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Original paper

Geospatial assessment of soil erosion of Ado Odo Ota local government area using revised universal soil loss equation (r.u.s.l.e)

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Abstract: The study examined soil erosion in Ado Odo Ota local government area using the revised universal soil loss equation (RUSLE). This study assessed area vulnerable to erosion by combining five factors: rainfall erosivity, soil erodibility, slope, land use/land cover, control practice. The resultant soil loss map shows that the highest soil loss was 324,522.34t/hr/yr. Furthermore the study reveals that combining the RUSLE model with GIS technology provides the advantage of visualization and statistics which was used to create a map of Ota soil loss. The study shows the area most prone to soil erosion based on the model used. All the factors of RUSLE was taken into account. The result generated from the maps showed that areas such as Ilasa, Iju and Atan are characterized with steeper slope from North Eastern part towards the North West. It is recommended that control measures such as drainage and proper disposal of waste be put in place to avoid loss of live and destruction of property to erosion. The soil loss map can be used by decision makers know the areas susceptible to erosion and also be used as future preventive measures against erosion. The findings of this research emphasizes the need for effective land management and conservation and can be used by decision makers to mitigate the negative effect of soil erosion.

Keywords: soil erosion, soil loss, revised universal soil loss equation (RUSLE)

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1. Introduction

In the nineteenth and twentieth centuries, soil erosion was recognized as one of the most significant environmental issues, particularly for emerging nations (Huang et al.,2019). One of the biggest scientific issues facing the globe today is soil erosion. The separation, movement, and deposition of soil through a variety of processes is known as soil erosion (Boakye et al., 2020). It happens as a result of several things, including wind, water, and disturbances brought on by human activity (Markose and Jayappa, 2016). Erosion occurs naturally when soil particles are moved away by water or wind and deposited in new sites. Erosion rates can be exacerbated further by human activities such as farming and forest conversion. This phenomena has significant impacts on agriculture, ecosystems, and the health of the environment as a whole (Thomas et al., 2017). Land degradation, declining water quality, river sedimentation, and road ruin are just a few of its detrimental effects (Ping et al., 2020). Soil erosion has a major impact on soil fertility in particular and environmental quality in general (Moisa et al., 2022). Wind, water, and gullies erode almost one billion hectares (ha) of land worldwide (Panagos et al., 2020). Nearly 30 t/ha of soil is lost annually across agricultural fields (Panditharathne et al., 2019).Sustainable management of land and water resources depends on an understanding of the mechanisms and trends of soil erosion, especially in large landscapes where the complex interactions between soil, water, and topography are evident. Effective conservation strategies and a comprehensive understanding of erosion are necessary to prevent soil erosion (Chen et al., 2020). Decision-makers and other stakeholders can use soil erosion models as useful tools to address soil erosion problems and put protective measures in place (Bezak et al., 2024).More than half of the soil's surface gets washed away on slopes where water rushes into valleys and streams. Soil type, slope, and plant cover all have a role in determining erosion rate. Based on rainfall patterns, soil types, geography, crop systems, and management techniques, the USLE forecasts the long-term average and yearly rate of erosion on a field slope (Kouli et al., 2009).

The application of geographic information system (GIS) and remote-sensing is widely used in soil loss assessment (Gelagay and Minale, 2016; Anees et al., 2018; Gyeltshen et al., 2021; Moisa et al., 2021; Negash et al., 2021; Bing and Lei, 2022; Dejene, et al., 2022; Getu et al., 2022). Remote sensing and GIS have the capacity to extract many elements from diverse dataset and assign suitable values for additional analysis and interpretation. The evaluation of soil erosion risk is made simpler, more manageable, and more economical by utilizing the RUSLE model in conjunction with GIS and remote sensing methods.

RUSLE multiplies a number of variables to determine the average annual erosion expected on hillslopes. These variables include rainfall runoff or rainfall erosivity factor (R), soil erodibility (K), slope length and steepness (LS), Cover management (C), and conservation practice (P) as supposed by (Renard et al., 1997). Because it is difficult to obtain the necessary data over vast geographic areas, it is the most popular model for assessing soil erosion over limited geographic areas. (Kumar et al., 2022).

Most people prefer the RUSLE to WEPP since it is easier to use. It was also proven to be an efficient method to estimate erosion amplitude and geographical distribution by combining RUSLE soil erosion models with remote sensing and GIS techniques. With the use of GIS, it is possible to combine numerous datasets and analyze dynamic processes like soil erosion. This study utilized GIS applications and erosion assessment. While the RUSLE model is typically used to study erosion, GIS and remote sensing approaches will also be employed.

Effective modeling tools may provide information on present erosion and trends, as well as possible future situations. Tools for statistical analysis, correlations and trends are added to GIS as an extension of the software. Calculating annual soil loss is made simple by combining the RUSLE model with GIS methods. Although the issue of land degradation is visible to all, correct facts and information need to be examined through scientific research. Therefore, determining the degree of land degradation can assist decision makers in creating conservation plans that can lessen the risks related to soil erosion in particular and land degradation in general.

As a key contributor to ecosystem decline, soil erosion has become an important social and economic concern. In order to address land and water management challenges, it is essential to evaluate erosion, including topsoil loss, sediment transport and storage in lowlands, reservoirs, estuaries, irrigation and hydropower systems. The main aim of this study was to assess erosion in Ota and its effect on Land use. In addition, this study is as follows: (1) creation of land use map for the area over years to detect temporal change in land use and land use cover, determination of rainfall pattern in Ota (2) soil mapping of Ota, (3) determination of slope map of Ota using remote sensing methods, (4) use of the revised universal soil loss equation to estimate erosion risk and (5) create a soil erosion map of Ota.

2. Study area and datasets

2.1. Study area

Abeokuta, Nigeria's southernmost city, is Ogun State's capital. Ogun State 2006 population was estimated at 3,751,140 people by Ogun smart city (2020). The state is situated at 7°00′N, 3°35′E and covers a total area of 16,980.55 square kilometers (6,556.23 square miles). There is a total of 20 local government areas in Ogun State (Fig. 1).

The Ado-Odo/Ota Local Government Area of Ogun State, Nigeria, is one of the state's 19 local government units. It was established on May 19, 1989, following the amalgamation of the Ado-Odo/Igbesa Areas of the Yewa South Local Government with Ota, a portion of the now-defunct Ifo/Ota Local Council. On the outskirts of Lagos' metropolitan area, Ado-Odo/Ota is located. Ota (or Otta) is the second-largest Local Government Area in Ogun State, located at 6°41′00″N, 3°41′00″E. Araromi-Alade, Ado-Odo, Agbara, Igbesa, Iju-Ota, Itele, Kooko Ebiye Town, Owode, and Sango Ota are a few more places in the state. As a result of its extensive industrial area and high number of businesses, Ado-Odo/Ota is Ogun state's most industrialized Local Government, with the greatest IGR (Fig. 2).

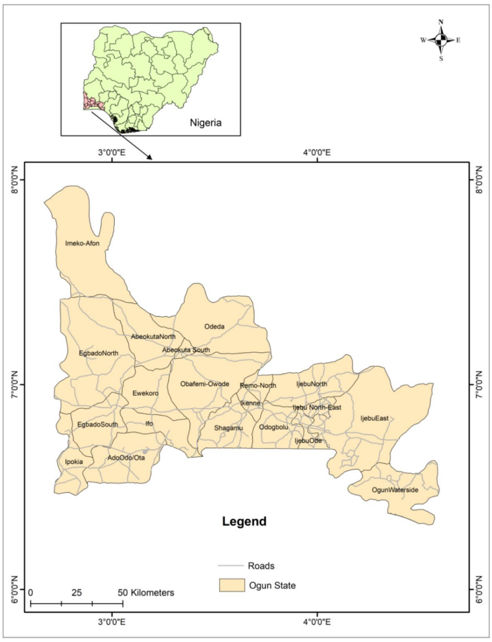

Fig. 1. Map of Ogun State

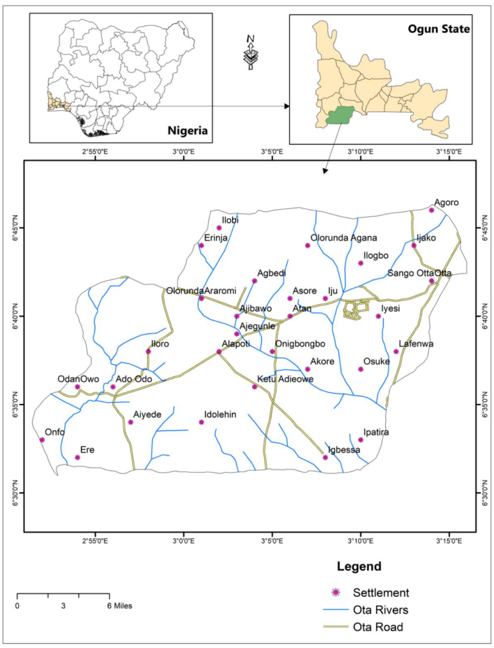

Fig. 2. Map of Ado Odo Ota Local Government Area

2.2. Data acquisition and data source

For image classification, Landsat 8 OLI/TIRS data was gotten from the United States Geological Survey (USGS) for the year 2020, as well as Shuttle Radar Topography Mission data which used to construct the slope map. The rainfall data was obtained from the Ota meteorological station. Soil data was collected obtained from NBBRI (Nigerian Building and Road Research Institute and FDALR (Federal Department of Agricultural Land Resources).

ArcGIS software version 10.7: ESRI developed a software package ArcGIS 10.7 which is a is a Geographic Information system (GIS) that provides its user with an environment to relate with Spatial and Attribute data for the production of efficient information in form of charts, maps. Microsoft suite was used for editing and producing reports. Hardware used was a high processing computer system with adequate memory and a printer for presenting the end result in hardcopy format.

3. Methodology

Figure 3 shows the step-by-step procedure for estimating the yearly soil loss in the study area. Due to its compatibility with the usage of geographic information systems, the RUSLE model (Renard et al., 1997) and geospatial technologies were widely employed

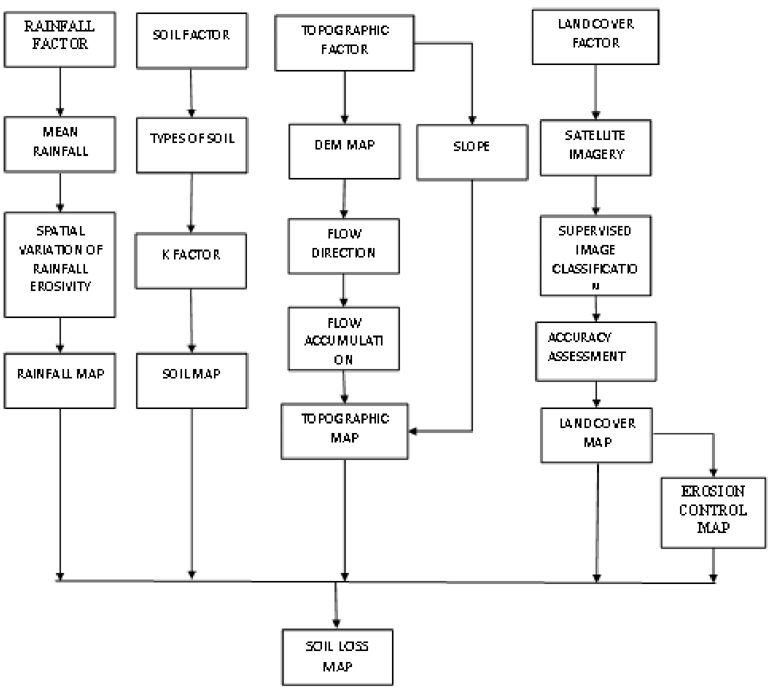

Fig. 3. Methodology workflow of the study

to quantify the annual soil loss (Prasannakumar et al., 2012). In order to compute the average yearly loss in soil erosion, the RUSLE model takes into account five elements known as the RUSLE factors:

- the rainfall erosivity factor (R);
- the soil erodibility factor (K);
- the topographic/slope factor (LS);
- the landuse landcover factor (C);
- the conservation practice factor (P).

RUSLE implementation involves estimating each of the model's parameters based on published literature. The primary equation of RUSLE method for predicting annual soil loss is as:

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

where A is the soil loss in t/ha/year, R is the rainfall-runoff erosivity factor in (MJ·mm)/ha/year, LS is the slope length and slope steepness factor. C is cover management factor, (P) is the conservation practice factor and K stands for the soil erodibility factor ((t/ha)/MJ·mm).

3.1. Rainfall erosivity factor (R factor)

The erosivity factor (R) of rainfall, which determines the amount of rainfall intensity that contributes to soil erosion, requires reliable and continuous rainfall data (Lee et al., 2021). One crucial metric for evaluating the possibility of soil erosion is rainfall erosivity. Rainfall intensity is typically used to calculate the R when it is available. Therefore, based on the degree of soil erosion, the R-factor is necessary to evaluate the danger of soil erosion in light of future land use and climate change which characterizes the intensity of precipitation in a certain place (Biswas et al., 2015; Thapa, 2020).The USLE model relies heavily on this word as an input variable. The annual mean rainfall of the study area gotten from Ota meteorological station was imported into ArcGIS software and a rainfall map was produced to depict zones with high and low precipitation.

3.2. Soil erodibility factor (K)

The soil erodibility factor measures how susceptible soil is to erosion and is influenced by various soil characteristics, including texture, structure, and organic matter content (Markose and Jayappa, 2016). Climate, geomorphology, soil type, and land use all influence how much and what sort of soil is lost in a certain region (Taleshian et al., 2018). The K-factor indicates the response of soil characteristics to soil loss (Moisa et al., 2022). For this study, the nomograph method, which is mathematically represented as follows and is based on the work by Wischmeier et al. (1978):

$$100K_{\text{fact}} = 2.1 \times 10^{-4} \cdot M^{1.14} \cdot (12 - a) + 3.25(b - 2) + 2.5(c - 3), \tag{2}$$

in which:

$$M = P_{\text{silt}} \cdot (100 - P_{\text{clay}})$$

where M is the particle size parameter (unitless), a is the percent organic matter (unitless), b is the soil structure index (unitless), c is the profile-permeability class factor (unitless), P_{silt} is the percent silt (unitless), P_{clay} is the percent clay (unitless). a is the percent of organic matter that each soil texture contains which was seen in the attribute table in ArcGIS, b and c are the soil structure index and the profile- permeability class factor, this was gotten from Table 1.

Table 1. Permeability code for soil type

Texture	Symbol	Structure code (b)	Permeability code (c)
Silty clay, clay	SiC, HC	1	1
Silty clay loam, sandy clay	SiCL, SC	2	2
Sandy clay loam, clay loam	SCL, CL	2	3
Loam, silty loam	L, SiL	2	4
Loamy sand, sandy loam	LS, SL	2	5
Sand	S	3	6

3.3. Topographic/Slope Factor (LS factor)

The LS-factor, which is the ratio of expected soil loss from a field slope to the initial USLE plot, is influenced by slope length and steepness (Wischmeier and Smith, 1978). The RUSLE strategy for one-dimensional hillslopes extends the USLE approach, which employs multiple formulae depending on whether the slope has a gradient higher than 9 percent. The LS-factor is determined using the USLE and RUSLE approaches, which take into consideration the length and angle of the slope as well as a parameter depending on the slope's percent steepness (Wischmeier and Smith, 1978).

Slope

The amount of surface runoff is determined by the slope of a given place. A low slope depicts level terrain, while a high slope depicts a steeper slope with a hill or mountain in the background. Locations with a lower slope, such as Odan, have a low risk of erosion, whereas areas with a high slope, such as Ilasa, have a high risk of erosion. The slope map was classified into 5 classes as shown in Table 2.

Table 2. Class value for slope map

Class	Value (%)
1	0–1.68
2	1.68–3.04
3	3.04–4.64
4	4.64–6.88
5	6.88–20.40

3.4. Landuse/land cover (C factor)

Land cover management (*C*-Factor): (Molla and Sisheber., 2017) state that the *C*-factor, which has values between 0.01 and 1, measures the combined effects of trees, crop sequences, and other land cover areas on land degradation. As much as possible, current land use and land cover data that represent the current state of the research region must be used to calculate the *C*-factor (Fagbohun et al., 2016). Land cover is basically the surface over the earth in a specified location, this contains the type of vegetation and man-made structures e.t.c. Land cover also represents the socioeconomic condition in a specified location. The area was classified into five features namely: Water Bodies, Thick Forest, Built up, Farmland, Baresoil.

3.5. Conservation practice factor (P factor)

The soil loss ratio with a standard support action to the corresponding loss with down and up slope cultivation was utilized as a practical factor for erosion control (Ghosh et al., 2023). Each land use type's erosion management measures determine this metric, which is also known as the P-factor. There's a difference in soil erosion rates depending on what sort of land is being used. Basically, the conservation practice is a factor that indicates the impacts of measures that will limit water runoff and hence reduce erosion.

4. Results and discussion

4.1. Rainfall map

The rainfall data was gotten from the metrological station in Ota. The map was prepared by making use of the ArcGis 10.7 software. The rainfall map was classified into 5 classes as shown in Table 3 in an ascending order:

Table 3. Class value for rainfall map

Class	Value (mm)
1	1542.54–1667.87
2	1667.87–1772.32
3	1772.32–1876.77
4	1876.77–1988.17
5	1988.17–2134.40

On the rainfall map we can see areas such as Sango Otta and Ijako are areas of very high precipitation, there is also a high precipitation in areas like Iju, Ilogbo, Iyesi but not as high as that of Sango otta and Ijako, areas like Erinja and Igbessa experience a moderate precipitation, we also have areas like Odan, Igbekun which have a low precipitation, we than have areas whose precipitation is very low such area is Idolehin (Fig. 4).

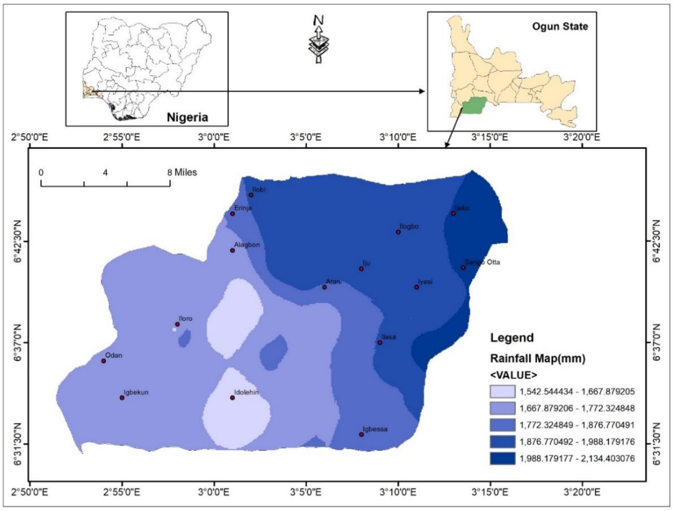

Fig. 4. Rainfall map

4.2. Soil erodibility

Soil texture and type have an impact on soil erosion vulnerability and are crucial factors in determining an area's water retention and infiltration characteristics. There are some soil types that produce a lot of runoff. The soil texture in the map is of two type which is the sandy loam and clay loam. Areas such as Idolehin, Iju, Igbekun, Sango otta, Ilasa are all sandy loam but they vary based on the percentage of the organic matter each area contains, then we have areas like Ilobi, Ijako, Alagbon which are the clay loam areas (Fig. 5).

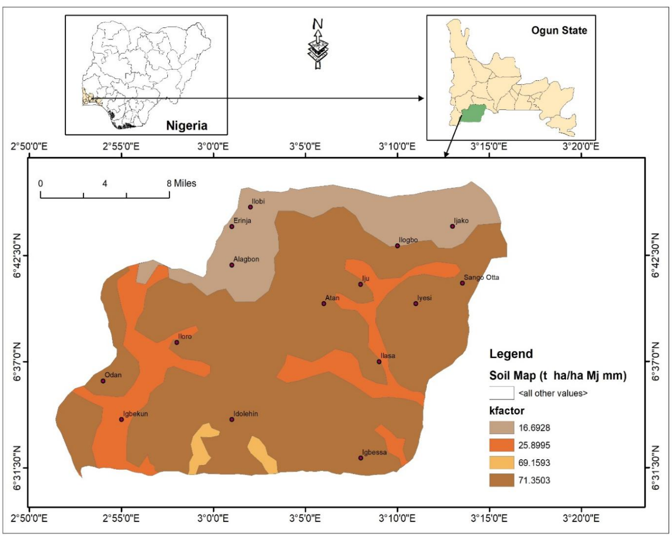

Fig. 5. Soil map

4.3. Landuse/Land cover

Land cover is basically the surface over the earth in a specified location, this contains the type of vegetation and man-made structures e.t.c. Land cover also represents the socioeconomic condition in a specified location. The area was classified into five features namely: Water Bodies, Thick Forest, Built up, Farmland, Baresoil. Figure 6 shows the map of the land cover.

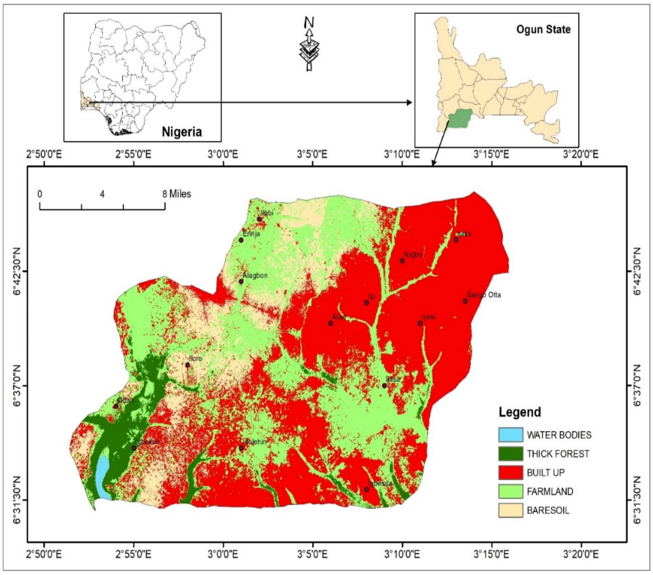

Fig. 6. Landuse/Land cover

Table 4. Accuracy assessment

	Water body	Thick forest	Built up area	Farmland	Baresoil	Total (user)
Water body	6	4	0	0	0	10
Thick forest	0	6	2	2	0	10
Built up area	0	1	8	1	0	10
Farmland	1	1	1	7	0	10
Baresoil	0	2	0	3	5	10
Total (producer)	7	14	11	13	5	50

Accuracy Assessment Using Error Matrix Method

$$\textit{Overall Accuracy} = \textit{Total number of correctly classified pixels (diagonal)} \cdot 100$$

$$\textit{Total number of reference pixels},$$

$$\frac{32}{50} \cdot 100 = 64\%.$$

User accuracy calculation

$$\textit{Users Accuracy} = \textit{Number of correctly classified pixels in each category} \cdot 100$$

$$\textit{Total number of classified pixels in that category (the row total)},$$

$$\textit{Water Body} = \frac{6}{10} \cdot 100 = 60\%,$$

$$\textit{Thick Forest} = \frac{6}{10} \cdot 100 = 60\%,$$

$$\textit{Built Up Area} = \frac{8}{10} \cdot 100 = 80\%,$$

$$\textit{Farmland} = \frac{7}{10} \cdot 100 = 70\%,$$

$$\textit{Baresoil} = \frac{5}{10} \cdot 100 = 50\%.$$

$$\textit{Producer Accuracy} = \textit{Number of correctly classified pixels in each category} \cdot 100$$

$$\textit{Total number of Reference pixels in that category (the column total)},$$

$$\textit{Water Body} = \frac{6}{7} \cdot 100 = 85.7\%,$$

$$\textit{Thick Forest} = \frac{6}{14} \cdot 100 = 42.8\%,$$

$$\textit{Built Up Area} = \frac{8}{11} \cdot 100 = 72.7\%,$$

$$\textit{Farmland} = \frac{7}{13} \cdot 100 = 53.8\%,$$

$$\textit{Baresoil} = \frac{5}{5} \cdot 100 = 100\%.$$

$$\textit{Kappa Coefficient}(T) = (TS \times TCS) - \sum \textit{Column Total} \times \textit{Row Total} \cdot 100$$

$$TS^2 - \sum \textit{Column Total} - \textit{Row Total},$$

$$1600 - 500 \cdot 100,$$

$$2500 - 500,$$

$$= 55\%,$$

$$TS = 50, \quad TCS = 32$$

where TS = *Total sample*, TCS = *Total collected sample*.

4.4. Slope

The amount of surface runoff is determined by the slope of a given place. A low slope depicts level terrain, while a high slope depicts a steeper slope with a hill or mountain in the background. Locations with a lower slope, such as Odan, have a low risk of erosion, whereas areas with a high slope, such as Ilasa, have a high risk of erosion. The slope map was classified into 5 classes as shown in Table 5:

Table 5. Class value for slope map

Class	Value (%)
1	0–1.68
2	1.68–3.04
3	3.04–4.64
4	4.64–6.88
5	6.88–20.40

This was accomplished using the ArcGIS 10.7 software. Figure 7 shows the slope map.

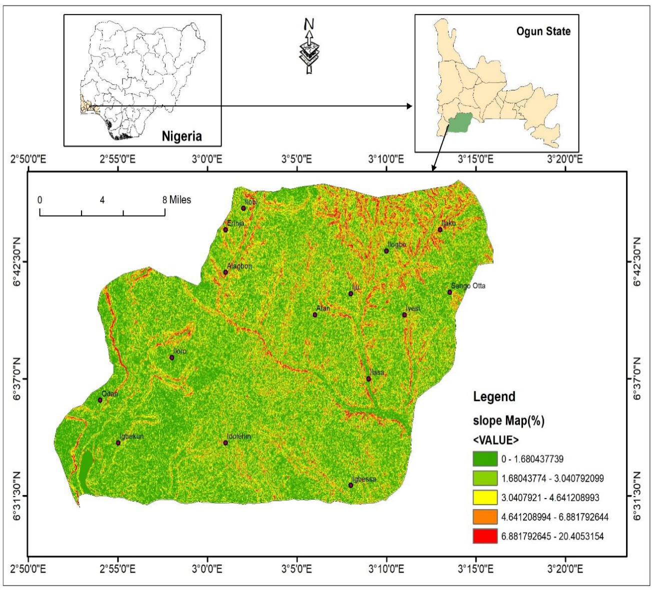

Fig. 7. Slope map

4.5. Conservation practice

In this research, P-factors were varied between 0.55–0.89 to indicate the presence of erosion resistance facilities. The areas with a P-factor of 0.55 have erosion resistance facilities and no erosion resistance facilities in the areas with a P-factor of 0.89 (Fig. 8).

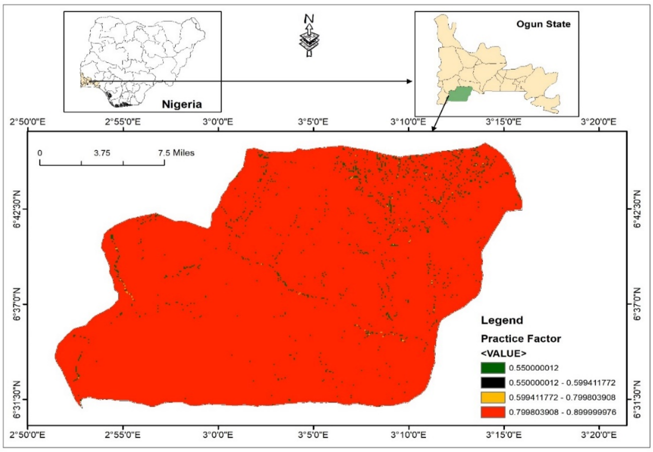

Fig. 8. Conservation practice map

4.6. Calculation of soil erosion

Every single map created for each component using the Raster Calculator, which is essentially the revised universal soil loss equation ($A = R \times K \times LS \times C \times P$). Then the soil erosion map was generated as shown in Figure 9.

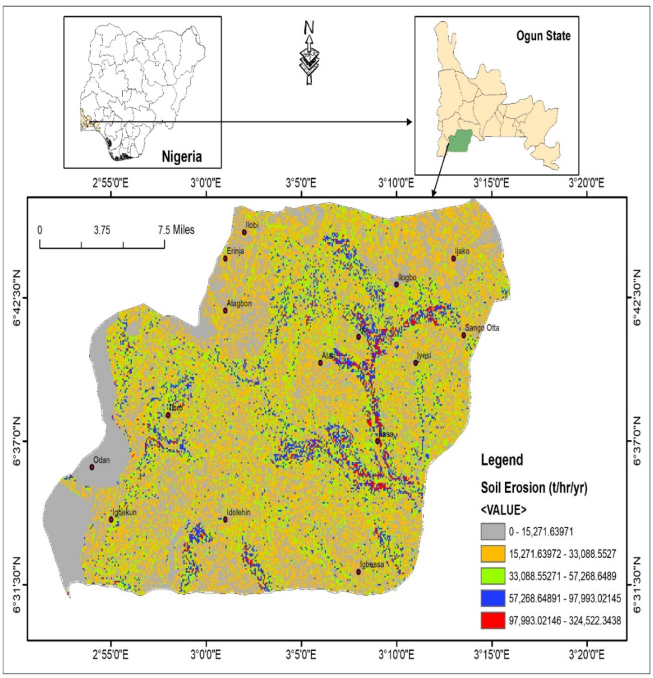

Fig. 9. Soil erosion map

Due to the factors considered from the map we can tell areas like Ilasa, Iju and Atan have a very high chance of experiencing erosion also areas like Alagbon, Ijako, Igbassa have the chance of experiencing erosion but it is not as high as that of Ilasa, Iju etc. Odan has the lowest chance of experiencing erosion.

4.7. Nature conservation and landuse

The findings of this study indicate a general lack of effective soil conservation practices within the study area (see Fig. 1). The rapid population growth in Ota has placed significant pressure on available land resources, leading to the excessive use and degradation of soil. As noted by Iheanacho (2018), the concept of conservation farming – which emphasizes the sustainable use of land, particularly soil, for long-term agricultural productivity – has been largely neglected due to increasing land scarcity.

Historically, indigenous soil conservation methods such as ridging, terracing, multiple cropping, and fallowing were widely practiced during the pre-colonial period (Igbokwe, 1996). During the colonial era, the British administration initiated several large-scale soil conservation projects; however, many of these efforts failed due to the unsuitability of imported technologies to local conditions. It was only after Nigeria's independence that soil fertility and conservation began to receive increased attention. Unfortunately, the economic downturn following the oil boom in the 1980s led to a reduction in funding for conservation initiatives (Slaymaker and Blench, 2002).

Despite the existence of numerous land use policies and regulations aimed at managing land sustainably, many soil conservation projects have failed due to the exclusion of farmers from the planning and implementation processes. Rural development strategies have often portrayed farmers as poor managers of soil and water resources (Iheanacho, 2018). Field observations further reveal the absence of permanent erosion control structures – such as terraces – within the Ado-Odo/Ota area, underscoring the need for more inclusive and locally adapted conservation efforts.

4.8. Limitations of RUSLE model

The revised universal soil loss equation (RUSLE) is a well-established empirical model widely employed to estimate average annual soil erosion, particularly by water. Although it has demonstrated effectiveness across various environmental contexts, its application in tropical regions presents several limitations due to the distinctive environmental and socio-economic conditions found in these areas.One major challenge is the seasonal variability of rainfall. Tropical regions often experience short, high-intensity storms that can cause severe erosion. However, RUSLE tends to rely on long-term rainfall averages, which may underestimate the erosive potential of these intense events. In addition, the lack of high-resolution rainfall data in many tropical areas compromises the accuracy of the rainfall-runoff erosivity (R) factor.

Another limitation lies in the complexity of land use systems in the tropics, such as mixed cropping, agroforestry, and shifting cultivation. These dynamic and heterogeneous land use patterns are difficult to categorize and assign accurate cover-management

(C) values to. Moreover, conservation practices in many tropical settings are informal, traditional, or poorly documented, making it challenging to evaluate their impact and assign suitable support practice (P) factors.

Topographic data also pose a concern. The calculation of slope length and steepness (LS factor) depends heavily on the availability of high-quality Digital Elevation Models (DEMs). However, in rugged or densely vegetated tropical landscapes, such data are often lacking or imprecise.

Overall, without proper local calibration and adaptation, the use of RUSLE in tropical regions can lead to significant underestimation or overestimation of soil erosion rates, thereby limiting its effectiveness for informed land management and conservation planning.

5. Summary and conclusions

One of the major environmental issues that has a substantial impact on land management is soil loss due to erosion, which lowers soil fertility. The yearly soil erosion was examined in Ado Odo Ota Local government area, Nigeria. By combining the RUSLE model with GIS technology, the soil loss map of Ota was produced. The study reveals the effectiveness of the RUSLE model in the investigation of soil loss, all the factors of RUSLE were very applicable in the study area and were taken into account. The result generated from the maps showed that areas such as Ilasa, Iju and Atan are characterized with steeper slope from North Eastern part towards the North West. Also, the rate of precipitation is noted to be higher along these areas therefore they have a higher chance of experiencing erosion. These areas were found to have the highest chance of experiencing erosion based on the soil loss map that was generated. The findings of this research emphasizes the need for effective land management and conservation and can be used by decision makers to mitigate the negative effect of soil erosion.

Author contributions

Conceptualization: G.O.O. and M. O. O.; data curation, M.O.O. and A.A. A.; formal analysis. G.O.O and M.O.O.; investigation, A.A.A. and M.O.O.; methodology, G.O.O. M.O.O. and A.A.A., supervision, A.A.A. and M.O.O., visualization, G.O.O.; writing – original draft, M.O.O., A. A. A. and G.O.O.; writing – review and editing, M.O.O., A.A.A., and G.O.O.

Data availability statement

The data presented in this study are available on request from the corresponding author. The data are not publicly available due to privacy restrictions.

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