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Article

Estimation of soil erosion using the RUSLE model and Geographic information system tools: Geospatial analysis of Anuppur district, Madhya Pradesh, India

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Abstract: Soil erosion is characterized by the wearing away or loss of the uppermost layer of soil, driven by water, wind, and human activities. This process constitutes a significant environmental issue, with adverse effects on water quality, soil health, and the overall stability of ecosystems across the globe. This study focuses on the Anuppur district of Madhya Pradesh, India, employing the Revised Universal Soil Loss Equation (RUSLE) integrated with Geographic Information System (GIS) tools to estimate and spatially analyze soil erosion and fertility risk. The various factors of the model, like rainfall erosivity (*R*), soil erodibility (*K*), slope length and steepness (*LS*), conservation practices (*P*), and cover management factor (*C*), have been computed to measure annual soil loss in the district. Each factor was derived using geospatial datasets, including rainfall records, soil characteristics, a Digital Elevation Model (DEM), land use/land cover (LULC) data, and information on conservation practices. GIS methods are used to map the geographical variation of soil erosion, providing important information on the area's most susceptible to erosion. The outcome of the study reveals that 3371.23 km^2, which constitutes 91% of the district's total area, is identified as having mild soil erosion; in contrast, 154 km^2, or 4%, is classified as moderate soil erosion, while 92 km^2, representing 2.5%, falls under the high soil erosion category. Additionally, 50 km^2, or 1.35%, is categorized as very high soil erosion and around 30 km^2 of the study area is classified as experiencing severe soil erosion. The analysis further discovers that the annual soil loss in the district varies between 0 and 151 tons per hectare per year. This study indicates that most of the district is classified under low soil erosion; only a tiny fraction of the area is categorized as experiencing high and very high soil erosion. The study provides significant insights into soil erosion for policymakers and human society to bring their attention to the need for sustainable soil conservation practices in the undulating terrain/topography and agriculturally dominated district of Anuppur.

Keywords: human activities; RUSLE equation; soil loss; soil health; ecosystem; sustainable conservation practices

1. Introduction

The process by which water, wind, and human activity erode topsoil is known as soil erosion. Around the world, soil erosion impacts ecological stability, land production, and water quality. The loss of the top layer of soil due to soil erosion reduces the fertility of agricultural land [1]; this is a serious farming issue in any society, mainly since food is primarily cultivated in the soil [2]. There are both in-situ and ex-situ effects of soil erosion [3]. The primary in-situ consequences of soil erosion are the loss of the soil's nutrient-rich top layer and a decrease in its ability to retain water. In addition, ex-situ issues include dam silting, lake ecosystem disruption, and contaminated drinking water [4]. Apart from this, soil erosion significantly impacts the socio-economic status of the population whose livelihood depends on agriculture directly or indirectly [5].

Erosion of soil is caused mainly by human-induced activities, including deforestation, agriculture, urbanization, and natural causes like rainfall and terrain [6]. A significant hazard to existence and well-being is soil erosion, which is pervasive throughout India. India is among the nations that suffer from extremely high soil erosion rates [7]. According to [8], soil erosion may be found in agricultural areas, forest areas, desert and semi-arid areas, and construction sites. Assessing soil erosion plays a pivotal role in conservation planning, minimizing soil loss impacts, and effectively managing land use [9]. Two primary types of models, empirical and physical models, serve as practical tools for accurately assessing soil erosion and sediment yield [10]. The USLE model and its various adaptations are notable examples among the empirical models. In contrast, several comprehensive models are based on physical models, including the Kyoto Erosion Model (KYERMO), European Soil Erosion Model (EUROSEM), Chemicals, Runoff, and Erosion from Agricultural Management Systems (CREAMS), Soil Loss Estimation Model for Southern Africa (SLEMSA), and Kinematic Runoff and Erosion Model (KINOROS) [11] RUSLE is one of the most widely utilized empirical models for predicting soil erosion [7,12].

Advancements in geospatial technologies have made digital mapping platforms vital for predicting soil degradation [13]. Remote sensing offers updated, high-resolution data on land use, vegetation, and topography, while GIS supports spatial analysis and integration of environmental variables [14]. Integrating models with RS and GIS enhances the accuracy of soil loss estimation, enabling broad assessments and targeted conservation [15]. Effective soil management not only reduces degradation but also supports agricultural productivity and food security [16]. In India, increasing land degradation and unsustainable farming highlight the need for erosion assessment to promote sustainable land use [17].

Madhya Pradesh’s varied terrain and intense monsoonal rainfall make it highly vulnerable to soil erosion. Recent studies using RUSLE integrated with GIS and remote sensing have provided valuable assessments [18] applied RUSLE in the Chambal basin and estimated an average soil loss of 3.04 t/ha/year, highlighting the influence of vegetation cover [19] found the highest erosion rates (13.44 t/ha/year) in the gully and barren lands within the same basin, with slope steepness as the dominant factor. Another study in the Kunwari River basin reported soil loss ranging from 0 to 176.9 t/ha/year, emphasizing the impact of rugged topography [20].

The Anuppur district experiences significant monsoonal rainfall, making it prone to water-induced soil erosion, especially in sloped and deforested areas. Additionally, shifting land use patterns, agricultural expansion, and mining activities in the eastern parts of the district have heightened the risk of soil degradation. Moreover, a focused analysis of the Anuppur district remains especially absent in the existing literature. While statewide assessments provide a general overview, there is a scarcity of detailed studies concentrating exclusively on the Anuppur district. This limits the understanding of localized erosion dynamics influenced by the district’s hilly topography and land use patterns. There is a need to evaluate the effectiveness of current soil conservation measures within the district, which requires integrating field data with RUSLE-GIS analyses.

2. Study area profile

Anuppur district is positioned in the easternmost region of Madhya Pradesh and was officially established on 15 August 2003, after the division of Shahdol district. This district is notable for its substantial Indigenous population, making it one of the tribal-rich regions in the state. It is also well known for Amarkantak Hill, an important pilgrimage site and the source of two major rivers, the Son and Narmada. Geographically, Anuppur lies within the latitudinal range of 22°7′N to 23°25′N and the longitudinal range of 81°10′E to 82°10′E. The district extends roughly 86 km in a north-south direction and approximately 117 km in an east-west direction **Figure 1**.

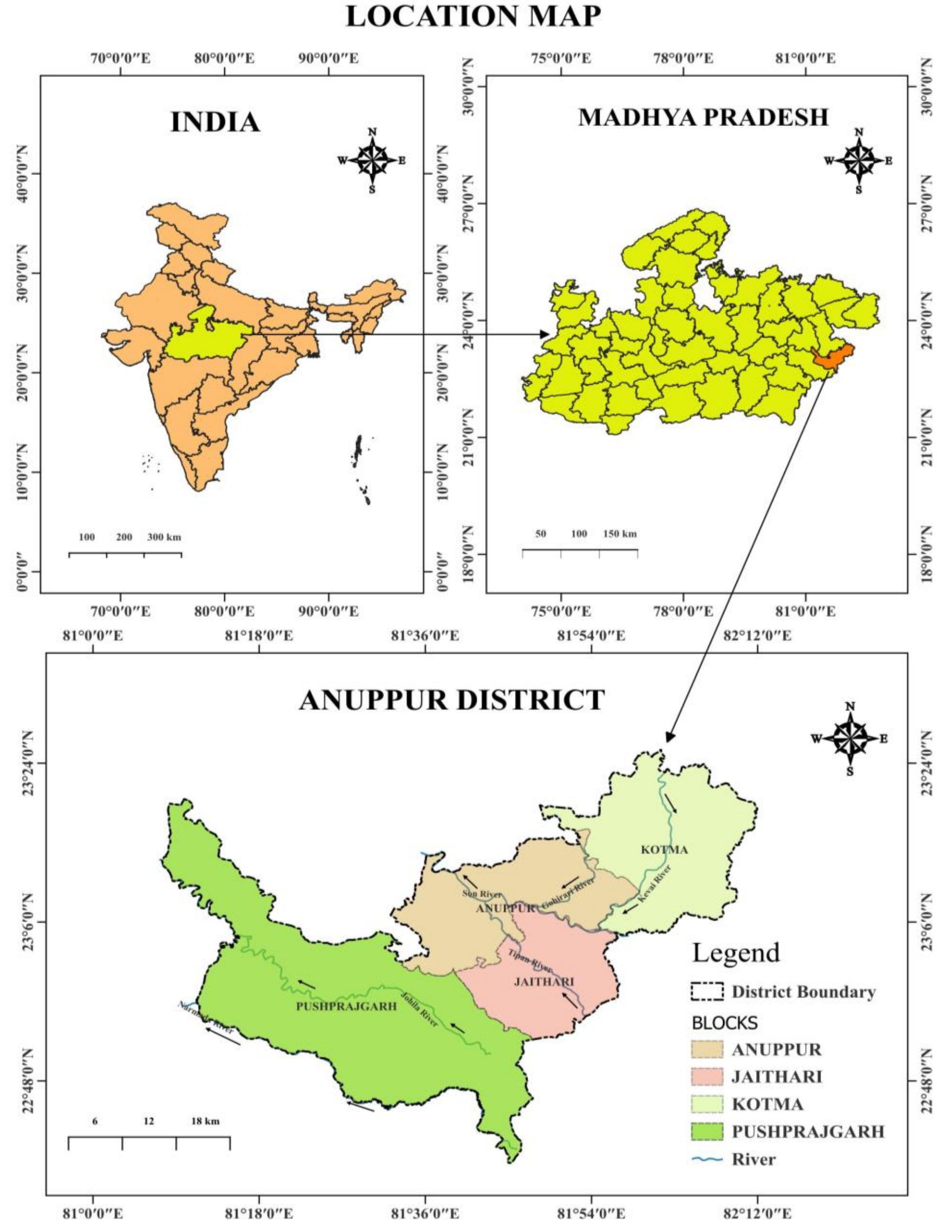

Figure 1. Study area map.

Source: Survey of India.

As per the 2011 Census, 749,237 reside in the Anuppur district, out of which 358,543 belong to Scheduled Tribes and 74,385 belong to Scheduled Castes, reinforcing its status as a tribal-dominated district. The region is predominantly hilly, with dense forests covering approximately 20% of the land. According to the Central Ground Water Board Report, 2021, the district primarily receives precipitation from the southwest monsoon, resulting in an annual rainfall of 1099.6 mm and a post-monsoon rain of 72.7 mm [21]. The district experienced an average maximum temperature of 31.6 degrees in May and an average minimum temperature of 18.2 degrees in December. The topographic landscape of Anuppur district is rugged and undulating, with elevations ranging from approximately 419 m to 1181 m above mean sea level.

3. Geology of the study area

According to the Central Ground Water Board Report, 2021 [21], the geology of Anuppur district includes basalt in the western and southern portions, indicating volcanic origins, while the northeastern region is dominated by sandstone and coal-bearing formations, reflecting Gondwana sedimentary deposits. Granite gneiss in the south of the central area represents ancient crystalline rocks. Other formations like dolerite, limestone, laterite, clay, and fine-grained sandstone appear in smaller patches across the district. This varied geology highlights the region's complex tectonic history and significant mineral resources, particularly sandstone, granite, bauxite, and coal.

The FAO's soil data show that the district's composition includes lithosols, chromic luvisols, ferric luvisols, and chromic vertisols. The distinct soil classifications present in the area profoundly impact the patterns of land utilization and the levels of agricultural productivity.

4. Objectives

1) To estimate the spatial distribution of annual soil erosion and its impacts in the Anuppur district using the RUSLE model.
2) To identify critical erosion-prone zones for prioritizing soil conservation measures.
3) To generate thematic maps for better policy-making and land use planning.

5. Data source and methods

5.1. Data source

Data for this research were obtained from multiple sources and combined using geospatial techniques to calculate annual soil erosion **Table 1**.

Table 1. Data source.

Data	Factor	Source
SRTM DEM (30 m, 2015)	LS	https://earthexplorer.usgs.gov
Soil Data	K	Digital Soil Map of the World https://www.fao.org/soils-portal/data-hub
Rainfall Data (2003–2023)	R	Indian Meteorological Department (IMD) https://imdpune.gov.in
Sentinel 2 (10 m, 2023)	C & P	https://livingatlas.arcgis.com/landcoverexplorer

5.2. Methodology

This study estimates soil erosion and identifies regions at risk of soil loss using the RUSLE model in conjunction with remotely sensed data and Geographic Information System (GIS) approaches. The following is the equation that is applied in this study.

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

where A is the annual average soil loss (t/ha/yr), R is the rainfall erosivity factor (MJ mm/ha h yr), K is the soil erodibility factor (t ha^{-1} MJ mm^{-1} annually), LS is the slope length/steepness factor, C is the cover management component, and P is the conservation practice factor [22]. The methodology integrates multiple data sources and analytical processes to compute RUSLE factors and provide a comprehensive soil loss map. Satellite images, such as 'Sentinel-2 10 m Resolution World Land Use Land Cover Time Series Data', have been downloaded from the website [23]. After that, the world LULC data were processed in ArcGIS software, where the study area, i.e., Anuppur district, was clipped using the Data Management Tool > Raster > Raster Processing > Clip tool to generate the land use/land cover of Anuppur district. The LS factor was computed using slope and flow accumulation data from an SRTM USGS Digital Elevation Model. A 30-m DEM and 10-m LULC were used for soil erosion analysis, as the DEM provides sufficient topographic detail while the higher-resolution LULC enhances land cover accuracy. The resolution difference does not significantly affect model quality or the results of the study. The rainfall erosivity (R) factor is calculated using monthly and yearly rainfall data from the Indian Meteorological Department (IMD). Soil data, including texture and organic matter, downloaded from FAO (Digital Soil Map World shapefile), were used to obtain the soil erodibility (K) factor, which was mapped using GIS tools.

Conservation practice (P) factors were assigned based on field surveys and existing land use land cover data, representing practices such as contour farming or terracing.

After collecting data from various sources, the obtained datasets were integrated into GIS software (ArcGIS 10.8) to derive the values of various factors for the RUSLE model. Finally, the Raster Calculator tool within the Spatial Analyst extension of ArcGIS 10.8 was utilized to input the derived factor values into the 'RUSLE Equation' and generate a spatial distribution of annual soil loss. Subsequently, the resulting annual soil loss was classified into distinct risk categories, ranging from low to extremely high, to facilitate a comprehensive assessment of erosion vulnerability. The results were validated by comparing the estimated erosion with a visual field observation in the study area. The final output identified erosion-prone regions and provided a basis for recommending site-specific sustainable conservation practices to mitigate soil loss effectively. The comprehensive process used in this study is diagrammatically shown in **Figure 2**.

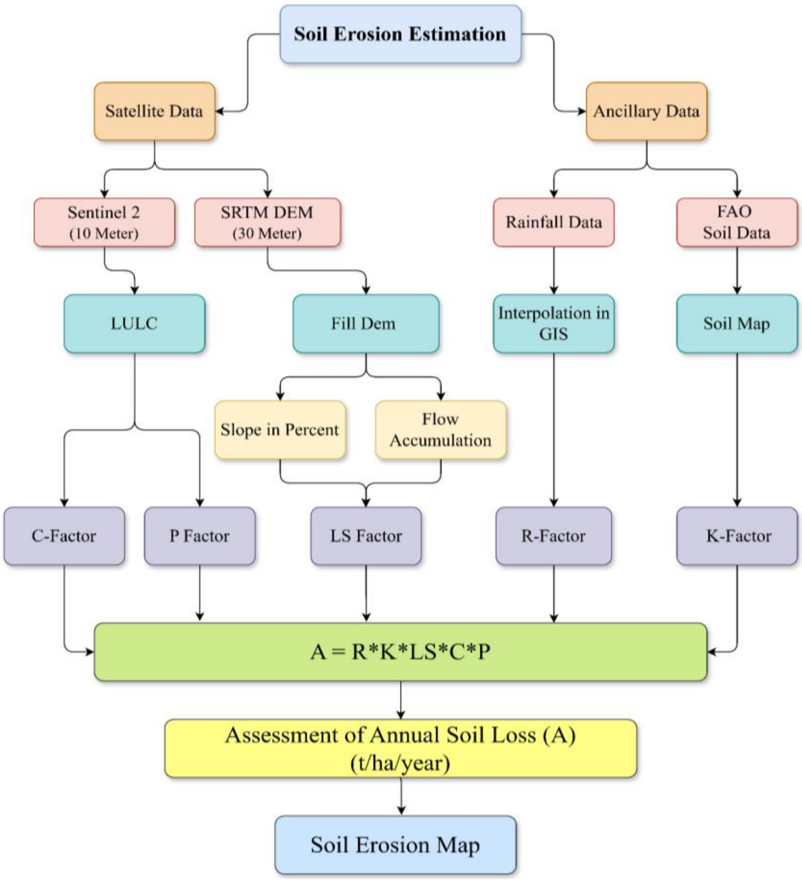

Figure 2. Flow Chart of the methodology adopted for the study.

6. Detailed description of RUSLE's soil erosion parameter

6.1. Rainfall erosivity (*R* factor)

Rainfall erosivity measures the impact of raindrops and the amount of runoff, which depends on rainfall intensity and duration [24]; soil loss and the *R* factor have a linear relationship [22]. Usually, rainfall duration and intensity statistics are used to measure it; higher values correspond to more significant erosive rainfall. For this study, the *R* factor was calculated using monthly and yearly rainfall data spanning 20 years (2003–2023) using the formula derived from **Table 2** [25].

$$R = 81.5 + 0.375 \times \text{MAP} \quad (2)$$

R represents Rainfall Erosivity Factor (MJ mm ha^{-1} hr^{-1} $year^{-1}$), and MAP represents Mean Annual Precipitation (mm).

Table 2. Rainfall data of Anuppur district (MAP: Mean Annual Precipitation in mm) [26].

Station Name	Latitude	Longitude	MAP (mm)	***R*** **Factor MJ mm** ha^{-1} hr^{-1} $year^{-1}$
Anuppur	23.11	81.70	976	647
Kotma	23.16	81.91	1054	678
Jaithari	23.00	81.75	1015	701
Pushprajgarh	22.90	81.55	1187	782

6.2. Soil erodibility (*K* factor)

The soil erodibility factor indicates the soil's susceptibility to erosion [9]. Under standard conditions, the rate and amount of runoff are determined by the soil erodibility factor. The standard condition consists of a 22.6-m-long plot with a 9% slope, kept in continuous fallow and plowed parallel to the hill slope [27]. Permeability of the soil profile, soil structure, soil texture, and organic matter content are the main characteristics of soil that influence the *K*-factor [28,29]. Its value lies between 0.01 for the sturdiest soil and 0.70 for the weakest soil [30]. The value of the *k* factor was calculated by using the equation developed by [31] because it incorporates parameters like soil texture, organic matter, and hydraulic conductivity, which are crucial for predicting soil erodibility in a region with limited data (**Table 3**).

$$K = f_{\text{c-sand}} \times f_{\text{cl-si}} \times f_{\text{org-c}} \times f_{\text{hi-sand}} \times 0.1317 \quad (3)$$

where K stands for Soil Erodibility Factor (t ha MJ^{-1} $mm^{-1)}$; f_{csand} accounts for reduced erodibility in soils rich in coarse sand; $f_{cl\text{-}si}$ reflects lower erodibility in soils with high clay-to-silt ratios; f_{orgc} represents the soil erodibility factor for soils that contain a lot of organic carbon; F_{hisand} is the soil erodibility factor for soils with high sand content.

Table 3. Computed *K* factor value for soil erosion.

FAO Soil Classes	Sand (%) Topsoil	Silt (%) Topsoil	Clay (%) Topsoil	Organic Carbon (%) Topsoil	*K*-Factor Value
Lithosols	58.9	16.2	24.9	0.97	0.14927
Chromic Luvisols	64.3	12.2	23.5	0.63	0.14213
Ferric Luvisols	74.6	9.6	15.9	0.39	0.13264
Chromic Vertisols	22.4	24.5	53	0.69	0.14395

Source: FAO.

6.3. Slope length/steepness factor (*LS*)

The LS factors are mainly used to measure 'how fast and severely soil erosion happens' [22,32]. It shows the proportion of soil loss under specific circumstances compared to that on a typical slope of 22.13 m long and 9% steep [33]. Longer and steeper slopes increase erosion risk by accelerating water flow and its erosive power. Depending on flow accumulation and slope gradient, the LS Factor is usually expressed in meters and radians, respectively [34]. The slope value, in percentage, is generated from the district's Digital Elevation Model (DEM). This 'slope value,' along with the 'flow accumulation' value, is then analyzed using the Raster Calculator in

'ArcGIS 10.8'. Therefore, the topographic factor is produced by using the following equation [34];

$$LS = (FAC \times (\text{cell size} / 22.13))^{m} \times (0.065 + 0.045\, S + 0.0065\, S^{2}) \quad (4)$$

where *LS* refers to the 'slope length and steepness factor', *FAC* is 'flow accumulation', cell size is the 'resolution of grid of DEM', i.e., 30 m, S is the 'slope variation in percent', and *m* is an exponent that depends on the steepness of the slope. '*m*' values of various slope classes used in the current study as per the guideline by [35]. (**Table 4**).

Table 4. Values of '*m*' for various slope categories.

Slope Class in %	*m* value
< 1	0.2
1–3	0.3
3–5	0.4
> 5	0.5

Source: Wischmeier & Smith, 1965 [34].

6.4. Cover and cropping management factor (*C*)

The cover-management factor (*C*) measures how different crop patterns and soil management practices influence the rate of soil erosion. It is characterized as the comparison of long-term soil erosion occurring in a vegetated region to that experienced in an uncultivated, bare area under consistent conditions of soil type and topography. Precisely, it is measured on a 22-m-long slope with a 9% gradient, cultivated in an up-and-down slope direction [36]. GIS-based modeling approaches, such as those used by [15], have improved large-scale estimation of soil erosion and land cover effects. The *C* factor is a non-dimensional parameter that varies from 0 (complete soil protection, such as dense forest cover) to 1 (bare soil, highly susceptible to erosion) [33,37]. The risk of soil erosion is directly related to the value of the *C* factor; as the value increases, so does the risk, and conversely. As per the classified LULC data of Anuppur district, a specific value of the *C*-factor was assigned. This classification aimed to illustrate the impact of various land use types on the potential for soil loss in the study area. These values were taken from previous research [38]. The values attributed to each Land Use and Land Cover (LULC) class are presented in **Table 5**.

Table 5. Value of *C* factor for various land use land cover classes.

Category	*C* Factor
Water bodies	0.60
Forest	0.25
Shrub	0.37
Crop Land	0.68
Built-up Area	0.47
Flood Plain	0.75
Barren Land	0.65

Source: Wagari & Tamiru, 2021 [37].

6.5. Conservation practice factor (*P*)

The *P* factor is described as the ratio of soil loss experienced under a designated conservation support practice relative to the soil loss that arises from standard up-and-down slope agricultural practices [22]. This illustrates the effect of conservation methods on the mitigation of soil erosion [39]. Advanced tillage methodologies, such as crop rotation and organic amendments, significantly mitigate soil erosion by improving soil aggregation and infiltration capacity [40]. Like the *C*-factor, the *P*-factor map, created from the classified LULC in conjunction with the study area's slope map, shows values between 0 and 1 [37,41]. After detailed observation in the study area, we found that certain parts of the Pushprajgarh block practice terrace farming, check bunds, check dams, and plantations. However, these conservation measures could not be confidently incorporated into the model due to the lack of systematic data.

Hence, in this study, the *P*-factor values have been assigned based on published literature applicable to the Indian context [22,42,43]. A value of 0.8 is designated for non-agricultural areas, and a 0.9 value is assigned to agricultural fields mentioned in **Table 6**.

Table 6. *P* factor value for categorized LULC.

LULC Class	*P* Factor
Water bodies	0.8
Forest	0.8
Shrub	0.8
Cropland	0.9
Built-up Area	0.8
Flood Plain	0.8
Barren Land	0.8

Source: Habtu & Jayappa, 2022 [42].

7. Results and discussion

This study conducts a comprehensive assessment of soil erosion estimation using the 'RUSLE' within a GIS framework. The statistical attributes of the multiple factors integrated into the model are detailed in **Table 7**. At the same time, a detailed analysis of each parameter used for soil erosion assessment is discussed below.

Table 7. Highest and lowest values of parameters.

	R Factor	*K* Factor	*LS* Factor	*C* Factor	*P* Factor
Highest	780	0.149	15	0.75	0.9
Lowest	650	0.133	0	0.46	0.8

7.1. Rainfall erosivity factor (*R* Factor)

The district's rainfall erosivity result indicates higher rainfall erosivity in the southwestern region of the study area, which corresponds to the area receiving the highest annual rainfall (**Figure 3**). The *R*-factor values across the district range from

647.60 to 782.56 MJ mm/ha h year (**Figure 4**), with the southwestern part exhibiting the maximum values due to its comparatively greater precipitation levels. This spatial variation highlights the direct influence of rainfall intensity and distribution on erosive potential within the district.

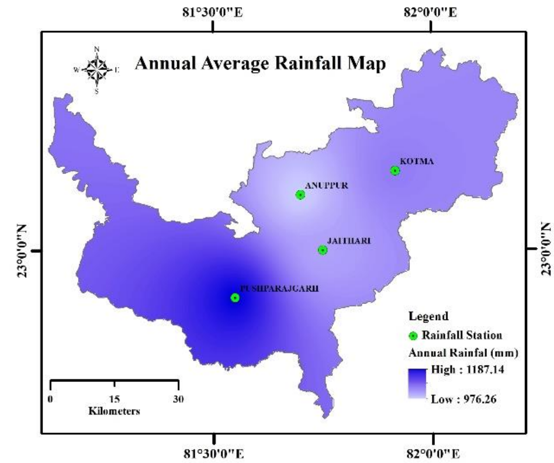

Figure 3. Annual average rainfall map.

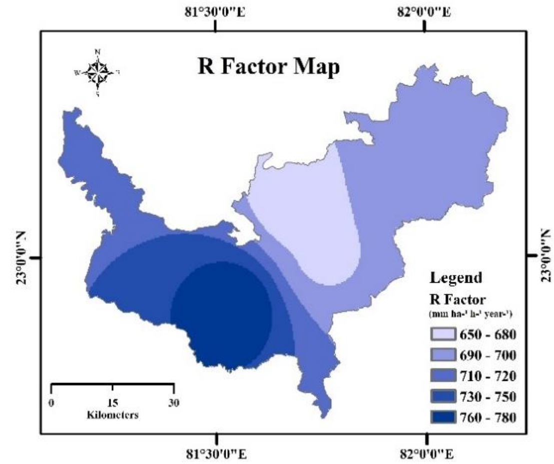

Figure 4. *R* factor map.

7.2. Soil erodibility factor

The concept of soil erodibility encompasses soil susceptibility to the displacement and transport of its particles, which is primarily influenced by precipitation and surface runoff events [44]. The proportions of sand, clay, silt, and organic carbon present in the soil influence the *K*-factor. Within the study area, four predominant soil types have been identified: Lithosols, Chromic Luvisols, Ferric Luvisols, and Chromic Vertisols (FAO) (**Figure 5**). The *K*-factor values in the Anuppur vary from 0.133 to 0.149 t. ha.hr/ha.MJ.mm (**Figure 6**). The *K*-factor map reveals that the western region of the study area shows a greater vulnerability to soil erosion compared to the eastern region.

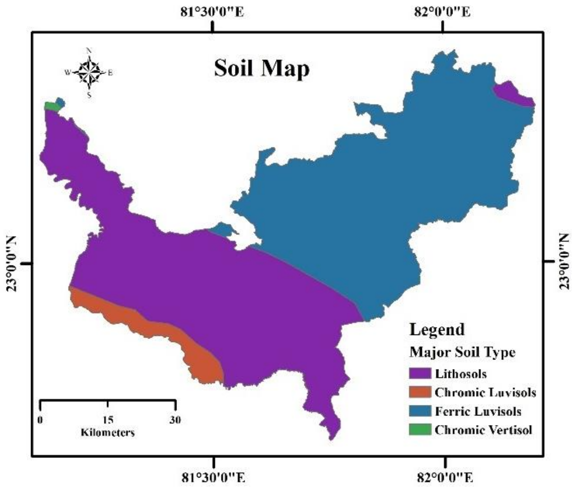

Figure 5. Type of soil map.

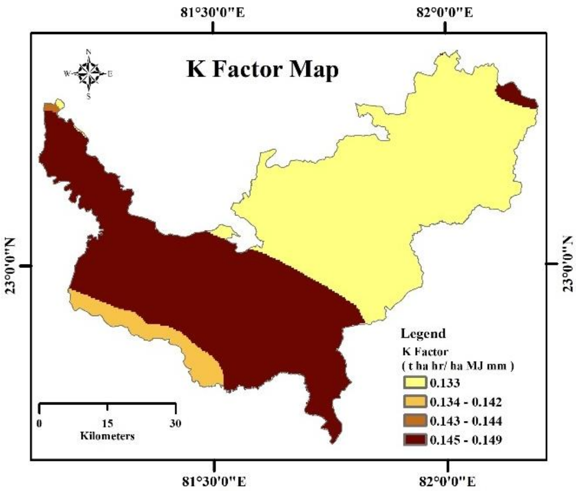

Figure 6. *K* factor map.

7.3. Topographic or slope length and steepness (*LS*)

The elevation in the Anuppur district varies from 419 m to 1181 m (**Figure 7**), and the slope ranges between 0% and 199% (**Figure 8**). The DEM map clearly depicts the district's topography and shows that the eastern area is mainly low-lying. At the same time, the western region is marked by numerous hills leading to steep slopes. In Anuppur district, the estimated topographic factor values range between 0 and 15, with the western side of the study area exhibiting higher values due to its steep slopes and more extraordinary slope lengths (**Figure 9**). The *LS*-factor map illustrates that higher values correspond to an increased potential for soil erosion [10].

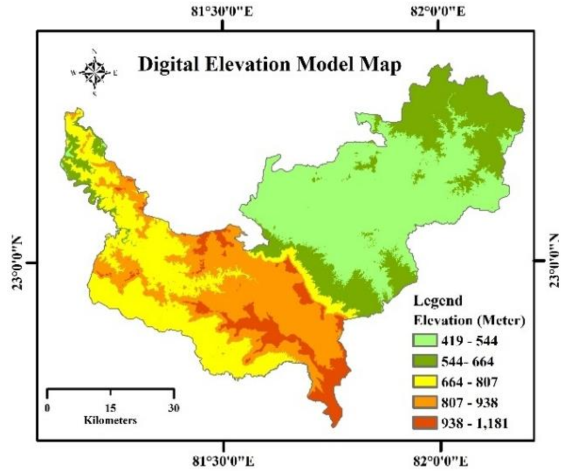

Figure 7. DEM map.

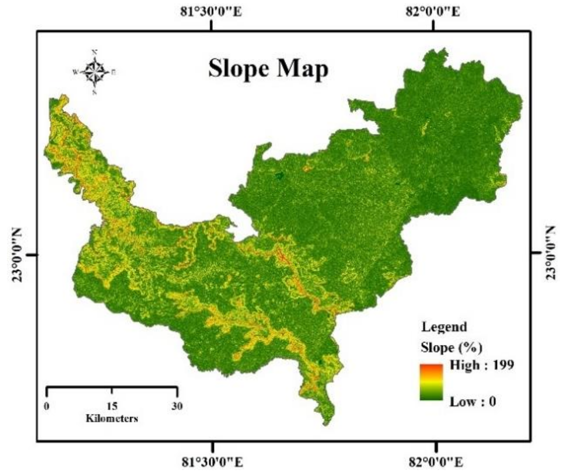

Figure 8. Slope map.

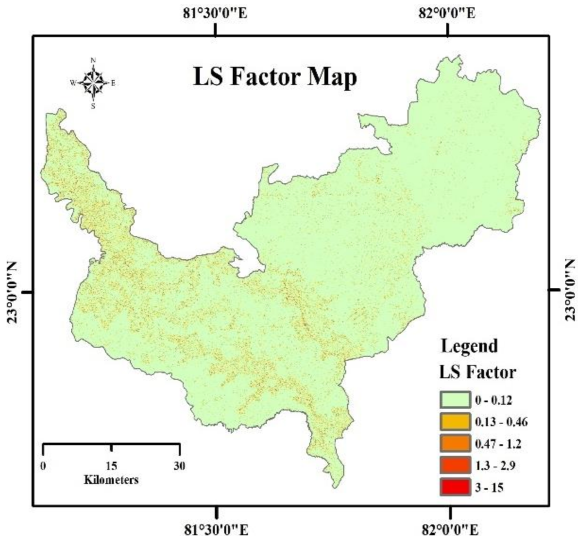

Figure 9. *LS* factor map.

7.4. Cover and cropping management factor(*C*)

The *C*-factor for the Anuppur district was determined utilizing a land use and land cover map derived from Sentinel-2 satellite imagery, which has a precision of 10 m The LULC classification for the district encompassed seven distinct categories **(Figure 10)**, with specific *C* factor values assigned to each category based on existing literature [38]. The *C*-factor values within the district range from 0.46 to 0.75 (**Figure 11**). The resulting map illustrates that hilly terrains possess comparatively lower *C*-factor values, while the low-lying regions exhibit elevated *C*-factor values.

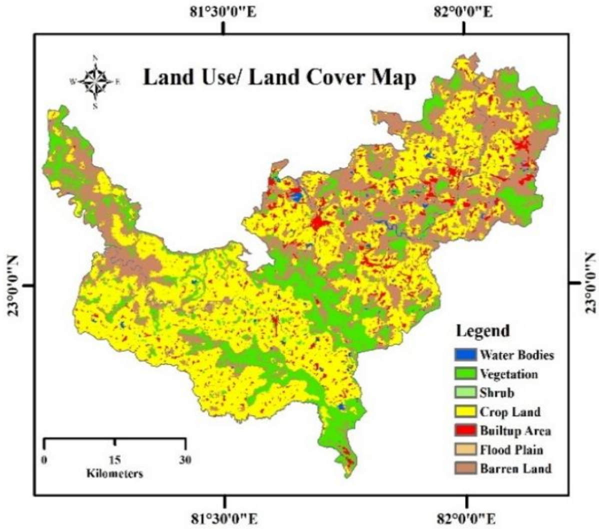

Figure 10. LULC map.

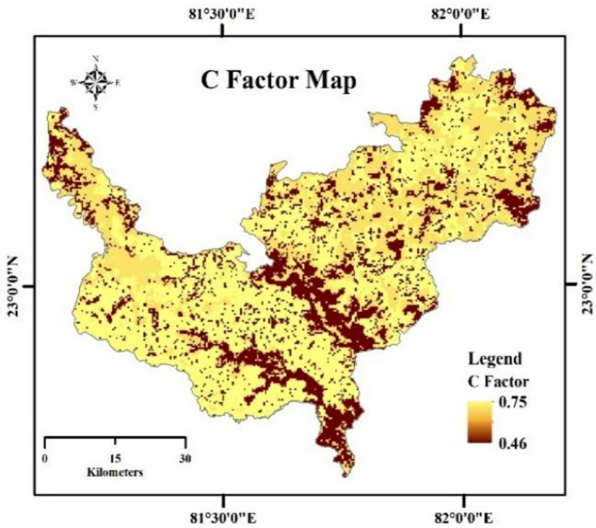

Figure 11. *C* factor map.

7.5. Support practice factor

This factor is mainly used to indicate the effects of conservation strategies on soil loss. Field observations conducted in the study region revealed the presence of various support practices, including check dams, bunds, canals, and agroforestry, particularly with Sal and eucalyptus plantations. However, due to the paucity of systematic data for these practices, it was not possible to integrate them into the RUSLE model. In this study, a *P*-factor value of 0.8 was assigned to non-agricultural areas, while 0.9 was assigned to agricultural fields [43] (**Figure 12**).

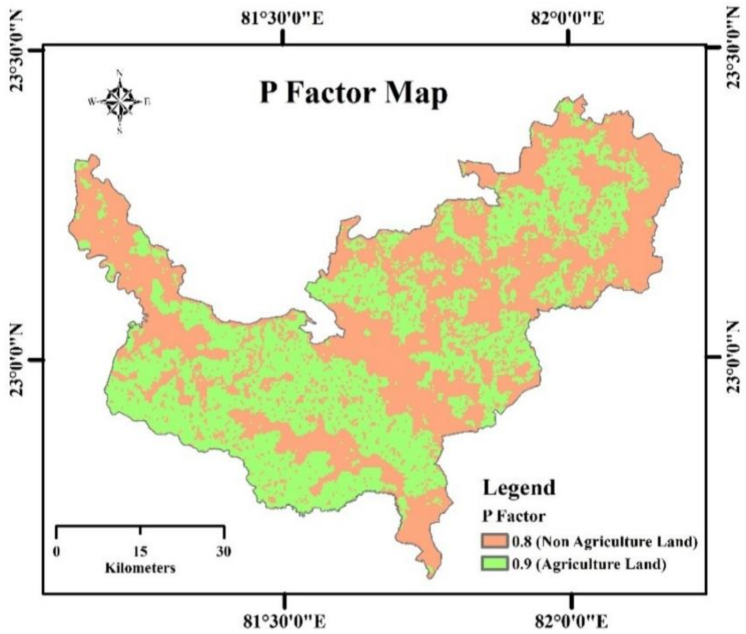

Figure 12. *P* factor map.

8. Estimation of potential annual soil erosion in the district

The annual average soil loss assessment in the study area, conducted using the RUSLE model within a remote sensing and GIS framework, revealed significant spatial differences in soil erosion rates. After multiplying all the factors of the RUSLE Model by putting them in an equation ($A = R \times K \times LS \times C \times P$), the final results revealed that in Anuppur district, the average annual soil loss was found to be 2.68 tons per hectare per year. The annual soil loss in the study area ranged from 0 to 151 tons per hectare per year, highlighting the diverse erosion potential across various land use types and topographical features (**Figure 13**).

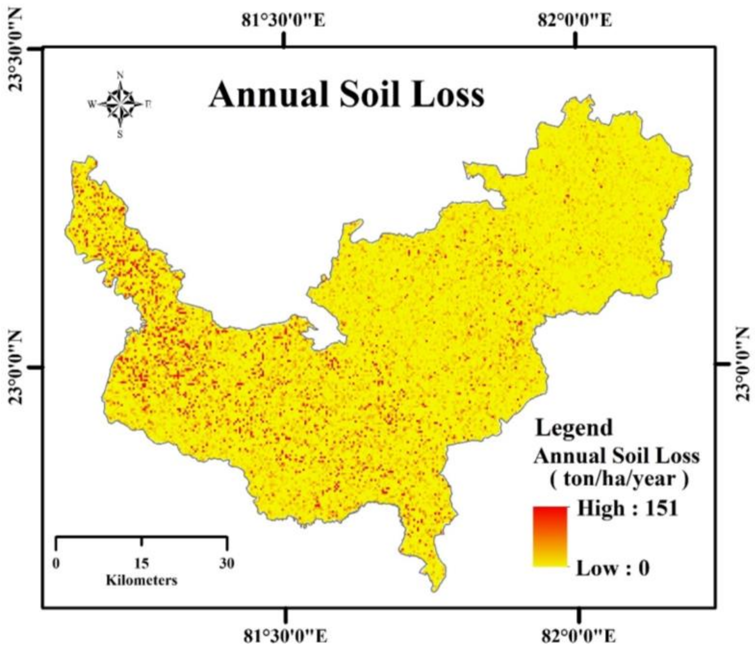

Figure 13. Annual soil loss map.

Further, the district's average yearly soil loss is divided into six classes: slight, moderate, high, very high, severe, and very severe [45] The final result of the study indicates that a large portion of the study area, i.e., 3371.23 km^2 (91%) of the area of the district, comes under the slight soil erosion category, followed by 154 km^2 (4.16%) in the moderate soil erosion category, 92 km^2 (2.5%) in the high soil erosion category, 50 km^2 (1.35%) in the very high soil erosion category and around 30 km^2 (1%) in the category of severe and very severe soil erosion (**Table 8**).

The spatial analysis of soil erosion reveals that steep slopes (as indicated by high *LS*-factor values) and agricultural areas with limited conservation practices (as indicated by high *C* and *P*-factor values) are the primary contributors to soil erosion. Additionally, the western portion of the study area, i.e., the Pushprajgarh block, which receives more rainfall and has a hilly landscape, exhibits higher erosion rates, indicating the role of rainfall erosivity (*R*-factor) in soil loss.

The findings offer critical insights for identifying erosion-prone areas and prioritizing efforts for soil conservation. This study underscores the necessity of implementing erosion control measures, such as contour plowing, afforestation, and the construction of check dams, particularly in regions characterized by high to severe erosion risk.

Table 8. Area under different categories of annual soil erosion.

Category	Soil loss (t/ha/yr)	Area (Sq km)	Area (%)
Slight	0–3	3371.23	91.08
Moderate	3–6	154	4.16
High	6–12	92.75	2.5
Very high	12–24	50.25	1.35
Severe	24–48	29.24	0.79
Very Severe	> 48	3.76	0.10

9. Conclusion and recommendation

Erosion of soil represents a significant environmental issue, with adverse effects on water quality, soil health, and the overall stability of ecosystems across the globe. The conventional approaches to estimating soil erosion are often expensive and require significant time investment. However, the application of remotely sensed data and geographical information systems for assessing annual soil loss has rendered this process more economical and efficient. Furthermore, in future research, the integration of machine learning algorithms alongside hydrological modeling techniques can improve the accuracy of soil erosion predictions.

Since the average annual soil loss in the district was found to be 2.68 tons per hectare per year, effective soil conservation strategies such as afforestation, the construction of small check dams, earthen bunds, and farm ponds are required. Top of form Bottom of form the contour farming should be prioritized in areas identified as moderately to highly vulnerable, e.g., Pushprajgarh Block. The government has implemented various programs and policies for the conservation of natural resources, but unfortunately, they are not objectively effective in the district. The local administration is not properly inspecting the implemented programs, and the local people are also responsible for not being aware of soil conservation and land management for the sustainable productivity of crops. Apart from this, sustainable mining practices to reduce the land degradation, implementing the watershed management programs to regulate water drainage and soil conservation, conducting training programs, and engaging local communities in soil conservation efforts through government schemes like MGNREGA and Rastriya Krishi Vikas Yojana (RKVY) are some notable suggestions to mitigate soil erosion in Anuppur district. It is needed to implement the sustainable practices, programs, and policies for soil conservation with the people's participation to conserve the fertility of the upper layer and maintain the ecosystem of the land surface in the district. Rainwater harvesting, forestation, contour bonding, terrace cultivation, and grazing control are effective processes for soil erosion. At last, the study provides significant insights into soil erosion for policymakers and brings their attention to the need for soil conservation in the tribal and agriculturally dominated districts of Madhya Pradesh**.**

Limitations

While effective in estimating soil erosion using the RUSLE model and GIS tools, this study has several limitations. RUSLE considers only sheet and rill erosion, excluding other forms like gully or streambank erosion. The accuracy of results depends on the quality and resolution of input data, which may be outdated or generalized. Static land use data and average rainfall values do not account for seasonal changes or extreme events. The support practice (*P*) and slope (*LS*) factors are often estimated using assumptions or low-resolution data, potentially reducing precision. Additionally, the lack of field validation limits the reliability of the model outputs, and the analysis does not reflect long-term or temporal erosion trends.

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