the % annual soil loss analysis computed for Imo state differs from the results observed in Anambra State. Imo State is experiencing a rather dynamic change with the low and moderate erosion classes areas recording higher amount of mean annual soil loss of 1169.99 (t/year) and 1043.17 (t/year) respectively. It is important to put in place good conservation management systems and good crop management systems to help reduce soil erodibility and thereby prevent soil erosion and soil loss. Similarly, knowing the predicted annual erosion rate is very important as this information will be useful for the improvement of conservation practices that will reduce rate of soil erosion thereby reducing soil loss in the study area.

Keywords: Soil erosion; Erodibility; Erosivity; Soil loss; Slope rate; Soil resource; Conservation

Introduction

Soil erosion is no doubts one of the greatest problems confronting agriculture worldwide. It is a major threat to the soil resource, soil fertility, productivity, and, lastly to food and fiber production, mainly on farm and range lands [1]. Although the problem is as old as settled agriculture, its extent and impact on human welfare and global environment are more now than ever before [2]. A continuation of high soil erosion will eventually lead to a loss in crop production even though fertilizers and other inputs often result in increased yield in the short term. These problems are referred to as on-site effects of erosion. Soil erosion also leads to environmental pollution. Further downstream, erosion leads to flooding, sedimentation of water reservoirs and poor water quality [3]. A decrease in soil quality invariably leads to a decrease in water quality, and often in air quality. These are off-site effects of erosion. Erosion control is the practice of preventing or controlling wind or water erosion in agricultural, land development, coastal areas, riverbanks, and construction sites. Effective erosion controls handle surface runoff and are important techniques in preventing water pollution, soil loss, wildlife habitat loss and human property loss [4]. Erosion controls are used in natural areas, agricultural settings, or urban environments and in urban areas, erosion controls are often part of storm water runoff management programs required [5]. The controls often involve the creation of a physical barrier, such as vegetation or rock, to absorb some of the energy of the wind or water that is causing the erosion [4]. It also involves building and maintaining storm drains. On construction sites they are often implemented in conjunction with sediment controls such as sediment basins and silt fences [6]. Soil erosion is a major threat to the soil resource, soil fertility, productivity, and, lastly to food and fiber production, mainly on farm and range lands. Although the problem is as old as settled agriculture, its extent and impact on human welfare and global environment are more now than ever before [7]. A continuation of high soil erosion will eventually lead to a loss in crop production even though fertilizers and other inputs often result in increased yield in the short term. These problems are referred to as on-site effects of erosion. Soil erosion also leads to environmental pollution. Further downstream, erosion leads to flooding, sedimentation of water reservoirs and poor water quality. A decrease in soil quality invariably leads to a decrease in water quality, and often in air quality. These are off-site effects of erosion [7-9]. Similarly, the removal of topsoil has caused several environmental degradations, which in turns makes life difficult in terms of agricultural participation because of loss of soil nutrient from the topsoil as well as reduction of the surface area for agricultural activities, transportation, housing, and desertification. The fact that erosion is a natural occurrence is not in doubt, but human activities have aided the rate at which erosion occurs globally [10]. This study therefore assesses the soil erosion and estimation of soil erodibility factors influencing gullies in Anambra and Imo States, southeastern Nigeria.

The Study Area

The study area is located geographically within latitudes 4° 47' 35"N and 7° 7' 44"N, and longitudes 7° 54" 26"E and 8° 27" 10"E (Figure 1) in the tropical rain forest zone of Nigeria and is made up of Anambra and Imo States. The area covers about 29095 km2 which is about 3.19% of the total area of Nigeria [11].

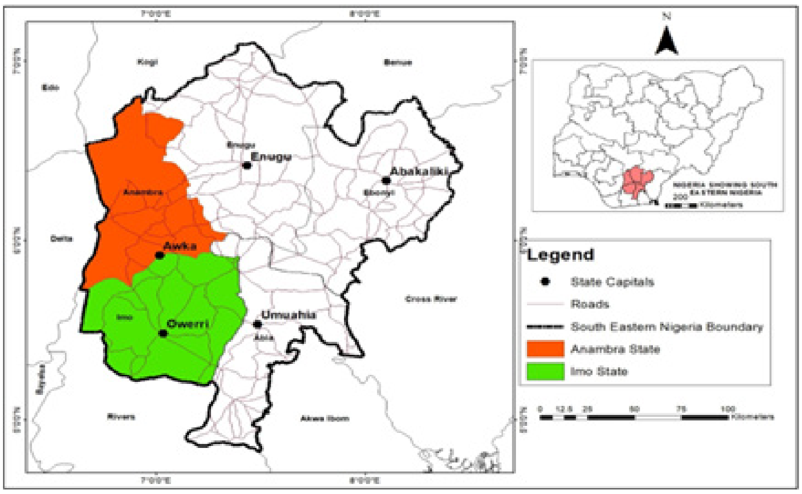

Figure 1: Map showing Anambra and Imo states.

Drainage and vegetation

The area is well drained. The notable lakes, rivers and streams that are found draining the area in this zone include Rivers Niger, Imo, Nike Lake, Anambra, Idemili, Njaba, Oguta Lake, Nkisi, Ezu, Oji etc. [12]. The River Niger Basin forms part of the almost north-south trending River Niger that catches up with the tributary dissections of the Anambra, Idemili and Njaba Rivers as well as their distributaries that flow from east to the west as they forcefully empty into the river Niger that flows southwards into the Atlantic Ocean. Similarly, in the eastern area, the Imo, and Cross Rivers together with their tributaries flow southwards and discharge their waters into the Atlantic Ocean [13]. The natural flow patterns of the rivers and their tributaries form dendritic kind of drainage pattern in the area [13]. The waters of these rivers, lakes, tributaries, and distributaries together with their groundwater components, their flows and fluxes contribute immensely to the origins, growth and dynamics of gullies and landslides all over southeastern Nigeria [12]. The forest flora in the southeastern part of Nigeria is the richest and very diverse, with many families in it being represented by small numbers of species. In the grassland flora most species belong to a few well-represented families [14]. The transition zone vegetation is poorest in species but in other respects intermediate between the forest and the grassland [15]. However, by way of classification, the vegetation in the southeastern states consist mainly of rain forest and woodland and tall [16]. Thus, geographically, Imo state as one of the states is located within the rainforest zone while the remaining states fall under the wood land and tall grass zone [17].

Brief geology of the study area

The area lies in the Anambra and Niger River basins. The Anambra River Basin is a NE-SW trending syncline that is part of the Central African Rift System which developed in response to the stretching and subsidence of major crustal blocks during a lower Cretaceous break-up phase of the Gondwana super-continent [18]. The tectonic movements for the formation of the Anambra Basin and the other areas were reactivated by further plate activity in lower Tertiary soon after the intermittent Upper Cretaceous rifting [18]. The separation of the African and South American plates left the Benue Trough as an Aulacogen. Geologic formations such as hills that elongate in the northeast to south westerly directions include Missions hill and Abakaliki hill [19]. The hills are generally of volcanic rocks and sandstones [9]. It is found that from these hills that several streams that recharge the rivers that drain the area originated. In Ebonyi, the outcrops of folded Cretaceous limestone and shale are found in so many places [20]. The Geology of the area is a major factor in gully erosion causation and massive landslides that occur in several communities. The sandy members of the Ajalli Sandstone, Ameki Formation and Nanka Sands are very prevalent to denudation where they become exposed as sandy outcrops. Sometimes these sandy Formations have overlying and underlying shaley members that may bind the sandy units together [12]. These Geologic Formations contain saturated groundwater members or aquifers whose pore water pressures enhance groundwater flows and movement of sedimentary materials. Sedimentary units of these Formations sometimes form escarpments or cuestas that may be folded and faulted with fractures of joints and faults all with planes of weaknesses which facilitate the incidences of gully erosion and landslides. Blocks of sedimentary units of rocky sands and shales may break out and slide downslope into the gully valleys [12].

Methods of Study

Revised Universal Soil Loss Equation (RUSLE)

RUSLE has been applied in GIS approach in a variety of contexts, including mountainous tropical watersheds, large-scale watersheds, agriculturally dominant watersheds, areas with distinct wet and dry seasons, and areas with dynamic changes in land cover patterns, agricultural farmlands, and development. The RUSLE model is composed of three primary databases: (i) Climatic and survey database, including monthly temperature and precipitation data, as well as contours necessary for computing the erosivity factor, slope length, and steepness factors (LS). (ii) The crop database stores data essential for calculating the surface cover factor (C). (iii) The soil data set comprises soil survey and characterization information, which is used to calculate the soil erodibility factor (K). The RUSLE model determines the yearly average loss of soil erosion, by considering the five elements indicated in Equation 1

$$A = R \times K \times LS \times C \times P \quad \text{.. Equ 1}$$

Where, A is the approximate average soil loss in tonnes per hectare per year (t ha-1 year-1),

R is the measure of rainfall erosivity factor expressed in (MJ·mm ha-1 h-1 year-1),

K is the soil erodibility index in (t·hr/MJ·mm),

LS is the topographic factor = slope length and slope steepness factor (dimensionless),

C is the cover management factor = cropping management factor (dimensionless),

P is the support measures/practice control factor (dimensionless)

The RUSLE parameters were determined using a separate equation, whose input was obtained from satellite imagery and DEM. The inputs, their origin, and the equations used are listed in Table 1. Equations available in the literature for calculating the variables were iteratively reviewed and the best equations were selected based on their suitability for use with the available data and their ability to provide estimates comparable to the reported field-based erosion measurements.

Table 1: Data types and sources.

Type of Data	Data Description	Nature of Data	Sources
DEM	SRTM DEM for 2020 (0.00083m resolution) Grid Format	Geotiff Raster Format	USGS/NASA SRTM data (Reuter et al, 2007) http://srtm.csi.cgiar.org
Soil Data	FAO Digital Soil map of the World (DSMW)	Shapefile Vector Format	Food and Agriculture Organization of the United Nations (2020)
Landuse/Land cover	Landsat Imagery	Geotiff Raster Format	United States Geological Survey Earth Explorer (www.usgs.gov)
Rainfall	WorldClim Historical Climate Data for Monthly Precipitation for 2020.	Geotiff Raster Format	Downscaled from CRU-TS-4.03 by the Climatic Research Unit, University of East Anglia, using WorldClim 2.1 (Harris et al., 2017; Fick and Hijmans, 2017)
Vegetation Index	MODIS/Tera Aqua Land Cover type yearly global 500m SIN Grid V006 for 2020	Geotiff Raster Format	NASA and the Japan Aerospace Exploration Agency (JAXA)

Results and Discussion

Annual soil loss computed for anambra state

The information for the annual soil loss computed for Anambra State is presented on Table 2 and Figure 2. The erosion rate computes the amount of soil mass lost over a period and the individual rate for each unit area was computed. The annual erosion rate for year 2020 was computed for the study. Climate (such as rainfall), soil texture types, vegetation and slope of the land are major factors affecting the erosion rate of a place. For instance, high rainfall amount promotes run-offs which break down the soil aggregate and impact the soil through erosion. However, vegetation when in abundance can reduce the rate of erosion as the roots of the vegetation impede run-offs thereby reducing erosion. Thus, conservation practices that promote quality vegetation in a place will help to reduce soil erosion and thereby reducing soil loss overtime. Similarly, steeper slopes influence more run-off and influences soil erosion from water erosion.

Table 2: Mean annual soil loss computed for anambra state.

S/N	Erosion Classes	Numerical Range (t/ha/year)	Soil Loss (t/year)	% Annual Soil Loss
1	Low	11.23-47.71	2216.93	46.57
2	Moderate	47.72-97.31	1236.65	25.98
3	High	97.32-157.12	756.48	15.89
4	Very High	157.13-244.65	378.86	7.96
5	Severe	244.66-383.24	171.67	3.6
Total			4760.59	100

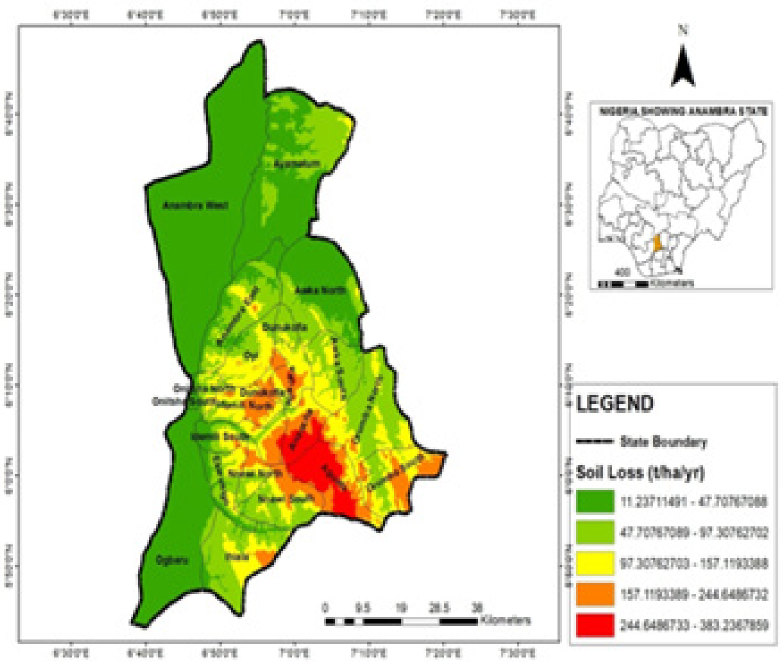

Figure 2: Numerical range for soil loss (t/ha/year) for Anambra state in year 2020.

To bring these factors (RKLSCP) to bear for the study, the Universal Soil Loss Equation (USLE) was used to predict the annual soil loss for Anambra State. The equation (A=Rx Kx L x S x C x P) as shown multiplies the factors to obtain the annual erosion rate. Recall that the R factor is based on rainfall and run-off (erosivity); K factor is the soil erodibility which depends on the type of soil; The L and S factors are considered together, and they indicate the topographic factors measured as the length and steepness of slope. The C factor or otherwise called the crop management factor or the C factor which is the crop support factor are related to cropland (farmland, arable land) or conserved land (land managed to conserve soil). The state was classified based on their erosion classes which were low, moderate, high, very high and severe. Each of this class recorded a numerical range (tons per hectare per year (t/ha/year)) alongside their respective annual soil loss (t/year) and the percentage soil loss for each class. The numerical range for areas classified as low erosion classes was between 11.23 and 47.71 and it indicated a total of 2216.93 tons of soil loss per year (46.57%). The areas classified under the moderate erosion classes recorded numerical range between 47.72 (t/ha/year) and 97.31 (t/ha/year) and indicated an annual average soil loss of 1236.654 (t/year) which is 25.98% from the total annual percentage loss in Anambra State. The areas classified as high erosion recorded a numerical range of between 97.32 (t/ha/year) and 157.12 (t/ha/year) which indicated an annual loss of 756.48 (t/year) (15.89%). The very high and severe erosion classes have numerical range values between 157.13 (t/ha/year) and 244.65 (t/ha/year) and between 244.66 (t/ha/year) and 383.24 (t/ha/year) respectively. These two classes recorded annual loss of 378.86 (t/year) and 171.67 (t/year) respectively. The land use systems (farming, built up areas (buildings), conservation projects need to know the predicted annual erosion rate as this information will be useful for the improvement of conservation practices that will reduce rate of soil erosion thereby reducing soil loss in the study area.

From the analysis, it thus means that there are low to severe erosion classes in Anambra State with each with its % annual soil loss. Thus, areas with low to high erosion classes recorded more soil loss when compared with areas from very high to severe erosion classes. This means that areas classified as high, very high and severe are locations with more highlands and have always been susceptible to more soil loss which are washed downwards (slope) depending on its gradient thereby contributing to higher soil erosion loss to the low and moderate areas which are mostly areas of deposition. The low and moderate areas therefore accounted for more soil loss due to their depositional tendencies and their lower elevation characteristics. Therefore, the numerical range describes their slope characteristics in relation to their surrounding land use systems. Thus, the land use practices in the areas with high soil erosion loss rates are poor when compared with areas with low soil erosion loss. The better the soil management practices the lesser the amount of soil loss. This means that poor conservation practices (cropping management systems, land use systems and others) will mean more soil loss with other contributing factors like rainfall, soil texture types and slope %. The erosion classes are soil erosion risk areas predicting levels of vulnerability to soil erosion overtime.

Mean annual soil loss computed for imo state

Table 3: Mean annual soil loss computed for imo state.

S/N	Erosion Classes	Numerical Range (t/ha/year)	Soil Loss (t/year)	% Soil Loss
1	Very Low	0-1.67	620.37	14.71
2	Low	1.68-6.71	1169.09	27.73
3	Moderate	6.72-15.11	1043.17	24.74
4	High	15.12-29.67	688.99	16.34
5	Very High	29.68-71.36	694.44	16.47
Total			4216.06	100

The information for the annual soil loss computed for Imo state is presented on Table 3 and Figure 3. The erosion rate computes the amount of soil mass lost over a period. The individual rate for each unit area was computed. The annual erosion rate for year 2020 was computed for Imo State. The same procedures which incorporate these factors of soil loss (RKLSCP) as indicated by the Universal Soil Loss Equation (USLE) was used to predict the annual soil loss for Imo State. The equation (A= R x K x L x S x C x P) as shown multiplies the factors to obtain the annual erosion rate. Recalled that the R factor is based on rainfall and run-off (erosivity); K factor is the soil erodibility which depends on the type of soil; The L and S factors are considered together, and they indicate the topographic factors measured as the length and steepness of slope. The C factor or otherwise called the crop management factor or the C factor which is the crop support factor are related to cropland (farmland, arable land) or conserved land (land managed to conserve soil).

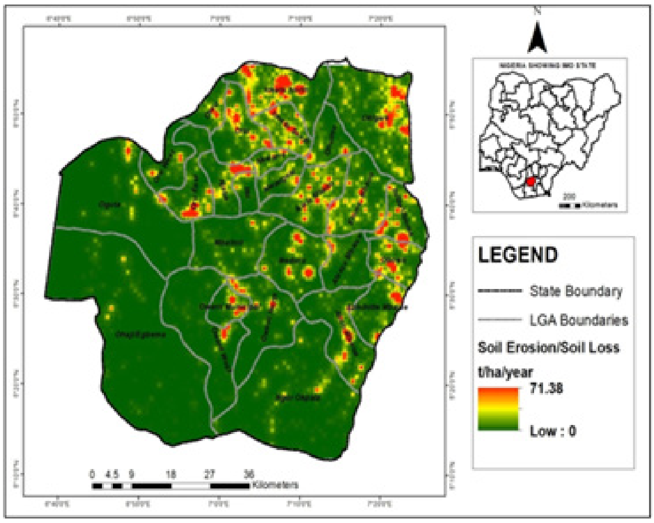

Figure 3: Numerical range for soil erosion/soil loss for imo state.

Imo state was classified based on their erosion classes which were very low, low, moderate, high, and very high. Each of this class recorded a numerical range (tons per hectare per year (t/ha/year)) alongside their respective annual soil loss (t/year) and the percentage soil loss. The numerical range for areas classified as very low erosion classes was between 0.1 (t/ha/year) and 1.67 (t/ha/year) and it indicated a total soil loss of 620.37 (t/year) which was about 14.71%. The areas classified under the low erosion recorded numerical range between 1.68 (t/ha/year) and 6.71 (t/ha/year) and indicated an annual average soil loss of 1169.09 (t/year) which is 27.73% when related with the total percentage loss in year 2020 in Imo state. The areas classified as moderate erosion recorded a numerical range of between 6.72 (t/ha/year) and 15.11 (t/ha/year) which indicated an annual loss of 1043.17 (t/year) (24.74%). The areas classified as high have numerical range values between 15.12 (t/ha/year) and 29.67 (t/ha/year) with a total annual soil loss of 688.99 (t/year) (16.34%). The last areas classified as very high erosion class recorded range values of between 29.68 (t/ha/year) and 71.36 (t/ha/year) with an annual soil loss of 694.44 (t/year) (16.47%).

The results of the % annual soil loss analysis computed for Imo state differs from the results observed in Anambra state. These are due to several factors ranging from the variations in their elevation characteristics, rainfall erosivity patterns, soil erodibility and topographic factors. Thus, as total soil loss is reducing with increasing elevation in Anambra State, Imo State is experiencing a rather dynamic change with the low and moderate erosion classes areas recording higher amount of mean annual soil loss of 1169.99 (t/year) and 1043.17 (t/year) respectively. The land use systems (farming, built up areas (buildings), conservation practices) are important indices determining the rate of surface run-off leading to soil loss in any area, Thus, it is important to put in place good conservation management systems and good crop management systems to help reduce soil erodibility and thereby prevent soil erosion and soil loss. Similarly, knowing the predicted annual erosion rate is very important as this information will be useful for the improvement of conservation practices that will reduce rate of soil erosion thereby reducing soil loss in the study area.

Conclusion

This study revealed that there are low to severe erosion classes in Anambra State, each with its % annual soil loss. The areas with low to high erosion classes recorded more soil loss when compared with areas from very high to severe erosion classes. This means that areas classified as high, very high and severe are locations with more highlands and have always been susceptible to more soil loss which are washed downwards (slope) depending on its gradient thereby contributing to higher soil erosion loss to the low and moderate areas which are mostly areas of deposition. The low and moderate areas therefore accounted for more soil loss due to their depositional tendencies and their lower elevation characteristics. The numerical range describes their slope characteristics in relation to their surrounding land use systems. Thus, the land use practices in the areas with high soil erosion loss rates are poor when compared with areas with low soil erosion loss. The better the soil management practices the lesser the amount of soil loss. This means that poor conservation practices (cropping management systems, land use systems and others) will mean more soil loss with other contributing factors like rainfall, soil texture types and slope %. The erosion classes are soil erosion risk areas predicting levels of vulnerability to soil erosion overtime. The results of the % annual soil loss analysis computed for Imo state differs from the results observed in Anambra State. These are due to several factors ranging from the variations in their elevation characteristics, rainfall erosivity patterns, soil erodibility and topographic factors. Thus, as total soil loss is reducing with increasing elevation in Anambra State, Imo State is experiencing a rather dynamic change with the low and moderate erosion classes areas recording higher amount of mean annual soil loss of 1169.99 (t/year) and 1043.17 (t/year) respectively. The land use systems (farming, built up areas (buildings), conservation practices) are important indices determining the rate of surface run-off leading to soil loss in any area, Thus, this study recommends that it is important to put in place good conservation management systems and good crop management systems to help reduce soil erodibility and thereby prevent soil erosion and soil loss. Knowing the predicted annual erosion rate is very important as this information will be useful for the improvement of conservation practices that will reduce rate of soil erosion thereby reducing soil loss in the study area.

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