RESEARCH

Spatial analysis and assessment of soil erosion in the southern Western Ghats region in India

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Abstract Soil erosion is expected to worsen in the future as a result of climate change, growing population demands, improper land use, and excessive exploitation of natural resources in India. Due to the growing population and changes in land use, it has become increasingly crucial to map and quantitatively assess soil for the purpose of sustainable agricultural usage and planning conservation efforts. The problem of soil erosion is mainly on steeper slopes with intense rainfall in parts of Western Ghats. The 20.17% of geographical area have been converted into wasteland due to soil erosion. The Revised Universal Soil Loss Equation (RUSLE) is a highly prevalent and effective technique utilized for estimating soil loss in order to facilitate the planning of erosion control measures. Despite the fact that RUSLE is accurately estimate sediment yields from gully erosion, it is an effective tool in estimating sheet and rill erosions losses from diverse land uses like agricultural to construction sites. The current study is mainly about combining the RUSLE model with GIS (Geographic Information System) to find out how much soil is being lost, particularly in Noyyal and Sanganur watersheds which is located in Coimbatore district of Tamil Nadu, India. This analysis is based on the soil order, with a significant proportion of alfisols and inceptisols being considered. The obtained outcome is contrasted with the established soil loss tolerance threshold, leading to the identification of the areas with the highest susceptibility to erosion. Within the narrower and more inclined section of the watershed, yearly soil loss scales from 0 to 5455 tonnes/ha/year, with an average annual loss of soil of 2.44 tonnes/ha. The severe soil erosion of 100 to 5455 tonnes/ha/year is found along the steep and greater slope length. The generated soil map was classified into six categories: very slight, slight, moderate, high, severe, and very severe. These classifications, respectively, occupied 6.23%, 14.88%, 10.56%, 15.70%, 7.73%, and 6.63% of the basin area. Based on the results of cross-validation, the estimated result of the present study was found to be very high compared to past studies conducted 0 to 368.12 tonnes/ha/year especially in very severe erosion zones. But very slight to severe erosion zones nearly matched with same level of soil loss. To protect the soil in the study area from erosion, more specific actions should be taken. These include micro-catchment, broad bed furrows, up-and-down farming,

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soil amendment with coconut coir pith composition, streambank stabilization with vegetation, and micro-water harvesting with abandoned well recharge. These actions should be carried out over time to make sure to work.

Keywords   Soil erosion · Noyyal · Soil losses · RUSLE · GIS

Introduction

Soil erosion is the process of the detachment and movement of soil particles from the point of origination through the action of water or wind (Patsios et al., 2021). Destroying the environment's natural barriers, such as uncontrollable clearance of forest and excessive grazing on vegetative growth, are the causes of soil erosion. Other causative factors are unsustainable use of land resources, such as leaving the land uncultivated and making it vulnerable to the effects of rain and wind, cultivating crops that hasten soil erosion, adopting an ill- cropping pattern, and incorrect irrigation techniques. Soil erosion is influenced by various factors, including climatic elements. The amount and intensity of precipitation play a significant role in soil erosion by water. This precipitation initially detaches the soil particles from the land surface and causes splash erosion. This further develops with the detachment of a thin layer of soil; this is known as sheet erosion. Rill and gully erosion are the advanced stages of sheet erosion. Adverse consequences of soil erosion are decreasing soil fertility and subsequently having an impact on crop output, lowering the capacity of streams and rivers by raising their beds, causing the floodwaters to overflow into nearby regions, siltation of reservoirs and other water-storing resources, and also affecting the hydraulic structures, which in turn reduce their strength and holding capacity. This might also lead to the collapse of the structure (Dastagir et al., 2020; Natarajan et al., 2010). According to (NAAS, 2017) report, the amount of soil erosion in India's arable land was estimated to be 92.4 million hectares; also, around 2308 hectares of cultivable land in Tamil Nadu are affected by soil erosion, and annual soil loss in India is estimated to be more than 10 tonnes/ha/year. Indian scenario states that roughly around 147 million hectares were degraded by various parameters such as water erosion, acidification,

wind erosion, and salinity. Out of all factors, water erosion is a major threat factor that degrades 94 million hectares out of 147 million hectares; whereas other factors are minimal risk factors (Bhattacharyya et al., 2015; Mahapatra et al., 2018). As per the literature (Saha et al., 2018; Singh & Panda, 2017), it says that approximately 113.3 million hectares of land affected by water erosion results in detachment of 5334 million tonnes of topsoil annually. of this soil loss, 29% is transported by river to sea, 10% by reservoirs causing sedimentation and the remaining 61% displace from one location to another location. From this, it is very clear that removal of topsoil is majorly affected by the water erosion. Hence, the soil conservation practices should take a wise decision of integrated planning of soil and water to preserve the topsoil. Coming to the Tamil Nadu scenario, soil erosion linked to farming in tropical and semi-arid regions, shows the decline in soil fertility and it results adverse effects in the ecosystem (Prasannakumar et al., 2012). In sloping area, soil erosion increases due to intensive farming and additionally socio-economic pressure for need of more land for cultivation (Shi et al., 2004). An assessment of the soil erosion was made for a boundary by considering the watershed boundary; downstream flow along with other soil erosion characteristics would yield dependable data for devising sustainable development plans for the study area. The RUSLE is the prevailing model used globally to compute soil loss. It is proven that this RUSLE is an effective planning tool in precisely measuring the soil erosion for various types of land uses (Renard et al., 1996; Sharma et al., 2011; Prasannakumar et al., 2012; Ranzi et al., 2012).

Thus soil erosion affects a country environmentally and economically so it must be considered as a serious factor and measures to conserve it in immediate actions. An estimation of soil loss will help in finding conservation practices suitable for the particular soil eroded area. In order to understand the precise impact of various land management techniques on soil loss, measurement of soil losses from areas under controlled conditions is required. Universal Soil Loss Equation (USLE) type models have undergone extensive use and modification. Wischmeier (1959) is optimized broadly in the approximation of soil loss under specific conditions. Modified Universal Soil Loss Equation (MUSLE) is developed by Willams (1975) and it is expressed with runoff

instead of precipitation. RUSLE type of approaches has been modified over the last two decades, but still is predominantly employed tool in analyzing spatial distribution of soil erosion in temporal scale (Borrelli et al., 2021).

Researchers have made several attempts to quantify soil loss. Runoff plots were one of the most extensively used techniques to quantify soil losses as a result of sheet erosion. Some of the researchers used runoff plots for estimation of soil loss (Das et al., 2022; Meena et al., 2023; Gupta et al., 1963; Lal & Mishra, 2014). The runoff plot studies were widely used to compute the factor involved in USLE. Its applicability to some situations in India has been reported (Tejwani et al., 1975). Furthermore, the crop management (C) and conservation practice factor (P) for silt loam soil at Dehradun had an average K value of 0.3 tonnes/h per EI result, where "E" is a kinetic energy and "I" is the intensity of rainfall mostly in 30 min. Thangam and Narayanan (2017) were used rainfall erosivity factor by calculating I30 and kinetic energy (E). Similar studies were undertaken to find out each factor of USLE under the Noyal River Basin area during 1978–1982 at the Department of Soil Conservation Engineering, TNAU, Coimbatore. The study area in the Noyal River Basin was comprised of various soil types, and runoff plot studies were conducted in the Veerapagoundanur, Chokanur, and Vadachittur regions (PL480 Scheme, USLE). The primary drawback of this approach is that relatively large collecting tanks are required to contain the anticipated runoff. Many other empirical models are used to estimate the erosion. A few of them are the following: The CORINE (Coordination of Information on the Environment) model is regarded as a useful tool for forecasting soil erosion and pinpointing the most severely affected areas (Khallouf et al., 2021). The Water Erosion Prediction Project (WEPP) is a physically dispersed model that simulates soil movement from hill slopes to channels and through channels to the watershed outlet. The impracticality of this model arises from the need for substantial quantities of data pertaining to soil and crop management practices in order to accurately estimate soil loss, thereby leading to an underestimating of soil loss (Chandramohan et al., 2015; Majhi et al., 2021). The Universal Soil Loss Equation (Wischmeier, 1958) is widely used to predict annual soil loss under specific conditions of erosivity, erodibility,

slope length and steepness, crop management factor, and conservation practice factor. Over the past few decades, the USLE type models have undergone extensive use and modification, hitting their peak in recent years (Alewell et al., 2019). This approach was only suitable for gently sloping lands and also did not identify the changes with respect to the process of erosion and the geometry of the slope (Moore & Burch, 1986). Hence, the Modified Universal Soil Loss Equation (MUSLE) was developed (Williams, 1975), which is expressed with event rainfall characteristics, soil erodibility, length and steepness of slope, crop management, and conservation practice factors. Wide differences between watersheds are evident in simulations run using MUSLE. The outcome was either over or under predicted (Chandramohan et al., 2015). Updated and computerized, the paper-based USLE model, renamed Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1996), is an empirical model. It determines soil loss over the hills or steep slope areas (Das & Poongothai, 2018). For a quantitative evaluation of the typical soil erosion in a watershed, the RUSLE method is very useful (Balasubramani et al., 2015). RUSLE type approaches have been modified over the last two decades, but they are still one of the most employed tools in analyzing the spatial distribution of soil erosion in a temporal manner (Borrelli et al., 2021). System software called Geographical Information System is able to compile, store, manipulate, and show information that is geographically referenced. It makes it easier to build databases with multiple information layers that can be modified to assess relationships between the chosen components in different layers under various circumstances as needed by users.

Utilizing the GIS environment with information and data from multiple sources, particularly using remote sensing data, leads to useful management outcomes for the RUSLE factors (Abdo, 2021; Aswathi et al., 2022; Karthick et al., 2017; Kim et al., 2005; Yirgu, 2022). The application of the RUSLE model in different regions, such as the Nethravathi Basin (Ganasri & Ramesh, 2016a) and the Kalu Ganga River Basin (Panditharathne et al., 2019), provides insights into the spatial variability of erosion and categorizes areas based on soil erosion hazard. The participatory watershed development (PWD) (Hagos et al., 2023), Soil conservation schemes (Abdi et al., 2023) and its principles were implemented in the

erosion prone areas. The urban expansion altered the agricultural practices and leads to erosion risk zones in downstream of Melleague watershed (Weslati et al., 2024). The Siran river basin is one of the unexplored river basin in manshera also indicates significant soil loss in the areas. RUSLE combined with geospatial techniques efficiently managed to identify the erosion prone areas to safeguarding the watershed (Mehwish et al., 2024). The model helps to restorate the erosion zones and reduce the soil loss in Sulakyurt Dam basin (Ozturk et al., 2023). Bagwan et al. (2024) found the average annual soil loss in plain areas was very similar but deviation occurs in final soil erosion zones. Hence, it is impacted LULC changes by the cell sizes, *P* factor, and slope gradient. This integration allows for a more in-depth evaluation on how historical soil management techniques may relate to present environmental and climatic circumstances. Furthermore, the creation and development of equations that combine historical aspects and the efficacy of conservation measures in the RUSLE model add to a more thorough knowledge of soil erosion dynamics and particularly in the context of agricultural land and natural resource management. Hence, the novel contribution of study is aimed to estimate the efficiency of RUSLE modeling in different agroecological areas of Westernghat regions, particularly in Noyal and Sanganur catchment; no studies have been conducted in recent years and this study identifies the potential disputes and provides future recommendation for development of various soil erosion strategies which very helpful to the stake holders, farmers, and policy makers. This study narrows down and gives the specific equation that is more appropriate for the study area by considering the soil erosion characteristics. Also, this study gives the insight of soil conservation practises for the study area based on the soil and water conservation practices guidelines (Singh et al., 2019).

For that, the objective of the present study is (i) to apply the RUSLE model to the Noyyal and Sanganur catchments in order to calculate soil erosion by producing a geodatabase and spatial data of each factor's themes. (ii) By using rainfall, the digital elevation model (DEM), soil type characteristics, and land use/land cover and create a soil erosion model with the average rate of soil loss along with the spatial spread of soil erosion and (iii) to suggest and recommend suitable land management practices.

Study area description

The study area comprises the Noyal and Sanganur watershed, which is mostly located within Coimbatore district of South Indian state of Tamil Nadu. Topographically the region is a part of the Southern Western Ghats. The geographical location of Sanganur and Noyyal watershed extends from 76°39′30″ to 77°3′45″ N latitude and 11°7′30″ to 10°53′30″ E longitude. This covers an area of 631.81 km². The seasonal river Noyyal is in the Tamil Nadu region in the Boluvampatti Valley of the Velliangiri Hills in the Western Ghats and flows through Coimbatore, Tirupur, Kasipalayam, Palayakottai, and portions of Erode before merging with the Cauvery River near Kodumudi after traveling about 160 km (Murali et al., 2020). The study area lies in the middle of six blocks of Coimbatore district, namely, Periyanayampalayam, Madukkarai, Sulur, Thondamuthur, Karamadai, and Sarcasamakulam. The Sanganur area covers with 2.09 km² falls on the Coimbatore region and major Sanganur canal which mainly focusses on development, stretches from mettupalayam road to sathyamangalam road with distance of 2300 m. The catchment area is associated with various major streams drain the city includes Sanganur Pallam, Kovilmedu Pallam, Vilankurichi-Singanallu Pallam, Karperyan Koil Pallam, and Trichy-Singanallur check drain (Selvakumar et al., 2017). The elevation of the district is 432 m above sea level (ASL). The mean average temperature in the rainy season is 26.99 °C from June to September. The average annual rainfall of the district lies in the range of 650 to 700 mm (Thyagarajan et al., 2021). The study area basin is surrounded by Western Ghats at the west; thus, it has a wide range of slope, with its highest in the west, in the range of 18 to 88°. Other parts, as well as the majority of the study area, are sloping in the range of 0 to 7°. At the least sloping area, the basin contains eleven water bodies. The longest flow path (49.23 km) of the basin is the Noyyal tributary, whose basin length is 51.12 km. The mean annual precipitation of the basin is 644.31 mm. The study area encompasses clayey, clayey skeletal, coarse loamy, fine loamy, loamy skeletal, and very fine types of textural classification of soil, which contain 0.9–27% of silt, 11–83.5% of sand, and 8.3–67% of clay (Padmavathi et al., 2014). Based on the soil order, the major percentages of alfisols and inceptisols are found. The change in land use pattern

was a serious issue among the agriculture planners to bring suitable development strategies (NADP, 2008). The increasing tendency to fallow land in view of the drought situation is reducing the cropping intensity have last 2 years. Owing to frequent drought and deep water table conditions (100–150 m), even a single crop could not be taken for consecutively for 2 years by farmers in drylands. Hence, fertility status of the soil is very low in some planted wasteland site, which leads to poor growth and stand of seedlings. The fencing for the control of trespass in the planted area is very difficult due to large area. For every monsoon, there should be a need of revival of micro-plot structures like "V," Semicircular bunds and Cresent bund to harvest rainwater. Majority of people living in the study area is depend upon the agriculture. A large portion of the population works in agriculture, as the study area encompasses around 116.73 km^2 area of crop land and 31.89 km^2 area of plantations. The nature of the region's topographical features and the high intensity and duration of rainstorms affect the stability of soil aggregates, especially when they exceed the soil resistance, which causes more soil water erosion (Kinattinkara et al., 2022). An area of 367.25 km^2 is fallow land, which is exposed to the force of rainfall. These factors lead to the high potential for extensive soil erosion and gully formation. Thus, taking into consideration the terrain conditions and the potentiality of soil erosion in the study area, it is highly important to estimate the amount of soil loss in the particular region. The study area map is shown in Fig. 1.

Materials and methodology

Data collection techniques

Data collection involving both primary and secondary resources was obtained from various sources in the assessment of soil erosion. Earth observation imagery of Landsat 9 with Path 144 and Row 52, containing nine spectral bands of 30 m spatial resolution from the years 2021 March and 2022 January, is procured from the USGS Earth Explorer website, and it is recognized as primary data for the study catchment, used in the assessment of vegetative indices for the estimation of the C factor and land cover classification of the catchment, respectively. Another

primary data source is the SRTM DEM, which is also obtained from the USGS Earth Explorer source and is used for understanding the topographical features of the catchment and assessing the estimation of the LS factor. Secondary datasets are data on precipitation and soil, of which precipitation data is procured from four rain gauge stations within the catchment, and precipitation is collected for the period of 2011 to 2022 (Table 1). Data on precipitation is cited along with the location of the rain gauge station and daily precipitation records. The source of precipitation data was collected from the State Ground and Surface Water Resources Data Centre, Taramani, Chennai. Another secondary data source is soil data, which is procured from the Department of Remote Sensing and GIS, Tamil Nadu Agricultural University. These data included the percentage amount of silt, clay, and sand, the amount of organic carbon, the order of the soil, etc., which are collected from 36 locations of entire study area such as Alangudi, Ambasamudram, Ammapettai, Anaikkulam, Anamalai, Anandur, Annur, Attakatti, Attipalaiyam, Avarangulam, Bhavanisagar, Dasarapatti, Ettinayakanpatti, Ilaiyamuttur, Irugur, Kallivalasu, Karonagipuram, Kattampatti, Kilayur, Kilpudupatti, Mukkulam, Niravi, Palathurai, Palaviduthi, Panaiyur, Pilamedu, Pillayarkulam, Pollachi, Pudur, Reedinguvayal, Sengalam, Sevalpatti, Sheikalmudi, Somayyanur, Tiruchuli, Varapatti, and Vellalur. These secondary datasets were used in the estimation of the R and K factors, as shown in Table 1. The detailed methodology workflow is shown in Fig. 2.

Calculation of RUSLE parameters

Rainfall erosivity factor (R)

Erosivity refers to the possibility of erosion being brought on by rain. The duration and intensity of rainstorms have an impact on the strength of soil aggregates, especially when they surpass the resistance of soil and lead to increased soil water erosion. Ambiguities in the rainfall factor prevail regarding the use of a formula in the Indian context of rainfall distribution pattern; also, the unavailability of hourly rainfall data and intensities makes the estimation of the R factor tedious. Arnoldus (1977a, 1977b) highlighted a measure known as FI (Fourier index) to describe the soil's aggressivity of rainfall in the absence of
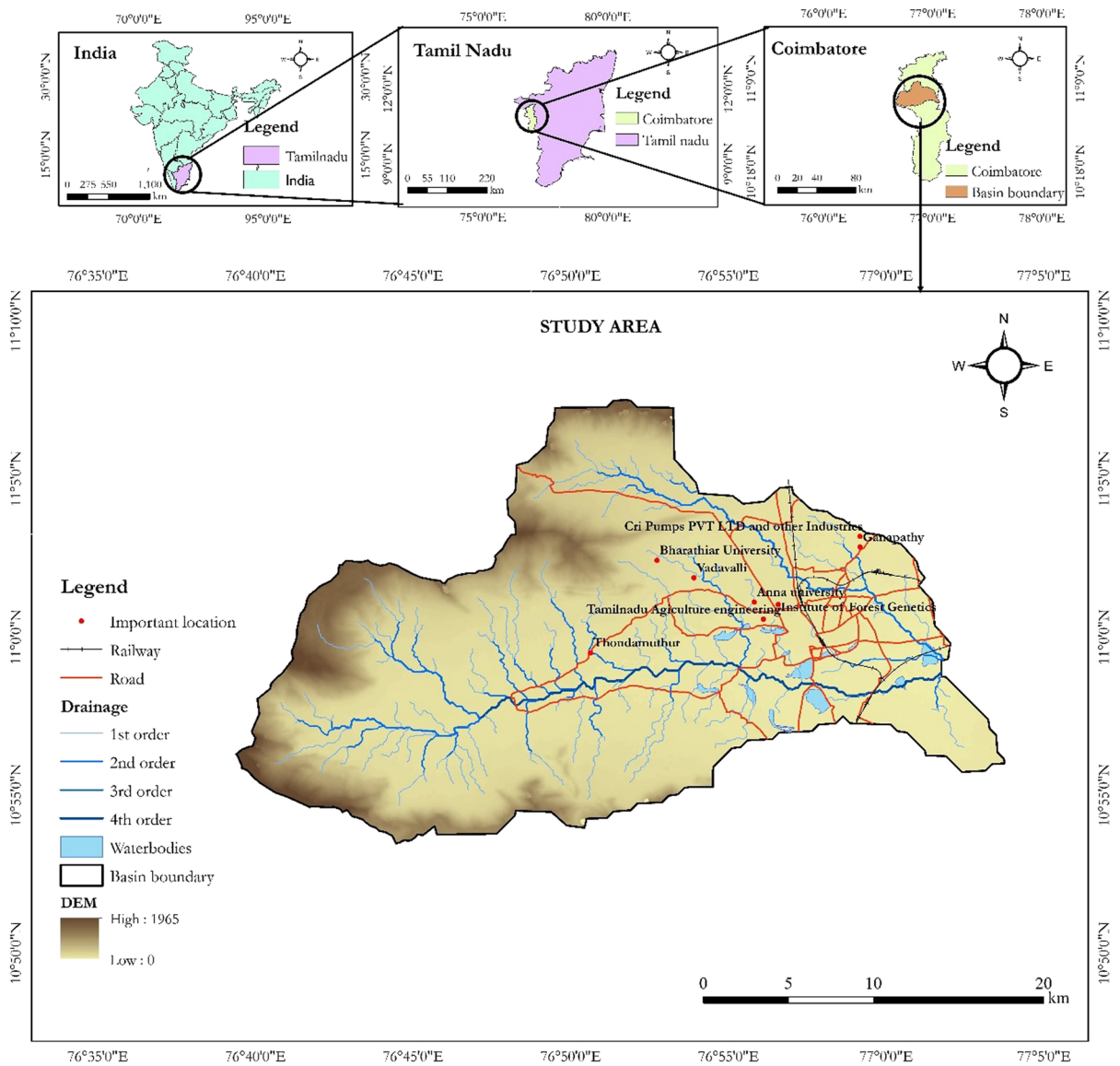
Fig. 1 Location representation of study area

Table 1 Data and its source of procurement

S. no	Data	Source	Description
1	Satellite image	https://earthexplorer.usgs.gov/	Landsat 9 (Date:24/01/2022 and 02/03/2021 Resolution:30 m Path:144 Row:52)
2	DEM	https://earthexplorer.usgs.gov/	SRTM (Resolution:30 m)
3	Rainfall	State Ground And Surface Water Resources Data Centre, Tharamani	Rainfall data for a period of 10 years (2011–2021)
4	Soil	Department of Remote sensing and GIS,TNAU	Soil data based on soil texture

Fig. 2 Detailed methodology work flow adopted for the study
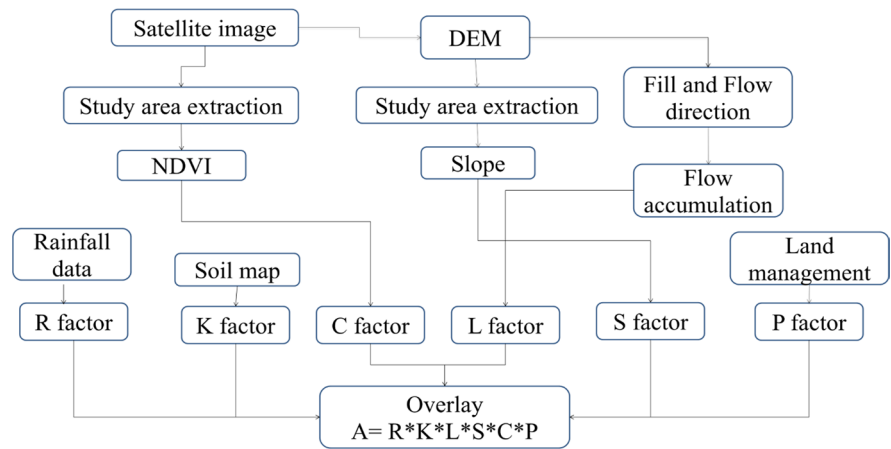
hourly data. It is described as the ratio of the monsoon month's square rainfall to total annual rainfall at a specific place, and MFI (modified Fourier index) is the addition of the square of monthly precipitation to the annual rainfall (Tiwari et al., 2016). Arnoldus (1977a) states that the equation demonstrates 94% similarity to the power function with a coefficient of 0.4043 and an exponent of 1.112 when using the MFI. Hence, the power function of annual average rainfall is used in the estimation of the rainfall factor in the present study, which is given by:

$$R = 0.4043 \times P^{1.112} \tag{1}$$

where R is the rainfall erosivity factor and.

P is the average yearly precipitation (mm).

In India, the power equation outperformed the exponential function. It is suggested to use the equation for Indian conditions to determine the average R (Tiwari, 2016). Rainfall data for 10 years (2011–2021) were obtained from 4 rain gauge stations shown in Table 2 and imported into a GIS environment. Plotted points are interpolated using the IDW interpolation technique (Anand et al., 2020; Chen et al., 2023; Goyal, 2014) in the ArcGIS 10.8.1

platform to bring about a raster map of the average annual rainfall.

Soil erodibility factor (K)

The most important element in the determination of erosion risk is the erodibility factor. It symbolizes soil vulnerability, manifested through various intrinsic and extrinsic characteristics, to increase or reduce the impact of the slope, land use, and rain erosivity. It measures how much soil is lost over time per unit of erosivity for a certain soil on a unit plot, which is a flat, 22.1-m stretch of land that has been tilled and is now fallow (Wischmeier & Smith, 1978). The soil organic matter, soil texture, and quantity of silt, sand, and clay in the soil of the catchment are shown in Table 3, which are all the factors that are considered into account in all formulae used to calculate the K factor. When all other variables affecting erosion are the same, the K factor illustrates how different soils erode at various rates (Yang et al., 2020). The multi-equations stated by Williams (2008) used in the current study to estimate the erodibility factor, which is the integration of factors considering different parameters contributing to low

Table 2 Average annual rainfall (2011–2022) values of raingauge stations in Noyyal and Sanganur Catchment

AAR, average annual rainfall; *mm*, millimeter

S. no	Station code	Station name	District	Longitude	Latitude	AAR (mm)
1	Pothanur_rly	Pothanur railway	Coimbatore	10°57′53″	76°59′21″	536.2
2	Citraicvd	Chithraichavadi Anicut	Coimbatore	10°58′09″	76°49′38″	752.43
3	Thondmutur	Thondamuthur	Coimbatore	10°59′18″	76°50′35″	733.48
4	Coimbtore_au	Agriculture College	Coimbatore	11°00′44″	76°56′06″	637.2

Table 3 Block level data on soil texture and soil organic carbon in the study area

Block name	Maximum of sand percent	Minimum of sand percent	Maximum of silt percent	Minimum of silt percent	Maximum of clay percent	Minimum of clay percent	Maximum of OC percent	Minimum of OC percent	Average of OC percent
Karamadai	75.00	42.00	27.60	5.50	47.00	13.00	1.40	0.31	0.73
Madukkarai	81.00	36.60	26.38	0.90	50.20	18.10	0.83	0.12	0.50
Periyanaick-enpalayam	82.55	41.48	27.60	2.50	42.60	8.30	1.40	0.12	0.47
Sarkarsam-akulam	63.30	44.90	13.90	2.50	41.20	34.20	0.52	0.12	0.32
Sulur	62.40	45.37	26.38	3.20	34.40	28.25	0.22	0.21	0.22
Thondamu-thur	82.55	11.00	27.86	0.90	67.00	8.10	1.40	0.12	0.53

erodibility with high clay to silt ratio, high carbon content, and high sand content. Each factor is individually calculated as shown below:

are shown below:

$$K = F_{csand} \times F_{si-cl} \times F_{orgc} \times F_{hisand} \times 0.1317 \qquad (2)$$

$$F_{csand} = \left[0.2 + 0.3 exp\left(-0.0256 SAN\left(1 - \frac{SIL}{100}\right)\right)\right] \qquad (3)$$

$$F_{si-cl} = \left[\frac{SIL}{CLA + SIL}\right]^{0}.3 \qquad (4)$$

$$F_{orgc} = \left[0.1 - \frac{0.25C}{C + exp(3.72 - 2.95C)}\right] \qquad (5)$$

$$F_{hisand} = \left[1.0 - \frac{0.70SN1}{SN1 + exp(-5.51 + 22.9SN1)}\right] \qquad (6)$$

where SAN is the percentage of sand, SIL is the percentage of silt, CLA is the percentage of clay, C is the content of organic carbon, and SN1 is the content of sand subtracted from 1 and divided by 100. F_{csand} is a factor of low soil erodibility for soil; F_{si-cl} is a factor of low soil erodibility with a high clay-to-silt ratio, F_{orgc} is a factor with high organic content reducing soil erodibility, F_{hisand} is a factor with high sand content reducing soil erodibility for soil.

Length of slope and steepness factor (LS)

The dimensions of the slope and the degree of its inclination are factors that contribute to the influence of topography on soil erosion. Due to the gradual accumulation of runoff on the downslope, total soil erosion and soil erosion per unit area typically rise as slope length (L) rises (Kim et al., 2005). Runoff accelerates and becomes more erosive as slope steepness (S) rises. LS is the anticipated proportion of soil loss per area from a field with a 9 percent uniform slope at 22.13 m in length under otherwise similar circumstances (Wischmeier & Smith, 1978). Hydrological processes that impact runoff, changes in slope geometry, surface flow, or erosion processes are not completely considered in the computation of the LS factor. To overcome the inconsistency of the LS equation, derived from the USLE equation, Moore and Burch (1986) independently developed the length-slope factor to explain the erosion processes connected to rill and sheet erosion on hillslopes using unit stream power theory. These factors influencing the sediment output are the shape factor of the catchment, the slope length factor, and the steepness of the slope factor, which is given by,

$$LS = 4.142 \times \left\{\frac{Facc \times Pixel\ size}{22.13}\right\}^{0.4} \times \left(\frac{Sin\theta}{0.0896}\right)^{1.3} \qquad (7)$$

where 4.142 is the shape factor of the watershed, $\left\{\frac{Facc \times Pixel\ size}{22.13}\right\}^{0.4}$ is slope length parameter, $\left(\frac{Sin\ \theta}{0.0896}\right)^{1.3}$ is slope steepness parameter, LS is the length of slope and steepness factor, F_{acc} is the flow accumulation, pixel size is 30 m in the case of Landsat, and S is the slope angle. Slope angle "θ" is derived from the SRTM DEM; flow accumulation is

also derived from the processed DEM, with the utilization of fill and flow direction assessed from the DEM.

Relationships predicted by McCool et al. (1987) indicate for long slopes two linear segments with a breakpoint at 9% slope, so a separate equation for long and short slope at 9% threshold is considered in calculation of steepness factor (S), which is given by,

$$S = \left(\frac{Sin\ \theta}{0.0896} \right)^{1.3}, \text{for} \tan\theta \geq 9\% \qquad (8)$$

$$S = 10.8\ Sin\ \theta\ + 0.33, \text{for} \tan\theta\ < 9\% \qquad (9)$$

where θ is the slope angle.

Hence, the L factor is resolved by only considering the slope length parameter of Moore and Burch (1986) with the inclusion of the shape factor of the watershed and S factor is estimated using Eqs. (8) and (9). L factor is given by,

$$L = 4.142 \times \left\{ \frac{Facc\ \times\ Pixel\ size}{22.13} \right\}^{0.4} \qquad (10)$$

Thus, the calculation of the LS factor was done by estimating L and S factor independently, then integrated to calculate LS factor, using the map algebra in the ArcGIS 10.8.1 tool.

Crop management factor (C)

The proportion of soil loss from land covered by vegetation under certain circumstances to the equivalent loss from continuous fallow that is tilled clean is factor C in the equation for soil loss. This factor assesses the overall impact of all the interconnected cover and managerial variables. This factor is defined as the dimensionless number on a scale of zero to one, compared with continuous bare fallow loss to the equivalent loss from rainfall erosion for a given land type and vegetation level. The comprehensive effect of crop cover in the reduction of erosion bank on the amount of erosive rain (Macedo et al., 2021) occurring on those times when least protection is given to the surface by the crop and management practices, which depends on the type of vegetative cover, nature of growth, and how much it was varied in different monsoon periods (Wischmeier & Smith, 1978). Hence, the suggested method of calculating the C factor by utilizing the

Table 4 Values of Pptx with respect to rain gauge stations

Station name	February (mm)	March (mm)	Total (mm)
Agriculture College	2.9	0.0	2.9
Chithraichavadi Anicut	1.6	0.0	1.6
Pothanur railway	0.0	0.0	0.0
Thondamuthur	0.0	0.0	0.0
Total	**4.5**	**0.0**	**Pptx = 4.5**

Pptx, integral precipitation; *mm*, millimeter

Table 5 Values of Lv with respect to rain gauge stations

Station name	Lv (mm)
Pothanur railway	1.69
Chithraichavadi Anicut	1.99
Thondamuthur	1.48
Agriculture College	1.94
Average	**1.77**

Lv, average daily precipitation; *mm*, millimeter

NDVI by accounting for the effects of vegetation over the band spectrum with low reflectance, reducing the impacts on erosion caused by the seasonality of rainfall, is used in the estimation of the C factor of the catchment. The variables used to interpret the impact of precipitation seasonality on the reflectance of vegetation from the satellite image are Pptx and Lv. Pptx is equivalent to the integral precipitation in the "a" day prior to the satellite's passage and Lv, indicating the average daily precipitation accumulated over the spell of "a" days in the series of rainfall under study. The duration of the overall amount of rainfall is represented by the "a" variable. The variable is taken as 15 days prior to the satellite's passage on calculating the Lv, where these days are lying in post-monsoon season. The daily precipitation of 10 years of data is considered to calculate the Pptx. From Tables 4 and 5, it is evident that Lv is lower than Pptx, i.e., total precipitation in the 15 days prior to the satellite's passage is greater than the average daily precipitation accumulated over periods of 10 years in the rainfall series under study. This denotes that dry vegetation with poor reflectance is thought to be less prevalent. So the "C" factor rescaled (Durigon et al., 2014)

is used for the calculation of the *C* factor, which is given by,

$$C = \frac{(-NDVI + 0.52)}{(2 \times 0.52)} \tag{11}$$

where 0.52 is the utmost pixel value of NDVI estimated with Landsat imagery.

Management practices factor (P)

Factor P is the percentage of soil loss caused by a particular management practice compared to losses caused by upslope and downslope cultures (Wischmeier & Smith, 1978). Enhanced tillage techniques, crop rotation based on sod, treatments on the fertility of the soil, and more agricultural remains left on the field all significantly reduce erosion and are frequently the primary control in a crop field. The *P* factor considers various control measures that influence the concentration of runoff, pattern of drainage streams, rate of runoff, and hydraulic forces applied to the soil by runoff to lessen its potential for erosion. The scale of the *P* factor is between zero and one, with values closer to zero denoting good management practices

and values closer to one denoting bad management practices. Many researchers have assigned the *P* factor value based on land use and land cover mapping of the area of interest, with the least values allocated to urban coverage and areas of plantation with strip and contour cropping, while the highest values are given to areas without conservation practices. The effectiveness of management increases with decreasing *P* values (Aswathi et al., 2022). Few more researchers considered the value of P as "1" where no conservation practices are implemented (Abdo, 2021; Ganasri & Ramesh, 2016a). The present study observed that certain conservation structures, such as check dams, stone masonry, gabion, and tillage practices, are available in the catchment. Hence, the weightage for the *P* factor is assigned in the range of 0.3 to 0.7 (Panagos et al., 2014), as shown in Table 6. As many management tasks heavily rely on the area's slope, *P* values were assigned to each relevant slope class. This approach of incorporating general land use type and slope was therefore used in this research (Gelagay & Minale, 2016).

Table 6 Conservation practices identified during site visit

Location	Latitude	Longitude	Elevation(m)	Management practice	P-factor
Thenkarai	10.9586	76.8503	445	Checkdam	0.3
Sennanur	10.9512	76.8459	461	Checkdam	0.3
Sennanur	10.9445	76.8492	462	Checkdam	0.3
Konda yampalayam	10.9776	76.8126	446	Checkdam	0.3
Pachapalayam	10.9591	76.9007	437	Checkdam	0.3
Unknown	10.9582	76.9002	483	Checkdam	0.3
Bharathiyar university	11.0420	76.8676	538	Checkdam	0.3
Aanaikatti	11.0785	76.8446	564	Checkdam	0.3
Aanaikatti	11.0683	76.8384	604	Stone	0.7
Aanaikatti	11.0791	76.8478	564	Checkdam	0.3
Aanaikatti	11.0792	76.8466	563	Checkdam	0.3
Aanaikatti	11.0792	76.8210	619	Checkdam	0.3
Aanaikatti	11.0791	76.8206	612	Checkdam	0.3
Aanaikatti	11.0786	76.8200	640	Stone masonary	0.7
Aanaikatti	11.0782	76.8195	622	Stone masonary	0.7
Aanaikatti	11.0772	76.8189	619	Stone masonary	0.7
Aanaikatti	11.0763	76.8178	638	Checkdam	0.3

Result and discussion

Rainfall erosivity factor (R)

The *R* factor represents the kinetic energy of raindrops, causing erosion (Wischmeier & Smith, 1978). It can be quantified using the maximum 30-min intensity (I30) of precipitation, but in the case of the non-availability of I30, either yearly rainfall or monthly rainfall can be used to identify the rainfall aggressivity. Therefore, in the present analysis, annual average rainfall is interpolated to estimate the rainfall erosivity factor of each grid cells. The *R* factor of the of the study area ranges from 536.2 to 752.42 mm, as shown in Fig. 3.

The estimated *R* factor ranges between 438.25 and 638.75 MJ mm/ha h. It was observed that the value of rainfall erosivity is high in the Thondamuthur block, which might be due to occasional intense storms occurring at this block due to its immediate proximity to the Western Ghats. Accurate determination of *R* factor requires rainfall intensity data; in the absence of it, use of such a model-based approach using annual precipitation averaged over a period of 10 years is being adapted in research, but rescaling of *R* factor for it to be adapted in Indian conditions is considered (Chen et al., 2023; Majhi et al., 2021).

Soil erodibility factor (K)

The texture of the soil, organic matter, and the proportion of silt, sand, and clay in the soil are the factors that are taken into account in all formulae used to calculate the *K* factor. The multi-equations stated by (Williams, 2008), consider the factor of low soil erodibility with a high clay-to-silt ratio, the factor of high organic content reducing soil erodibility, and the factor of high sand content reducing soil erodibility for soil. Using William's relation of the *K* factor, resulting in values ranging from 0.00694 to 0.0384, as represented in Fig. 4.
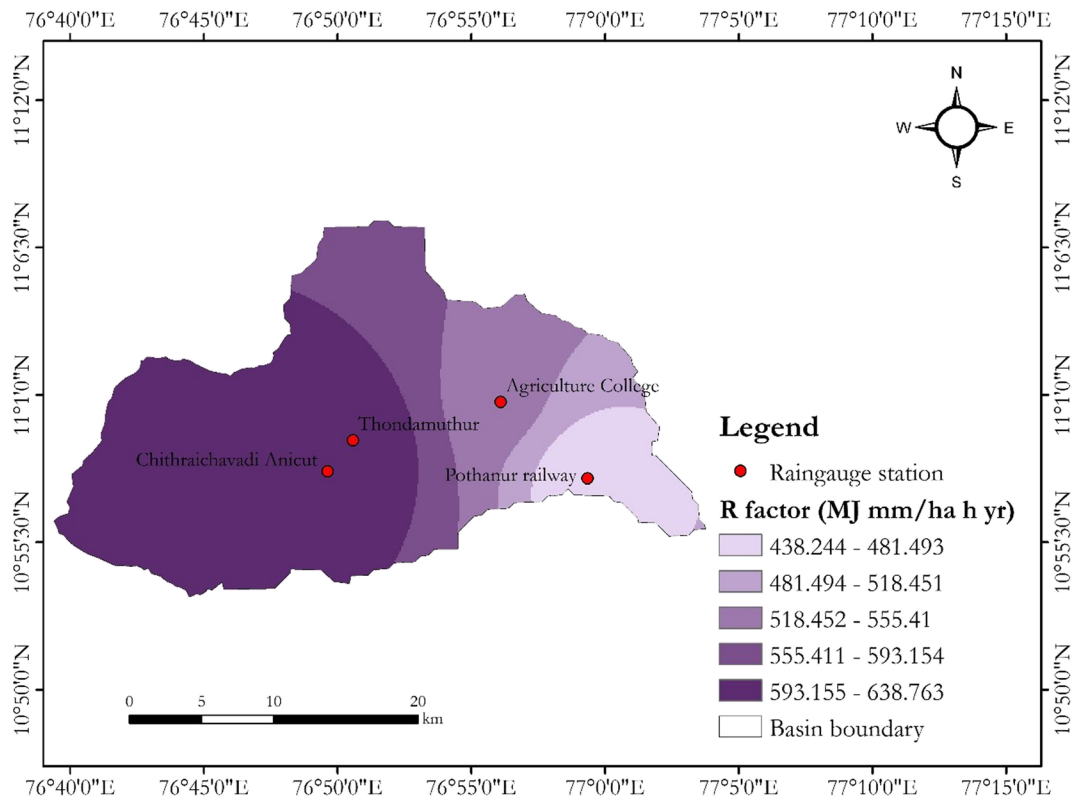

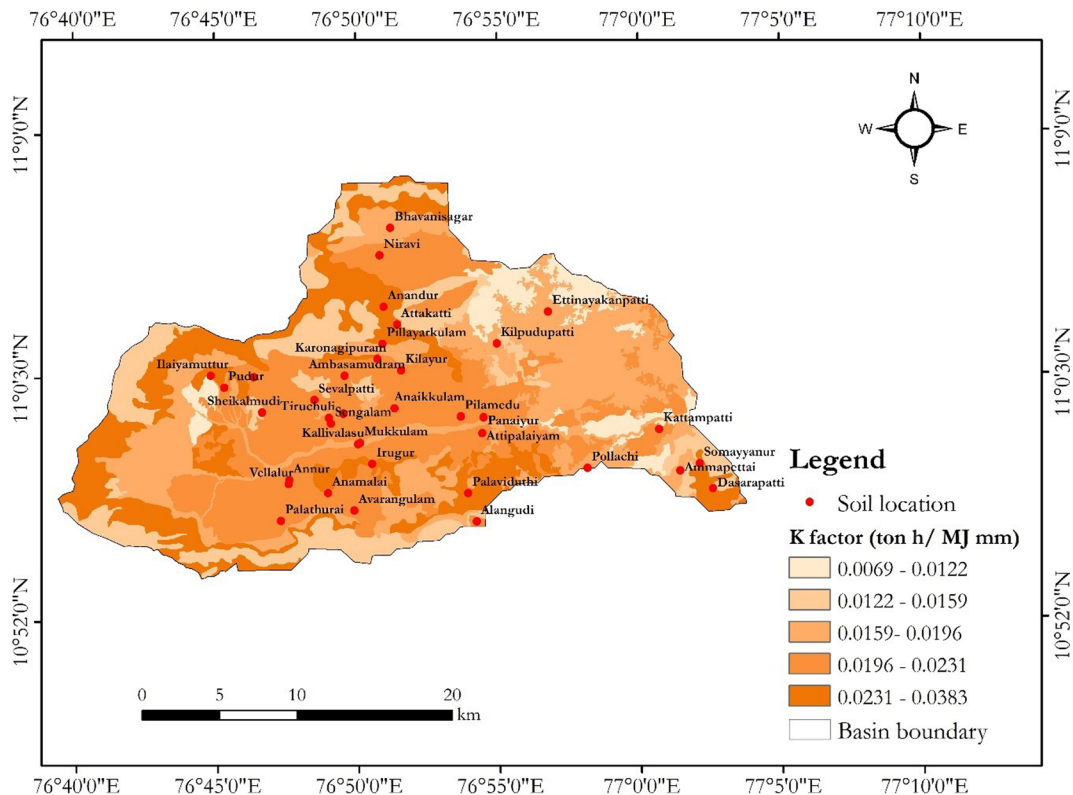**Fig. 3** Spatial representation of rainfall erosivity factor (*R*)

Fig. 4 Spatial representation of soil erodibilty factor (*K*)

The silt fraction is a parameter that influences the erodible nature of the soil, regardless of whether sand or clay is present. The presence of free iron and aluminum oxides in desurfaced high-clay subsoils is second only to the dispersion of particle sizes as a measure of erodibility. The catchment's lowlands have the lowest *K* values, whereas its high-elevation regions have the greatest of *K* values, which might be due to the high clay-to-silt ratio and organic matter in the lower lands. The minimum value of *K* factors is connected with soils of low permeability and low antecedent moisture content.

Topographic factor (LS)

Length of slope and steepness are the factors that are directly proportional to soil loss (Wischmeier & Smith, 1978). Stream power theory states that the shape factor of a catchment, along with the length of the slope and steepness, affects soil loss (Moore & Burch, 1986).

The resulting length of slope factor is in the range of 0 to 2404.31 (Fig. 5). The highest topographic values are identified along the streams of the catchment. This result shows that, along the flow, accumulation influences the length of the slope factor. Also, the sine of the slope angle influences the steepness of the slope.

Crop management factor (C)

In regions where the impact of precipitation on the vegetative cover reflectance occurs more intensely, using precipitation data related to the acquisition of a C factor that is highly accurate for soil conditions is an important addition to be considered in the assessment of soil loss. The most challenging aspect of separating herbaceous targets from wetlands and dry areas when classifying soil cover regions is the use of tools like NDVI (Macedo et al., 2021). So, it is feasible to enhance the RUSLE's final response by using additional data in addition to NDVI. Thus, the
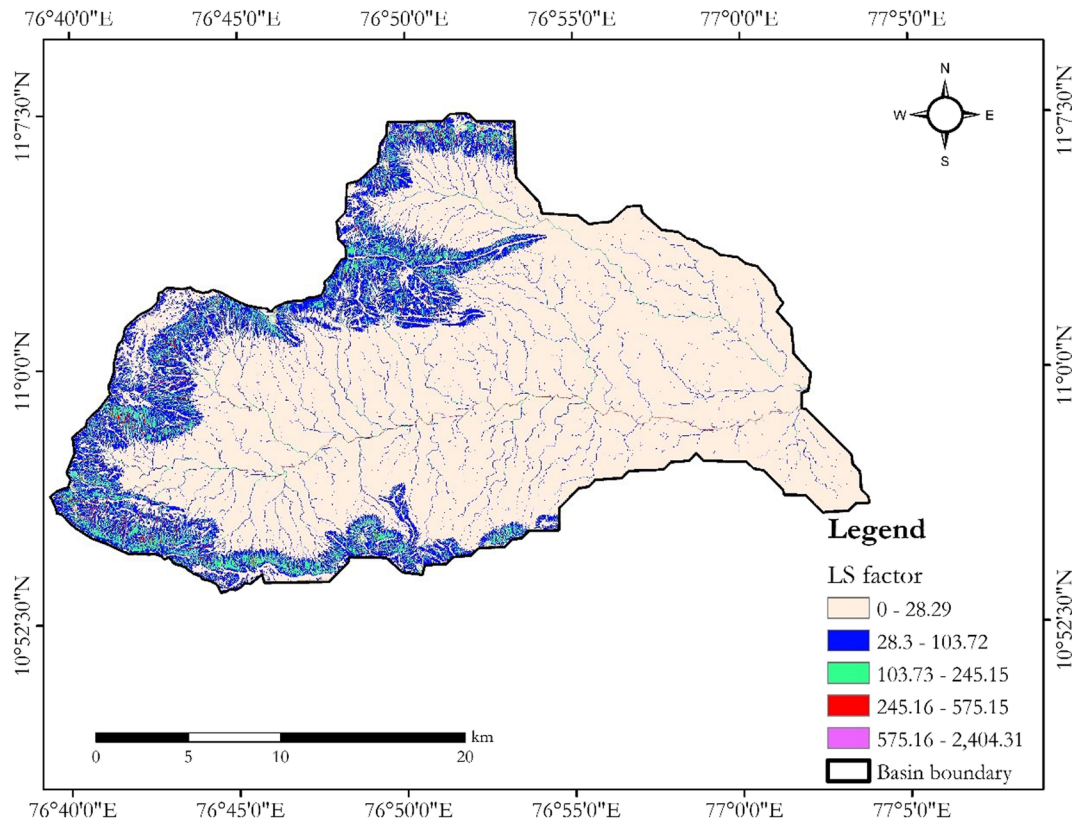
Fig. 5 Spatial representation of slope length and steepness factor (LS)

C factor was calculated with NDVI in relation to the seasonality of rainfall.

The findings indicate that the value of the C factor scales between 0.0008 and 0.6093, as shown in Fig. 6, where the lowest values show high vegetative cover and higher values show bare lands. Values ranging between 0.3 and 0.6 indicated less to no vegetative cover. The Western Ghats of the catchment covered with forest showed the least value (0.0008 to 0.1965) of the *C* factor, indicating a high vegetative cover. These lands with light green portions are field-checked for forest and shrub cover. The NDVI-based approach offers an optimal method for estimating the *C* factor as it can represent various values among the vegetative classes (Karaburun et al., 2010); also, consideration of precipitations produces suitable results for tropical regions (Almagro et al., 2019). Also, this result was found to be similar to that of (Dastagir et al., 2020) *C* factor, who estimated the *C* factor using NDVI for the Noyyal Basin.

Management practice factor (P)

The *P* factor takes into account preventative measures that influence the concentration of runoff, the pattern of drainage streams, the velocity of runoff, and the hydraulic forces applied to the soil by runoff to lessen its potentiality for erosion. The estimated value of the *P* factor ranges from 0.3 to 0.699, with values closer to zero denoting good management practices and values closer to one denoting bad management practices.

The regions where good conservation practices were found have values closer to 0, i.e., in the range of 0.3 to 0.33, and values in the range of beyond 0.5 are found to be poor to no conservation practices, as shown in Fig. 7. The existing management practices were identified in the study area, especially in the Anaikatti region, such as Check Dam and Stone masonry shown in Fig. 8.
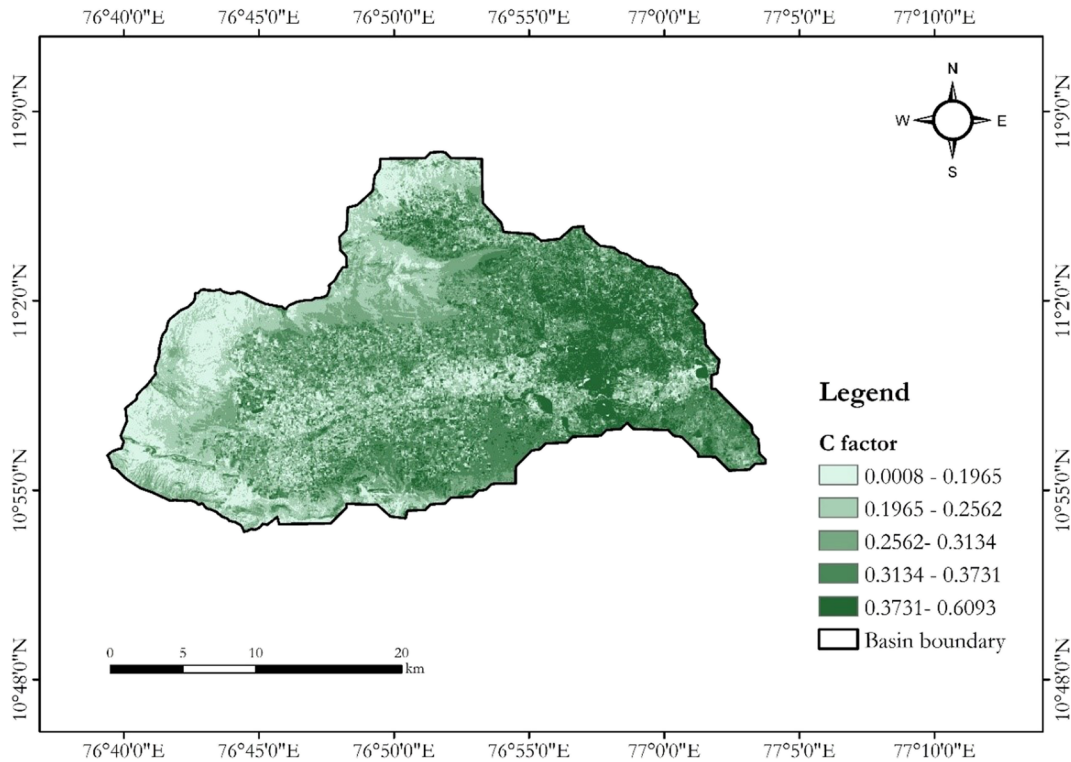
Fig. 6 Spatial representation of crop management factor (*C*)

Estimated loss of soil

Levels of predicted soil loss in the catchment shown in Table 7 vary from "very slight erosion" to "very severe erosion" (Morgan, 2005). Predicted soil loss ranges from 0 to 5455 tonnes/ha/year. The mean annual loss of soil is estimated to be 2.44 tonnes/ha. The data indicate that 30.06% of the total watershed was made up of a region where the loss of soil was more than 10 t/ha/year, i.e., the indicated percentage of area is beyond the acceptable limit of soil loss tolerance. Soil loss is varying a factor with reference to soil type, slope, rainfall, and geomorphological conditions of the watershed. Specifically, the hill areas having steep slopes with high rainfall will have soil tolerance value of 10 to 15 tonnes/ha/year. In flat areas having the slope of below 6%, the soil tolerance limit is 2 to 3 tonnes/ha/year, this determination was made based upon various studies conducted at different locations in India (Tejwani et al., 1975; Ramaroa et al., 1994; Singh et al., 2019). About 14.36% of the entire area of the watershed is exposed to severe to very severe

erosion, and 21.11% is exposed to very slight to slight erosion. 38.27% of the total area is under very little or no exposure to erosion. Estimations indicate a total soil loss of 1,541,086.5 tonnes in the study basin, with 37,447.9 tonnes of loss due to slight erosion, 47,933.5 tonnes of soil loss on account of moderate erosion, and 1,446,253.6 tonnes on account of high to very severe erosion. 52.59% of total soil loss is due to very severe erosion, as shown in Fig. 9.

The RUSLE parameter analysis outcome suggests that the main influencing factors are gradient factor and slope length (LS) (Gelagay & Minale, 2016; Liu et al., 2020; Dastagir et al., 2020). Very severe soil erosion of 100 to 5455 tonnes/ha/year is found along the steep and greater slope length. Extremely severe soil loss was identified at a rate that exceeded the allowable soil loss limit in the upper portion of the watershed's narrower, steeper slope. Extremely severe soil loss was seen at a rate that exceeded the allowable soil loss constraint. Furthermore, field evidence was also shown in Fig. 10. This might be because there are no supporting practices in the
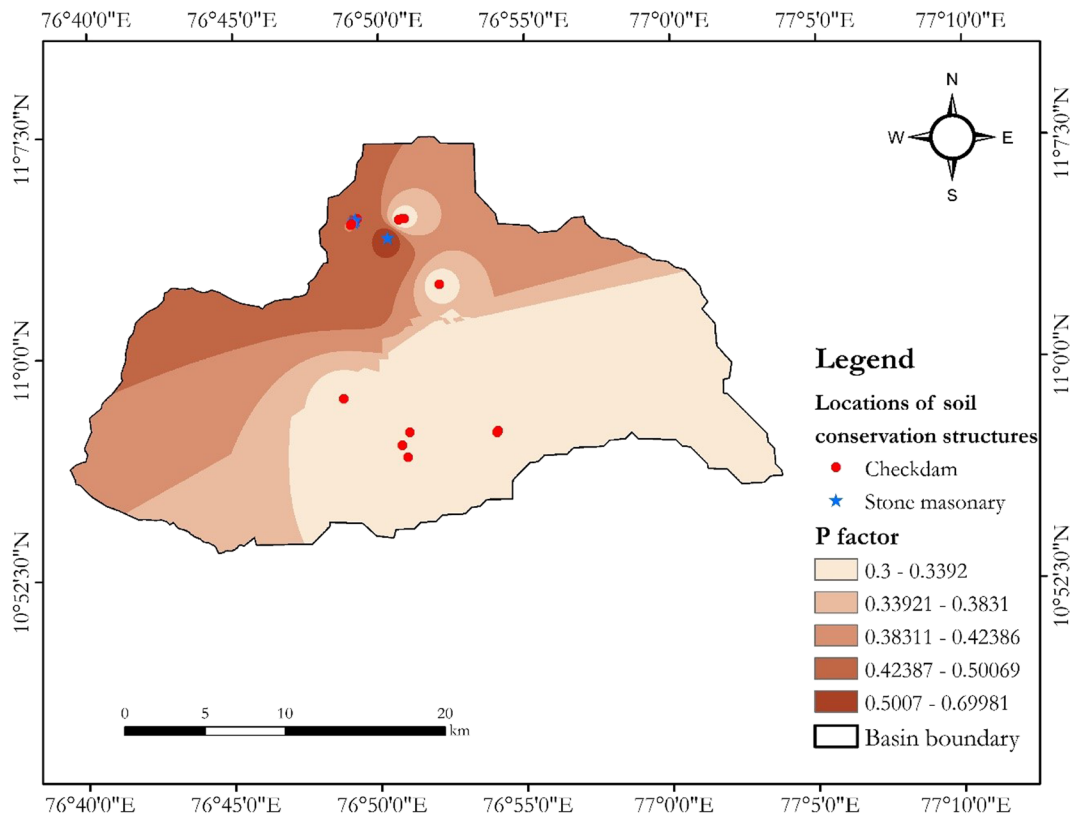
Fig. 7 Spatial representation of management practices factor (*P*)

Fig. 8 Field evidences of existing management practice structures: (**a**) Checkdam and (**b**) Stone masonary

(**a**)

(**b**)

research region, the slope is steep, and rainfall has a strong eroding effect. The sedimentation in the downslope hydraulic structures and the irrigated downslope of the watershed extends this area's off-site impact, which is noted to be a menace to the productivity of agriculture. According to the cross validation, the estimated result of the present study was found to be very high compared to past studies conducted by (Dastagir et al., 2020) 0 to 368.12 tonnes/ha/year especially in very severe erosion zones. But very slight to severe erosion zones nearly matched with same level of soil loss in the prioritized sub-watersheds of the Noyyal Basin, encompassing this study area.

Table 7 Soil loss values and area under different erosion severity classes

Numeric range of soil loss (t ha^{-1} yr^{-1})	Soil erosion risk class	Area (km^2)	Percent of total area	Annual soil loss (ton)	Percent of total soil loss
0	No erosion	241.84600	38.27		
0–2	Very slight	39.38500	6.23	9451.5	0.61
2–5	Slight	94.04500	14.88	37,447.90	2.43
5–10	Moderate	66.72400	10.56	47,933.50	3.11
10–50	High	99.19900	15.70	265,690.60	17.24
50–100	Severe	48.87200	7.73	370,083.80	24.01
>100	Very severe	41.87200	6.63	810,479.20	52.59

(t ha^{-1} yr^{-1}), metric tonnes per hectare per year; km^2, square kilometers; ton, Tonnes
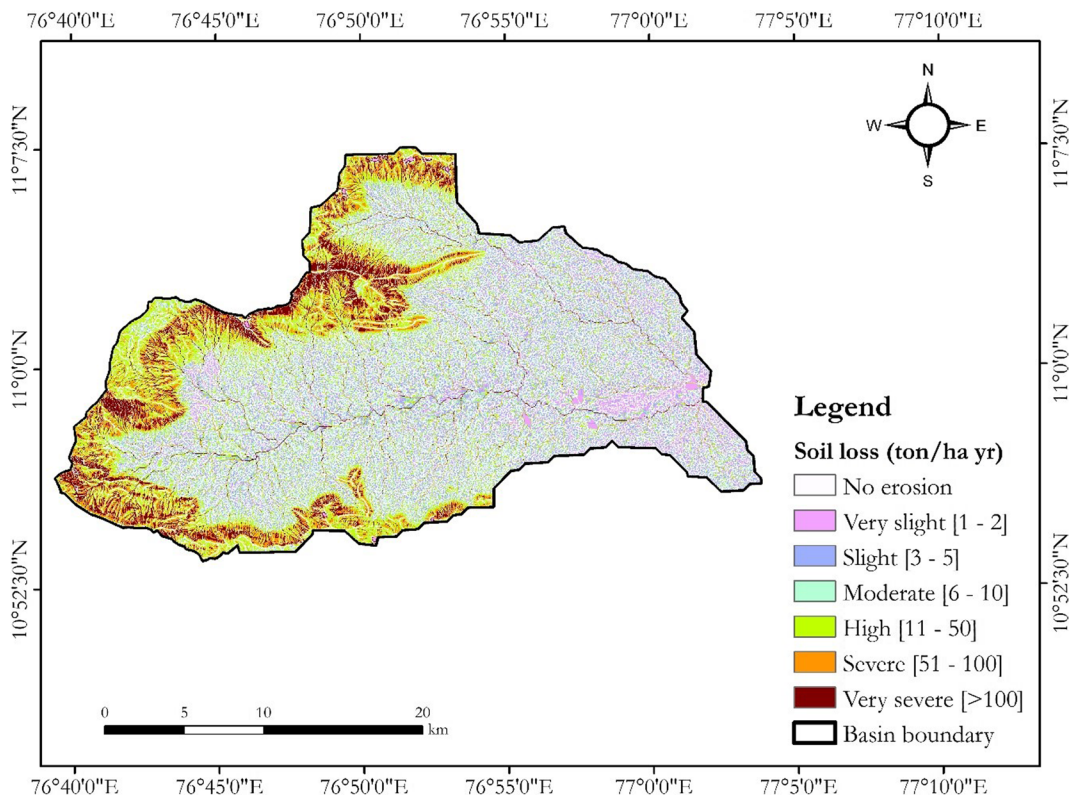
Fig. 9 Spatial representation of annual soil loss of study area

Conclusion

Identification of risk zones for erosion involves various computational tasks and consumes a large amount of time. In such instances, spatial estimation of soil loss with the aid of geospatial techniques is a very efficient tool in evaluating the annual loss of soil in contemplation to spatially visualize areas prone to erosion and also forecast the amount of soil loss in a region. The RUSLE model is put in to assess the approximate loss of soil in the region of Noyyal and Sanganur watershed, whose area is about 631.81 km^2. In the smaller, steeper portion of the watershed, yearly soil loss scales from 0 to 5455 tonnes/ha/year, with an

Fig. 10 Field evidences of erosion prone areas: (**a**) rill erosion and (**b**) gully erosion
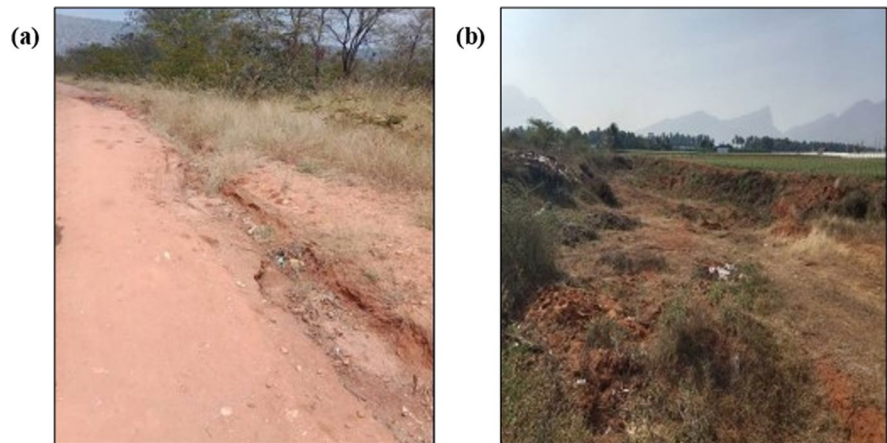
average annual loss of soil of 2.44 tonnes/ha. The generated soil map was classified into six categories: very slight, slight, moderate, high, severe, and very severe. These classifications, respectively, occupied 6.23%, 14.88%, 10.56%, 15.70%, 7.73%, and 6.63% of the basin area. The lower portion of the watershed, which is of 0 to 2% slope, is exposed to nil erosion, which covers an area of 241.84 km^2. In the upper portion of the watershed's narrower, steeper slope, extremely severe soil loss was seen at a rate that exceeded the allowable soil loss limit. This might be because of the slope's steepness, the predominance of soil types that are inherently more susceptible to the eroding effects of rainwater due to desertification, inappropriate management of land by local people, the increased soil erosion rate found in hilly areas, and a lack of supporting practices. Consequently, it is determined that this can pose a threat to the production of agriculture and that it expands its effects offsite. Integration of RUSLE and GIS is used for appropriate planning and governing for the conservation of soil and water. Therefore, recommendations for measures for conservation should be made along the gullies as well as along the regions where only very slight erosion, about 6.23% of the total area, is discovered. These areas might become prone to erosion continuously and might form gullies in the near future. The following recommendations and suggestions are made based on slope and soil type for Indian condition suggested by (Dhruva Narayanan et al., 1990; Ramarao et al., 1994; Murty, 2013; Singh et al., 2019).

- In the areas of steep slopes demarcated by the mapping, the areas are prioritized for soil conservation measures. Anaikatti and Bharathiyar University foothill ranges need suggestive measures like contour trenches, stone walls, and terraces for farming on hill slopes.

- Likewise, the Pachapalayam and Kodayampalayam areas of the study region require land leveling, grading, compartmental/contour bundling, and vegetative waterways. The low-level incipient erosion prevailing on farmlands and first- and second-order channels is prominent in the majority of the study area, for which water conservation, runoff control, and re-use measures like farm ponds and percolation ponds are suggested.

- In addition to the above suggestive measures, a few more specific interventions like in situ moisture conservation measures like micro catchment, broad bed furrows, up-and-down farming, soil amendment like coconut coir pith composition, streambank stabilization with vegetation, and micro water harvesting with abandoned well recharge are prevalent in this study area.

Author contribution All authors contributed to the study and conceptualization, the first author (Anand Balasubramanian) has done substantial work in data collection, data preparation, analysis, modeling, and drafting of the manuscript. The second author (Remitha Ramakrishnan K) has worked on the data collection, analysis model calibration, and drafting of the manuscript. The third Author (Shanmathi Rekha Raju) made a significant contribution to the conceptualization and final drafting of the manuscript. The fourth Author (Midhuna Devi Manikandan) contributed to field investigation and analysis and the Fifth author (Ramaswamy Karuppagounder) contributed to the final drafting of the manuscript. All authors have reviewed the manuscript and approved the version of the manuscript for the submission process.

Data availability No datasets were generated or analysed during the current study.

Declarations

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Consent to participate Not applicable.

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