www.gondwanags.org.in

Original Article

ISSN : 2455-1953

JGSR
Journal of Geosciences Research
Vol. 7, No.2, July, 2022, pp. 202-208

Annual Soil Loss Estimation in a Tropical River Basin of Southern India Using RUSLE Model and AHP Techniques

Sreelakshmi Prakash[1], Baiju K.R.*[1,4], Abin Varghese[2] and Anish A.U.[3]

[1]School of Environmental Sciences, Mahatma Gandhi University, Kottayam-686560 (KL), India
[2]Dr.R. Satheesh Centre for RS and GIS, School of Environmental Sciences, Mahatma Gandhi University, Kottayam-686560 (KL), India
[3]Department of Geology, Government College, Kottayam-686560 (KL), India
[4]Charitable Society for Humanitarian Assistance and Emergency Response Training (CHAERT), Vadavathoor P.O. – 686010 (KL), India
(**Corresponding author, E-mail: baijukr@gmail.com)*

Abstract

Remote sensing and geographic information system (GIS) techniques have been shown to be effective tools for geohazard mapping. The Western Ghats of southern India are a classic terrain with a variety of geohazards such as landslides and soil erosion. The current study employs RUSLE methodology in conjunction with remote sensing and GIS to estimate annual soil loss and identify zones of high erosion potential in one of southern India's major tropical river basins, the Chalakkudy River Basin. The resulting map elaborates on the area's annual soil erosion to the tune of 14.7008 t ha^{1} year^{1}. The map also divides the terrain into zones based on the likelihood of soil erosion. According to the study, approximately 4.70 percent of the total area (67.13 km^{2}) is prone to severe soil erosion, while the remaining 67.13 percent (972.32 km^{2}) is prone to high erosion. Soil erosion prognosis analysis assists decision-makers in developing a proper conservation planning programme to reduce soil erosion. Analytical Hierarchy Process (AHP) was used to identify critical soil erosion-prone areas by integrating geo-environmental variables such as land use/land cover, geomorphology, lithology, drainage density, lineament density, slope, aspect, elevation, LS factor, rainfall, soil texture, and soil depth after determining their relative contribution in conditioning the terrain susceptible to soil erosion. Only 4.70% of the total area is highly prone to soil erosion.

Keywords: Remote Sensing, GIS, RUSLE, Soil Erosion, AHP, Chalakkudy

Introduction

Soil is a critical resource that provides a variety of critical ecosystem services. It is the medium used to produce 99 percent of our food, fodder, fiber, raw materials and biofuels (FAO, 2003). However, soil erosion is now a worldwide environmental problem, and the conservation of soil in terms of quality and quantity is a major concern. Erosion is more than just soil loss; it also involves the loss of on-site and off-site ecosystem services, which are rarely considered in current erosion assessments (Bilotta *et al.*, 2012). Soil erosion, combined with a decrease in soil fertility, destroys our natural ecosystems such as grasslands, forests and agricultural (Bayramin *et al.*, 2003). It is estimated that approximately 2 billion hectars of total land area in India is subject to human-induced soil degradation, with 1100 Million hectars (Mha) eroded by water and 550 Mha eroded by wind (Ganasri and Ramesh, 2016).

Kerala is a narrow strip of land (width varies between 15 and 120 kilometers) in India's southwestern tip, located on the western slopes of the Western Ghats (the Sahyadri). Physiographically, 90 percent of its geographical area is above 300m MSL in altitude. The steep slopes in Kerala's physiography facilitate quick rainfall run off, resulting in a high rate of soil displacement and movement (Jose *et al.,* 2011), which has resulted in an alarming average soil loss of 16.3 t/ha/yr. – which needs to be checked (Aulakh and Sidhu, 2015). In hilly areas, the rate is much higher, ranging from 30 to 50 t/ha/yr. Every year, approximately 5 to 10 cm of top soil (ranging in depth from 0.05m to 0.1m) is removed. It is also estimated that soil erosion affects 9-5 lakh hectares of cultivated land in the state (Upadhyay *et al.,* 2005). A quantitative assessment is required to determine the extent and magnitude of soil erosion so that effective management strategies can be implemented. However, the complexity of the variables makes precise estimation or prediction of soil erosion difficult (Vijith and Madhu, 2007). Field-based methods of quantifying soil loss are time-consuming, and a lack of sufficient sampling plots may limit the reliability of the actual spatial extent of soil erosion. Since the 1930s, physical and empirical models have been developed to estimate soil erosion and develop optimal soil erosion management plans. WEPP, LISEM, SWAT, EUROSEM, ANSWERS (physical models), USLE, RUSLE, and MUSLE (empirical models) are among the regional soil erosion models used (Boggs *et al.*, 2001; Bhattarai and Dutta, 2007; Tian *et al.*, 2009; Dutta *et al.*, 2015). RUSLE (Revised Universal Soil Loss Equation), an extended version of USLE, is a practical and popular

(Received : 22 October 2021 ; Revised Form Accepted : 28 March 2022)
https://doi.org/10.56153/g19088-021-0068-8

formulation among erosion models for predicting soil loss owing to its capacity to account for various control management with limited data requirements (Sujatha and Sridhar, 2018). Soil loss for the rubber growing areas of Kerala and Karnataka is estimated using Universal Soil Loss Equation. The estimated erosivity factor (R) using the Modified Fournier Index showed that this region is categorized as high aggressive with risk of flooding and high intensive rains (MFI =549.3±195.6mm) and low erodability of ultisols and associated soils (K = 0.03 to 0.08).Severe to very severe soil loss in Kerala is estimated in 2.45% of area (1850.83km^2) (Maske *et al*., 2019). In this study, an attempt was made to assess the spatial vulnerability of soil erosion in the Chalakkudy River Basin using the Analytical Hierarchy Process (AHP), as well as to quantify the annual average soil loss using remote sensing and a geographical information system-based implementation of the RUSLE model. Soil erosion assessment and mapping of erodible areas can have significant implications for watershed management and soil conservation (Sharma *et al.,* 2012). It is well understood that a variety of biophysical and human factors can influence erosion and sedimentation processes, which occur at varying intensities across the landscape. However, the spatial scale of the processes is still poorly understood, making monitoring and assessing erosion and deposition processes a complex and time-consuming task fraught with uncertainty.

Study Area

The Chalakkudy River Basin (10º 05' to 10°35' N latitude and 76°15' to 76º 55' E longitude) of 1449 km^2 area drained by the Chalakkudy River flowing westward from the Western Ghats, South India (Fig. 1) and originating from the Anamalai Hills. It is the fifth-longest river in Kerala, with tributaries Parambikulam and Sholayar from Tamil Nadu and Karappara, Kuriarkutty, Anakkayam from Kerala (Babu *et al.*, 2012).

Geologically, it flows through high-grade granulitic rocks such as charnockites, gneisses and intermittent granitic intrusive (Soman, 2002). The river maintains its youth stage until it reaches the plains at Athirapally, as evidenced by numerous rapids and waterfalls (Babu *et al.*, 2012; Singh *et al.*, 2016). The Chalakudy sub-basin contains six reservoirs, one in Tamil Nadu and the other five in Kerala. From November to March (Thulavarsham), this area experiences northeast monsoon, and from June to September, it experiences a strong and consistent southwest monsoon (Edavapathi). It also has two inter-monsoon seasons, in April-May and October-November (Soman, 2002).

Material and Methods

RUSLE-Based Annual Soil Loss Estimation

The RUSLE equation is a function of five raster data input factors (which vary over space and time): rainfall erosivity, soil erodability, slope length and steepness, cover management, and support practice. Soil erosion of each pixel was estimated using RUSLE.

The RUSLE method is expressed as:

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

Where, A is the computed spatial average of soil loss over a period selected for R, usually on yearly basis ($t\ ha^{-1}\ y^{-1}$); R is the rainfall-runoff erosivity factor ($MJ\ mm\ ha^{-1}\ h^{-1}\ y^{-1}$); K is the soil erodability factor ($t\ ha^{-1}\ MJ^{-1}\ mm^{-1}$); LS is the slope length steepness factor (dimensionless); C is the cover management factor (dimensionless, ranging between 0 and 1.5); and P is the erosion control (conservation support) practices factor(dimensionless, ranging between 0 and 1) (Wischmeier and Smith, 1978; Renard, and Freimund, 1994; Agarwal *et al*., 2016). The RUSLE model was run by means of ESRI ArcGIS 10.3 and ERDAS Imagine 9.3 software. The climatic and terrain factors were derived from rainfall data collected from mirrador, satellite image, soil texture map of soil survey organization, Kerala and Survey of India (SOI) toposheets. Landsat 8 OLI/TIRS satellite image of the year 2019 with resolution of 30 m was used for assessment of vegetation parameters in the area. The cell size of all the data generated was kept in to 10m-10m, in order to make uniform spatial analysis environment in the GIS.

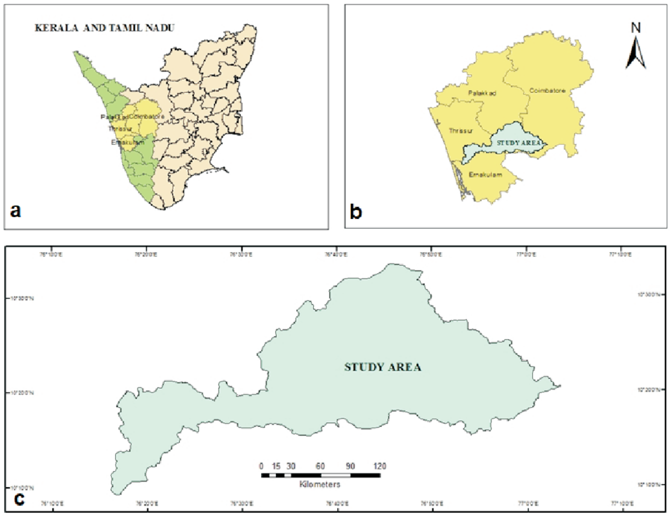

Fig.1. a) Map Showing South India, b) Location of the Study area, c) Chalakkudy River Basin

Rainfall Erosivity (R)

The rainfall erosivity factor is an index that measures the erosive force of a specific intensity of rainfall and is defined as a function of rainfall volume, intensity, and duration (Renard and Freimund, 1994). Rainfall data from the NASA open data portal, *Mirador-Weather* were used to calculate R-factor over a ten-year period (2009-2018) using the following relationship developed by Arnoldus (1980)

$$R = \sum_{(i=1)}^{12} 1.735 \times 10\,(1.5 \log 10\,(Pi^2/P) - 0.08188)$$

Where, R is the rainfall erosivity factor ($MJ\ mm\ ha^{-1}\ h^{-1}\ y^{-1}$), Pi is the monthly rainfall (m) and P is the annual rainfall (m).

Soil Erodability Factor (K)

The K factor is an empirical measure of soil erodibility that is influenced by intrinsic soil properties (Fu *et al.,* 2006). It represents a variety of factors such as soil erodibility, sediment transportability, and the amount and rate of runoff. The K factor map was created using a generalised soil texture map obtained from the Kerala soil survey organisation. The corresponding K values for the soil types were determined using the soil erodabilitynomograph

(Wischmeier and Smith, 1978) while taking particle size, organic matter content, and permeability class into account. Soils with low soil erodibility have 0 values, while soils with high soil erodibility have high values (Goldman *et al*., 1986).

Slope Length and Steepness Factor (LS)

The topographic factor, also known as the slope length and steepness factor (LS), account for the effect of the site's topography on erosion. The effects of a slope length factor (L) and a slope steepness factor (S) are combined in the LS factor (S)

$$LS = (\text{Flowaccumulation} \times \text{cellsixe}/22.13)^{0.4} \times (\sin \text{slope}/0.0896)^{1.3} \qquad \text{(Moore and Burch, 1986)}$$

The flow accumulation and slope steepness were computed from the DEM using ArcGIS and SAGA.

Crop Management Factor (C)

The crop management factor reflects the impact of cropping and management practices on the natural environment (Wischmeier and Smith, 1978). The C factor can be calculated using the following equation:

$$C = \exp\left[-\alpha\,(NDVI/\beta\,NDVI)\right]$$

Where α and bβ are unit less parameters that determine the shape of the curve relating to NDVI and the C-factor, and where α and β are assumed to be 1 and 2, respectively (Van der Knijff *et al.*, 2000). High NDVI values and low C values are found in areas with dense and healthy vegetation.

Conservation Practice Factor (P)

The P-factor is the ratio of soil loss caused by a support practice (Prasannakumar *et al.*, 2011). P-factor values range from 0 to 1, with the highest value corresponding to areas with no conservation practices (deciduous forest) and the lowest values corresponding to built-up-land and plantation areas with strip and contour cropping.

Soil Erosion Proneness Analysis (AHP Method)

Soil erosion proneness was calculated using a raster overlay of various thematic layers such as LULC, slope, elevation, aspect, LS, soil texture and depth, geomorphology, lithology, line density, stream density, and rainfall. All thematic layers were converted to raster data with grid cell sizes of 10m x 10m. The raster layers were then reclassified and ranked according to their significance and influence on the soil erosion process. Using the Arc Map GIS raster calculator, the reclassified layers were integrated by assigning weightage to a linear combination equation (Table 1).

Results and Discussion

Rainfall Erosivity Factor (R)

In the study area, the average R factor (2009-2018) ranged from 0.166 to 0.28 MJ m ha^{-1} year $^{-1}$ (Fig 2). The highest r values are found in the upper part of the study area. The highest value of R factor (0.75 MJ m ha^{-1} year^{-1}) was observed in 2010 and the lowest value in 2016 (0.24MJ m ha^{-1} year $^{-1}$). The area prone to high erosion rates receives a lot of rain (Prasannakumar *et al.*, 2011).

Soil Erodability Factor (K)

In the study area, soil erodibility values range from 0 to 0.37 ton ha^{-1} MJ^{-1}mm^{-1} in the study area. Gravelly sandy clay loam has a high value of area 564.31km2 on the K factor map, making it more susceptible to soil erosion.

Topographic Factor (LS)

The topographic factor (LS), which combines the effects of a slope length factor (L) and a slope steepness factor (S), is very important in RUSLE because it characterizes the surface runoff speed. In general, as the L-factor rises, total soil erosion per unit area rises due to the progressive accumulation of runoff in the down slope direction, and as the S-factor rises, runoff velocity and erosivity rise (Prasannakumar *et al.*, 2011). The LS value ranges between 0 and 21.47. A basin with a low slope or a low value of the LS factor indicates that the area has low to moderate soil loss.

Cover Management Factor (C)

C values in this study range from 0.0674 to 1.234 which is considerably low, since 34.51 percent (500.58 km^2) of the study area possess high vegetative cover.

Erosion Proneness Area

The basin's vulnerable areas for soil erosion were determined by integrating twelve geo-environmental variables, namely slope, elevation, aspect, topography, soil texture, soil depth, drainage density, lineamentdensity, geomorphology, lithology, land use/land cover, and rainfall after statistically assessing their role in making the terrain vulnerable to soil erosion using the AHP method. The slope category in the study area ranges from 0° to 69.30°, with 0.23 km^2 (0.02%) of the total area falling under the 55.44° - 69.30° slope category, which can be considered a high erosion prone area. 5.19km^2 of the total area has a higher elevation of 1871.05 - 2340.3m.

Another critical parameter for delineating erosion-prone areas that can be obtained from slope is aspect (Weaver, 1991). It specifies the slope's direction. North-facing slopes are more heavily eroded than south-facing slopes and this category accounts for more than 20% of the study area. High LS factor values indicate a more prone area to erosion (Prasannakumar *et al.,* 2011). In the current study, the highest LS value ranges from 17.17 to 21.47, covering an area of approximately 9121.12 km^2.

Pore size of the lithology has a direct proportion to the erosion rate, *i.e.* gravelly soils with larger pore sizes are more prone to erosion. The study area is made up of three types of gravelly soils: gravelly sandy clay, gravelly sandy clay loam, and gravelly sandy loam, covering 130.76 km^2, 130.76 km^2, and 564.31 km^2, respectively. Similarly the soil erosion proneness increases as stream density decreases (Moeini *et al*., 2015). Stream density values in this study area range from 0 to 10.96, with 548.73 km^2 (37.86%) having an average density of 2.19 to 4.38.

Kuriakose *et al.* (2009) elaborates on the landslide proneness of Western Ghats pointing that area covered by denudational hills

Table 1: Themes weightage and class score assigned for Analytical Hierarchy Process (AHP)

Sl. No.	Theme	Weight-ages	Class	Rank
1	SLOPE (degree)	2	0 - 13.86	1
			13.86 - 27.72	2
			27.72 - 41.58	3
			41.58 - 55.44	4
			55.44 - 69.30	5
2	LS FACTOR	1	0 - 4.29	1
			4.29 - 8.58	2
			8.58 - 12.88	3
			12.88 - 17.17	4
			17.17 - 21.47	5
3	ELEVATION (m)	1	> 463.14	1
			463.14 - 932.45	2
			932.45 - 1401.75	3
			1401.75 - 1871.05	4
			1871.05 - 2340.36	5
4	ASPECT	0.5	Flat	1
			East/south east/South/South west	2
			West/North west	3
			North/ East	4
			North/ North east	5
5	SOIL TEXTURE	0.5	Clay	3
			Clay loam	4
			Gravelly sandy clay	5
			Gravelly sandy clay loam	5
			Gravelly sandy loam	5
			Highway	2
			Water body	1
			Sandy clay loam	4
6	SOIL DEPTH (cm)	0.5	0	1
			75	2
			100	3
			115	3
			125	4
			175	5
7	GEOMORPHOLOGY	0.8	Denudational Hills Complex	4
			Flood Plain	2
			Plateau	3
			Reservoir Islands	2
			Structural Hills Complex	5
			Water Body Mask	1
8	LITHOLOGY	0.2	Charnockite	1
			Coastal sand and Aluvium	4
			Garnet-Bitotite Gneiss	4
			Horn Blende Gneiss	3
			Laterite	4
			Pink Granite	2
			Pink Granite Gneiss	2
			Synite	2
9	LAND USE LAND COVER (2019)	1	River	1
			Plantation	2
			Reservoir	3
			Mixed crop with built-up	3
			Marshy field	1
			Settlement	3
			Paddy	2
			Water body	1
			Mixed Plantation	2
			Rock Exposure	1
			Grassland	4
			Teak plantation	4
			Tea plantation	4
			Forest	4
			Mixed junk forest	5
			Dense forest	5
			Barren land	1
10	STREAM DENSITY (km²)	0.8	0-2.19	1
			2.19-4.3	2
			4.3-6.57	3
			6.57-8.77	4
			8.77-10.96	5
11	LINE DENSITY (km²)	0.2	0 - 0.94	1
			0.94 - 1.89	2
			1.89 - 2.84	3
			2.84 - 3.79	4
			3.79 - 4.74	5
12	RAINFALL (m)	1.5	0.16 - 0.18	1
			0.18 - 0.21	2
			0.21 -0.23	3
			0.23 - 0.25	4
			0.25 - 0.28	5

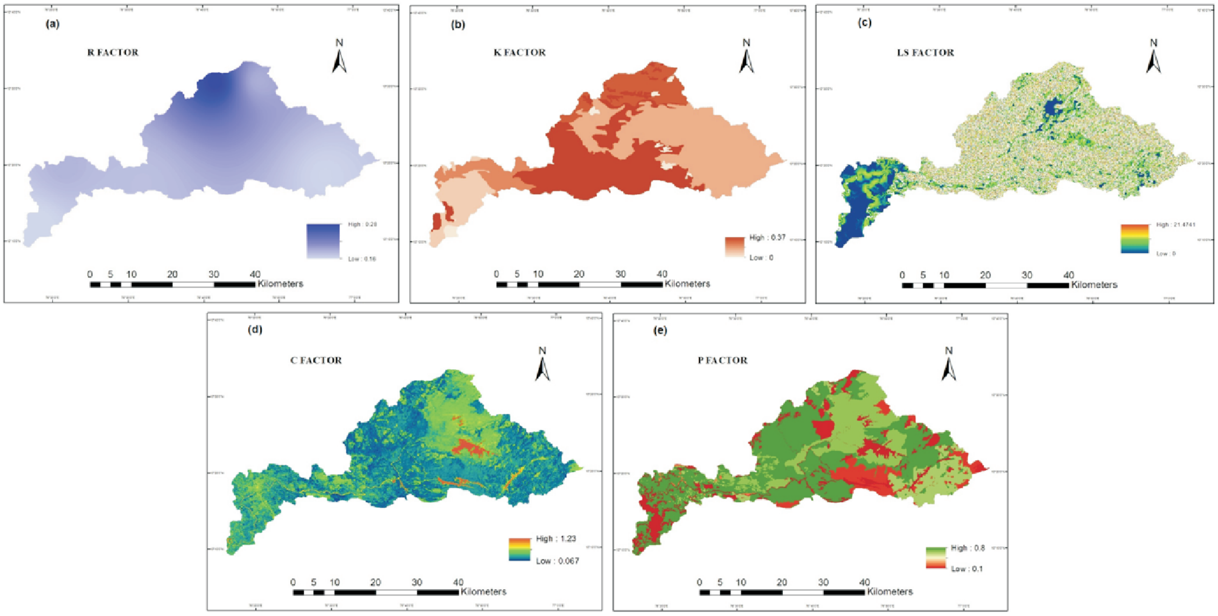

Fig. 2. RUSLE parameters: a) R factor, b) K factor, c) LS factor, d) C factor and e) P factor

complexes has a high slope. Similarly, the Chalakkudy River Basin is also covered by denudational hills of approximately 940.95km^2 (64.87 percent) with a moderate slope, implying a high erosion prone zone.Soil erosion risk is also influenced by different land use types in terms of area, size, and pattern. Areas with less land cover obviously have a higher risk of soil erosion than areas with more land cover (Wischmeier and Smith, 1978; Ganasri and Ramesh, 2016). The land use/land cover in the current study is calculated to be approximately 10.67 % of the total area, consisting of mixed crop with built-up that is highly prone to soil erosion (Table 2; Fig.3).

The final output of the soil erosion prone area map was divided into four categories: low, moderate, high, and very high (Fig.4 a-b). The majority of the area (972.32 km^2) is classified as high (67.16%), with only 4.70 % classified as very high (Table 3).

Annual Soil Loss

The annual soil erosion rate in the Chalakkudy River Basin is estimated to be as high as 14.7008 t h^{-1}year^{-1}, in areas with a high slope or LS factor (Fig.4a). The outcome is comparable to that of other river basins in various parts of the southern Western Ghats (Prasannakumar *et al.,* 2011, 2012; Pradeep *et al.*, 2015). For example, the Attappadivalley has an annual soil erosion rate of 29 t h^{-1}year^{-1} (CWRDM 1997), whereas the Siruvani watershed, which is part of the Attappadi valley, has a maximum erosion rate of 14.917 th^{-1} year^{-1} (Prasannakumar *et al.,* 2011). Similarly, the estimated average soil erosion rate for the Pamba sub-watershed ranges from 0 to 17.73 t h¯1 year¯1 (Prasannakumar *et al.,* 2012).

Compiling the results from the study, it can be concluded that the majority of the study area, 92.4% (1332.826 km^2), has a low soil erosion rate of less than 3.6t h^{-1}year^{-1}. Only 0.002961% (0.0427km^2) of the area has the highest soil erosion rate, which ranges from 10.98 t h^{-1}year^{-1} to 14.7008 t h^{-1}year^{-1} (Table 4).

Conclusions

The study demonstrates the use of RUSLE in conjunction with GIS to quantitatively model soil erosion and predict erosion proneness over a large area. The results of soil erosion modelling revealed that the Chalakkudy River Basin has varying erosion rates ranging from 0 to 14.7008 t ha^{-1} y^{-1}. Soil erosion risk zones with severe and high levels of severity are found in grassland, degraded plantation, and forest areas. When actual annual soil loss is compared to potential soil erosion prone maps, it is discovered that

Table 2: Geographic coverage of various classes of thematic factors at Chalakkudy River Basin

Sl. No	Type	Classes	Area (Km²)	Area %
1	SLOPE (degree)	0 - 13.86	899.97	62.07
		13.86 - 27.72	434.57	29.97
		27.72 - 41.58	108.62	7.49
		41.58 - 55.44	6.51	0.45
		55.44 - 69.30	0.23	0.02
2	ELEVATION (m)	> 463.14	391.559	27.006
		463.147664 - 932.45	683.924	47.17
		932.451568 - 1401.7	341.225	23.53
		1401.7 - 1871.05	27.8797	1.92
		1871.05 - 2340.3	5.31	0.36
3	ASPECT	Flat	0	0
		East/southeast/South/Southwest	634.75	43.78
		West/North west	358.39	24.72
		North/ East	221.98	94.55
		North/ North east	234.77	16.19
4	LS (degree)	0 - 4.29	224.55	15.49
		4.29 - 8.589	42.437	2.93
		8.58- 12.88	128.066	8.83
		12.88 - 17.17	142.752	9.85
		17.17 - 21.47	912.112	62.9
5	SOIL TEXTURE	Clay	95.1	6.56
		Clay loam	137.48	9.48
		Gravelly sandy clay	130.76	9.02
		Gravelly sandy clay loam	348.06	24.01
		Gravelly sandy loam	564.31	38.92
		Highway	8.77	0.61
		Water body	17.07	1.18
		Sandy clay loam	148.35	10.23
6	SOIL DEPTH (cm)	0	736.3	50.8
		75	105.26	7.26
		100	129.08	8.91
		115	95.01	6.56
		125	34.64	2.39
		175	349.06	24.08
7	STREAM DENSITY (km²)	0 -2.19	156.96	10.83
		2.19- 4.38	548.73	37.86
		4.38- 6.57	472.11	32.58
		6.57-8.77	246.6	17.02
		8.77-10.96	24.84	1.71
8	LINEAMENT DENSITY (km²)	0 - 0.94	1142.79	78.82
		0.94 - 1.89	192.1	13.25
		1.89- 2.84	86.26	5.95
		2.84- 3.79	26.56	1.83
		3.79 - 4.74	2.21	0.15
9	GEOMOR-PHOLOGY	Denudational Hills Complex	940.95	64.87
		Flood Plain	30.48	2.1
		Plateau	400.3	27.6
		Reservoir Islands	1.24	0.09
		Structural Hills Complex	40.37	2.78
		Water Body Mask	37.25	2.57
10	LITHOLOGY	Charnockite	567.85	39.16
		Coastal sand and Aluvium	0.4	0.03
		Garnet-Bitotite Gneiss	4.76	0.33
		Horn Blende Gneiss	630.07	43.45
		Laterite	91.81	6.33
		Pink Granite	143.66	9.91
		Pink Granite Gneiss	9.16	0.63
		Synite	2.51	0.17
11	LULC/2019	River	12.7422	0.88
		Plantation	20.8464	1.43
		Reservoir	40.2274	2.77
		Mixed crop with builtup	154.917	10.69
		Marshy field	8.1831	0.56
		Settlement	4.6185	0.31
		Paddy	42.3455	2.92
		Water body	1.0979	0.075
		Mixed Plantation	5.7192	0.39
		Rock Exposure	30.9278	2.13
		Grassland	12.3634	0.85
		Teak plantation	284.495	19.64
		Tea plantation	121.532	8.39
		Forest	110.282	7.61
		Mixed junk forest	545.887	37.70
		Dense forest	51.237	3.53
		Barren land	0.508	0.035
12	RAINFALL (m)	0.28-0.29	644.06	4.44
		0.29-0.31	543.59	37.49
		0.31-0.32	145.50	10.03
		0.32-0.33	65.56	4.52
		0.33-0.34	51.18	3.52

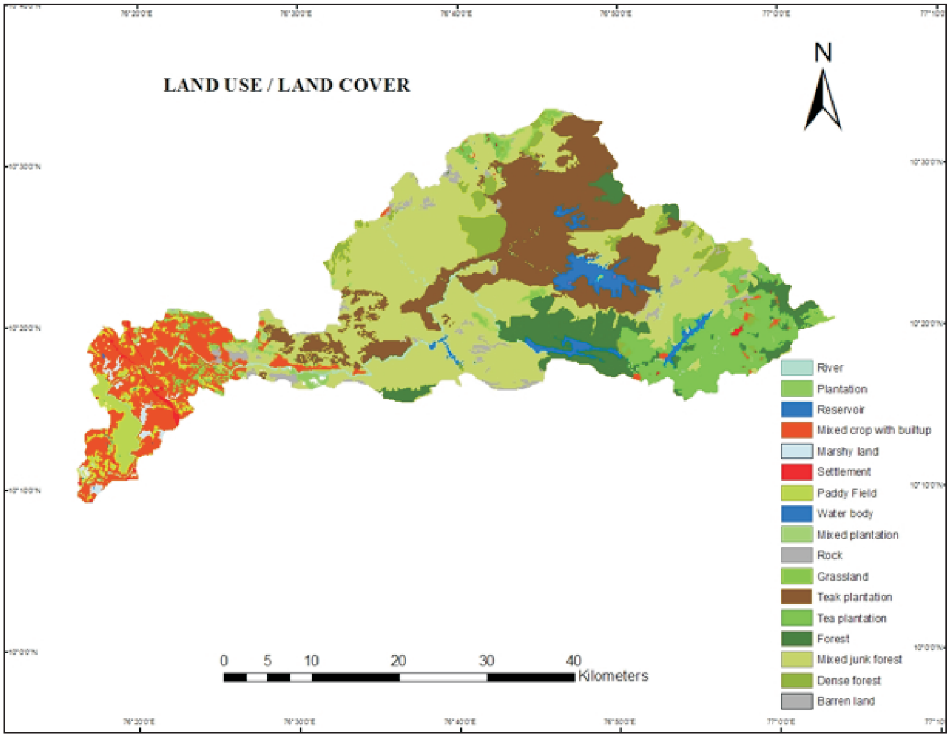

Fig. 3. Annual Soil Loss and Classified soil erosion prone area map of Chalakkudy River Basin

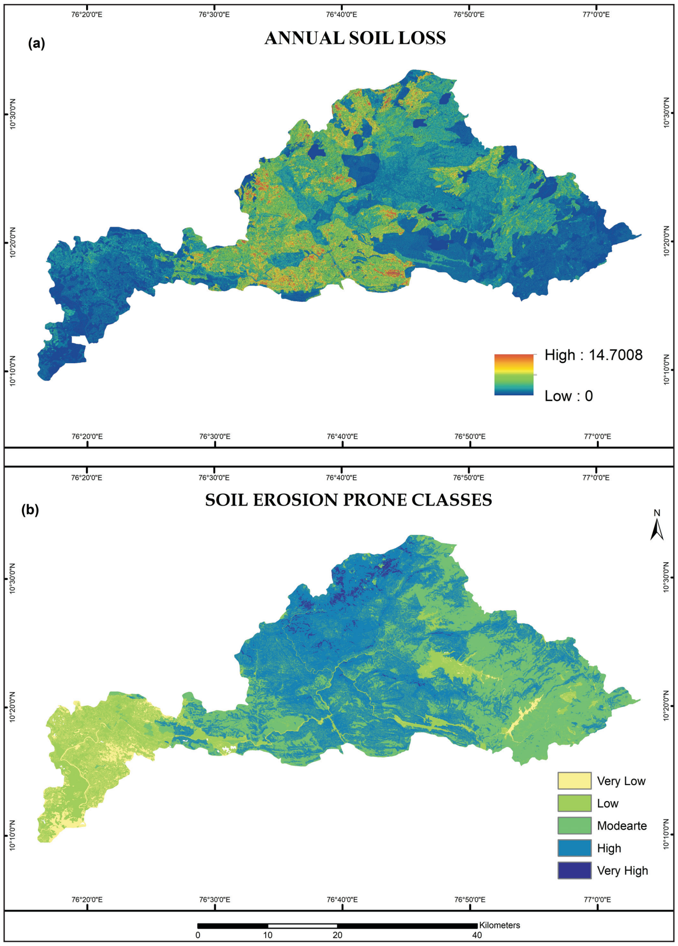

Fig. 4. Land use /land cover (2019) classification of the study area

Table 3: Soil erosion proneness of Chalakkudy River Basin

SL. No	Soil erosion risk classes	Area (Km²)	Area (%)
1	Low	149.26	10.29
2	Moderate	257.53	17.83
3	High	972.32	67.16
4	Very High	67.13	4.70

Table 4: Quantity of soil loss in the study area

SL. No	Range of Soil loss (ton ha^{-1} $year^{-1}$)	Area (Km²)	Area (%)
1	0-3.66	1339.35	92.44
2	3.66-7.32	103.89	7.17
3	7.32-10.98	5.55	0.38
4	10.98-14.64	0.043	0.0029

potential soil erosion exceeds actual soil erosion. These findings can also be used as foundational data to aid in water and soil conservation management and land use planning.

Authors' Contributions

Sreelakshmi Prakash: Investigation, Visualization, Methodology, Writing - Original Draft, Formal Analysis. **Baiju K. R.:** Conceptualization, Visualization, Supervision, Reviewing and Editing. **Abin Varghese:** Conceptualization, Visualization, Supervision , Reviewing and Editing, Software. **Anish A. U.:** Investigation

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

Agarwal, D., Tongaria, K., Pathak, S., Ohri, A and Jha, M. (2016). Soil erosion mapping of watershed in Mirzapur district using RUSLE model in GIS environment.*Int.* Jour. Students' Res. Technol. Manag., v. 4, pp. 56-63.

Arnoldus, H.M.J. (1980). An approximation of the rainfall factor in the universal soil loss equation. *In*: De Boodt M. and Gabriels D. (*Eds.*) Assessment of erosion. Wiley, Chichester, UK, pp. 127–132.

Aulakh, M.S. and Sidhu, G.S. (2015). Soil degradation in India: Causes, major threats, and management options. In: MARCO Symposium 2015 - Next Challenges of Agro-Environmental research in Monsoon Asia. pp. 151-156. National Institute for Agro-Environmental Sciences (NIAES), Tsukuba, Japan.

Babu, K. J., Sreekumar, S., Aslam, A., & Midhun, K. P. (2012). Hypsometry and geomorphic development of a watershed: A case study from South India. Interntl. Jour. Sci. Res., v. 3(10), pp. 1495-1500.

Bayramin, I., Dengiz, O., Baskan, O. and Parlak, M. (2003). Soil erosion risk assessment with ICONA model; case study: Beypazarı area. Turk. Jour. Agri. Forest., v. 27(2), pp. 105-116.

Bhattarai, R. and Dutta, D. (2007). Estimation of soil erosion and sediment yield using GIS at catchment scale. Water Resour. Managemt., v. 21(10), pp. 1635-1647.

Bilotta, G.S., Grove, M. and Mudd, S.M. (2012).Assessing the significance of soil erosion. Transact. Instit. Brit. Geograph., v.37 (3), pp. 342-345.

Boggs, G, Devonport, C., Evans, K. and Puig, P. (2001). GIS-based rapid China. Environ. Geol., v. 57 pp. 937–942.

CWRDM (1997). Attapady wasteland comprehensive environmental conservation project. Eco-restoration plan, Vol 1. Center for Water Resources Development and Management, Kerala

Dutta, D., Das, S., Kundu, A. and Taj, A. (2015). Soil erosion risk assessment in Sanjal watershed, Jharkhand (India) using geo-informatics, RUSLE model and TRMM data model. Earth Syst. Environ., v.1 (4), 37p.

FAO (2003). The State of Food Insecurity in the World 2003.Food and Agriculture Organization of the United Nations VialedelleTerme di Caracalla, 00100 Rome, Italy, 40p.

Fu, G., Chen S and Mc Cool, D.K. (2006). Modelling the impacts of no-tillage practices on soil erosion and sediment yield with RUSLE, SEDD and ArcView GIS. Soil Till Res., v. 85 (1-2), pp.38–49.

Ganasri, B.P. and Ramesh, H. (2016). Assessment of soil erosion by RUSLE model using remote sensing and GIS-A case study of Nethravathi Basin. Geosci. Front., v.7 (6), pp. 953-961.

Goldman, S.J., Jackson, K. and Bursztynsky, T.A. (1986). Erosion and Sediment Control Handbook. McGraw Hill Book Co., New York, 243p.

Jose, S.K, Varghese, A., Kumar, S, Madhu, G., Rakhi C. and Sreekala T.K. (2011). Soil erosion modeling using GIS and Remote sensing. A case study of Shendurney Wildlife sanctuary Southern Western Ghats, Kerala. Ecol. Environ. Conserv., v. 17(4), pp. 685-690.

Kuriakose, S.L., Sankar, G. and Muraleedharan, C. (2009). History of landslide susceptibility and a chorology of landslide-prone areas in the Western Ghats of Kerala, India. Environ. Geol., v. *57*(7), pp. 1553-1568.

Maske, Sunil, Anil Kumar, K.S., Nair, K.M., Hegde, Rajendra, Srinivas, S., Sujatha, K. and Bhaskar, B.P. (2019). Estimation of Soil loss in Rubber (Hevea brasiliensis) growing areas of Kerala and Karnataka, India. Intl. Jour. Chem. Stud. Ref: Chemi-7-6-2907-2914.

Moeini, A., Zarandi, N.K., Pazira, E. and Badiollahi, Y. (2015). The relationship between drainage density and soil erosion rate: a study of five watersheds in Ardebil Province, Iran. WIT Trans. Ecol. Environ., v. 1, pp.129-138.

Moore, I.D. and Burch, G.J. (1986).Physical basis of the length-slope factor in the universal soil loss equation 1.Soil Sci. Soc. Amer. Jour., v. 50(5), pp. 1294-1298.

Pradeep, G.S., Krishnan, M.V.N. and Vijith, H. (2015). Identification of critical soil erosion prone areas and annual average soil loss in an upland agricultural watershed of Western Ghats, using analytical hierarchy process (AHP) and RUSLE techniques. Arab. Jour. Geosci., v. 8, pp. 3697–3711. https://doi.org/10.1007/s12517-014-1460-5

Prasannakumar, V., Shiny, R., Geetha, N., and Vijith, H. (2011). 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., v.64 (4), pp. 965-972.

Prasannakumar, V., Vijith, H., Abinod, S. and Geetha, N. (2012).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., v. 3(2), pp. 209-215.

Renard, K.G. and Freimund, J.R. (1994).Using monthly precipitation data to estimate the R-factor in the revised USLE. Jour. Hydro., v. 157(1-4), pp. 287-306.

Sharma, S.K., Pathak, R. and Suraiya, S. (2012). Prioritization of sub watershed based on morphometric analysis using Remote Sensing and GIS technique. JNKVV Res. Jour., v. 46(3), pp. 407-413.

Singh, Y., John, B., Ganapathy, G.P., George, A., Harisanth, S., Divyalakshmi, K.S. and Kesavan, S. (2016). Geomorphic observations from southwestern terminus of Palghat Gap, south India, and their tectonic implications. Jour. Eart. Sys. Sci., v. 125, pp. 821-839. https://doi.org/10.1007/s12040-016-0695-9.

Soman, K. (2002). Geology of Kerala: Geological Society of India. Bangalore.

Sujatha, E. and Sridhar, V. (2018). Spatial Prediction of Erosion Risk of a Small Mountainous Watershed Using RUSLE: A Case-Study of the Palar Sub-Watershed in Kodaikanal, South India. Water, v. 10 (11), 1608.

Tian, Y.C., Zhou, Y.M., Wu, B.F. and Zhou, W.F. (2009). Risk assessment of tropics of Australia. Land Degrad. Dev., v.12, pp. 417-434.

Upadhyay, T.P., Sankhayan, P.L. and Solberg, B. (2005). A review of carbon sequestration dynamics in the Himalayan region as a function of land-use change and forest/soil degradation with special reference to Nepal. Agri. Ecosys. Environ. v. 105(3), pp. 449-465.

Van der Knijff, J.M., Jones, R.J.A. and Montanarella, L. (2000). Soil erosion risk: assessment in Europe. Europ. Soil Bureau, 32p.

Vijith, H. and Madhu, G. (2007). Application of GIS and frequency ratio model in mapping the potential surface failure sites in the Poonjar sub-watershed of Meenachil River in Western Ghats of Kerala. Jour. Indian Soc. Rem. Sens., v. 35(3), pp. 275-285.

Weaver, A.V.B. (1991). The distribution of soil erosion as a function of slope aspect and parent material in Ciskei, Southern Africa. Geo. Jour., v. 23(1), pp. 29-34.

Wischmeier, W.H. and Smith, D.D. (1978).Predicting rainfall erosion losses-a guide to conservation planning. Science and Education Administration United States Department of Agriculture in cooperation with Purdue Agricultural Experimental Station. 67p.