Harmonizing Models and Measurements: Assessing Soil Erosion through RUSLE Model

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Abstract:

Soil erosion poses significant ecological and socioeconomic challenges, driven by factors such as inappropriate land use, extreme rainfall events, deforestation, farming methods, and climate change.. This study focuses on the Kozhikode district in Kerala, South India, which has seen increased vulnerability to soil erosion due to its unique geographical characteristics, increase in extreme events and recent land use trends. The research employs RUSLE - Revised Universal Soil Loss Equation, considering multiple contributing factors such as rainfall erosivity (R), slope length and steepness (LS), cover management (C), conservation practices (P) and soil erodibility (K). . The study is unique and novel, since it integrates extensive field data collected from agricultural plots across Kozhikode with the RUSLE model predictions, providing a more accurate and context-specific understanding of soil erosion processes and also suggesting management strategies based on risk priority. The study found that Kozhikode experiences an average annual soil loss of 28.7 tons per hectare.. A spatial analysis revealed varying erosion risk levels across the district. 52.0% of the area experiences Very Slight Erosion, 10.31% has Slight Erosion, 6.18% undergoes Moderate Erosion, 3.88% is Moderately Severe 7.34% is at Severe Erosion Risk, 5.6% has Very Severe Erosion and 14.65% faces Extremely Severe Erosion. Field data collected from agricultural plots across Kozhikode were compared with RUSLE-predicted values, revealing a low root mean square error, indicating a strong correlation between observed and simulated data.. Based on these findings, the district was categorized into low, medium, and high-priority regions, with tailored recommendations proposed for each. Implementing these measures could mitigate erosion, preserve soil fertility, and support the long-term sustainability of natural and agricultural ecosystems in Kozhikode..Given the practical challenges in estimating RUSLE factors in Southern India, where data scarcity is a common issue, this preliminary study underscores the need for expanded, long-term field observations to enhance understanding of soil erosion processes at the watershed level..

Keywords: Soil Erosion; RUSLE; Kozhikode-Kerala

1. Introduction

Soil erosion, an age-old phenomenon, occurs either naturally or is induced by human development (Butzer, 2005) and this poses a substantial threat to global sustainable ecological development, leading to considerable threat to agricultural productivity through land degradation (Benavidez, Jackson, Maxwell, & Norton, 2018; Panagos et al., 2015). Soil erosion is a worldwide issue that results in soil loss, reduction in agricultural land, and decreased crop yields (Sinshaw et al., 2021).Moreover, the main causes of the decline in vegetation cover are soil erosion and geological disasters (Alkharabsheh, Alexandridis, Bilas, Misopolinos, & Silleos, 2013; Zhou et al., 2020). The consequences of soil erosion are further exacerbated by human activities such as widespread deforestation, overgrazing, intensive agriculture, and population growth (Kebede et al., 2021).This process poses a significant threat not only to the areas where erosion takes place but also to those where the eroded soil is deposited, impacting the soil organic carbon dynamics (Cheng et al., 2010) making it a major environmental concern. Agricultural productivity is increased and life on Earth is encouraged by healthy soil ecosystems (Senanayake et al.,2024) and the soil thickness is influenced by soil erosion and deposition processes (Liu et al., 2023) revealing that soil erosion has significant ecological and socioeconomic repercussions (Ferreira et al.,2022; Jin, Yang, Fu, & Li, 2021). It describes the procedure by which topsoil is transported by elements of nature, including wind, water, and human activity. Inappropriate land use, deforestation, agricultural practices, and climate change are the primary causes of soil erosion (Ahmad, Mustafa, & Didams, 2020; Borrelli et al., 2020; Hossain et al., 2020; Kouassiet al.,2021; Nayakekorale, 2020). Three processes of soil deposition, soil transportation, and soil looseningare often involved in soil erosion. Fertile topsoil deteriorates as a result of soil erosion, which lowers its ability to support agricultural productivity (Cannell & Hawes, 1994; Laflen, Lal, & El-Swaify, 2020). Currently, agriculture occupies 40% of the available global land, where natural vegetation was converted into agricultural land, resulting in increased water erosion (Foley, 2017). Severe soil erosion causes an excessive amount of silt to be exported to reservoirs or rivers, disrupting aquatic life and degrading the environment (Osman & Osman, 2013; Rashmi et al., 2022; Rhodes, 2014). Water bodies may become clogged with sediments from eroding soil, resulting in higher water treatment costs and harm to aquatic habitats (Rashmi et al., 2022; Rickson, 2014). Additionally, sedimentation in rivers and lakes can make floods worse, endangering infrastructure and habitations (Arnaud-Fassetta, Cossart, & Fort, 2005; Thomas, 2017). A significant and intricate environmental issue, soil erosion directly contributes to degradation of soil and lowers land productivity (Wang et al., 2024). The process of eroding of soil changes both in time and space, and is impacted by non-stationary processes (Herbozo et al., 2022).

Researchers have been working on quantification of soil erosion to understand the mechanisms and dynamics of soil erosion, including the factors that contribute to it. Quantification of soil erosion in the laboratory involves simulating erosion processes under controlled conditions to measure erosion rates and understand the factors affecting soil loss. Such experiments were carried out by Mutchler et al. (Mutchler, Murphree, & McGregor, 2017). Models play a pivotal role in predicting soil erosion, offering a structured framework for understanding complex erosion processes and estimating erosion rates under diverse conditions. While numerous models exist, a significant knowledge gap persists regarding their accuracy, quality, and reliability (Mutchler et al., 2017). Different models have been employed to predict and calculate soil erosion risks across different geographical regions and land use scenarios. These models include the USLE-Universal Soil Loss Equation (Wischmeier & Smith, 1978) estimates soil loss potential, while its modified version, USLE-M (Kinnell& Risse, 1998), refines these predictions. Additionally, USLE-MM (Modified- Modified) enhances erosion estimations (Kinnell & Risse, 1998). Pan European Soil Erosion Risk Assessment- PESERA (Kinnell & Risse, 1998), focusing on European soil erosion risks. The SedNet model (Wilkinson et al., 2004), addresses sediment transport within river networks. The Unit Stream Power-based Erosion Deposition model- USPED (Arnaud-Fassetta et al., 2005), utilizes stream power for erosion predictions. The Water and Tillage Erosion Model and Sediment Delivery Model- WaTEM/SEDEM integrated approach, introduced by Van Oost et al.(2000) and further refined by Van Rompaey et al. (2001);Verstraeten et al. (2002), focuses on erosion of water and tillage together with modeling of sediment transport. Flanagan and Nearing ,1995's The Water Erosion Prediction Project- WEPP model provides predictions for water erosion. Due to its adaptability across diverse landscapes, user-friendly interface, ability to provide quantitative analyses, extensive validation, and flexibility in incorporating new data, RUSLE model was used in this study.

RUSLE takes into account a number of important variables that affect erosion rates, including rainfall, topography, land cover, and soil properties (Renard et al.,1996). Its ability to integrate GIS improves its accuracy and suitability for use in a variety of landscapes (Wischmeier & Smith, 1978). Although designed for forecasting water erosion in temperate regions, the adaptability of the RUSLE model to tropical climates surpasses that of other currently utilized models. The USLE served as the foundation for the empirically based RUSLE model, which is more diversified and incorporates databases that weren't available during when USLE was created (Renard et al., 1996). RUSLE uses updated and region-specific rainfall erosivity factors that consider temporal variations in rainfall patterns. It includes modifications to account for the seasonality and variability of rainfall, making it more accurate across different climatic regions.

Soil erosion poses a significant environmental challenge for Kerala State. Kerala is part of the Western Ghats, a mountainous region that receives a lot of rainfall (Vijaykumar et al., 2021). This, along with its steep slopes and weak soil structure, makes Kerala more vulnerable to erosion and land slidingprocesses. Belonging to the Western Ghats regions, over the years, this region has undergone significant deforestation, turning large tracts of old forests into pastures, waste fields, and agricultural regions (Athiraet al.,2017). Kozhikode, a district within Kerala, faces similar challenges exacerbated by its geographical features and land use practices. Due to its monsoonal climate and frequent rainstorms, Kozhikode is prone to erosion (Das, Jain, & Gupta, 2022; Prasannakumar, Vijith, Abinod, & Geetha, 2012). An additional factor for the complex soil erosion dynamics is its diverse land uses, which include horticulture, agriculture, and urban development in the region (Krishnan & Firoz, 2021). To access the reliability and accuracy of the model in predicting soil erosion, it is necessary to compare the erosion value obtained by RUSLE model with field data, enhancing its utility for soil conservation planning and land management practices.A key strategy for enhancing soil fertility, increasing crop and water production, and boosting the income of smallholder farmers is the adoption and implementation of integrated soil fertility management practices (Gadana et al., 2020; Dessie et al., 2023). This integrated approach improves soil quality, enhances biodiversity, reduces environmental degradation, and ultimately increases crop yields, income, and food security (Horner &Wollni, 2021). However, farmers in Kozhikode are forced to rely on fallow and marginal lands due to inadequate soil conservation and management practices. The Western Ghats is a biodiversity hotspot with significant ecological and socioeconomic importance. However, it is also highly susceptible to soil erosion due to steep slopes, heavy monsoon rains, and land use changes. Understanding and managing soil erosion in this region is crucial to preserving its ecological integrity and supporting sustainable agricultural practices. The study addresses this critical need by providing a scientifically robust erosion assessment

This study intends to assess soil erosion rates within Kozhikode using the RUSLE model and compare them with field data. Field data collection involves measuring soil loss rates at various locations over time. By analyzing the agreement between observed and predicted erosion rates, this study aims to recommend suitable structures to control soil erosion, contributing to a deeper comprehension of (Surendranet al., 2019)effective erosion control and land management strategies. The study is unique, since it integrates extensive field data collected from agricultural plots across Kozhikode with the RUSLE model predictions, providing a more accurate and context-specific understanding of soil erosion processes. This harmonization of empirical measurements with model outputs is an innovative approach that enhances the reliability of erosion estimates and validates the model's applicability in this region

2. Study area

For this study, Kozhikode district in Kerala is considered. Kozhikode lies between 75.694ºE, 11.799ºN to 76.830ºE, 11.123ºN (Fig 1.). It is spread across an area of 2364.872 km^2. Kozhikode district, located in the southern part of the Indian state of Kerala, exhibits unique geographical and climatic features. It is located in India along the southwest coast, sharing a border with the Arabian Sea. The district's topography varies from coastal plains to the rugged terrain of the Western Ghats. Kozhikode experiences a climate characterized by tropical monsoons (Surendran et al., 2019). It obtains heavy precipitation during the June-September (South West monsoon) and October-November (North East monsoon) with a net yearly precipitation of 3177mm (Surendran et al., 2019). The area is characterized by a mosaic of different land uses, reflecting a blend of urban, agricultural, and natural landscapes. Numerous rivers, streams, and backwaters traverse the region, adding to its hydrological complexity. The soil types found in Kozhikode district vary due to its diverse topography and climatic conditions. Common soil types include: Laterite, Alluvial and Red Lateritic soils are predominant in the region and are formed by the weathering of underlying rocks, often characterized by a reddish colour. Lateritic soils vary in texture and can be sandy or clayey(Chinnadurai et al.,2021; Dubeyet al.,2016; Sushama, 2015). Alluvial soils are prevalent along riverbanks and floodplains. These soils are typically fertile and well-suited for agriculture. Red soils are found in the hilly regions and are formed from weathered granite or gneiss rocks. They are often loamy and suitable for agriculture (Kullu et al., 2021).

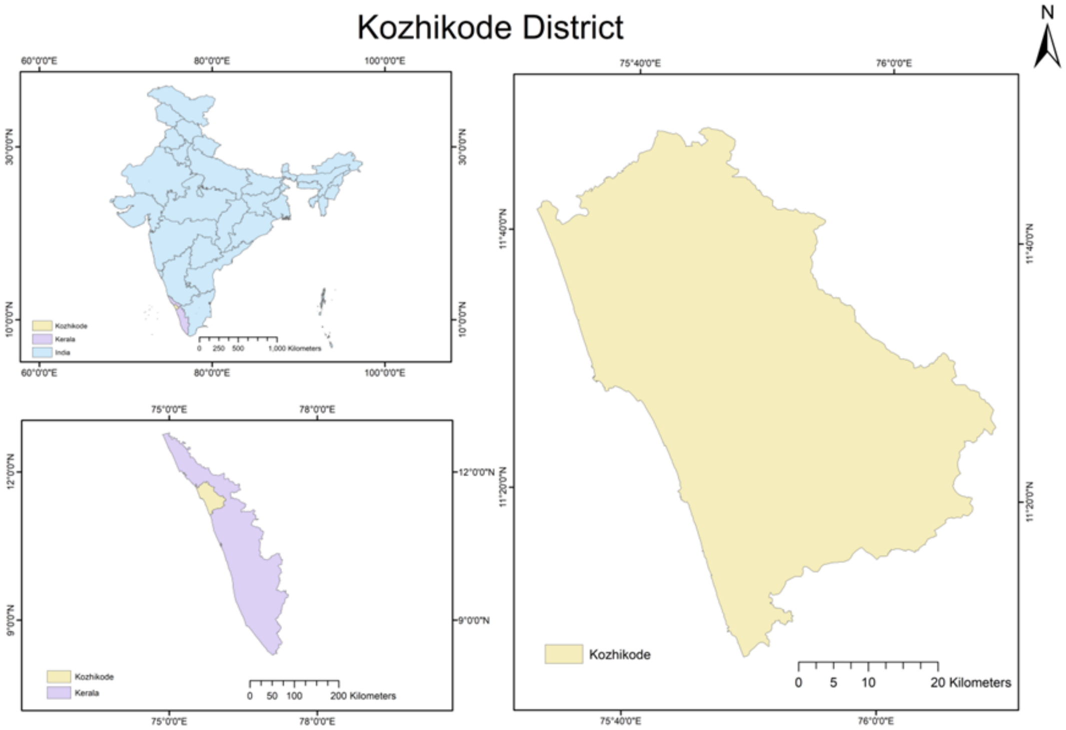

Fig. 1. Study area of Kozhikode District.

3. Methodology

The methodology involves calculating soil erosion in Kozhikode using RUSLE. Subsequently, soil erosion is quantified through field techniques in twenty agricultural fields across Kozhikode district. Following this R-Squared statistic is employed. If the R^2 value demonstrates a strong correlation, appropriate erosion control structures and conservation recommendations are proposed for the entire study area of Kozhikode. The same is depicted schematically in Fig. 2. In terms of land use and land types, Kozhikode District exhibits a predominant allocation of 62% to plantations and 17% to deciduous forests. Details on the land use and land cover classes and their percentages signify the major land uses within the district, as shown in Figure 3.

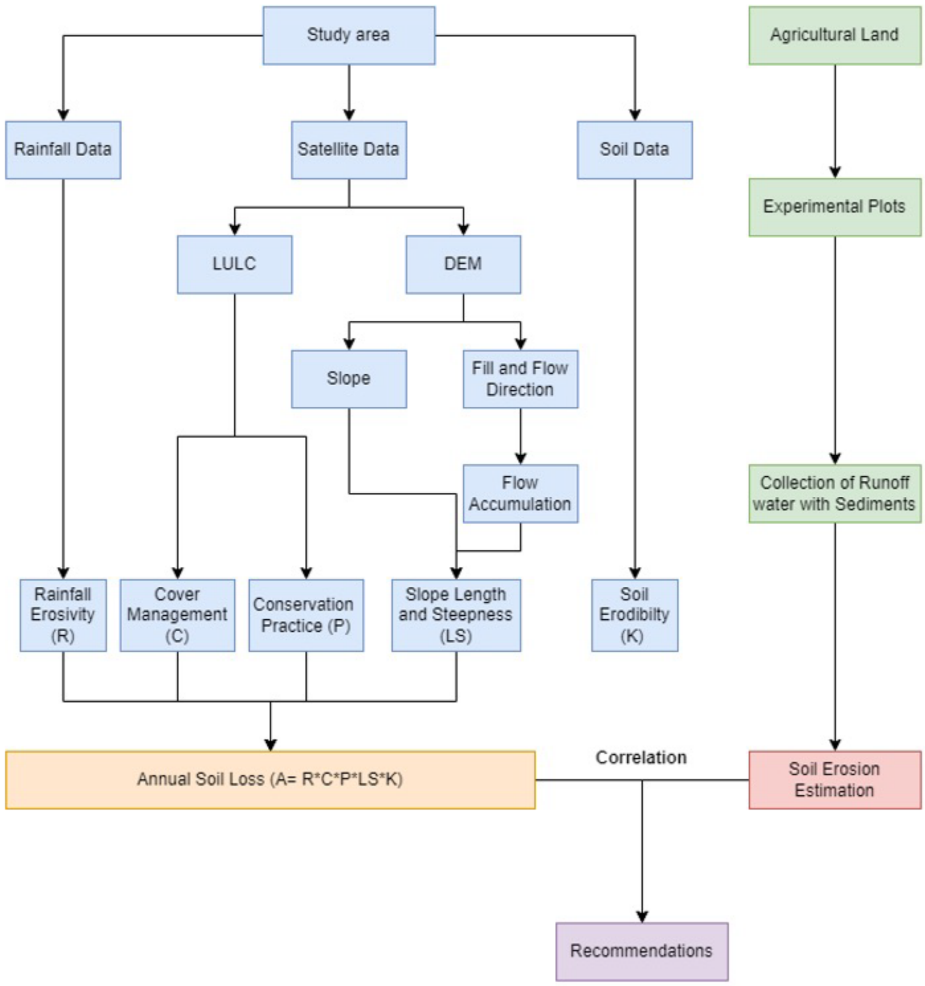

Fig. 2. Methodology adopted for computing soil erosion

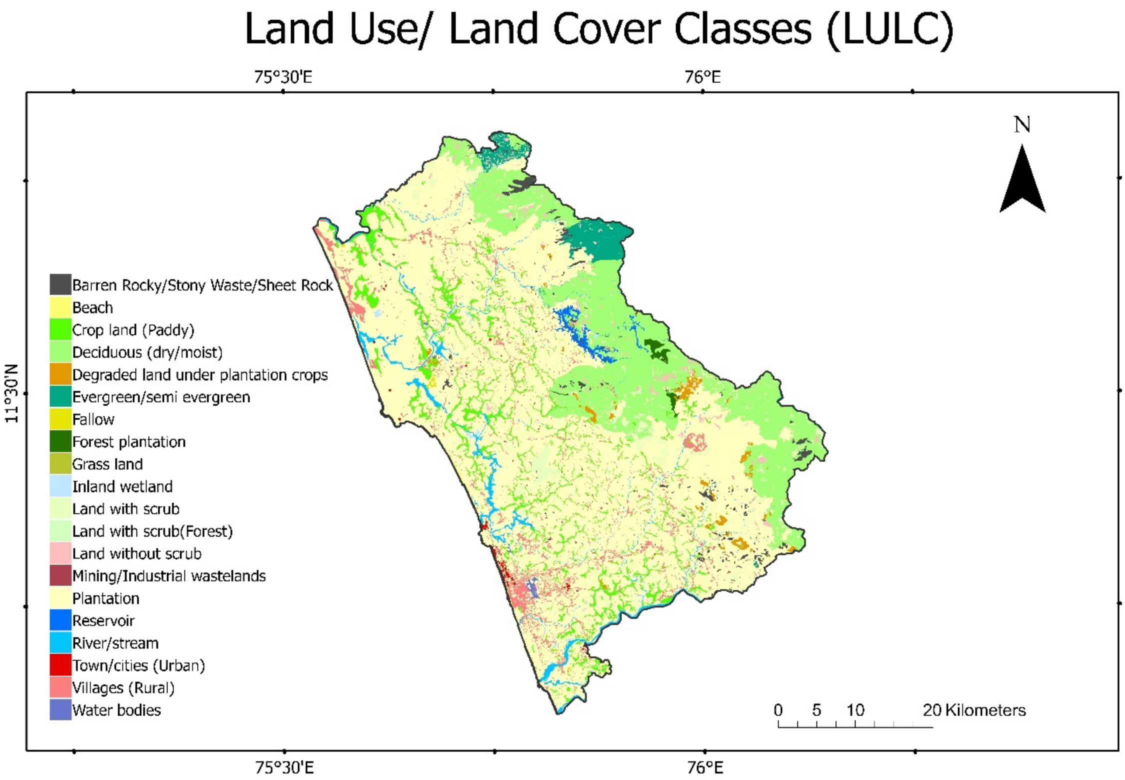

Fig. 3. Land Use Land Cover map (LULC) of Kozhikode district

3.1 RUSLE Model

The study area is analyzed using RUSLE by conceptualizing the area as a grid comprised of cells that are square, and the calculations are conducted for every cell.

RUSLE determines the projected average yearly soil loss by utilizing the following equation (Wischmeier & Smith, 1978).

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

The formula consists of various parameters: A is the annual soil erosion in mega grams per hectare per year (Mg ha^{-1} $year^{-1}$), K denotes soil erodibility in mega grams per hour per mega joule per millimetre (Mg h MJ^{-1} mm^{-1}), R is rainfall erosivity measured in mega joules per millimetre per hectare per hour per year (MJ mm ha^{-1} $h^{-1}yr^{-1}$), P is conservation practice factor, C stands for the cover management factor and LS represents the slope length and steepness factor.

3.1.1 R Factor

The significance of rain lies in its pivotal role as the primary catalyst for erosion, directly influencing the removal of soil, the disintegration of aggregates leading to the movement of the particles that are eroded through runoff. R factor was computed using 36 year (1986-2022) station data employing the subsequent correlation (Wischmeier & Smith, 1978).

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5\log_{10}\left(\frac{P_i^2}{P}\right)-0.08188\right)}$$

- R is rainfall erosivity (MJ mm ha^{-1} h^{-1} $year^{-1}$)
- Pi is monthly rainfall (mm)
- P is annual rainfall (mm)

3.1.2. K Factor

Soil erodibility encapsulates both the soil's vulnerability to getting eroded and the pace of movement of the soil, assessed within the conditions of the plot in standard units. K-factor, varies significantly based on soil composition and texture. Clay-rich soils, characterized by their fine particles, display lower K-values. Their inherent resistance to detachment contributes to this lower erosion susceptibility, thereby minimizing erosion potential. In contrast, soils enriched with high silt content has K-values of over 0.4, making them highly erodible compared to other soil types (Wischmeier & Smith, 1978).

Table 1. Soil erodibility factor pertaining to different soil types in Kozhikode District.

Sl.No	Texture	K Factor
1	loam	0.3
2	sandy	0.02
3	gravelly loam	0.13
4	clay	0.22
5	gravelly clay	0.14

3.1.3. LS Factor

The slope length and steepness factor represent soil loss ratio under particular conditions in the area. For instance, under the standard method, a slope length of 22.13m and a slope steepness pertaining to nine percent are considered. The fundamental data to be utilized for calculating LS factor is DEM data. The following formula was used for calculating the LS factor

$$LS = \left(\frac{As}{22.16}\right) m \left(\frac{\sin\beta}{0.0896}\right) n$$

$$L = \left(\frac{\lambda}{72.76}\right) m$$

A refers upslope contributing area
β is the slope angle
m is the slope length exponent

n is the slope steepness exponent

3.1.4. C Factor

Nature of vegetation cover and it's quantity influences soil loss extent (Benkobi, Trlica, & Smith, 1994). Essentially, floral cover plays a crucial role by catching the rain before it reaches the surface of the soil, thus preventing raindrops from directly impacting the soil. The species of vegetation, its growth stage, and the proportion of the area covered by plants all directly affect the cover management factor (C) (Panagos et al., 2015). These factors are quantified on a scale from 0 to 1, where 1 signifies the highest erosion potential. Table 2 illustrates the C Factor values for different LULC in Kozhikode.

Table 2. Cover management factor across various types of Land Use.

Sl.No	Land Use	C Factor
1	Rocky Terrain	0
2	Crop land (Paddy)	0.5
3	Deciduous (dry / moist)	0.4
4	Degraded land under plantation crops	0.5
5	Evergreen/Semi evergreen	0.12
6	Fallow	0.7
7	Forest plantation	0.12
8	Grass land	0.3
9	Inland wetland	0.2
10	Land with scrub	0.18
11	Land with scrub (Forest)	0.12
12	Land without scrub	1
13	Land without scrub (Forest)	0.12
14	Mining/Industrial wastelands	1
15	Plantation	0.14
16	River/stream	0
17	Town/cities (Urban)	0
18	Villages (Rural)	0
19	Water bodies	0
20	Waterlogged and marshy land	0
21	Beach	1

3.1.5. P- Factor

It is defined as the assessment of soil erosion levels on cultivated land within specific conditions in comparison to the erosion observed on land that is regularly plowed and left fallow (Wischmeier & Smith, 1978). This factor illustrates the implemented practices aimed at mitigating soil erosion. The P or Support practice factor was obtained from LULC map and quantified from a scale of 0 to 1, in which the 0 is allocated to regions lacking any practices for conservation of soil (Xiong, Sun, & Chen, 2019) Table 3 displays the P Factor corresponding to various LULC.

Table 3. P Factor for different LULC.

Sl. No	LandUse	P Factor
1	Barren rocky\Stony waste\Sheet rock	1
2	Crop land (Paddy)	0.5
3	Deciduous (dry / moist)	0.8
4	Degraded land under plantation crops	0.9
5	Evergreen/Semi evergreen	1
6	Fallow	0.9
7	Forest plantation	0.8
8	Grass land	0.8
9	Inland wetland	0.9
10	Land with scrub (Forest)	0.8
11	Land without scrub (Forest)	1
12	Land with scrub	0.8
13	Land without scrub	1
14	Mining/Industrial wastelands	1
15	Plantation	0.5
16	River/stream	1
17	Town/cities (Urban)	1
18	Villages (Rural)	1
19	Water bodies	1
20	Waterlogged and marshy land	1
21	Beach	1

3.3. Data Source

For the present study, the Kozhikode district was delineated from Survey of India toposheet using ArcGIS 10.7 software. Then the study area was extracted using the prepared base from satellite image (Indian Remote Sensing satellite, linear image self scanning sensor-3 IRS LISS-3) and Carto DEM (digital elevation model obtained by cartographic satellite). ArcGIS 10.7 was used for unsupervised classification for the creation of LULC map.The detailed description of the data source is given in Table. 4.

Table 4. Data source and its description.

Sl. No.	Data type	Description	Source
1	Satellite image	Landsat-8 (year-2016 with resolution 30 m)	https://earthexplorer.usgs.gov.
2	Soil data	Soil map for the year 2016.	The National Bureau of Soil Survey and Land Use Planning, India
3	Rainfall data	Rainfall data for a period of 36 years (1986–2022).	Station data
4	DEM (Digital	CARTO DEM (30 m Resolution)	www.bhuvan.nrsc.gov.in

Sl. No.	Data type	Description	Source
	elevation model)		

3.4 Data Resampling

All the factors used in the modelling exercise were resampled to a resolution of 30 m in order to make the calculations consistent.

3.5. Field Data Collection

In this study, a total of twenty agricultural plots, each dedicated to different crop cultivation and varying in land area, were meticulously visited and sampled for the purpose of quantifying soil erosion. These plots were strategically chosen and distributed across Kozhikodedistrict, aiming to encompass a wide spectrum of agricultural practices and land utilization prevalent within the region by considering the agro ecological units (AEU). The diversity in crops grown within these plots provides a comprehensive representation of the agricultural landscape, allowing for a thorough assessment of soil erosion dynamics. The geographical distribution of these plots across different terrains and microclimatic conditions ensures a holistic analysis of soil erosion, considering the local environmental factors at play. The experimental plots, measuring 4m x 3m, were enclosed with vertical G.I sheets to contain runoff within the plots and prevent external runoff from entering. Surface runoff from these plots during categorized low, moderate, and substantial precipitation events was separately gathered to evaluate various losses from the experimental plots such as water, nutrient and soil loss. Rainfall was categorized as low if it was less than 20 mm per day, medium if it ranged from 20 to 50 mm per day, and high if it exceeded 50 mm per day. A 125liters aluminum container collected water and sediments from each plot, with overflow into a 50liters secondary tank through a thirteen-multi slot divisor. Out of the thirteen slots, only one remains closed and is connected to the secondary tank, while the other twelve slots are left open so that the sediments flow through them and the amount of erosion is evaluated by multiplying the collected amount of sedimentby 13 (Fig.4). The collected flow in these tanks represented plot runoff (Fig. 4). Estimation of eroded soil involved filtering a combined sample after thorough mixing of the sediment and run off collected from both the tanks, following methodologies detailed by Heron (1990); Hudson(1993).

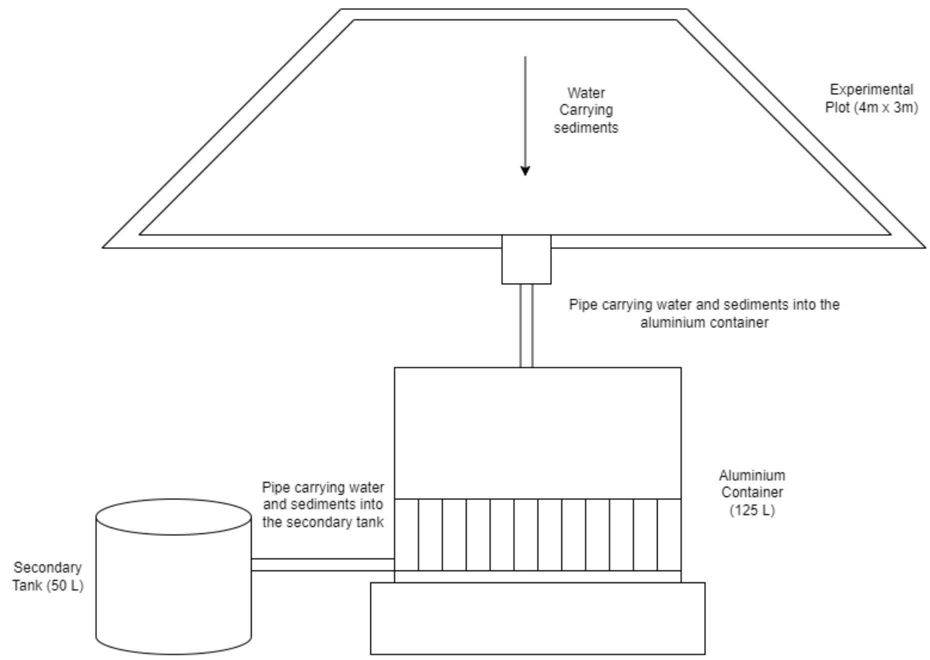

Fig. 4. Pictorial representation of Field Estimation of Soil Erosion

4. Result and Discussion

4.1. Soil erodibility factor (K)

To generate the soil erodibility (K-factor) map, each soil type within the study area was assigned a specific K-factor value based on its physical and chemical properties. These values were derived from a combination of existing soil survey data, predictive models, and validated against regional benchmarks where available. This was verified with the observed 20 points field data were sampling has been carried out. The K-factor values in our study area ranged from 0.02 to 0.30, as shown in Figure 5.

Soils with lower K-factor values, closer to 0.02, are typically associated with high permeability, which facilitates rapid water infiltration and reduces surface runoff, thus lowering the potential for soil erosion. Additionally, these soils often have lower antecedent moisture content, meaning they are less likely to be saturated before a rainfall event, further minimizing erosion risks. Factors such as organic matter content, soil structure, and texture also contribute to the reduced erodibility observed in these soils.

On the other hand, the majority of the area in our study was found to have a K-factor of around 0.14. This value is reflective of the predominant soil type in the region, which is gravelly clay. Gravelly clay soils generally exhibit moderate to low permeability, leading to an intermediate level of erodibility. The presence of gravel reduces the soil's ability to hold water, while the clay component contributes to soil cohesion. This combination results in a K-factor that is neither excessively high nor low, indicating a moderate susceptibility to erosion under typical rainfall conditions. The distribution of K-factor values across the study area is a direct reflection of the underlying soil characteristics, which are influenced by factors such as soil texture, structure, organic matter content, and permeability. By assigning specific K-factor values to each soil type, we were able to create a detailed and accurate representation of the soil erodibility potential across the landscape.

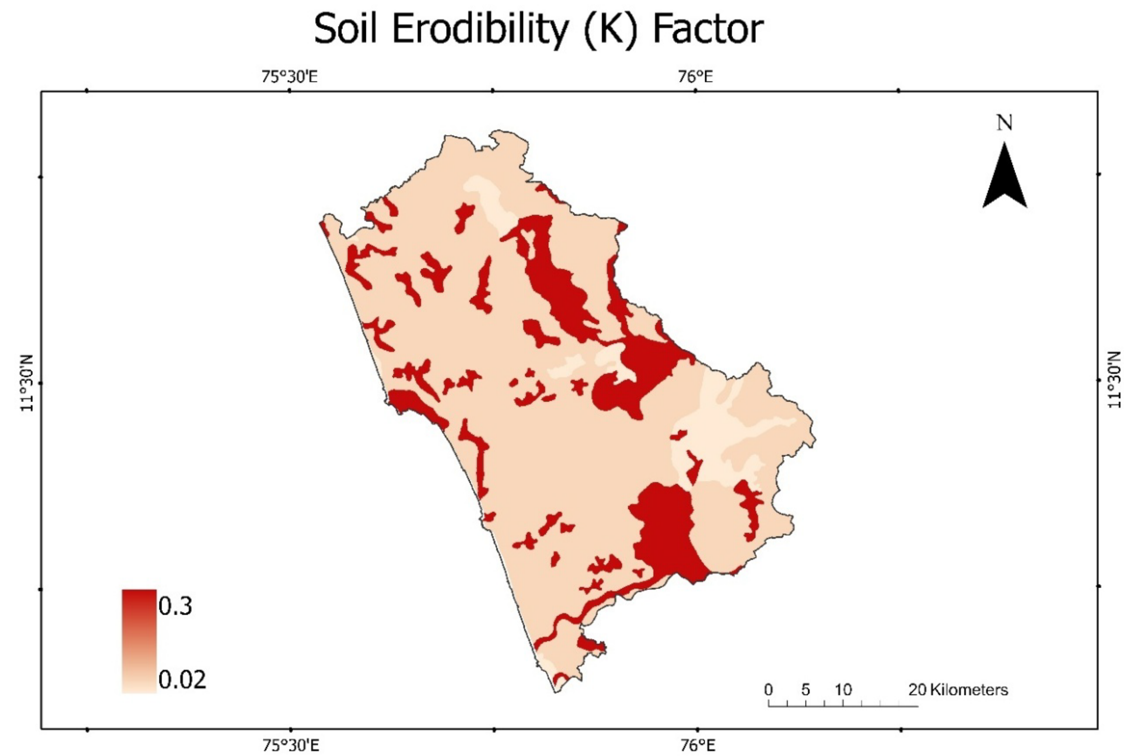

Fig.5. Soil erodibility factor (K) of Kozhikode distrcit.

4.2. Rainfall erosivity factor (R)

Net precipitation for the selected period was utilized to compute the Rainfall Erosivity (R factor), which is a key component in assessing the potential for soil erosion. The R factor quantifies the impact of rainfall on soil, considering both the intensity and the amount of precipitation. It is expressed in units of MJ mm ha^{-1} h^{-1} $year^{-1}$, reflecting the energy exerted by rainfall to detach soil particles and contribute to erosion. In this study, the R factor values ranged from 1719.55 to 2074.58 MJ mm ha^{-1} h^{-1} $year^{-1}$, indicating significant variation in rainfall erosivity across the study area (Fig. 6). This is in accordance with the some of the earlier reported results (Prasannakumar et al., 2012). The lowest R value was observed in the

Kottamparambu region, where rainfall intensity and duration are relatively moderate, resulting in lower erosive force. In contrast, the highest R value was recorded in the Vadakkara region, which experiences more intense and frequent rainfall events, leading to greater potential for soil erosion. To provide a more detailed analysis, we also computed the R factor on both a monthly and seasonal basis. This approach allowed us to capture the temporal variability in rainfall erosivity, which is critical for understanding erosion patterns throughout the year. For example, during the monsoon season, the R factor is significantly higher due to the heavy and sustained rainfall, whereas in the dry season, the R factor is considerably lower as precipitation events are less frequent and less intense.

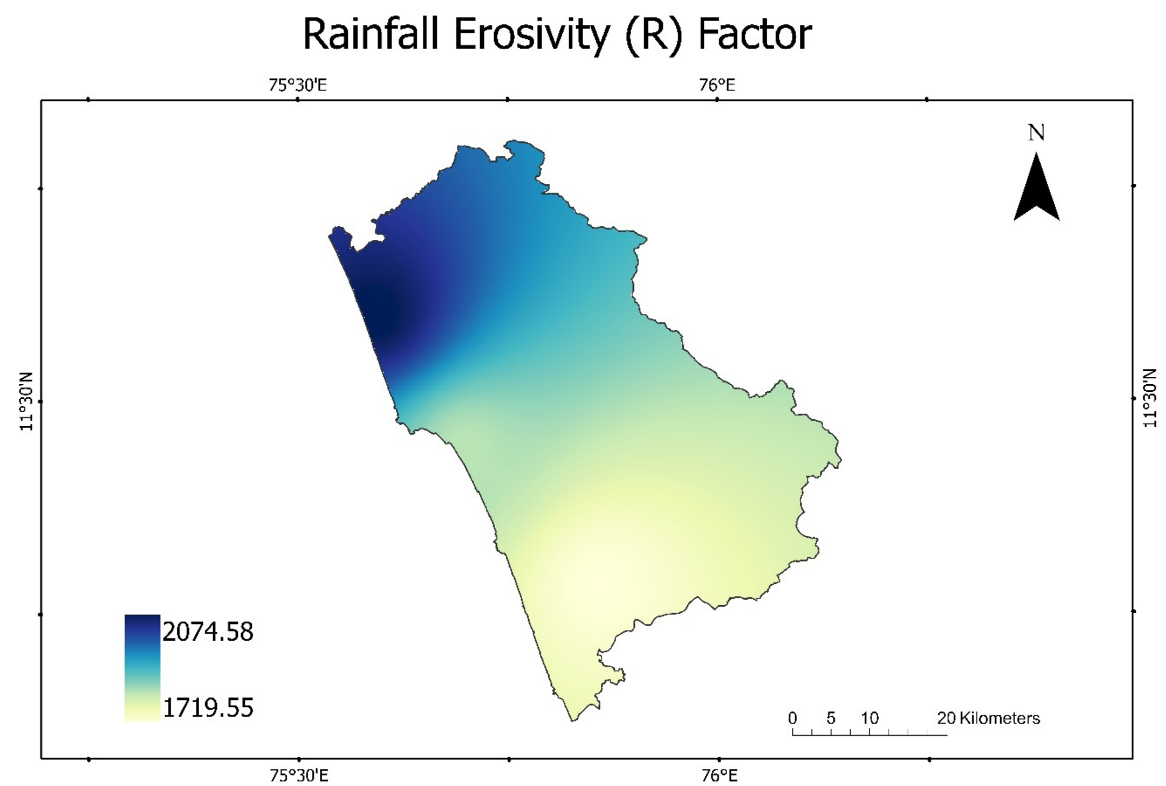

Fig. 6. Rainfall Erosivity Factor (R) of Kozhikode district

4.3. Crop management factor (C)

To assess the impact of different land use patterns on soil erosion, we assigned each land use type a specific crop management factor (C factor) based on the values provided in Table 2. The C factor is a crucial component in the Revised Universal Soil Loss Equation (RUSLE), as it represents the influence of vegetation cover and agricultural practices on soil erosion rates. The values assigned to the C factor ranged from 0 to 1, with each value corresponding to a different level of ground cover and associated erosion potential. A C factor value of 0 indicates that the land is fully covered by vegetation or crops, which provides maximum protection against soil erosion. This could be a dense forest, well-maintained grassland, or a field with continuous cover crops. In such scenarios, the risk of soil erosion is minimal, as the vegetation intercepts rainfall, reduces runoff velocity, and stabilizes the soil. On the other end of the spectrum, a C factor value of 1 represents bare soil or land with no vegetative cover, where the potential for erosion is at its highest. This could occur in areas of fallow land, overgrazed pastures, or recently plowed fields without any protective crop cover. In these situations, the soil is fully exposed to the erosive forces of rainfall and wind, leading to a high likelihood of soil loss. Figure 7 provides a visual representation of the spatial distribution of C factor values across the study area, highlighting the regions with varying levels of erosion risk based on land use patterns

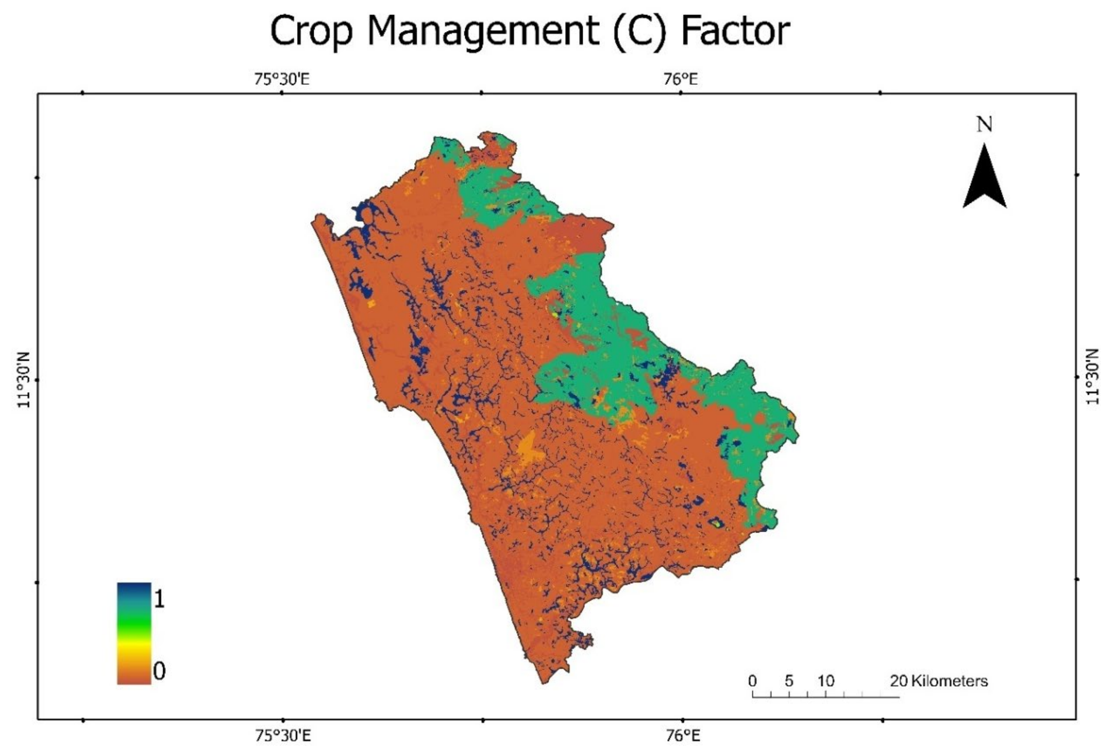

Fig.7. Crop management factor (C) of Kozhikode district.

In this study area, approximately 62% of the land was characterized by a C factor value of 0.14 (Fig. 7). This indicates that a significant portion of the area is under moderate to good vegetative cover, such as cropland with partial cover, orchards, or managed forests, where the erosion risk is relatively low. The presence of vegetation helps to anchor the soil, reduce surface runoff, and limit the detachment of soil particles. Conversely, 17% of the area had a C factor value of 0.4, which suggests that these regions have less ground cover and are more vulnerable to erosion. This could correspond to areas with sparse vegetation, degraded pastures, or lands under cultivation where crops are not fully established, leaving the soil more exposed to the elements.

4.4. Slope Length and Steepness Factor (LS)

By factoring in the input from flow accumulation and slope percentage, the LS factor was actively computed. The value escalates from nil to 22.095 with the increase in slope and flow accumulation, as illustrated in Figure 8. Low values of LS factor throughout the basin indicate very gentle to moderately slopping topography (Nagaraju et al., 2011)

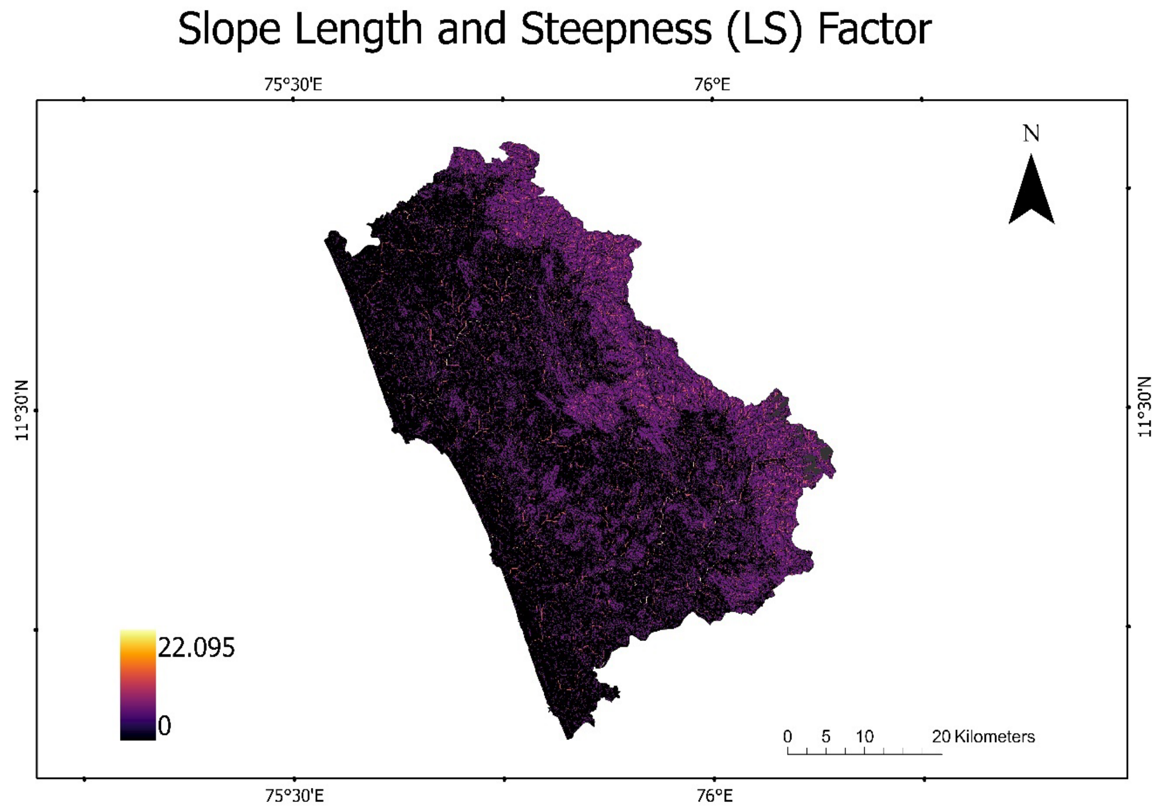

Fig. 8. Slope Length and Steepness Factor (LS) of Kozhikode district.

4.5. Conservation practice factor (P)

Based on the LULC and support factors, the P-factor map was created. Values vary between 0 and 1, with 1 allocated to regions devoid of practices of soil conservation (such as dense vegetation, built-up areas, and water bodies); whereas Agricultural Cropland corresponds to minimum values. A lower value suggests efficient practices of conservation. Approximately 68% of the area exhibited a P value of 0.5, while roughly 10% area demonstrated a value of 1, as depicted in Figure 9.

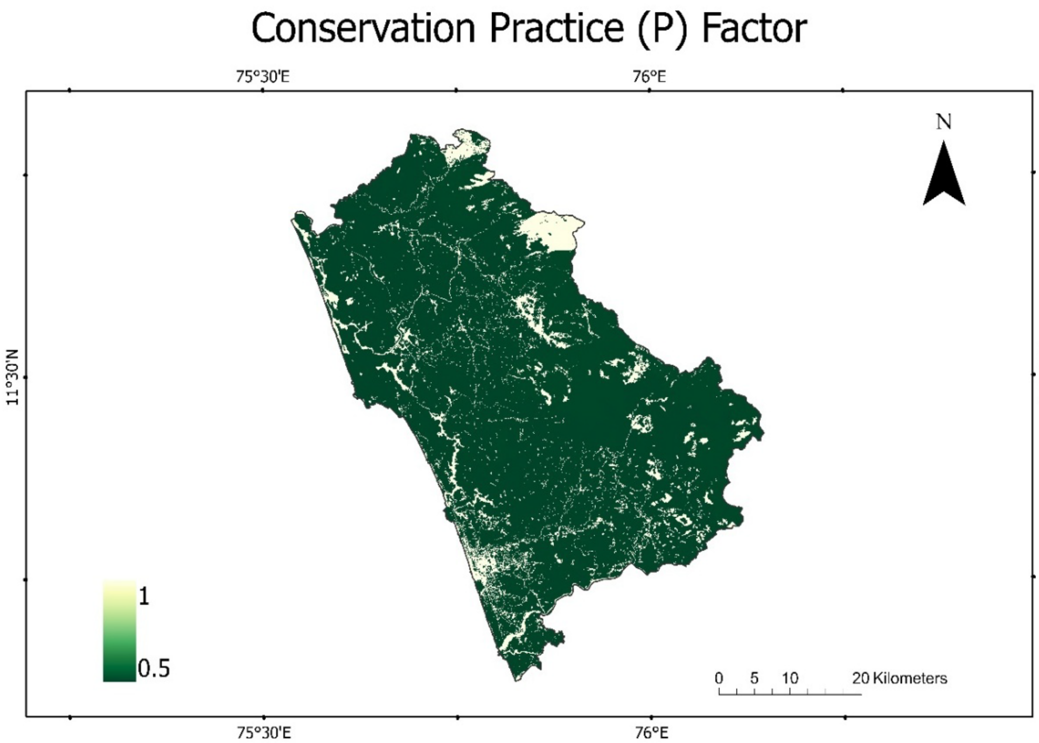

Fig 9. Conservation practice factor (P)

4.6 Annual Soil Loss (A)

The Soil loss values calculated using RUSLE were classified into 7 classes as given in table 4. In Kozhikode district, the spatial distribution of erosion risk reveals a diverse range of erosion intensities across the landscape. According to our analysis, 52.0% of the area is classified as experiencing Very Slight Erosion, indicating minimal soil loss (Fig. 10). In these regions, the combination of protective vegetation cover, favorable soil properties, and relatively gentle slopes contribute to the low erosion risk, making them less vulnerable to the erosive forces of wind and water. Slight Erosion is found in 10.31% of the area, where erosion rates are low but not negligible. These regions may experience some soil loss, particularly during heavy rainfall events, but generally maintain better soil stability compared to areas with higher erosion risks. Moderate Erosion occurs in 6.18% of the district. Here, soil loss is more manageable, but ongoing monitoring and conservation practices are still important to maintain soil health and prevent further erosion.

Moderately Severe Erosion affects 3.88% of the area. While not as intense as the higher categories, these areas still face considerable soil loss that could impact agricultural activities and necessitate erosion control measures to prevent escalation. Severe Erosion Risk is present in 7.34% of the district. In these areas, the erosion rates are high enough to cause significant damage to the soil structure, potentially leading to loss of arable land and adverse effects on water quality due to sedimentation.

Table 5. Soil Erosion risk of Kozhikode district.

Severity	Soil Erosion (t/ha/yr)
Very Slight	<5
Slight	5-10
Moderate	10-15
Moderately Severe	15-20
Severe	20-40
Very Severe	40-80
Extremely Severe	>80

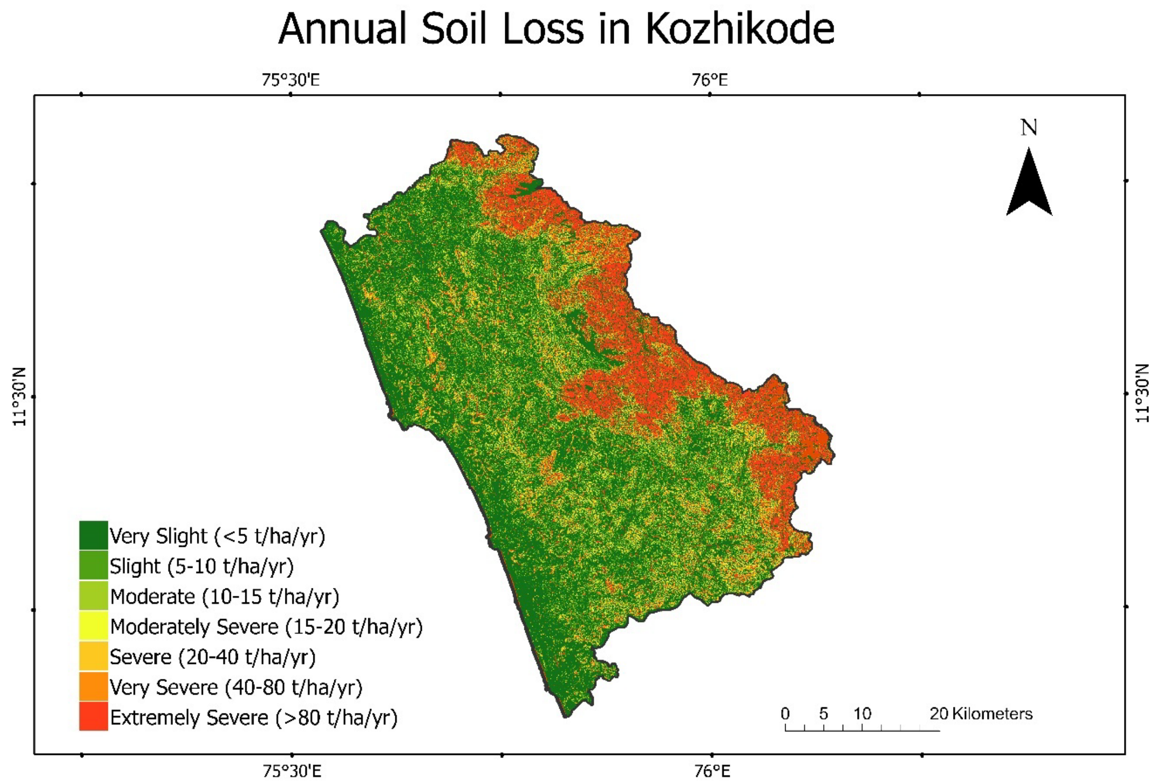

Fig.10. Soil Erosion risk in Kozhikode.

Very Severe Erosion is observed in 5.6% of the area, where soil loss is substantial but slightly less extreme than in the areas categorized as Extremely Severe. These regions are still at high risk and require immediate attention to prevent further degradation. However, a significant portion of the district faces more severe erosion challenges. Extremely Severe Erosion affects 14.65% of the area, representing regions where the landscape is highly susceptible to intense soil loss. This level of erosion is often associated with steep slopes, poor vegetation cover, and highly erodible soils. The severity of erosion in these areas poses a serious threat to soil fertility, agricultural productivity, and environmental sustainability. Overall, the district experiences an average annual soil loss of 28.7 t/ha/yr. This figure reflects the cumulative impact of various erosion intensities across the region, emphasizing the need for targeted soil conservation strategies to mitigate erosion and sustain agricultural productivity. Figure 10 illustrates the distribution of these erosion risk categories, providing a visual representation of the area's most in need of intervention.

4.7 Field data

Field data were collected from 20 agricultural plots across Kozhikode district(Table 5), and amount of soil erosion was measured. These values were then compared to those predicted by RUSLE.

Table 6. Measured yearly soil erosion and the erosion rate computed via RUSLE.

Plot No	Latitude	Longitude	Field value (t/ha/yr)	RUSLE Value (t/ha/yr)
1	11.515571	75.635407	4	2.86
2	11.48086	75.63574	3.3	2.64
3	11.491645	75.641512	2.6	9.27
4	11.66693	75.599569	30.8	21.76
5	11.677185	75.59785	28.6	25.93
6	11.420087	76.045209	66.7	47.12
7	11.739199	75.69794	12.6	8.50
8	11.725932	75.687444	17.6	12.14
9	11.534111	75.843065	69	53.00
10	11.542963	75.831165	88	30.52
11	11.435983	75.975256	106.7	43.65
12	11.449478	75.69906	3.3	19.55
13	11.463873	75.706726	5.5	3.27
14	11.420697	75.724937	5.7	2.91
15	11.472709	75.671843	8.9	10.87
16	11.528477	75.777098	9.1	9.57
17	11.325614	75.911233	16.3	13.31
18	11.684883	75.761344	38.1	30.68
19	11.315367	75.85256	9.2	12.79
20	11.651951	75.812899	23.4	19.45

4.8 Data analysis

R^2 or coefficient of determination was used to correlate the two data. Correlation measures how one variable vary with respect to the other. So, this statistical analysis was employed in our study. The R^2 value of the observed and simulated data was 0.7514, suggesting significant correlation among the sets of data.

Graphical representation of R^2 value between the field values and RUSLE values is depicted in the Fig. 11.

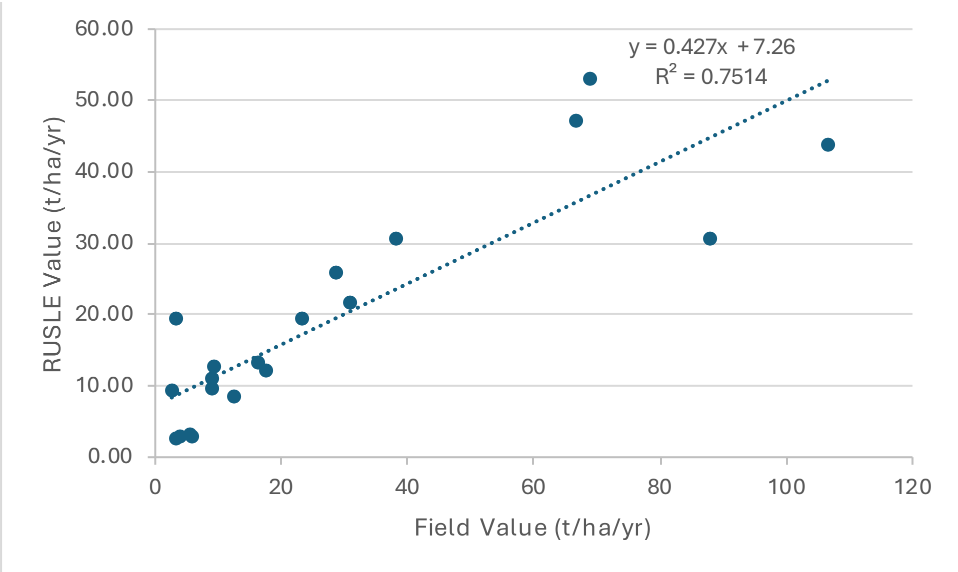

Fig. 11. R^2 of field and RUSLE values.

4.9. Recommendations

An understanding of soil erosion and event-based runoff is beneficial for both managing current water harvesting schemes and introducing novel approaches like check dams, percolation ponds and micro-dams (Grum et al., 2017). There is evidence that conserving water and soil can effectively minimize soil erosion (Silva et al.,2024). Based on the erosion results, the average erosion values were calculated for each village in Kozhikode district. Prioritization was subsequently undertaken to manage soil erosion in these regions. Villages with very slight and slight erosion were classified as low priority. Villages experiencing moderate and moderately severe erosion were classified as medium priority areas. Villages with severe, very severe, and extremely severe erosion were categorized as high priority regions as shown in Fig. 12.

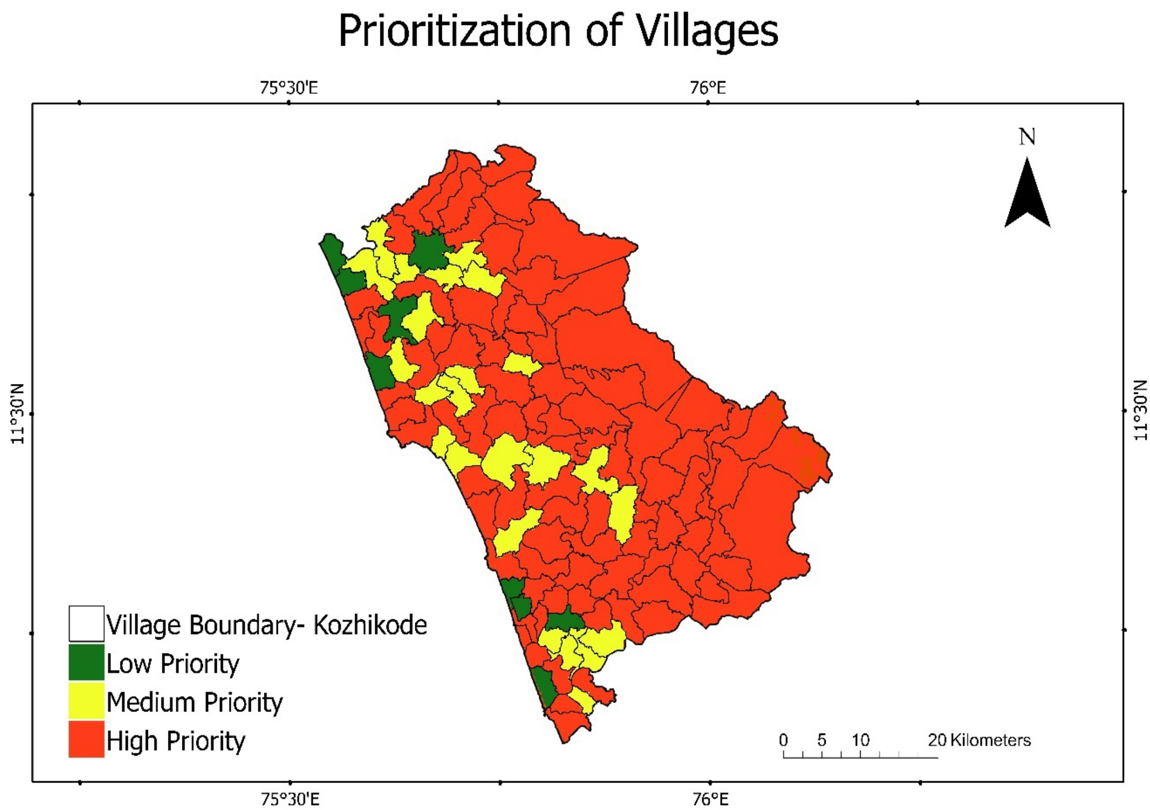

Fig. 12. Villages classified as Low, Medium and High Priority for erosion.

Implementing soil erosion control techniques is of utmost importance in alleviating and rehabilitating eroded areas (Kumarasinghe, 2021). Recommendations for water harvesting structures were suggested accordingly by considering various factors such as Land use patterns, soil composition, elevation and drainage patterns for each priority classification to address and manage the erosion concerns effectively (Jeetet al., 2022). In table 5 presents the recommended water harvesting structures in villages based on their priority levels.

Table 7. Recommended water harvesting structures in villages based on their priority levels.

Priority Level	Villages	Water harvesting structures recommended
Low	Azhiyar, Kachcheri, Beypore, Iringal, Nadapuram, Nellikkod, Onchiyam, Pudiyangadi, Villiappalli	Check dam, farm pond, grassed waterways, tanks, gully plugging, and reservoirs
Medium	Ferokh, Kottappalli, Kunnummal, Kuttiyadi, Menjeryam, Meppayur, Pallayad, Pantalayini, Perumanna, Ullieri, Viyyur, Balusseri, Edacheri, Eramala, Kizhakkot, Kozhukkallur, Olavanna, Panthirankavu, Purameri, Sivapuram, Talakkulattur, Turayar, Valayanad	Conservation bench terrace, contour trenches, contour bunding, graded bunding, broad bed and furrow, and conservation ditches.
High	Arikulam, Attoli, Chevayur, Chorod, Eravattur, Ingapuzha, Kakkur, Koyanna, Kadalundi, Karuvanturutti, Kozhikode, Kuttikkattur,	Conservation bench terrace, contour trenches, contour bunding, graded bunding, broad

	Madavadi, Mavur, Maniyur, Nadakkuthazha, Naduvannur, Narikkuni, Nenmanda, Nochad, Panangad, Ramanattukara, Rarot, Vadakara, Ayancheri, Avidanallur, Changarott, Chekkyad, Chelannur, Chelavar, Chemancheri, Chengottukavu, Kattuli, Kizhariyar, Koyakkodi, Kakkodi, Kinellar, Koduvalli, Kottali, Kottur, Kudatti, Kumaranelloor, Kunnamangalam, Kuruvattur, Madavar, Marudonkara, Narippatta, Puthur, Panniakara, Peruvayal, Tanneri, Vanimal, Valayam, Velam, Vengeri, Chakkittapara, Chembanode, Cheruvannur, Chettamangalam, Elattur, Kadarangi, Karachundu, Kavilampara, Kakkad, Kantilad, Kedavur, Kodiyattur, Nileswaram, Nagaram, Nellipoyil, Palakkod, Payyoli, Perambra, Puduppadi, Puttur, Tazhakkod, Tikkodi, Tinar, Tiruvallur, Tiruvambadi, Unnikulam, Vayod, Vilangad.	bed and furrow, and conservation ditches.

6. Limitations

Although the RUSLE model is widely used for estimating soil loss due to its user-friendliness and minimal data requirements, it has several limitations. A significant drawback, as noted by Jeet et al. (2022), is that RUSLE primarily addresses sheet and rill erosion and does not fully account for other erosion types. Despite these limitations, RUSLE remains popular in both research and practical applications due to its simplicity and ease of use. For a more comprehensive assessment of different erosion processes, alternative models that capture a wider range of erosional mechanisms may be necessary. Additionally, using higher resolution data could improve the accuracy of soil erosion predictions.

7. Conclusion

The location of Kozhikode, nestled close to the beach and neighbouring the Western Ghats, makes it susceptible to erosion challenges. The region's soil erosion patterns are significantly affected due to its geographical positioning, which exposes it to diverse environmental influences, including coastal effects and hilly terrains. Soil Erosion values were classified into seven categories, depicting the erosion levels in the Kozhikode district. Within this area, 52.02% encounters Very Slight Erosion, whereas 14.65% deals with the significant challenges posed by Extremely Severe Erosion. Field data were meticulously gathered from 20 agricultural plots spread across Kozhikode, allowing for the measurement of annual soil erosion rates. These carefully chosen plots provided a wide-ranging perspective on farming techniques throughout the region. The different plot sizes and diverse crops allowed studying the dynamics pertaining to erosion of soil thoroughly. Dispersed among diverse topographies and microclimates, these plots allowed for a comprehensive examination, taking into account regional environmental influences on soil erosion. The r^2 value of 0.7514, obtained from comparing the soil erosion rates between observed values and those calculated by RUSLE, highlights a robust correlation between the observed and simulated datasets. This signifies the reliability of RUSLE predictions within this context.

An average erosion value was calculated for each village to establish a prioritization strategy for managing soil erosion effectively. Villages with Very Slight and Slight erosion were classified as low priority, while those with Moderate and Moderately Severe erosion were designated as medium priority. Villages experiencing Severe, Very Severe, and Extremely Severe erosion were identified as high priority zones, requiring immediate intervention. To address these erosion issues, tailored recommendations were provided based on priority levels. Low priority villages were advised to implement water harvesting techniques such as farm ponds, grassed waterways, gully plugging, reservoirs, check dams, and tanks. Medium and High priority areas were recommended to adopt measures including conservation bench terraces, contour trenches, contour bunding, graded bunding, compartmental bunding, broad bed and furrow, and conservation ditches. These strategies aim to reduce erosion, protect soil fertility, and maintain the long-term sustainability of natural and agricultural ecosystems in the Kozhikode district. Ongoing monitoring and further research are crucial for refining these strategies and ensuring their effective implementation. Field validation is essential for confirming the accuracy and relevance of predictive models like RUSLE, as it evaluates how well these models reflect real-world conditions and provides insights into their performance in specific locations. Regular updates and calibration of the model using new field data are necessary to maintain its applicability to current environmental conditions.

Overall, the RUSLE and GIS-based methods used in this study provide valuable tools for identifying areas most susceptible to water-induced soil erosion and prioritizing them for effective land management planning based on erosion severity. This highlights the need for detailed soil erosion investigations at the watershed level. Additionally, the study offers crucial information for policymakers, decision-makers, stakeholders, and international organizations working together to develop sustainable watershed management strategies.

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curation, SM.,and G.S.; writing—original draft preparation, U.S.; writing—review and editing, U.S., and K.K.; visualization, U.S and K.K. supervision, U.S.; project administration, J.S.. funding acquisition, Y.Y. All authors have read and agreed to the published version of the manuscript.

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