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Soil Erosion Estimation of Kuttiyadi River Basin Using RUSLE

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Abstract: The study integrates the Revised Universal Soil Loss Equation (RUSLE) with Geographic Information System (GIS) to model the erosion potential within a tropical river system, Kuttiyadi in Kozhikode. Soil erosion was estimated for the year 2006 and the maximum value found to be 3470 t/ ha. Soil eroded from the whole area accounts to about 1.2 Mt. The spatial erosion map prepared could be used for planning and modifying erosion management measures in the sensitive mountainous region.

Keywords: DEM, GIS, RUSLE, Sediment yield, Soil Erosion.

I. INTRODUCTION

Soil erosion by water is a highly significant and threatening spatiotemporal phenomenon throughout the world. It is the process of detachment and transportation of surface soil particles from original location and accumulation of it to a new area. Soil erosion as "soil cancer", is complex due to its multiple obvious and hidden social and environmental impacts [1]. It is figured out that in India, about 53% of the total land area is prone to erosion and about 5334 metric tons of soil is being detached annually due to various reasons [2]. The main issues associated with soil erosion include decreased soil fertility and productivity, risk to food security, declined aesthetic landscape beauty, increase in the probability of flood in flood plains, reduced quality of water and transformation of land into fallow land not suitable for reforestation.

Due to the large areal extent of many catchments and requirement of huge amount of data, Remote sensing and GIS techniques have become valuable tools while assessing erosion at large scales. These techniques have been widely adopted and there are several studies that show the potential of remote sensing techniques integrated with GIS in soil erosion mapping [1] - [4].

To predict soil erosion numerous models have been developed over the past few decades, utilising different scientific methods and modelling approaches. These models are mathematical representation of natural processes that influence primarily the movement of water and soil of a watershed. In general, these models are categorized depending on the data requirement, physical processes simulated by the model, and the model algorithms used to describe these processes.

In the present study, soil erosion of Kuttiyadi river basin in the Western Ghats estimated for the year 2006 using RUSLE Model in GIS platform. It is an empirical model having strong physical support. It groups numerous physical and management parameters into five factors.

They are soil erodibility factor (K), topographic factor (LS), cover management factor (C), support practice factor (P) and rainfall erosivity factor (R) using datasets of rainfall pattern, soil type, topography, crop cover and management practices. The data sources used for the generation of RUSLE model input factors were stored as raster layers in the ArcGIS software. Potential annual soil loss is estimated as the product of factors (R, K, LS, C and P) using spatial analyst extension of Arc GIS software.

II. STUDY AREA

The Kuttiyadi River as in Fig. 1 is also known as the Murat River located in Northern Kerala having length of about 74 km. The River encompasses an area of 583 km^2. It originates from Narikotta in Western Ghats at an elevation of 1220 m (msl) and flow towards west then joins the Lakshadweep Sea near Vadakara. It is a sixth order basin and has maximum relief and gradients in the eastern part. The River flows through Badagara, Koyilandy and Kozhikode Taluks. The main tributaries are Onipuzha, Thottilpalampuzha, Kadiyangadupuzha, Mannathilpuzha and Madappallipuzha. Agricultural crops occupy most of the study area followed by deciduous and evergreen forest cover in the upper reaches. Clay is the dominant soil type followed by sandy clay as per the textural classification, USDA [5]. Geologically, the area is underlain by hard rocks of Archean age forming part of peninsular shield. Charnockites forms the dominant rock type in the mid land region. Fluvial and marine sediments cover the coastal stretch. Geomorphologially, the area consists of lower plateau (laterite), young coastal plain, valley, flood plain and river channel.

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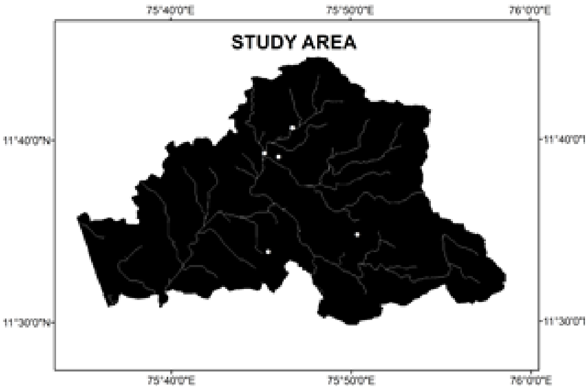

Fig.1. Study Area

III. MATERIALS AND METHODOLOGY

A. Soil Erosion Modelling

The Universal Soil Loss Equation (USLE) is the most widely applied soil erosion model due to its simplicity. However, the model has been criticized as inefficient especially for areas outside the USA [6]. Several modifications were done in the USLE model to generate Revised Universal Soil Loss Equation (RUSLE) [7]. RUSLE contains the same factors as USLE, but all the equations used to obtain factor values have been revised. The equation used in RUSLE Model is given below, "(1)"

$$A=R\times K\times LS\times C\times P \qquad (1)$$

Where,
A= Average annual soil loss (t/ha)
R= rainfall runoff erosivity factor (MJ/ha.mm/h)
K = soil erodibility factor (t ha h/ha/MJ/mm)
LS = slope length /topographic/steepness factor
C = cover & crop management factor
P = supporting practice (land use) factor

The RUSLE model has been widely used for both agricultural and forest watersheds to predict the soil loss. The datasets necessary for this model is relatively lower than most other methods. The model was integrated in GIS environment for the calculation of specific factors and annual soil loss for the area under investigation. The climatic and terrain factors used in the equation were derived from monthly rainfall, Landsat 8 satellite image, soil texture map and Land use/land cover data. The cell size was kept at 30 m X 30 m for all the data generated, in order to make uniform spatial analysis environment in the GIS.

B. Rainfall Erosivity Factor (R)

Rainfall erosivity factor is a numerical description of the potential of rainfall to erode soil in an area. It is defined as the long-term average product of the total rainfall energy (E) and the maximum 30 min rainfall intensity (I_{30}) for storm events [8, 9]. Due to the dearth in data for rainfall intensity and storm kinetic energy for the study area, monthly rainfall data were used to estimate the R factor using the relationship developed by Wischmeierand Smith [8] (modified by Arnoldus [9]) is given below as "(2)".

$$R = \sum_{i=1}^{12} \frac{P_i^2}{P} \qquad (2)$$

where, R is the rainfall erosivity factor (MJ/ha/mm/h), Pi is the monthly rainfall (mm) and P is the annual rainfall (mm).

C. Soil Erodability Factor (K)

Erodibility of soil is its resistance to both detachment and transport. On account of thick-forested nature of whole of the watershed, detailed field surveys of soils in the area were not possible. So, soil series map was collected from the Soil Conservation Department, Kerala, for the preparation of K factor map. There are 17 soil types present in the study area. The soil types were grouped into four major textural classes. They were clay, sandy clay, sandy loam and sandy clay loam. The corresponding K values for the soil types were identified from the soil erodibility nomograph [10] by considering the particle size, organic matter content and permeability class.

D. Slope Length and Steepness Factor (LS)

Length and steepness of a slope affects the total sediment yield as represented by the LS factor. The parameters such as compaction, consolidation and disturbance of the soil also influence the factor. For the computation of LS Factor proposed by [11], given in "(3)", flow accumulation and slope steepness areconsidered. These were obtained from DEM using ArcGIS Spatial analyst and arc hydro extension.

$$LS = 1.4\,[(\text{flow accumulation x cell size}/22.13)^{0.4} \text{ x } (\sin \text{slope}/0.0896)^{1.3}] \qquad (3)$$

Where, flow accumulation denotes the accumulated upslope contributing area for a given cell and cell size is the size of grid cell (for this study 30 m).

E. Cover Management Factor (C)

The C factor represents the effect of soil disturbing activities, plants, crop sequence and productivity level, soil cover and subsurface biomass on soil erosion. It is defined as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled, continuous fallow land [8]. Since land cover patterns show temporal variations, satellite remote sensing data sets were found to be very suited for the assessment of C factor, as per "(5)" [7]. For the preparation of C factor map, NDVI map was prepared from the satellite image using model maker in ERDAS imagine 2013 to assess the vegetation distribution and health using "(4)".

$$NDVI = (NIR - R) / (NIR + R) \qquad (4)$$

$$C = \exp\,[-\alpha\,(NDVI/\,\beta\text{-}NDVI)] \qquad (5)$$

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where, α and β are unit less parameters with values1 and 2 respectively that determine the shape of the curve relating to NDVI and the C factor. This equation was successfully applied for assessing the C factor of areas with similar terrain and climatic conditions [12].

F. Conservation Practice Factor (P)

The support practice factor (P factor) is the soil-loss ratio with a specific support practice to the corresponding soil loss with up and down slope tillage [9]. In the present study the P factor map was derived from the land use/land cover and support factors. This was then digitized as polygons and then converted into raster format. The values of P factor ranges from 0 to 1, the highest value was assigned to areas with no conservation practices (deciduous forest); the minimum values forbuilt-up-land and plantation area with strip and contour cropping. The lower the P value, the more effective the conservation practices numerically

TABLE I P VALUES FOR VARIOUS LAND USE/LAND COVER CLASSES

CLASS	P VALUE
WATER BODY	0
BUILT UP	0.5
BARE LAND	1
FOREST	1
PADDY	0.25
PLANTATION	0.4

IV. RESULTS AND DISCUSSIONS

The study area received a seasonal rainfall (May-November) of 5045.2 mm and the corresponding R factor value was 866.14MJ mm/ha/h/yr. The soil series of the study area was digitized from the soil map with the help of ArcGIS Software. The soil erodibility factor (K) was then calculated. The estimated K values for the textural groups are 0.1 t ha h/ha//MJ/ mm for sandy clay, 0.14 t ha h/ha/MJ/mm for sandy loam, 0.2 t ha h/ha/MJ/mm for sandy clay loam and 0.24 t ha h/ha /MJ /mm for clay. The K Factor map obtained is shown in Fig.2.

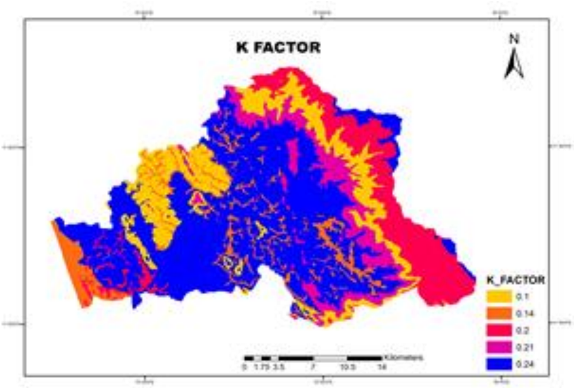

Fig.2. K Factor Map

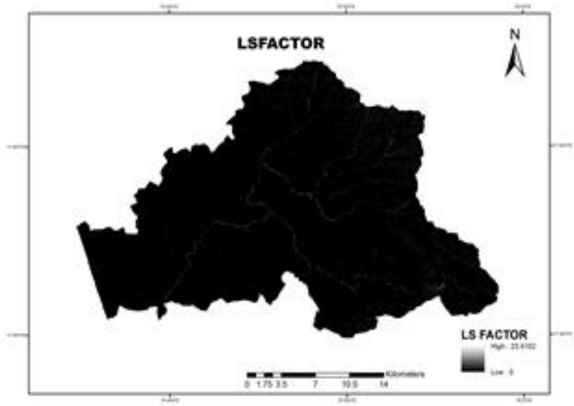

Fig.3. LS Factor Map

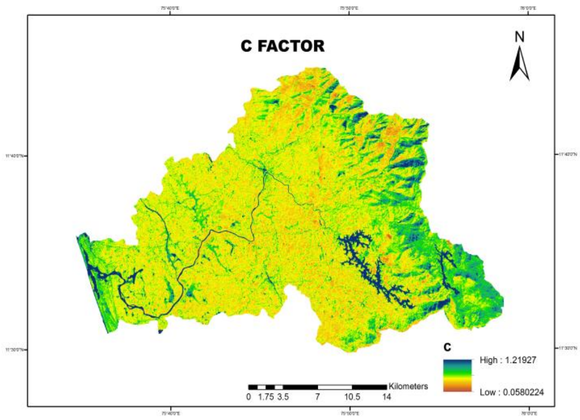

Fig.4. C Factor Map

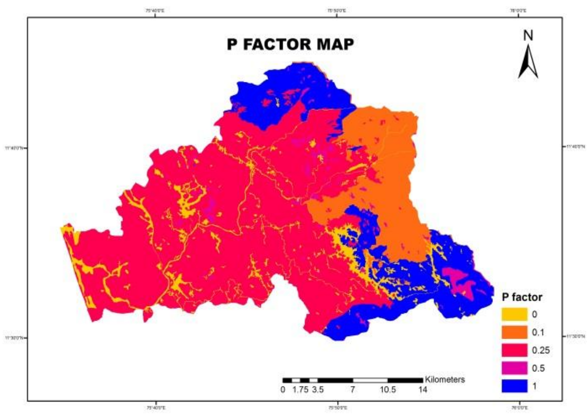

Fig.5. P Factor Map

The LS factor value in the study area varies from 0 to 23.41, with mean and standard deviation of 2.04 and 1.95 respectively. Majority of the study area has LS value less. The map prepared is shown in Fig. 3. NDVI values varied from -0.11 to 0.59. Lower values represent water body and higher values represent vegetation. C factor values range from 0.058 to 1.22. The C Factor map obtained is shown in Fig.4. Support practices factor (P) was assigned based on land use and the land cover map. As shown in Fig. 5, P factor varies from 0 to 1.

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The annual soil loss (t/ha/y) in the catchment for the year 2006 is shown in Fig.5. It shows a maximum value of 3470.1 t /ha/ y. The mean value and standard deviation were 3.11 t/ha/y and 14.93 respectively. Soil eroded from the whole area accounts to about 1.2 Mt. The annual loss values were classed based on Erosion Intensity Classification given by [13] as in Table II. The pie-chart shown in fig.6 shows the relative distribution of the classes. The percentage of land use classes falling under the erosion intensity classes were tabulated and given in Table III.

TABLE II EROSION INTENSITY CLASSIFICATION

Erosion Intensity (t/h/y)	Type
<5	Insignificant Erosion
5-10	Low Erosion
10-25	Moderate Erosion
25-50	High Erosion
50-100	Very High Erosion
>100	Extreme Erosion

A. Figures and Tables

From the soil erosion map it was clear that most of the area in the basin falls in low risk category. High erosion is found in eastern part of the area. It may be due to steeper terrain. Erosion is low in the d/s sections of the basin. From the Table IV, it can be concluded that the estimated values of soil loss depend highly on the LS factor and R factor.

TABLE III VALUE OF DIFFERENT FACTORS

Value	LS	P	K	C	R
Minimum	0	0	0.1	0.058	997.98
Maximum	23.41	1	0.24	1.22	
Mean	0.093	0.348	0.198	0.35	
Standard Deviation	0.318	0.318	0.053	0.13	

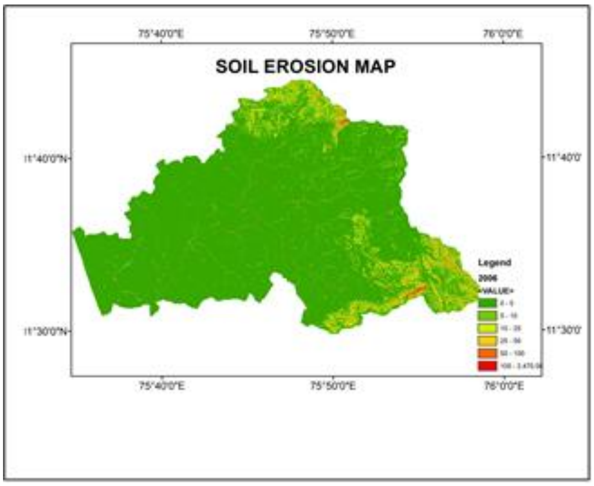

Fig.6. Annual Soil Erosion Map

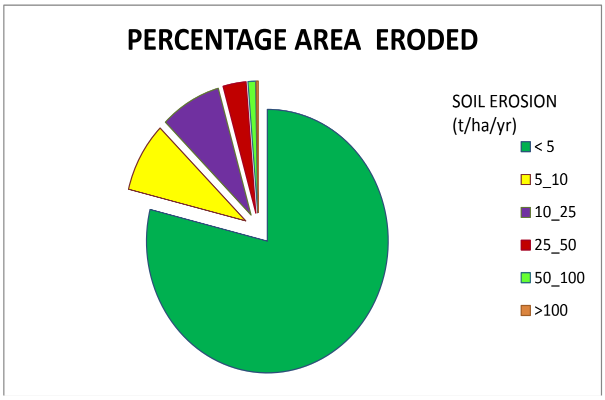

Fig.7. Percentage Area Eroded Under Erosion Risk Classes

V. CONCLUSION

By combining GIS with RUSLE, a comprehensive approach for estimating spatial distribution of soil erosion was presented. Soil erosion estimated for the year 2006 was about 1.2 Mt from the entire catchment. Maximum rate of 3470.1 t/ ha/ y was obtained.

TABLE IV AREA OF LAND USE/LAND COVER TYPES FALLING UNDER EROSION INTENSITY CLASSES

	Insignificant Erosion	Low Erosion	Moderate Erosion	High Erosion	Very High Erosion	Extreme Erosion
Landuse/ land cover classes	% area	% area	% area	% area	% area	% area
Builtup	59.30	11.43	11.12	7.28	5.72	5.16
Waterbody	59.14	11.44	11.13	7.32	5.76	5.21
Forest scrub	78.84	8.59	8.17	3.09	1.02	0.28
Agricultural plantation	66.26	10.14	10.03	5.88	4.15	3.53
Forest evergreen	32.75	15.28	15.46	12.99	11.95	11.57
Agricultural cropland	4.17	19.80	19.90	19.01	18.62	18.50
Forest deciduous	32.72	14.45	13.59	13.15	13.07	13.02
Waste scrub	77.99	8.68	8.27	3.29	1.25	0.52

Soil erosion was found to be less in most of the area in the basin. Rainfall and slope are found to be the main deciding factors of soil erosion in the basin. The soil erosion risk map could be used for both planning and modifying the erosion management measures in the hilly areas.

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