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Assessing the risk of soil loss using geographical information system (GIS) and the revised universal soil loss equation (RUSLE)

Ekundayo Adesina*[1], Oluibukun Ajayi, [2], Joseph Odumosu[3], Abel Illah[1]

[1]Federal University of Technology, School of Environmental Technology, Surveying and Geoinformatics Department, Minna, Nigeria
[2]Namibia University of Science and Technology, Faculty of Engineering and the Built Environment, Department of Land and Spatial Sciences, Windhoek, Namibia
[3]Federal University of Oye Ekiti, Faculty of Environmental Science, Department of Surveying and Geoinformatics, Oye Ekiti, Nigeria

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Abstract

Soil erosion poses a significant environmental challenge in many developing nations, and critically evaluating the threat of soil erosion is paramount for sustainable land management practices. This study aims to identify the contributing factors to erosion and estimate the amount of soil loss in the Bosso Local Government Area of Niger State, Nigeria, using the Revised Universal Soil Loss Equation (RUSLE) model. Factors like rainfall erosivity (R), soil erodibility (K), topography (LS), cover and management (C), and support practices (P), were integrated into a Geographic Information System (GIS) environment to generate variable layers. The estimated values of $R, K, LS, C, and\ P$ ranged between 438.866 and 444.319 MJmmha-1 h-1 yr-1, 0.06 to 0.015 megajoules per hectare hour megajoules-1 hectare-1 millimeter-1, 0 and 572, 0 to 0.2, and 0 to 1, respectively. GIS raster calculations derived from these factors revealed a mean estimated soil loss rate of 0-6672.83t/h/yr-1 (tons per hectare per year). Notably, rainfall emerged as the most influential factor driving soil erosion within the study area. The study highlights the necessity for immediate intervention to mitigate soil erosion in the study area. Furthermore, to formulate effective conservation and management strategies, this study advocates for further research prioritizing severity analysis areas and estimating sediment loss across the region.

1. Introduction

The initial layer of organic and mineral components of the earth surface is known as soil (Roy et al., 2023). While its organic components come from the breakdown of living materials, its mineral components come from weathering processes (Strahler & Strahler, 2013). Soil is an essential part of the earth system that regulates hydrological cycles, and biogeochemical processes, and provides human civilizations with a wealth of resources, products, and services (Berendse et al., 2015). Soil has the most significant function and holds a central place in human connection with the physical environment, especially when it comes to economic and subsistence needs (Alewoye et al., 2020).

Soil is an abundant natural resource essential to agricultural productivity (Dutta et al., 2015). Therefore, the productivity of soil is crucial to the well-being of both the current and future generations, especially in a nation where agriculture is one of the primary sources of income for the populace (Pal & Chakrabortty, 2022b). But since humans first arrived on the planet, it has deteriorated dramatically (Adediji et al., 2010; Ugese et al., 2022; Balabathina et al., 2020; Yesuph & Dagnew, 2019). Land degradation puts pressure on the global economy and ecology, and it is also a menace to food production, food security, and the preservation of natural resources, especially in Africa (Balabathina et al., 2020; Belayneh et al., 2019). One of the problems the continents have faced is the loss of land's ability to produce due to the depletion of soil fertility, soil biodiversity, and other land surface resources because of the physical, chemical, and biological characteristics of soil deterioration (Egbueri et al., 2022; Getu et al., 2022).

These days, many natural and human-induced activities have negatively disrupted the ability of land to supply essential nutrients and sustain the development of plants. According to Pal et al. (2021), Chakrabortty & Pal (2023) and Pal & Chakrabortty (2019a), soil erosion caused by climate change continues to be one of the most dangerous problems facing the world's ecosystems in the twenty-first century. Hurni et al. (2015) estimated that erosion negatively affects around 50% and 80% of the world's pasture and agricultural land, respectively. While

***Corresponding Author**

*(adesinageoworldsolutions@gmail.com) ORCID 0000-0001-9526-4540
(oajayi@nust.na) ORCID 0000-0002-9467-3569
(joseph.odumosu@fuoye.edu.ng) ORCID 0000-0003-1604-4924
(abelillah56@gmail.com) ORCID 0009-0002-6315-2821

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soil erosion is a global concern, its effects are particularly noticeable in nations like India with dense populations and complicated topography (Pal et al., 2022a; Pal & Chakrabortty, 2019b).

In most of the third-world countries in Africa, anthropogenic forces such as deforestation, steep slope cultivation, overgrazing, over cultivation, and unsustainable use of land resources have had significant impacts on soil erosion (Pal et al., 2022b; Pal & Chakrabortty, 2019b; Roy et al., 2023). Estimates of the loss in agricultural output in Africa as a result of soil erosion range from 2 to 40% (Smaling & Oenema, 2020). Flooding and soil erosion-related land degradation is a common occurrence throughout Sub-Saharan Africa (Odumosu et al., 2014). According to Kiptoo & Mirzabaev (2014), erosion affects more than 61% of Tanzania's total land area, and it destroys 15% of Malawi's and Zambia's arable land.

A significant issue facing Nigeria, a developing nation in sub-Saharan Africa where agriculture is one of the primary sources of income for over 75% of the people, is the country's ongoing decline in agricultural output (Andualem et al., 2020; Tsegaye & Bharti, 2021). Soil erosion-induced deterioration of land resources is the primary cause of this. For example, in the study by FAO (2015), it was projected that during the previous 15 years, from 1985 to 2010, soil erosion cost the nation 1.9 billion US dollars. Deressa et al. (2020) estimated that Nigeria loses over 2 billion tons of productive topsoil per year or 8% of all land surface erosion. It accounted for around 1 mm of the vertical soil depth nationwide and cost the nation 3% of its Agricultural Gross Domestic Product (GDP) (Balabathina et al., 2020).

In addition to causing a decline in agricultural productivity, water-induced soil erosion has also led to an increase in sediment output and reservoir layering from sedimentation. As a result, Nigeria has the greatest rate of soil erosion in all of sub-Saharan Africa (Ayalew et al., 2020; Erol et al., 2015; Gessesse et al., 2015).

Despite having plans in place since 1980 to reduce soil erosion, the country has not been able to carry them out because of gaps and limitations with the implementing body as well as a lack of community-based discussion about land reforms and reclamation (Legesse et al., 2004; Getu et al., 2022). The issue in the Nigerian highlands became more severe due to poor and antiquated farming practices, mismanaged land cover degradation, a lack of community involvement, unmanageable planning units, and a lack of in-depth knowledge and expertise in the characterization of watersheds (Hurni et al., 2015).

The Nigerian highlands are susceptible to soil erosion, which causes an annual loss of over 1 billion tons of net soil and a 2.2% reduction in land productivity (Getu et al., 2022). Among the main driving causes in the Nigerian highlands are extensive deforestation to accommodate the increase of agricultural land and the resulting need for wood, grazing on steep slopes, population growth, and the ensuing strain on arable areas (Teshome et al., 2021). Some farm plots these days are in a condition that makes rehabilitation difficult. Similar to this, soil erosion has emerged as one of the main issues facing the Bosso Local Government Area in Minna, Niger State, Nigeria. This is due to a combination of the region's varied terrain, fluctuating climate, and human activity.

Soil erosion is currently a serious concern to food security for smallholder farmers due to the depletion of soil fertility and the ensuing decline in agricultural production. The main impacts of erosion in the Bosso Local Government Area of Minna, Niger State, Nigeria, include soil loss, productivity drop, soil depth decline, plot size reduction, soil color change, and gully development. The Bosso Local Government of Minna, Niger State, Nigeria has reduced the vulnerability of soil erosion; nonetheless, there is still a dearth of objectively measurable quantitative data on the extent of soil erosion, which could inform methodological choices for conservation planning.

Models are crucial in easing these restrictions since, even though field studies are highly helpful in characterizing the scope and size of field conditions, they are often expensive, time-consuming, and complicated (2020; Ghafari et al., 2017; Tsegaye & Bharti, 2021; Aneseyee et al., 2020). Even though several soil erosion models have been created since the 1980s, the majority of them are regionally restricted and challenging to extend (Bastola et al., 2019). It is a result of the models' internal data not taking into account universal standard circumstances during their evolution. Among the frequently utilized methods for estimating soil erosion and sediment loss are the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978), Soil Water Assessment Tool (SWAT) (Piniewski et al., 2019), Sediment Delivery Distributed Model (SEDD) (Ferro & Porto, 2000), Revised Universal Soil Loss Equation (RUSLE) (Renard, 1997), and Agricultural Non-Point Source (AGNPS) (Williams et al., 2008). The USLE has a few drawbacks despite being a strong empirical model that is very simple at both the regional and national levels.

According to Tesfaye (2015), a few of these restrictions are as follows: Its application in forest land, rangeland, and disturbed areas was limited. It was designed to predict soil loss from agricultural fields; it does not take into account gully and stream channel erosions; it assumes uniform runoff throughout the catchment; it is not designed to operate at large scales; it cannot handle undulating terrains; it does not examine the relationship between rates of infiltration and intensity of runoff; and it does not account for sediment deposition at the lowest point of concave slopes. However, the RUSLE model (Pal & Chakrabortty, 2019a) is an enhanced version of the first USLE model. According to Bombino et al. (2004) and Egbueri et al. (2022), the RUSLE model has several improvements when it comes to analysis of the factors that govern soil erosion, considering various Land Use Land Cover (LULC) scenarios, such as forestlands, and rangelands (Ashiagbor et al., 2013; Colman et al., 2018; Thapa, 2020).

According to Haile & Fetene (2012), the RUSLE model is a cost-effective soil loss assessment tool for successful conservation planning in locations where the necessary quantity and kind of data are sufficiently accessible. According to Belayneh et al. (2019), the RUSLE model is more effective at forecasting the long-term average yearly rate of soil erosion on-field slopes due to its simplicity, flexibility, compatibility, and application with the limited amount of data that is currently available (Zanchin et al., 2021).

Since each cell in a raster picture now represents a field-level event, the development of GIS technology has made it possible to compute the soil erosion equation (Ayalew & Selassie, 2015). Because of this, several studies have discovered that the GIS-integrated RUSLE model produces findings even for vast regions and is a cost-effective soil loss estimating tool for efficient conservation planning. Thus, the purpose of this study is to assess the yearly soil loss rate in the Bosso Local Government of Minna, Niger State, Nigeria, and to ascertain the relative impacts of erosion-controlling elements using the RUSLE model and Arc GIS.

2. Materials and methods

Data

The rainfall data used for this study was obtained from https://dsp.imdpune.gov.in/, while the soil data was downloaded from the Soil Grids website (https://soilgrids.org/). These datasets are publicly available (open source). The study also used the SRTM Digital Elevation Model (DEM) downloaded from the United States Geological Survey (USGS) Earth Explorer (https://earthexplorer.usgs.gov/) with a resolution of 30 m. Landsat8 imageries of the year 2023 was used to prepare land use land cover map and the NDVI map. Table 1 presents the data used for the study and their corresponding sources.

Table 1: Input data used and corresponding sources.

Input data	Data source
Daily rainfall	IMD stations and WRD stations (https://dsp.imdpune.gov.in/)
Soil	Soil Grids (https://soilgrids.org/)
DEM	USGS Earth Explorer
Landsat8	(https://earthexplorer.usgs.gov/)

Data processing and RUSLE factor generation

The study employed remote sensing and field data integrated into a GIS framework to generate the RUSLE input parameters for predicting soil erosion. The various RUSLE factor maps were designed using Arc GIS 10.4. The RUSLE model was used to integrate these factor images and determine the annual severity of soil erosion rates.

RUSLE model description

RUSLE is the most well-known and often-used soil erosion model for agricultural watersheds globally (Kebede & Fufa, 2023). It was selected for this study based on the recommendations of Renard (1997) and Wischmeier & Smith (1978). According to Moisa et al. (2022), RUSLE model is flexible enough to modify parameters and situations, making it easy to integrate with a GIS for geographical analysis. It also analyses soil erosion adaptively.

The model formulation considers five parameters: rainfall, soil, topography, LULC, and conservation practices. Renard et al. (1991) produced the general universal equation for soil loss, which is as follows:

$$A = R \times K \times LS \times C \times P \quad (1)$$

where A is the average annual soil loss (tonnes ha-1 year-1), R is the rainfall-runoff erosivity factor (MJ mm ha-1 hr-1 year-1), K is the soil erodibility factor (tonnes ha-1 MJ-1 mm-1), LS is the slope which is defined as the ratio of soil loss from the field slope length under identical conditions, and Length of Slope Factor (defined as the ratio of soil loss from the field slope gradient under otherwise identical conditions), P is an abbreviation for the contributing conservation practice factor, and C stands for cropping management element. Secondary data acquired for the analysis included soil and meteorological data, satellite imagery, rainfall data, and SRTM DEM. Sections 2.1 through 2.6 provide information about the study area and the parameters of the soil-loss model.

2.1. Study area

Bosso Local Government Area of Niger State was used as the study area for this study. It covers about 72 km^2 and has a rocky environment with a typical middle belt zone climate (Adesina et al., 2023). The mean monthly temperature is 30-50^{0}C (83^{0}F) 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. According to Abdulfatai et al. (2014), the geological map of Niger State shows three main types of lithology: fine-grained biotite granite, porphyritic and biotite hornblende granite, and undifferentiated schist. Figure 1 presents the map of the study area.

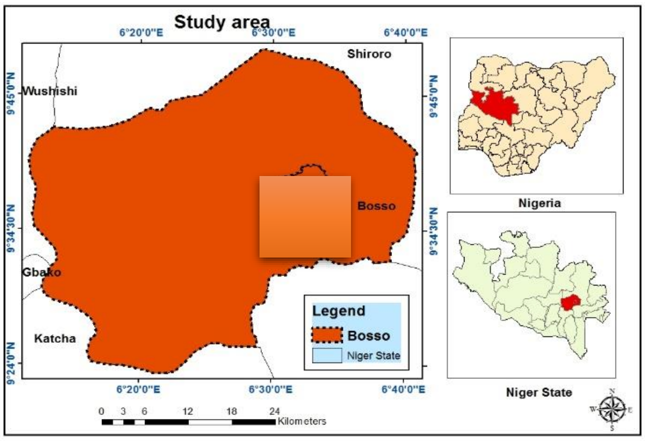

Figure 1. Study area map of Niger State's Bosso Local Government area

Data Analysis and Derivation of RUSLE Parameters

2.2. Rainfall erosivity factor (R)

The yearly average of the number and severity of individual rainstorms is known as rainfall erosivity (R), and it is proportionate to the total annual precipitation. R stands for the two storm components that are most crucial in determining a storm's erosivity: the amount of precipitation and the highest level sustained for an extended length of time. Previous studies have demonstrated a clear relationship between soil loss in agricultural regions and the strength and duration of each downpour (David Raj & Kumar, 2022; Yousuf et al., 2022; Kushwaha et al., 2022; Sharma et al., 2023). The rainfall erosivity factor in RUSLE must take into consideration the effect of raindrops as well as the expected amount and rate of runoff from the rainfall. According to Morgan et al. (1984), the formula in Equation 2 was used to determine the amount of rainfall in the study area.

$$R = 38.5 + 0.35P \quad (2)$$

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

2.3. Soil erodibility K-factor

The soil erodibility factor (K) quantifies how easily soil particles can be transported or carried away by rain and runoff. The K factor depends on the soil profile's permeability, organic matter content, and texture (Erencin, 2000). The quantity of soil loss per erosion index unit from the plot size unit is known as the soil erodibility factor (K) (Wischmeier & Smith, 1978). On a particular terrain, other factors that affect the pace of soil erosion include crop productivity, precipitation, and alternative land uses. The properties of the soil that affect soil erodibility include soil texture, soil structural stability, soil permeability and infiltration, organic matter, and soil mineralogy (Singh et al., 1992). Since it is expensive and time-consuming to directly measure K from an experimental run-off plot, Wischmeier & Smith (1978) developed a simple nomograph. Equation 3 was used to calculate the K factor for each grid point in the watershed of the study area (Reddy et al., 2016).

$$K = 0.2 + 0.3\exp\left(0.0256 * S_a * \left(1 - \left(\frac{S_i}{100}\right)\right)\right) * \left(\frac{S_i}{C_i + S_i}\right)^{0.3} * \left(1.0 - \frac{0.25 * C}{C + \exp(3.72 - 2.95C)}\right) * \left(1.0 - \frac{0.7 * SN}{SN + \exp(-5.51 + 22.9SN)}\right) \quad (3)$$

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

Higher values indicate higher sensitivity, with potential k-factor values listed in Table 2.

Table 2. The 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 erodibility
Sandy soil/ gravelly soil	0.8-1.0	High erodibility

The study area's soil erodibility factor was calculated by implementing Equation 3 in ArcGIS 10.4.

2.4. Slope length and steepness LS-factor

The topographic factor is the relationship between slope length (L) and slope steepness (S). It illustrates how topography affects erosion. The L and S variables show how vulnerable a particular site is to topographic erosion. The digital elevation model (DEM) from the Shuttle Radar Topographic Mission (SRTM) served as the source data for estimating the L and S components. We used the maximum downhill direction approach to determine the slope to get the LS values. The angle established between each 30 x 30 m raster cell and its lowest neighbouring cell was utilised to get the slope value for each cell. Tarboton (1997) developed the "D" (infinite directions) technique, which predicts the scattered or grilled flow from slopes to lower neighboring cells for each cell and used it to predict the flow direction. Using the flow direction raster, the computation of flow accumulation involved determining the number of cells that contributed flow to each cell. Using ArcGIS, it was possible to estimate the DEM sinks' filling, slope angle, flow direction, and flow accumulation. Moore & Burch (1986) gave the following formula for LS factor computation:

$$LS = \left(\frac{\lambda}{72.6}\right) m^{\times[}(65.41 \times \sin 2\theta) + (4.56 \times \sin\theta) + 0.065] \quad (4)$$

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%.

Using the raster calculator, the slope length and steepness factor equation from Moore & Burch (1986) was used for this study and it was implemented in the ArcGIS 10.4 environment.

2.5. Cover management C-factor

One of the most important RUSLE components which shows how easily controllable the soil conditions are to reduce erosion is the C-factor. The calculation of C factor is done using weighted average soil loss ratios (SLRs), which are calculated as the ratio of soil loss for a particular status of vegetative cover over a given period as compared to the soil loss that occurred on the unit plot during that period. This site-cover and site-management-related C-factor assesses the correlations between several factors. Several studies have experimented with soils covered in different kinds of vegetation types to study the C factor (Reddy et al., 2016) and the findings proved that several factors influence soil loss. Nonetheless, the slope's length, steepness, and vegetation cover factor are the most crucial factors. Assigning C values to various LULC classes based on field research or literature is necessary to obtain the C factor map.

Chalise et al. (2019) proposed that the cover management factor (C), which monitors the dynamics of plant development and rainfall, is the most spatiotemporally sensitive factor (Nearing et al., 2004). It takes into consideration the impact of cropping and other practices on erosion rates. This factor, which compares the similar loss from continuous bare fallow to the soil loss from precipitation erosion under certain land and vegetation circumstances, is defined as a non-dimensional number between 0 and 1 (Wischmeier & Smith, 1978). The study looked at several land use types, which were then integrated into a single class using ArcGIS 10.4 software after being transformed from a raster map to a polygon using the raster-to-polygon tool. Each land-use example has a C value, which runs from 0 to 1, according to sources (Erencin, 2000; Panagos et al., 2015a; Panagos et al., 2015b) (Table 3). A larger C value denotes significant odds of soil loss, whereas a smaller C value denotes no loss.

Table 3. Land use land cover and C factor

S/No.	LULC	C Factor
1	Water bodies	0.00
2	Forest	0.03
3	Flooded vegetation	0.01
4	Crop land	0.21
5	Barren land	0.45
6	Built up area	0.70
7	Scrub land	0.03

2.6. Support practice P-factor

The support practice component indicates the rate of soil erosion in accordance with agricultural practice. Three strategies are necessary to control erosion: terraces, cropping, and contouring (Heald et al., 2015). Kouli et al. (2009) stated that the contouring approach with P values is based on a scale of 0 to 1, where 1 represents a non-anthropogenic.
erosion facility and 0 represents suitable anthropogenic erosion.

Table 4. P factor values for slope (Kumar et al., 2016b

S/No.	Slope %	P Factor
1	0.0-7.0	0.55
2	7.0-11.3	0.60
3	11.3-17.6	0.80
4	17.6-26.8	0.95
5	>26.8	1.0

Conversely, the P factor is dependent on land management activities carried out by humans. According to Ganasri & Ramesh (2016), there is a relationship between the rate of soil erosion and straight-row upslope and downslope tillage farming techniques. Runoff is the primary cause of runoff-triggered soil erosion. Therefore, different conservation support techniques can lessen the hydraulic forces, runoff velocity, and runoff concentration. A P factor value between 0 and 1 indicates a strong conservation practice factor that helps to prevent soil erosion, while a value of 1 indicates a bad practice factor that causes soil loss.

The value of the P factor was assigned based on insights derived from the LULC as surveying the entire watershed was impractical. The RUSLE model parameters were integrated using the ArcGIS 10.4 toolbox, yielding the mean yearly soil loss for the research area map, as indicated by Equation (1).

3. Results and discussion

The rainfall erosivity factor (R) values ranged from 438.866 to 444.319 mm/ha/yr, whereas the topographic factor (LS) values ranged from 0 to 572, according to the obtained results. The range of values for the soil erodibility factor (K) was 0.06 to 0.015. Throughout the entire region, the values of the support practice factor (P) ranged from 0 to 1. The cover management factor (C) values fell between 0.01 and 0.25.

RUSLE, an experimentally based modelling approach, uses five variables to forecast the long-term average yearly rate of soil erosion on slopes. It computes soil loss under comparable topographical and climatic conditions, according to Prasannakumar et al. (2012). Five parameters that exacerbate site erosion were compounded using the ArcGIS raster calculator to produce a potential erosion map of the study area. Most of the land is in the low erosion hazard zone which amounted to about 6672.83 t/ha/yr, based on the information.

Using information from multiple sources, this study used ArcGIS software to compose a potential soil erosion rate map for the study area. Other research projects with similar geographic characteristics also used the same methodology (Prasannakumar et al., 2012; Panagos et al., 2015a; Panagos et al., 2015b; Kumar et al., 2016a). Considering the R-factor, LS-factor, K-factor, P −factor, and C-factor appropriately will help reduce the amount of uncertainty in erosion modelling.

Details of the obtained result which consists of the components of soil loss modelling used for the study and their discussions are presented in sections 3.1–3.6.

3.1. Rainfall erosivity factor (R)

The study area's average annual rainfall erosivity factor is shown in Figure 2.

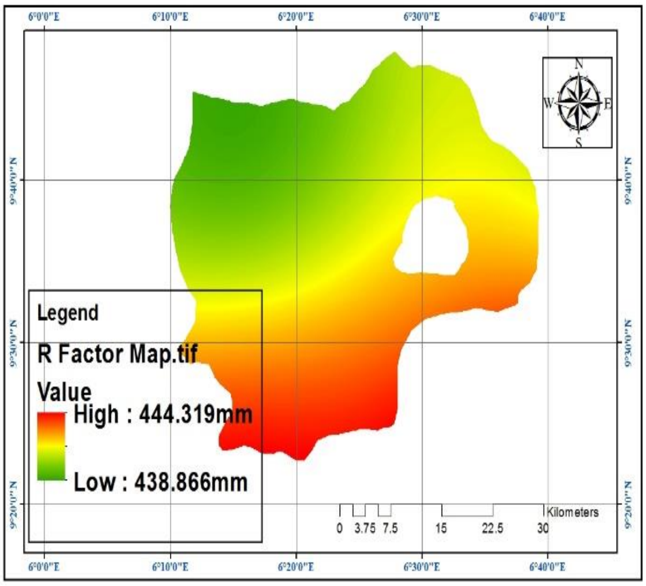

Figure 2. Rainfall erosivity factor map

Using a map of the rainfall erosivity factor, Figure 2 depicts the distribution of rainfall in the study area. This is particularly important because erosion cannot occur until the erosivity factor is greater than the erodibility factor. The runoff factor was found using the Climatic Study Unit Time Series (CRUTS), which includes monthly time series data on temperature, precipitation, cloud cover, and other variables and spans the Earth's surface from 1905 to 2022. Gridding the datasets to a resolution of 0.5 x 0.5 degrees is based on an analysis of over 4000 individual weather station records. The average yearly rainfall map in Figure 2 and the computation by Morgan et al. (1984) indicate that the study area receives between 438.866 and 444.319 MJmmha1yr1 (megajoules millimeter per hectare per hour per year). However, additional factors that might result in the loss of the soil surface and induce erosion, such as slope, vegetation cover, and rainfall intensity, also affect soil erosion. Put differently, when the rainfall becomes heavier and more intense such that it exceeded 25 mm per hour, it caused serious erosion.

3.2. Sol erodibility factor (K)

The key factor influencing the soil's ability to erode is its texture, which is determined by the various soil types. The K factor is impacted by a few more elements as well, such as organic matter and soil texture. Figure 3 shows a map with the soil erodibility factor of the study area overlaid on it while Table 5 displays the different soil types within the study area together with their corresponding volumes and erodibility factors (k).

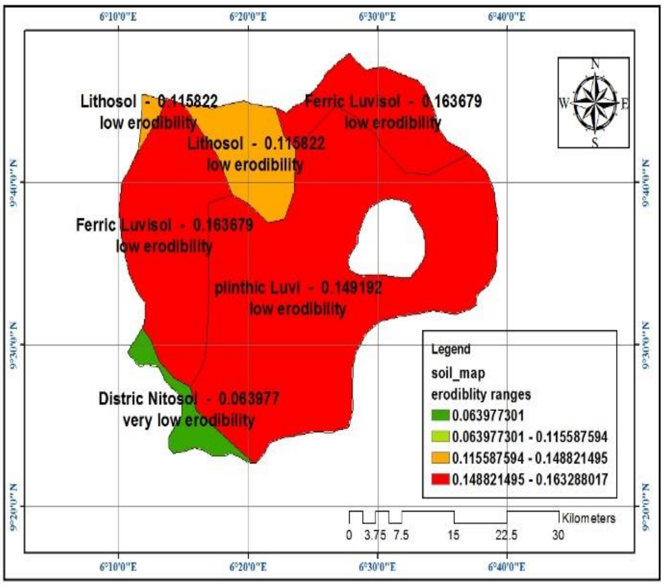

Figure 3. Map of the study area's soil erodibility factor

The Food and Agricultural Digital Soil Map of the World (DSMW), a digitalized version of the FAO-UNESCO soil map of the world produced in a paper edition at a scale of 1:5000000, provided the data necessary to compute the erodibility factor k. It displays 4931 soil associations, or mapping unit—sets of different soil types combined. According to Table 2, the erodibility of the soil in the study area ranges from 0.06 to 0.015 megajoules per hectare hour megajoules-1 hectare-1 millimetre-1. Table 5 shows the types of soil in the study area.

Table 5. Types of soil in the study area

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

3.3. Slope length and slope steepness factor (LS)

The slope steepness and length that ArcGIS generates from the DEM served as the basis for this topographic component. Calculating the LS factor involves using the slope and flow accumulation percentages. Figure 4 shows the digital elevation map of the study area, while Figure 5 displays the slope length and steepness factor.

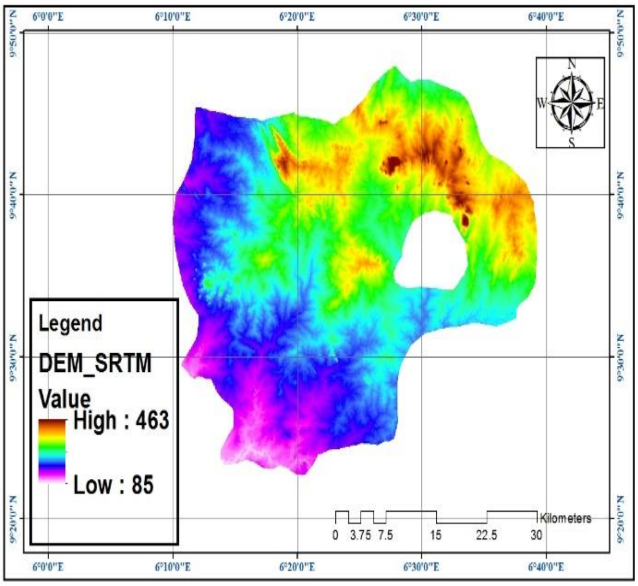

Figure 4. Digital elevation map (DEM) of the study area

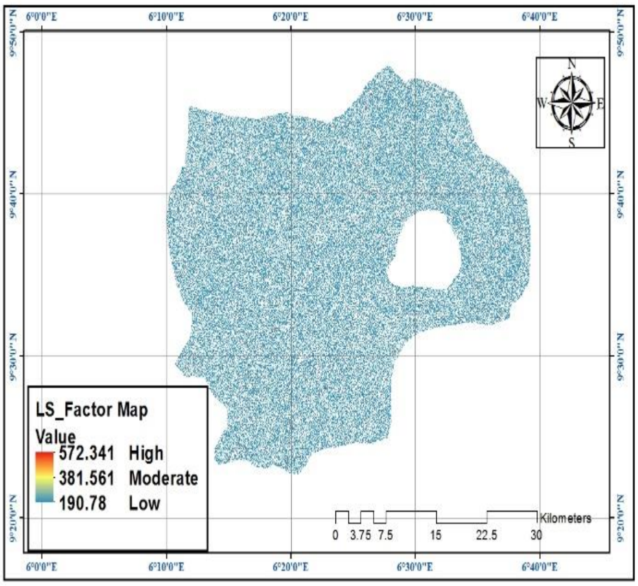

Figure 5. Slope length and steepness factor map of the study area

Using the 12.5 m resolution Digital Elevation Model (DEM) of the study area, the slope length and steepness factor were computed. The different support practice variables for conservation strategies are shown in Table 5. As seen in Figure 5, soil erosion affected topography through slope length and steepness, with steeper slopes resulting in more intense runoff, and this influence was most noticeable between 0 and 572. The higher number suggests that the deep valley and rough terrain are naturally erosive. The watershed's south and southwest, where the river valley is excessively wide and deep, have higher *LS* values. This area is especially susceptible to soil erosion in the study area due to its high runoff and topographic erosion. Table 6 lists the various LULC classes' *C* and *P* factors.

Table 6. *C* and *P* Factor value of different LULC

Catchment	*C* Factor	*P* Factor
River	0	0
Lake	0	0
Medium Dense Forest	0.05	1
Temperature Forest	0.2	1
Sedimentation	0.18	1
Agriculture Land	0.2	0.5
Fallow Land	0.18	1
Built-up Area	0	0
Waste/Barren Land	0.18	1

3.4. Cover and management *C*-factor

The Land Use and Land Cover data produced from Landsat 8 OLI data were used to estimate the *C* factor. The *C* factor had a value between 0 and 0.2. The four-land use and land cover classes assigned in this study are agricultural land, barren land, built up area, and vegetation (Figure 6). The land receives the highest value (0.2) because it is bare. While Figure 7 shows the Conservation factor map.

The higher numbers imply that there is either very little or no plant cover, which increases the rate of soil erosion and leaves the soil more susceptible to it. The lower *C* value (0.05) indicates a substantial plant cover that inhibits or stops soil erosion.

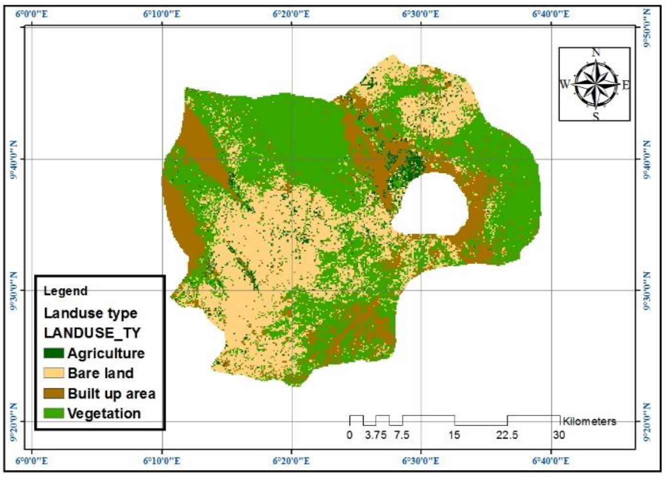

Figure 6. Land use map of the study area

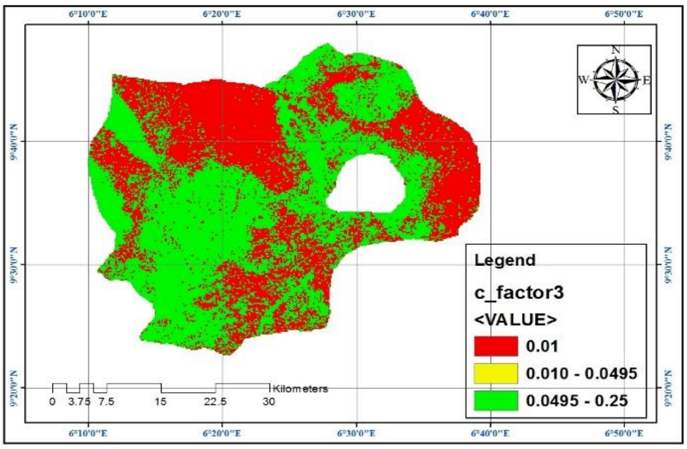

Figure 7. Conservation factor map

The conservation factors in Figure 7 span from 0.01 to 0.25, indicating that while efforts are being made to decrease the rate of soil erosion in the study area, they are still extremely inadequate. In the study area, green areas signify conservation initiatives that have reduced erosion, whereas red spots denote severe or high severity. Table 5, which is integrated into the GIS environment, displays the conservation factor value for various land use and land cover characteristics in the study area.

3.5. Conservation support practice factor *P*-factor

The source image for the *P* factor estimation is the same land cover and land use map. The *P* factor in RUSLE is the ratio of soil loss with straight-row upslope and downslope tillage to soil erosion with a particular support practice. The lower value denotes the implementation of conservation measures aimed at protecting agricultural land's soil. Gaining knowledge of the mechanisms underlying human-caused soil erosion raises the *P* factor. The study area's support practice component is shown in Figure 8, where values vary from 0 to 1. This is because conservation practices are seen in agricultural land. Table 7 presents the list of the different practice variables influencing support for different conservation initiatives.

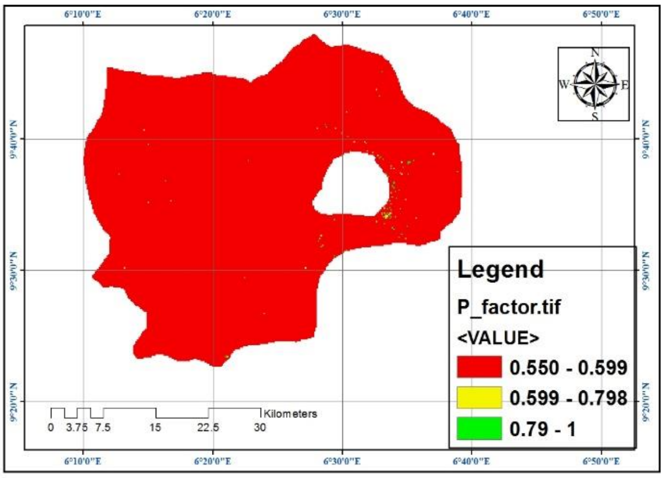

Figure 8. Support practice factor map of Bosso Local Government

Table 7. Support practice elements for various conservation practices (Singh et al., 1992)

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

The Support Practice Element (SPE) of the RUSLE model is used to evaluate how well conservation practices reduce soil erosion; a score of 1 indicates a good result.

3.6. Soil loss estimation

The mean annual soil loss in the study area ranges from 0-6672.83t/h/yr-1 ((ton per hectare-1 per year-1). The loss rate, though significant, is still small compared to the larger expanse that is unaffected by the soil erosion in the study area as shown on the map (Figure 9), the red color depicts area with low erosion rate while the orange and green color depicts area with moderate and high soil loss rate, respectively, which is evenly spread across the study area.

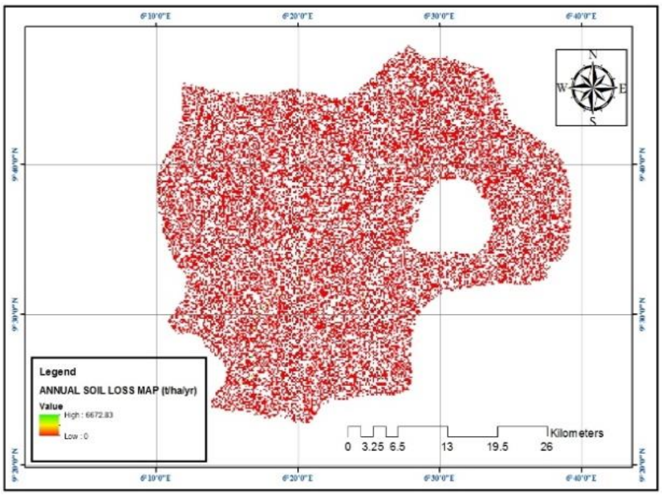

Figure 9. Mean annual soil loss map

4. Conclusion

Using remote sensing, GIS, and existing data sets in conjunction with the RUSLE model, this study has assessed the soil erosion rate of the study area. The study yielded practical outcomes that can facilitate focused attention towards an improved soil conservation strategy for the study area. It makes it possible to identify areas at high risk of soil erosion and provide soil conservation efforts with targeted attention.

This study examined the eroding properties of soil, the impact of cover and management techniques on the erosion process, the influence of rainfall and the runoff it generates, the magnitude of yearly soil losses, and the impacts of topography on erosion rates. The predicted yearly soil loss indicates that soil erosion poses a risk to the sub-catchment area's agricultural productivity and sustainability. It also highlights the possibility that if prompt corrective action is not provided, the issue may worsen in the future.

The study yielded significant results, such as thematic maps that illustrate the various factors that govern erosion and the estimated potential and actual soil loss rate. These maps can serve as a basis for developing appropriate strategies and action plans to protect soil and improve management. They will also guide the decision-making processes.

Furthermore, the RUSLE model's results offer first-hand knowledge to local government and non-governmental organizations, and land management specialists to help them create programs for immediate attention and long-term soil conservation structures, particularly in areas where soil erosion rates are high enough to become irreversible. Policymakers, development planners, local land managers, concerned NGOs, and other responsible authorities will find this study useful, especially if they are interested in creating soil conservation initiatives and sensible management plans for the sub-catchment region.

Our estimate of soil erosion gives a notional basis that the region needs rapid action to support the soil of the area given the extent of the watershed area, the severity of the problem, and the resources. To create workable strategies for conservation and management, more investigation into the severity analysis area prioritization and sediment loss estimation in this area is strongly recommended.

Author Contributions

The contributions of the authors to the article are as follows: **Author1**: Conceptualization, Investigation, Supervision, and validation. **Author2**: Visualization, study supervision, Writing-Reviewing and Editing. **Author3**: Visualization, Investigation and Draft Review. **Author4:** Data collection and processing, Software and methodology, writing original draft.

Statement of Conflicts of Interest

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

Research and publication ethics were complied with in the study.

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