Original Research Article

SOIL EROSION ESTIMATION OF KUNTHIPPUZHA WATERSHED USING GIS AND RUSLE MODEL

ABSTRACT

Soil erosion is an environmental crisis in the world today that threatens the natural environment and also agriculture. Erosion removes the top fertile soil, degrades soil fertility, water quality and soil productivity. The soil erosion risk assessment is helpful for land evaluation in the regions where soil erosion is a major threat for sustainable agriculture. Modelling can provide a quantitative and consistent approach to estimate soil erosion and sediment yield under a wide range of conditions. The soil erosion and erosion prone areas in the Kunthippuzha sub-watershed of Bharathapuzha river basin, Kerala, India was estimated using RUSLE. The study area is having a drainage area of 950 km^2 up to the gauging station. The estimation was done for 1990 to 2021. The estimated rainfall erosivity, soil erodibility, Slope length and slope steepness factor and crop management factors range from 929.36 and 980.38 MJ mm ha^{-1} h^{-1} yr^{-1}, 0.01387 to 0.0385 t ha h ha^{-1} MJ^{-1} mm^{-1}, 0 to 9.77 and 0.057796 to 1.0999. The results indicate that the estimated total annual potential soil loss of about 842175 t/y is comparable with the measured sediment of 845500 t/yr during the years 1990-2021. The soil erosion rate categorized into six classes based on the erosion severity, the major portion (60%) of the study area comes under very slight erosion zone and only a small portion (14%) comes under severe and very severe erosion zone. Result suggests the area of the north-eastern part suffers from a high soil erosion risk due to steep slope. The results can certainly aid in implementation of soil management and conservation practices to reduce the soil erosion in the Kunthippuzha sub-watershed.

Keywords: Soil Erosion, RUSLE, Kunthippuzha, Google earth engine

1. INTRODUCTION

Rise in population, urbanization and agricultural intensification have led to the over exploitation of the natural resources ultimately resulting in resource depletion and degradation [1]. A worldwide process that leads to loss of nutrient rich top soil, decreased water availability and increased impermeable subsoil runoff is agricultural land degradation by soil erosion. The land area impacted by erosion due to water and wind are estimated to be 1100 Mha and 550 Mha respectively [2]. It has been estimated that in India about 5334 million tonnes of soil is displaced annually either due to natural reasons or by unscientific human interventions [3]. It has been estimated that in Kerala about 17.73 t/ha of soil is displaced annually [4]. One of the causes of soil erosion is the intrinsic propensity of a soil to erode, and this propensity is greatly influenced by a variety of soil characteristics, including the rate of infiltration, permeability, structure, texture, organic matter content, overall water holding capacity, etc. [5].

In the area where soil erosion is a serious danger to sustained agriculture, the soil erosion risk assessment is useful for land evaluation. Its quantification aids in setting the watershed's priority for planning soil conservation and watershed management. There are several methods for the prediction and evaluation of soil erosion, which are field studies and erosion models. Field experiments to measure soil erosion are costly and time-consuming. Traditional techniques include field surveys, the use of runoff plots, multi-slot devices, Coshocton wheel samplers [6] and erosion pin approaches, which are primarily used for prediction and assessment of soil erosion. These procedures need considerable data collecting, are costly, and take a lot of time.

A subset of geographic models known as erosion models simulates the flow of water and the accompanying processes that affect both the quantity and quality of the water. Benefits of using soil erosion models are to estimate agricultural land’s soil loss and runoff rates, preparation od land use plans, calculating relative soil loss indices, and guiding government policy and strategy on soil and water conservation [7]. Soil erosion models have gained traction as a way to get around the drawbacks of the traditional approaches. There are empirical, semi-empirical and process-based models. The model selection is focused on the input materials or information required for a model like data related to soil, vegetation, climate and topography, drainage networks, morphology etc. The empirical models like Universal Soil Loss Equation (USLE) [8], the Modified Universal Soil Loss Equation (MUSLE) [8], and the Revised Universal Soil Loss Equation (RUSLE) [9] have been widely employed to analyse the soil loss. One of the extensively used empirical models to forecast soil erosion caused by water loss is the RUSLE model.

The RUSLE model can forecast erosion potential on a cell-by-cell basis [10], which is useful when seeking to understand the spatial pattern of soil loss across a broad area. In view of the above facts the main objective of the present study was to find soil erosion using RUSLE in the Kunthippuzha sub-watershed.

2. MATERIAL AND METHODS

2. 1 Study area

Kunthippuzha is one of the principal tributaries of Kerala’s second-longest river, the Bharathapuzha river. The Anginda Mountain in Kerala’s Silent Valley National Park, which is a section of the Western Ghats, is where the Kunthipuzha river originates. It begins by meandering through the steep terrain and tropical evergreen forests of Silent Valley National Park and enters the plains of Palakkad. Near Irimbiliyam, the Kunthipuzha joins the main river. The Kunthippuzha sub-basin, with a total areal extend of about 950 km^2, makes up 15.8% of the total catchment area (6400 km^2) of Bharathapuzha. It is located between latitudes and longitudes within the range of 10^o 53’ N to 11^o 14’ N, and 76^o 04’ E to 76^o 41’ E respectively. Twenty-five per cent of the catchment area is in the Malappuram district and 75% is in the Palakkad district. The study area lies in the midland (7.5–75 m above MSL) and highland (>75 m above MSL) regions of Kerala. The elevation of the sub-basin ranges from 2 m to 2373 m.

Kunthippuzha sub-basin falls under humid tropical climatic region. The rainfall distribution in the catchment varies seasonally. The maximum amount of rainfall is received from south west monsoon in which average annual rainfall of catchment is 2300 mm. Approximately 80% of the rainfall falls during the monsoon, 15% during post- monsoon and remaining 5% is received during winter and summer. The mean temperature of the watershed is 27.3^{o}C. The location map of the study area is shown in the Fig.1.

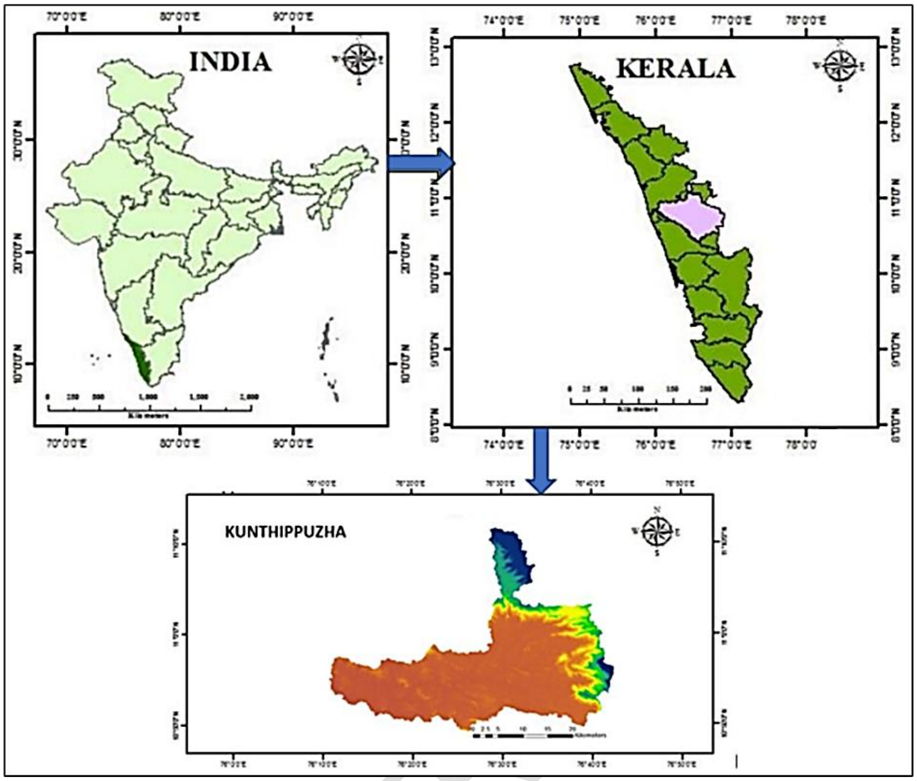

Fig. 1. Location map of the study area

2. 2 Data

In the current work, satellite pictures, soil data, DEM, and rainfall data were used to quantify soil loss in the basin. Details of these datas are shown in the Table 1.

Table 1. Details of input datas for the study

Sl. No.	Data type	Source	Description
1	Digital elevation model	https://earthexplorer.usgs.gov	SRTM DEM (30 m Resolution)
2	Satellite image	https://earthexplorer.usgs.gov	Band4 and Band 5 of Landsat 8 ETM$^+$
3	Soil data	The Soil Survey and Soil Conservation Directorate, Kerala	Soil map for the year 2013. 19 categories of soil based on the soil series
4	Rainfall data	RARS (Regional Agricultural Research Station), Pattambi, Kerala	Rainfall data for a period of 32 years (1990-2021)
5	Sediment	Central Water Commission (CWC), Pulamanthole, Kerala	Sediment data for a period of 28 years (1990-2017)
6	Land use and Land cover map	Google Earth Engine	Supervised classification (CART Classifier)

2. 3 Methods

RUSLE is a known standard erosion model to determine the average erosion risk on arable land. It is a modelling approach based on empirical data that predicts the long-term average annual rate of soil erosion. RUSLE estimates average annual soil loss by sheet and rill erosion. The United States Department of Agriculture (USDA) Soil and Water Conservation Agency initially introduced it in 1993. The fundamental equation of RUSLE model is same as that of USLE model. The RUSLE model parameters were estimated using DEM, rainfall events, soil type, and land cover. Each factor was extracted separately in raster data format, and the erosion was estimated using map algebra methods. Fig. 2 depicts the framework for the RUSLE model calculation, which is expressed by an equation (1).

$$A=R*K*LS*C*P \tag{1}$$

where A= estimated soil loss per unit area ($t\ ha^{-1}\ y^{-1}$), R= Rainfall erosivity factor ($MJ\ mm\ ha^{-1}\ h^{-1}\ y^{-1}$), K= Soil erodibility factor ($t\ ha\ MJ^{-1}\ mm^{-1}$), LS=Topographic factor (dimensionless), C=land management factor (dimensionless), and P= Conservation support practice factor (dimensionless).

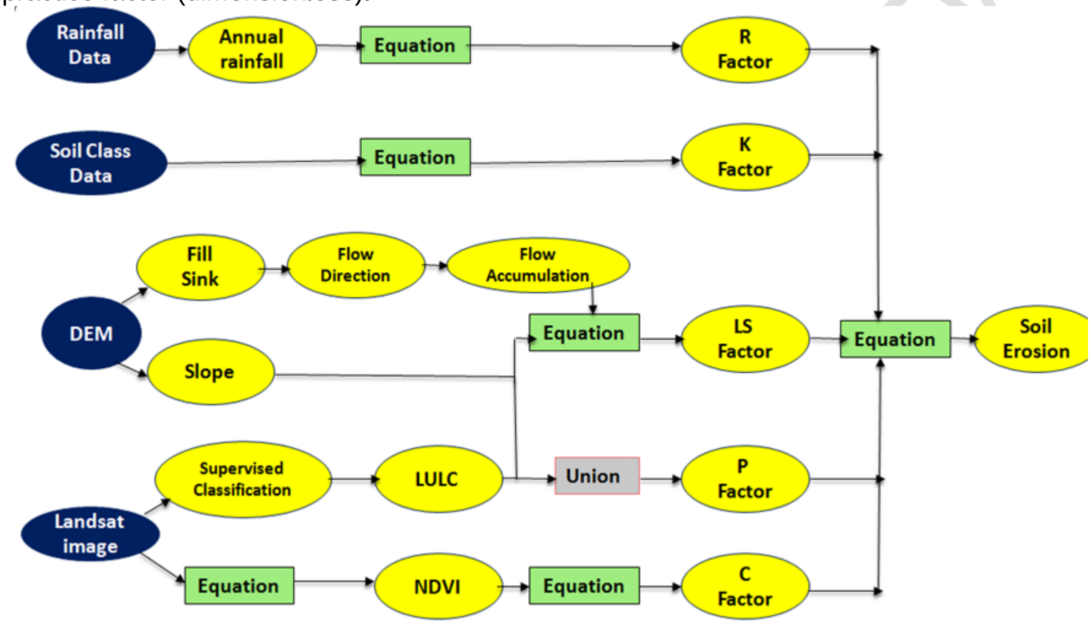

Fig. 2. Flow chart of methodology

2. 3.1 RUSLE parameter estimation

2.3.1.1 Rainfall erosivity factor (R)

The 'R' factor records the effects of rainfall, particularly its ability to accelerate erosion. It calculates the percentage of erosion that is related to storm occurrences. It quantifies the influence of raindrop amount and runoff rate associated with rainfall and its unit expressed in $MJ\ mm\ ha^{-1}\ h^{-1}\ y^{-1}$. To estimate the R factor Babu *et al.*, 2004 [11] equation (2) were used, which is as follows;

$$R = 81.5 + 0.375*P_a\ (340 \le P_a \le 3500mm) \tag{2}$$

Where P_a = average annual rainfall, mm and R is the rainfall erosivity factor ($MJ\ mm\ ha^{-1}\ h^{-1}\ y^{-1}$)**.** The location (latitude and longitude) of the rain gauge station and the erosivity index acquired at each station were input into the ArcGIS 10.4 programme to create the iso-erodent map. The erosivity index value was interpolated throughout the watershed using the Inverse Distance Weighted (IDW) interpolation tool in ArcGIS.

2.3.1.2 Soil erodibility factor (K)

The tendency of the soil to erode is referred to as the K factor or erodibility factor. The erodibility of the soil is influenced by elements such as soil structure, particle size distribution, organic matter content, permeability, etc. The K factor was calculated using Wischmeier *et al*., 1971 [12] equation (3).

$$K = [2.1*10^{-4}(12-M)\ [(Si+v_{fS})\ (100-C)]^{1.14} +3.25(A-2) +2.5(P-3)]/759] \qquad (3)$$

Where, M = percentage of organic matter content in the soil

$$M = (\%silt + \%\ very\ fine\ sand) * (100-\%\ clay) \qquad (4)$$

Si is the percentage composition of silt, v_{fS} shows the percentage composition of very fine sand, C is the percentage composition of clay, Structural classes are represented by the value A, while permeability classes are represented by the value P. This formula can be used to determine the A value: Very fine granularity is indicated by 1, fine granularity by 2, medium or coarse granularity by 3, and blocky, platy, or enormous structure by 4. A variation of the P value is as follows: A permeability rate of 1 indicates rapid, 2 indicates moderate to rapid, 3 indicates moderate, 4 indicates slow to moderate, 5 indicates sluggish, and 6 indicates a very slow rate [13].

Five different textural classes and 19 different soil series with a range of soil properties make up the Kunthippuzha subbasin. Based on soil texture, permeability, and antecedent moisture content, soil erodibility values were assigned to several soil types.

2.3.1.3 Topographic factor (LS)

The LS factor is a comparison between soil loss in a given situation and soil loss at a location with a "standard" slope steepness of 9% and a slope length of 22.6 m [14]. The slope gradient factor (S) and the slope-length factor (L), both derived from the Digital Elevation Model (DEM), are the two subfactors that make up the topographic factor (LS). In order to calculate overland flow (surface runoff), the slope-length and gradient parameter is required [15]. The impact of slope length on erosion is measured by slope length (L). The length of the slope is the distance from the point where overland flow starts to the point where deposition starts to occur or where runoff water enters a clearly defined channel. As a result, the slope length grows, so does the soil loss per unit area. The slope steepness (S) indicator shows how a slope's steepness affects erosion. In comparison to slope length, slope steepness has a bigger effect on soil loss. The erosion increases with slope steepness. The worst erosion happens when the slope is between 10% and 25%. The following equation (5) is used to calculate the slope-length factor.

$$L = (\text{Flow accumulation} * \text{cell size} / 22.13)^{m} \qquad (5)$$

Where, 22.13 = the RUSLE unit plot length (in metres) and m = a variable slope length exponent. Exponent m = 0.5 where $\theta \geq 9\%$; m = 0.4; $9 > \theta \geq 3\%$; m = 0.3; $3 > \theta \geq 1\%$; m = 0.2; $1 > \theta$ [16].

The relationships provided by McCool et al., (1987) [17] are used to estimate the slope steepness factor (S).

$$S = 10.8 \times \sin\theta + 0.03 \text{ for slope} < 9\% \qquad (6)$$
$$S = (\sin\theta / \sin 5.143)^{0.6} \text{for slope} \geq 9\%$$

Where, θ is the slope angle.

2.3.1.4 Cover management factor (C)

The effect of cropping and other activities on erosion rates is reflected by the cover-management factor (C) [18]. As it tracks changes in plant growth and rainfall dynamics, most spatiotemporal sensitive factor is C [19]. The NDVI method is the best and most extensively used method for determining the C factor from remote sensing data, such as satellite photos [9]. For the computation, the red and near-infrared band reflectance values are required, and the equation (7) is as follows:

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \tag{7}$$

For the NDVI estimate, a Landsat 8 satellite picture from March 2020 that was retrieved from USGS Earth Explorer was used. ArcGIS's image analysis tool was used to produce an NDVI map. Red is indicated by band 4 and NIR by band 5 of the satellite image's seven bands.

2.3.1.5 Conservation support practice factor (P)

The rate of soil loss in accordance with agricultural practice is indicated by the conservation support practice factor. Typically, conservation measures are put into action in the field based primarily on the slope and land use. The P factor values suggested by Wischmeier and Smith (1978) [13] based on the land use and field slope in percentage were used in the current investigation. The P factor values with respect to land use and slope are given in table 2.

Table 2. Variation of P factor with respect to land use and land slope

Land use	**Land slope**	**P factor**
Agriculture	0-5	0.10
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
	>100	0.35
All other land use		1.00

In the current study, LULC map is created by use of Google Earth Engine. Google earth engine platform used for doing the land use classification by supervised classification. The LULC map created by importing Landsat image to the google earth engine platform and visualize image. From visualized image training data is created and for training each image points are overlayed. Image is classified using CART classifier and for each classification specific palette is defined. Accuracy assessment of image created is done and import the LULC map to google drive. Slope map was created by using slope option in archydro tool's analysis tool function from DEM and reclassified in to seven classes.

2.3.1.6 Estimation of Average Annual Soil Erosion

The maps for the five factors of RUSLE were prepared by the various data inputs. The RUSLE relation was used to create composite maps of the estimated erosion loss on the research region using these raster maps integrated within the ArcGIS environment [14]. All of the map layers were produced using the transverse Mercator projection and the coordinate system WGS_1984_UTM_43N.

3. RESULTS AND DISCUSSION

3.1 Rainfall erosivity factor (R)

Many studies ([20], [21]) revealed that the soil erosion rate in the catchment is more sensitive to rainfall. The daily rainfall is a better predictor of variation in the rate of soil erosion and can be used to describe the seasonal distribution of sediment production. While using yearly rainfall has benefits such as easy computation, accessibility, and more regional consistency of the exponent [10]. Therefore, in the current analysis, the R factor (Equation (2)) was calculated using the average yearly rainfall (obtained by dividing the total precipitation by the total number of wet days). The estimated R factor value ranges from 929.36 and 980.38 MJ mm ha^{-1} h^{-1} yr^{-1} with a mean of 939.857 MJ mm ha^{-1} h^{-1} yr^{-1} (Fig. 3). In R factor map, the erosivity values fluctuate spatially from pixel to pixel; more particularly, erosivity reduces when slope changes from steep to moderate. The sites at higher elevation display higher erosivity values compared to the downstream ones. The Mannarkad area has a high rating for erosivity.

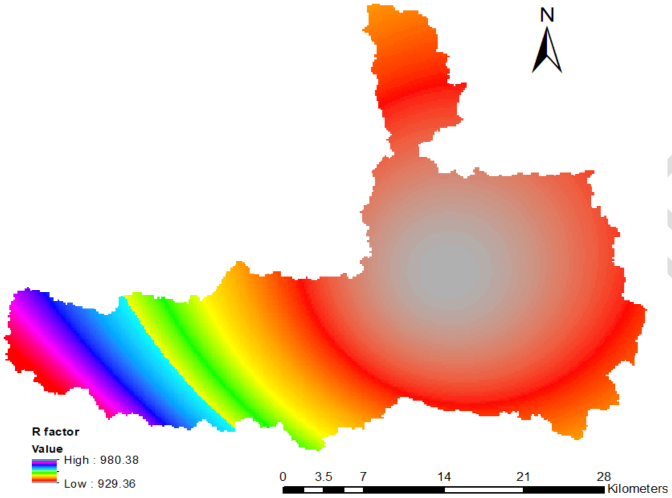

Fig. 3. Spatial distribution map of R factor

3.2 Soil erodibility factor (K)

To create the soil erodibility map, K factor values were applied to the appropriate soil types in the soil map. The values of K factor are found to be ranging between 0.01387 to 0.0385 t ha h ha^{-1} MJ^{-1} mm^{-1} (Fig. 4). The soils with poor permeability, low antecedent moisture content, and other characteristics are linked to the lower value of the K factor. Higher K values are found in soils with low clay concentration relative to sand and silt, whereas lower K values are found in soils with higher clay content. Soil present in Anjur, Tholuvannur, Vazhikadav region has more clay content and has a lower K value, while soil present in Agali, Chelari, Kottamala region has less clay content and has a higher K value.

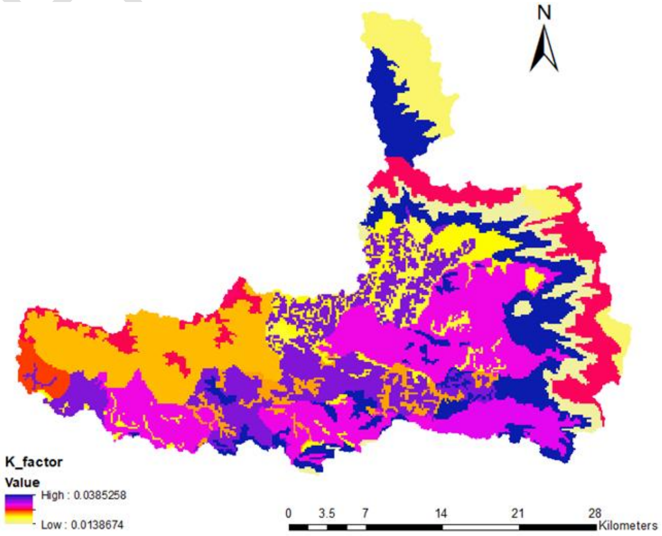

Fig. 4. Spatial distribution map of K factor

3.3 Topographic factor (LS)

The influence of slope length and slope steepness on the erosion process is represented by the topographic factor. The flow accumulation and slope in percentage were used as inputs in the calculation of the LS factor. From the analysis, it can be shown that when the flow accumulation and slope increases, the value of the topographic component rises in the range of 0 to 9.77, with a mean of 1.257 and an average variance of 1.32 (Fig. 5).

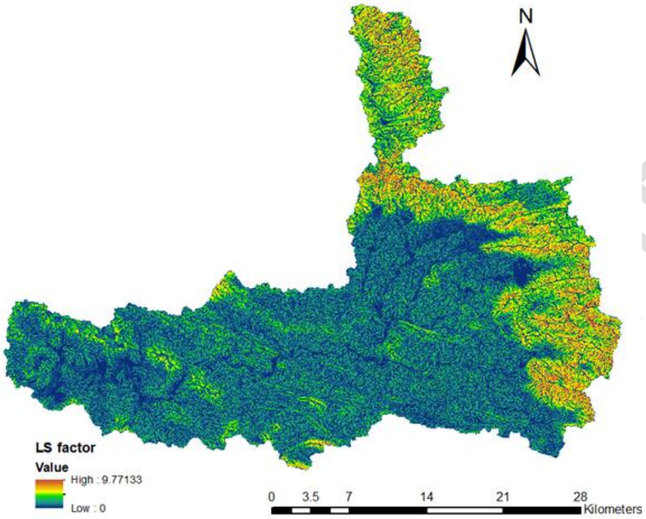

Fig. 5. Spatial distribution map of LS factor

3.4 Cover management factor (C)

The amount of vegetation and canopy cover existing in the region strongly influences the crop cover management factor, or C factor. The NDVI maps from Landsat imageries, which take into account the field's urbanisation and significant vegetation changes, were used to generate the C factor values. In this study, C factor was calculated by exponential scaling methods and was found to be in the range of 0.057796 to 1.0999 (Fig. 6). The map made it is evident that built-up and barren land regions, as well as water bodies have lower NDVI values and so have higher C factors. Since the NDVI values are comparably high for the regions bearing substantial canopy cover, lands with vegetation have a lower C factor than built-up and barren areas.

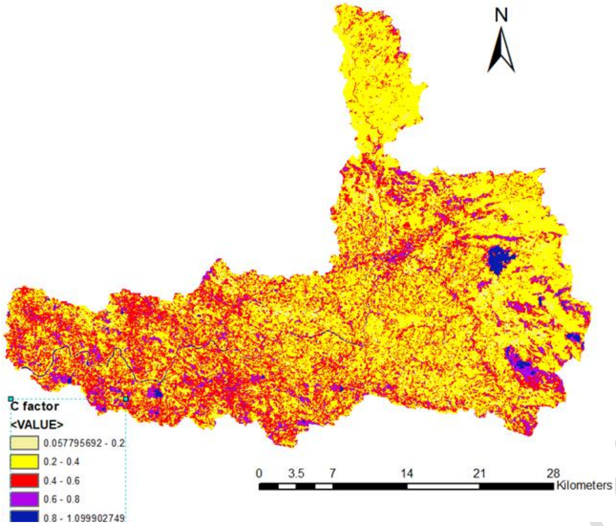

Fig. 6. Spatial distribution map of C factor

3.5 Conservation support practice factor (P)

As suggested by Wischmeier and Smith (1978), the P factor in the current study takes into account slope and land use characteristics. The land use map prepared using Google earth engine is shown n Fig.7 and P factor in Fig. 8. The accuracy assessment of the prepared LULC map was done and is presented in Table 3. The overall accuracy was found to be 85.71%.

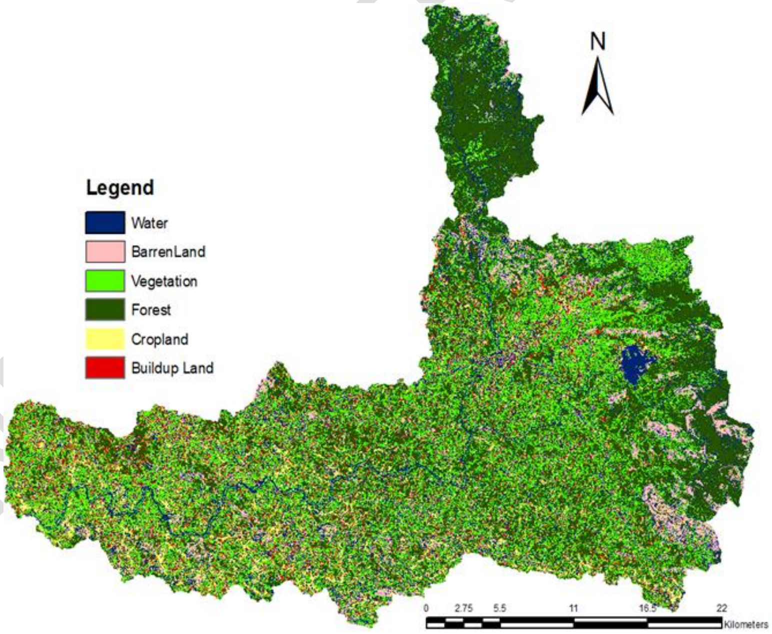

Fig. 7. Spatial distribution map of LULC factor

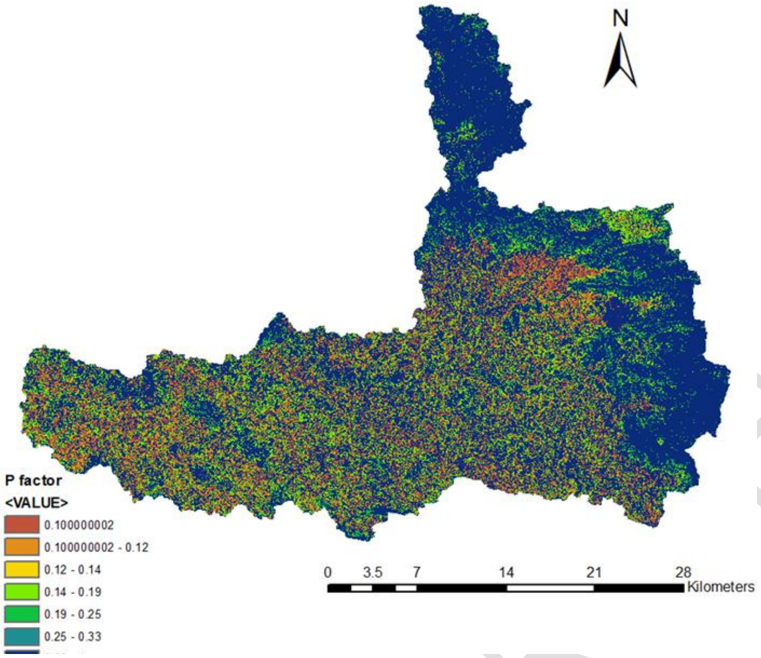

Fig. 8. Spatial distribution map of P factor

Table 3. LULC accuracy assessment

Landuse Classes	Producers Accuracy (%)	Consumers Accuracy (%)	Overall Accuracy (%)
Water	88.0	92.3	85.71
Barren Land	79.8	85.7	
Vegetation	81.1	82.3	
Forest	80.0	84.6	
Crop Land	76.1	78.1	
Build-up	75.0	75	

3.6 Soil erosion map

The mean soil erosion was found to be about 8.865 t/ha/y (Fig. 9). The total quantity of soil eroded was 842175 t/y. Six forms of probable soil loss have been identified in the research region and about 60% of the basin is in slight erosion category (Table 4). The results of several researches carried out in various regions of Kerala with tropical climates and mountainous terrain are in agreement with the observed soil erosion. The north-east portion of the sub-basin is prone to more erosion. About 3.6% of the basin is in very severe erosion category. It may be due to the higher precipitation and steeper slope. Comparing the Kunthippuzha sub-basin's findings to those of numerous studies conducted in the Western Ghats, it was found that they were reasonably similar and comparable ([22], [4], [23]).

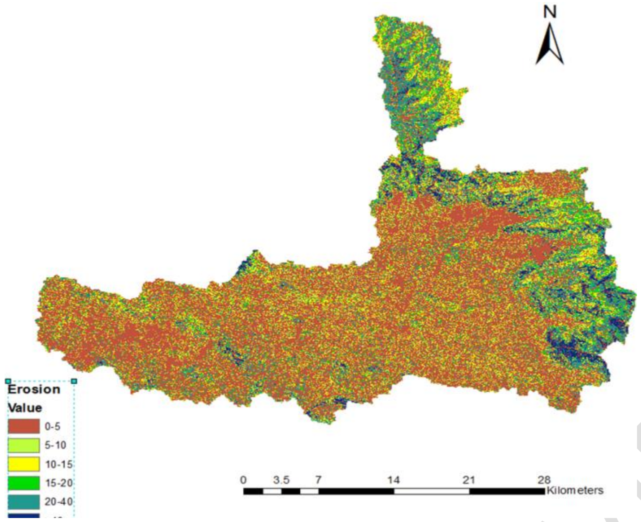

Fig. 9. Spatial distribution map of Erosion

Table 4. Soil erosion severity classes with area covered

Soil erosion class	Soil loss (t/ha/y)	Area(ha)	Area (%)
Very slight	< 5	57486.18	60.02
Slight	5 - 10	8827.23	9.30
Moderate	10 - 15	8956.26	9.35
Moderately severe	15-20	6513.55	6.59
Severe	20 - 40	10606.87	11.07
Very severe	> 40	3385.44	3.53

4. CONCLUSION

The spatial distribution analysis of soil erosion of the Kunthippuzha sub-watershed was carried out using RUSLE model. The estimation was done using the data from 1990 to 2021 (32 years). For the execution of RUSLE model, map layers corresponding to R factor, K factor, LS factor, C factor as well as P factor were prepared and analysed for its spatial variation within the watershed. The mean value of R factor was estimated as 939.857 MJ mm ha^{-1} h^{-1} y^{-1} using the daily rainfall data for the years 1990 to 2021. The estimated K factor ranged from 0.0138 to 0.0385 t ha h ha^{-1} MJ^{-1} mm^{-1}. Soil present in Anjur, Tholuvannur, Vazhikadav region has more clay content, has a lower K value, and the soil present in Agali, Chelari, Kottamala region has less clay content and a higher K value. The average value of LS factor was found to be 1.257. The C factor was calculated using NDVI data derived from satellite imagery. C factor ranges from 0.05779 to 1.099903. Highest C factor value was observed for built-up plus barren lands as it carries less NDVI values. Lands with vegetation carries less C factor compared to built-up plus barren lands. The P factor was calculated by allocating values from the literature based on land use and percentage slope.

The average annual soil loss was estimated to be 8.65 t ha^{-1} yr^{-1}, with 842175 t/y being the total amount of soil lost from the watershed. According to the RUSLE model, six erosion classes were found in the research area: 0-5, 5-10, 10-15, 15-20, 20-40, and > 40 t ha^{-1} yr^{-1}. Around 60% of the region experience very mild erosion, 9.3% experienced slight erosion, 9.35% experienced moderate erosion, and 6.59% experienced moderately severe erosion. The proportion in the severe erosion range was 11.07%, while the percentage in the very severe erosion range was 3.53%. North eastern region of sub basin (Mannarkkad, Pottasserry, Puthupariyaaram etc.) is more prone to erosion due to steep slope.

The results obtained are helpful for giving recommendations for proper soil conservation measures in the area. Since most of the watershed (around 60% area) comes under slight erosion category, soil erosion can be controlled by practicing agronomical measures. In the moderate erosion risk areas (around 9.35%), contour bunds and terraces are suggested. Soil conservation strategies such as contour farming, intercropping, strip cropping, tillage practice, and mulching are recommended for slopes ranging from 0-3%, having a moderate slope with very slight and slight erosion. Since the watershed receives yearly rainfall of around 2300 mm, Graded bunds are more suitable for these areas with gentle slope.

REFERENCES

1. Amore E, Modica, C, Nearing, MA, Santoro, VC. Scale effect in USLE and WEPP application for soil erosion computation from three Sicilian basins. J Hydrol. 2004;293(1-4):100-114.
2. Saha SK. Water and Wind induced soil erosion assessment and monitoring using remote sensing and GIS. In: Satellite remote sensing and GIS applications in agricultural meteorology. 2003;315-330.
3. Pandey A, Chowdary VM, Mal BC. Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing. Water Resour Manag.2007;21:729-746.
4. Prasannakumar V, Vijith H, Abinod S, Geetha NJGF. Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. Geosci Front. 2012;3(2):209–215.
5. Belasri A, Lakhouili A. Estimation of soil erosion risk using the universal soil loss equation (USLE) and geo-information technology in Oued El Makhazine watershed, Morocco. J Geogr Inf Syst. 2016;8(1):98-107.
6. Miller MF. Waste through soil erosion. Agron J. 1926;18(2):153-160.
7. Smith HJ. Application of Empirical Soil Loss Models in Southern Africa: A Review. S Afr J Plant Soil. 1999;16(3):158-163.
8. Balasubramani K, Veena M, Kumaraswamy K, Saravanabavan V. Estimation of soil erosion in a semi-arid watershed of Tamil Nadu (India) using revised universal soil loss equation (RUSLE) model through GIS. Model Earth Syst Environ. 2015;1(10):1-17.
9. Kouli M, Soupios P, Vallianatos F. Soil erosion prediction using the revised universal soil loss equation (RUSLE) in a GIS framework, Chania, Northwestern Crete, Greece. Environ Geol. 2008;57:483-497.
10. Shinde V, Tiwari K, Singh, M. Prioritization of micro watersheds on the basis of soil erosion hazard using remote sensing and geographic information system. Int J Water Resour Environl Eng. 2010;2(3):130-136.
11. Babu R, Dhyani BL, Kumar N. Assessment of erodibility status and refined iso-erodent map of India. Indian J Soil Conserv. 2004;32(3):171-177.
12. Wischmeier WH, Johnson CB, Cross BV. A soil erodibility nomograph for farmland and construction sites. J Soil Water Conserv. 1971;26 (5):189-193.
13. Wischmeier WH, Smith DD. Predicting Rainfall Erosion Losses – A Guide to Conservation Planning. Agriculture Handbook No. 537: US Department of Agriculture Science and Education Administration, Washington; 1978.
14. Ganasri BP, Ramesh H. Assessment of soil erosion by RUSLE model using remote sensing and GIS - a case study of Nethravathi basin. Geosci Front. 2016;7(6):953-961.

15. Morgan RPC, Quinton JN, Smith RE, Govers G, Poesen JWA, Auerswald K, et al. The EUROSEM model: documentation and user guide. Silsoe College, Cranfield university, Silsoe Bedford UK, 1998.
16. Smith DD Wischmeier WH. Factors affecting sheet and rill erosion. Trans Am Geophys Union. 1957;38(6):889-896.
17. McCool DK, Brown LC, Foster GR, Mutchler C, Meyer LD. Revised slope steepness factor for the USLE. Trans ASAE. 1987;30:1387-1396.
18. Chalise D, Kumar L, Spalevic V, Skataric G. Estimation of sediment yield and maximum outflow using the IntErO model in the Sarada river basin of Nepal. Water. 2019;11(5):952.
19. Nearing MA, Pruski FF, O’Neal MR. Expected climate change impacts on soil erosion rates: a review. J Soil Water Conserv. 2004;59(1):43–50.
20. Jain KS, Kumar S, Varghese J. Estimation of soil erosion for a Himalayan watershed using GIS technique. Water Resour Manag. 2001;15(1):41-54.
21. Dabral PP, Baithuri N, Pandey A. Soil erosion assessment in a hilly catchment of North Eastern India using USLE, GIS and remote sensing. Water Resour Manag. 2008;22 (12):1783-1798.
22. Prasannakumar V, Shiny R, Geetha N, Vijith H. Spatial prediction of soil erosion risk by remote sensing, GIS and RUSLE approach: a case study of Siruvani river watershed in Attapady valley, Kerala, India. Environ Earth Sci. 2011;64(4):965-972.
23. Thomas J, Joseph S, Thrivikramji KP. Assessment of soil erosion in a tropical mountain river basin of the southern Western Ghats, India using RUSLE and GIS. Geosci Front. 2018;9(3):893-906.