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Spatial Estimation of Soil Erosion Using RUSLE Model: A Case Study of Sangareddy Telangna State, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil erosion is a major environmental challenge that affects agricultural productivity, water quality, and land management. To address this issue, accurate estimation and spatial mapping of soil erosion rates are essential for effective soil conservation planning and management. This study focuses on utilizing the Revised Universal Soil Loss Equation (RUSLE) model to estimate and map soil erosion rates in the Sangareddy district of Telangana State, India. The RUSLE model integrates several factors contributing to soil erosion, including rainfall erosivity, soil erodibility, slope length and steepness, cover management factor, and conservation practices. These factors were derived from geospatial datasets, including rainfall records, soil characteristics, topographic data, land use/land cover maps, and conservation practices information. By applying the RUSLE model, the study estimates the average annual soil erosion rates across the Sangareddy district. The spatial distribution of soil erosion is then mapped using geographic information system (GIS) techniques, providing valuable insights into the area's most susceptible to erosion. These findings

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can inform decision-makers and land managers in prioritizing and implementing appropriate soil conservation strategies to mitigate erosion and protect valuable soil resources. The spatial estimation of soil erosion using the RUSLE model provides a scientific basis for land-use planning, conservation program implementation, and policy formulation to promote sustainable land management practices. It highlights the need for effective erosion control measures, such as contour farming, terracing, afforestation, and appropriate land use practices, in order to minimize soil erosion and preserve the soil quality in Sangareddy and similar regions.

Keywords: Soil erosion; RUSLE model; Sangareddy; Telangana State; GIS.

1. INTRODUCTION

Soil erosion is a pressing environmental issue that poses significant challenges to agricultural productivity, land management, and the overall sustainability of ecosystems. It leads to the loss of fertile topsoil, degradation of water quality, and disruption of natural ecosystems. Therefore, accurate estimation and spatial mapping of soil erosion rates are crucial for understanding the extent of the problem and developing effective strategies for soil conservation. In the context of Sangareddy, a district located in the state of Telangana, India, soil erosion has emerged as a critical concern due to various factors such as intensive agricultural practices, deforestation, and rapid urbanization. The region's semi-arid climate, characterized by irregular rainfall patterns and vulnerable soil conditions, exacerbates the susceptibility to erosion [1-3]. To address the challenges posed by soil erosion in Sangareddy and formulate appropriate conservation strategies, it is essential to have a comprehensive understanding of the spatial distribution and magnitude of erosion rates across the district. In this regard, the Revised Universal Soil Loss Equation (RUSLE) model offers a valuable tool for estimating soil erosion rates and identifying the contributing factors. The RUSLE model is widely recognized as a robust method for predicting soil erosion by integrating key variables such as rainfall erosivity, soil erodibility, slope length and steepness, cover management factor, and conservation practices [4,5]. By considering these factors, the model enables the assessment of erosion rates across diverse landscapes and provides insights into the areas most vulnerable to erosion. In this study, we focus on applying the RUSLE model to estimate and spatially map soil erosion rates in Sangareddy, Telangana State. By utilizing geospatial datasets encompassing rainfall records, soil characteristics, topographic data, land use/land cover maps, and information on conservation practices, we aim to provide an accurate assessment of the average annual soil erosion rates across the district.

The spatial mapping of soil erosion will not only contribute to a better understanding of the current erosion patterns but will also help identify specific areas that require immediate attention for soil conservation measures. This information is vital for land managers, policymakers, and agricultural practitioners in implementing targeted erosion control strategies and promoting sustainable land management practices. Furthermore, the findings of this study will have broader implications beyond Sangareddy, as the methodology employed can be replicated and applied in similar regions facing soil erosion challenges [6-8]. By sharing insights into the spatial distribution of erosion rates and the effectiveness of conservation practices, this research can contribute to the development of evidence-based policies and practices that safeguard soil resources and promote sustainable agriculture. Overall, this study aims to address the knowledge gap in understanding soil erosion dynamics in Sangareddy, Telangana State, and provide valuable insights for effective soil conservation planning and management. By utilizing the RUSLE model, geospatial analysis, and interdisciplinary approaches, we strive to contribute to the ongoing efforts in promoting sustainable land use practices and mitigating the adverse effects of soil erosion in the region.

The most frequent kind of land degradation is probably runoff-induced erosion in sparsely vegetated areas since it is both widespread and irreversible, inflicting significant harm to the environment [9]. The complicated phenomena of soil erosion is studied using a variety of methods, one of which is the prevalent use of spatial data fusion.This strategy makes use of the Revised Universal Soil Loss Equation (RUSLE) model.

Recent decades have seen significant global attention paid to soil and water issues. The soil resources and agricultural output are severely hampered on approximately 549-1094 million acres of land [10]. According to the FAO [11], the global average rate of erosion is between 12 and 15 t/h/ year, or 0.90-0.95 mm of soil are lost annually.More than 1 billion ha of agricultural land are in a zone that is sensitive to water erosion, and 550 million ha are in a zone that is vulnerable to wind erosion (Wawer et al. 2005). The spatial distribution of soil erosion in Sangareddy was measured using the RUSLE model. RUSLE, however, is only suitable for the assessment of sheet erosion and rill erosion; gully erosion is not included. The model integrates a number of characteristics to provide accurate estimates of soil erosion despite its limitations.The study may provide a benchmark for the entire Sangareddy district and add to the body of knowledge regarding soil erosion.

2. MATERIALS AND METHODS

2.1 Study Area

The Study area was carried out in the year 2023 in Sangareddy district covering an area of 4996km^2 with a population of 1,97,860 and located in the Central region of the Telangana state with 17^{o}31'50.4" N and 78^{o}1'6.96" E. The district is one of the most industrialized regions in Telangana state. This province is characterized by an arid climate being cold and semi-humid in the northern areas and cold with long winters in the higher regions. The boundary of the study area was chosen in a way that could well represent a complex landscape and involved densely built-up area, wet lands, forests, water bodies, croplands, shrubs, and barren lands (Fig. 1).

2.2 Data Collection

The Revised Universal Soil Loss Equation is a powerful tool and used for estimate the soil loss. The RUSLE model can be used to estimate the yearly soil loss value and the intensity of soil erosion in a catchment area. The Wischmeier & Smith (1978) developed USLE erosion model's framework is the foundation for the RUSLE model, which Renard et al. [12] enhanced and modified (Table 1).

$$A= [R]*[K]*[LS]*[C]*[P] \qquad \text{………….(1)}$$

Where A = Annual soil loss (t ha−1 year−1), R = Rainfall erosivity factor (MJ mm ha−1 h−1 year−1), K = Soil erodibility factor (t ha h ha−1 MJ−1 mm−1), LS = Slope length factor (dimensionless), C = Crop cover management factor (dimensionless), P = Conservation practices factor (dimensionless)

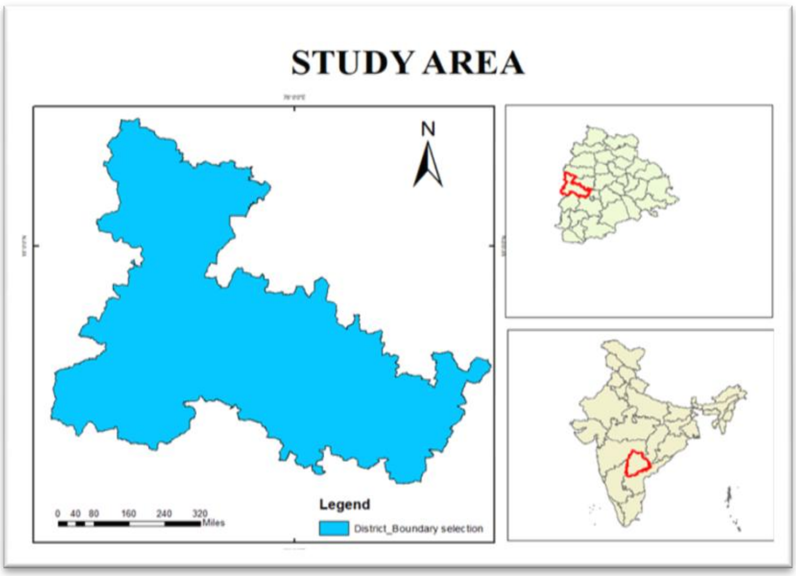


Fig. 1. Location map of the Study Area

Table 1. The spatial datasets for this research

Datasets	Data Source
DEM	https://earthexplorer.usgs.gov/
Soil Map	Digital soil map of the World www.fao.org/geonetwork/srv/en/metadata.show
LULC map	https://earthexplorer.usgs.gov/
Rainfall data	Collected data from District office

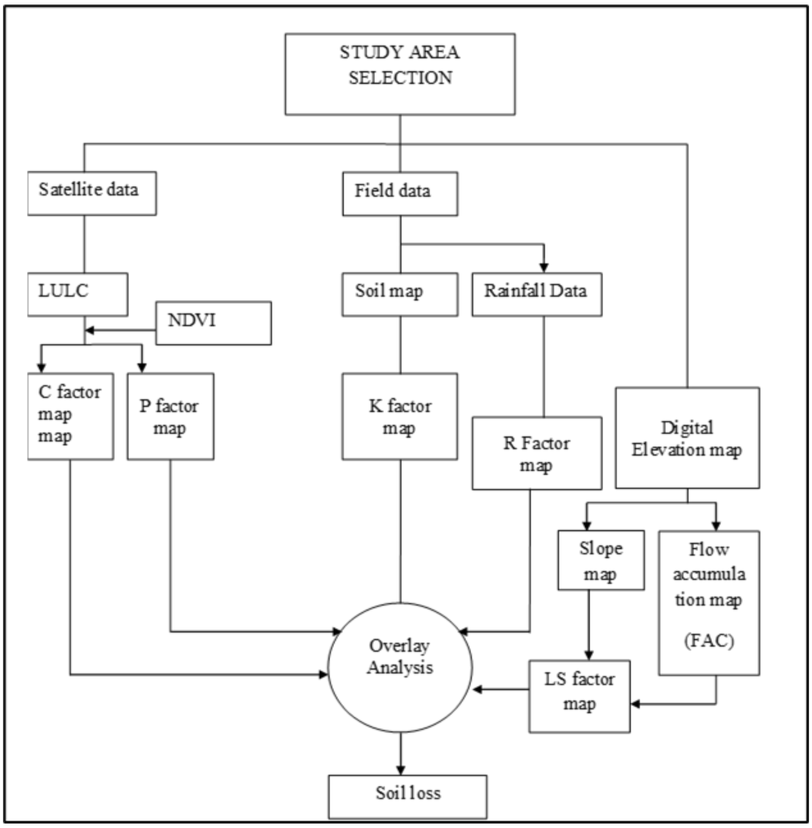


Fig. 2. Flow chart for estimation of soil erosion

2.3 Rainfall Erosivity Factor (R)

The ability of rain to affect or separate soil particles based on the amount of rainfall is known as the rainfall erosivity factor (R).The RUSLE's erosivity criteria must take into account the influence that raindrops have on the soil as well as the amount of runoff that results from rainfall.In current study, the rainfall data was collected from Chief planning office, Collectorate Sangareddy, Telangana. The rainfall map that was created represents the district of Sangareddy's average yearly precipitation. Given equation is used to calculate R-factor given by [13].

$$R = 38.5 + 0.35P \quad \text{………………(2)}$$

Where R= Rainfall erosivity factor, P= Mean Annual Rainfall (mm)

2.4 Soil Erodibility Factor (K)

The soil erodibility factor (K) gauges how easily soil particles can separate and be carried away by rain and runoff. According to Erencin et al. [14], the soil profile's permeability, organic content, and texture all affect the K factor.To calculate the soil loss, an equation from the reference is employed [15].

$$K = Fcsand * Fsi\text{-}cl * Forgc * Fhisand * 0.1317 \quad \text{…….(3)}$$

WhereFcsand=low soil erodibility factor for soil Fsi-cl=low soil credibility factor with high clay to silt ratio. Forgc=factor that reduces soil erodibility for soil with high organic content. Fhisand=factor that reduces soil erodibility for soil with high sand content.

Table 2. K Factor data [14]

Textural Class	K Factor (tons/acre)
Clay loam	0.67
Sandy clay loam	0.45
Clay	0.2

2.5 Topographic Factor (LS)

Topographic factor is the function of slope length (L) and slope steepness (S). It represents the effect of topography on erosion. In the present study, the LS factor maps were generated from thematic layers of slope and flow accumulation maps derived from ASTER DEM using the following equation (4) [16]:

$$LS = \left(\frac{flow\ accumulation * cell\ value}{22\cdot 1}\right)^m (0.065 + 0.045s + 0.0065s2 \quad \ldots(4)$$

2.6 Cover Management Factor (C)

According to Chalise et al. [17], the cover management factor (C) accounts for the impact of cropping and other practises on erosion rates.It is the most spatiotemporally sensitive because it tracks the dynamics of plant development and rainfall [18]. This factor is described as a non-dimensional number between 0 and 1 that compares the comparable loss from continuous bare fallow to the soil loss due to rainwater erosion under certain land and vegetation conditions (Wischmeier and Smith 1978). The study examined nine different forms of land use, which were converted from a raster map to a polygon using the raster to polygon tool and combined into a single class using ArcGIS 10.8 software (Table 3). Each land-use example has a C value assigned by reference that is in the range of 0 to 1, with a lower C value signifying no loss and a larger C value signifying significant odds of soil loss [14,19,20].

Table 3. Land use land cover and C factor

S. No	LULU	C Factor
1	Water bodies	0.00
2	Forest	0.03
3	Floddedvegitation	0.01
4	Crop land	0.21
5	Build up area	0.70
6	Barren land	0.45
7	Scrub land	0.03

2.7 Conservation Practice Factor (P)

According to agricultural practise, the support practise component shows the rate of soil erosion. In order to control erosion, three techniquescontours, cropping, and terracesare essential [21]. According to Table 4 of Kouli et al. [15], the contouring approach utilised with P values runs from 0 to 1, with 0 denoting proper anthropogenic erosion and 1 denoting a non-anthropogenic erosion facility.

Table 4. P factor values for slope [22]

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

3. RESULTS AND DISCUSSION

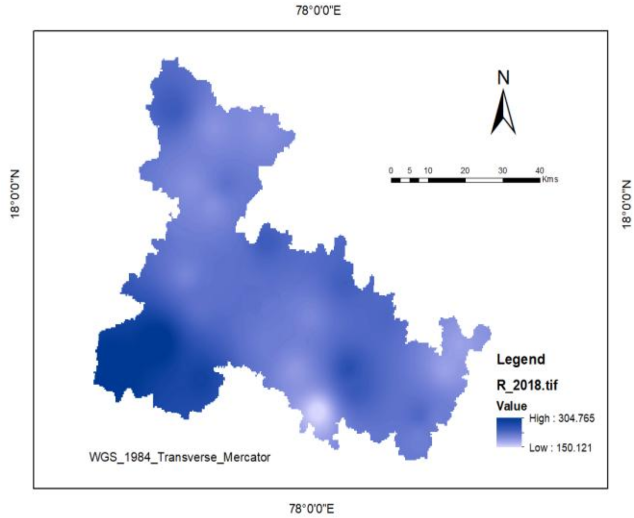
The findings showed that rainfall erosivity factor (R) values ranged from 150.12 to 304.76mm/ha/yr, whereas topographic factor (LS) values ranged from 0 to 6.02. The values of the soil erodibility factor (K) were 0.45 to 0.71. For the entire area, the support practise factor (P) values ranged from 0.55 to 0.95. Values for the cover management factor (C) were between 0.01 and 0.7.

3.1 Potential Soil Erosion Rates of Sangareddy District

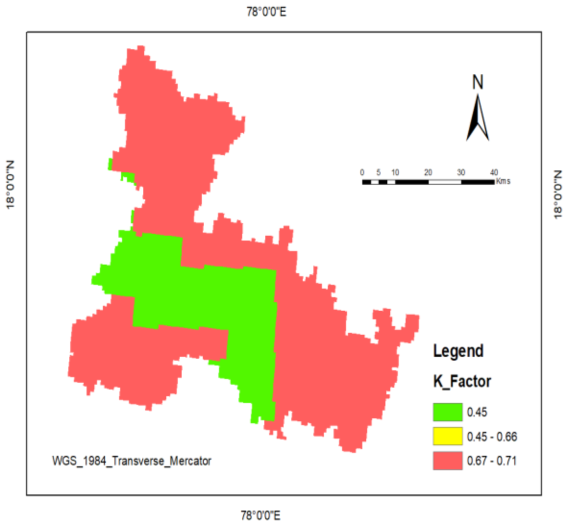
Using the Arc GIS raster calculator, five factors that exacerbate site erosion were multiplied to create a possible erosion map of the Sangareddy district.The results indicate that majority of land falls under the low erosion hazard zone (0-5 t/h/yr.).

3.2 Discussions

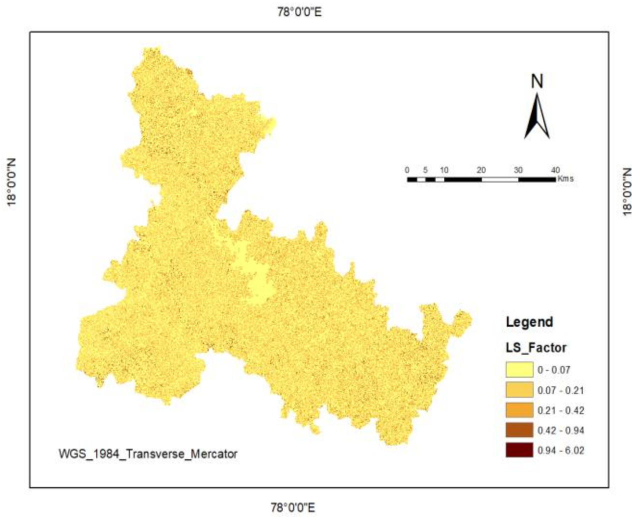
The long-term average yearly rate of soil erosion on slopes is predicted using RUSLE, an empirically based modelling approach, employing five variables. According to Prasannakumar et al. [23], it calculates soil loss under comparable topographical and climatic conditions.This study used ArcGIS software to create a possible soil erosion rate map for the Sangareddy district utilising data from several sources. This methodology still has certain drawbacks, but it is the first time that erosion risk has been assessed across an entire mountainous region.It once more identifies key regions for mitigating soil erosion. The same methodology was also applied by other research projects with comparable geographic characteristics [23,19,20,22]. The uncertainties in an erosion model should be kept to a minimum by properly taking into account the R-factor, LS-factor, K-factor, P-factor, and C-factor.



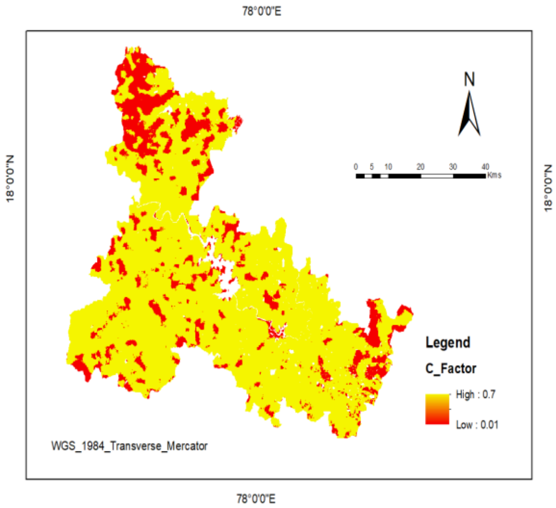
a. Rainfall erosivity factor map



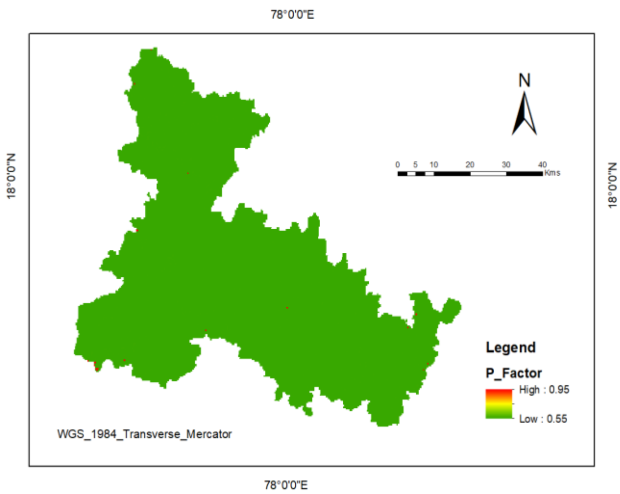
b. soil erodibility factor map



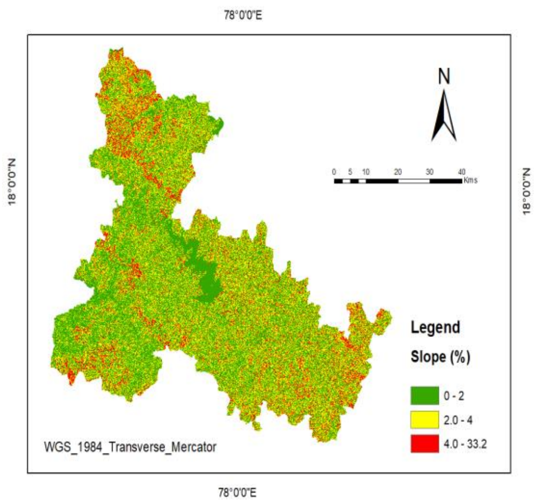
c. Topographic factor map



d. Cover management factor map



e. Consrvation practice factor



f. Slope map

Fig. 3. Five factors maps of soil erosion of the study area

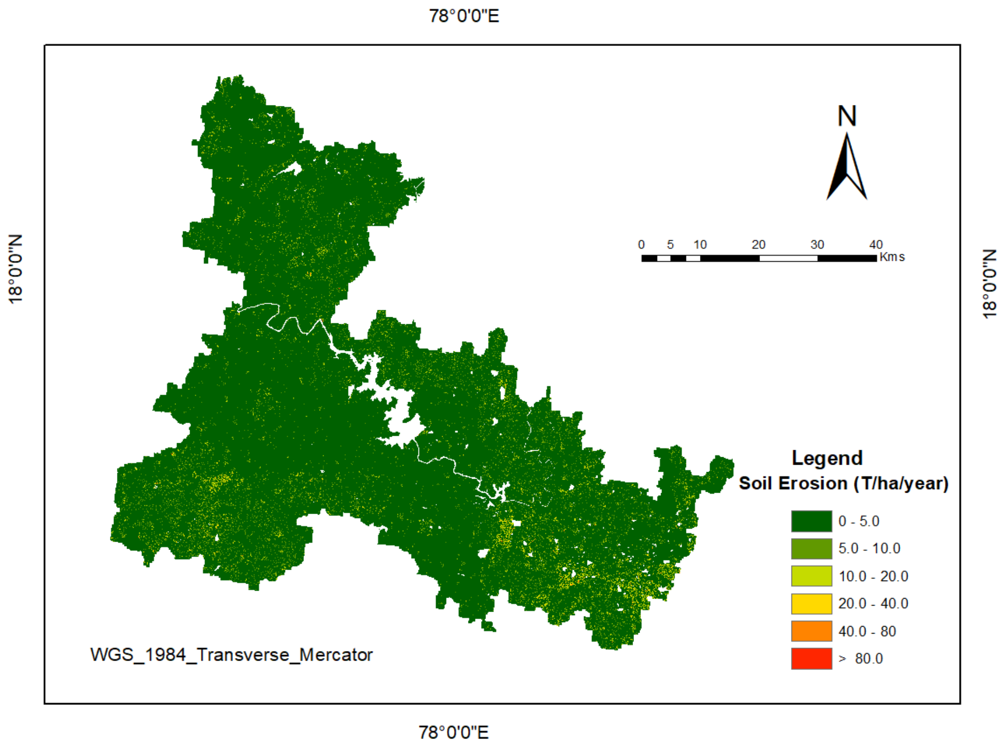


Fig. 4. Potential map of soil erosion rate of Sangareddy district

Table 5. Potential soil erosion rate of Sangareddy district

Class	Rate of Erosion (tons/ha/year)	Severity
1	0.0-5.0	Low
2	5.0-10.0	Moderate
3	10.0-20.0	High
4	20.0-40.0	Very High
5	40.0-80.0	Severe
6	>80.0	Very Severe

4. CONCLUSIONS

The GIS-based RUSLE equation used to calculate the severity of soil erosion takes into account rainfall, soil, DEM, land use, and land cover. Less than 1% of the regions were classified as being at extremely high risk (> 80 t ha per year), while 94.98% of the whole area was classified as being at low risk. This illustration depicts a region susceptible to soil erosion due to its high elevation and frequent rains. The decision-makers' planning and conservation efforts can be supported by the expected severity. Special priority and control measures are required in places with severe to severe soil erosion. While the mapping and prediction of susceptibility zones using remote sensing and GIS-based research is the cornerstone of this model, such studies are advised for model conservation and enhancement in the future.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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