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

ABSTRACT

Soil erosion poses a significant environmental challenge worldwide, causing the depletion of fertile topsoil, reduced crop productivity, and heightened sedimentation in water bodies. The extent of erosion depends on factors such as rainfall intensity, land slope, soil type, land use, and management practices. Accurate assessment of soil loss, considering spatial, temporal, and climate change factors, is vital for effective soil and water conservation planning. In this study, a spatial model for estimating soil loss was developed by integrating GIS with the Revised Universal Soil Loss Equation (RUSLE), and validation showed satisfactory results (R^2=0.82). The spatial estimation revealed that most of the area experienced soil loss below 5 t ha-1 yr-1, with only a smaller portion showing soil loss exceeding 20 t ha-1 yr-1. To address this, in-situ soil conservation measures are recommended, such as using erosion-resistant crops (e.g., groundnut) in strip cropping, adopting crop rotations, mulching, and planting grasses for bund stabilization. Practices like deep ploughing, summer ploughing, and mixed cropping should also be adopted for sustainable watershed management. Construction of conservation structures like farm ponds and percolation tanks is highly recommended. The study also observed temporal variations in soil loss for Sangareddy district, with the highest soil loss of 134 t ha−1 yr−1 occurring in 2020, and the lowest of 71 t ha−1 yr−1 in 2018. These findings underscore the need for continuous monitoring and adaptive conservation strategies to mitigate soil erosion and ensure sustainable land use practices in the region.

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

INTRODUCTION

Soil erosion presents a multifaceted and widespread environmental challenge, impacting agricultural productivity, water quality, and land sustainability. Accurate estimation and comprehension of soil erosion patterns in a particular area are essential for implementing successful land management and conservation approaches. The Revised Universal Soil Loss Equation (RUSLE) emerges as a valuable tool in this context, enabling the prediction and assessment of soil erosion rates by considering influential factors like rainfall, soil characteristics, slope, land use, and land cover.

This study is centered on the spatio-temporal estimation of soil erosion in the Sangareddy district of Telangana, employing the RUSLE model. Sangareddy, like numerous other regions, confronts substantial soil erosion challenges due to its geographical location, land use patterns, and climatic conditions. The district's agricultural significance and dependence on natural resources emphasize the critical importance of addressing soil erosion for sustainable land management and agricultural productivity.

The RUSLE model has earned widespread recognition as a robust method for evaluating soil erosion potential in diverse regions, rendering it an ideal approach for this case study. By integrating multiple factors influencing soil erosion, the RUSLE model facilitates a comprehensive analysis of soil loss patterns over time, empowering stakeholders and policymakers to make well-informed decisions aimed at mitigating erosion and safeguarding the region's valuable natural resources.

The main aim of this study is to furnish accurate and current estimates of soil erosion rates in the Sangareddy district, considering changes in land use, climate variations, and other pertinent factors over a defined period. The research outcomes will prove invaluable to local authorities, farmers, and environmentalists in formulating sustainable land management practices, erosion control measures, and customized conservation strategies for the region. By comprehending the soil erosion dynamics in Sangareddy, this study seeks to make a significant contribution to the broader domains of soil science and environmental management, underscoring the significance of proactive approaches in addressing soil erosion challenges not only in Telangana but also beyond its borders.

In India, approximately 130 million hectares of land, accounting for 45% of the total geographical area, is facing severe soil erosion (Kothyari 1996; Ganasri and Ramesh, 2016). Annually, around 5,334 million metric tons of soil is eroded, with 29% of it being carried by rivers into the sea and 10% settling in reservoirs, leading to a reduction in storage capacity (Narayana and Babu, 1983). Accurate spatial estimation of runoff and soil loss is of utmost importance for planning in-situ soil and water conservation interventions, as well as the implementation of water harvesting structures in watersheds (Rejani et al., 2016 and 2017).

The Revised Universal Soil Loss Equation (RUSLE) is a widely adopted empirical model utilized for estimating soil erosion, taking into account essential factors such as rainfall erosivity, soil erodibility, slope length and steepness, land cover, and conservation practices. RUSLE serves as a valuable tool for assessing the potential for soil erosion, guiding decision-making processes concerning land use planning and erosion control strategies.

MATERIALS AND METHODS

Study Area

The study area conducted in the Sangareddy district encompasses an expanse of 4996 km^2, with a population of 197,860. It is situated in the Central region of Telangana state, precisely located at 17°31'50.4" N and 78°1'6.96" E. This district stands out as one of the most industrialized regions in Telangana. The climate in this area is classified as arid, with the northern regions experiencing cold and semi-humid conditions, while the higher areas have cold winters. The study area's boundary (Fig.1) was thoughtfully selected to represent a diverse and complex landscape, comprising densely built-up areas, wetlands, forests, water bodies, croplands, shrubs, and barren lands. The mean annual average rainfall recorded in the study area amounts to 910 mm.

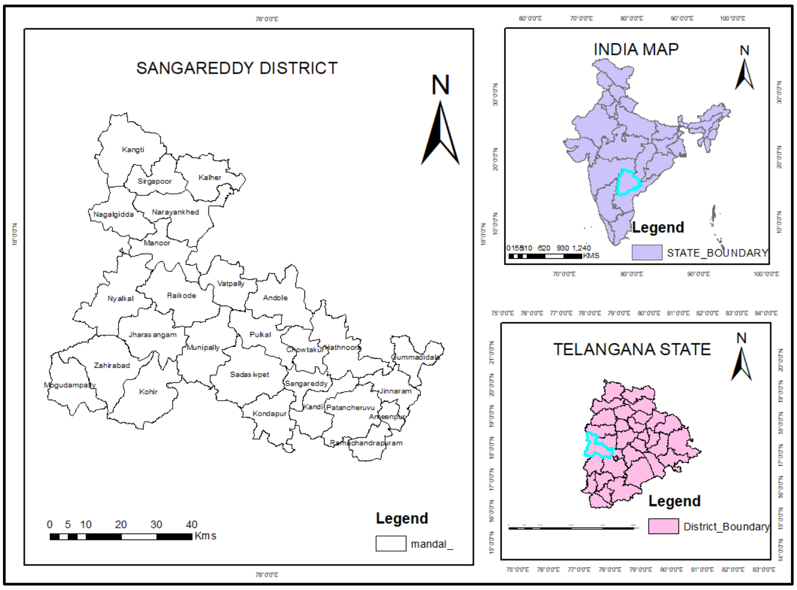


Fig: 1. Location map of the Study Area

Data Collection

Table: 1.The spatial datasets for this research are shown

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

METHODOLOGY

The Revised Universal Soil Loss Equation (RUSLE) is a robust and widely utilized tool for estimating soil loss. It enables the calculation of yearly soil loss values and the intensity of soil erosion within a catchment area. The RUSLE model builds upon the framework of the USLE erosion model developed by Wischmeier and Smith (1978) and was further enhanced and modified by Renard et al. (1997). By employing five parameters, the RUSLE model calculates soil loss and provides long-term annual averages of soil erosion. The model is user-friendly, utilizing physically relevant input values that can be easily gathered from sources like ASTER DEM and satellite imagery through the GIS interface.

Among the most effective erosion prediction models available, the RUSLE model can be implemented at the local or regional level and seamlessly combined with various characteristics, including slope data from ASTER DEM and land use/land cover information from satellite imagery. The RUSLE equation (1) functions as a multiplicative expression of five factors governing rill and inter-rill erosion and can be mathematically represented as:

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

In the RUSLE equation, the variables are represented as follows:

- A represents the annual soil loss (t ha−1 year−1),
- R stands for the rainfall erosivity factor (MJ mm ha−1 h−1 year−1),
- K denotes the soil erodibility factor (t ha h ha−1 MJ−1 mm−1),
- LS represents the slope length factor (dimensionless),
- C stands for the crop cover management factor (dimensionless), and
- P denotes the conservation practices factor (dimensionless).

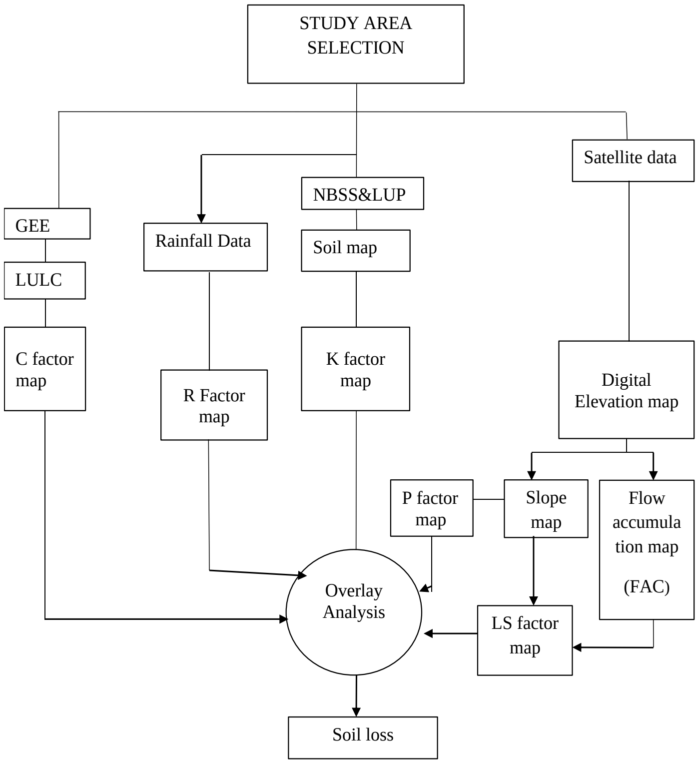


Fig:2. Flow chart for estimation of soil erosion

VARIOUS PARAMETERS USED IN RUSLE

Rainfall Erosivity Factor (R)

The rainfall erosion factor (R) is a significant parameter that characterizes the intensity of precipitation at a specific location and directly impacts the amount of soil erosion (Koirala et al., 2019; Tapa and Upadhyaya, 2019). Its importance lies in the assessment of soil erosion risk, particularly in the context of future land use and climate change conditions (Stocking, 1984).

For this study, daily rainfall data spanning from 2005 to 2022 was collected from the Chief Planning Office (CPO) in CollectorateSangareddy, Telangana. The R factor is computed using equation (2) as defined by Morgan et al. (1984).

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

In this context, the symbol R represents the Rainfall erosivity factor, while P denotes the Mean Annual Rainfall measured in millimeters (mm).

Soil Erodibility Factor (K)

The reference soil map, based on NBSSLUP world soil data, was utilized and then tailored to the specific study area by clipping it accordingly. The study area comprises various soil types, including Clayey (Clayey, Calcareous), Cracking Clay (Cracking Clay, Calcareous), Gravelly Clay, and Loamy, as presented 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

Topographic Factor (LS)

The topographic factor is a combination of slope length (L) and slope steepness (S), representing the impact of topography on erosion. For this study, LS factor maps were generated by processing thematic layers of slope and flow accumulation maps derived from ASTER DEM, using the equation (2) specified by Tirkey et al. (2013).

$$LS = \left(\frac{flow\ \ accumulation\ \ *cell\ \ value}{22 \cdot 1}\right)^{m} (0.065 + 0.045s + 0.0065s^{2}) \ldots\ldots\ldots\ldots (2)$$

In the given equation, the variable 's' represents the slope measured in degrees from the ASTER DEM data, the cell value stands for the resolution of the ASTER DEM, and 'm' is a dimensionless constant that depends on the slope. The specific value of 'm' is assigned as follows: 0.5 for slopes greater than 5°, 0.4 for slopes between 3° and 5°, and 0.3 for slopes less than 3°. In this study, the ASTER DEM data with a resolution of 30 meters (cell size = 30) was utilized. Using the spatial analyst tools in ArcMap 10.3, the LS factor map for the watershed was prepared.

Cover Management Factor (C)

According to Chalise et al. (2019), the cover management factor (C) plays a crucial role in considering the impact of cropping and other practices on erosion rates. As explained by Nearing et al. (2004), this factor holds the highest sensitivity to spatiotemporal changes as it reflects the interaction between plant development and rainfall dynamics. C is a non-dimensional value ranging from 0 to 1, used to compare the soil loss under specific land and vegetation conditions to the equivalent loss from continuous bare fallow due to rainwater erosion (Wischmeier and Smith 1978).

The study examined nine distinct land use forms, which were transformed from a raster map to a polygon using the raster to polygon tool and then combined into a unified class with ArcGIS 10.8 software (Table 3). Each land-use category was assigned a reference C value between 0 and 1, where lower C values indicate minimal soil loss, and higher C values indicate a higher likelihood of significant soil loss (Erencin 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	Floddedvegitation	0.01
4	Crop land	0.21
5	Build up area	0.70
6	Barren land	0.45
7	Scrub land	0.03

Conservation practice factor (P)

The support practice component, based on agricultural practices, serves as an indicator of soil erosion rates. Effective erosion management necessitates the implementation of three fundamental techniques: contours, cropping, and terraces, as highlighted by Park et al. (2005). As per Table 4 from Kouli et al. (2009), the contouring approach employs P values ranging from 0 to 1, where 0 denotes proper anthropogenic erosion control, and 1 indicates 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

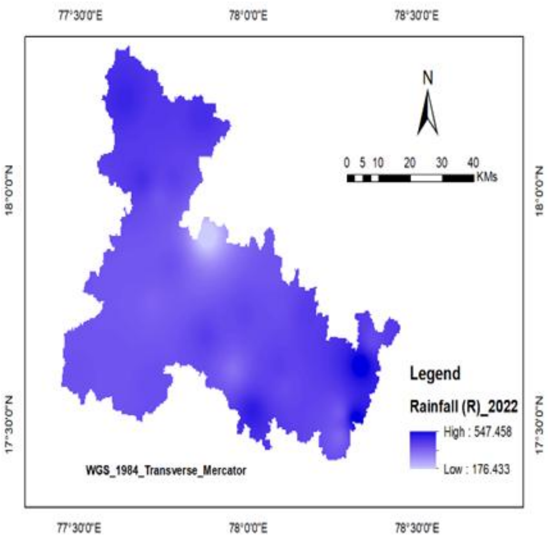
RESULTS AND DISCUSSION

The study's results revealed varying values for the rainfall erosivity factor (R) across different periods. For the normal years (2005 to 2022), R ranged from 277.145 to 382.049 mm/ha/yr. During the dry year of 2018, it ranged from 120.228 to 304.77 mm/ha/yr, while for the wet year of 2020, it varied between 185.368 to 603.969 mm/ha/yr. In the year 2022, R ranged from 176.433 to 547.458 mm/ha/yr.

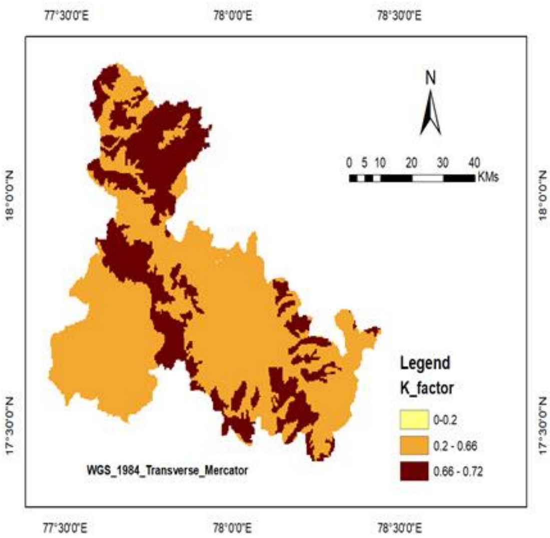
Regarding the topographic factor (LS), its values ranged from 0.02 to 2.32. The soil erodibility factor (K) showed values within the range of 0 to 0.72 for the entire area. For the support practice factor (P), the values ranged from 0.55 to 1.0 across the study area. Finally, the cover management factor (C) exhibited values between 0.01 and 0.7.

The potential soil erosion rates for Sangareddy District were assessed in the study

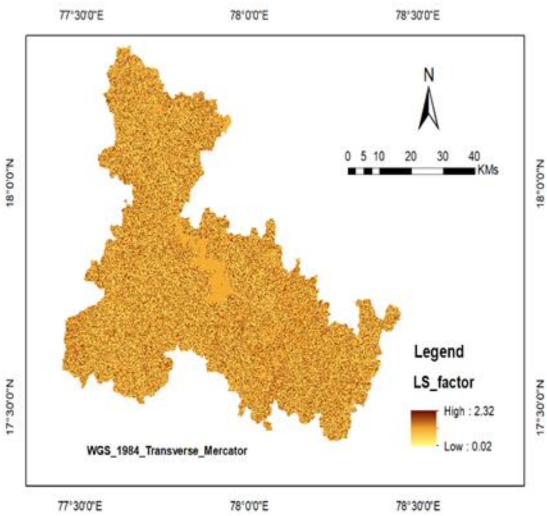
By utilizing the ArcGIS raster calculator, the study combined five factors that contribute to site erosion, generating potential erosion maps for Sangareddy district. The outcomes reveal that a significant portion of the land lies within the low erosion hazard zone, with erosion rates ranging from 0 to 5 tons per hectare per year (t/ha/yr).



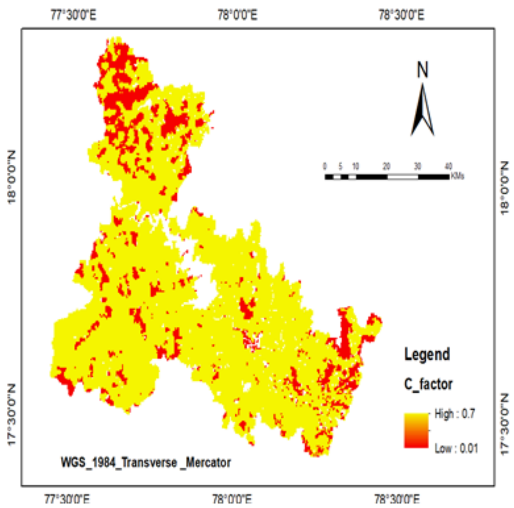
a. Rainfall erosivity factor map



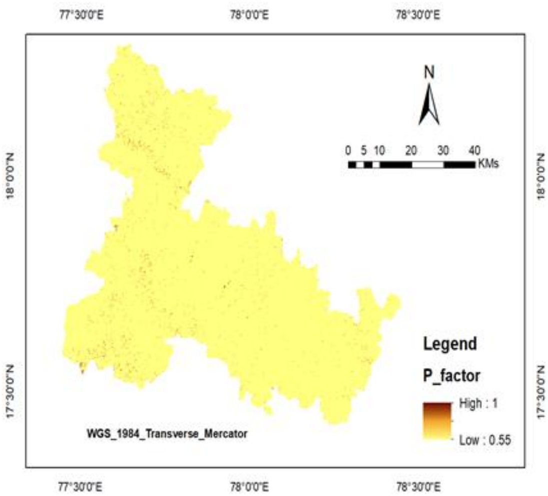
b. soil erodibility factor map



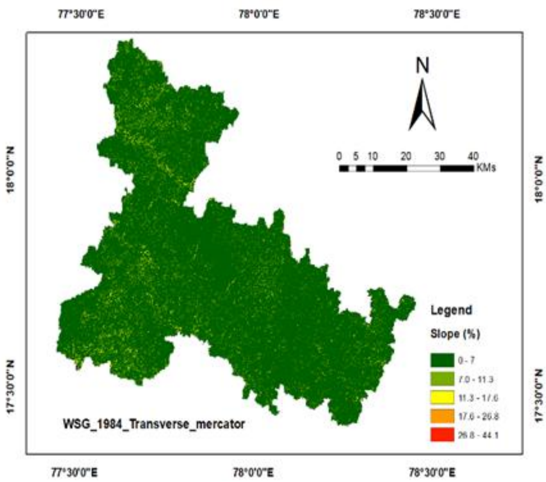
c. Topographic factor map



d. Cover management factor map



e. Conservation practice factor

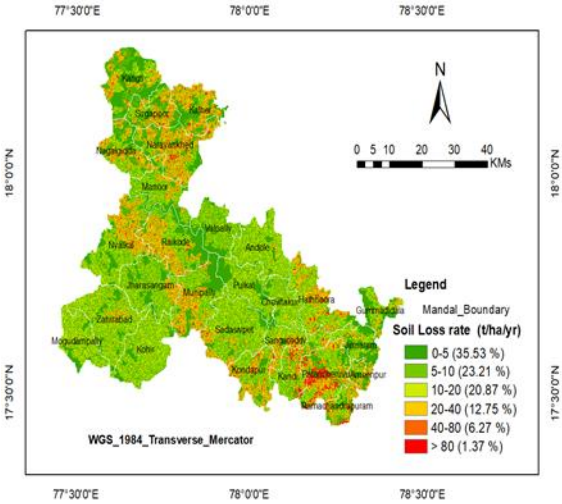


f. Slope map

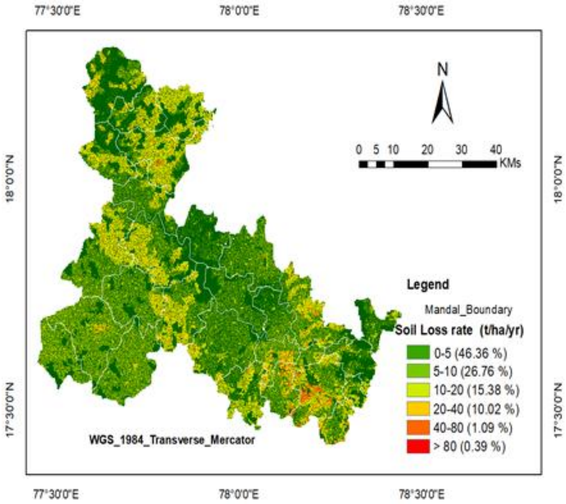
Fig:3. Five factors maps of soil erosion of the study area

DISCUSSIONS

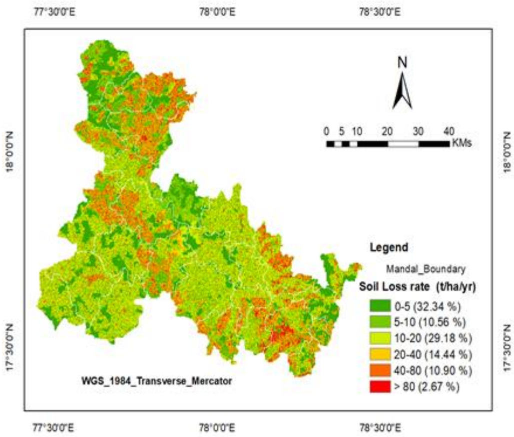
RUSLE, an empirically based modeling approach, utilizes five variables to predict the long-term average yearly rate of soil erosion on slopes. Prasannakumar et al. (2012) mentioned that this method estimates soil loss under similar topographical and climatic conditions. In this study, ArcGIS software was employed to integrate data from various sources and create a potential soil erosion rate map for Sangareddy district. Despite some limitations, this pioneering methodology addresses erosion risk assessment across an entire mountainous region, highlighting critical areas for soil erosion mitigation. Other research projects have also adopted this approach due to similar geographic characteristics (Prasannakumar et al., 2012; Panagos et al., 2015; Kumar and Kushwaha, 2013). To minimize uncertainties in the erosion model, it is crucial to thoroughly consider the R-factor, LS-factor, K-factor, P-factor, and C-factor.



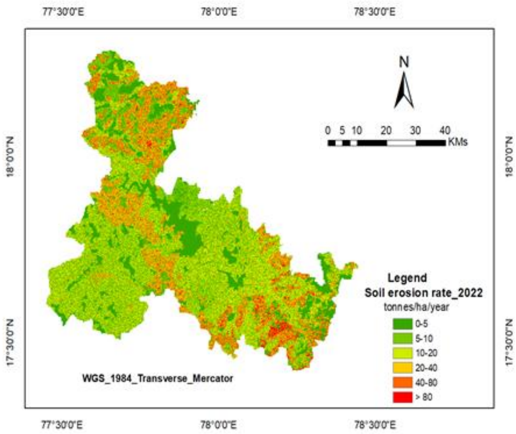
a. Soil erosion map of Sangareddy district during 2005 to 2022



b. Soil erosion map of Sangareddy district during 2018



c. Soil erosion map of Sangareddy district during 2020



d. Soil erosion map of Sangareddy district during 2022

Fig: 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 GIS-based RUSLE equation is employed to assess the severity of soil erosion, considering rainfall, soil, ASTER DEM, land use, and land cover data for Sangareddy district. The temporal analysis revealed varying soil loss levels, with the highest being 134 t ha−1 yr−1 in 2020 and the lowest at 71 t ha−1 yr−1 in 2018. This depiction indicates the region's susceptibility to soil erosion due to its elevated terrain and frequent rainfall. The projected severity can inform decision-makers for planning and conservation efforts, emphasizing the need for special priority and control measures in areas with high to very severe soil erosion. While the model's foundation lies in remote sensing and GIS-based vulnerability zone mapping, further research is recommended to enhance and refine the model for conservation purposes.

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