GEOMATICS MODEL OF SOIL EROSION IN CHITTAR SUB-WATERSED, VAMANAPURAM RIVER BASIN, KERALA, INDIA

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Abstract - *Now a day's soil erosion becomes a dangerous land degradation problem. Due to the indiscriminate human activities it accelerates day by day. This negative impact largely affects natural resources. That's why Assessment of soil erosion is mandatory. The main objective of this study is the prediction soil erosion in the Chittar Sub watershed of Vamanapuram River basin, Kerala, India using GIS tools and Remote Sensing data. A mathematical model called Revised Universal Soil Loss Equation (RUSLE) was applied in this study for the analysis. The analysis shows that nearly 3.9 % of the watershed area devoid of any erosion, whereas 77% of the falls under low level of erosion risk;.while remaining areas are under moderate to very high erosion risk. Very high zone covers about 1.2 % of the basin area. The final map of annual soil erosion shows a maximum soil loss of 227.74 t/ha/yr and an average soil erosion of about 6.1 t/ha/yr in the Chittar sub-water shed. Prediction of Soil erosion by using GIS and remote sensing couple is considerably reliable and time saving process.*

Key Words: **GIS, Rainfall, Remote Sensing, RUSLE, Soil erodiblity, Soil erosion**

1. INTRODUCTION

Since the last century, accelerated soil erosion via human activities has become a dangerous ecological problem. It is one of the most serious issues that we are facing today. Soil loss is the volume of soil lost in a specified time period over an area of land, which has experienced net soil loss. Studies show that about 75 billion tons of soil loss occurred from land, which is about 13-40 times which is faster than the natural rate of erosion. Compared to other continents, Asia has higher soil erosion rate in the range of [1] about 74t/ha/yr [2]. About 5334 m-tons of soil are being removed annually due to various reasons in India [3, 4]. Due to undulating topography, Kerala is facing serious problems of soil erosion. Soil loss affects the soil quality, structure, texture and stability. Human activities have raised erosion rate by 10–40 times globally. Human operations like land modification, construction activities, deforestation etc. are the main reasons of soil loss. Erosion is a natural geological process resulting from the removal of soil particles by water or wind, transporting them elsewhere. Impact of slope and aspect cause a major effect on erosion process. As the slope increases the tendency of erosion along the slope increases. The soil loss from an agricultural area may be reflected in reduced crop production potential, lower surface quality and damaged drainage networks. Soil erosion is not always as apparent as the on-site effects.

India is blessed with lot of water resources such as rivers, lakes, glaciers etc. Mainly two types of agents cause soil erosion, which are water and wind. Among that 90% of the soil erosion is due to water, considering the cause of erosion due to water, where soil particles are either removed by impacting raindrops or run-off water moving over soil surface. Water during heavy rains remove a lot of top soil. When rain drops strike the surface, sands and silts are removed from the soil platform and it is called splash erosion. Detachment of soil particles by winds is named as wind erosion. Soils of low water content and soils having no plant cover have also more tendencies to erosion [5].

Remote sensing (RS) and geographic information systems (GIS) are important tools in hydrological analysis and natural resource management. The RS-GIS enable manipulation of spatial data of various types. The coupled use of GIS-RS produces fair estimates of soil loss based on different models. In 1965, Wischmeier and Smith [6] developed a mathematical model called Universal Soil Loss Equation (USLE) for predicting soil erosion, which estimates long term average annual soil loss. They modified this model in 1978 and since then the model is called Revised Universal Soil Loss Equation (RUSLE). RUSLE has widely been used for both agriculture and forest watersheds.

The objective of this work is to develop soil erosion severity map using RUSLE in the GIS platform.

2. STUDY AREA AND DATA SOURCES

2.1 Study Area

Study area, the Chittar sub basin (CSB), is a sub watershed of Vamanapuram River Basin (order=6; area = 787.0 km2;

Fig.1) of Thiruvananthapuram Dist., Kerala. CSB, with a catchment of 110.3 km^2 and main stem length of 57 km., (bounds N.Lat. 8° 42' 24'' and 8° 49' 15'' and E. Long. 76°58' 24'' and 77°6' 45'') is located at the northeastern part of Thiruvananthapuram District, while a small part falls in adjoining Kollam District to the north. The CSB, originating from Madamukalilkunnu North West of Kadakkal village in Chadayamangalam Block of Kollam district, flows southerly through Kilimanoor Block of Thiruvananthapuram District before joining with Vamanapuram river at Munnumukku in Kallara Panchayat. From the place of origin, river flows through rugged terrain of the Western Ghats and subsequently merges with Vamanapuram River. The CSB receives several non- perennial tributaries before joining the Vamanapuram River.

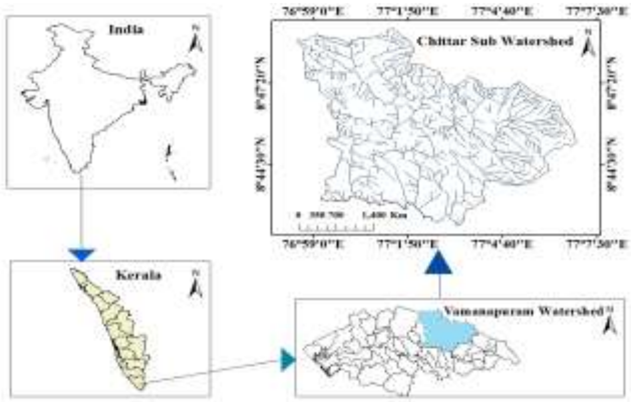

Fig -1: Location map- Chittar sub basin

2.2 Data

From ASTERG-DEM data (downloaded from www.earthexplorer.usgs.gov) or thematic maps of slope, aspect, contours and drainage network have been created in ArcGIS 10.2.

Fig.2 is a colorized DEM of the study area (30 m pixel resolution). Rainfall data for 2013 to 2017 came from IMD, India, while others such as Soil data and satellite images used in the study are shown in Table 1.

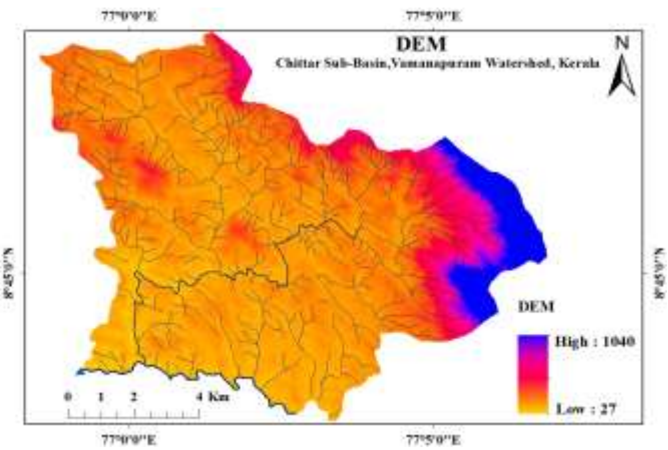

Fig -2: Colorised DEM, CSB

Table -1: Data Types and sources/sites

No	Type	Site/Source	Description
1	DEM	www.earthexplorer.usgs.gov	ASTER-G-DEM(30m resolution)
2	Satellite Image	www.earthexplorer.usgs.gov	Sentinel-2 imagery
3	Rainfall	IMD, India	5 y (2013-2017) for rain gauge station
4	Soil Data	Soil atlas of Kerala	Soil types

3. METHODOLOGY

RSLE model works based on certain specific factors, such as Rainfall erosivity factor (R), Soil erodiblity factor (K), Slope length and steepness factor (LS), Crop management factor (C), and conservation practice factor (P), which are either derived from RS data or through conventional data collection systems.

The RUSLE equation can be expressed as follows

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

where, A is the annual average soil loss expressed as (t/ha/yr), R is rainfall erosivity factor (MJ mm/ha/h/yr), K is the soil erodiblity factor (t ha h/ha/MJ/mm); LS is slope length and steepness facto(r (dimensionless) and finally C is the cover management factor(also dimensionless).

3.1 Rainfall Erosivity factor (R)

R factor reflects the effect of rainfall intensity on soil erosion, and requires detailed, continuous precipitation data for its calculation [6]. R factor is defined as the long term average of the product of total rainfall energy (E) and the maximum 30 min rainfall intensity (I30) for storm events. The numerical value of R quantifies the effect of raindrop impact and reflects the amount and rate of runoff associated with the rain [6, 7]. 5 yr rainfall data came from IMD sources.

Computation of R factor for a given study requires high-resolution pluviograph data for at least 20 yr and in the absence of sufficient data, several simplified models have been proposed to estimate the rainfall erosivity using correlation between R factor and monthly and annual rainfall. Since E and I30 data for the study area are not available, the R factor was calculated using the modified Fournier index (F) defined as [8]:

$$F=\sum_{i=1}^{12} [(P_i)^2 / P] \text{ .... (2)}$$

where, Pi is monthly rainfall (in mm) and P is the annual rainfall (in mm). According to Arnolodus [8], the F index is a good approximation of R to which it is linearly correlated and various researchers used regression relationship for estimation of local erosivity values. In order to account for the spatial variability of R factor, monthly rainfall data of 5 years (2013-2017) were used to calculate the *R* factor [8].

R factor is computed as:

$$\text{R factor} = 0.264 * F^{1.5} \quad \ldots\ldots\ldots (3)$$

Rainfall erosivity map (Fig. 3) prepared by rainfall data collected from Rain gauge station located in Nedumangadu village office (8°36' N and 77° 00' E), Trivandrum. Since there is only one rain gauge station for collecting whole Vamanapuram basin rain fall data a single R factor value could be inserted in the map. Fig.3 shows the rainfall erosivity map.

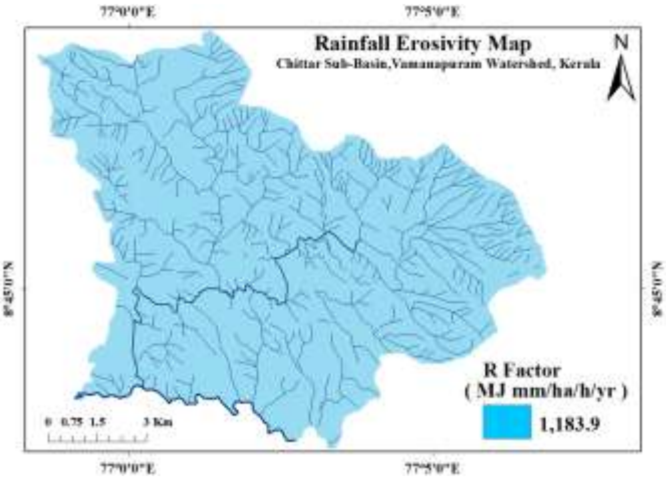

Fig -3: Rainfall Erosivity, CSB

3.2 Soil Erodibility factor (K)

Soil erodibility factor, K, *(*Fig.4) depends on the soil texture. There are only three typ es of soil in the CSB such as clay, loam and gravelly clay. Soil erodibility (K) is the tendency of a soil to erosion by runoff and raindrop impact. K factor determined, based on its texture, viz., % silt plus very fine sand, % sand, % organic matter, soil structure, and permeability [9].

$$K_{fact} = (1.292) \times (2.1\text{x}10^{-6} f_p^{1.14} (12 - P_{om}) + 0.0325(S_{stuct}2) + 0.025\,(f_{perm} - 3)) \quad \ldots\ldots (4)$$

Where, $f_p = P_{Silt}\,(100 - P_{Clay})$ ………. (5)

f_p = Particle size parameter (dimensionless)

P_{om} =organic matter

+$P_{Clay=}$ Permeablity of clay (dimensionless)

S_{stuct} =Structure index, where (1) very structured, (2) fairly structured, (3) moderate, (4) moderate to slow, (5) slow and (6) very slow

f_{perm} = profile permeability code, where (1) rapid, (2) moderate to rapid, (3) moderate, (4) moderate to slow, (5) slow and (6) very slow

Eq. 4, is modified to yield result in metric units used in this report. Generally K values range from 0.0 to 1.0

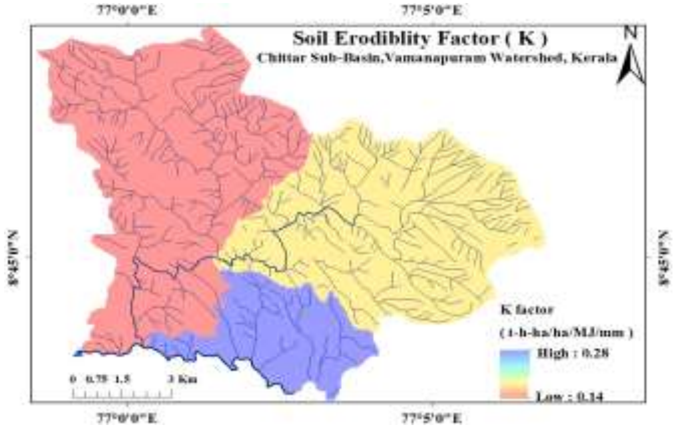

Fig -4: Soil Erodiblity, CSB

3.3 Topographic factor (LS)

Topographic factor includes two elements, viz., slope length (L) and slope steepness (S). Slope, a crucial factor, has a direct effect on soil erosion. As slope length / steepness increases, soil erosion increases severely. From flow accumulation and slope map (Fig.5) the LS factor can be calculated as:

$$LS = ([\text{flow accumulation}] \text{ x cell size}/22.13)^{0.6} \text{ x } (\sin \text{slope}] \text{ x } 0.01745/0.0896)^{1.3} \text{x} 1.4) \quad \ldots\ldots (7)$$

Where, flow accumulation indicates the accumulated upslope consists of area for a given cell. LS is the topographic factor (Fig.6). Cell size is 30.0 m and slope is the sine of slope in degree.

Fig -5: Slope (in degree), CSB

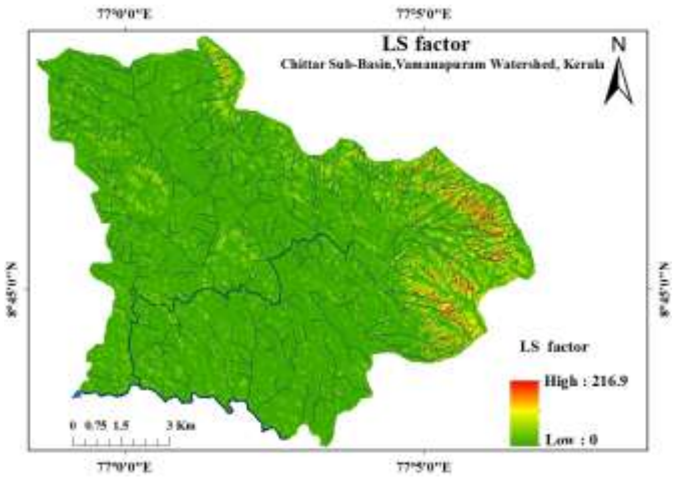

Fig -6: LS Factor, CSB

3.4 Crop management factor (C)

The C factor is the ratio of soil loss from crop land under specific conditions to the corresponding loss from clean tilled, continuous fallow [6]. Since C-factors are not available for most Indian crops, the C-factors used by Karaburun [10] are used to indicate the effect of cropping and mangement practices on soil erosion rates. The effects of vegetation canopy and ground covers on reducing soil erosion in forested regions [7] vary with seasons and crop production system. C-factor on soil erosion is calculated as: [8, 11, 12]

$$c=e^{\wedge}([-\alpha\, NDVI/(\beta - NDVI)]) \quad ...... (8)$$

where, α, β are unit less parameters and it determines the shape of curve relating to Normalised Difference Vegetation Index (NDVI)and C factor. Values provided are 2 and 1 [13] Estimated NDVI values (see NDVI map Fig 7) are in the range of -0.4 to 0.71.

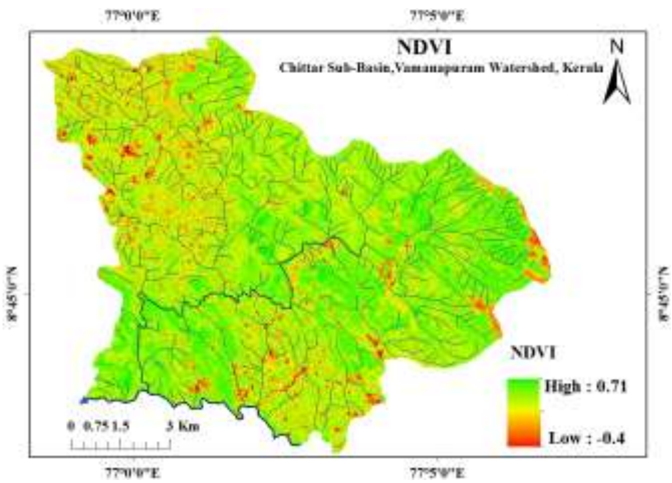

Fig -7: NDVI, CSB

Fig -8: Land use-Land cover, CSB

The crop management factor (Fig 9), estimated from the land use-land cover (LULC) map (Fig. 8), derived from supervised classification of Sentinel 2 image (analysed using ERDAS Imagine 4.0 software), falls under four types, viz., paddy, forest area/vegetation, built-up land and plantation.

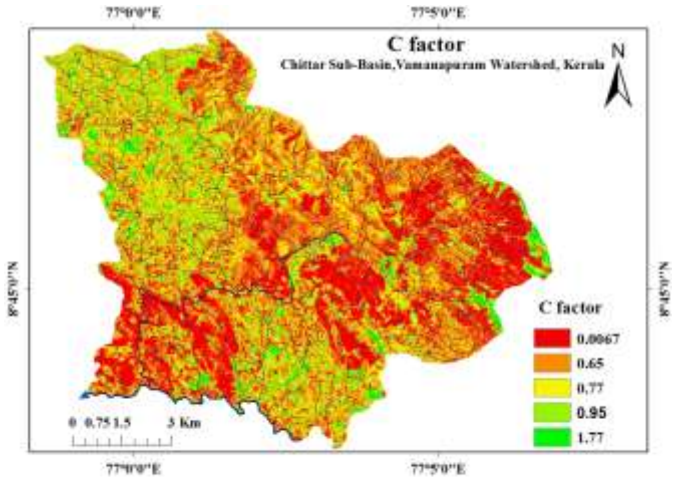

Fig -9: Crop Management factor, CSB

3.5 Conservation support practice factor (P)

The conservation practice factor (P) (Fig.10) defined as the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. 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.

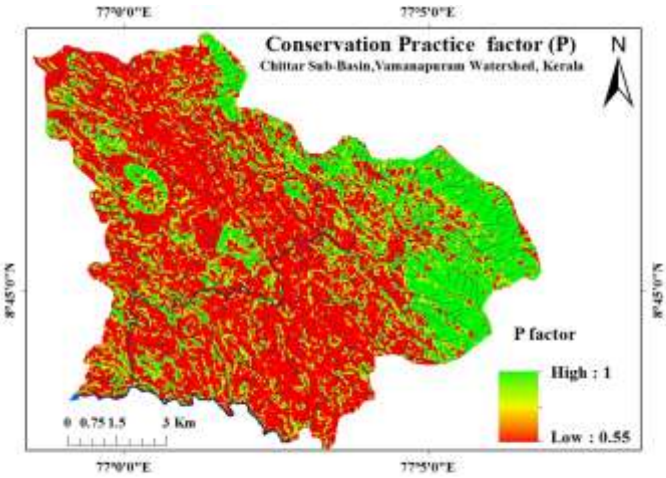

Fig -10: Conservation support factor

4. RESULTS AND DISCUSSIONS

4.1 Rainfall erosivity factor (R)

Many studies [14, 15] showed that the soil erosion rate in a catchment is more sensitive to rainfall. The daily rainfall is a better indicator of variation in the rate of soil erosion to characterize the seasonal distribution of sediment yield. The advantages of using annual rainfall are ready availability, ease of computation and greater regional consistency of the exponent [16]. Therefore, in the present analysis, average annual rainfall was used for R factor calculation. The average R factor value is 1183.9 MJ mm ha/hr/year.

4.2 **Soil Erodibility factor (K)**

The values of K factor range between 0.14 and 0.28. The lower value of K factor indicates the soils having low permeability, low antecedent moisture content, etc. Soil erodibility values nearer to 0 are less prone to soil erosion.

4.3 Topographic factor (LS)

LS factor was calculated by considering the Flow accumulation and slope in degree as inputs. From the analysis, it is observed that the value of topographic factor is in the range of 0 to 216.96 as the flow accumulation and slope increases.

4.4 Crop management factor (C)

The CSB has been classified into four land use classes. Crop management factor was allocated to different land use types. Using LULC map and C factor value, the C factor map was prepared. C values range from 0 to 1.7.

4.5 Conservation support practice factor (P)

Since there is a lack of field data regarding the conservation practices that have been taken place in the CSB, P values were assigned based on the literature [17,18] -Plantation -0.5, Vegetation -1, forest-1,Built up-0.3, and paddy as 0.5.

4.6 **Soil erosion probability zones**

Fig.11 shows the annual soil loss of the CSB produced by overlay analysis of five parameters (K, R, LS, C and P) and using raster calculator (geoprocessing tools) in Arc GIS environment. The soil erosion probability zones have been categorized into four types viz., low, medium, high and very high erosion. In Fig 10, it is observed that nearly 3.9 % of the basin area produces no erosion, whereas 77% of the study area is classified as one of low potential erosion risk, .while the remainder is under moderate to very high erosion risk. Very high zone covers about 1.2 % of the basin area. The final map of annual soil erosion shows a maximum soil loss of 227.74 t/ha/yr and average soil erosion about 6.1 t/ha/yr. Soil erosion results are summarised in Table 2

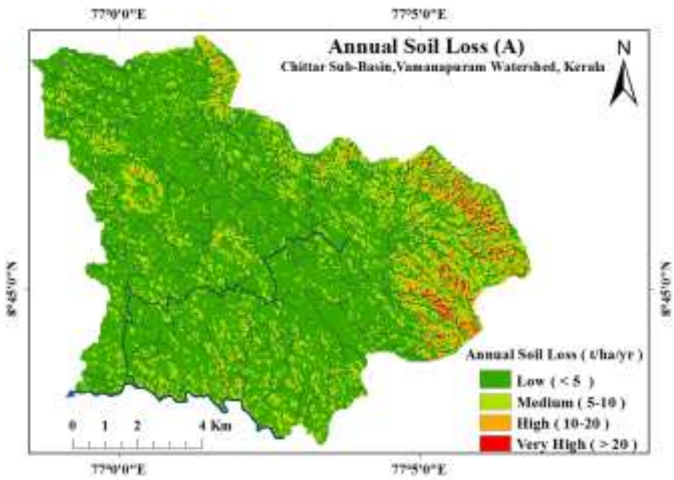

Fig -11: Soil erosion map

Table -2: Soil erosion severity zonesCSB

Erosion Risk Class	Gross Erosion (t/ha/yr)	Area (km²)	Area (%)
Nil	0	4.3	3.9
Low	0-5	84.9	77
Medium	5-10	12.4	11.2
High	10-20	7.4	6.7
Very High	>20	1.3	1.2

5. CONCLUSION

Soil loss in the CSB of the Vamanapuram River basin, Kerala has been assessed with the tools in Arc GIS 10.2, ERDAS IMAGINE 2013 and RUSLE. Empirical soil erosion models, though relatively simple, are easy to interpret physically, require minimal resources and can be worked out with readily available inputs to precisely predict the areas exposed to high erosion risk. This paper demonstrates the application of empirical soil erosion model such as RUSLE integrated with GIS to estimate soil erosion potential and the potential zones in CSB. The analysis suggests that the annual soil loss estimated using RUSLE model, is about 227.74 t/ha/yr. By analyzing the impact of increase in crop land on soil erosion, it can be concluded that areas with higher slopes, cause high erosion. The study helps in assessing the erosion impact of various cropping systems and conservation support practices.

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