

# SPATIO-TEMPORAL ESTIMATION OF SOIL EROSION USING RUSLE MODEL: A CASE STUDY OF SANGAREDDY DISTRICT OF TELANGANA

## ABSTRACT

Soil erosion poses a significant environmental challenge worldwide as it depletes fertile topsoil, diminishes crop productivity, and leads to heightened sedimentation in streams and reservoirs, ultimately reducing their storage capacity. The extent of soil erosion primarily relies on factors such as the intensity and duration of rainfall, the land slope, soil type, land use and cover, as well as the land management practices employed. Accurate assessment of soil loss, considering spatial, temporal, and climate change factors, is crucial for effectively planning soil and water conservation interventions in watersheds. Therefore, a spatial model for estimating soil loss was created by integrating GIS with RUSLE, and its validation demonstrated satisfactory results ( $R^2=0.82$ ). The spatial estimation of soil loss revealed that a majority of the area experienced soil loss below  $5 \text{ t ha}^{-1} \text{ yr}^{-1}$ , with only a smaller portion showing soil loss exceeding  $20 \text{ t ha}^{-1} \text{ yr}^{-1}$ . Hence, it is recommended to implement in-situ soil conservation measures, such as strip cropping with erosion-resistant crops (e.g., groundnut), crop rotations, mulching, and planting grasses for bund stabilization. Additionally, practices like deep ploughing, summer ploughing, and mixed cropping should be adopted. For sustainable management of the watershed, the construction of conservation structures like farm ponds and percolation tanks is also highly recommended. The temporal variation in soil loss for Sangareddy district revealed that the highest soil loss of  $134 \text{ t ha}^{-1} \text{ yr}^{-1}$  occurred in 2020, while the lowest soil loss of  $71 \text{ t ha}^{-1} \text{ yr}^{-1}$  was observed in 2018.

*Key words: RUSLE, Sangareddy, GIS, Spatial distribution, Soil Erosion*

## 1. INTRODUCTION

Soil erosion is a complex and pervasive environmental issue that affects agricultural productivity, water quality, and overall land sustainability. The estimation and understanding of soil erosion patterns in a specific region are crucial for implementing effective land management and conservation strategies. In this regard, the Revised Universal Soil Loss Equation (RUSLE) has proven to be a valuable tool in predicting and assessing soil erosion rates, considering various influential factors such as rainfall, soil characteristics, slope, land use, and land cover.

This study focuses on the spatio-temporal estimation of soil erosion using the RUSLE model, with a particular emphasis on the Sangareddy district of Telangana. Sangareddy, like many other regions, faces significant soil erosion challenges due to its geographical location, land use patterns, and climatic conditions. The district's agricultural significance and reliance on its natural resources make soil erosion a critical concern for sustainable land management and agricultural productivity.

The RUSLE model has gained prominence as a robust method to assess soil erosion potential in various regions, making it an ideal approach for this case study. By incorporating multiple factors that contribute to soil erosion, the RUSLE model allows for a comprehensive analysis of soil loss patterns over time, enabling stakeholders and policymakers to make informed decisions to mitigate erosion and protect the region's natural resources.

The primary objective of this study is to provide accurate and up-to-date estimates of soil erosion rates in the Sangareddy district, taking into account changes in land use, climatic variations, and other relevant factors over a specified period. The findings of this research will serve as a valuable resource for local authorities, farmers, and environmentalists to devise sustainable land management practices, erosion control measures, and conservation strategies tailored to the specific needs of the region. By understanding the dynamics of soil erosion in Sangareddy, this study aims to contribute to the broader field of soil science and environmental management, emphasizing the importance of proactive approaches to tackle soil erosion challenges in Telangana and beyond.

In India, 130 M.ha of land i.e. 45% of the total geographical area is having serious soil erosion (Kothyari 1996; Ganasri and Ramesh, 2016). Approximately 5,334 Mt of soil is detached yearly; of which 29% is transported by rivers into the sea and 10% is settled down in reservoirs reducing the storage capacity (Narayana and Babu, 1983). The spatial estimation of runoff and soil loss is very essential for planning of in-situ soil and water conservation interventions and water harvesting structures in watersheds (Rejani *et al.*, 2016 and 2017).

The Revised Universal Soil Loss Equation (RUSLE) is a widely used empirical model that estimates soil erosion by considering various factors such as rainfall erosivity, soil erodibility, slope length and steepness, land cover and conservation practices. RUSLE provides a valuable tool to assess soil erosion potential and guide decision-making processes related to land use planning and erosion control.

## **2. MATERIALS AND METHODS**

### **2.1 Study Area**

The Study area was carried out in the Sangareddy district covering an area of 4996km<sup>2</sup> with a population of 1,97,860 and located in the Central region of the Telangana state with 17°31'50.4" N and 78°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 (Fig.1) 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. The mean annual average rainfall in the study area was 910 mm.

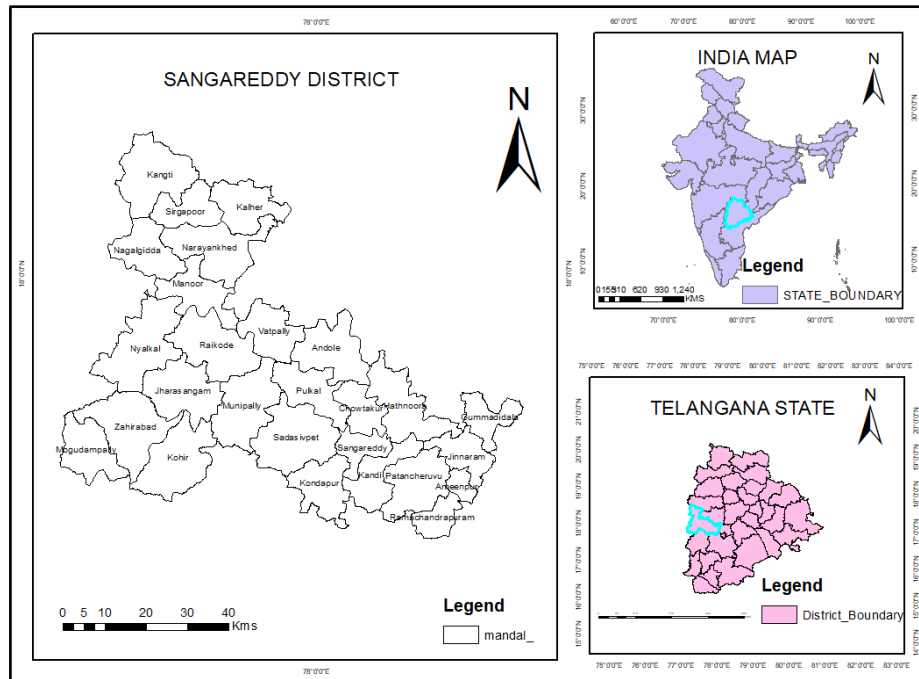


Figure 1: Study Area Map

## 2.2 Data Collection

Table 1. The spatial datasets for this research are shown

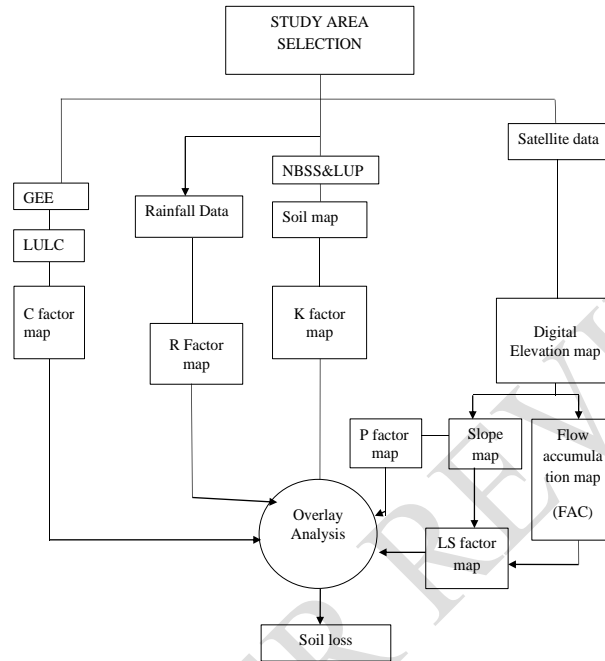
Datasets	Data Source
ASTER DEM	<a href="https://search.earthdata.nasa.gov/">https://search.earthdata.nasa.gov/</a>
Soil Map	NBSSLUP
LULC map	GEE
Rainfall data	Chief Planning Officer (CPO), Collectorate, Sangareddy District

## 2.3 Methods

The Revised Universal Soil Loss Equation (RUSLE) 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 and Smith (1978) developed USLE erosion model's framework is the foundation for the RUSLE model, which Renard *et al.* (1997) enhanced and modified. The RUSLE model uses five parameters to calculate soil loss and to forecast long-term annual averages of soil loss. RUSLE uses physically relevant input values that are easily collected from ASTER DEM, satellite images and is made simple to use through the GIS interface. The most effective erosion prediction model now in use that is simple to implement at the local or regional level and it may be easily combined with a wide range of characteristics, including slope obtained from ASTER DEM and LULC (land use land cover) from satellite imagery. The RUSLE equation (1) is a multiplicative function of five factors controlling the rill and inter-rill erosion and can be expressed as:

$$A = [R] * [K] * [LS] * [C] * [P] \dots \dots \dots (1)$$

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)



**Figure 2 : Flow chart for estimation of soil erosion**

## 2.4 Various parameters used in RUSLE

### 2.4.1 Rainfall Erosivity Factor (R)

The rainfall erosion factor (R) characterizes the precipitation intensity at a specific location, influencing the amount of soil erosion (Koirala *et al.*, 2019; Tapa and Upadhyaya, 2019). Crucial for assessing soil erosion risk under future land use and climate change conditions (Stocking, 1984). In this study, the daily rainfall data for the period from 2005 to 2022 was collected from Chief Planning Office (CPO), Collectorate Sangareddy, Telangana. R factor is calculated as per the equation (2) reported by Morgan *et al.* (1984).

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

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

### 2.4.2 Soil Erodibility Factor (K)

The soil map developed by using NBSSLUP world soil data has been taken as reference map and clipped to the study area. The different types of the soils in study area were Clayey, (Clayey, Calcareous), Cracking Clay, (Cracking Clay, Calcareous), Gravelly Clay, Loamy as shown in Table 2.

Table 2: K factor values for different soil classes

Textural Class	K Factor
Clayey	0.32
Clayey, Calcareous	0.32
Cracking Clay	0.32
Cracking Clay, Calcareous	0.32
Gravelly Clay	0.32
Loamy	0.12

### 2.4.3 Topographic Factor (LS)

The topographic factor is determined by both the length of the slope (L) and its steepness (S). It signifies the influence of topography on erosion. In this study, the LS factor maps were created by processing thematic layers of slope and flow accumulation maps obtained from ASTER DEM, utilizing the equation (2) as described by Tirkey *et al.* (2013):

$$LS = \left( \frac{\text{flow accumulation} * \text{cell value}}{22.1} \right)^m (0.065 + 0.045s + 0.0065s^2) \dots \dots \dots (2)$$

Where, s is the slope of ASTER DEM in degrees, cell value is the resolution of the ASTER DEM and m is dimensionless constant which depends upon slope. The value of 'm' is equal to 0.5 for slopes greater than 5°, 0.4 for slopes of 3° to 5° and 0.3 for slopes of less than 3°. For the proposed study, ASTER DEM (30 m) was used and hence, the cell size was considered as 30. The LS factor map for watershed was prepared by means of the spatial analyst tools in ArcMap 10.3.

### 2.4.4 Cover Management Factor (C)

As stated by Chalise *et al.* (2019), the cover management factor (C) takes into consideration the influence of cropping and other practices on erosion rates. Nearing *et al.* (2004) explain that it is the most spatiotemporally sensitive factor since it monitors the interplay of plant development and rainfall dynamics. This factor is defined as a non-dimensional value ranging from 0 to 1, which compares the equivalent loss from continuous bare fallow to the soil loss caused by rainwater erosion under specific land and vegetation conditions (Wischmeier and Smith 1978). The study analyzed nine distinct land use forms, which were transformed from a raster map to a polygon using the raster to polygon tool and then merged into a unified class using ArcGIS 10.8 software (Table 3). Each land-use category is assigned a reference C value ranging from 0 to 1, where a lower C value indicates minimal soil loss, and a higher C value indicates a higher likelihood of significant soil loss (Erencia *et al.* 2000; Panagos *et al.* 2015).

Table. 3 Land use land cover and C factor.

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

#### 2.4.5 Conservation practice factor (P)

Based on agricultural practices, the support practice component indicates the rate of soil erosion. To manage erosion effectively, three essential techniques they are contours, cropping, and terraces are required (Park et al., 2005). As per Table 4 from Kouli et al. (2009), the contouring approach utilized with P values ranges from 0 to 1, where 0 represents proper anthropogenic erosion, and 1 represents a non-anthropogenic erosion scenario.

Table. 4 P factor values for slope (Kumar and Kushwaha 2013)

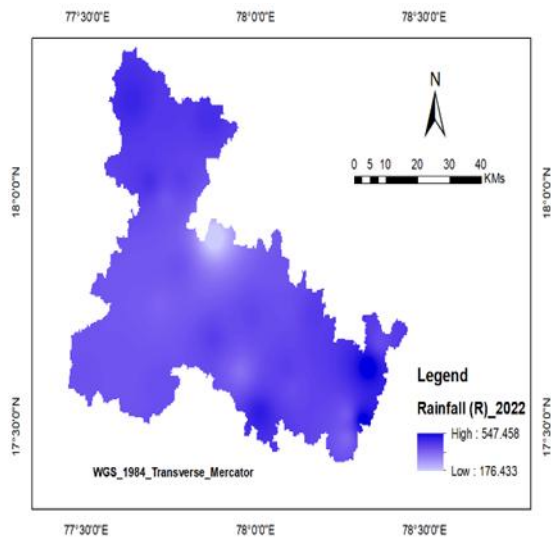
S. No	Slope %	P Factor
1	0.0-7.0	0.55
2	7.0-11.3	0.60
3	11.3-17.6	0.80
4	17.6-26.8	0.95
5	>26.8	1.0

### 3. RESULTS AND DISCUSSION

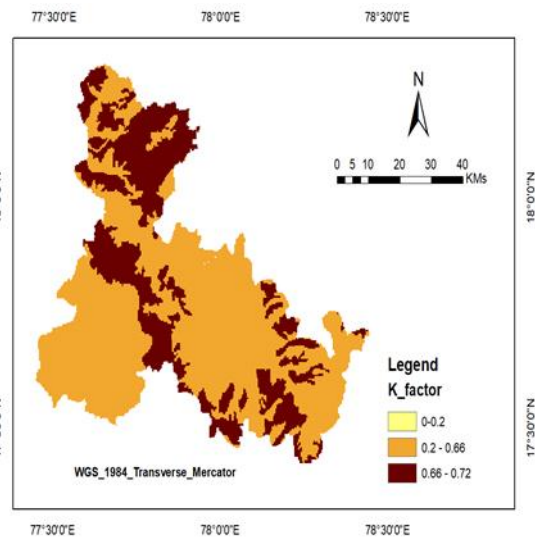
The findings showed that rainfall erosivity factor (R) values ranged from 277.145 to 382.049 mm/ha/yr for the Normal of (2005 to 2022) years, 120.228 to 304.77 mm/ha/yr for the 2018 Dry year, 185.368 to 603.969 mm/ha/yr for the 2020 Wet year and 176.433 to 547.458 mm/ha/yr for the 2022 year whereas topographic factor (LS) values ranged from 0.02 to 2.32. The values of the soil erodibility factor (K) were 0 to 0.72. For the entire area, the support practise factor (P) values ranged from 0.55 to 1.0. Values for the cover management factor (C) were between 0.01 and 0.7.

#### 3.1 Potential soil erosion rates of Sangareddy District

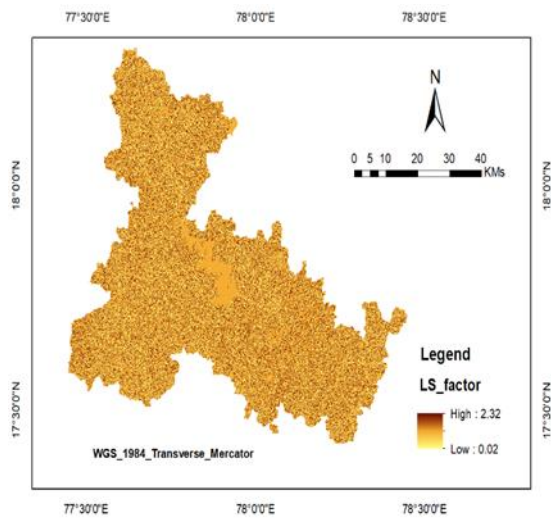
Using the Arc GIS raster calculator, five factors that exacerbate site erosion were multiplied to create a possible erosion maps of the Sangareddy district. The results indicate that majority of land falls under the low erosion hazard zone (0-5 t/h/yr.).



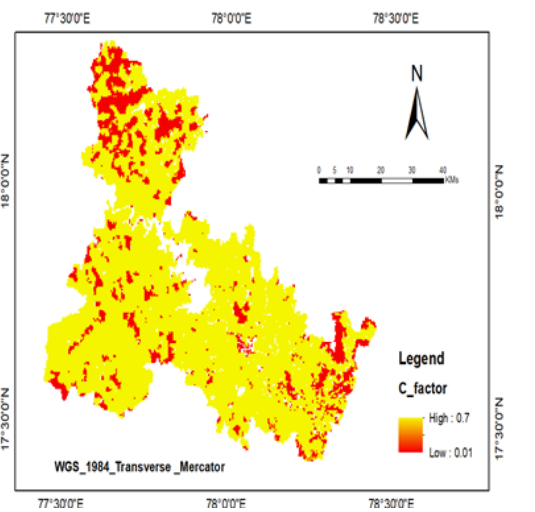
a. Rainfall erosivity factor map



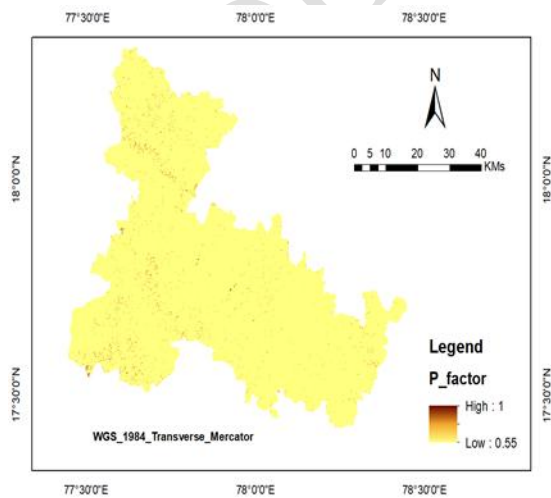
b. soil erodibility factor map



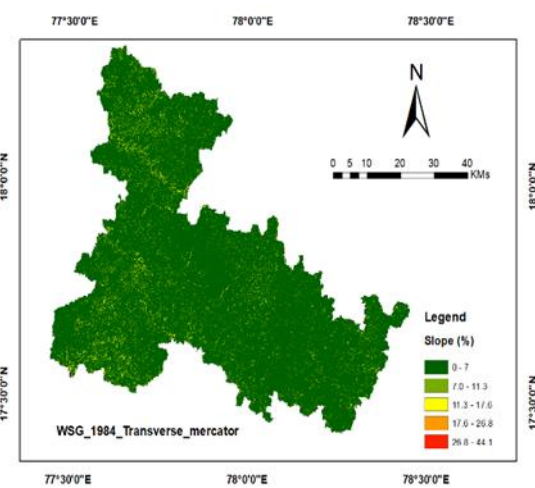
c. Topographic factor map



d. Cover management factor map



e. Conservation practice factor



f. Slope map

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

### 3.2 Discussions

RUSLE, an empirically based modeling approach, employs five variables to predict the long-term average yearly rate of soil erosion on slopes. As stated by Prasannakumar et al. (2012), the method calculates soil loss under similar topographical and climatic conditions. In this study, ArcGIS software was employed to generate a potential soil erosion rate map for the Sangareddy district by integrating data from multiple sources. Despite some limitations, this methodology represents the first-ever attempt to assess erosion risk across an entire mountainous region. Once again, it highlights critical areas for soil erosion mitigation. Similar geographic characteristics led other research projects to apply the same methodology (Prasannakumar et al., 2012; Panagos et al., 2015; Kumar and Kushwaha, 2013) To minimize uncertainties in an erosion model, it is essential to adequately consider the R-factor, LS-factor, K-factor, P-factor, and C-factor.

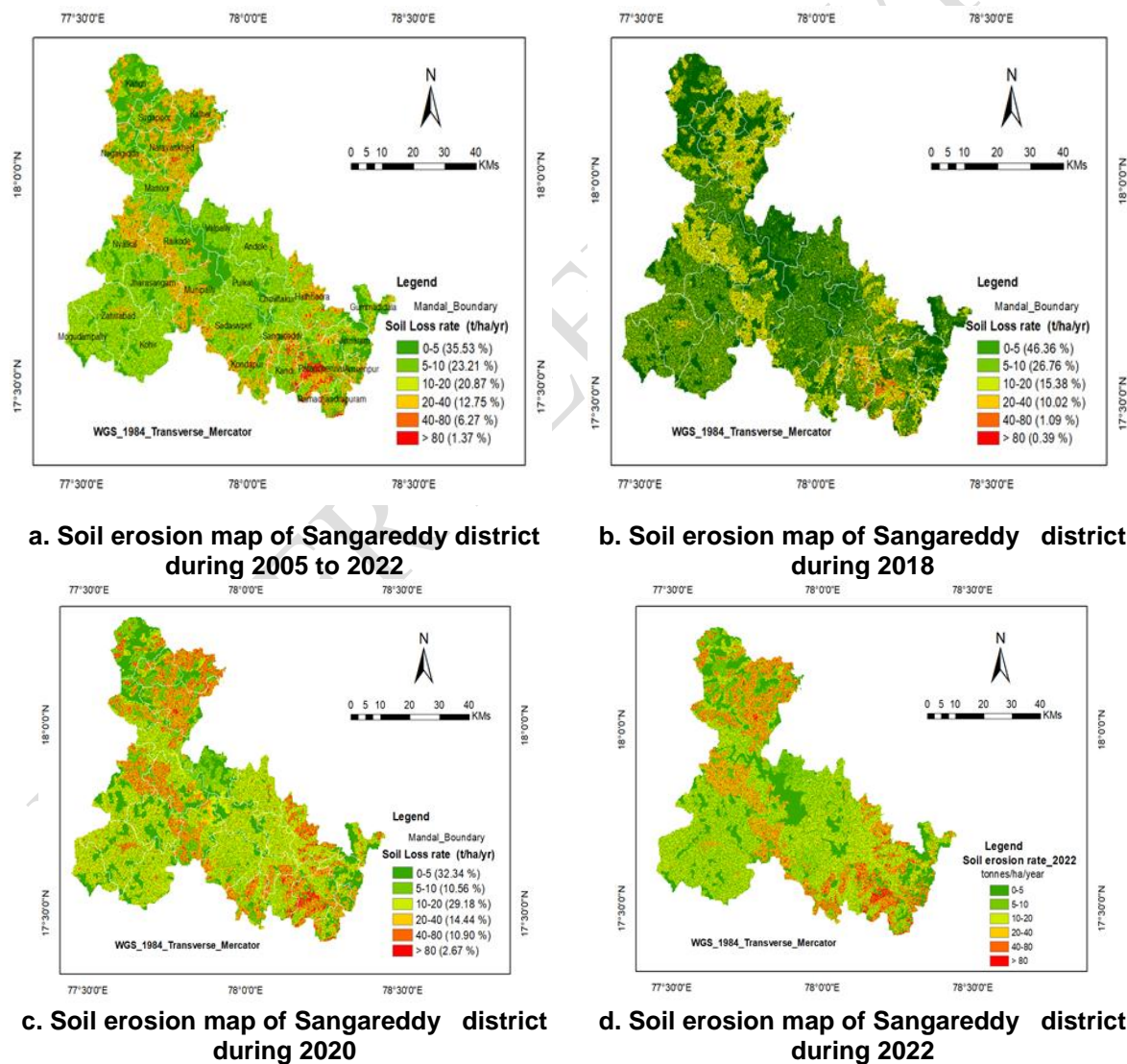


Figure. 4 Potential maps of soil erosion rate of Sangareddy district

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

## CONCLUSIONS

The severity of soil erosion is calculated using the GIS-based RUSLE equation, which incorporates rainfall, soil, ASTER DEM, land use, and land cover. The temporal variation in soil loss for Sangareddy district revealed that the highest soil loss of  $134 \text{ t ha}^{-1} \text{ yr}^{-1}$  occurred in 2020, while the lowest soil loss of  $71 \text{ t ha}^{-1} \text{ yr}^{-1}$  was observed in 2018. This illustration portrays a region prone to soil erosion because of its elevated terrain and frequent rainfall. The projected severity can aid decision-makers in their planning and conservation efforts. Special priority and control measures are required in areas with high to very severe soil erosion. While the foundation of this model lies in mapping and predicting vulnerability zones using remote sensing and GIS-based research, future studies are recommended to enhance and refine the model for conservation purposes.

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