



# Mapping of Soil erosion and Probability Zones using Remote Sensing and GIS in Arid part of South Deccan Plateau, India

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## Abstract

The Revised Universal Soil Loss Equation (RUSLE) model by using a large-scale soil mapping dataset, remote sensing, and GIS techniques were adopted to determine the soil erosion vulnerability in part of South Deccan Plateau, India. Based on the detailed soil survey information, 11 soil series were identified, and R, K, LS, C, P factors were computed to assess the soil erosion. Results revealed that annual soil loss was extremely severe ( $> 40$  t/ha/yr) and very severe (20–40 t/ha/yr) in 447.2 ha (15.19%) and 314.3 ha (10.68%) in *kharif* and 502.73 ha (17.1%) and 907.74 ha (30.8%) in *rabi* season, respectively. Among the soil series, Mittapalle (MTP) series (17.9%) was highly prone to erosion followed by Venukayagayyapalle (VGP) (16.55%) and Inagalur (IGR) (13.57%) series in both seasons. The Weighted Index Overlay technique was adopted to estimate the soil erosion probability zones and the result showed that erosion risk was high in 8.90% area, medium in 55%, and low in 35% area. Spatial assessment of soil erosion using plot-wise information is a key factor for identifying site-specific suitable soil conservation measures for sustainable crop production.

**Keywords** Soil erosion · RUSLE · Soil survey · GIS · Inagalur · South Deccan Plateau

## Introduction

Land degradation is a widespread and serious problem due to the overexploitation of natural resources. The worldwide scenario of drastic decline in the productivity of croplands and rangelands raises alarming concerns on environmental quality and food security (D’Odorico et al. 2012; Ayoubi et al., 2018; Maximillian et al., 2019). Huge expansions in degraded areas are witnessed by humankind with other areas becoming more vulnerable to various forms of degradation (FAO, 2011; UNCCD 2013). The rise of land degradation in India is frightening the existence of human life. Land degradation, resulting in the deprivation of life-supporting land resource, through soil erosion, salinization, desertification, acidification and nutrient depletion (Moges and Gebregiorgis 2013; Scholes & Scholes, 2013; Stanichi et al., 2021) could be a consequence of a combination of

intensive agriculture, intense rainstorms or land-use changes (Babur et al., 2021; Pandey et al., 2007; Wang et al., 2021). During the last few decades, an area of 120.72 Mha is under threat due to the different categories of land degradation, of which 82.57 Mha is uniquely accounted for soil displacement by water erosion over  $10 \text{ Mg ha}^{-1} \text{ yr}^{-1}$  (Maji, 2007). Soil erosion is a serious environmental problem and a major threat to the soil as it reduces soil productivity by decreasing the clay, organic matter content, reducing the pedon thickness and volume of soil contributing towards water and nutrients to plants (Prasanakumar et al., 2012; Quinton et al., 2010). It also affects geomorphic processes and sediment fluxes (Swarnkar et al., 2018). The impacts of soil erosion could be still severe due to increased sedimentation levels and siltation in rivers and reservoirs (Boardman & Poesen, 2006; Pandey et al., 2007). South Deccan plateau mainly covers the states of Karnataka, Andhra Pradesh, and Telangana extending with an area of 330,743 sq. km at an elevation ranging from 305 to 610 m above MSL. Andhra Pradesh, the third most susceptible state in terms of soil erosion possesses nearly 40% (10.93 Mha) of the total geographical area being eroded by water (Maji et al., 2010; Reddy et al., 2005). The

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situation exacerbated to such an extent that conservation of agricultural soils proved to be the only solution to ensure food security (Gates et al., 2011; Tufa et al., 2019). Thus, assessment of soil erosion is a prerequisite for land resources conservation planning (Atalay, 2016; Surya et al., 2020). Large-scale soil mapping at 1:10,000 scale accruing of detailed information of each parcel of the farm on cadastral number wise soil information provides a precise and scientific inventory of various soils, their kind and nature, and extent, so that one can predict their characteristics and potentialities for farm planning of each parcel of land resources (Verachtert et al., 2010; Nisha et al. 2016; Rajendra Hegde et al., 2018). It also provides adequate information in terms of landform, terrain, vegetation with their characteristics through different thematic soil layers (viz., texture, depth, organic carbon, stoniness, drainage, acidity, salinity etc.), which can be utilized for erosion assessment and sustainable development (Manchanda et al., 2002; Srivastava & Saxena, 2004).

In several parts, unchecked soil erosion and connected land degradation have made vast areas economically unproductive. Often, a quantitative estimation through ground truth checking information is ideal for assessing accurate extension of soil erosion so that appropriate management strategies can be developed to implement. But, the complexity of the variables makes the exact prediction of erosion difficult. The latest advances in spatial information technology have augmented the existing methods and provided efficient methods of monitoring, analysis, and management of natural resources. Digital Elevation Model (DEM) along with remote sensing data and GIS can be successfully used to enable rapid as well as a detailed assessment of erosion hazards (Bennett et al., 2012; Sepuru & Dube, 2018; Thompson et al., 2009). Soil erosion vulnerability has been assessed using empirical models like the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) with the help of Remote Sensing and GIS (Fu et al., 2005; Lee, 2004; Senanayake et al., 2020). The study area is situated in an arid agro-ecological zone of the Anantapuramu district of Andhra Pradesh. Depletion of land resources in this region due to soil erosion has influenced the agriculture, livelihood activities, and industries of the area and resulted in the deterioration of soil quality (Reddy et al., 1996). The earlier studies of course-scale soil mapping makes it difficult in the decision-making by the policymakers due to limited ground truth. Therefore, using large-scale (1:10,000 scale) soil information for mapping the severity of soil erosion in any parcel of land is appropriate and accurate for conservation and crop management. Keeping this in view, a case study was attempted in Inagalur Panchayat, Obuladevaracheruvu Mandal, Anantapuramu district of Andhra Pradesh belongs to the Deccan plateau region to

mapping soil erosion and delineates the probability zones using Remote Sensing and GIS techniques.

## Materials and Methods

### Study Area

The study area, Inagalur Panchayat of Obuladevaracheruvu Mandal, Kadiri, Anantapuramu district of Andhra Pradesh covers 2938 ha of total geographical area and comes under the arid part of the Southern Deccan Plateau region. It lies within 14°0' to 14°5' N latitude and 78°0' to 78°3' E longitude (Fig. 1) under the Agro-Ecological Region 3, Deccan Plateau, hot arid eco sub-region with deep loamy and clayey mixed red and black soils, low to medium available water capacity, and length of growing period < 90 days (Sehgal et al., 1992). This region is critical for drought in two out of three years due to scanty rainfall. Hence, falling in the arid tract of the state, the area records an average annual rainfall of 574 mm, which is very low and is categorized as drought-prone with a 30% coefficient of variation (CV) in rainfall considering the data from 1989–2019. The maximum rainfall of 320 mm is received during the southwest monsoon from June to September and the northeast monsoon contributes about 190 mm from October to December and the remaining 64 mm is received during the rest of the year (Fig. 2). September and October are the wettest months with 40% of the mean rainfall. The temperature ranges from a minimum of 17–19 °C to a maximum of 30–40 °C. Major geological formations are granite gneiss and alluvium. The elevation ranges between 495 to 568 m above MSL, and landforms are divided into summits, upper slopes, middle slopes, and lower slopes, plains, narrow valleys, and low lands. Major land uses in the area are agriculture, horticulture, plantation, fallow, open scrub, and forestry.

### Methodology and Parameter Estimation

The Cartosat-2 DEM + IRS-P6 LISS\_ IV satellite imageries from April 2018 were used for deriving land resource information. This in conjunction with the village cadastral map was used for the preparation of the base map. This process of merging the village cadastral map with Cartosat imagery has helped in the identification of variations in color texture, tone, etc. based on survey number. The slope was measured using the contour interval from toposheets of 1:50,000 scale. Based on the differences in slope, different landforms (like hills, uplands, valleys, salt-affected areas, etc.) were identified while preparing the base map. Based on the landform, slope and color tones

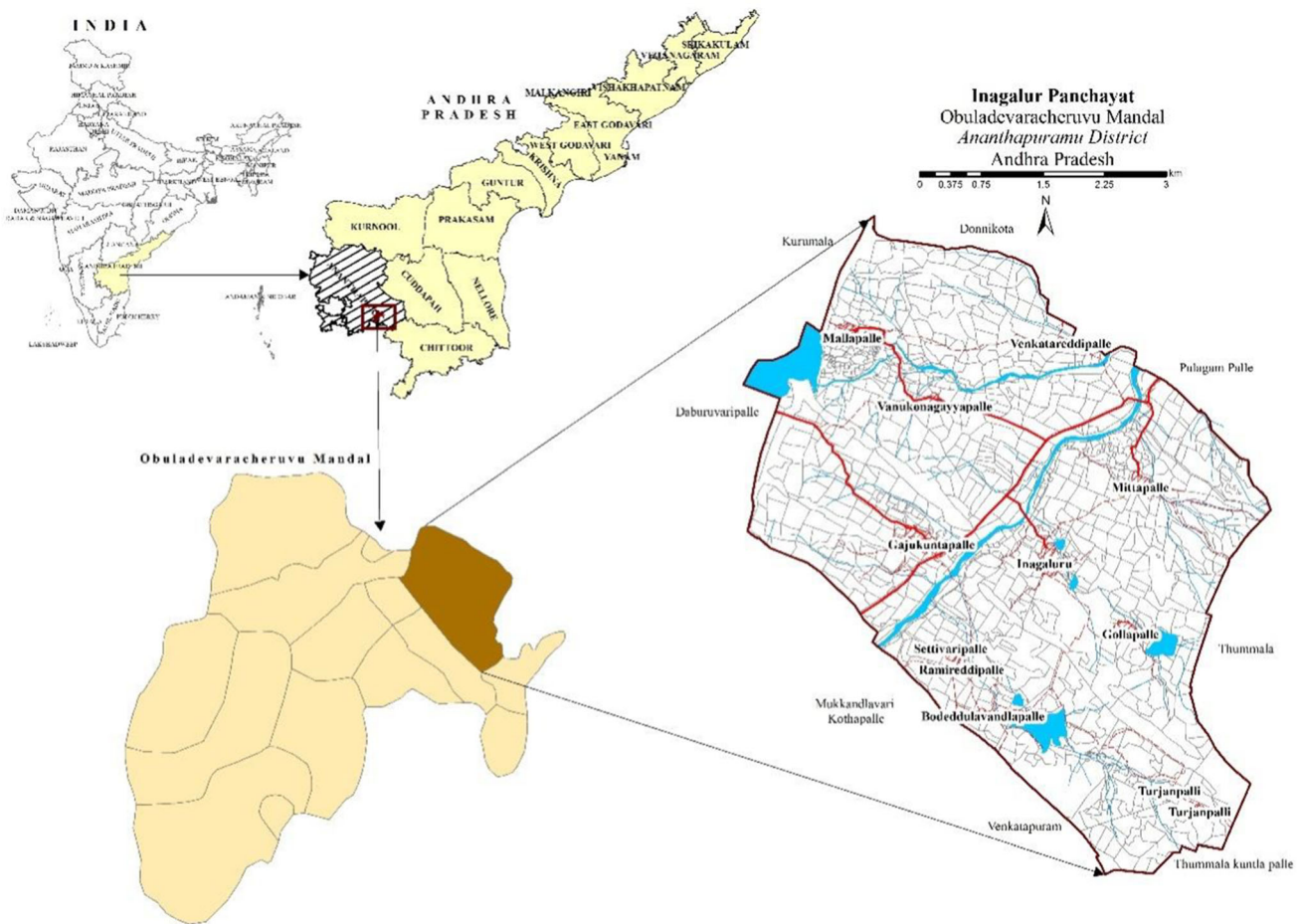


Fig. 1 Location map of the study area

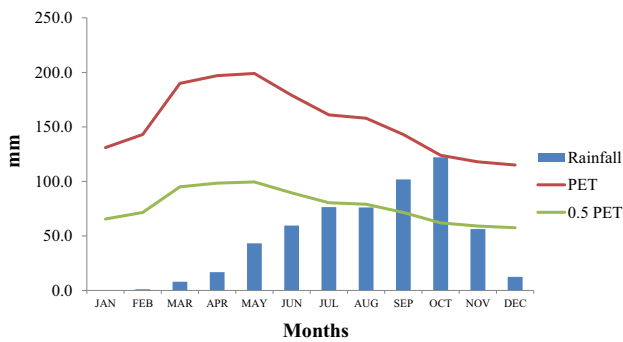


Fig. 2 Rainfall and Length of growing period in study area (1989–2019)

were used for checking the soil variability (profile study). These were then delineated and mapping units were prepared.

The detailed soil survey was carried out at a 1:10,000 scale during 2018–2019. Soil profile locations were identified after extensive traverse of the area and ground truth checking to ensure capture of entire variability on site. Soil profiles were excavated up to 200 cm of depth or hard

bedrock and studied in detail. One hundred and fifteen (115) soil profiles were studied as per the standard methods (Soil Survey Staff, 1999). Resource maps at a cadastral level were generated for site characteristics like slope, erosion, drainage, salinity, rock fragments, etc., and soil characteristics like depth, texture, color, structure, consistency, gravel content, available water content, and soil reaction. Based on soil-site characteristics, soils were grouped into relatively homogeneous units called soil series.

### Soil Mapping and Classification

Soil series were identified based on differentiating attributes like depth, texture, slope, erosion, presence of gravel, salinity, etc. After correlation, soils were grouped into 11 soil series and the established series were mapped in a GIS environment using Arc GIS 10.2 software (Fig. 3). The identified soil series were classified at the family level in accordance with the internationally accepted system of soil

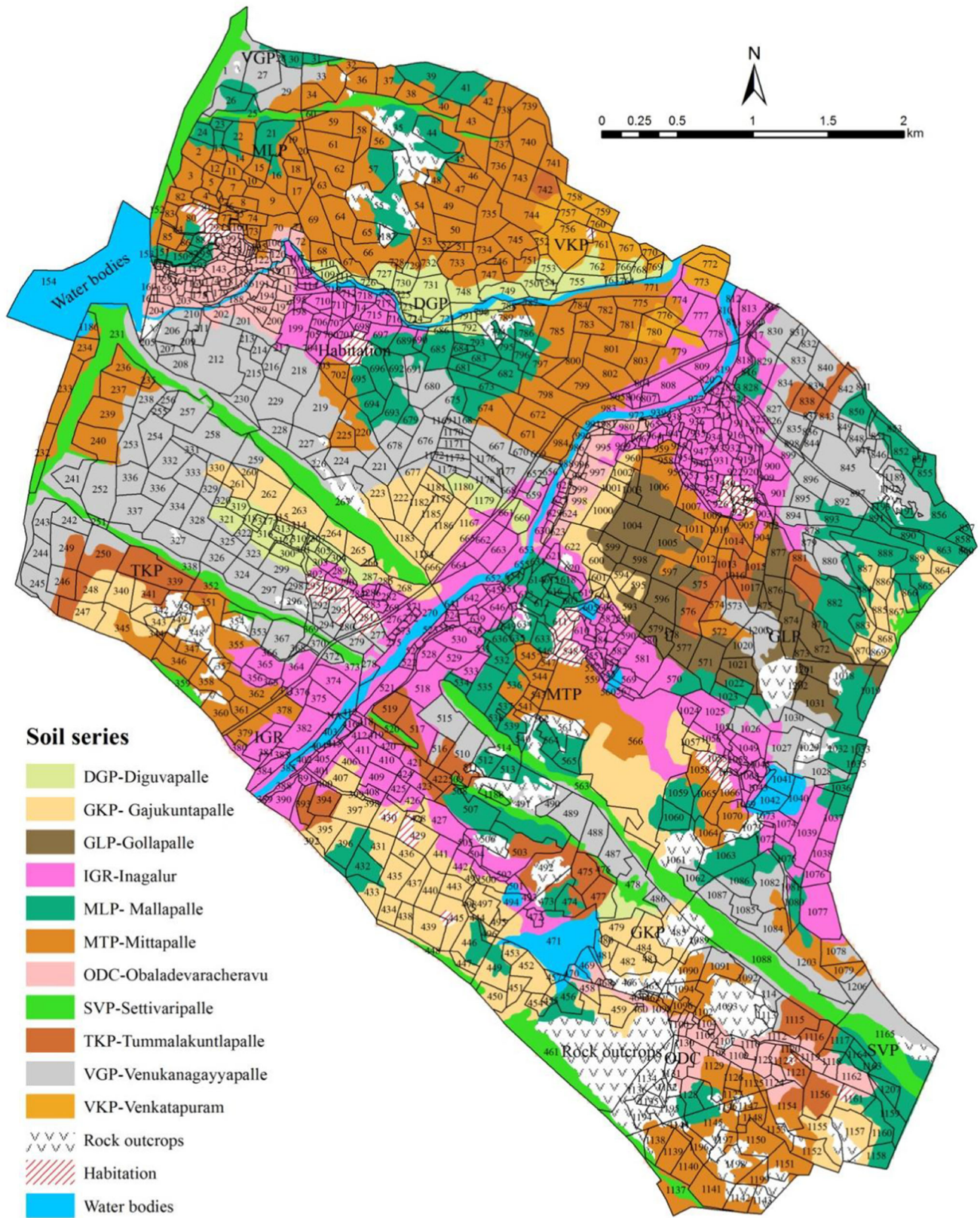


Fig. 3 Soil series map of the study area

**Table 1** Soil classification and extent in the study area

Sl. No	Soil series	USDA-Classification	Area (ha)	TGA %
S1	Mallapalle (MLP)	Clayey-skeletal, (Paralithic) Haplargids	337	11.46
S2	Mittapalle (MTP)	Loamy-skeletal, Typic Paleargids	533	18.12
S3	Gajakuntapalle (GKP)	Loamy-skeletal, Typic Paleargids	279	9.51
S4	Gollapalle (GLP)	Fine-loamy, Typic Paleargids	96	3.25
S5	Venukayagayyapalle (VGP)	Fine-loamy, Typic Paleargids	489	16.65
S6	Tummalakuntlapalle (TKP)	Fine-loamy (Cal), Typic Haplargids	111	3.77
S7	Venkatapuram (VKP)	Fine-loamy, Typic Paleargids	42	1.42
S8	Settivaripalle (SVP)	Clayey-skeletal, (Paralithic) Haplargids	149	5.09
S9	Diguvapalle (DGP)	Sandy, Typic Torripsamments	80	2.74
S10	Inagalur (IGR)	Fine, Typic Haplocambids	400	13.62
S11	Obaladevarucheruvu (ODC)	Fine, Vertic Haplocambids	98	3.34
	Rock outcrop and others		178	6.06
	Habitation & Water bodies		146	4.97
	Total		2938	100

classification, USDA Soil Taxonomy. The geographical extent of these soil series is represented in Table 1. Major soils belong to the orders *Aridisols* and *Entisols*. The soils of *Aridisols* have keyed out to suborders *Argids* and *Cambids* and great groups *Haplargids*, *Paleargids*, and *Haplocambids*. The soils of *Entisols* are keyed out to *Psamments* suborder and a great group of *Torripsamments*. The dominant soils of the study area are Mittapalle (MTP) series covering an area of 533 ha (18.12%). This was followed by the Venukayagayyapalle (VGP) series in an area of 489 ha (16.65%). The other major soils of the area are Mallapalle (MLP) series occurring in 337 ha (11.46%), Gajakuntapalle (GKP) in 279 ha (9.51%), Settivaripalle (SVP) in 149 ha (5.09%), Tummalakuntlapalle (TKP) in 111 ha (3.77%), Gollapalle (GLP) in 96 ha (3.25%) and Venkatapuram (VKP) in 42 ha (1.42%). Soil series information and different surface thematic maps were used for assessing soil erosion and identification of erosion probability zones.

## RUSLE Parameter Estimation

The RUSLE model assists in predicting the soil loss mainly from inter-rill or rill erosion from fields or farm units as a result of changes in management practices for the long term. The model was developed to predict long-term annual average losses of soil and the best suited at local or regional scales to assess soil erosion practically. This model for estimating soil erosion and loss could aid in formulating appropriate soil conservation and management plans.

The equation RUSLE (Renard et al., 1997) for computing average annual soil loss is given as

$$A = R \times K \times LS \times C \times P$$

where,

A is the mean annual soil loss (tonne ha<sup>-1</sup>).

R -Rainfall erosivity factor (MJ mm ha<sup>-1</sup> h<sup>-1</sup> year<sup>-1</sup>);  
K-Soil erodibility factor (t ha h MJ<sup>-1</sup> ha<sup>-1</sup> mm<sup>-1</sup>);  
L-Slope length & S- slope steepness factor; C- Crop cover and management factor; and P- Conservation support practices factor.

All these factors were mapped as rasters in the GIS environment to predict average annual soil loss at the pixel level. Since the GIS-based RUSLE model assesses potential soil loss at the pixel level, it can extract details on spatial variability as well as the design of soil erosion in detail (Millward & Mersey, 1999). The flow chart of the methodology is given in Fig. 4.

## Rainfall Erosivity Factor (R)

The intensity of rainfall on soil erosion is denoted using this factor R. Rainfall is the major factor contributing to the erosion of soil particles and it varies with the intensity of rainfall. Determination of erosivity is through volume, speed, intensity, and duration of rainfall from a single storm or different storms in a particular period. Thus, splash and sheet erosion occurring on barren lands are quicker than soils with vegetative cover. Rainfall data of 30 years (1989–2019) collected from Agricultural Research Station (ARS), Kadi, Andhra Pradesh were used for calculating the R factor. Since the rainfall erosivity is directly linked to average annual rainfall, their relationship can be used as a proxy to estimate the R-value (Kumar & Kushwaha, 2013). To estimate the R factor, the following formula (Choudhury & Nayak, 2003) was used.

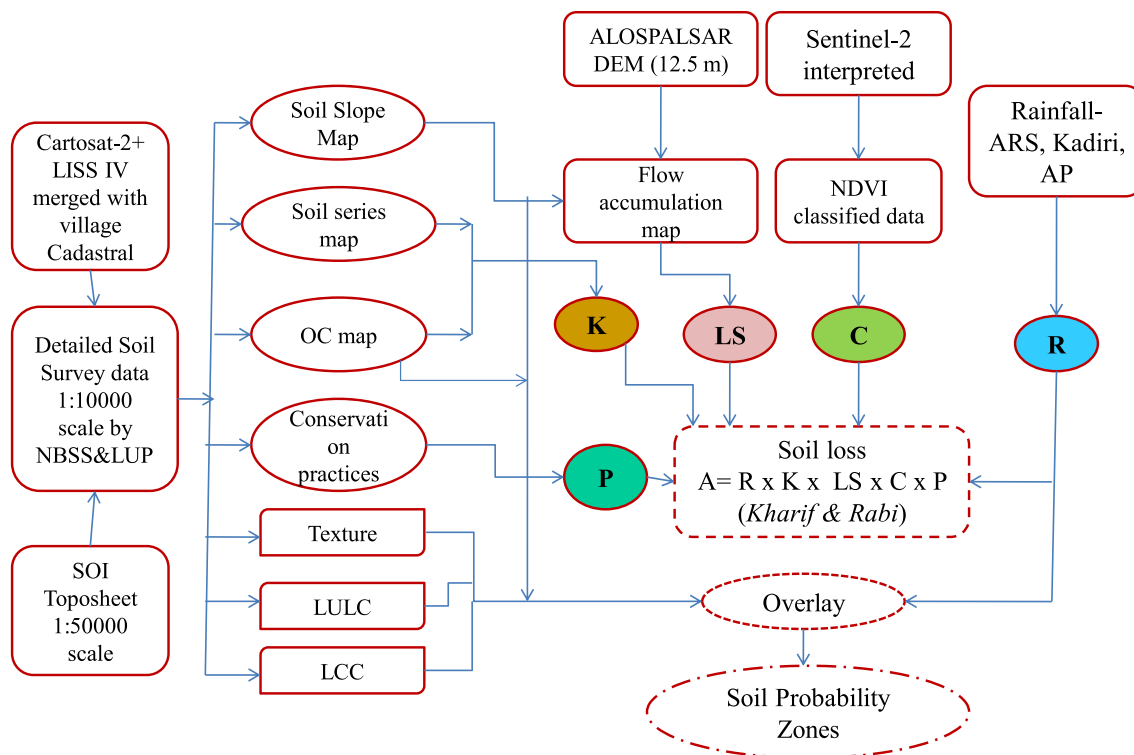


Fig. 4 Flow chart of methodology adopted

$$R = 79 + 0.363 * X_a$$

where R is the rainfall erosivity,  $X_a$  is the average annual rainfall in mm over the study area.

### Soil Erodibility Factor (K)

Soil erodibility is determined by the size and shape of grains, organic carbon content, plasticity, drainage pattern, structure, etc. In this study, soil texture and soil organic carbon data generated from detailed soil resource mapping (1:10,000 scale) were used to compute the soil erodibility (K) factor (Fig. 6). The factor, K, represents the susceptibility of soil towards erosion, transportability of sediment, and the amount and rate of runoff under a particular rainfall considered against a standard condition which is a unit plot of continuous fallow of 22.6 m length and 9% slope (Kim, 2006; Kirkby & Morgan, 1980). The equation used in calculating the K factor is given by Wawer et al. (2005) and Williams (1995).

$$K_{USLE} = K_w = f_{csand} * f_{cl-si} * f_{org} * f_{hisand}$$

where  $f_{csand}$  is a factor, that lowers the K indicator in soils with high coarse-sand content and higher for soils with little sand;  $f_{cl-si}$  gives low soil erodibility factors for soils with high clay-to-silt ratios;  $f_{org}$  reduces K values in

soils with high organic carbon content, while  $f_{hisand}$  lowers K values for soils with extremely high sand content:

$$f_{csand} = \left[ 0.2 + 0.3 * \exp \left[ -0.256 * ms * \left( 1 - \frac{msilt}{100} \right) \right] \right]$$

$$f_{cl-si} = \left( \frac{msilt}{mc + msilt} \right)^{0.3}$$

$$f_{org} = \left( 1 - \frac{0.0256 * orgC}{orgC + \exp [3.72 - 2.95 * orgC]} \right)$$

$$f_{hisand} = \left[ 1 - \frac{0.7 * \left[ 1 - \frac{msand}{100} \right]}{\left[ 1 - \frac{msand}{100} \right] + \exp \left[ -5.51 + 22.9 * \left[ 1 - \frac{msand}{100} \right] \right]} \right]$$

$ms$  = Sand (%);  $msilt$  = Silt (%);  $mc$  = clay (%);  $orgC$  = Organic carbon (OC) (%).

K, estimated mainly on the basis of soil texture has lower values for clay soils, due to its better resistance to erosion; sandy soils due to reduced runoff and better infiltration (Zhang et al., 2004). Higher values are associated with silt soils owing to their higher runoff. The values ranged from 0 to 1 where 0 indicates low or almost no erosion and 1 indicates soils more prone to erosion.

## Topographic Factor (LS)

The topographic factor denoted by LS constitutes two factors namely slope length (L) and slope steepness (S) that represent the ratio of soil loss under standard conditions. The LS factor in the RUSLE model considers the soil loss as this factor influences the total sediment yield from the site. Soil compaction and consolidation, other disturbances to soil are also considered along with length and steepness of slope while generating the LS-factor from ground truth (Fig. 5). RUSLE considers the L factor representing the effects of slope length, however, makes no differentiation between rill and inter-rill erosion in the S-factor that computes the effect of slope steepness on soil loss (Lu et al., 2004; Moore & Burch, 1986). The flow direction and flow accumulation were calculated from DEM. The integrated LS-factor was computed by using the ArcGIS tool using the ALOS PALSAR Digital Elevation Model (DEM) of 12.5 m spatial resolution. The longer and steeper the slope, the higher are the erosion rates (Zhang et al., 2017a). When the slope is between 10 and 25%, the maximum erosion happens. The flow accumulation and slope steepness were calculated from the DEM using the ArcGIS environment.

$$LS = \left( \frac{\text{Slope length}}{12.5} \right)^{0.4} * \left( \frac{0.01745 \sin \theta}{0.0896} \right)^{1.4} * 1.4$$

Slope length = Flow accumulation;  $\theta$  = Slope in degree.

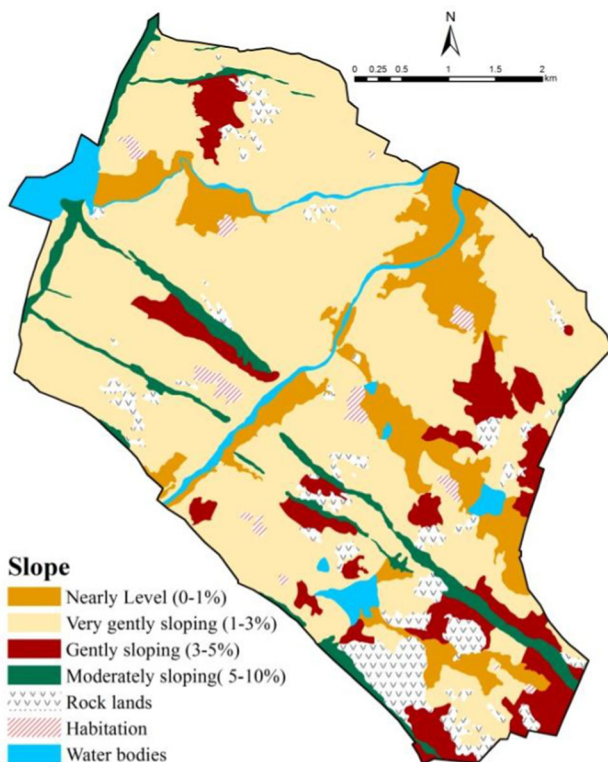


Fig. 5 Slope map of the study area

## Crop Management Factor (C)

Changes in soil cover, the cultivation activities that disturb the soil, effects of crop sequence and productivity level and changes in subsurface biomass on soil erosion are represented using the C factor in RUSLE (Karaburun, 2010; Wang et al., 2021). It is defined as the ratio of loss of soil from a regular cropped area to that of continuous fallow land with the latter facing severe erosion under specific conditions (Wischmeier & Smith, 1978). Currently, due to the diversity of land cover patterns with spatial and temporal variations, satellite remote sensing datasets were used for the estimation and assessment of C-factor (Jasinski, 1990; Lillesand et al., 2004 and Parveen & Kumar, 2012; Senanayake et al., 2020). The Normalized Difference Vegetation Index (NDVI) acquired from Sentinel 2 imagery, an index of the vegetation robustness and health is used (*kharif*- October-2018 and *rabi*-April -2019) along with the following formula.

$$NDVI = \left( \frac{NIR - RED}{NIR + RED} \right)$$

NDVI is calculated as a ratio between the red (R) and near-infrared (NIR) values in traditional fashion.

## Conservation Support Practice Factor (P)

The factor P represents the ratio of soil loss by a support practice. The P factor accounts for conservation practices that reduce the erosion potential of the runoff by their effect on aggregation and velocity of runoff, drainage patterns, hydraulic forces exerted by runoff on soil, and thereby indicate the positive impact of conservation practices in controlling soil erosion (Stanchi et al., 2021; Wischmeier & Smith, 1978). The values of the P-factor range from 0 to 1, in which the highest value is assigned to areas with no conservation practices (Barren land or open field); the minimum values correspond to built-up-land and plantation and dense scrub with adopted strip and contour cropping system (Reddy et al., 2005). From the soil series map, soil slope map was derived and conservation practices were integrated into GIS framework to arrive at P values for both *kharif* and *rabi* seasons.

## Estimation of Potential Soil erosion

The data layers of R, K, LS, C, and P components of the revised USLE model (RUSLE) were integrated into GIS to assess the potential soil loss in the study area. Natural factors that contribute towards soil erosion in the RUSLE model include R, K, and LS factors, which together could estimate the susceptibility towards erosion and estimate

potential soil loss. Assessment of soil erosion is appropriate using daily rainfall to seasonal (*kharif* and *rabi*) than annual rainfall and identification of probability zones (Dabral et al., 2008; Jain et al., 2001).

## Delineation of Soil Erosion Probability Zones

Different soil thematic maps and DEM derived data were integrated into ArcGIS 10.2 to delineate susceptible zones of soil erosion, considering major factors like slope (Fig. 5), soil texture, soil organic matter (Fig. 6), rainfall, land use, and land cover and land capability class. Individual themes were assigned with weightage based on their influence on soil erosion and later these themes were overlaid following the technique of Weighted Index Overlay (WIO), in which the theme most prone to erosion was given the maximum value and the theme least prone to erosion was given the minimum value (Table 4).

## Results and Discussion

### Rainfall Erosivity Factor (R)

The rainfall erosivity factor (R) quantifies the impact of rainfall on the quantity and rate of runoff (Xu et al., 2008).

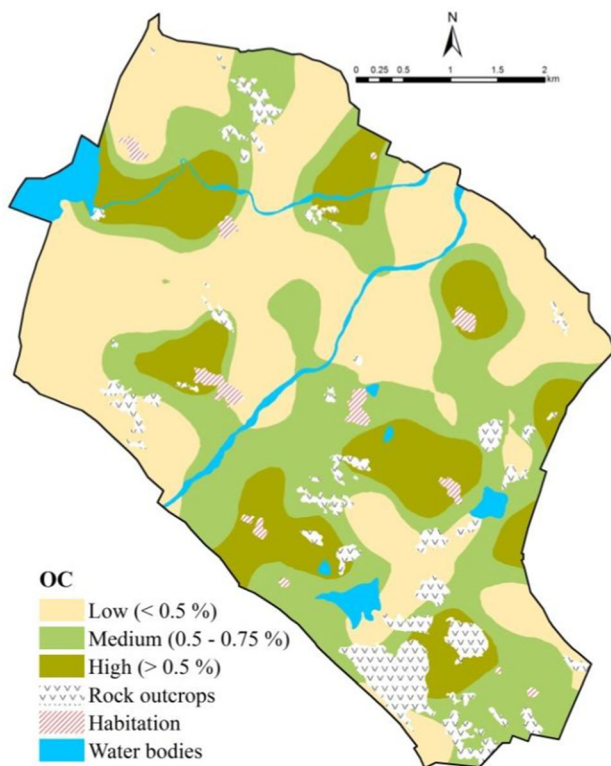


Fig. 6 Soil organic carbon map of the study area

In Inagalur, the estimated R factor value ranged from 288.8 to 290.8 MJ mm ha<sup>-1</sup> h<sup>-1</sup> yr<sup>-1</sup> (Fig. 7a). Soil erosion rates are affected by rainfall (Dabral et al., 2008). To estimate the sediment yield and its seasonal distribution, daily rainfall is considered a better indicator. However, annual rainfall as an indicator for estimating soil loss has certain advantages of ready availability, ease of computation, and greater regional consistency of the exponent (Shinde et al., 2010).

### Soil Erodibility Factor (K)

The inherent capacity of soil to resist the detachment and transporting power of rainfall is manifested using the term erodibility of soil. In the study area, K values ranged from 0 to 1.64 depending on the soil type and susceptibility to erosion (Fig. 7b). This factor represents the physical and chemical properties of soil such as the mineralogical composition, organic matter content and particle size, etc. (Efe et al., 2008; Wischmeier et al., 1971). The K values are the reflection of the rate of soil removed based on the intensity of rainfall (Kim, 2006).

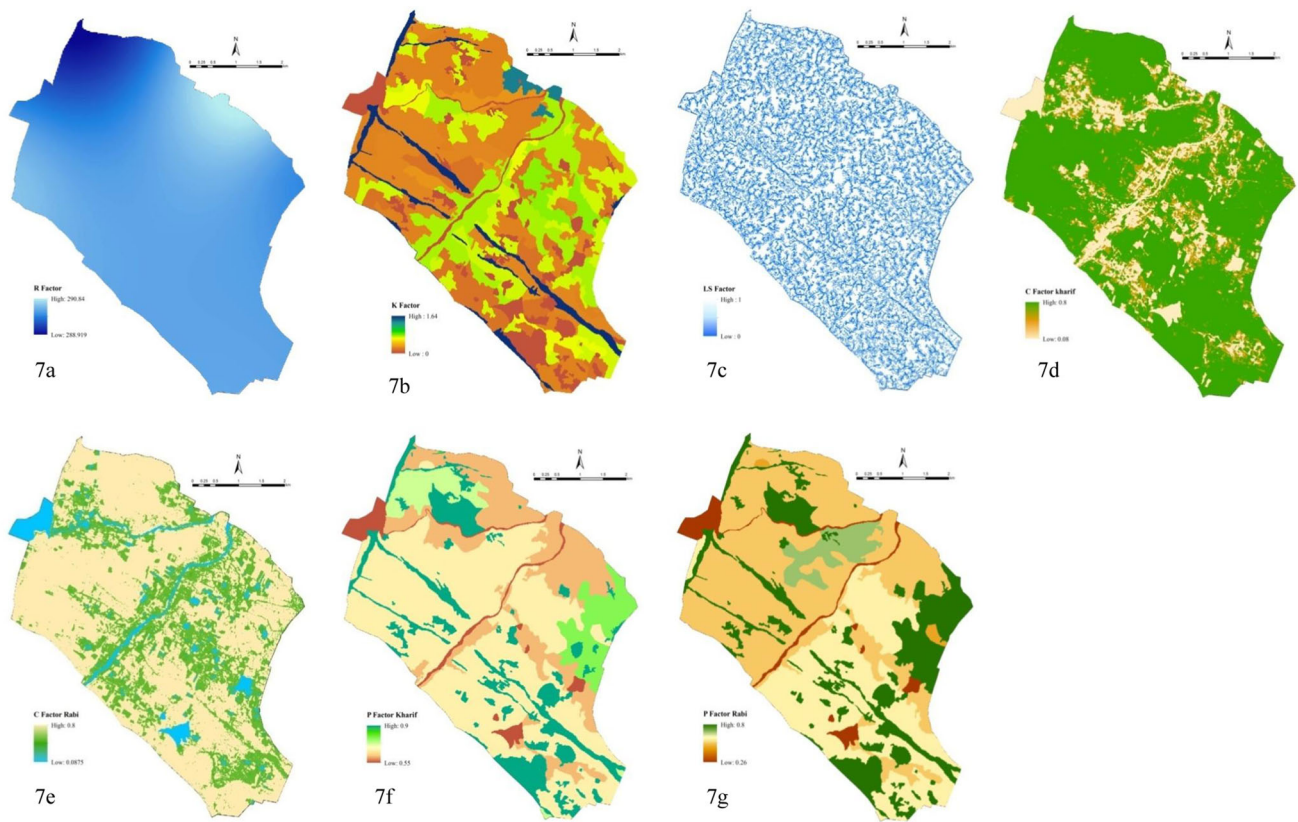
### Topographic Factor (LS)

In RUSLE, slope length and slope steepness are together represented using LS factor, which is known as the topographic factor. The slope length is calculated on the basis of the idea that the erosion will be more with increased slope, without considering the terrain complexities (Robert & Hilborn, 2000). LS factor considers the flow accumulation and slope as inputs and in the study area the LS factor varied from 0 to 1 (Fig. 7c). The LS factor in RUSLE measures the flow capacity to transport the sediments (Moore & Wilson, 1992). Steepness in slope is explained using the S factor, which provides the knowledge that the steeper the area, the more will be the soil loss through erosion (Zhang et al., 2018). Similarly, the longer the slope, the more will be the flow accumulation, which is an indication of increased total soil erosion and soil erosion per unit area (Wang et al., 2020).

### Crop Management Factor (C)

The crop management factor (C) compares the soil erosion from cultivated land and fallow while considering the plant cover, extent of cropping, and production techniques (Tirkey et al., 2013). Crop cover protects soil from erosion. The better the crop cover, the lesser will be the soil erosion. Crop management factor (C) ranged from 0.08 to 0.8 in the





**Fig. 7** Different soil erosion factors a) R factor; b) K factor; c) LS factor; d) C factor- *kharif*; e) C factor- *rabi*; f) P factor *kharif*; g) P factor- *rabi*

season of *kharif* (Fig. 7d) and 0.09 to 0.8 in *rabi* (Fig. 7e). There were six classes of land use/land cover observed during ground truth verification namely cropland, barren land, plantation, scrub and dense scrub, and water bodies along with NDVI. The C factor was determined from NDVI values and these two are inversely related. The lower the NDVI value, the higher the C factor. The C factor was the maximum 0.80 in the open field which recorded the minimum NDVI value of < 1 (Table 2). The open field was maximum prone for erosion due to lack of vegetation cover followed by a scrub, and dense scrub. Plantation soils recorded lower C factors indicating lesser rates of soil erosion due to better ground cover. Seasonal analysis indicated that the *rabi* season has lesser vegetation than the *kharif* season, which could result in strong to very severe soil erosion. A similar result was also reported by Fu et al. (2011).

### Conservation Support Practice Factor (P)

The P factor map is utilized to understand the conservation practices in the study area. The conservation support practice factor deals with the control practices to reduce

**Table 2** Land use/ Land cover and NDVI and C values

LULC	NDVI value	C value
Barren land	< 0.1	0.80
Scrub	0.2–0.3	0.60
Dense Scrub	0.4–0.5	0.40
Crop land	0.4–0.6	0.38
Plantation	0.7– 0.9	0.09
Water body	0	0.00

soil erosion by affecting velocity and concentration of runoff, drainage patterns, and hydraulic forces exerted by runoff on soil (Tirkey et al., 2013). The common conservation practices include contour cultivation, terracing, or strip cropping. P factor ranged from 0.6 to 0.9 in *kharif* (Fig. 7f) and 0.3 to 0.8 in *rabi* (Fig. 7g). In both seasons, a higher P factor was estimated in rock lands (0.9) followed by moderately sloping lands (0.8) with a 5–10% slope (Table 3). This is obviously due to no or poor conservation measures in these areas. Lower P values were observed in nearly level (0–1%) to gently sloping (3–5%) areas with soil and water conservation measures of trenches and

**Table 3** Soil Slope and corresponding P values during *Kharif* and *Rabi* seasons

Slope	SWC	P Value ( <i>Kharif</i> )	P Value ( <i>Rabi</i> )
Nearly Level (0–1%)	Strengthening of existing bunds	0.3	0.3
Very gently sloping (1–3%)	Trench cum bunding	0.3	0.3
Gently sloping (3–5%)	Trench cum bunding	0.4	0.3
Moderately sloping (5–10%)	Terracing	0.8	0.8
Rock lands	Rock outcrops	0.9	0.9
Habitation	Habitation	0.8	0.8
Water bodies	Water bodies	0	0

**Table 4** Weighted index overlay of different soil layers

Factors	Class	Weight age/ Ranking
Rainfall (mm)	High	6
	Medium	4
	Low	2
Texture	Loamy sand	9
	Sandy loam	7
	Sandy clay loam	5
	Sandy clay	3
	Slope	Moderately sloping (5–10%)
Slope	Gently sloping (3–5%)	6
	Very gently sloping (1–3%)	3
	Nearly level (0–1%)	1
	OC (%)	Low (< 0.5%)
OC (%)	Medium (0.5–0.75%)	5
	High (> 0.75%)	3
	LULC	Barren land
Scrub		7
Cropland		6
Dense Scrub		5
Plantation		4
Water body		0
LCC		Fairly Good land (IVes)
LCC	Fairly Good land (IVs)	7
	Moderately Good cultivable land (IIIes)	6
	Moderately Good cultivable land (IIIs)	5
	Good cultivable land (IIes)	4

**Table 5** Extent of soil loss in the study area during *Kharif* and *Rabi* seasons

Soil loss	<i>Kharif</i>		<i>Rabi</i>	
	Area (ha)	TGA %	Area (ha)	TGA %
Extremely Severe (> 40 t/ha/yr)	447.22	15.19	502.73	17.06
Very Severe (20–40 t/ha/yr)	314.32	10.68	907.74	30.81
Severe (15–20 t/ha/yr)	151.17	5.13	115.56	3.92
Strong (10–15 t/ha/yr)	549.80	18.68	26.22	0.89
Moderate (5–10 t/ha/yr)	175.48	5.96	189.25	6.42
Slight (< 5 t/ha/yr)	1279.15	43.45	1177.50	39.96

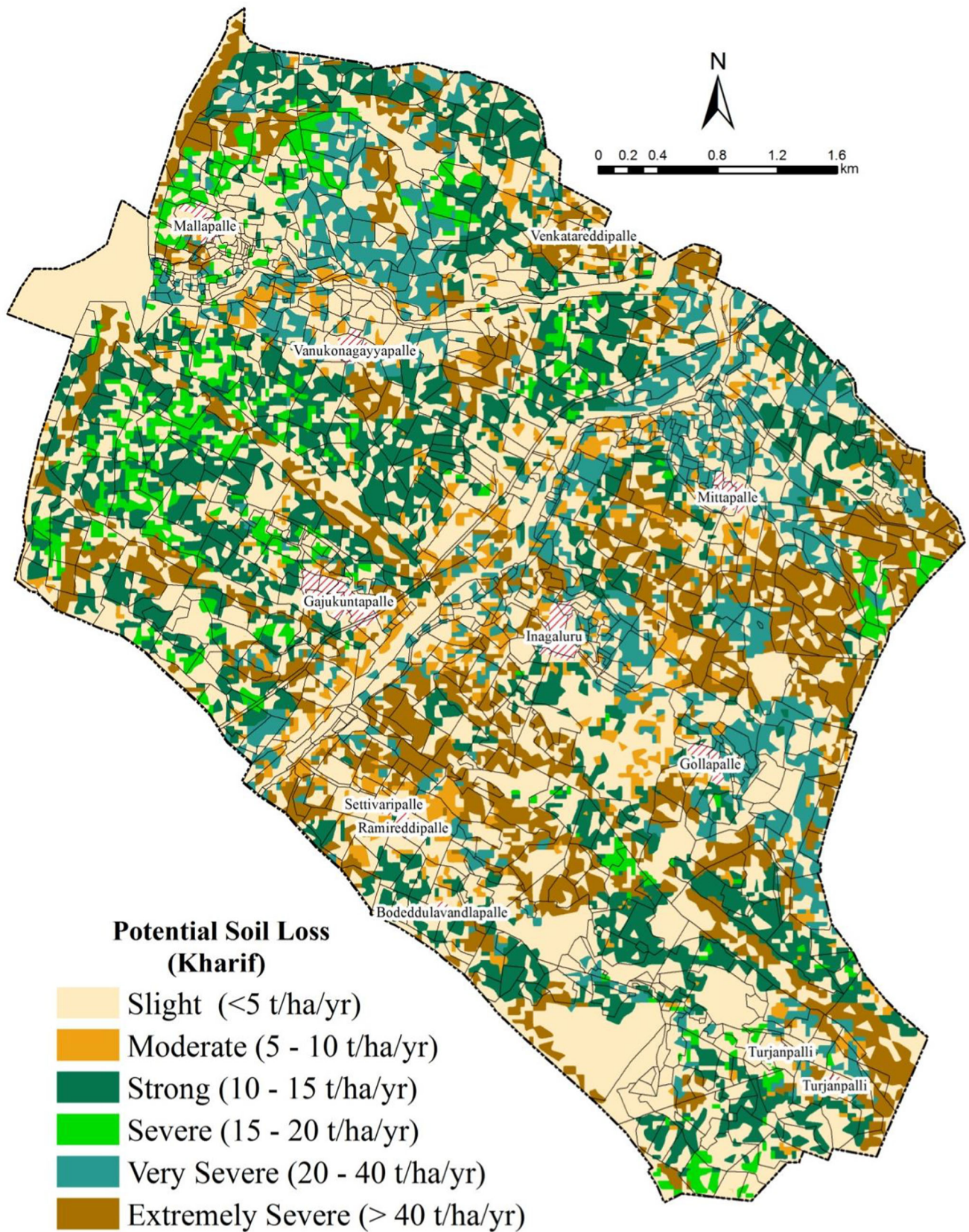


Fig. 8 a Potential soil loss in *kharif* season b Potential soil loss in *rabi* season

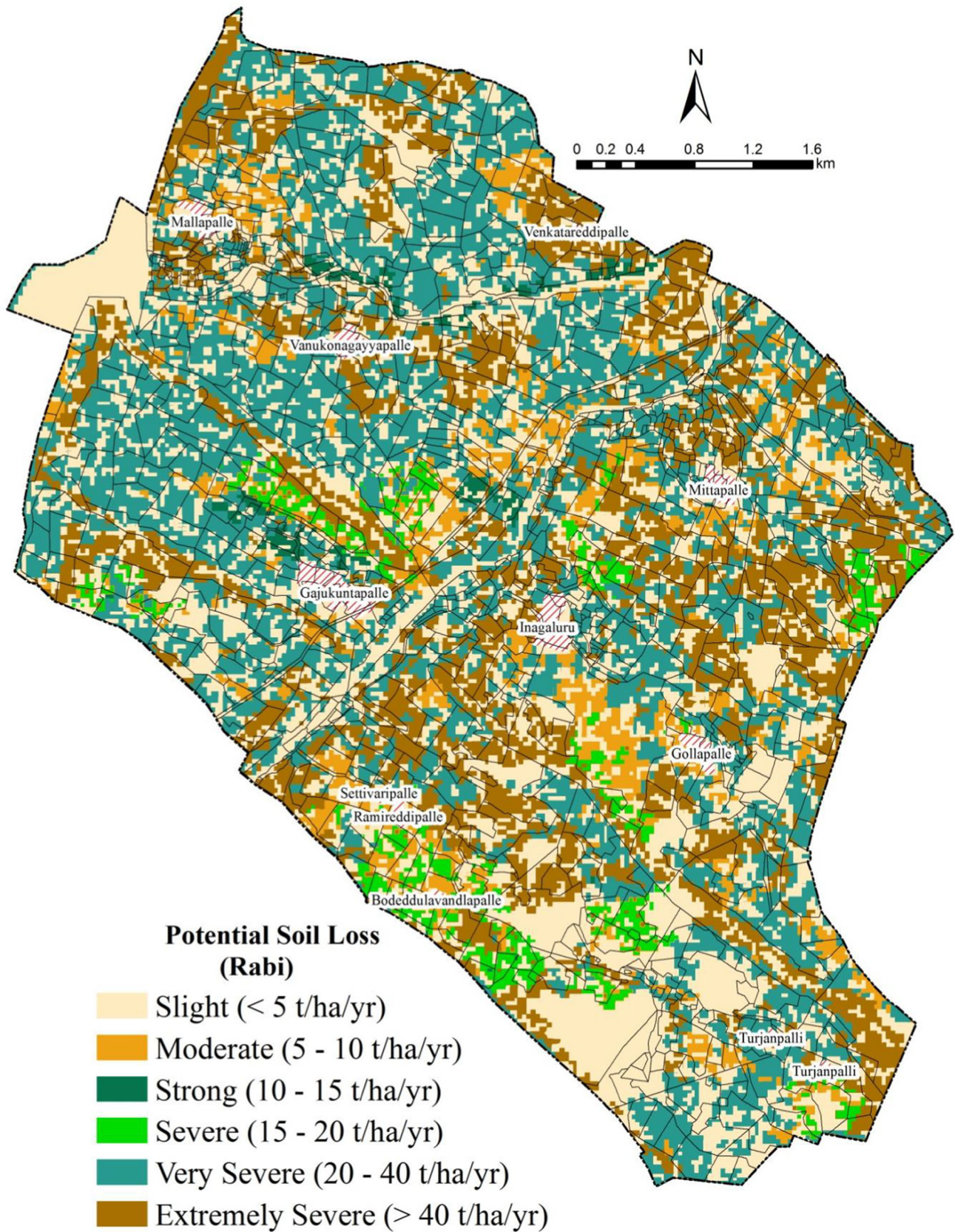
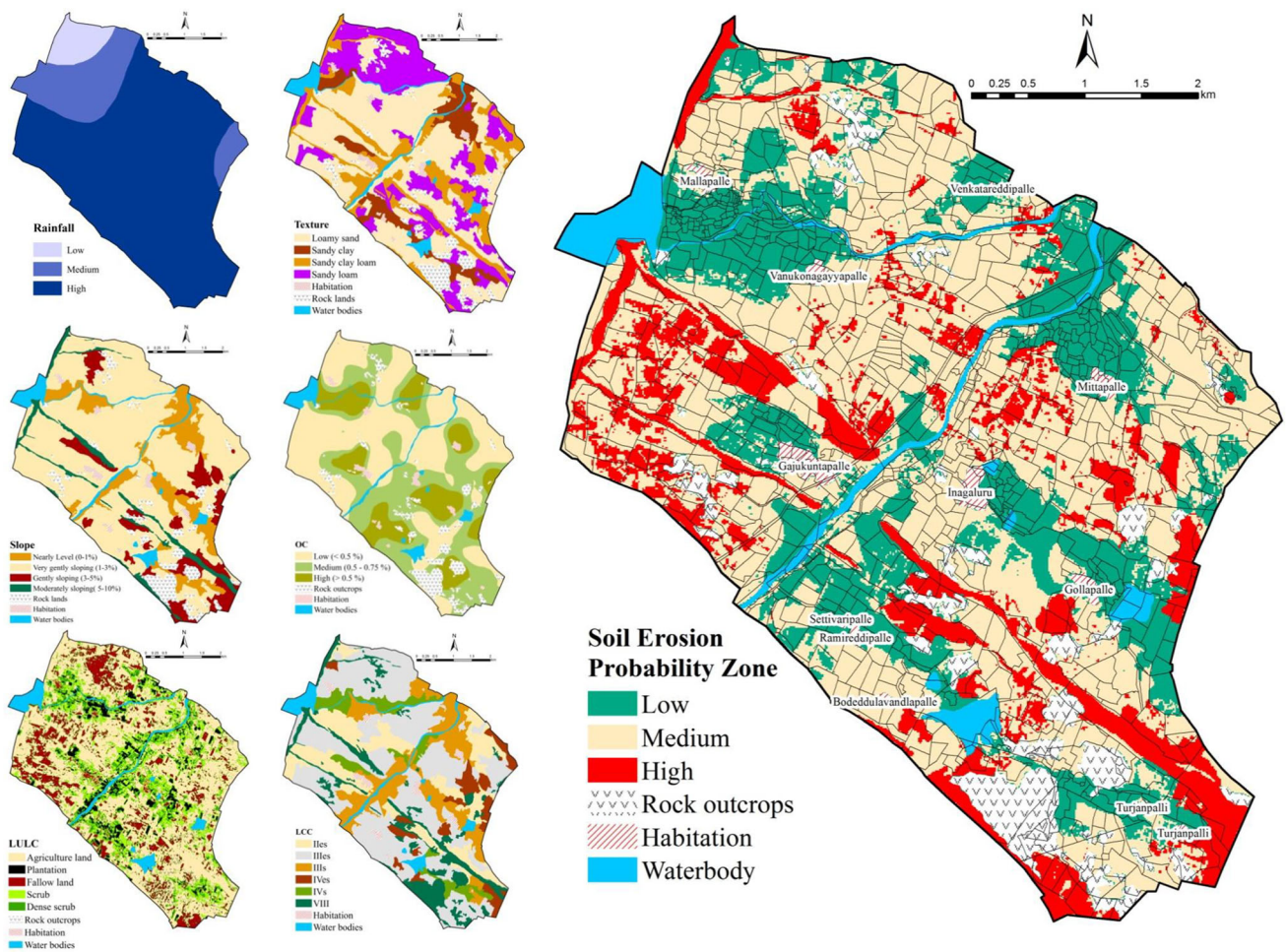
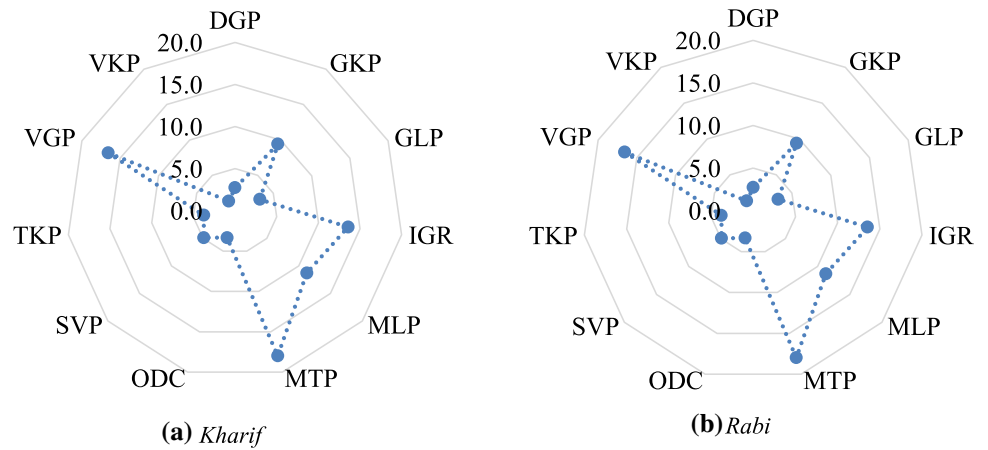


Fig. 8 continued

**Fig. 9** Soil Series wise soil loss in (a) *kharif* and (b) *rabi* seasons

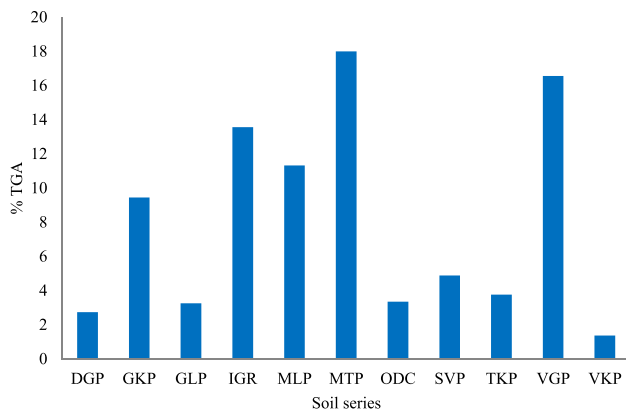


**Fig. 10** Different Soil Erosion Probability Zones in the study area

bunds. The lower P values indicate better conservation practices in effect (Prasannakumar et al., 2012; Reddy et al., 2005).

**Potential Annual Soil Erosion Estimation**

The potential soil loss map generated using GIS software by integrating all the factors of the RUSLE model was reclassified into six classes viz. slight (< 5 t/ha/yr), moderate (5–10 t/ha/yr), strong (10–15 t/ha/yr), severe (15–20



**Fig. 11** Series wise soil erosion probability in study area

t/ha/yr), very severe (20–40 t/ha/yr) and extremely severe (> 40 t/ha/yr). The data (Table 4) indicate that majority of the area under both the seasons had slight erosion (< 5t/ha/yr) and this comprised 43.45% and 39.96% of the area in *kharif* and *rabi* seasons respectively (Table 5 and 8a & b). Of the total geographical area, 18.68%, and 15.19% faced the threat of having strong erosion (10–15 t/ha/yr) and extremely severe (> 40 t/ha/yr) soil erosion respectively in *kharif* season. Whereas in *rabi* season, very severe soil loss (20–40 t/ha/yr) was estimated in an area of 30.81%, followed by extremely severe (> 40 t/ha/yr) soil loss in 17.06% of the total geographical area. A similar view was expressed by Biswas et al. (2015) and Ganasri and Ramesh (2015).

Potential soil erosion was estimated in different soil series of the area. The Mittappalle (MTP) series was estimated to have maximum soil erosion during the *kharif* season (17.99% of the TGA); followed by the Venukayagayyapalle (VGP) series (16.55% of the TGA) and Inagaluru (IGR) series (13.57% of the TGA) (Fig. 8). A similar result was found in the *rabi* season too (Fig. 9b). The soil loss was the least in Venkatapuram (VKP) series (1.37%), Diguvalpalle (DGP) series (2.73%) and Gollapalle (GLP) series (3.24%). The assessment of the severity of soil loss at soil series level immensely helps to decide the proper conservation measures for arrest the erosion, and improve the crop productivity (Mandal & Sharda, 2011).

### Soil Erosion Probability Zones (SEPZ)

Soil erosion probability zones (SEPZ) were generated by integrating different thematic layers such as rainfall, soil slope, organic matter, soil texture, land use land cover, and land capability classes in GIS by mapping the areas susceptible to soil erosion (Fig. 10). Erosion probability zones were delineated by carrying out Weighted Index Overlay (WIO) technique in which individual themes were assigned

with weightage based on their influence on soil erosion and later these themes were overlaid. The theme most prone to erosion was given the maximum value and the least prone to erosion was given the minimum value. The SEPZ in the study area were categorized into three types viz., low, medium, and high erosion. Results revealed that only 10 percent of the study area was found to be under the high soil erosion risk and 35% of the area under low risk (Fig. 10). However, the maximum of the total geographical area (55%) was found to be at medium risk towards soil erosion problems which is a cause of serious concern. Among the soil series, Mattapalle (MTP) series was found to have the maximum probability of soil erosion (Fig. 11) followed by the Venukayagayyapalle (VGP) and Inagaluru (IGR) series, respectively.

Identification of season-wise plot-specific erosion, levels are essential to understand existing erosion severity which in turn is essential in the implementation of need-based developmental activities in these areas. Identification of erosion-prone areas are very useful to adopt different restoration activities based on erosion severity and priority. Land managers and policymakers need precise information on the severity and extension of soil erosion and risk to measure land degradation and better plan for various cost-effective land-based interventions and implementation (Brady & Weil, 2002). The delineation of erosion probability zones envisages the implementation of suitable conservation measures in bringing the erosion losses within permissible limits, to optimize the crop production which may otherwise be very severely affected.

### Conclusion

The average annual soil loss of Inagaluru Panchayat, a part of South Deccan Plateau was quantitatively estimated based on RUSLE equation considering different soil thematic layers, rainfall, land cover, and DEM derived datasets in this study along with delineation of erosion probability zones. The study incorporated a land resource database and information on soil series with GIS techniques and utilized RUSLE methodology to identify the spatial distribution of different erosion-prone areas of the study area. The results revealed that soil erosion in the *kharif* season was strong in 18.68% area followed by extremely severe in 15.19% area and very severe in 10.68% area. Whereas, in *rabi*, soil erosion severity increased and the extent of very severe (30.81%) and extremely severe (17.06%), erosion areas increased due to poor vegetation or the lands that are left fallow. Higher soil erosion and probability zones were recorded in MTP, VGP, IGR, MLP, and GKP soil series than others. The erosion

probability map showed that 55% of the area was prone to medium and 10% area was prone to high soil erosion.

Analyzing the impact of the increase in aridity in the case of fallow land, marked by its increased susceptibility to soil erosion indicates that the severity enhances if the proper assessment of soil erosion is not carried out and conservation measures are not undertaken timely. The season-wise comparison of potential soil loss and soil series and probability zones of soil loss help in evaluating the impact of soil erosion on crop production and soil and water conservation practices. The results from the study would be of great use to suggest suitable conservation practices in areas of higher erosion risk and in turn would be helpful for the conservation of agricultural soils. Soil erosion depletes the quality of soil hindering agricultural productivity, hence conservation of agricultural soils becomes essential in proper planning and management of natural resources arriving at a solution to overcome the deficit in food production and ensure food security.

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