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Abstract
Soil loss estimation plays a vital role in the management and conservation of land and water resources, offering vital insights for watershed-level development in various regions. This study focuses on the development of a soil loss model for Bosso Local Government Area in Minna, Nigeria, utilizing the Revised Universal Soil Loss Equation (RUSLE). Integration of Landsat images, Digital Elevation Models (DEM), rainfall and precipitation records, and soil erodibility factors was employed to estimate the average annual soil erosion within the study area. The individual parameters of the RUSLE model were integrated into the ArcGIS environment using the raster calculator in the Arc toolbox. The results reveal that an alarming 6672.83 tonnes per hectare per year of soil are lost annually in the study area. This rate of soil erosion raises concerns about the sustainability of agricultural practices in the study area. The findings underscore a critical absence of conservation practices or plans to combat and mitigate soil erosion in the region. In light of these findings, it is imperative that local government authorities, in collaboration with various ministries, take immediate action to promote and enforce conservation measures aimed at combating soil erosion within the area.

1. Introduction

Soil erosion is a significant global issue influenced by natural and anthropogenic factors, causing land degradation and negative impacts on the economy and environment (Bakis *et al.,* 2021). Accurate assessment and estimation of soil loss are crucial for sustainable land and water resource management (Yusof *et al.,* 2019). The Universal Soil Loss Equation (USLE), modified by Wischmeier and Smith (1978), is a widely used empirical model for predicting long-term average yearly soil loss on agricultural land, with its improved and modified versions still widely used in studies (Wajesundara *et al.,* 2018).

The Revised Universal Soil Loss Equation (RUSLE) model, which forecasts erosion potential on a cell-by-cell level, is useful for ecosystem services related to soil erosion and protection (Yusof *et al.,* 2019). It finds the spatial distribution of yearly soil loss at catchment size and can be applied using GIS applications to determine individual variables contributing to erosion potential values (Ganasri and Ramesh, 2016). Numerous studies have been conducted on the estimation of long-term soil loss using geospatial techniques in different parts of the world, including the Fincha Catchment of Ethiopia (Wagari and Taimur, 2021), the Dolapha district of Nepal (Thapa, 2020), the Kalu Ganga River Basin (Panditharathne *et al.,* 2020), the Pabaragamuwa Province of Sri Lanka (Senanayake *et al.,* 2020), the tropical mountain river basin of the southern Western Ghats (Thomas *et al.,* 2018), the Padma River Basin, the Siruvani River watershed in Attapady valley, Kerala (Prasannakumar *et al.,* 2011), the Barakar River Basin of Jharkhand (Biswas and Pani, 2015) etc. Thus, this study is aimed at evaluating soil loss in the Bosso Local Government Area of Minna in North Central Nigeria using RUSLE and ArcMap interface. The findings can help in providing valuable information which can valuable for effective management of land and water resources, reduction of soil erosion, and for promoting environmental protection for policy and decision-makers.

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2. Materials and Methods

2.1. Study Area

Minna, the capital of Niger State, is the administrative centre for the Bosso and Chanchaga Local Government Areas. It covers about 72 km^2 and has a rocky landscape with a typical middle belt zone climate. The mean monthly temperature is 30-500C (830F) and the rainy season starts in April of every year. Literature suggests that gully development is influenced by the underlying geology, with rock types being key factors. The Niger State geological map reveals three types of lithology: porphyritic and biotite hornblende granite, fine-grained biotite granite, and undifferentiated schist (Abdulfatai *et al.,* 2014).

2.2. Method

RUSLE was used to estimate soil loss in the study area using primary and secondary data processed within GIS software environments. The following subsections describe some of the parameters integrated for the soil loss modelling.

2.2.1. Rainfall Erosivity Factor (R)

To calculate the quantity of rainfall experienced in the study area, equation (1) suggested by Morgan *et al.* (1984) was implemented and integrated ArcGIS software environment using the raster calculator tool.

$$R = 38.5 + 0.35P \tag{1}$$

where, R= Rainfall erosivity factor, P = Mean annual rainfall in mm

2.2.2. Soil Erodibility Factor (K)

Soil erodibility factor k measures soil susceptibility to erosion, influenced by organic matter, texture, structure, and permeability. Higher values indicate higher sensitivity, with potential k-factor values listed in Table 1.

Table 1. Different ranges of the K factor and their meanings

Soil types	K factor	Meaning
Rocky soil/deserted land	0-0.2	Very low erodibility
Silt or clay loam	0.2-0.5	Low erodibility
Sandy loam	0.5-0.8	Moderate erodiblity
Sandy soil/gravelly soil	0.8-1.0	High erodibility

The study area's soil erodibility factor was calculated using Wischmeier and Smith's (1978) equation (see equation 2) in ArcGIS.

$$K = 0.2 + 0.3\exp\left(0.0256 * S_a * \left(1 - \left(\frac{S_i}{100}\right)\right) * \left(\frac{S_i}{C_i + S_i}\right)^{0.3} * \left(1.0 - \frac{0.25 * C}{C + \exp(3.72 - 2.95C)}\right) * \left(1.0 - \frac{0.7 * SN}{SN + \exp(-5.51 + 22.9SN)}\right)\right) \tag{2}$$

where, Sa = Sand %; Si = Silt %; CL = Clay %; SN = 1-(Sa/100); C = Organic Carbon.

2.2.3. Slope length and steepness factor (LS)

Slope length, also known as slope steepness, measures a slope's inclination, while steepness is the ratio of its vertical rise to run. The slope's length and steepness, measured in meters and percentages/degrees, influence erosion which increases the likelihood of soil loss with each increase. This study used Wischmeier and Smith's (1978) slope length and steepness factor equation in ArcMap, incorporating parameters from Equation (3).

$$LS = \left(\frac{\lambda}{72.6}\right)^{m} \times [(65.41 \times \sin 2\theta) + (4.56 \times \sin\theta) + 0.065] \tag{3}$$

where, λ= slope length in meters. θ= Angle of slope m= dependent on slope: (i) 0.5 if slope > 5% (ii) 0.4 if slope is between 3.5% and 4.5% (iii) 0.3 if slope is between 1% and 3% (iv) 0.2 if slope is less than 1%

2.2.4. Annual Soil Loss Map

The ArcMap toolbox was utilized to integrate the RUSLE model parameters, resulting in the mean yearly soil loss for the study area map, as shown in Equation (4).

$$A = R * K * LS * C * P \tag{4}$$

3. Results and discussions

This section presents the obtained results and their analysis. The result of each of the component of the soil loss modelling as described in subsections 2.2.1 – 2.2.4 are discussed in subsections 3.1-3.6

3.1 Rainfall Erosivity Factor (R)

Figure 1 displays the study area's average annual rainfall erosivity factor.

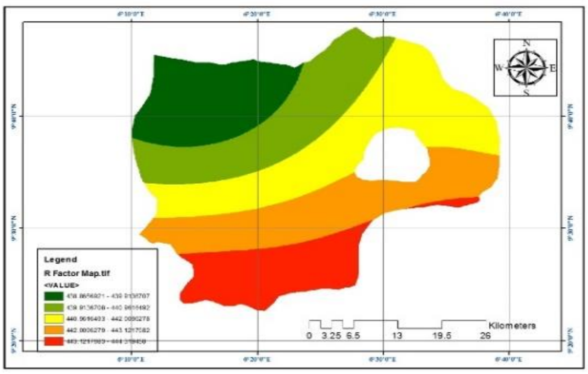

Figure 1. Rainfall erosivity factor map

The study area receives between 438.866 and 444.319 MJmmha1yr1 of annual rainfall, which can cause soil erosion. Intense rain can lead to more erosion, with significant damage resulting from sustained rainfall exceeding 25 mm per hour. Figure 1 shows that the study area experiences soil erosion due to 444.319 mm annual precipitation and four soil types, with a high k factor indicating soil susceptibility to erosion.

3.2 Soil Erodibility Factor (K)

Figure 2 shows the soil erodibility factor map of the study area, while Table 2 lists different soil types found in the study area.

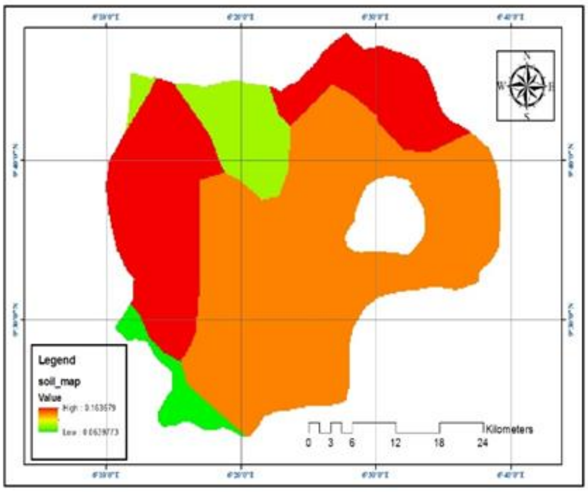

Figure 2. Soil erodibility factor map of Bosso local government Area

Table 2. Soil types found in the study region

Soil type	Sand %	Silt %	Clay %	OC %	(K) Factor
Distric Nitosol	38.9	17.6	43.6	1.57	0.06
Ferric Luvisol	74.6	9.6	15.9	0.39	0.16
Lithosol	58.9	16.2	24.9	0.97	0.12
Plinthic Luvisol	69.9	10.5	19.5	0.73	0.15

The digital soil map of the world (DSMW), a digital version of the FAO-UNESCO soil map, generated the erodibility factor k by displaying 4931 soil associations, a combination of different soil types. Soil erodibility in the study area, ranges from 0.064 to 0.016 m/h and comprises four distinct soil types, such as Distric Nitosol (73%), Ferric Luvisol (8%), Lithosol (9%), and Plinthic Luvisol (9%).

3.3 Slope Length and Slope Steepness Factor (LS)

Figure 3 displays the map of the study area's slope length and steepness factor.

The digital elevation model (DEM) of the study area with 12.5m resolution was used to generate the slope length and slope steepness factor. Table 3 describes various support practise variables for various conservation strategies. Figure 3 shows that topography influences soil erosion through slope length and steepness, with steeper slopes causing more intense runoff, with a more pronounced influence observed between 0 and 572.

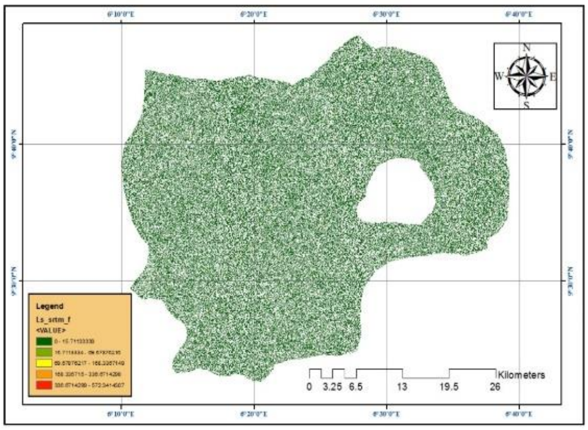

Figure 3. Slope length and steepness factor map of the study area

Table 3. Support practise elements for various conservation practises

Slope (%)	Contouring	Strip cropping	Terracing
0-7	0.55	0.27	0.2
7-11.3	0.66	0.3	0.12
11.3-17.6	0.8	0.4	0.16
17.6-26.8	0.9	0.45	0.18
26.8>	1	0.5	0.2

Source: (Shin, 1999)

The RUSLE model employs the Support Practise Element (SPE) to assess the effectiveness of conservation practices in reducing soil erosion, with 1 indicating greater success. Examples include terracing, contour farming, and cover crop application.

3.5 Conservation Factor (C)

The RUSLE model includes a conservation factor, which indicates the likelihood of soil erosion, the effectiveness of conservation measures, and land management strategies. The factor ranges from 0 to 1, with 1 indicating no conservation practice while 0 indicates a complete protection. Figure 4 displays the study area's conservation practise factor map.

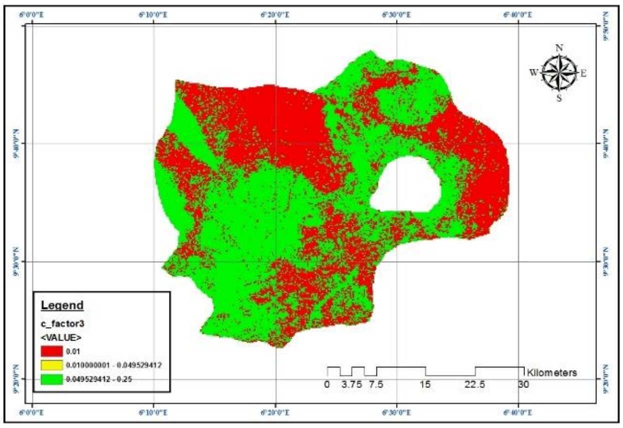

Figure 4. Conservation factor map

The conservation map shows that the area's conservation factors ranges from 0.01 to 0.25 which indicates that while there are ongoing efforts to curb soil erosion in the area, the efforts are inadequate and not even distributed.

3.6. Mean Annual Soil Loss

The study area's mean annual soil loss was calculated using the RUSLE, summed up using relation and expressed as t/ha/yr. The annual soil loss map (figure 5) reveals a significant annual loss of 6672.83t/h/yr, which suggests a high erosion rate. Agricultural practice in the area, involving subsidence and large-scale farming, leads to soil loss which invariably impacts food production and environmental degradation.

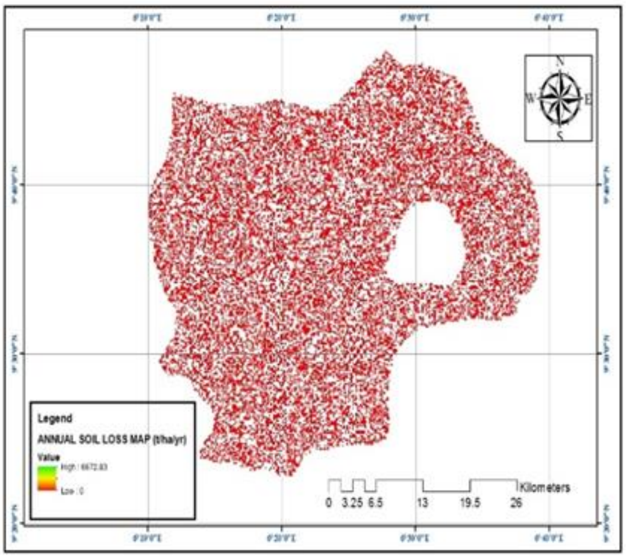

Figure 5. Mean annual soil loss map

Figure 5 shows that the mean annual soil loss in the study area, ranging from 0 to 6672.83 t/ha/yr, This means that the area exhibits considerable variability in terms of soil erosion rates. The range also indicates that there are likely different factors and conditions contributing to soil erosion in different parts of the area. It shows that while some areas are well-protected against erosion, other areas are more susceptible due to factors like topography, land use, vegetation cover, and climate. These high soil erosion rates can have negative environmental impacts, including sedimentation in water bodies, reduced soil fertility, and land degradation.

4. Conclusion

Soil erosion in the study area is primarily caused by varied topography, cover management, and land use practices. Excessive erosion occurs during rainy seasons, with an estimated rate of 6672.83 t/h/yr. The study suggests that using a GIS-based RUSLE model can simplify long-term estimation in an upland-lowland watershed, aiding in watershed management, resource planning, and identifying water harvesting sites to reduce soil erosion.

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