Application of RUSLE integrated with GIS and remote sensing techniques to assess soil erosion in Anambra State, South-Eastern Nigeria

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ABSTRACT

Soil erosion and mass movement processes spread across Anambra State in Nigeria, therefore making management and conservation techniques expensive and difficult in execution across the entire state. This study employed the Revised Universal Soil Loss Equation (RUSLE) model with the integration of geographic information system (GIS) and remote sensing techniques to assess the risk of soil erosion and hotspots in the area. Remotely sensed data such as Landsat 8 imagery, Shuttle Radar Topography Mission (SRTM) imagery, Era-Interim coupled with world soil database were used as digital data sources for land use map, digital elevation model, rainfall and soil data, respectively, to generate the Universal Soil Loss Equation (USLE) parameters. The results indicated vulnerability levels in low, medium and high cover areas of 4,143.62 (91%), 332.29 (7%) and 84.06 (2%) km^2, respectively, with a total soil loss between 0 and 181.237 ton/ha/yr (metric ton per hectare per year). This study revealed that high rainfall erosivity, steep and long slopes, and low vegetation cover were the main factors promoting soil loss in the area. Thus, the amount of soil loss in Anambra State is expected to increase with climate change and anthropogenic activities.

Key words | erodibility, erosion risk assessment, erosivity, GIS, RUSLE, soil erosion

HIGHLIGHTS

- Comprehensive analysis of the environmental and anthropogenic factors and their impacts on soil loss were studied.
- The combination of RUSLE and GIS with remote sensing yields improved results for erosion prone areas.
- The prone area maps exhibit the severity of erosion and the need to protect for future occurrence.
- The study offers local stakeholders and decision makers to adopt efficient soil conservation systems.

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doi: 10.2166/wcc.2020.222

INTRODUCTION

Soil erosion is a form of soil degradation involving detachment, transportation, sedimentation and deposition of soil particles from one place to another by the dynamic force and activity of erosive agents. The erosive agents include water, ice (glaciers), snow, air (wind), plants, animals and humans. Erosion is, at times, divided into water erosion, glacial erosion, snow erosion, wind or aeolian erosion, zoogenic erosion and anthropogenic erosion according to the causative agent (Apollo *et al.* 2018). Wind and water are the main agents of soil erosion; high winds knock out loose soil, mainly from level or mountainous topography, and energy exerted on the soil by falling and run water over the surface also detaches and transports soil particles (Kouli *et al.* 2009). Soil erosion has attracted global research attention as various ecological and environmental problems such as soil fertility loss, land degradation, drainage and river siltation substantially evolve from its occurrence (Anees *et al.* 2018; Wang *et al.* 2018). It equally reduces reservoir capacity and negatively affects aquatic habitats, hydrologic systems and quality of water downstream as sediments are usually attached with nutrients, toxic chemicals and metals (Kouli *et al.* 2009; Zhang *et al.* 2009; Kim 2014; Lamyaa *et al.* 2018). Soil erosion processes also enhance the chance of flood risk as a result of the inducement by rainfall (Ouyang & Bartholic 2001; Adewumi *et al.* 2017). Soil erosion is a natural phenomenon which causes adverse economic and environmental impressions across the globe (Kouli *et al.* 2009; Zhang *et al.* 2009). However, certain human activities such as overexploitation of land resources have accelerated the erosion processes in many parts of the world. In general, the prominence of soil degradation is dependent upon some natural and anthropogenic elements that favour the initiation and the advancement of soil erosion. These elements are categorized into: quasi-static factors (infiltration, erodibility and morphology) and temporally variable factors (vegetation cover, land use, rainfall intensity and agricultural practices) (Roose & Lelong 1976; Vrieling 2005; Boukheir *et al.* 2006; Bouhadeb *et al.* 2018). Hence, soil erosion is also regarded as a spatio-temporal land degrading phenomenon with significant adverse impacts in many countries (Fistikoglu & Harmancioglu 2002; Hoyos 2005; Pandey *et al.* 2009; Prasannakumar *et al.* 2012).

In Anambra State of Nigeria, water erosion is the leading cause of soil degradation, with varying intensities across the state. Anambra State has a varied geography, geology and geomorphology, with a wide range of land-use systems. The state is also intensely influenced by soil attrition, sediment transport and land degradation. Significant soil erosion developments in the state comprise rill, sheet and gully formations. The existence of gullies across the state has not only resulted in the loss of agricultural lands but also led to inadequate land for sustainable infrastructures. With regards to the presumed increasing risk of soil erosion and its pervasiveness, it is important to quantify soil loss and delineate degraded areas to help in effective decision-making and conservation planning.

In the course of estimating soil loss and promoting optimum soil protection practices, many researchers have established and employed various models. Major soil erosion models that have been used in regional scale evaluation include Universal Soil Loss Equation (USLE) or Revised Universal Soil Loss Equation (RUSLE), Watershed Erosion Prediction Project (WEPP), Agricultural Non-Point Source model (AGNPS), Areal Non-point Source Watershed Environment Response Simulation (ANSWERS) model, Limburg Soil Erosion Model (LISEM), European Soil Erosion Model (EUROSEM), Soil Erosion Model for Mediterranean Regions (SEMMED), Soil and Water Assessment Tool (SWAT), Simulator for Water Resources in Rural Basins (SWRRB), Morgan-Morgan-Finney Model (MMFM) and Chemical Runoff and Erosion from Agricultural Management System Model (CREAMS). Moreover, Mosavi *et al.* (2018) reviewed the encouraging results already documented for the implementation of the commonly known machine learning methods such as artificial neural networks (ANNs), support vector machines (SVM), support vector regression (SVR), adaptive neuro-fuzzy inference system (ANFIS), wavelet-based neural network (WNN) and decision trees (DTs). They also stated that there should be important research and investigation for further development and advancement. The above-mentioned models have their specific characteristics and application scopes (Boggs *et al.* 2001; Lu *et al.* 2004; Dabral *et al.* 2008; Tian *et al.* 2009; Prasannakumar *et al.* 2012). Among the stated models, USLE and its derivatives Revised USLE (RUSLE) and Modified USLE (MUSLE), are highly employed practical models owing to their minimum statistics, computation necessities (Lal 2001; Merritt *et al.* 2003; Lim *et al.* 2005; Erdogan *et al.* 2007; Xu *et al.* 2008; Zhang *et al.* 2009) and compatibility with GIS (Lu *et al.* 2004; Jasrotia & Singh 2006; Dabral *et al.* 2008; Kouli *et al.* 2009; Pandey *et al.* 2009; Bonilla *et al.* 2010; Prasannakumar *et al.* 2012). The USLE and RUSLE standards evaluate mean yearly gross loss as a role of rainfall energy (Zhang *et al.* 2009). Angima *et al.* (2003) concluded that USLE or RUSLE equally give the spatial heterogeneity of soil loss that is very practicable for both economic and improved precision in many regions (Prasannakumar *et al.* 2012).

Numerous researchers have applied and established the fact that the integration of remote sensing and GIS technology with the USLE/RUSLE method makes soil erosion assessment easier, with improved results on the evaluation and estimation of soil erosion at various locations (Boggs *et al.* 2001; Lu *et al.* 2004; Dabral *et al.* 2008; Agarwal *et al.* 2016). Saini *et al.* (2015) affirmed that the integration of RS, GIS and RUSLE effectively estimate soil erosion on a cell-by-cell basis. Digital elevation model (DEM) in the GIS environment helps in generating and processing the key soil erosion modelling input data (terrain, slope, gradient and slope length), while multi-temporal RS data (satellite imageries) help in providing information connected with land use and land cover dynamics. As soil is an important resource for the economy of Nigeria, especially in terms of food security, the application of effective management and conservation measures to check further soil erosion is necessary. This will, in no small measure, forestall further depreciation in the soil fertility with expected significant improvement in agricultural practices and productivity. Therefore, the specific objectives of the present study were to integrate the RUSLE model and GIS technique to assess erosion risk and hotspots in Anambra State; and to develop soil erosion intensity maps for the state, which could be useful for decision-making and sustainable land conservation management.

MATERIALS AND METHODS

Description of study area

Anambra is one of the five states of the south-east region of Nigeria with Awka as the administrative capital, while Onitsha, Nnewi and Ekwulobia are the major commercial hubs. The name Anambra is an anglicized form of the fundamental ‘Oma Mbala’, the local term for the Anambra River, which is an offshoot of the River Niger. The west is bordered by Delta State, on the east by Enugu State, on the south by Imo State and Rivers State, and on the north by Kogi State. It lies about $6^\circ 20'$ north of the equator and $7^\circ 10'$ east of the Greenwich Meridian. The state is situated at an elevation of 112 m above sea level (Figure 1). Anambra State covers a land area of about 4,416 km^2 and has a population of about 4,182,022 (Ejikeme *et al.* 2017). It has a tropical climate with two distinctive seasons: a wet or rainy season from March to October and a somewhat dry season from November to February. Also, Anambra State has an average annual temperature and rainfall of 25.9 °C and 1,386 mm, respectively, with relatively high humidity ranging between 65 and 80% through the year. The warmest month is usually March, with an average temperature of 28.1 °C, while the coldest month is August with an average of 24.2 °C. The month of January is the driest with about 8 mm of rainfall, while September has the peak rainfall with an average of about 279 mm. The five main rivers and their tributaries that drain Anambra State are River Niger, Anambra River, Mamu/Ezu River, Idemili River and Ulasi River. Other smaller perennial streams in the state are Oyi, Nkisi and Obizi. The geological formation of the place contributes to the erosion progression as there exist vulnerable sandy formations that are more susceptible to erosion and other environmental problems (Ofomata 1981; Fagbohun *et al.* 2016; Ejikeme *et al.* 2017). In general, the south-east region of Nigeria lies within Awka-Orlu uplands and Enugu-Awgu-Okigwe escarpment where gully erosion is a common problem, reducing the availability of land resources. Anambra State lies within the dip section of the east facing scarp slopes of the Awka-Orlu landscape (Ejikeme *et al.* 2017).

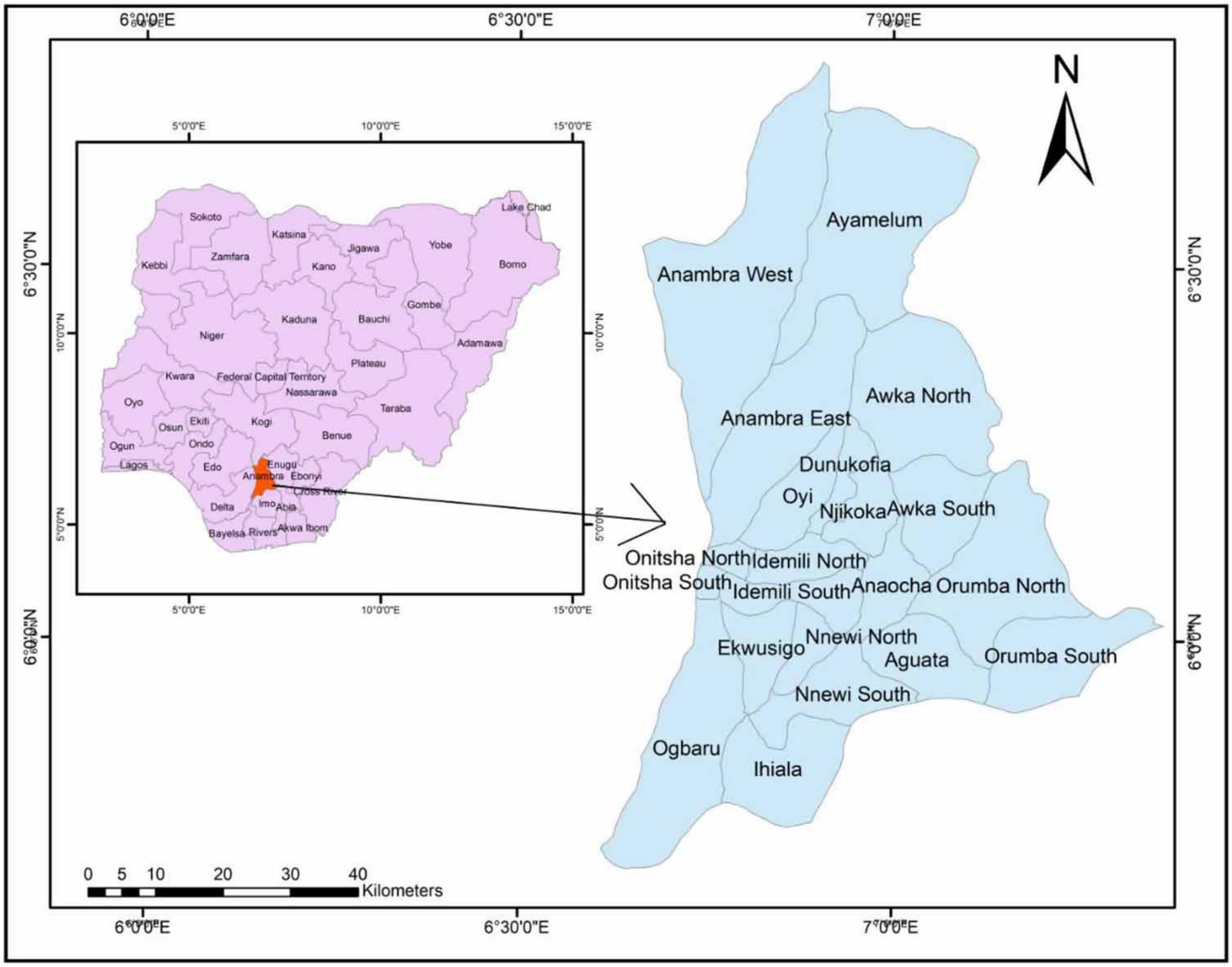

Figure 1 | Map of the study area location.

Data acquisition

Landsat imagery

Landsat 8 imagery that covers Anambra State was acquired from the United States Geological Survey (USGS) website. The Landsat imagery was pre-processed for compatibility with the GIS software. This imagery was used to generate the land use and land cover map. Landsat 8 is an American Earth surveillance digital satellite introduced on February 11, 2013. It is the eighth satellite in the Landsat platform and the seventh to reach the flight path fruitfully. It was initially named the Landsat Data Continuity Mission (LDCM). It is a collaboration between the National Aeronautics and Space Administration (NASA) and the USGS. NASA Goddard Space Flight Center helped in providing development, mission systems engineering and acquisition of the launch vehicle while the USGS provided development of the ground systems and will conduct ongoing mission operations. These data are required for the development of spatial distribution maps of cover and management practice (C-factor) and support practice components (P-factor) required for the computation of soil loss in the study area.

Digital elevation model (DEM)

SRTM imagery for Anambra region was downloaded from the Global Land Cover Facility (GLCF) website. The SRTM was used as the DEM input data for the slope length and slope steepness factor as factors for soil erosion assessment. The SRTM is a universal investigation effort that acquired digital elevation models on a near-global measure from 56° S to 60° N to generate wide-ranging high-resolution digital geographical facts of the terrain before the ASTER GDEM was issued in 2009. The SRTM comprised a specifically reformed locating system that hovered on board the space shuttle Endeavour during the February 2000, 11-day STS-99 mission, established on the older Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) which was formerly used on the shuttle in 1994. The DEM data are required for the computation of length-slope (LS) factor and development of its spatial distribution map for the study area.

Digital soil data

Soil information for Anambra State was acquired from the Harmonized World Soil Database (HWSD) viewer. The facts were pre-processed to a layout that can be employed for the investigation by means of ArcGIS software. The statistics were converted to digital form and then transformed to a raster arrangement. The digital soil raster data were used for the computation and development of a soil erodibility (K) factor map in the study area. The HWSD is the result of a collaboration between the Food Agriculture Organization (FAO) with the International Institute for Applied Systems Analysis (IIASA), ISRIC-World Soil Information, Institute of Soil Science, Chinese Academy of Sciences (ISSCAS) and the Joint Research Centre of the European Commission (JRC). The HWSD is of direct use in the background of the Climate Change Convention (CCC) and the Kyoto Protocol for soil carbon measurements and for the FAO/IIASA Global Agro-ecological Assessment studies, for which HWSD was primarily established. For sustainability in agricultural production, biodiversity and bio-energy demand, the HWSD is an efficient tool for providing scientific information for both domestic and transnational policymakers. The HWSD is a 30 arc-second raster databank consisting of more than 1,600 diverse soil mapping entities that joins present provincial and national updates of soil facts globally with the data encompassed in the FAO-UNESCO (United Nation Educational, Scientific and Cultural Organization) World Soil Map scale of 1:5,000,000. The ensuing raster databank comprises 21,600 rows and 43,200 columns, which are connected to harmonize soil physical science facts. The application of a consistent arrangement grants the connection of the characteristic facts with the raster record to show or query the arrangement as regarding the soil components and description of nominated soil parameters such as pH, water storage capacity, soil depth, organic carbon, cation exchange capacity of the soil, proportion of clay, total replaceable nutrients, lime and gypsum contents, sodium exchange percentage, salinity and texture. Generally, low resolution digital data including soil data have been adopted in many studies with considerably good results, as reported in the literature. However, high-resolution data would show substantial spatial diversity in the resulting soil erosion risk map (Drzewiecki *et al.* 2014).

Precipitation data

Gridded rainfall data for Anambra State from 1985 to 2015 were acquired from Era-Interim. The data were averaged, to calculate the climatic rainfall over Anambra State. The gridded rainfall data were interpolated to show the spatial distribution of rainfall over the state. This is required for the computation of the erosivity factor (R-factor) and establishment of spatial rainfall erosivity distribution in the study area.

Method

Universal soil loss equation (USLE) model

The USLE is a practical soil loss model which was originally established in the 1960s by Wischmeier and Smith of the United States Department of Agriculture as a field scale model (Kim 2014). It was, however, reworked in 1997 for more accurate results from the assessment of the various relevant parameters (Renard *et al.* 1997). Kim (2014) concludes that the erosion statistics gathered using the RUSLE give a supplementary accurate long-standing average representation. The model considers the influences of geophysical and land cover elements to evaluate the possible yearly soil loss from an area of land (Uddin *et al.* 2016). In order to evaluate the soil loss of the study area, these factors were assessed and the meteorological data, soil data, remote sensing data and DEM acquired by the integration of the RUSLE model with the GIS technique to obtain more accurate results. The soil loss (A) per unit area per year (ton/ha/yr) was computed via RUSLE expressed with Equation (1) as stated:

$$A = R \times K \times LS \times C \times P \tag{1}$$

where A is the computed mean soil loss by water erosion (ton/ha/yr), R is the rainfall-runoff erosivity component (MJ mm $\mathrm{ha^{-1}\,h^{-1}\,yr^{-1}}$), K is the soil erodibility factor ton ha hr $\mathrm{ha^{-1}\,MJ^{-1}\,mm^{-1}}$, L is the slope length component (dimensionless), S is the slope steepness component (dimensionless), C is the cover and management practice component (dimensionless) and P is the support practice component (dimensionless).

Digital data such as Landsat imagery, DEM and digital soil data were obtained from the archive of USGS. These data were obtained through remote sensing technology for the area under consideration and archived by USGS for retrieval by users. GIS software (ArcGIS) was used for processing (pre and post) these digital data in order to extract useful information from them such as LS-factor from the DEM, K-factor from the digital soil map, C-factor and P-factor from the Landsat imagery and R-factor from the rainfall data. In ArcGIS environment, these factors were integrated and processed for the computation of soil loss using Equation (1). The methodological flowchart for the implementation of USLE model is presented in Figure 2.

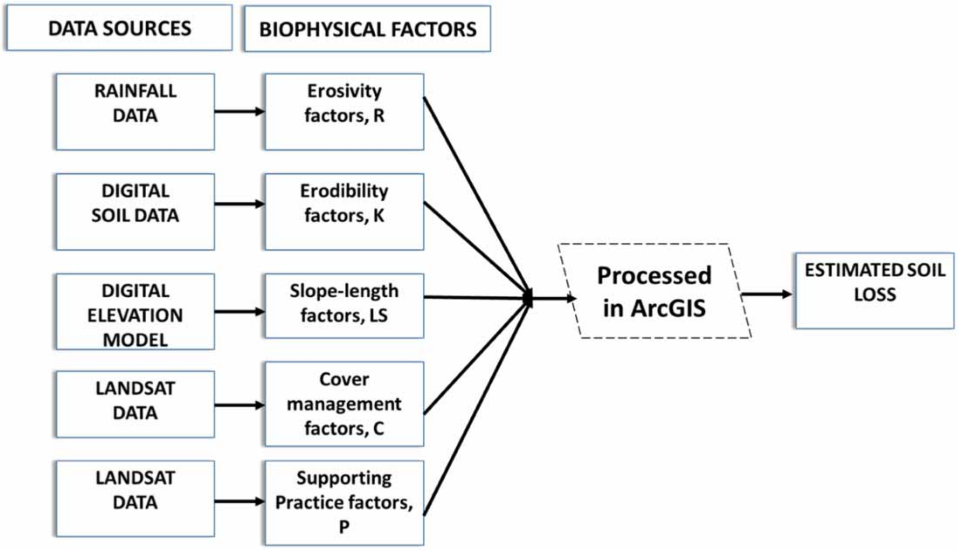

Figure 2 | Methodological flowchart for the implementation of USLE.

Rainfall and runoff factor (R-factor)

The R-factor denotes the influence of energy and rainfall intensity (Kunta & Carosio 2007). Rainfall intensity, duration and potential are known to have great influence on rainfall-runoff erosivity. The rainfall-runoff erosivity factor is the enduring yearly average of the effect of rainfall kinetic energy (KE) in MJ $\mathrm{ha^{-1}}$ and the concentrated rainfall intensity in 30 minutes measured in mm $\mathrm{ha^{-1}}$ (Wischmeier & Smith 1978; Renard & Friedmund 1994). The best appropriate demonstration of the erosivity of precipitation is an index centred on K.E. of the rain. The R-factor can be evaluated using various methods proposed by early researchers. Some of the methods are:

$$R = 9.28 \times P - 8838 \tag{2}$$

Average yearly erosivity ($\mathrm{KE} > 25$); P is the average yearly rainfall;

$$R = 0.276 \times P \times I_{30} \tag{3}$$

Average yearly $E1_{30}$; P is the average yearly rainfall (Morgan 1994);

$$R = 0.5 \times P \text{ (in US unit)} \tag{4}$$

$$R = 0.5 \times P \times 1.73 \text{ (in metric unit)} \tag{5}$$

$$R = 38.5 + 0.35 \times Pr \tag{6}$$

Pr denotes the average yearly rainfall (mm/yr) (Lee & Lee 2006).

In this study, Equation (5) was used for the determination of the R-value as it has been found to work well in tropical regions. Therefore, every grid cell of the average yearly rainfall was considered using the third equation to get the R-value via ArcGIS. The mean annual precipitation surface was applied to compute the R-factor by the spatial analyst section of the ArcGIS.

Soil erodibility (K-factor)

The soil erodibility factor K is a measure of the intrinsic susceptibility of any given soil to soil erosion. Precisely, the susceptibility of any soil to erosion is controlled by the particle size distribution, organic matter content, structure and permeability (i.e., duration and degree of waterlogging) of such soil (Renard *et al.* 1997). In this study, these characteristics were used for calculating the K-factor. The erodibility value of each soil group was determined using Equation (7) suggested by Wischmeier & Smith (1978):

$$K = [27.66m^{1.14} \times 10^{-8} \times (12 - a)] + [0.0043 \times (b - 2)] + [0.0033 \times (c - 3)] \tag{7}$$

where K is the soil erodibility factor ton ha hr ha^{-1} MJ^{-1} mm^{-1}; m is the (silt % + sand %) × (100 − clay %), a is the % organic matter; b is the structure code: (1) very structured or particulate, (2) fairly structured, (3) slightly structured, and (4) solid; c is the profile permeability code: (1) rapid, (2) moderate to rapid, (3) moderate, (4) moderate to slow, (5) slow and (6) very slow.

Slope length and slope steepness factors (LS)

The topographical aspect comprises dual sub-divisions: slope gradient and slope length factors. The L- and S-factors delineate the topographic erosion vulnerability of a particular location. They were calculated from the DEM. The DEM was made by digitizing the contours of the topographic chart of the location of study. The L- and S-factors were evaluated with the help of the filled DEM and were introduced in Equation (8) to create the topographic factor network.

$$LS = (L/22)^{0.5}(0.065 + 0.45S + 0.0065S^2) \tag{8}$$

where $L = (X/22.13) \wedge m$; x is the slope length (in m); m is 0.5 for slope >5%, 0.4 for slope within the range of 3–5%, 0.3 for slope within the range of 1–3% and 0.2 for slope <1% and L is the slope length factor; $S = (0.43 + 0.30s + 0.043s^2)/6.613$, where s is the gradient (%) and S is the slope gradient factor.

Cover and management (C-factor)

The cover and management factor represents the ratio of soil erosion experienced with a specified crop to that experienced on a base soil (Morgan 1994). Land use sorts in the location were allotted C-factor standards established on their degree of canopy cover, fall height and ground cover. The land use atlas of Anambra was utilized for the analysis of the C-value. The C-factor was verified for every land use and land cover category from values for comparable land cover types given by Wischmeier & Smith (1978). The coverage grid was changed afterwards, and the re-class system was employed in ArcINFO9 to assign a conforming C-value to the individual land use classes as stated by Wischmeier & Smith (1978).

Support practice (P-factor)

The P-factor is the degree of the usefulness of land management customs designed to reduce soil loss in a given area of land. Contour ploughing, strip cropping, terracing, etc. are the most common land management practices (May & Place 2005). P-values range from 0 to 1. On this scale, 0 represents an appropriate man-made erosion-resistant facility while 1 denotes no man-made erosion-resistant facility.

The P-factor values in the place were obtained by field surveillance.

RESULTS AND DISCUSSION

Rainfall-runoff erosivity (R-factor)

The rainfall erosivity factor (R) characterizes the likelihood of soil attrition by the effect of precipitation (Renard *et al.* 1997; Kayet *et al.* 2018). The R-factor reveals the influence of precipitation concentration on soil loss, and necessitates comprehensive, unceasing rainfall statistics for its computation (Wischmeier & Smith 1978). The state has a rainy season which starts in March and ends in October with peak rainfall of about 279 mm in September. The average annual rainfall of Anambra State is about 1,386 mm. ERA-Interim precipitation data for 1985–2015 were acquired for Anambra State. The average precipitation was calculated for a 30-year period. The average precipitation in Anambra State for the 30-year period ranges from 315 to 428 mm. The R-factor in the same period was 2.72682–3.70812 MJ mm ha^{-1} hr^{-1} yr^{-1}. The calculated average precipitation value was fitted into the R-factor formula in Equation (9) (Roose 1975):

$$R = 0.5 \times P \times 1.73 \text{ (in metric unit)} \tag{9}$$

The R-factor for the study area was computed and ranges between 2.73 and 3.71 and this represents the rainfall regime. The rainfall erosivity of the study area generally increases from the central region to the southern part of the state with the highest occurrence in the south-western part. It should be noted that the rainfall erosivity increases as the mean annual rainfall increases due to the occurrence of more erosive and high-intensity rainfall. Figure 3 depicts the R-factor for Anambra State. Thus, the rapid changes in climate could influence the degree of soil erosion.

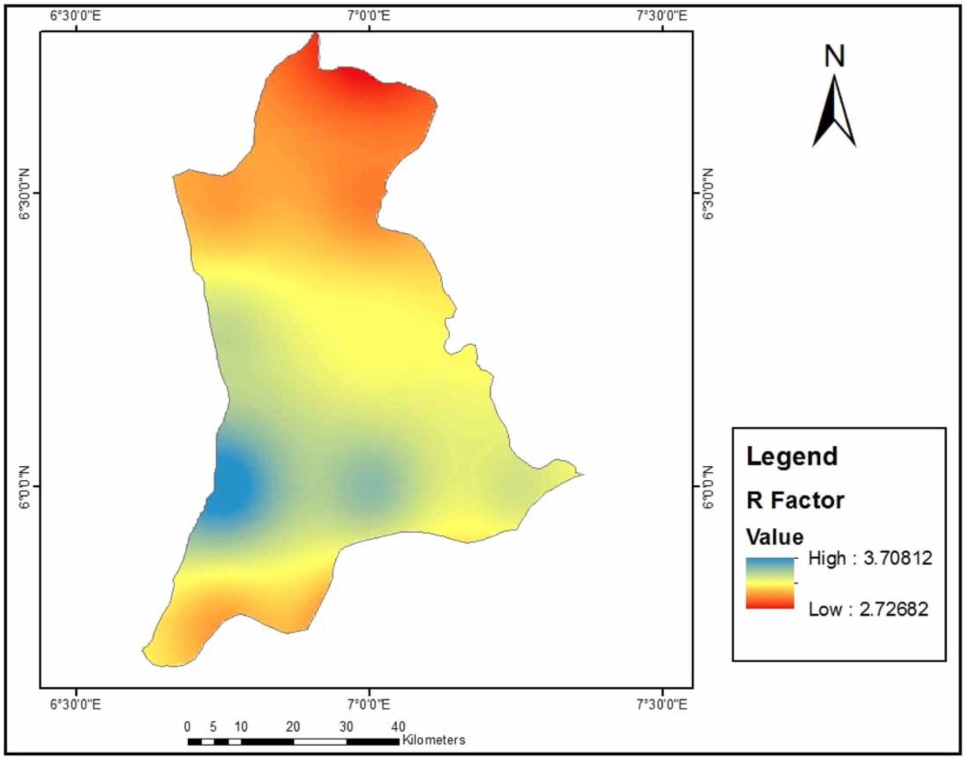

Figure 3 | Spatial distribution of erosivity (R) for Anambra State.

Soil erodibility factor (K)

The K-factor is the soil erosion level per erosion index division aimed at an identified soil as considered on a standard scheme, which is well-defined as a 72.6 ft (22.1 m) span of unvarying 9% gradient in unceasing clean-tilled fallow (Sahaar 2013). Soil erodibility aspect measures susceptibility of the soil constituent part or outward constituents to conveyance in addition to disengagement by means of rainfall volume and runoff contribution. K-factor accounts for the influences of soil properties on soil loss for the duration of rainstorm happenings on highlands (Renard *et al.* 1997). K-factor is collectively influenced by rainfall, runoff and infiltration (Sahaar 2013). K-factor measures the unified nature of a soil type and its opposition to extrication and conveyance as a result of rainwater effect as well as shear forces of flow across land. The amount of energy needed to extricate and convey soils varies with the soil type (Tirkey *et al.* 2013). Soil has low erodibility if the silt content is low, regardless of corresponding high content in sand and clay fractions (Emeribeole & Iheaturu 2015). The K-factor formula is as shown in Equation (10):

$$K = [27.66m^{1.14} \times 10^{-8} \times (12 - a)] + [0.0043 \times (b - 2)] + [0.0033 \times (c - 3)] \tag{10}$$

where K is the soil erodibility factor ton ha hr ha^{-1} MJ^{-1} mm^{-1}; m is the (silt % + sand %) × (100 − clay %); a is the % organic matter; b is the structure code: (1) very structured or particulate, (2) fairly structured, (3) slightly structured and (4) solid; c is the profile permeability code: (1) rapid, (2) moderate to rapid, (3) moderate, (4) moderate to slow, (5) slow and (6) very slow.

From the digital soil map of the study area, three different soil types with different characteristics were identified. The erodibility characteristics of the existing soils in the study area varied with the range of K-factor values of 0.05–0.80 ton ha hr ha^{-1} MJ^{-1} mm^{-1}. As the K-factor values approach 1, it indicates the soil has higher susceptibility to erosion and as the K-factor values are close to 0, it indicates the soil has erosion resistance capacity. Clay and silt contents of soils significantly affect the K-factor too. Hence, Dystric Nitosols spanning from the central to southern part of the area have the highest K-factor value of 0.8, followed by the Gleysols existing within the north-western and a small part of the south-western part of the area with intermediate value of 0.06, while the Calcaric Fluvisols spanning from the north-east to the south-eastern region have the least K-factor value of 0.05. This shows that the region within the Dystric Nitosols soil type is the most susceptible county. Thus, in terms of soil erodibility condition, the central and south-western parts are highly vulnerable to erosion, the north-western part has moderate vulnerability, while the eastern part is characterized as low vulnerability to erosion. Table 1 illustrates the soil type, properties and K-factor of every soil type in Anambra State. Figure 4 describes a map of K-factor for each soil type.

Table 1 | Soil properties and soil erodibility (K) factor for Anambra State

Soil type	Sand (%)	Silt (%)	Clay (%)	Organic matter (%)	K-factor
Dystric Nitosols	76	13	11	0.61	0.8
Calcaric Fluvisols	49	32	19	1.1	0.05
Gleysols	38	40	22	1.27	0.06

Topography factor (LS)

L-factor is the function of slope length and S-factor is the function for slope steepness. The two together, termed LS-factor, are used to characterize the topographical factor influence on soil erosion. The LS-factor takes care of the topographic component of soil erosion of any given location. Slope length refers to the stretch from the location of the beginning of flow across land to either the spot the slope declines to the level where sedimentation originates or the spot at which runoff flows into definite waterways (Wischmeier & Smith 1978). The slope length aspect determines the concentration of water. The greater the slope length of an area, the more intense the flow and runoff produced (Nnabugwu & Uwadiegwu 2015; Kadam *et al.* 2018). The steepness (S-factor) accounts for the influence of slope steepness or elevation on erosion. The sharper and lengthier the slope, the greater the soil loss hazard. In the present study, the LS-factor varied within 0 (flatter and lower part) and 362 (steeper and upper part). There is dominance of higher LS-factor values within the central and the

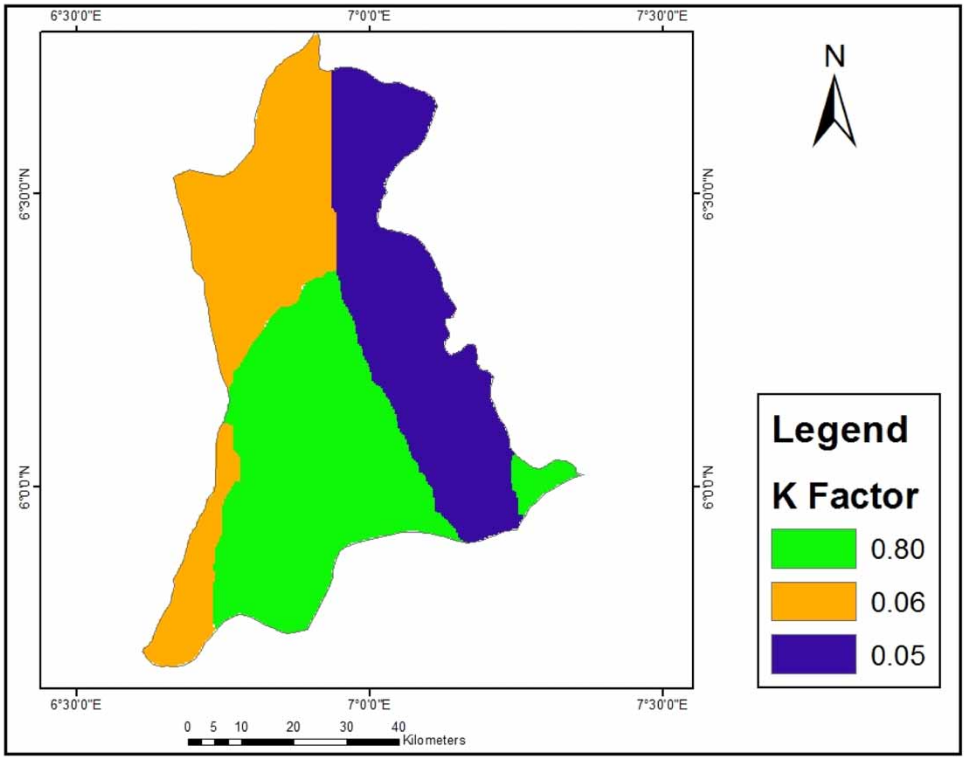

Figure 4 | Spatial distribution of soil erodibility (K) for Anambra State.

south-western part of Anambra State; this indicates that those regions are mountainous and hilly. A few other parts with some levels of high LS-factor would be the result of hills and river banks. The presence of higher LS-factors in these areas is because LS-factor values increase with slope gradient increase. Thus, the areas with smaller LS-factor values have less soil erosion due to this factor while the regions with larger values would experience more soil erosion due to the LS-factor. The joint influence of slope length and steepness contributes to the degree of soil loss, as shown in Figure 5.

Cover management (C-factor)

The C-factor gives vital information about the effect of land use/land cover (prime indicator of spatial impact extent) on erosion rate as well as how land is being utilized at present and in the future (Adewumi *et al.* 2016, 2017). The C-factor indicates how flora shelter, cropping and policymaking practices affect soil erodibility. It is the percentage of soil erosion from a specific location with specified cover and management to soil erosion from a standard division scheme (Sahaar 2013). This equally means the fraction of soil erosion of any particular crop in relation to the soil erosion under the uninterrupted bare uncultivated condition (Renard *et al.* 1997). This assessment includes the influences of cover, crop order, production degree, cropping season length, cultivation system, residue management and the probable temporal spreading of erosive downpours. The C-factor shows the relationship between erosion on bare soil and erosion observed under a cropping system. It expresses the protection of soil by cover type and density (Farhan *et al.* 2013). The C-factor was generated by means of the Normalized Difference Vegetation Index (NDVI), a vegetation health indicator, in Equation (11):

$$C = \exp\left[-\alpha \frac{NDVI}{(\beta - NDVI)}\right] \tag{11}$$

where α and β are dimensionless limits that govern the profile of the curve connecting to NDVI in addition to the C-factor. This method gives a more appropriate result than presuming a direct affiliation and the value of 2 was

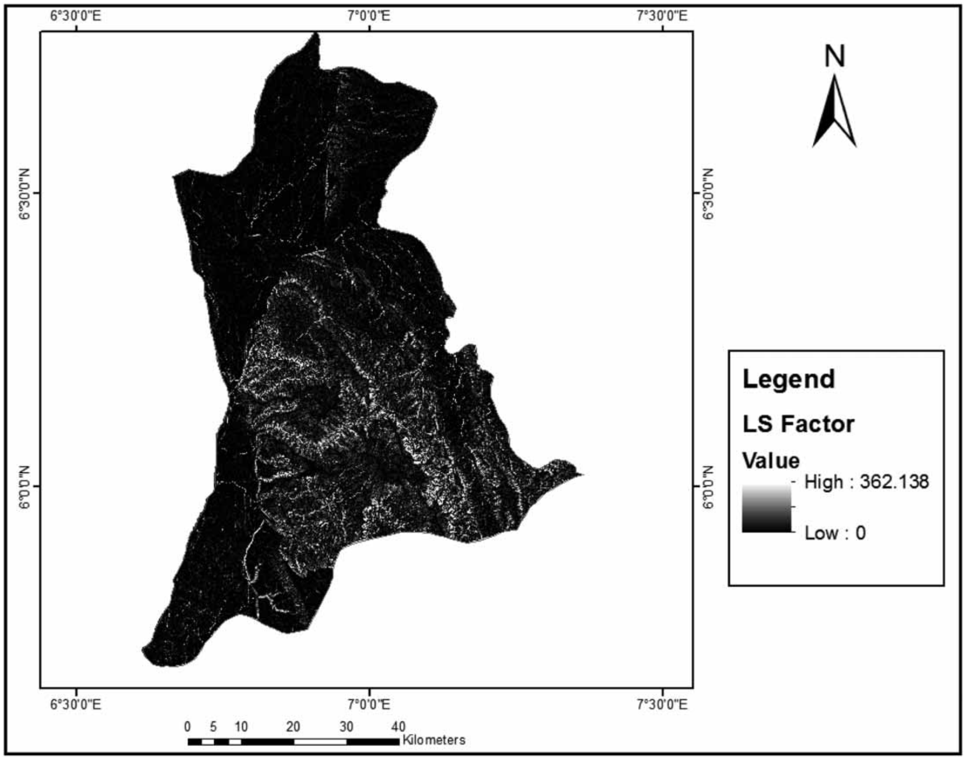

Figure 5 | Slope length (LS)-factor map of the study area.

designated for α, whereas 1 is for β (Van der Knijff *et al.* 2000). Over the study area, the C-factor values generated vary between 0.27 (low) and 1.22 (high). C-factor values closer to 0 show well-protected land cover and good conservational practices while values in the close neighbourhood of 1 show barren land and poor conservational practices. Some of these areas with high values are agricultural lands that are exposed to direct rainfall during the time of crop production; soil erosion from these areas was expected to be high due to the exposure of the soil to first rainfall events without any cover. Generally, higher C-factor values result in more soil erosion and vice versa. Thus, the eastern part of Anambra has low C-factor while the region within the north to the southern part has higher to moderate contributions to soil erosion in the state. Figure 6 demonstrates the C-factor.

Conservation practice (P-factor)

The P-factor considers the soil erosion compared to a particular support practice to the equivalent soil erosion with up and down slope tillage (Renard *et al.* 1997). It explains the degree of erosion with the particular management practices carried out. Plantations prevent erosion and protect soil loss depending on the land use and soil types (Pham *et al.* 2018). Farmers tend to plough their farmlands without engaging in soil conservation practices such as contouring, stippling and terracing and this leads to higher P-values. Lower P-values would be attained if conservation practices were carried out by farmers. These practices principally influence soil loss by altering the watercourse configuration, grade or way of overland flow and by decreasing the volume and degree of runoff (Nwakor *et al.* 2015). Generally, the P-value for Anambra State was set at 1 since there are no specified management practices used in the region. However, because P-factor values are highly influenced by slope steepness conditions, the central and south-western parts of the study area are characterized with higher values of P-factor; also, there is a possibility that other areas may have P-factor values less than 1 because of existing low slope gradient.

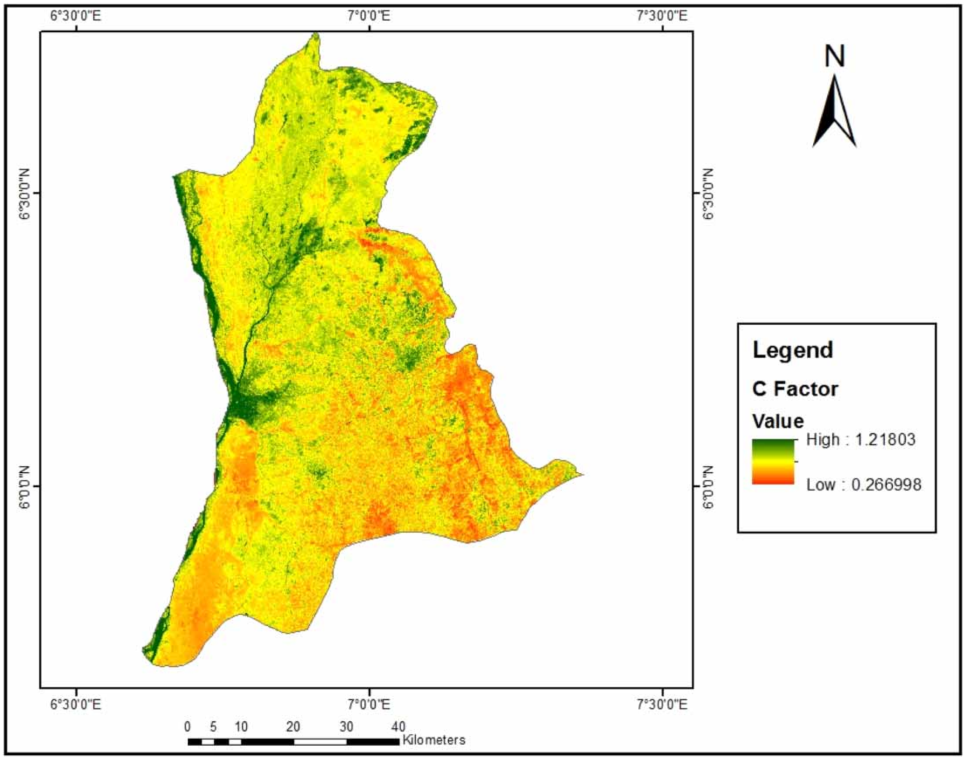

Figure 6 | Spatial distribution of cropping management (C) for Anambra State.

Soil loss

The soil erosion was computed by multiplying the R-factor, K-factor, LS-factor, C-factor and P-factor. The soil loss is often measured in ton/ha/yr. The soil erosion ranges from 0 to 181.237 tons/ha/yr. The soil loss was categorized as low, medium and high vulnerability. The low vulnerability covers an area of 4,143.62 km^2 (91%), the medium vulnerability covers an area of 332.29 km^2 (7%) and high vulnerability covers an area of 84.06 km^2 (2%). The total area of Anambra State is 4,559.97 km^2. Twelve (12) towns and villages lie within the high vulnerability zones with Agulu, Nanka, Oko and Ekwulobia as the most pronounced towns, 13 towns and villages lie in the medium vulnerability zones and 220 towns and villages lie in the low vulnerability zones. The total number of towns and villages in Anambra State is 245. The soil erosion is active from mid Anambra State towards the south. This is the result of high erodibility factor coupled with high slope length and steepness. Consequently, the soil is no longer sufficiently preserved by vegetal cover, thereby laying the soil bare to heavy rainfall. Sustainable farming is also greatly affected in Anambra because of the decline in soil fertility based on the rate of soil loss. Also, the issue of long-term agricultural productivity has become increasingly pressing in this region because there is a need for more agricultural lands with the drastic rise in population. Figures 7 and 8 portray the soil loss and the soil erosion vulnerability maps, respectively.

CONCLUSION

This study reported a far-reaching synopsis of the standing of soil erosion in Anambra State and its distribution in the state under the existing watershed conditions. The combination of the RUSLE model and GIS is an effective means of estimating the potential of soil erosion for the study area. A combined effect of high precipitation, soil erodibility, high slope length and steepness, and lack of soil management practices in the central to southern part of Anambra state has caused soil erosion to be prevalent in those areas. The

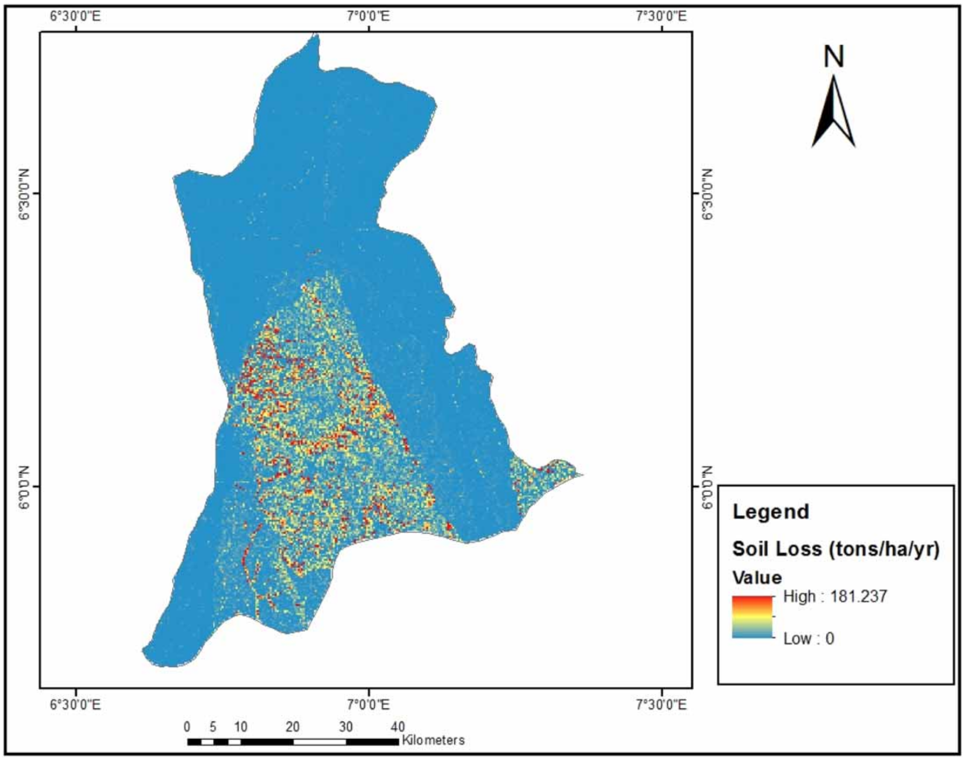

Figure 7 | Soil loss (tons/ha/yr) map for Anambra State.

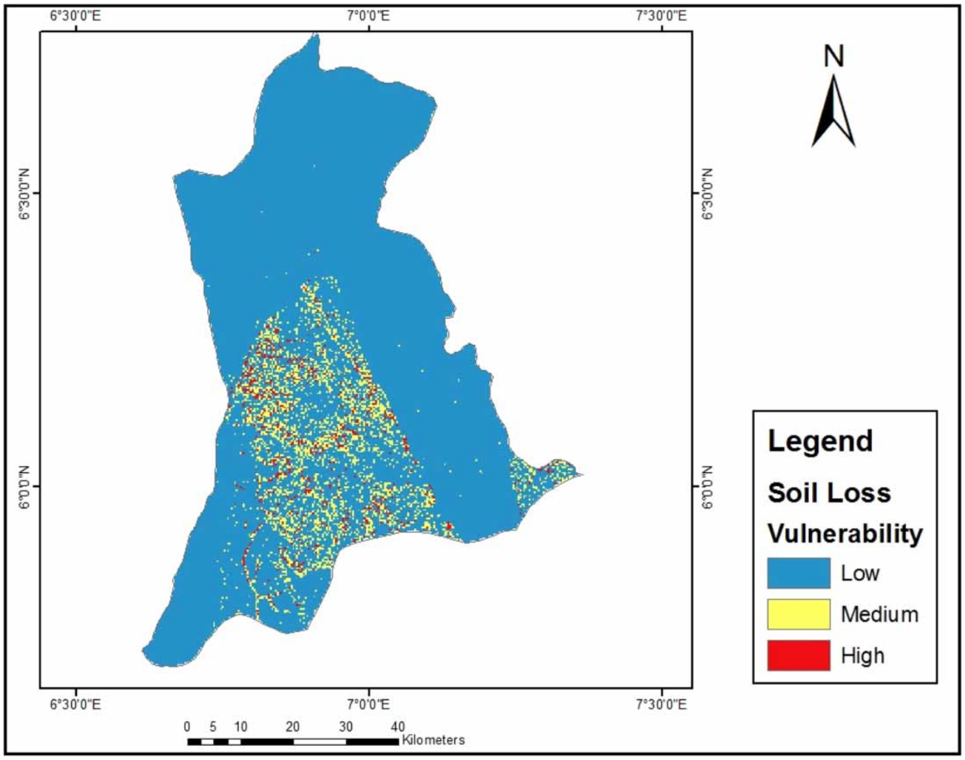

Figure 8 | Soil erosion map showing the vulnerability spatial distribution for Anambra State.

amount of soil loss is likely to surge with time as urbanization, agricultural practices and deforestation persist in the region. About 91% of the state has low susceptibility to soil attrition, 7% has medium vulnerability to soil loss and 2% has high vulnerability to soil loss. The erosion susceptibility atlas achieved from this research would serve as a relevant guide for stakeholders, policymakers and government in erosion disaster management planning. The map provides information for urgent erosion control measures targeted at mitigating the impact of erosion in Anambra State. It is recommended that similar studies be carried out on other states/regions of south-east Nigeria at high risk of erosion.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

REFERENCES

Adewumi, J. R., Akomolafe, J. K., Ajibade, F. O. & Fabeku, B. B. 2016 Application of GIS and remote sensing technique to change detection in land use/land cover mapping of Igbokoda, Ondo State, Nigeria. *Journal of Applied Science and Process Engineering* **3** (1), 34–54. https://doi.org/10.33736/jaspe.173.2016.

Adewumi, J. R., Akomolafe, J. K. & Ajibade, F. O. 2017 Development of flood prone area map for Igbokoda Township using geospatial technique. *Journal of Applied Science and Process Engineering* **4** (2), 158–178. https://doi.org/10.33736/jaspe.433.2017.

Agarwal, D., Tongara, K., Pathak, S., Ohri, A. & Jha, M. 2016 Soil erosion mapping of watershed in Mirzapur District using RUSLE model in GIS environment. *IJSRTM* **4** (3), 56–63. https://doi.org/10.18510/ijsrtm.2016.433.

Anees, M. T., Abdullah, K., Nawawi, M. N. M., Norulaini, N. A. N., Syakir, M. I. & Omar, A. K. M. 2018 Soil erosion analysis by RUSLE and sediment yield models using remote sensing and GIS in Kelantan state, Peninsular Malaysia. *Soil Research* **56**, 356–372. https://doi.org/10.1071/SR17193.

Angima, S. D., Stott, D. E., O'Neill, M. K., Ong, C. K. & Weesies, G. A. 2003 Soil erosion prediction using RUSLE for central Kenyan highland conditions. *Agriculture, Ecosystems and Environment* **97** (1–3), 295–308.

Apollo, M., Andreychouk, V. & Bhattarai, S. S. 2018 Short-term impacts of livestock grazing on vegetation and track formation in a high mountain environment: a case study from the Himalayan Miyar Valley (India). *Sustainability* **10** (4), 951. https://doi.org/10.3390/su10040951.

Boggs, G., Devonport, C., Evans, K. & Puig, P. 2001 GIS-based rapid assessment of erosion risk in a small catchment in the wet/dry tropics of Australia. *Land Degradation and Development* **12**, 417–434.

Bonilla, C. A., Reyes, J. L. & Magri, A. 2010 Water erosion prediction using the Revised Universal Soil Loss Equation (RUSLE) in a GIS framework, central Chile. *Chilean Journal of Agricultural Research* **70** (1), 159–169.

Bouhadeb, C. E., Menani, M. R., Bouguerra, H. & Derdous, O. 2018 Assessing soil loss using GIS based RUSLE methodology. Case of the Bou Namoussa watershed – North-East of Algeria. *Journal of Water and Land Development* **36**, 27–35. https://doi.org/10.2478/jwld-2018-0003.

Boukheir, R., Cerdo, O. & Abdallah, C. 2006 Regional soil erosion risk mapping in Lebanon. *The Journal of Geomorphology* **82** (3), 347–359.

Dabral, P. P., Baithuri, N. & Pandey, A. 2008 Soil erosion assessment in a hilly catchment of North Eastern India using USLE, GIS and remote sensing. *Water Resources Management* **22**, 1783–1798.

Drzewiecki, W., Wezyk, P., Pierzchalski, M. & Szafrańskaetal, B. 2014 Quantitative and qualitative assessment of soil erosion risk in Malopolska (Poland), supported by an object-based analysis of high-resolution satellite images. *Pure and Applied Geophysics* **171**, 867–895. doi:10.1007/s00024-013-0669-7.

Ejikeme, J. O., Ojiako, J. C., Onwuzuligbo, C. U. & Ezeh, F. C. 2017 Enhancing food security in Anambra State, Nigeria using remote sensing data. *Environmental Review* **6** (1), 27–44.

Emeribeole, A. C. & Iheaturu, C. J. 2015 Mapping of potential soil erosion risk areas in Imo State using the Revised Universal Soil Loss Equation (RUSLE), Remote Sensing (RS) and Geospatial Information System (GIS) techniques. *International Journal for Research in Emerging Science and Technology* **2** (10), 36–44.

Erdogan, E. H., Erpul, G. & Bayramin, I. 2007 Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed. *Environmental Monitoring and Assessment* **131**, 153–161. https://doi.org/10.1007/s10661-006-9464-6.

Fagbohun, B. J., Anifowose, A. B., Odeyemi, C., Aladejana, O. O. & Aladeboyeje, A. I. 2016 GIS-based estimation of soil erosion rates and identification of critical areas in Anambra sub-basin, Nigeria. *Modeling Earth Systems and Environment* **2**, 159. https://doi.org/10.1007/s40808-0.

Farhan, Y., Zregat, D. & Farhan, I. 2013 Spatial estimation of soil erosion risk using RUSLE approach, RS and GIS techniques: a case study of Kufranja Watershed, Northern Jordan. *Journal of Water Resource and Protection* **5**, 1247–1261.

Fistikoglu, O. & Harmancioglu, N. 2002 Integration of GIS with USLE in assessment of soil erosion. *Water Resources Management* **16**, 447–467.

Hoyos, N. 2005 Spatial modeling of soil erosion potential in a tropical watershed of the Colombian Andes. *Catena* **63** (1), 85–108.

Jasrotia, A. S. & Singh, R. 2006 Modeling runoff and soil erosion in a catchment area, using the GIS, in the Himalayan region, India. *Environmental Geology* **51**, 29–37.

Kadam, A. K., Umrikar, B. N. & Sankhua, R. N. 2018 Assessment of soil loss using Revised Universal Soil Loss Equation (RUSLE): a remote sensing and GIS approach. *Remote Sensing of Land* **2** (1), 65–75.

Kayet, N., Pathak, K., Chakrabarty, A. & Sahoo, S. 2018 Evaluation of soil loss estimation using the RUSLE model and SCS-CN method in hillslope mining areas. *International Soil and Water Conservation Research* **6**, 31–42. https://doi.org/10.1016/j.iswcr.2017.11.002.

Kim, Y. 2014 *docplayer.net*. Available from: https://docplayer.net: https://docplayer.net/50812309-Soil-erosion-assessment-using-gis-and-revised-universal-soil-loss-equation-rusle.html (accessed 13 September 2019).

Kouli, M., Soupios, P. & Vallianatos, F. 2009 Soil erosion prediction using the revised universal soil loss equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. *Environmental Geology* **57**, 483–497. https://doi.org/10.1007/s00254-008-1318-9.

Kunta, K. & Carosio, A. 2007 Effect of DEM resolution on soil erosion, production of RUSLE model with VBA calculation in ArcGIS. In: *11tth Annual National Symposium on Computational Science and Engineering*, Phuket, Thailand.

Lal, R. R. 2001 Soil degradation by erosion. *Land Degradation & Development* **12**, 519–539. https://doi.org/10.1002/ldr.472.

Lamyaa, K., M'bark, A., Brahim, I., Hicham, A. & Soraya, M. 2018 Mapping soil erosion risk using RUSLE, GIS, remote sensing methods: a case of mountainous sub-watershed, Ifni Lake and high valley of Tifnoute (High Moroccan Atlas). *Journal of Geography, Environment and Earth Science International* **14** (2), 1–11.

Lee, G. S. & Lee, K. H. 2006 Scaling effect for estimating soil loss in the RUSLE model using remotely sensed geospatial data in Korea. *Hydrology and Earth System Sciences* **3**, 135–157.

Lim, J. K., Sagong, M., Engel, B. A., Tang, Z., Choi, J. & Kim, K. 2005 GIS based sediment assessment tool. *Catena* **64**, 61–80.

Lu, D., Li, G., Valladares, G. S. & Batistella, M. 2004 Mapping soil erosion risk in Rondonia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. *Land Degradation and Development* **15**, 499–512.

May, L. & Place, C. J. 2005 A GIS-based model model of soil erosion and transport. *Freshwater Forum* **23**, 48–61.

Merritt, W. S., Letcher, R. A. & Jakeman, A. J. 2003 A review of erosion and sediment transport models. *Environmental Modeling and Software* **18**, 761–799. https://doi.org/10.1016/S1364-8152(03)00078-1.

Morgan, R. C. 1994 *Soil Erosion and Conservation*. Silsoe College, Cranfield University, UK.

Mosavi, A., Ozturk, P. & Chau, K. W. 2018 Flood prediction using machine learning models: literature review. *Water* **10**, 1536. https://doi.org/10.3390/w10111536.

Nnabugwu, O. U. & Uwadiegwu, I. 2015 Mapping gully erosion in Abia State, Nigeria using Geographic Information Systems (GIS) and remote sensing techniques. *Journal of Soil Science and Environmental Management* **6** (10), 284–300. https://doi.org/10.5897/JSSEM15.0510.

Nwakor, E. K., Mbajiorgu, C. C. & Ogbu, K. N. 2015 Assessment of soil erosion using RUSLE2 model and GIS in upper Ebonyi River watershed, Enugu State, Nigeria. *International Journal of Remote Sensing & Geoscience (IJRSG)* **4** (4), 7–17.

Ofomata, G. K. 1981 Actual and potential erosion in Nigeria and measures for control. *Soil Science Society of Nigeria Special Monograph* **1**, 151–165.

Ouyang, D. & Bartholic, J. 2001 Web-based GIS application for soil erosion prediction. In: *Proceedings of An International Symposium – Soil Erosion Research for the 21st Century*, January 3–5, Honolulu, HI, USA, pp. 1–5.

Pandey, A., Mathur, A., Mishra, S. K. & Mal, B. C. 2009 Soil erosion modeling of a Himalayan watershed using RS and GIS. *Environmental Earth Sciences* **59** (2), 399–410.

Pham, T. G., Degener, J. & Kappas, M. 2018 Integrated Universal Soil Loss Equation (USLE) and Geographical Information System (GIS) for soil erosion estimation in a sap basin; Central Vietnam. *International Soil and Water Conservation Research* **6** (2), 99–110. https://doi.org/10.1016/j.iswcr.2018.01.001.

Prasannakumar, V., Vijith, H., Abinod, S. & Geetha, N. 2012 Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. *Geoscience Frontiers* **3** (2), 209–215. https://doi.org/10.1016/j.gsf.2011.11.003.

Renard, K. G. & Friedmund, J. R. 1994 Using monthly precipitation data to estimate the R-factor in the RUSLE. *Journal of Hydrology* **157**, 287–306.

Renard, K. J., Foster, G., Weesies, G. & Mccool, D. 1997 *Predicting Soil Erosion by Water: A Guide to Conversion Planning with the Revised Universe Soil Loss Equation (RUSLE). Agricultural Handbook, 703*. US Department of Agriculture, Washington, DC, USA.

Roose, E. J. 1975 *Universal Soil Loss Equation (RUSLE). Agriculture Handbook No. 703*. Department of Agriculture, Washington, DC, USA.

Roose, E. J. & Lelong, F. 1976 Les facteurs de l'érosion hydrique en Afrique Tropicale. Études sur petites parcelles expérimentales de sol (The factors of water erosion in tropical Africa. Studies on small experimental soil plots). *Revue de Géographie Physique et de Géologie Dynamique* **18** (4), 365–374.

Sahaar, A. S. 2013 *Erosion Mapping and Sediment Yield of the Kabul River Basin, Afghanistan*. M.Sc Thesis, Department of Civil and Environmental Engineering, Colorado State University, Fort Collins, CO, USA.

Saini, S. S., Jangra, R. & Kaushik, S. P. 2015 Vulnerability assessment of soil erosion using geospatial techniques. A pilot study of upper catchment of Markanda River. *International Journal of Advancement in Remote Sensing, GIS and Geography* **3** (1), 9–21.

Tian, Y. C., Zhou, Y. M., Wu, B. F. & Zhou, W. F. 2009 Risk assessment of water soil erosion in Upper Basin of Miyun Reservoir. *Environmental Geology* **57**, 937–942.

Tirkey, A. S., Pandey, A. C. & Nathawat, M. S. 2013 Use of satellite data, GIS and RUSLE for estimation of average annual soil loss in Daltonganj watershed of Jharkhand (India). *Journal of Remote Sensing Technology* **1** (1), 20–30. https://doi.org/10.18005/JRST0101004.

Uddin, K., Murthy, M. R., Wahid, S. M. & Matin, M. A. 2016 Estimation of soil erosion dynamics in the Koshi Basin using GIS and remote sensing to assess priority areas for conservation. *PLoS ONE* **11** (3), 1–19. https://doi.org/10.1371/journal.pone.0150494.

Van der Knijff, J. M., Jones, R. J. & Montanarella, L. 2000 *Soil Erosion Assessment in Europe*. European Commission Directorate General, Joint Research Centre, European Soil Bureau, pp. 1–34.

Vrieling, A. 2005 Satellite remote sensing for water erosion assessment, a review. *Catena* **65** (1), 2–18.

Wang, L., Qian, J., Qi, W.-Y., Li, S.-S. & Chen, J.-L. 2018 Changes in soil erosion and sediment transport based on the RUSLE model in Zhifanggou watershed, China. *Proceedings International Association of Hydrological Sciences* **377**, 9–18. https://doi.org/10.5194/piahs-377-9-2018.

Wischmeier, W. H. & Smith, D. D. 1978 *Predicting Rainfall Erosion Soil Losses, A Guide to Conservation Planning. Agriculture Handbook No. 537*. US Department of Agriculture Science and Education Administration, Washington, DC, USA.

Xu, Y., Shao, X., Kong, X., Peng, J. & Cai, Y. 2008 Adapting the RUSLE and GIS to model soil erosion risk in a mountains karst watershed, Guizhou Province, China. *Environmental Monitoring and Assessment* **141**, 275–286. https://doi.org/10.1007/s10661-007-9894-9.

Zhang, Y., Degroote, J., Wolter, C. & Sugumaran, R. 2009 Integration of modified universal soil loss equation (MUSLE) into a GIS framework to assess soil erosion risk. *Land Degradation & Development* **20**, 84–91. https://doi.org/10.1002/ldr.893.

First received 20 October 2019; accepted in revised form 7 May 2020. Available online 3 July 2020