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Evaluating Soil Erosion within the Neyyar Basin in Kerala through RUSLE and Geospatial Analysis

R. Gladis [a*], G. V. Asha Rani [b], Rema K. P. [c], B. Rani [b], Biju Joseph [d] and M. R. Rehana [b]

[a] Department of Soil Science and Agricultural Chemistry, Agricultural Research Station, Thiruvalla, Kerala, India.
[b] Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani, Kerala, India.
[c] Department of Irrigation and Drainage Engineering, KCAET, Tavanur, Malappuram, Kerala, India.
[d] Department of Soil Science and Agricultural Chemistry, Rice Research Station, Moncompu, Kerala, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Soil erosion represents a significant issue in the Western Ghats, especially within the Neyyar river basin in the southern region of Kerala. To address this problem, a research project was conducted in three sub-watersheds of the Neyyar river basin, specifically Neyyar, Mullayar, and Chittar, with the primary goals of quantifying annual loss of soil and creating erosion maps. To predict this, researchers employed the Revised Universal Soil Loss Equation (RUSLE) in conjunction with Geographic Information System (GIS). To compute the RUSLE factors viz., R, K, LS, C and P for these sub-watersheds, monthly and yearly rainfall, soil texture and organic matter content, length

**Corresponding author: E-mail: gladis.r@kau.in;*

and steepness of slope, crop cover and conservation practices data were used.The results showed that the extent of soil loss varied among the three watersheds. Soil loss ranged from 0 to 92, 257, and 28 tons per hectare per year for Chittar, Mullayar, and Neyyar sub-watersheds, respectively. In 38% of Mullayar, 41% of Chittar, and 45% of Neyyar watersheds, soil loss was relatively low, being less than 10 tons per hectare per year. However, in 35% of Mullayar, 30% of Chittar, and 25% of Neyyar sub-watersheds, soil loss was moderate to very high, ranging from 15 to over 40 tons per hectare per year. These variations in soil loss were attributed to factors beyond just rainfall, such as slope (LS) and soil erodibility (K), indicating that other elements influenced the soil erosion risk. Moreover, it was observed that Mullayar had the highest erosion risk, followed by Chittar watershed, highlighting the significance of factors like slope and soil erodibility in contributing to the loss of soil.

Keywords: Soil loss; erosion; watershed; GIS; RUSLE.

1. INTRODUCTION

Soil erosion is a significant form of land degradation resulting from changes in land use. It poses a substantial problem with economic, social, and environmental repercussions, both on-site and off-site [1]. On a global scale, approximately 80% of agricultural land is affected by soil erosion [2]. Roughly 53% of the total area in India is susceptible to soil erosion, leading to an annual loss of 5,334 metric tons of topsoil due to the combined effects of water and wind erosion. The cultivable land in the country has been affected, with soil erosion impacting 92.4 million hectares [3]. The notable increase in loss of soil and its associated monetary consequences elevated erosion to one of the most critical worldwide challenges [4].

Water-induced soil erosion is a significant issue in dry and moist regions of India. The Universal Soil Loss Equation, which has been derived experimentally [5], provides a valuable means of calculating soil erosion in watersheds experiencing net erosion. This equation has demonstrated its effectiveness in assisting planners who aim to control soil erosion and keep it within acceptable levels of soil loss. This management involves strategies such as adjusting slope length, terrace spacing, and cropping practices.

The integration of Geographic Information Systems (GIS) has proven to be highly beneficial in erosion delineation studies [6]. The application of geospatial tools for quantifying soil loss is particularly useful in prioritizing watersheds for conservation planning and management [7]. These technological tools facilitate a more informed and data-driven approach to addressing soil erosion and its associated challenges in the affected regions.

Several factors play a role in influencing erosion of soil, including precipitation, overflow, soil characteristics, slope, crop factors, and preservation practices [8]. Common causes of soil erosion include heavy rainfall, absence of crop cover, low organic carbon in soil, and non adoption of protection measures [9]. The local climatic conditions, characterized by an extended dryness followed by intense rains, make the region particularly susceptible to erosion [10]. Soil erosion is indeed influenced by various factors, including relief, plants, soil properties, and land use, which can vary significantly across different geographical areas [11]. This dynamic process, particularly when driven by water, underscores the importance of obtaining knowledge about the extent of erosion-prone regions and the severity of erosion. Geoinformatics plays a prime role in this regard by providing the tools for spatial analysis, allowing for the estimation of erosion distribution. This, in turn, enables the identification of preference areas in terms of soil erosion, facilitating the development of appropriate conservation and management strategies [9].

Globally, soil erosion has escalated to a level that poses a threat to food production and the delivery of ecosystem services. This challenge is particularly pronounced in India, where out of a total land area of 328 million hectares (M ha), approximately 121 M ha is experiencing soil degradation, with 68% of that attributed to water erosion. Water erosion rates vary widely, ranging from 5 to 80 tons per hectare per year, indicating varying degrees of severity. The average soil loss in India has been quantified at 15 t ha^{-1} yr^{-1}, but it's important to approach this figure with caution.

Consequently, there is an urgent need for a systematic regional appraisal of soil degradation due to erosion using appropriate techniques [12]. Hence, the present investigation was undertaken to quantify the annual soil removal from the sub-watersheds of the Neyyar river basin using the RUSLE and to create erosion maps for conservation planning by leveraging GIS techniques. The objective of this method is to offer a more thorough and data-driven comprehension of soil erosion within the area, a vital aspect for the successful implementation of conservation measures.

2. MATERIALS AND METHODS

2.1 Study Area

The Neyyar basin is situated in the southern part of the Western Ghats within the state of Kerala. It stretches approximately 56 kilometers through Thiruvananthapuram district. For the purpose of this investigation, three watersheds of the Neyyar basin, namely Chittar, Neyyar, and Mullayar, were chosen. These sub-watersheds represent the highland ecosystems within two agro-ecological units, namely AEU 12 and 14. The key characteristics of these watersheds are detailed in Table 1.

To delineate these watersheds, the Kerala Land Use Board's watershed atlas of Kerala, created on a 1:50000 scale, was utilized. The corresponding codes for each watershed are provided in Table 1. The map showing the location of these sub-watersheds is depicted in Fig. 1. The study area covers an expanse of 252 square kilometers and spans an elevation range of 200 to 1500 meters above mean sea level.

The sub-watersheds are located between latitudes 8° 41′7″ N to 8° 55′7″ N and longitudes 77° 07′9″ E to 77° 55′7″ E. The climate in this region is of the tropical humid monsoon type. The topography includes medium hills and isolated hill rocks in the upper areas, while lateritic mounds and uplands dominate the lower reaches of the watershed. The primary land uses within the study area encompass forests, agriculture, and plantations.

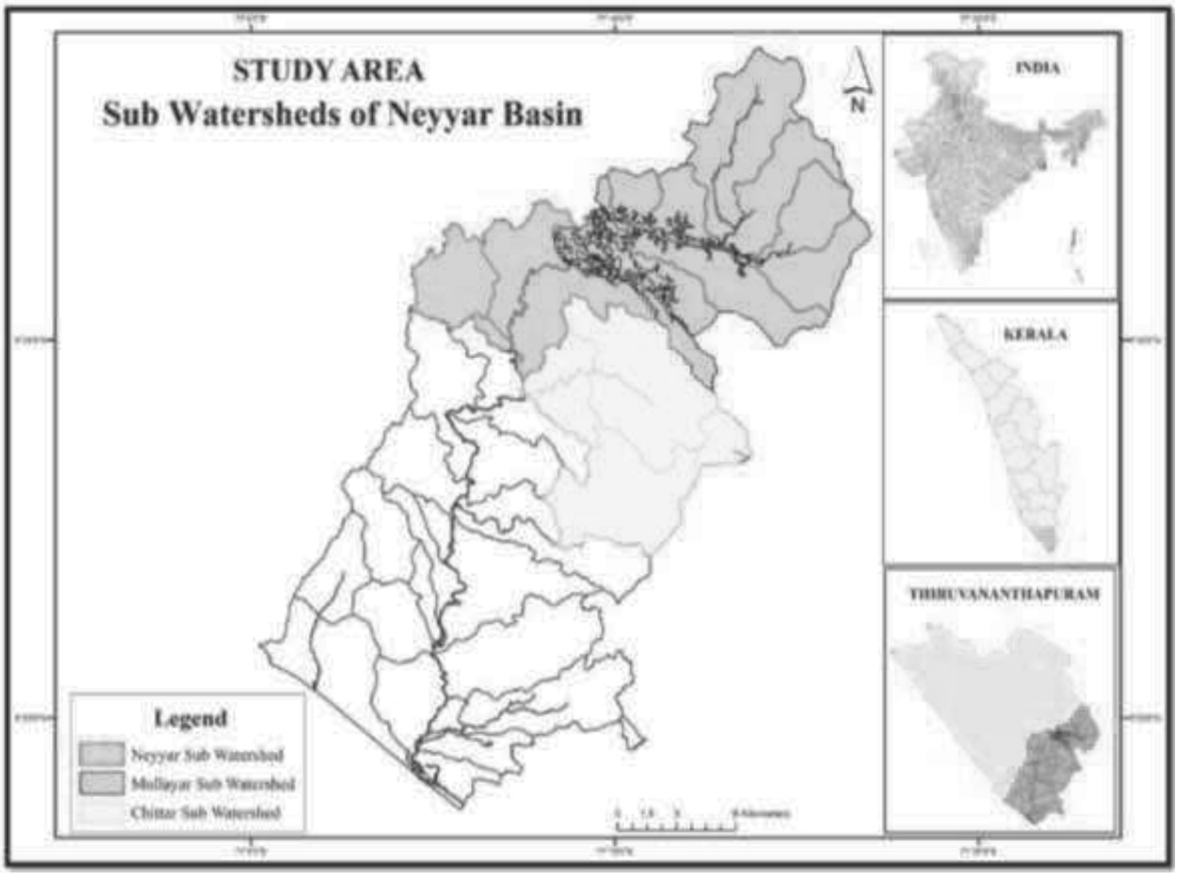

Fig. 1. Map showing sub wetersheds in the study area

Table 1. Key features of watersheds in Neyyar river basin

Name of sub watershed	Number of micro watersheds and their codes	Total area (ha)	Agro Ecological Unit	Mean annual rainfall (mm)	Land use types	Soil texture	Slope classes
Mullayar	9 (1N10a,1N11a,1N12a,1N13b,1N13a, 1N14a, 1N15a, 1N14b, 1N16a)	12692	AEU 14	1719	Forest Agriculture	Loamy sand	Level to extreme steep sloping
Neyyar	4 (1N8b, 1N9a, 1N8c, 1N17a)	8077	AEU 12	1748	Agriculture Forest	Sandy clay loam	Level to moderate sloping
Chittar	5 (1T1a, N21b, 1N18b, 1N18c, 1N18a)	4658	AEU 12	1699	Agriculture	Clay loam	Level to steep sloping

2.2 Methodology

In this investigation the soil loss was determined using RUSLE along with geospatial tools.

$$A = R \times K \times LS \times C \times P \quad \text{Eq. (1)}$$

where,

A = Average annual soil loss (t $h^{-1}y^{-1}$);
R = Rainfall - runoff erosivity factor (ha h^{-1} $year^{-1}$);
K = Soil erodibility factor (t ha h);
L = Slope length factor;
S = Slope steepness factor;
C = Cover and management factor:
P = Conservation support practices factor.

Here, Land sat 8 data and land cover maps from Kerala State Land Use Board, rainfall data of 10 years (2009-2018) obtained from IMD, soil analysis data and DEM were used to compute factors.

The R factor was derived following the relationship proposed by [5].

$$R=\sum_{i=1}^{12} 1.735 * 10^{\left(1.5log10\left(\frac{Pi2}{P}\right)-0.08188\right)} \quad \text{Eq. (2)}$$

where,

R = Rainfall erosivity (ha h^{-1} $year^{-1}$),
*P*i = Monthly rainfall (mm),
P = Yearly rainfall (mm).

Soil erodibility was estimated by an empirical equation developed by [13]

K = 2.8 * 10-7 M1.14 (12-a) + 4.3 * 10-3 (b-2) + 3.3*10-3 (c-3) Eq. (3)

The combined length and steepness of a slope was computed using the DEM [14].

$$LS = (\text{Flow accumulation} \times \text{Cell size}/ 22:13)^{0.4} \times (\sin \text{slope}/ 0.0896)^{1.3} \quad \text{Eq. (4)}$$

Eq. (4)

cell size = 30 m

Crop cover and management is a measure of soil loss and spatial data have been employed to assess the C factor [15]. The assessment also utilizes the NDVI, which indicates health and vigor of vegetation [16].

$$C = \exp\left[- . \frac{NDVI}{(\beta-NDVI)}\right] \quad \text{Eq. (5)}$$

where α and β are unit less parameters that determine the shape of the curve relating to NDVI and the C factor [17].

The P component encompasses both land cover and slope factors. These values are determined through field observations and data derived from satellite imagery. The P factor signifying effective conservation practices and values approaching 1 indicating less effective or poor conservation practices.

In the present analysis, Survey of India toposheets (58H2, 58H3, 58H6) on 1:50000 scale, Landsat 8 image, monthly precipitation, DEM, field data and soil texture were used with the aid of Arc GIS software, and the output map of erosion in the study area was obtained

It was classified into very low (0–5 t ha^{-1} yr^{-1}), low (5–10 t ha^{-1} yr^{-1}), moderate (10–15 t ha^{-1} yr^{-1}), moderately high (15– 20 t ha^{-1} yr^{-1}), high (20–40 t ha^{-1} yr^{-1}) and very high (>40 t ha^{-1} yr^{-1}) as per [18].

3. RESULTS AND DISCUSSION

The results pertaining to the various input factors of RUSLE and the annual soil loss from three sub- watersheds of Neyyar river basin are depicted and discussed below.

3.1 Runoff Erosivity

The mean annual precipitation in these areas falls within the range of 1699.50 to 1748.50 milli meters. The annual erosivity index (R) was found to be highest in the Neyyar sub-watershed, measuring 990.8. In contrast, Mullayar had an R value of 974.7, and Chittar had an R value of 963.2. This difference in erosivity is likely due to the fact that Neyyar receives a higher average annual rainfall of 1748.5 milli meters.

The majority of erosive rainfall events occur during the southwest and northeast monsoon periods in all three watersheds. This observation aligns with the findings reported in [19], confirming that the erosive rain events are consistent with the monsoon seasons in these areas.

3.2 Soil Erodibility

The soil erodibility parameter was determined based on various soil characteristics, including texture, structure, organic matter content, and permeability, in the Neyyar basin. The K-factor estimated is detailed in Table 3. The K-factors varied across the different soil types in Mullayar, Neyyar, and Cittar watersheds. Specifically, they were 0.449 for loamy sand, 0.392 for sandy clay loam, and 0.159 for clay loam soils.

The organic matter content, soil structure and stability help to prevent erosion. Soils with organic matter content less than 3.5% are more erodible. The highest K-factor of 0.449 was observed in the Mullayar watershed, indicating that the soils in this area are more erosive. It is due to the low organic carbon content (1.74%) found in surface soil samples in this watershed. Additionally, the coarse texture of the soil, characterized by a higher sand content (28.6%) compared to clay and silt, contributed to the higher K-values, making the soil more erodible.

3.3 Length and Steepness of Slope

In the Neyyar sub-watershed, the predominant slope steepness classes ranged from level land (0-1% slope) to moderately sloping (5-8% slope). Steeper slopes, such as strong (8-15% slope) and very steep (30-60% slope) areas, were relatively rare in this sub-watershed. In the Mullayar watershed, the observed slope classes encompassed a broader range, including 0-1%, 1-3%, 8-15%, and 30-60% slope categories. The major portion of the total area in this watershed exhibited strong sloping terrain (8-15% slope), followed by very steep slopes (30-60% slope). In the Chittar watershed, the majority of the area was characterized by level land (0-1% slope) to moderately sloping (5-8%) terrain. Areas with strongly steep (8-15% slope) and very steep (30-60% slope) topography were limited in extent. Comparing these three watersheds, Neyyar and Chittar had more nearly level to gently sloping terrain, while Mullayar featured a greater extent of strong to very steep sloping topography. This suggests a higher potential for soil loss and erosion in the Mullayar watershed due to its steeper terrain.

3.4 Cover Management and Conservation Practice

The values for the C and P factors were determined based on LULC classes. In the Mullayar watershed, the majority of the area (9641 hectares) is forest, while in the Neyyar (3401 hectares) and Chittar (6248 hectares) watersheds, the predominant land use is agriculture, accounting for approximately 76%, 73%, and 77% of the total area, respectively. Barren rock occupies 9.7% of the total area in Mullayar, while wasteland accounts for 2.5% and 3.7% of the total area in Neyyar and Chittar, respectively. Consequently, the assigned C values ranged from 0.3 to 1.0 in Mullayar, 0.2 to 1.0 in Neyyar, and 0.4 to 1.0 in Chittar watersheds.

Specifically for agriculture 0.3 in Mullayar, 0.2 in Neyyar, and 0.4 in Chittar watersheds were given (as detailed in Table 4). However, a C value of 1.0 was assigned to barren rocks, forests, and wastelands within these watersheds. These C values align with those assigned in reference [20], which range between 0.30 and 1.0.

Regarding the P value 1.0 was assigned to forest, barren rock, and wastelands in Mullayar and Chittar, as no conservation measures were adopted in these land types. In the Neyyar watershed, the P factor value assigned was 0.5 for forest areas due to runoff, erosion, and field management practices like field bunds, terrace farming, and across-slope farming. The P values for agricultural lands in Neyyar ranged from 0.3 to 0.5 based on the management practices implemented.

3.5 Quantification of Soil Loss

The estimated annual soil loss for the selected sub-watershed areas in the Neyyar basin using the Universal Soil Loss Equation (USLE) is summarized in Table 5. In the Mullayar watershed, the major portion of the area (38.3%) experienced less than 10 tons per hectare per year loss of soil because it primarily consists of level slopes of less than 3%. Moderate (10-15 t ha-1 yr-1) and moderately high (15-20 t ha-1 yr-1) soil loss rates were observed in 25.8% and 19.3% area, respectively. Similar observations were made by [21]. The categorized erosion risk classes ranging from low to high in different watersheds, which can be attributed to variations in average annual rainfall and slope conditions in different areas (see Fig. 2).

Table 2. Mean annual rainfall and erosivity in the watersheds of Neyyar basin

Sl. No	Name of watershed	Mean annual rainfall (mm)	R factor
1.	Mullayar	1719.80	974.70
2.	Neyyar	1748.50	990.80
3.	Chittar	1699.50	963.20

Table 3. Soil erodibility in the watersheds of Neyyar river basin

Sl. No	Name of watershed	Soil Texture	Clay (%)	Silt (%)	Very fine sand (%)	Organic matter (%)	Structure code	Permeability code	K factor
1.	Mullayar	Loamy sand	11.8	16.5	28.6	1.74	2	2	0.449
2.	Neyyar	Sandy clay loam	21.4	23.2	14.8	2.52	1	3	0.392
3.	Chittar	Clay loam	29.4	32.6	10.2	3.24	1	4	0.159

Table 4. Cover management and conservation practice factors for land uses

Sl.No.	Watersheds	Land use/ cover type	Area in ha and (% of total area)	C factor	P factor
1.	Mullayar	Agriculture	836 (6.5)	0.3	0.5
		Forest	9641 (76)	1.0	1.0
		Barren rock	1230 (9.7)	1.0	1.0
2.	Neyyar	Agriculture	3401 (73)	0.2	0.3
		Forest	16.50 (0.35)	0.8	0.5
		Waste land	117 (2.5)	1.0	0.8
3.	Chittar	Agriculture	6248 (77)	0.4	0.4
		Waste land	275 (3.7)	1.0	1.0

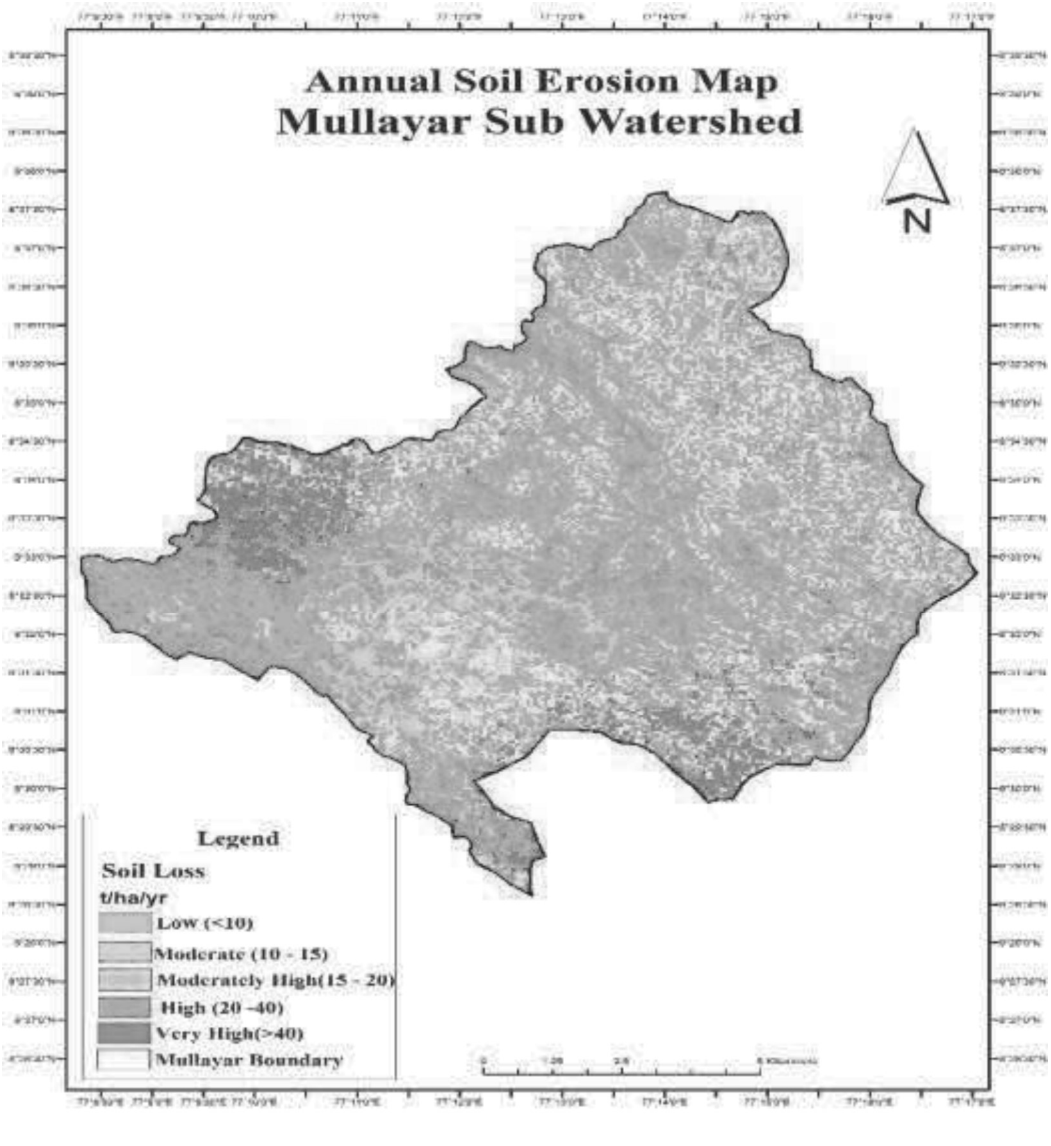

Fig. 2. Erosion map of Mullayar

In the Neyyar watershed, low soil erosion in 45.8% of the area and moderate in 28.9% of the area was observed. This distribution is linked to the predominantly level land (0-1% slope) to moderately sloping (5-8% slope) topography. The presence of steep slopes and intensive agriculture (3401 hectares) in the region likely contribute to the observed soil erosion. These findings are consistent with reports on steep slopes [22] and intense cultivation [23]. Areas with nearly level land and slopes less than 1% exhibited very low soil erosion (45.8% of the total area) (see Fig. 3).

In the Chittar watershed, the results indicate that approximately 30% of the total area (2500 hectares) experienced moderately to very high erosion (see Fig. 4). The high erosion levels are attributed to intense rainfall, strong (8-15% slope) to very steep (30-60% slope) topography, and the type crop. The high rainfall erosivity of 963.2 in Chittar watershed is a significant contributing factor to the extent of erosion. Very low erosion was observed in areas with a slope of 0-1%. Nearly level land (1-3% slope) resulted in 5-10 t ha-1 yr-1 of soil loss annually, representing a low erosion risk under agriculture but a high risk under forest. This discrepancy may be due to conservation practices being employed in the agricultural land in that area. Only 8.92% of the total area exhibited very high erosion risk, primarily found in waste land areas. This can be due to the occurrence of heavy rainfall and steeper slopes in this watershed.

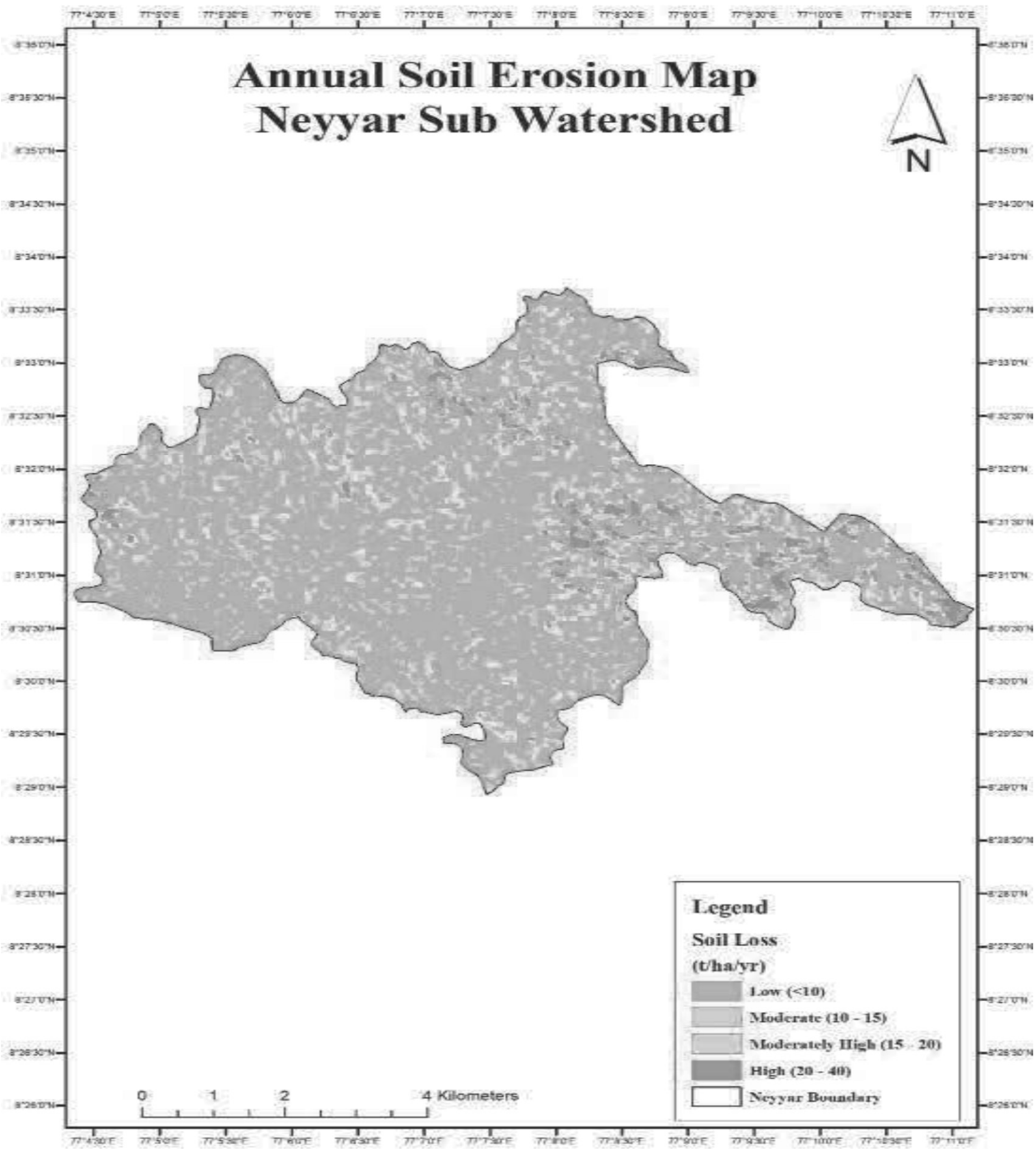

Fig. 3. Erosion map of Neyyar

Table 5. Soil loss from the selected sub-watersheds of Neyyar

Sl. No.	Annual soil loss ($t\ ha^{-1}\ yr^{-1}$)	Erosion risk classes	Mullayar		Neyyar		Chittar	
			Area (ha)	% of total area	Area (ha)	% of total area	Area (ha)	% of total area
1.	<10	Low	4862	38.3	2131	45.8	3328	41.2
2.	10-15	Moderate	3278	25.8	1348	28.9	2303	28.5
3.	15-20	Moderately high	2453	19.3	554	11.9	1481	18.3
4.	20-40	High	1279	10.1	341	7.32	243	3.01
5.	>40	Very high	820	6.46	284	6.09	721	8.92
		Total	12692	100	4658	100	8077	100

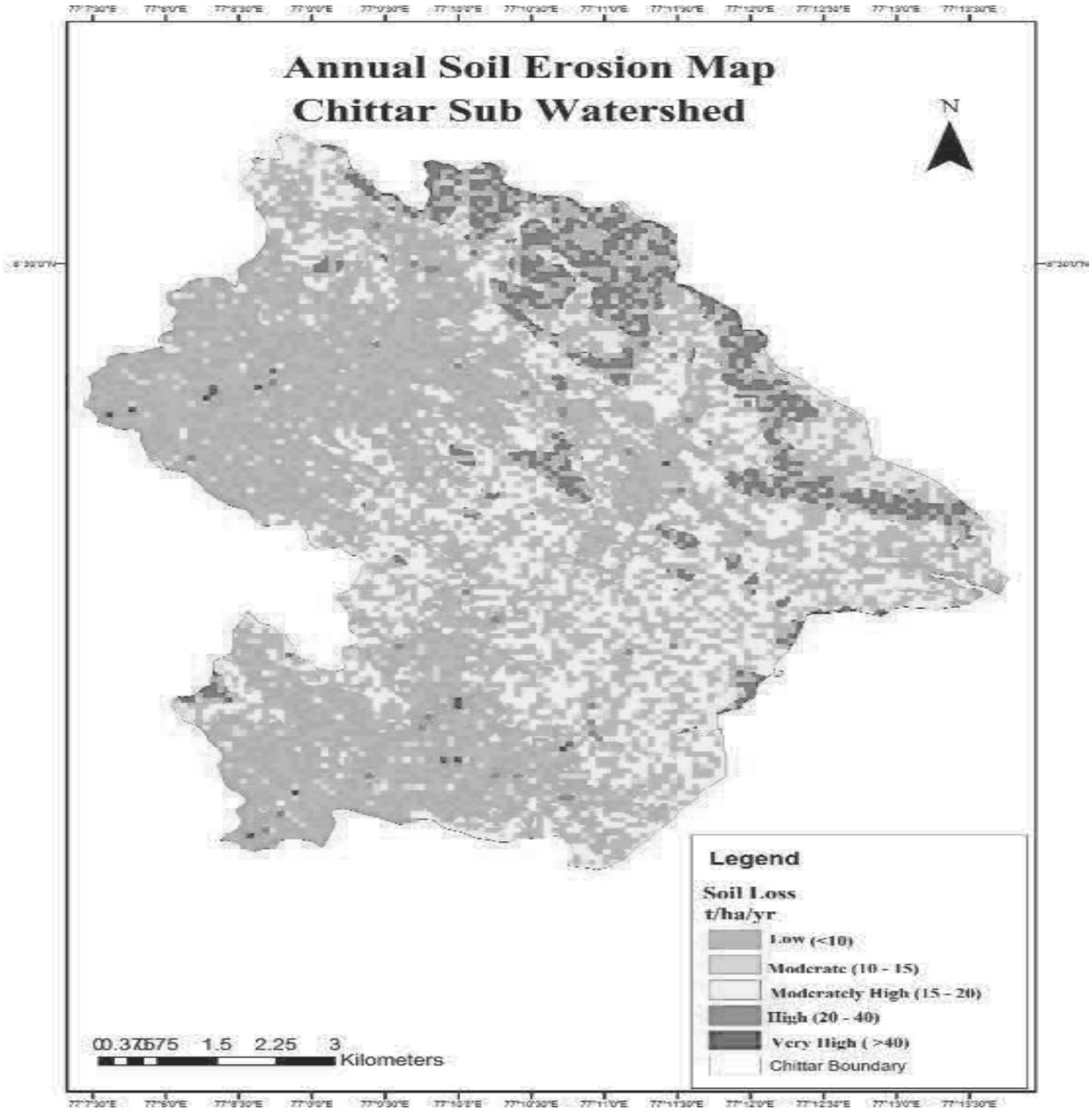

Fig. 4. Erosion map of Chittar

4. CONCLUSION

The loss of soil in the Mullyar, Neyyar, and Cittar watersheds was assessed through a GIS-based RUSLE equation that utilized data on rainfall, soil, crop, and topography [24]. Erosion in these watersheds is primarily driven by factors such as heavy rainfall, absence of crop cover, low organic carbon content, and a lack of soil protection practices.

The findings of the study revealed that despite higher rainfall, the Mullayar watershed experienced more annual soil loss compared to the Chittar and Neyyar watersheds, because of the influence of slope and land use characteristics. The analysis of land use patterns in erosion-prone areas demonstrated that regions covered by natural forests had the lowest rates of soil erosion, while areas used for agriculture and subjected to human intervention had significantly higher rates of soil erosion. The combination of altered terrain, steep slopes, and heavy rainfall makes these areas particularly susceptible to soil erosion.

To mitigate soil loss, it is essential to implement effective crop cover management and conservation strategies. The spatial mapping of soil erosion variability can serve as a foundation for comprehensive land management and sustainable land use planning within these watersheds. Special priority should be given to areas within the Mullyar and Chittar watersheds where soil erosion is very high or severe, exceeding 40 tons per hectare per year, for the implementation of erosion control measures.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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