Estimation of Soil Loss in Watersheds of Neyyar River Basin in Thiruvananthapuram District of Kerala Using RUSLE and GIS

ABSTRACT

Soil erosion is a growing problem in Western Ghats of Kerala and particularly in the watersheds of Neyyar river basin in southern part of Western Ghats. A study was conducted in three sub watersheds of Neyyar river basin namely Neyyar, Mullayar and Chittar to quantify the annual soil loss and to prepare erosion risk maps. In the current study, to predict potential annual soil loss the Revised Universal Soil Loss Equation (RUSLE) was adopted with Geographical Information System (GIS) framework. The RUSLE factors were calculated for the sub watersheds Neyyar, Mullayar and Chittar. The R-factor was calculated from monthly and annual precipitation data. The K-factor was estimated using soil data. The LS-factor was calculated from digital elevation model. The C-factor was calculated using Remote Sensing techniques. The P-factor was assigned based on field observations and crop management strategies. Slope gradient map was prepared from DEM and the R, K and LS factors in USLE were determined from the established equations. Information on conservation was obtained from field survey. Using grid-based approach, soil loss was quantified and erosion risk map was prepared in GIS environment. The predicted soil loss varied among the three watersheds and it ranged from 0 to 92, 257 and 28 t ha-1 yr-1 for Chittar, Mullayar and Neyyar sub-watersheds respectively. The soil loss was low (< 10 t ha-1yr-1) in 38 % area of Mullayar, 41 % of Chittar and 45% of Neyyar watersheds whereas, it was moderately to very high (15 - >40 t ha-1 yr-1) in 35% area of Mullayar,30 % of Cittar and 25% of Neyyar sub watersheds due to slope and land use characteristics. Soil erossion risk was more for Mullayar followed by Chittar watershed suggesting that factors other than rainfall such as slope (LS) and soil erodibility (K) contributed to soil loss.
Key words*: Soil loss, erosion risk assessment, watershed, GIS, RUSLE*

1. INTRODUCTION

Soil erosion is one of the most widespread forms of land degradation resulting from changes in land use. The problem has a far reaching economic, political, social and environmental implication due to both on-site and off-site damages [1]. In view of global erosion and sedimentation, about 80% of agricultural land suffer from significant erosion [2]. In India, about 53% of the total land area is prone to erosion and 5,334 metric tons of soil is being detached annually due to various reasons. The extent of soil erosion (soil loss more than 10 t ha^{-1} yr^{-1}) in cultivable land of the country was 92.4 million hectares [3]. Unprecedented increases in soil loss and its economic and environmental impacts have made erosion one of the most serious global problems [4].

Problems associated with soil erosion, movement and deposition of sediment in rivers, lakes and estuaries persist through the geologic ages in almost all parts of the earth. Soil erosion due to water is a serious problem in semi- arid and sub-humid areas of India. Universal soil loss equation (USLE) derived empirically from approximately 10,000 plot-years of data [5] may be used to calculate erosion at any point in a watershed that experiences net erosion. The equation has become a useful tool for planners to keep soil erosion within permissible limits of soil loss tolerance by managing slope length, terrace spacing and cropping practices. GIS has proved to be an efficient tool in drainage and erosion delineation [6]. The application of RS and GIS for the analysis of soil erosion parameters is found to be of immense utility in watershed prioritization for soil, water conservation and natural resources management [7].

The factors, which influence the rate of soil erosion are rainfall, runoff, soil properties, slope, biological factors and the presence or absence of conservation measures [8]. High intensity rains during pre-monsoon season when there is no crop cover, low organic carbon in these soils and lack of adoption of soil conservation measures by farmers are the common causes of soil erosion [9]. Climatic characteristics of the region such as having a long dry period followed by heavy erosive rainfall have made the region very susceptible to soil erosion [10]. Soil erosion is influenced by the spatial heterogeneity in topography, vegetation, soilproperties and land use, among other factors [11]. Water induced soil erosion is a very dynamic spatial phenomenon. The information on the spatial extent of erosion risk area and its severity are pre- requisites for soil conservation planning and watershed management programmes. While conventional methods yield point-based information, geographical information system (GIS) integrates the spatial analytical functionality for spatially distributed data on soil loss to identify the priority areas in terms of soil erosion intensity so as to evolve appropriate conservation management strategies [9].

Globally soil erosion has reached a level that endangers the sustainable supply of food for the growing global population. It already threatens food production and ecosystem service delivery and therefore, there is a pressing need to address this threat. This is especially true in India where, in a total area of 328 million hectares (Mha), 121 Mha is undergoing soil degradation, 68% of which is attributed to water erosion. Water erosion rates range from 5 t ha^{-1} yr^{-1}in dense forest regions to rates in excess of 80 t ha^{-1} yr^{-1} where erosion is most severe, such as in the mountainous region. India's average soil loss has been estimated to be 15 t ha^{-1} yr^{-1}; however, given the limited coverage of measurements, this should be treated with caution. In the light of the serious threat that soil erosion poses in the country, there is a pressing need for a systematic nationwide assessment of land degradation due to erosion using appropriate techniques [12]. Hence, the present study envisages the application of RUSLE (Revised Universal Soil Loss Equation), a predictive empirical model, along with remote sensing and GIS techniques to predict and quantify the annual soil loss from sub watersheds of Neyyar river basin and also preparation of erosion risk maps for conservation planning.

2. MATERIALS AND METHODS

2.1. Study area

The Neyyar river is one among the 44 west flowing streams of Kerala. It runs for a length of 56km in Thiruvananthapuram district and is the south most river of Kerala State. The Neyyar river basin is located in southern part of the Western Ghats. The three sub watersheds of Neyyar river namely Chittar, Neyyar and Mullayar were selected representing the highland ecosystems in two agro-ecological units (AEU 12 and 14) of the district. The salient features of which are presentedin table 1. These sub watersheds were selected from the watershed atlas of Kerala prepared by the Kerala Land Use Board on 1:50000 scale and the codes furnished are presented in table 1. The location map of sub-watersheds is shown in fig. 1. The study area extends over 252 sq. km with an elevation between 200-1500 above from MSL. The sub-watersheds lie between 8° 41′7″ N to 8° 55′7″ N latitude and 77° 07′9″ E to 77° 55′7″ E longitude. The climate is tropical humid monsoon type. The broad land-forms include medium hills and isolated hill rocks in theupper region, lateritic mounds and uplands at the lowerregion of the watershed. The forest, agriculture and plantations are the predominant land uses in the study area.

Table 1. Salient features of sub watersheds of 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

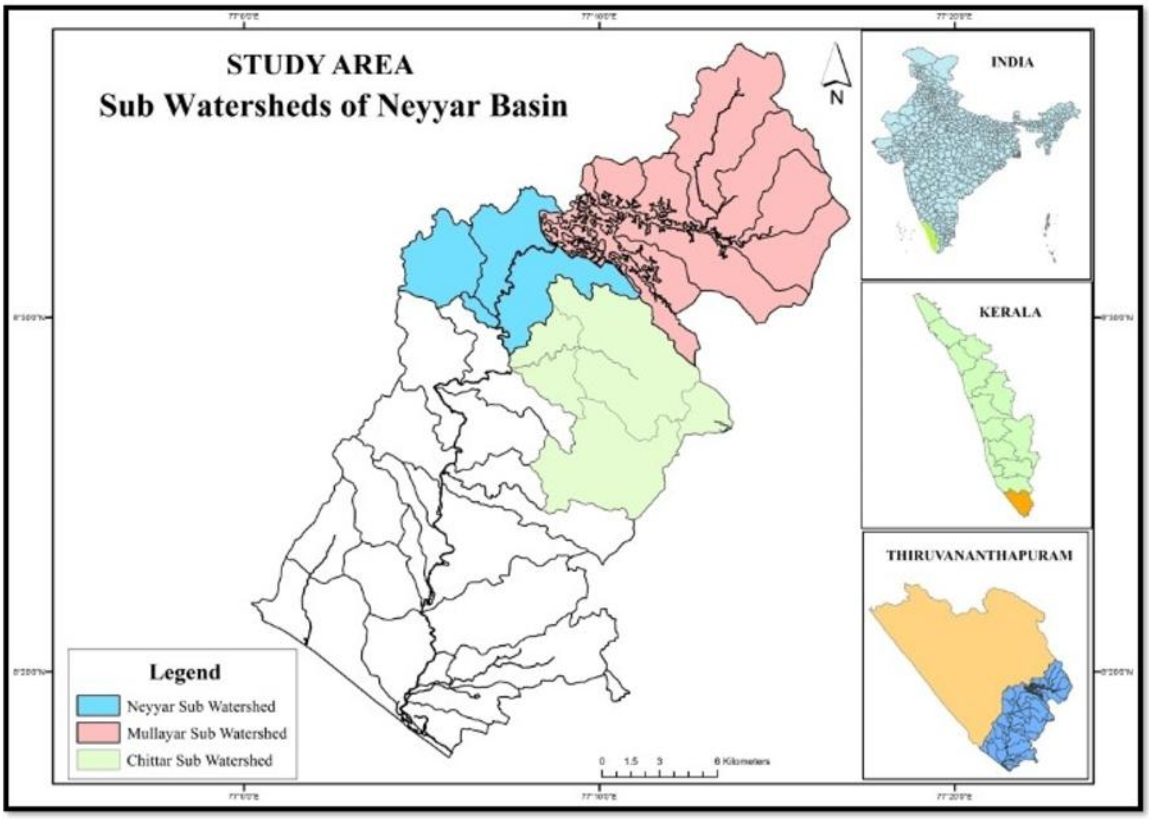

Fig. 1 Location map of sub wetersheds in the study area

2.2. Methodology

This study was done using RUSLE along with RS and GIS techniques. The equation used in RUSLE model has a general format with the product of five factors as given below

A = R x K x LS x C x P, where A is the computed spatial average of soil loss over a period, usually on yearly basis (t $h^{-1}y^{-1}$); R is the rainfall - runoff erosivity factor [MJ mm/(ha h $year^{-1}$)]; K is the soil erodibility factor [t ha h/(ha MJ mm)]; L is the slope length factor; S is the slope steepness factor; C is the cover and management factor. In this study, Land sat 8 data and land use maps from Kerala State Land Use Board were used to identify the present land use status of the study area; and P is the conservation support practices factor. The LS, C, and P values are dimensionless. The following sections describe the computation of the R-, K- and LS-factors from precipitation data of 10 years (2009-2018) obtained from IMD, soil analysis data and digital elevation model (DEM), respectively.

Within the RUSLE rainfall erosivity factor (R) was estimated using the monthly rainfall data in annual R factor calculations using the following relationship proposed by [5] and modified by Arnoldus (1980).

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

where R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} $year^{-1}$), *P*i is the monthly rainfall (mm), and P is the annual rainfall (mm).

Soil erodibility (K) factor was estimated by an empirical equation developed by [13] and an attribute table was prepared for different soil types using the following relation

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

where, OM = organic matter (%), M = (% silt + % very fine sand) (100 - %clay), S = soil structural code (very fine granular,1; medium or coarse granular,3; blocky, platy or massive, 4), P = profile permeability class (rapid, 1; moderate rapid, 2; moderate, 3; slow to moderate 4; slow, 5; very slow, 6) .

The combined length and steepness of a slope (LS) factor was computed for the watershed by means of ArcGIS spatial analyst extension using the Digital Elevation Model of the study area following the equation proposed by [14].

LS = (Flow accumulation X Cell size/ 22:13)$^{0.4}$ X (sin slope/ 0.0896)$^{1.3}$

Where flow accumulation denotes the accumulated upslope contributing area for a given cell, LS = combined slope length and slope steepness factor, cell size = size of grid cell (for this study 30 m) and sin slope = slope degree value in sin.

The cover and management factor (C), is the ratio of soil loss from land use under specified conditions to that from continuously fallow and tilled land.Due to the spatial and temporal variations in land use/ land cover pattern, satellite remote sensing data sets were used for the assessment of C factor [15]. The Normalized Difference Vegetation Index (NDVI), an indicator of the vegetation vigour and health along with vegetation data, is used along with the following formula to generate the Cfactor value image for the study area [16].

$$C = \exp\left[-\alpha \cdot \frac{NDVI}{(\beta - NDVI)}\right]$$

where α and β are unit less parameters that determine the shape of the curve relating to NDVI and the C factor. [17] found that this scaling approach gave better results than assuming a linear relationship and the values of 2 and 1 were selected for the parameters α and β respectively. The values of C factor can vary from 0 for very well protected soils to 1.5 for finely tilled, ridged surfaces that produce much runoff, leaving it susceptible to rill erosion.

The P factor is a soil management factor and is closely related to the land cover and slope factor. It is the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to that with straight-row farming up and down the slope. The values are assigned based on field observations and data generated from the satellite images. The value of P factor generally ranges from 0 to 1, the value approaching to 0 indicates good conservation practice and the value approaching 1 indicates poor conservation practice.

In the present analysis, Survey of India toposheets (58H2, 58H3, 58H6) on 1:50000 scale, Landsat 8 image, monthly rainfall, DEM, field level data and soil texture data were used to generate the parameters that are needed for running the RUSLE. With the aid of spatial analyst extension in Arc GIS 9.3, each thematic layer for the RUSLE model was overlaid on the respective map layers. The output map showed the distribution of soil erosion for the sub watersheds of Neyyar

P

basin.

Predicted soil loss was classified into soil erosion risk classes *viz*., 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

In the present research, the annual soil was calculated and erosion risk map was generated for three sub- watersheds of Neyyar river basin. The results pertaining to various input factors of RUSLE and soil loss estimation are depicted and discussed appropriately.

3.1. Rainfall runoff erosivity (R) factor

The mean annual precipitation and R-factor presented in the table 2 revealed that the annual erosivity index (R) for Neyyar watershed (990.8) was higher compared to that of Mullayar (974.7) and Chittar (963.2) watersheds due to higher average annual rainfall of 1748.5 mm received in Neyyar watershed. These values are used to predict average annual soil loss from the respective watersheds. The distribution of erosion index values clearly indicated that most of the erosive rain occurs during south west monsoon period in all the three watersheds in conformity with results of [19].

Table 2. R-factor and average annual rainfall in the watersheds

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

3.2 Soil erodibility (K) factor

The soil erodibility parameter is based on the soil texture, structure, organic matter, and even permeability. The K-factor used for the estimation of average annual soil loss in the selected watersheds are presented in table 3. The K-factors observed were 0.449, 0.392 and 0.159 for loamy sand, sandy clay loam and clay loam soil types, respectively in Mullayar, Neyyar and Cittar watersheds. Organic matter in the soil influences the aggregation of soil particles into stable soil structure. Soils with less than 3.5 per cent organic matter are considered to be erodible. Higher K-factor (0.449) was observed in Mullayar watershed indicating higher susceptibility of these soils to erosion. The reason might be the low organic carbon status observed in surface samples of the watershed.

Table 3. K-factor for different soils of the selected watersheds

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

3.3. Length and steepness of slope (LS) factor

The major slope steepness classes observed in Neyyar watershed were from Level (0-1%) to moderately sloping (5-8% slope). Strong (8-15% slope) and very steep (30-60% slope) sloping areas are very less in Neyyar. The slope classes observed in Mullayar watershed were 0-1, 1-3, ,8-15, 30-60 per cent slope with major portion of the total area was strongly sloping (8-15% slope) followed by very steep (30-60% slope). In Chittar major area is coming under level land (0-1% slope) to moderately sloping (5-8%) classes. Strongly steep (8-15% slope) and very steep (30-60% slope) topography was observed in very limited area. While comparing the three watersheds, nearly level to gently sloping topography was more in Neyyar and Chittar watersheds, strong to very steep sloping topography was more in Mullayar watershed indicating the possibility of higher soil loss from Mullayar watershed.

3.4. Cover management(C) and conservation practise (P) factor

The land use land cover (LULC) classes obtained from remote sensing imagery were used for assigning C and P factor values. The majority of area in Mullayar watershed (9641 ha) is under forest whereas in Neyyar (3401 ha) and Chittar (6248 ha) majority of area is under agriculture land use which accounting for 76, 73 and 77 % of total area respectively. Barren rock occupies 9.7 percent of total area in Mullayar and waste land accounts to 2.5 and 3.7 percent of total area in Neyyar and Chittar respectively.

The C value assigned to agricultural land use in Mullayar, Neyyar and Chittar watersheds were 0.3, 0.2 and 0.4 respectively (Table 4). Whereas, C value of 1.0 was assigned to barren rocks, forest and wastelands in the watersheds. The C value assigned was in accordance with [20] who assigned C value between 0.30 and 1.0. As such no mechanical or biological measures are adopted in forest area; a conservation practice (P) factor value of 1.0 was assigned to forest land, barren rock and wastelands. Based on runoff, erosion and field management practices such as field bunds, terrace farming and across slope farming in watersheds, P factor values were assigned from 0.3 to 1.0. The agriculture lands were assigned the P values 0.3 to 0.5 based on management practices.

Table 4. C and P factors for different land use classes in the watersheds

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

3.5 Soil loss and erosion risk assessment

The predicted soil loss in the selected sub- watershed areas using USLE is presented in table 5. Major portion (38.3%) of Mullayar watershed recorded average annual soil loss of < 10 t ha^{-1} yr^{-1} as it constitutes nearly level lands with slope <3%. Moderate (10-15 t ha^{-1} yr^{-1}) and moderately high (15-20 t ha^{-1} yr^{-1}) rate of soil loss was observed in 25.8 % and 19.3 % of total area.[21] also observed very slight (0–5 t ha^{-1} yr^{-1}) and slight (5–10 t ha^{-1} yr^{-1}) soil erosion in the flat areas in the Deccan plateau of Karnataka. The entire watershed is categorized into low to high erosion risk rating class which might be because of varying amount of average annual rainfall received in that area and slope being 1-3%, 8-15% and 30-60% in major areas (Fig. 2).

The spatial distribution of low soil erosion risk class (10 t ha^{-1} yr^{-1}) and moderate (10-15 t ha^{-1} yr^{-1}) observed in 45.8 % and 28.9 % of area in Neyyar watershed respectively is associated with areas of topography level (0-1% slope) to moderately sloping (5-8% slope). The reason might be the steepness of slope and intensive agriculture (3401 ha) in that area. The results of the study are in agreement with those reported for steep slope [22] and for intense cultivation [23]. The nearly level land with < 1 per cent slope had shown very low soil erosion risk (45.8% of total area). (Fig. 3)

The results of the mapping of potential soil erosion in Chittar watershed revealed that about 30% of the total area (2500 ha) was affected by moderately high to very high erosion risk class (Fig. 4). The high erosion was because of intense rainfall, strong (8-15 % slope) to very steep (30-60% slope) topography and land use/ land cover. Of all the factors, the high R factor (rainfall erosivity) of 963.2 in Chittar watershed appears to be an important factor contributing to the amount of soil eroded. Very low soil erosion risk class observed was with slope class of 0-1%. Whereas, nearly level land (1-3% slope) was observed to cause 5-10 t ha^{-1} yr^{-1} of annual soil loss (low soil erosion risk) under agricultural land and high soil erosion risk under forest land use. The reason might be the conservation measures being practiced in the agricultural land in that area. Only 8.92% of the total area was subjected to very high erosion risk and it was concentrated in waste land area. This may be attributed to high rainfall intensity and steeper slopes in the watershed.

Table 5. Estimated rate of soil loss in the selected sub-watersheds of Neyyar basin

Sl. No.	Average annual soil loss (t ha^{-1} yr^{-1})	Soil 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

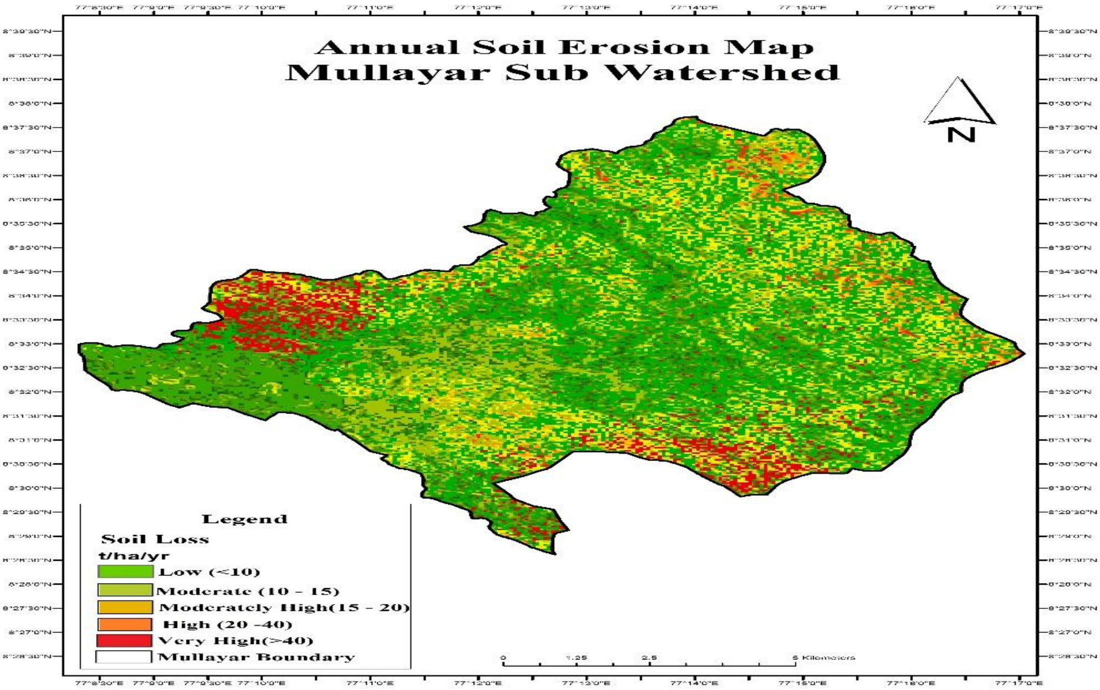

Fig.2. Soil loss and erosion risk map of Mullayar watershed

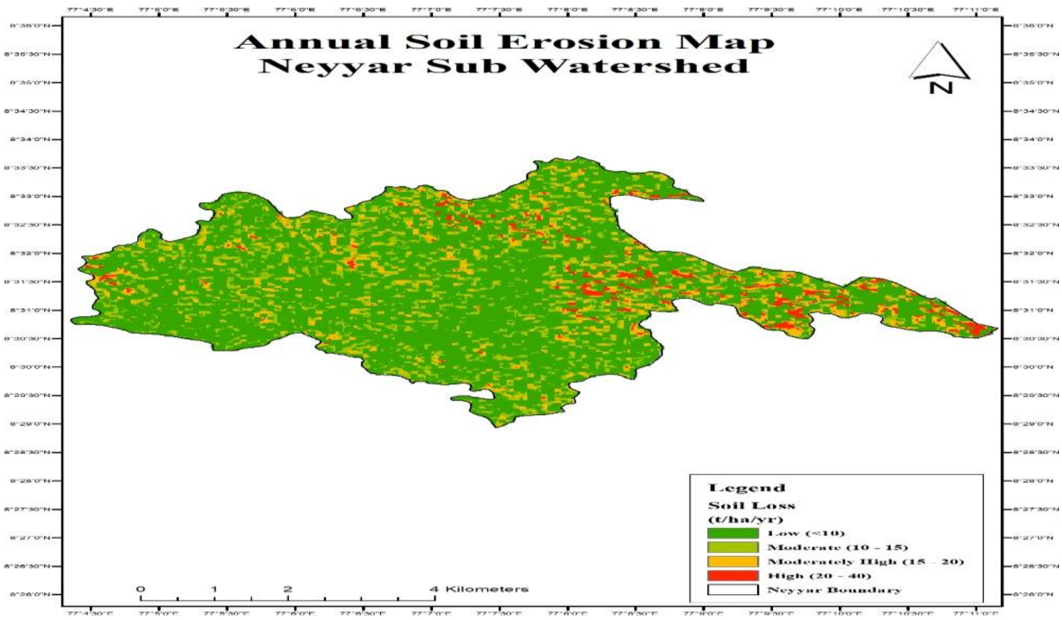

Fig.3. Soil loss and erosion risk map of Neyyar watershed

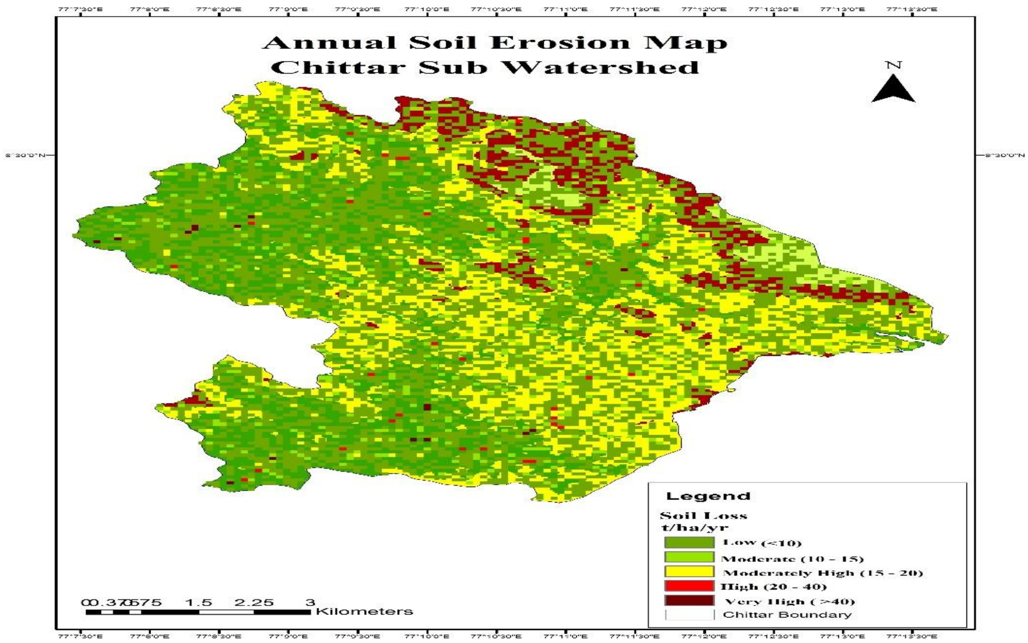

Fig.4. Soil loss and erosion risk map of Chittar watershed

4. CONCLUSION

A quantitative assessment of average annual soil loss for Mullyar, Neyyar and Cittar sub-watersheds of Neyyar river basin was made with GIS based RUSLE equation considering rainfall, soil, land use and topographic datasets. High intensity rains during monsoon season when there is no crop cover, low organic carbon in these soils and lack of adoption of soil conservation measures by farmers are the common causes of soil erosion across the watersheds. The soil loss determined using RUSLE with overlapping influence of different components indicated that the the annual soil erosion was more in Mullayar watershed than in Chittar and Neyyar watersheds due to slope and land use characteristics despite higher rainfall. The land use pattern in areas prone to soil erosion indicates that areas with natural forest cover have a minimum rate of soil erosion while areas with agriculture and human intervention have a high rate of soil erosion. Terrain alterations along with high LS-factor and rainfall prompt these areas to be more susceptible to soil erosion. It is understood that functions of C and P are factors that can be controlled and thus can greatly reduce soil loss through management and conservational measures. The predicted amount of soil loss and its spatial distribution can provide a basis for comprehensive management and sustainable land use for the watershed. The areas with high and severe soil erosion warrant special priority for the implementation of control measures.

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