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Estimation of Soil Loss using Remote Sensing Data in a Regional Tropical Humid Catchment Area

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Abstract

Soil erosion has been and continue to be a major threat to environmental degradation especially in the developing countries. Accurate estimation of soil loss will provide reliable information in the management and mitigation solutions to soil erosion. In this study, the soil loss in an erosion prone Anambra State of South East region of Nigeria was estimated. Due to the complex nature of the catchment characteristics of Anambra State, soil loss cannot be estimated precisely by mere application of conventional soil erosion model. Hence a site-specific methodology was developed and applied. Revised Universal Soil Loss Equation (RUSLE) was integrated with the Geographic Information System (GIS) of the environment using remote sensing to build the model. 40-years rainfall data was collated from the Nigeria Meteorological Agency and analyzed. The various parameter of RUSLE which includes: Rainfall Erosivity (R), Soil Erodibility (K), Topography (LS), Land Use and Land Cover (C), and Erosion Control practices (P) were developed and imposed into ArcGIS 10.6 to estimate the amount of annual soil loss in the area. The result indicated that about 27.58km^2 (0.59%) of the study area have very low erosion rate of 0 – 5 t ha^{1}year^{-1} , while the rates of erosion in 1311.52km^2 (28.01%), 538.59km^2 (11.50%), 1649.08km^2 (35.22%), 959.09km^2 (20.48%), and 196.76km^2 (4.20%) of the study area are 5 – 10, 10 – 15, 15 – 25, 25–50 and >50 t ha^{-1}year^{-1} respectively. This knowledge will help decision makers in managing the land degradation problems in Anambra State of Nigeria.

Keywords: Soil Loss; RUSLE; Soil Erosion; Land Degradation; Anambra State Nigeria.

1. Introduction

Soil erosion processes occur by nature, and it is a usual geologic activity that relates with the cycle of hydrology. Soil erosion routine is through detaching and transporting soil material naturally, aided by erosivity-promoting factors. Among these erosivity factors are flood, wind, gravitational pressure, and human activities [1]. Eroding the watershed and depositing the silts eventually into streams and water reservoirs generates two main issues for the environment: In the first instance, the soil nutrients are washed away from the catchment basin. The second is reducing the reservoir capacity and compromising the quality of water down the stream. Erosion of soil occurs more where the first layer of the soil has been cleared away due mainly to urban projects, cultivation practices, undulating surface terrain of the site, and/or level change resulting from consistent movement on the soil surface. Erosion of soil by water is of utmost concern globally to the degradation of land [2, 3]. Erosion of soil creates a strong effect on the environment with associated huge economic implications whenever it occurs on the site. It also causes an aftereffect on the infrastructure and quality of stream water wherever it occurs [4].

Erosion of soil causes loss of soil. Consequentially, the soil becomes less fertile, and the yield of the plants drops. Complete stoppage of erosion of soil is not possible; however, mitigation of it is achievable. Great potential exists in the

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application of GIS technology to assist in constructing soil erosion models and assess the erosion hazard. The Nigerian state most affected by erosion is Anambra. Scholars have classified the gullies in Anambra State, Nigeria, as disastrous [5]. Since many of them are wider and deeper than tens of kilometers, it would be more appropriate to refer to them as canyons. Some regions in Anambra State are fast becoming hazardous for human habitation. Research conducted by Ofomata [6] reveals that the Anambra State topography and the soil type are directly related to the magnitude and ease at which gullies develop in the area. Odumodu et al. [5] stated that a number of natural and man-made variables, such as the type of soil, vegetation, overgrazing, overcropping, deforestation, and other topographic features, have a significant influence on the rate of soil erosion in the studied region. These have all contributed to soil erosion, which has led to ecological imbalances. Ekwueme [7], when quantifying floods in the region, explained that the climate change effect also increases the susceptibility of the zone to erosion. Also, Igwe [8] collaborated on these reports and further explained that the gullies emanate from the cuestas, slopes, joints, and fractures, as is customary in erosion susceptible catchment areas. In recent years, unquantized huge tracts of land have deteriorated in places like Agulu-Nanka and Ekwulobia. In addition, there have been several car accidents and residential housing relocations as a result of damage to the infrastructure, particularly the roadways. The study area's main erosion sites, which are renowned for their size and devastation, are in the Savanna vegetation, which has been burned and chopped due to growing human density, the need for farming, and other projects.

Merem et al.'s [9] investigation examined land use and identified modification in the eastern part of Nigeria using remote sensing and GIS. The investigation revealed changes in the study region, including increases and decreases of hydrogeological values even on close catchments [10]. The zone did see a rise in the number of woods and urban land cover in addition to an increase in agricultural and bare soil regions. However, there is also an increase in bush burning, which exposes the forest under severe heat and encourages soil erosion. This practice was identified by Arinze et al. [11] as a causative agent to soil loss. Considering the opportunities of a varied environment and the close vicinity to the virgin rainforests, the area has presence of extensive network of various groups of land cover within it. The region's inclination towards several land degradation scenarios, including erosion and other hazards, has hindered the full realization of ecological stability and biodiversity. In this location, gully erosion is a result of both natural and man-made influences, as stated by Igbokwe et al. [12].

Chukwuka & Ifeyinwa's [13] research postulated that the region will be experiencing geometrical increments in the development of huge gullies if these endemic and weighty causes are left unchecked. To comprehend and forecast erosion of upland soil and streams, as well as the movement and deposit of sediment, several erosion models have been created. Based on the tangible procedure's simulation, the algorithms of the mathematical framework explaining these processes, and the model's data reliance, models generally fall into three broad types. The empirical, abstract, as well as physically based models fall under these three groups [14-16]. The Revised Universal Soil Loss Equation (RUSLE) is a representation of soil type, climate, land use, and topography that influences interrill and rill soil erosion due to precipitation and surface runoff impact [17]. RUSLE is widely used in the estimation of loss of soil, erosion risk assessment, and planning erosion mitigation guidelines, especially in varieties of conditions of the land, like range, grass, and forestry [18-20].

The U.S. Department of Agriculture's RUSLE is a tool that helps in making decisions on land use planning and soil conservation. It describes the biological processes connected to erosion and conservation strategies in each landscape using a system of mathematical equations. The most noted limitation of the RUSLE model is their non-conformity with catchment areas that are not within the United States of America [21–23]. Based on research of soil erosion in US agricultural land, the first USLE was developed. Applying this tool to estimating mean yearly soil loss in regions with dissimilar climatic and landscape conditions may result in increased irregularities [24]. Because the RUSLE variables were constructed on the basis of research conducted on a small-scale piece of agricultural land, there may be some irregularities that will evolve when transposing the original USLE to a region of bigger catchment [23]. As previously mentioned, the RUSLE's geographical applicability is a restriction that necessitates modifying and adjusting the sub-factors in light of the unique features of the scholar's study location [25, 26].

The two limiting factors of routing and deposition are of great concern when the model is to represent a terrain with diverse topography. This has necessitated the improvement of the LS factor through the involvement of contributions from upstream as a solution by some researchers [27]. Geographic Information System (GIS) brings together geostatistical analysis, cartographic, and database functions, allowing the user to find out the geographical information, trends, patterns, and their relationship [28]. A multi-component environment called a geographic information system (GIS) is used to produce, organize, visualize, and analyze geographical data. It's crucial to remember that the majority of datasets you come across in your lifetime may all be given a physical position, whether it be inside an arbitrary coordinate system or on the surface of the globe. GIS has been applied in managing the environment since the 1970s [29]. Two decades later, GIS applications started to appear in flood mapping, hydrologic modeling, and hydraulic modeling. Renschler & Harbor [30] found out that the Geographic Information System is a powerful decision-making tool that allows spatial information and interaction to be handled with erosion models, thereby helping in solving problems of erosion. From the research work of Zhang et al. [31] and Yashraj [32], GIS performs a useful analytic and spatial role of developing the model input data at various scales through the provision of the tedious georeferencing function and spatial overlay. GIS has the capability to look at the variation spatially, thus simulating the areas at a user-defined resolution [33].

According to Haboudane et al. [34], ArcGIS is a software of geographic information systems (GIS) that permits the analysis of geographical information by observing it statistically through layer-building maps like climate data or trade flows. As described by Singh et al. [35], remote sensing is a geospatial technology that functions by sampling radiated and reflected electromagnetic (EM) emission from the globe's terrestrial, atmospheric, and aquatic ecosystems to discover and observe the physical characteristics of an area without making body contact. It can be deployed effectively in soil erosion mapping [35, 36]. Hydrologists have applied the combination of RUSLE and GIS to model soil erosion reliably [35]. Millward & Mersey [18] incorporated Geographic Information System (GIS) into the Revised Universal Soil Loss Equation (RUSLE) to model erosion potential for a soil conservation plan within the Sierra de Manantlán Biosphere Reserve (SMBR), Mexico. This resulted in a RUSLE-GIS model that is a robust tool for planning soil conservation and can easily be applied to other land managers with characteristically similar environments.

Many research studies on soil erosion have been conducted in the study area. Eze et al. (2024) [37], Egbueri et al. (2022) [38], Ayadiuno et al. (2022) [39], Fagbohun et al. (2016) [40], and Ajibade et al. (2020) [41] have all studied the erosion situation in Anambra State. Owing to the scarcity of data, RUSLE models used for the predictions could not be validated [37]. It was also observed that in some of the previous studies, the values of K, C, and LS factors were universally assaigned. In this study therefore, the methodology was modified by creating many more smaller sub-catchments to increase the accuracy of the estimated K, C, and LS factors. The result was also compared with those of the previous works and used to validate the applied methodology.

The structured methodology in this work is first to analyze 40-year rainfall data to determine the R factor. The second is to parcellate the study area into many greater numbers of smaller sub-catchments than the number considered by previous researchers (especially in gully erosion-developing sectors). This increment in the number of sub-catchments for investigation will help in arriving at better K, C, P, and LS factors as suggested by RUSLE parameter assessment literature [27, 37]. Finally, the model will be constructed, results obtained, soil loss estimated, and conclusions drawn.

2. Material and Methods

2.1. Study Area

Located in southeast Nigeria, Anambra State lies within longitudes 6° 43' and 7° 22'E and latitudes 5° 32' and 6° 45' N, respectively [42]. Delta State borders it on the west; Rivers and Imo States border it on the south; Kogi State borders it on the east; and Abia State borders it on the north. The Igbo people, who make up the third biggest ethnic group in Nigeria, live there in twenty Local Government Areas. The Igbos have 98% of the population and a small population of Igala (2% of the population), who live mainly in the north-western part of the state [5]. Anambra State has an area of 4,844 km^2 with a population of 7,821,858. There are gullies, steep hills, sloping slopes, and sections that are flooded, making for a typically diversified landscape. In many Anambra State communities, the Land Use Intensity Index—which measures the proportion of farmed land to uncultivated terrestrial plus unplanted—is 70%. This is particularly the case in highland areas, where intensification leads to nutrient and organic matter loss as well as structural degradation (see Figure 1).

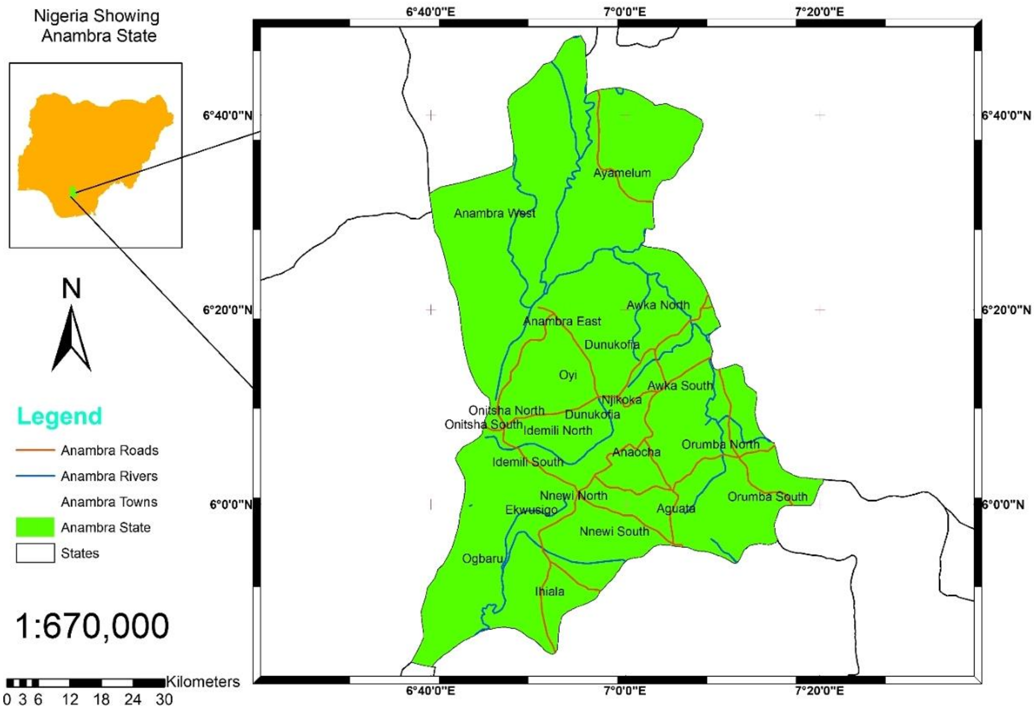


Figure 1. Geographic Map of Anambra State (Study Area) showing the major cities

Anambra State is divided into two primary landform regions: low plains to the west, north, and east of the highlands, and a moderately elevated highland area that encompasses most of the state south of the Anambra River. According to the underlying geological formations, the highland area is a low, asymmetrical ridge or cuesta in the northern part of the Awka Orlu Uplands that trends roughly southeast to northwest. Its highest point is around 410 meters above mean sea level in the southeast, and it progressively descends to barely 33 meters in the northwest at the banks of the Anambra River and the Niger. The cuesta at Onitsha and Otuocha offers low, well-drained ground that is extremely near to the river, allowing towns to stretch to the river's banks. It is shown in Figure 2.

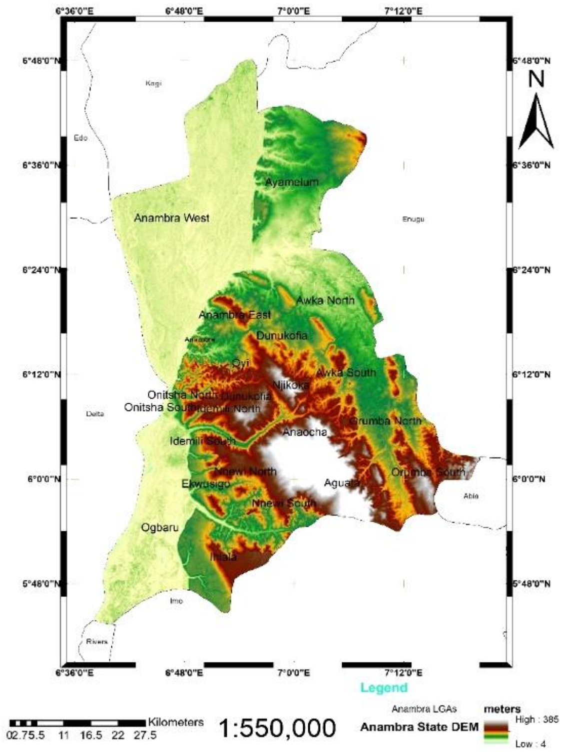


Figure 2. Digital Elevation Map of Anambra State showing the major cities

2.2. Source of Materials and Methodology

A 40-years annual rainfall data spanning from 1981 to 2020 of the study area capital city (Awka) and its environs (Enugu, Owerri, and Asaba) was obtained from the Nigerian Meteorological Agency (NiMET) as tabulated in Table 1. The mean annual rainfall of Awka and the environs (Enugu, Owerri, and Asaba) from NiMET was assessed as shown in Table 2. The Digital Elevation Map (DEM) and the Landset Image (GIS) were processed as shown in the flowchart of the research methodology (Figure 3).

Table 1. Annual rainfalls for the project location and its environs

S/N	Year	Awka	Enugu	Owerri	Asaba
1	1981	1838.6	1710.9	2136.9	1838.6
2	1982	1715.7	1549.6	2404.4	1715.7
3	1983	1417.6	917.1	1695	1417.6
4	1984	1683.9	1781.1	2163.6	1683.9
5	1985	1799.6	1939.9	2376.3	1799.6
6	1986	1617.9	1450.6	2121.1	1617.9
7	1987	1503.7	1467.3	2070	1503.7
8	1988	2008	1532.4	2698.4	2008
9	1989	1798.4	1643.7	2581.5	1798.4
10	1990	2009.6	2083.4	2731.9	2009.6
11	1991	2095	1961.9	2565.1	2095
12	1992	1804.9	1706.5	2424.1	1804.9
13	1993	1654.1	1577.7	2182.8	1654.1
14	1994	2081.7	1663.1	2626.1	2081.7

15	1995	2478.5	2170.9	2622.3	2478.5
16	1996	1826.7	1919.4	2705.5	1826.7
17	1997	2277.4	2284.6	2272.5	2277.4
18	1998	1375.3	1496.1	1641.5	1375.3
19	1999	2093.6	1623.1	2496.5	2101.2
20	2000	2069.1	1677.2	2296.4	2069.1
21	2001	1516.6	1677.2	2304.2	1516.6
22	2002	1928.1	1725.8	2042.2	1928.1
23	2003	1671.1	1891	1893.7	1671.1
24	2004	1861.5	1770.8	1735.6	1861.5
25	2005	1914.7	1716.5	2545.5	1756.4
26	2006	1910.3	2084.3	2914.8	1906
27	2007	2026.8	1859.6	2392.9	1796.3
28	2008	2056.2	1737.4	2748.9	1790.4
29	2009	2157.6	1769.7	2916.7	1765.8
30	2010	1585.9	1669.5	2331.6	1841.7
31	2011	1957.5	1729.3	2351.7	2924.3
32	2012	1986.1	2137.7	2260.7	1647.9
33	2013	1447.3	1941.1	2199.9	1635.1
34	2014	1528.7	1929.6	1972.3	1819.3
35	2015	2518.4	2008.9	2369.9	2548.2
36	2016	2084.8	1882.5	2238.4	2478.4
37	2017	3507	2152.5	1933.8	2890.2
38	2018	3663.6	1905.7	2488.2	2770.4
39	2019	3821.2	1944	2917.8	3290.9
40	2020	2803.9	1953.2	2259.5	2120.3

Table 2. Mean Annual Rainfalls for the project location and its environs

S/N	Data Location	Latitude	Longitude	Mean Annual Rainfall (mm)
1	Awka	6.2	7.07	2027.4
2	Enugu	6.47	7.55	1791.1
3	Owerri	5.48	7.03	2340.8
4	Asaba	6.82	6.23	1977.9

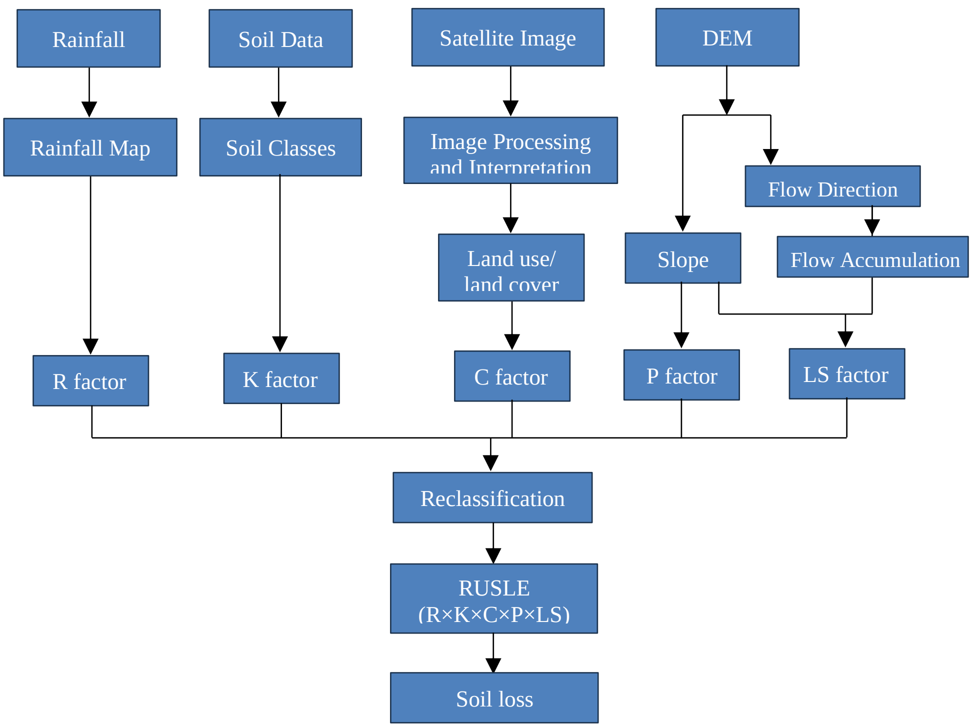


Figure 3. Flow chart of the research methodology

The soil erodibility factor was estimated using the results from soil laboratory analysis for soil particle distribution, organic matter content, soil permeability of the soil samples collected from ten (10) different erosion sites, and soil information of 20 different locations within the study catchment area [39]. Thus, k-factor estimation was for a total of thirty (30) different locations within the study area. After soil sample collection and testing in the soil laboratories, the percentage of silt, sand, clay, and organic matter content were determined to investigate the soil erodibility factor (K) of Anambra State as shown in Table 3.

Table 3. Soil laboratory Analysis

S/N	Location	X	Y	Silt (%)	Clay (%)	Textural class	OM (%)
1	Aguleri	267724.5	699254.6	3	11	LS	0.802
2	Agulu	285830.1	673542.6	7	11	LS	1.194
3	Akpo	293284.2	659128.7	7	13	SL	3.12
4	Anaku	271345.1	715998.3	11	13	LS	2.205
5	Awka	288384.9	685747.5	9	11	SL	1.126
6	Ekwulobia	290094.2	666458.6	5	13	SL	0.987
7	Ideani	275258.6	676714.4	9	10	LS	2.089
8	Ihiala	265837.3	645071.9	13	13	SL	2.845
9	Mgbakwu	290023.7	679146.5	3	8	LS	1.194
10	Nibo	290096.4	683657.2	7	8	LS	3.258
11	Nimo	279278.3	680906.3	5	8	LS	3.052
12	Nise	287206	681491	9	17	SL	1.813
13	Nkpologwu	290849.9	661512.4	9	11	SL	1.951
14	Nnewi	271150.1	666031.7	11	13	SL	2.295
15	Ojoto	264793.9	670093.1	5	8	LS	1.861
16	Okija	266692.5	652250.1	11	13	SL	2.983
17	Okpuno	286376.6	692929	3	16	SL	0.279
18	Omor	280774.9	720275.2	9	15	SCL	1.792
19	Ozubulu	265135.4	660532.9	11	11	SL	2.708
20	Ukpor	271460	659379.1	9	21	SCL	1.951

2.3. Estimating RUSLE Parameter

The primary factors that affect soil erosion are topography, climate, soil type, vegetation, land use, and anthropologic activities [43, 44]. Among these, climate is regarded as uncontrollable by man. Management practices can largely control the vegetation, soil, and topography of the catchment [45, 46]. For better agricultural practices, including shifting cultivation, combining cropping systems, control of erosion, and other technical management practices, soil erosion prediction equations have been developed [45]. The components that describe these erosion-influencing properties are combined in these equations.

Uncertainties and limitations exist in modeling soil erosion with the application of the RUSLE technique. The major discrepancy is in the model parameter estimation. Similar land covers are assumed to possess the same C factor, which may not always hold truth. The assumption that soil of the same type has the same value of the K factor irrespective of the geographical location may be incorrect due to the spatial changes across the catchment [10, 37]. These limitations, if not checked, will likely cause differences in the results from different studies and will not represent the real condition of the catchment area. This study therefore modified the methodology by creating many more smaller sub-catchments to increase the accuracy of the estimated K, C, and LS factors.

Due to paucity of data, the RUSLE model developed in this research was not validated before application, just like many other erosion estimation studies in Nigeria. This was observed by Ezeh et al. [37] in their review of RUSLE model applications in Nigeria, that over 90% of RUSLE models could not be validated due to a lack of field data. Despite these limitations, the RUSLE model still presents the most acceptable estimation of soil loss in Nigeria. In this study, validation of the developed model was done by comparing the result from this research with findings from previous works conducted in the area by other researchers.

2.3.1. Rainfall – Runoff Erosivity Factor (R)

Renard & Freimund (1994) [17] analyzed data from 155 locations across the United States. They discovered a correlation between erosion rates (the R factor), total yearly rainfall, and a modified version of the Fournier coefficient (which uses monthly rainfall data) as shown in Equation 1:

$$F = \frac{\sum_{i=1}^{12} P_i^2}{P_a} \tag{1}$$

This part talks about average rainfall each month (P_i in millimetres) and average yearly rainfall (P_a in millimetres). It also mentions a study by Lee & Lee [47] that found connections between a factor called "R" and another factor called "F":

$$R = 0.07397 \times F^{1.847} \qquad [r^2 = 0.81] \tag{2}$$

$$R = 95.77 - 6.081F + 0.477 \times F^2 \qquad [r^2 = 0.75] \tag{3}$$

When F was less than 55 mm, they advised using Equation 2, and when F was greater than 55 mm, Equation 3.

From [47-49],

$$R = 38.5 + 0.35 \times Pr \tag{4}$$

Note that, Pr is the average rainfall (mm/yr).

2.3.2. Soil Erodibility (K)

In the study area, researchers assigned numerical values to different soil types to assess their susceptibility to erosion. These values represent the inherent susceptibility of each soil type to erosion [50]. Large soil sample databases are often unavailable at the regional level; nonetheless, the soil taxonomy map has the data needed to calculate the K factor. Using the texture analysis survey's units as a guide on compound maps, K values may be determined at the watershed scale. The assessment of soil erodibility within the research area involved the attribution of corresponding numerical values to the diverse soil typologies present. These values quantify the relative susceptibility of each soil type to erosion [51].

$$Dg = exp[\sum_i 1/100 \times f_i \times In(m_i)] \tag{5}$$

This equation, proposed by Römkens et al. [52], can be used to assess a factor (K) related to soil erodibility. The equation includes terms related to particle size viz:

$$K = 0.0035 \times 0.0388 \times exp\left[-0.5 \times \left(\frac{LogD_g + 1.519}{0.7584}\right)^2\right] \tag{6}$$

In cases where additional information, such as soil structure, organic matter content, and permeability, was available, a more comprehensive equation developed by Wischmeier and Johnson [53] was employed to evaluate soil erodibility.

$$K = \frac{0.01317}{100}[2.1 \times 10^{-4} \times M^{1.14} \times (12 - OM) + 3.25 \times (S - 2) + 2.5 \times (P - 3)] \tag{7}$$

$$K = 2.73 \times 10^{-6} M^{1.14}(12 - OM) + 3.25 \times 10^{-2}(S - 2) + 2.5^{-2}(P - 3) \tag{8}$$

Scientists typically predict how readily soil erodes by analysing its properties using a formula devised by Wischmeier and Smith [54]:

$$K = [27.66 \times m^{1.14} \times 10^{-8} \times (12 - a)] + [0.0043 \times (b - 2)] + [0.0033 \times (c - 3)] \tag{9}$$

where K is Soil erodibility factor in ($ton.hr^{-1}.ha^{-1}.MJ.mm$), a is % organic matter content that could be determined in laboratory, b is type of soil structure (e.g., solid, reasonably organised, slightly structured, and extremely structured or particulate), c is Drainage rate of the soil, m is (% silt + % very fine sand) or (100 - % clay).

2.3.3. Land Topography (LS)

An arbitrary slope and its length can be used to calculate the LS factor.

$$LS = \left(\frac{\lambda}{72.6}\right)^m (65.41sin^2\theta + 4.56sin\theta + 0.065) \tag{10}$$

where m = 0.5 if the percent slope is 5 or more, = 0.4 on slopes of 3.5 to 4.5%, = 0.3 on slopes of 1 to 3%, and 0.2 on uniform gradients of less than 1%. Where λ is the slope length in feet, and θ is the angle of slope.

2.3.4. Land Use and Cover (C)

Think of C-factor as a score telling you how well different types of land cover, like crops or forests, hold onto soil compared to a bare patch of dirt. The lower the score, the less soil washes away [54]. Classifying land uses is a common method for mapping plant kinds that have varying degrees of soil protection efficacy. Following categorization, vegetation types are ranked qualitatively, or C-factors are assigned.

2.3.5. Conservation/Support Practice (P)

Reduced soil loss is achieved by conservation techniques including terracing, contouring, and strip cropping—particularly in agricultural settings. The support technique factor explains how tillage and contouring techniques affect soil erosion. Wischmeier and Smith, in 1978, created a score (P-factor) to show how planting affects soil loss. A lower score means the planting method is better at stopping soil from washing away. The effectiveness of a conservation technique in minimizing soil erosion is shown by a lower P value.

The conservation practice factor is determined on the basis of the relationship between terrace and area slope of the paddy field, estimated in conformity with the characteristics of both the area contour and slope in the crop field [55].

3. Result and Discussion

3.1. R Factor

Using Equation 4, the R-factor was estimated, and it is given in Table 4. The chart of the corresponding area of coverage for R is given in Figure 4.

Table 4. Estimated R-factor of project area and other 3 different locations

S/N	Data Location	Latitude	Longitude	Mean Annual Rainfall (mm/yr)	R-factor (MJ·mm·ha^{-1}·hr^{-1}·year^{-1})
1	Awka	6.2	7.07	2027.4	748.090
2	Enugu	6.47	7.55	1791.1	665.385
3	Owerri	5.48	7.03	2340.8	857.780
4	Asaba	6.82	6.23	1977.9	730.765

From Figure 4, about 18% (843.01 km^2), 51% (2389.41 km^2), 16% (774.70 km^2), 8% (363.80km^2), and 7% (351.43km^2) have very low, low, medium, high, and very high R factors, respectively. This is an indication that half of the study area has a low R factor value between 739.7909224 - 752.5598001 based on the natural breaks classification.

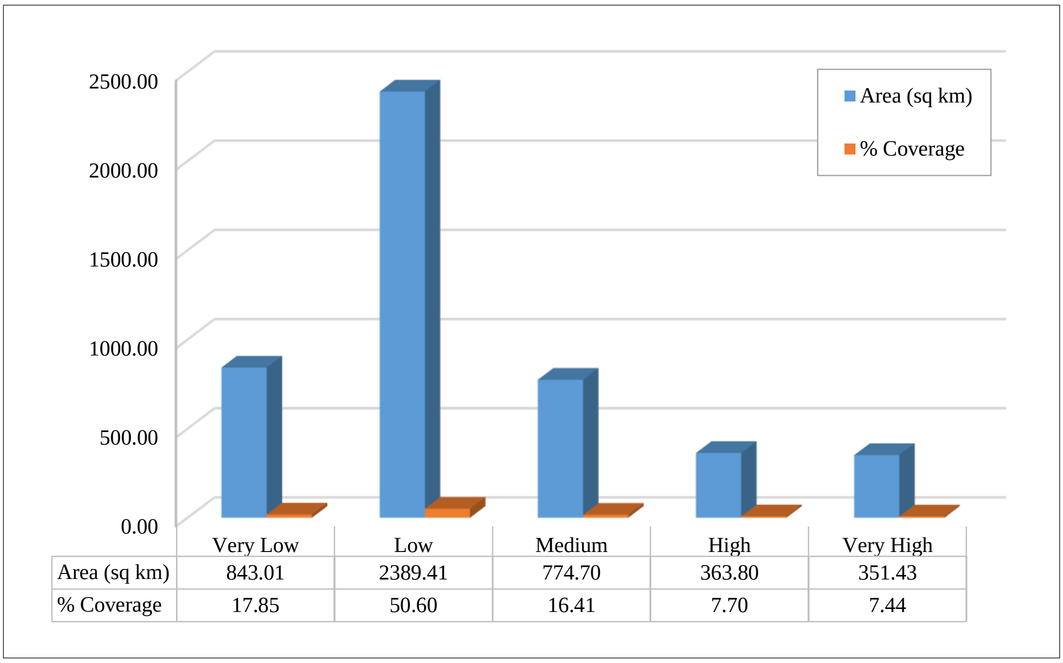


Figure 4. Chart of corresponding area of coverage of Rainfall-Runoff Factor (R)

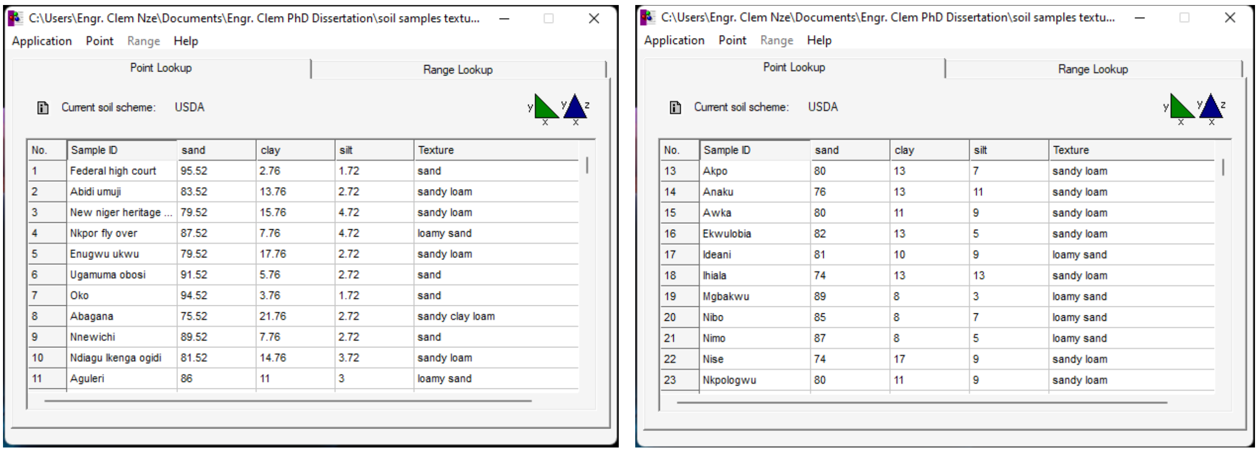
3.2. K Factor

The results of the laboratory analysis for the erodibility estimation parameters are given in Table 5.

Table 5. The results of the laboratory analysis for erodibility estimation

Sample Location	% Organic Matter	Ave. OM	% Sand	% Silt	% Clay
Federal High Court Ekwueme	0.413 0.414 0.413	0.413	95.52	1.72	2.76
Abidi Umuji	0.31 0.312 0.314	0.312	83.52	2.72	13.76
New Niger Heritage Omagba	0.172 0.174 0.172	0.173	79.52	4.72	15.76
Nkpor fly over	0.619 0.619 0.621	0.620	87.52	4.72	7.76
Enugwu Ukwu	0.712 0.176 0.174	0.354	79.52	2.72	17.76
Ugamuma Obosi	0.413 0.414 0.414	0.414	91.52	2.72	5.76
Oko	0.482 0.483 0.483	0.483	94.52	1.72	3.76
Abagana	0.653 0.655 0.653	0.654	75.52	2.72	21.76
Nnewichi	0.413 0.413 0.414	0.413	89.52	2.72	7.76
Ogidi	0.379 0.378 0.376	0.378	81.52	3.72	14.76

The results of the TAL software analysis are presented in Figure 5 (a, b, c and d).

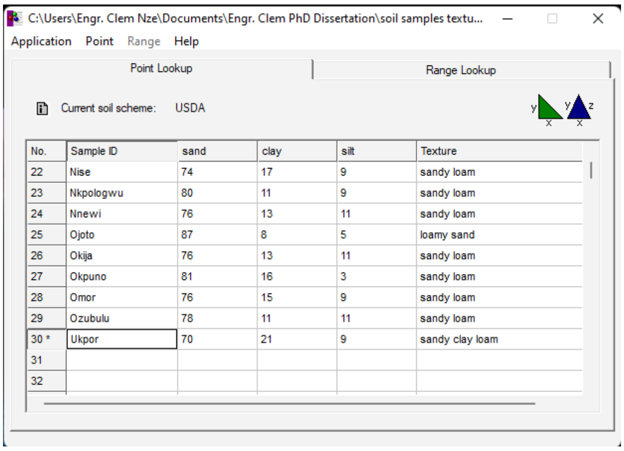


No.	Sample ID	sand	clay	silt	Texture
1	Federal high court	95.52	2.76	1.72	sand
2	Abidi umuji	83.52	13.76	2.72	sandy loam
3	New niger heritage ...	79.52	15.76	4.72	sandy loam
4	Nkpor fly over	87.52	7.76	4.72	loamy sand
5	Enugwu ukwu	79.52	17.76	2.72	sandy loam
6	Ugamuma obosi	91.52	5.76	2.72	sand
7	Oko	94.52	3.76	1.72	sand
8	Abagana	75.52	21.76	2.72	sandy clay loam
9	Nnewichi	89.52	7.76	2.72	sand
10	Ndiagu Ikenga ogidi	81.52	14.76	3.72	sandy loam
11	Aguleri	86	11	3	loamy sand

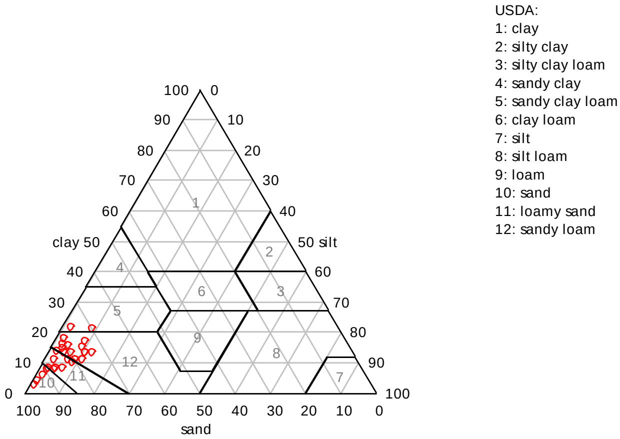
(a)

No.	Sample ID	sand	clay	silt	Texture
13	Akpo	80	13	7	sandy loam
14	Anaku	76	13	11	sandy loam
15	Awka	80	11	9	sandy loam
16	Ekwulobia	82	13	5	sandy loam
17	Ideani	81	10	9	loamy sand
18	Ihiala	74	13	13	sandy loam
19	Mgbakwu	89	8	3	loamy sand
20	Nibo	85	8	7	loamy sand
21	Nimo	87	8	5	loamy sand
22	Nise	74	17	9	sandy loam
23	Nkpologwu	80	11	9	sandy loam

(b)



(c)



(d)

Figure 5. (a) The soil texture class using TAL software from No 1-12. (b) The soil texture class using TAL software from No 12-23. (c) The soil texture class using TAL software from No 23-30. (d) Distribution of sand, silt, and clay contents in the soil samples (n =30).

Analysis of particle size distribution (Figure 5-d) revealed that most soils in the research region are sandy, with some containing varying degrees of loam and clay. This soil test result shows that the soils lack cohesiveness, making them extremely prone to erosion. Calculated K-factors for the researched area are shown in Table 6 using the standard K-factor calculation equation created by Wischmeier & Smith [54].

Table 6. Summary of estimated K-factor of Anambra States

S/N	Sample Location	K factor (ton.hr^{-1}.ha^{-1}.MJ.mm)	Texture
1	Federal High Court Ekwueme	0.106852	Sand
2	Abidi Umuji	0.080453	Sandy Loam
3	New Niger Heritage Omagba	0.077037	Sandy Loam
4	Nkpor Fly Over	0.091763	Loamy Sand
5	Enugwu Ukwu	0.071588	Sandy Loam
6	Ugamuma Obosi	0.099322	Sand
7	Oko	0.103671	Sand
8	Abagana	0.068407	Sandy Clay Loam
9	Nnewichi	0.094474	Sand
10	Ndiagu Ikenga Ogidi	0.077797	Sandy Loam
11	Aguleri	0.082917	Loamy sand
12	Agulu	0.079899	Loamy sand
13	Akpo	0.061619	Sandy Loam
14	Anaku	0.068308	Sandy Loam
15	Awka	0.080423	Sandy Loam
16	Ekwulobia	0.077211	Sandy Loam
17	Ideani	0.074978	Loamy sand
18	Ihiala	0.063629	Sandy Loam
19	Mgbakwu	0.086431	Loamy sand
20	Nibo	0.069293	Loamy sand
21	Nimo	0.071004	Loamy sand
22	Nise	0.063596	Sandy Loam
23	Nkpologwu	0.074071	Sandy Loam
24	Nnewi	0.06765	Sandy Loam
25	Ojoto	0.080893	Loamy sand
26	Okija	0.06262	Sandy Loam
27	Okpuno	0.075798	Sandy Loam
28	Omor	0.074058	Sandy Loam
29	Ozubulu	0.068243	Sandy Loam
30	Ukpor	0.062247	Sandy Clayey loam

From Figure 6, about 12% (547.27 km2), 34% (1595.53 km2), 29% (1390.72 km2), 23% (1081.05 km2), and 2% (107.56 km2) of the study area have very low, low, medium, high, and very high K factors. This is an indication that a greater part of the study area is less erodible by the K factor.

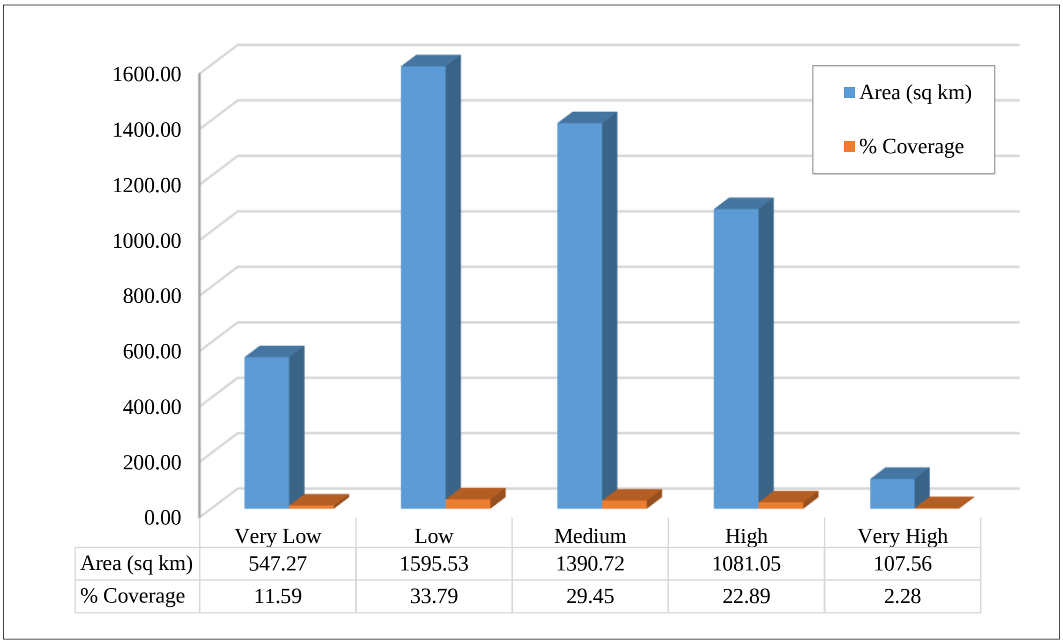


Figure 6. Chart of the corresponding rate of K-factor impact by Area

3.3. LS Factor

The result of topographic data analysis for the generation of LS using Raster calculator in ArcMap environment shows that the that part of most of the LGAs in the central part are strongly acted upon by soil erosion. Slope and soil characteristics are especially important factors. Steep slopes and weak, crumbly soils in some areas cause high water runoff after heavy rains, which worsens erosion. Based on this data, one may conclude that LS contributes to soil erosion in the research region by working with areas that have weak and friable soils. The matching area coverage of the LS factor in the study region is displayed in Figure 6.

From Figure 7, about 72% (2266.56 km^2), 20% (917.88 km^2), 7% (346.55 km^2), 1% (64.64 km^2), and 0.07% (3.52 km^2) of the study area have very low, low, medium, high, and very high LS factor. This is an indication that more than 50% of the study area is less erodible by LS factor.

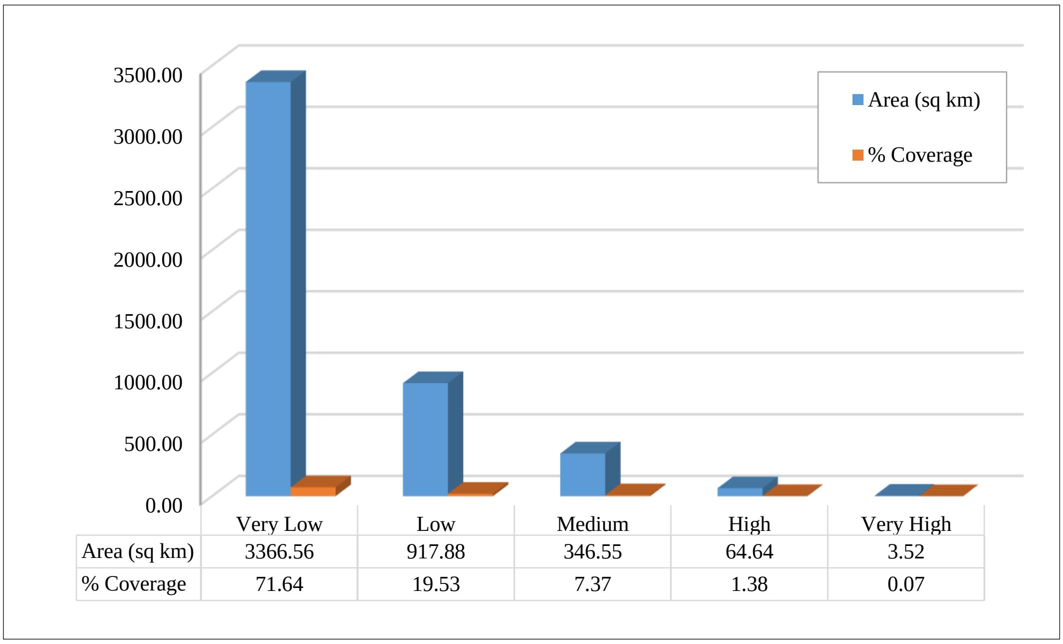


Figure 7. Chart of the corresponding rate of LS factor by area

3.4. C Factor

The result of the C factor shows that the tendency of the ground cover to be eroded varies from 0 to 0.5 with an average of 0.199. This is an indication that bare land has a high propensity to be eroded when compared to other cover types. Thus, susceptibility is higher in such areas.

From Figure 8, about 4% (207.68 km^2), 31% (1455.81 km^2), 28% (1306.01 km^2), and 37% (1754.77 km^2) of the study area have very low, low, medium, and high C factor values. This is an indication that less than 50% of the project area is highly erodible by this causative factor of erosion.

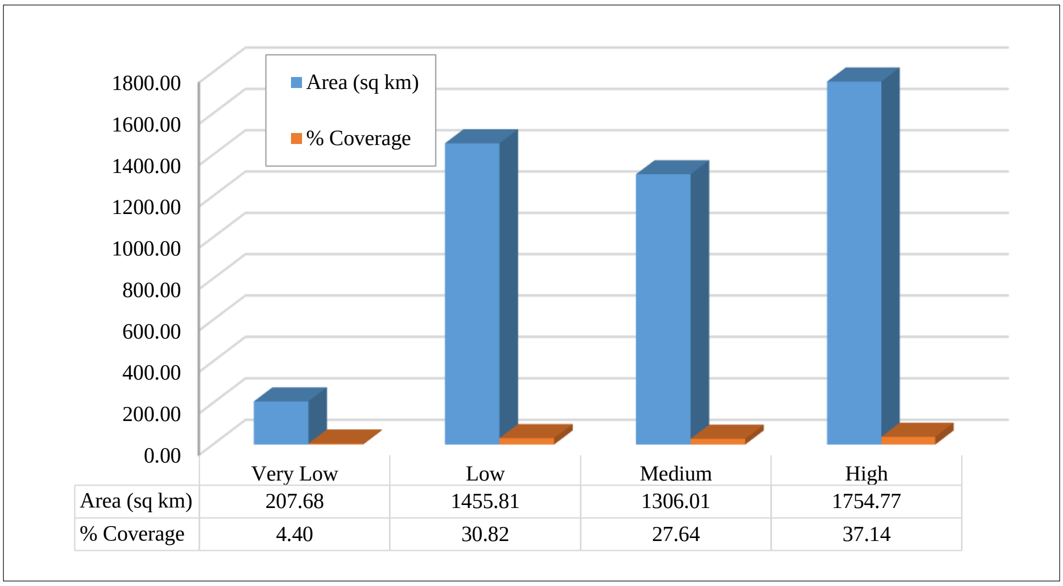


Figure 8. Chart of the corresponding area of coverage for C factor

3.5. P Factor

The result of the P Factor shows that greater percentage of the study area has a slope between 0 - 7%. The P factor of the project area is majorly within 0.55 and 0.6 having very low and low priority class respectively. The corresponding area of coverage given in Figure 9, shows that about 99% of the study area has very low P-factor. This is an indication that the study area is not erodible by this factor of erosion.

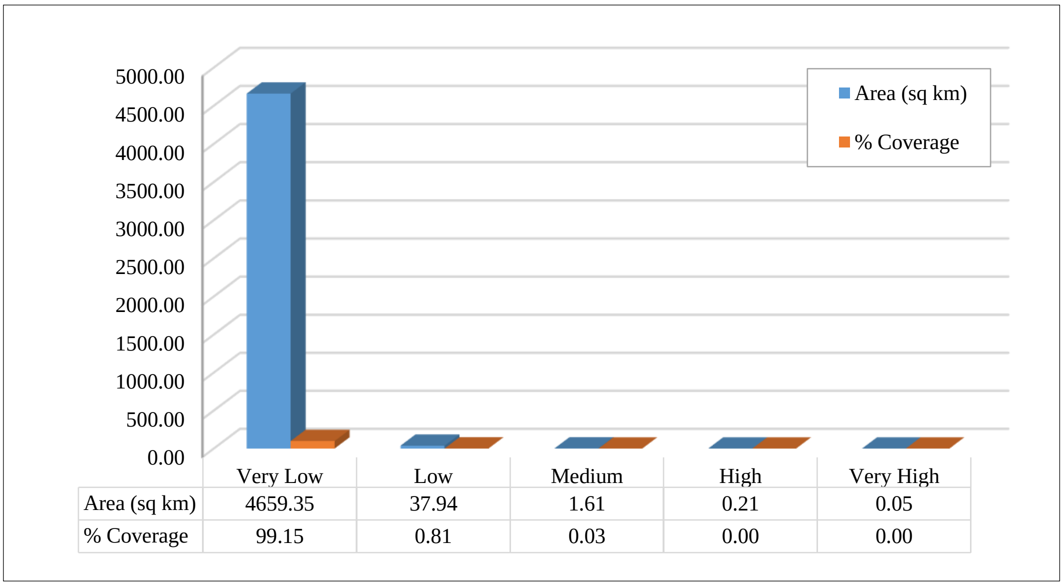


Figure 9. Chart of the corresponding rate of P factor

3.6. Soil Loss Quantification

From the result of the RUSLE model parameters (R, K, LS, C, and P), the predicted amount of soil loss can be presented in a map as shown in Figure 10.

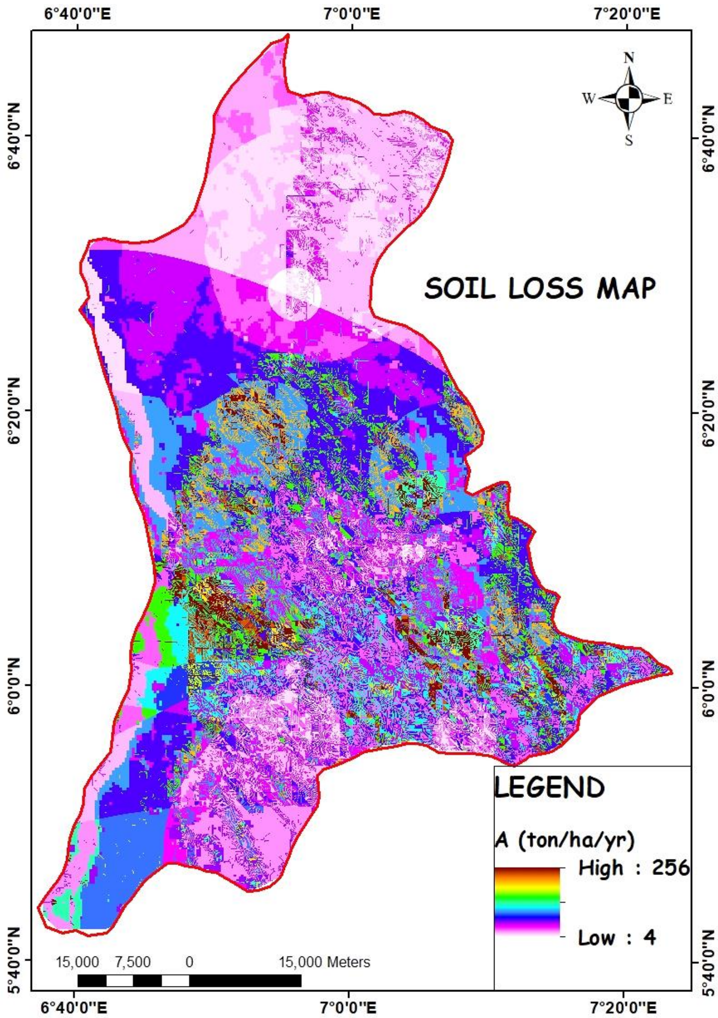


Figure 10. Visual representation of soil loss across the study area

The soil loss rate in the LGAs is predominantly medium, moderately high, and high class, corresponding to 10-15, 15-25, and 25-50 t/ha/yr. The soil loss rates are Anambra West, Anambra East, Awka North, Awka South, Oyi, Idemili South, Idemili North, Anaocha, Ogbaru, Aguata, Orumba North, Nnewi North, Onitsha North, and Orumba South LGAs. By incident, a greater number of the mentioned LGAs in the project area are of huge population density. Majorly endangered by soil erosion are the communities, which include Nanka, Agulu, Abagana, Nnewichi, Ire Obosi, Ugamuma-Obosi, Abidi-Umuoji, Ekwulobia, Nnewi, Awka, Okpuno, Ojoto, and Omagba, among others. These communities fall within these high soil loss zones, as shown in Figure 10.

Higher rates of erosion occurred in locations with higher slopes. The study reveals that the main variables causing soil erosion in the region are rainfall, soil type, and slope. A high rate of soil loss is caused by a combination of poor cover, moderate to high K and LS factors, and a high R factor.

Soil loss in the project area varies between 4 and 256 tons per hectare per hour, with an average of 24.8 tons per hectare per hour. This value differs with some of the values from literature. The variation accounts for climate change impact and conservative support practices in the study catchment area. This was exposed by the adopted methodology.

A comparison of the result from this study and the findings from previous works of other researchers is presented in Table 7.

Table 7. Comparison of the results from this study with results from previous researcher

Researcher	R	K	LS	C	P	Soil Loss
Fagbohun et al. (2016) [40]	3894.5–4510	0.08–0.19	0–193.5	0–0.5	1	0–220
Ajibade et al. (2020) [41]	2.73–3.71	0.052–0.82	0–362	0.27–1.22	1	0–181.237 tons/ha/yr
Ayadiuno et al. (2022) [39]	7995.56–9458.11	0.09072–0.17523	7–384	0.397705–0.109748	–	0.245–111.34.7
Egbueri, et al. (2022) [38]	460.51–582.08	0.100–0.310	–	0–1	0.5–1	0–600
Present Study	719.361–812.391	0.0616191–0.106851	0–156.939	0–0.5	0.55–1	4–256 tons/ha/yr

From Table 7, the developed RUSLE model in this study predicted soil loss relatively well. The variation in some of the values of causative factors is because of the situational watershed and the present climatic conditions of the study area.

4. Conclusion

An approximate quantification of soil loss in Anambra State, Nigeria, was realized. Implementation of RUSLE, GIS, and RS reveals that the watershed is under different categories of erosion level. The average soil loss rate of the project area ranges from 4 to 256 t/ha/hr, with a mean value of 24.8 ton/ha/hr. This value tallies with some of the values from literature with a slight variation, which accounts for climate change and conservative support practices in the study area. The categorization reveals that only about 27.58 km^2 (1%) has an erosion rate of 0–5 t ha^{-1} $year^{-1}$ that can considerably be classified as low, while about 1311.52 km^2 (28%) experience low soil loss between 5–10 t ha^{-1} $year^{-1}$. The areas of medium, moderately high, high, and very high classes are 538.59, 1649.08, 959.09, and 196.76 km^2, corresponding to 12, 35, 21, and 4%, respectively. The central part of the study area is seen to have a high soil loss rate compared to other parts of the study area. From the reclassified map, the LGAs that are predominantly medium, moderately high, and high class, corresponding to 10-15, 15-25, and 25-50 t/ha/yr soil loss rates, are Anambra West, Anambra East, Awka North, Awka South, Oyi, Idemili South, Idemili North, Anaocha, Ogbaru, Aguata, Orumba North, Nnewi North, Onitsha North, and Orumba South LGAs. Incidentally, the majority of these LGAs are the most densely populated areas of the study area. The communities majorly threatened by soil erosion include Agulu, Nanka, Abagana, Nnewichi, Ire Obosi, Ugamuma-Obosi, Abidi-Umuoji, Ekwulobia, Nnewi, Awka, Okpuno, Ojoto, and Omagba, among others. This community falls within these high soil loss zones.

It is no doubt that Anambra, like most Southern States in Nigeria, is a high rainfall region, but it is worthy to note also that the study area has poor soil type and is highly erodible even by as little as a raindrop. But if the soil is sufficiently shielded by vegetal cover, the rate of soil loss will be minimal. Therefore, land conservation through tree planting, proper channeling of rainwater, and rain harvesting (to prevent direct impact of rainwater on the bare ground) are highly recommended in the study area. It is further recommended that machine learning algorithms be employed to aid the application of RUSLE model validation and its reliability in estimating soil loss in Anambra State.

5. Declarations

5.1. Author Contributions

Conceptualization, C.O.N. and J.C.A.; methodology, C.O.N. and J.C.A.; Analysis C.O.N. and J.C.A.; investigation, C.O.N.; data curation, C.O.N.; writing—original draft preparation, C.O.N.; writing—review and editing, C.O.N. and J.C.A.; supervision, J.C.A.; project administration, C.O.N.; funding acquisition, C.O.N. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in Appendix I.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

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Appendix I: Estimation of Soil Loss using Remote Sensing Data in a Regional Tropical Humid Catchment Area

Table A-I. Laboratory soil test analysis

S/N	Sample Location	Percentage sand	Percentage silt	Percentage clay	M	OM	S	P	K	Texture	K	K*0.1317
1	Federal High Court	95.52	1.72	2.76	9455.62	0.41	3	1	0.1069	Sand	0.81133	0.1068519
2	Abidi Umuji	83.52	2.72	13.76	7437.34	0.31	2	2	0.0805	Sandy Loam	0.61088	0.0804529
3	Omagba	79.52	4.72	15.76	7096.38	0.17	2	2	0.0770	Sandy Loam	0.58494	0.0770368
4	Nkpor	87.52	4.72	7.76	8508.22	0.62	2	2	0.0918	Loamy Sand	0.69676	0.0917627
5	Enugwu Ukwu	79.52	2.72	17.76	6763.42	0.35	2	2	0.0716	Sandy Loam	0.54357	0.0715884
6	Obosi	91.52	2.72	5.76	8881.18	0.41	3	1	0.0993	Sand	0.75415	0.0993219
7	Okoh	94.52	1.72	3.76	9262.14	0.48	3	1	0.1037	Sand	0.78718	0.1036713
8	Abagana	75.52	2.72	21.76	6121.50	0.65	2	4	0.0684	Sandy Clay Loam	0.51942	0.0684071
9	Nnewichi	89.52	2.72	7.76	8508.22	0.41	3	1	0.0945	Sand	0.71734	0.0944739
10	Ogidi	81.52	3.72	14.76	7265.86	0.38	2	2	0.0778	Sandy Loam	0.59071	0.0777972
11	Aguleri	86	3	11	7921.00	0.802	2	2	0.0829	Loamy sand	0.62959	0.0829169
12	Agulu	82	7	11	7921.00	1.194	2	2	0.0799	Loamy sand	0.60667	0.0798991
13	Akpo	80	7	13	7569.00	3.12	2	2	0.0616	Sandy Loam	0.46787	0.0616190
14	Anaku	76	11	13	7569.00	2.205	2	2	0.0683	Loamy sand	0.51866	0.0683076
15	Awka	80	9	11	7921.00	1.126	2	2	0.0804	Sandy Loam	0.61065	0.0804226
16	Ekwulobia	82	5	13	7569.00	0.987	2	2	0.0772	Sandy Loam	0.58626	0.0772110
17	Ideani	81	9	10	8100.00	2.089	2	2	0.0750	Loamy sand	0.56931	0.0749775
18	Ihiala	74	13	13	7569.00	2.845	2	2	0.0636	Sandy Loam	0.48314	0.0636293
19	Mgbakwu	89	3	8	8464.00	1.194	2	2	0.0864	Loamy sand	0.65627	0.0864310
20	Nibo	85	7	8	8464.00	3.258	2	2	0.0693	Loamy sand	0.52615	0.0692934
21	Nimo	87	5	8	8464.00	3.052	2	2	0.0710	Loamy sand	0.53913	0.0710038
22	Nise	74	9	17	6889.00	1.813	2	2	0.0636	Sandy Loam	0.48288	0.0635957
23	Nkpologwu	80	9	11	7921.00	1.951	2	2	0.0741	Sandy Loam	0.56242	0.0740712
24	Nnewi	76	11	13	7569.00	2.295	2	2	0.0676	Sandy Loam	0.51366	0.0676497
25	Ojoto	87	5	8	8464.00	1.861	2	2	0.0809	Loamy sand	0.61422	0.0808928
26	Okija	76	11	13	7569.00	2.983	2	2	0.0626	Sandy Loam	0.47548	0.0626205
27	Okpuno	81	3	16	7056.00	0.279	2	2	0.0758	Sandy Loam	0.57554	0.0757984
28	Omor	76	9	15	7225.00	1.792	2	4	0.0741	Sandy Clayey loam	0.56232	0.0740579
29	Ozubulu	78	11	11	7921.00	2.708	2	2	0.0682	Sandy Loam	0.51817	0.0682433
30	Ukpor	70	9	21	6241.00	1.951	2	4	0.0623	Sandy Clayey loam	0.47264	0.0622471

Table A-II. Gully sites and their geographic coordinate

S/N_	GULLY_SITE	L.G.A	X	Y
1	Agulu	Anaocha	285830.1	673542.6
2	Nanka	Orumba North	287193.3	671256.2
3	Ekwulobia	Aguata	290094.2	666458.6
4	Ukpor	Nnewi South	271460	659379.1
5	Oko	Orumba North	292159.2	670575.1
6	Alor	Idemili North	275215.4	673387.6
7	Uke	Idemili North	270675.2	676282.4
8	Umueje	Oyi	274998	739067.2
9	Omasi	Oyi	287865.9	733841.5
10	Ifite Ogwari	Oyi	274275.5	731331.8
11	Igbaukwu	Oyi	272861.5	725569.6
12	Omor	Oyi	280774.9	720275.2
13	Anaku	Oyi	271345.1	715998.3
14	Olumbanasa	Anambra West	248142.1	720917
15	Igbariam	Oyi	274077.8	707340.9
16	Aguleri	Anambra West	267724.5	699254.6
17	Umuleri	Anambra West	268898	697104.9
18	Umuewelum	Anambra West	252081.7	704511.5
19	Amanuke	Awka North	284534.9	696849.2
20	Urum	Awka North	282728.6	694297.8
21	Njorgu	Njikoka	275951.6	692302.8
22	Awkuzu	Oyi	272306.8	691424.4
23	Nteje	Oyi	270453.3	693132.8
24	Umunya	Oyi	269584	687461.2
25	Abba	Njikoka	276551.9	688682.3
26	Amawbia	Awka South	286702.2	685342.1
27	Ifite Dunu	Njikoka	275498.8	686094.7
28	Nise	Awka South	287206	681491
29	Mbaukwu	Awka South	290023.7	679146.5
30	Ideani	Idemili North	275258.6	676714.4
31	Nkpor	Idemili North	263454.3	679621.1
32	Ichi	Nnewi North	267561.2	668321.6
33	Ihembosi	Ihiala	268523.2	654306.7
34	Ezira	Orumba South	305532.1	66149.23
35	Uga	Aguata	288756.5	657036.8
36	Umuchu	Aguata	294160.5	654993.6
37	Nkpologwu	Aguata	290849.9	661512.4
38	Amesi	Orumba South	291434.2	657377.4
39	Agbudu	Orumba South	299272.5	661707
40	Ogbunka	Orumba South	311297.4	664391.9
41	Umuonwu Nteje	Oyi	270685.2	695102.7
42	Enugu Agidi	Njikoka	281397.2	690267.6
43	Nibo	Awka South	290096.4	683657.2
44	Nimo	Njikoka	279278.3	680906.3
45	Ogbunike	Oyi	265573	683466.5
46	Nri	Anaocha	282569.2	679542.8
47	Ogbu	Orumba North	289614.2	675511.9
48	Ndiokpalanze	Orumba North	299861.4	668702.7
49	Ufuma	Orumba North	302441.7	671835.5
50	Nawfija	Orumba South	304338.1	666961.3

51	Ndiowu	Orumba North	295432.1	671088.8
52	Ogbaji	Orumba South	297759.4	665733.6
53	Oro Eri	Aguata	284613	668921.1
54	Isuofia	Aguata	285975.8	667463
55	Ndiukwuenu	Orumba North	301555.9	680687.4
56	Awa	Orumba North	300901.1	676222.9
57	Owere Ezukola	Orumba South	314053.9	665842.1
58	Eziagu	Orumba South	305224	663189.6
59	Aguluezechukwu	Aguata	293576.3	665258.3
60	Ikenga	Aguata	284423.5	664771.8
61	Ebenator	Nnewi South	282979.9	658146.5
62	Akpo	Aguata	293284.2	659128.7
63	Achina	Aguata	296205.3	658009.8
64	Enugu Umuonyiba	Aguata	296531.3	656706.4
65	Akwuata Utu	Nnewi South	279262.9	659615.1
66	Osumenyi	Nnewi South	277169.4	658390.3
67	Ezinifite	Nnewi South	284569.6	663215.1
68	Utuh	Nnewi South	277120.7	661366.5
69	Amichi	Nnewi South	274291.4	663473.9
70	Okija	Ihiala	266692.5	652250.1
71	Mbosi	Ihiala	270318.6	647567.2
72	Lliu	Ihiala	274423.5	646507.5
73	Oguaniocha	Ogbaru	249941.4	641157.4
74	Oguikpele	Ogbaru	245747.2	645391.7
75	Ossomoka	Ogbaru	247001.1	647552
76	Ozubulu	Nnewi North	265135.4	660532.9
77	Ojoto	Idemili South	264793.9	670093.1
78	Ojoto Obinofia	Idemili South	269467	673884.6
79	Umuoji	Idemili North	267259.3	676757.6
80	Abatete	Idemili North	272318.3	679090.8
81	Abagana	Njikoka	277199.6	684284.8
82	Adazi Nnukwu	Anaocha	282218.9	676739.5
83	Ihite	Orumba South	307646.3	655917.9
84	Uli	Ihiala	265399.7	638574.3
85	Igbo Ukwu	Aguata	281010	666246.8
86	Ukwulu	Njikoka	275555.6	694523.3
87	Awka	Awka South	288384.9	685747.5
88	Ebenebe	Awka North	292880.1	700466.1
89	Okpuno	Awka South	286376.6	692929
90	Ishiogu	Awka South	294648.7	683079.5
91	Umuawulu	Awka South	292770.4	681177.7
92	Isulo	Orumba South	304107	664267.2
93	Umuomoku	Orumba South	298055.4	659323.3
94	Ekwulumili	Nnewi South	284423.5	661171.9
95	Ifite	Aguata	279403.3	664933.3
96	Orsumoghu	Ihiala	275962.9	648114.1
97	Ihiala	Ihiala	265837.3	645071.9
98	Nnewi	Nnewi North	271150.1	666031.7
99	Oraukwu	Idemili North	274783	675634.3
100	Obosi	Idemili South	260038.3	675646.1
101	Odekpe	Ogbaru	252547.4	669940.6