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ASSESSMENT OF SOIL EROSION BASED ON USLE MODEL AND APPLICATION OF GIS

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ABSTRACT

Soil erosion is one of the major ecological troubles which threaten our natural reserves. In developing countries the soil erosion evaluation is tough task mainly because the important data are insufficient or sometime are not accessible. USLE is the most widely used empirical formulae for evaluating gross erosion from any basin. Merging the same with recent technology of remote sensing could provide us with more precise results. The model separates the soil erosion process into a water phase and a sediment part. It considers soil erosion to result from the detachment of soil particles by raindrop impact and the transport of those particles by overland flow. The model tries to cover some of the recent advances in perceptive of erosion processes. In this paper the application of USLE model and GIS, for soil loss estimation has been attempted for Ravi Shankar Sagar Reservoir catchment area, Dhamtari district, Chhattisgarh in Mahanadi river basin. This study was envisaged to map the distribution of soil erosion in the watershed and to compute the average annual soil loss (tones/hectare/year) by combining the USLE method, GIS and Remote Sensing Technique. The results show that the average value of erosion was 22.7 t/ha/yr. The area under very severe soil erosion was 14246 ha.

Keywords: *Soil Erosion, USLE, GIS, Ravishankar Sagar, Mahanadi river.*

INTRODUCTION

The soil has been defined by the International Soil Science Society as: The soil is a limited and irreplaceable resource and the growing degradation and loss of soil means that the expanding population in many parts of the world is pressing this resource to its limits. In its absence the biospheric environments man will collapse with devastating results for humanity. Fertile soils by carrying erosion fills dam reservoir and reduces dams economical life, hence economy of country get debilitated big amount. To specify hazard and damage of soil erosion is very important for this reason (Choudhary and Nayak). Among many environmental hazards, checking land degradation is of utmost importance as it has direct bearing on decline in productivity on arable and non arable lands. It is estimated that about 80 % of current degradation on agricultural land in the world is caused by soil erosion due to water (Angima et.al.). It is estimated that India suffers an annual loss of 13.4 million tones in the production of major cereal, oilseed and pulses crops due to water erosion equivalent to about 2.6 billion dollars (Sharda et.al.). Reservoir sedimentation, resulting from degradation of the watersheds in India is on multiple rises as compared to the rate that was assumed at the time the projects were designed hence the catchment is deteriorated and thus the operational life of reservoir is diminished. Climate, soil, vegetation, topography and man are the factors that affect soil erosion, and out of these vegetation and soil to some extent are the only factors which man can control. To prevent the erosion and rapid siltation, management of water, soil cover and vegetation resources on watershed is must. USLE model and ILWIS GIS has been used for determining the quantity of soil erosion.

STUDY AREA – RAVI SHANKAR SAGAR RESERVOIR

The Ravishankar Sagar reservoir is situated in Dhamtari district of Chhattisgarh state. The reservoir is constructed on river Mahanadi. The Ravishankar Sagar dam is one of the major dams of Multipurpose Mahanadi project, which consists of Pairi, Ravishankar Sagar, Moorumsilli, Dudhawa, Sondur and Sikasar reservoir. The index map of the study area has been presented in Fig 1**.**The location of dam is 20^{0}37’0”N to 81^{0}33’0”E.The Ravishankar Sagar Reservoir supplies annually 61 Mm^3 water to municipal requirements of Dhamtari town and Raipur City. It converted Protective Irrigation of Kharif paddy in about 1,82,500 hectare (1,47,500 hectare in Mahanadi old command and 35,000 hectare New area) to Productive irrigation by providing timely, reliable and equitable supply of water of the land to boost present per hectare Yield of 1.4 tonnes to about 3 tonnes. It expanded irrigation in new area of 1, 56,500 hectare. It also increased the irrigation intensity in the CCA for present 72% to 100% in Kharif and 1% to 35% in Rabi season. Additional agricultural production of 11.95 lakhs tonnes values at Rs.152 Crores at 1990 prices. It generated farm and non-farm employment to about 1,80,000 persons. The mean annual rainfall is 142 cm. About 90% rainfall occurs during the monsoon month (June to September) and the balance 10% is distributed in the winter and summer months.

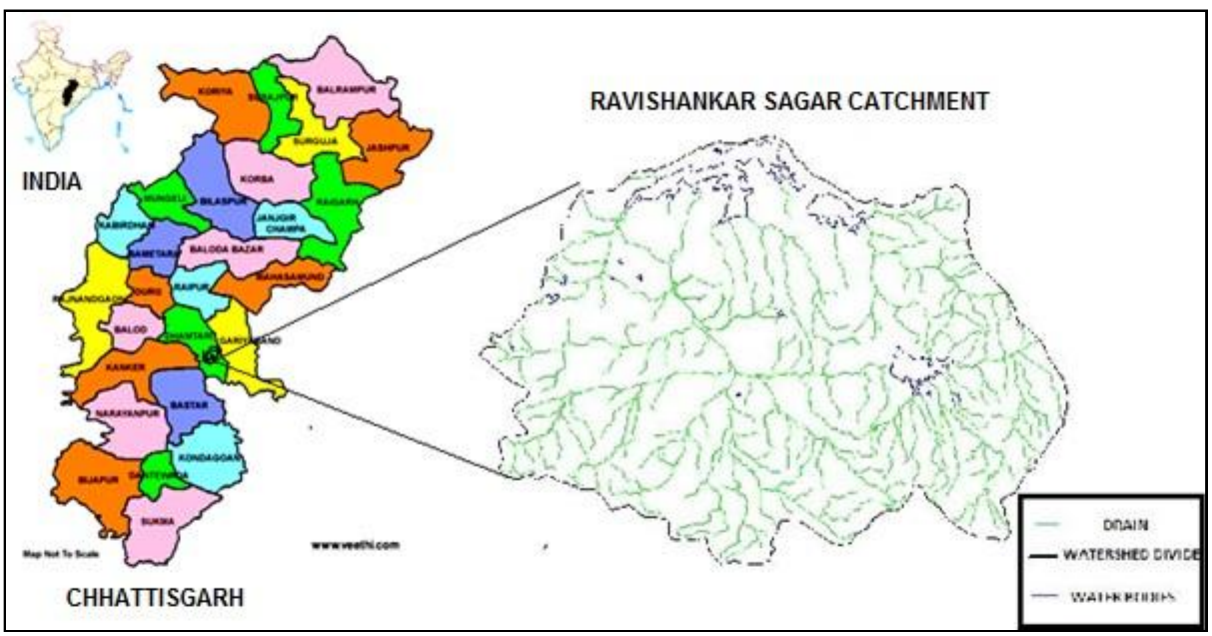

Fig. 1: Index map showing the catchment of Ravishankar Sagar reservoir

METHODOLOGY

In the present study, the well-known model for soil erosion estimation from a watershed, the Universal Soil Loss Equation (USLE) has been used. The thematic maps were prepared using remote sensing imageries and data storage & analysis were done using ILWIS Geographic Information System (GIS).

The Universal Soil Loss Equation Model

In 1958, Wischmeier, a statistician with the Soil Conservation Service, was put in charge of analyzing and collating over 10000 annual records of- erosion on plots and small catchments at 46 stations on the Great Plains. The model with the greatest acceptance and use is the Universal Soil Loss Equation (USLE), developed by Agriculture Research Services (ARS) scientists Wischmeier and D. Smith (1978) to estimate soil erosion from fields. Mathematically the equation is denoted as:

$$\mathbf{A = R * K * L * S * C * P} \qquad (1)$$

A = Annual soil loss (tons/ha/year)
R = Rainfall and runoff erosivity index
K = Soil-erodibility factor
L = Length of slope factor
S = Degree of slope factor
C = Cropping-management factor
P = Conservation practice factor

Rainfall Erosivity index (R)

R, the rainfall erosivity index,is equal to product of E, the kinetic energy of rainfall, and I_{30} (maximum rainfall intensity in 30 minutes expressed in cm per hour). This index corresponds to the potential erosion threat in a given region where sheet erosion appears on a bare plot with a 9% slope. In India, simple relationship between erosivity index (R) and annual or seasonal rainfall (X) has been developed by Singh et al, 1981 after analyzing the data collected from 45 stations distributed in different rainfall zones throughout the country (Choudhary and Nayak).

$$R_a = 79 + 363.079 * X_a \qquad (2)$$
$$R_s = 50 + 389.050 * X_s \qquad (3)$$

For this study seasonal rainfall index i.e R_s is used for R value.

Soil Erodibility Factor (K)

The K factor represents both susceptibility of soil to erode by an amount and rate of runoff. K depends on the texture and organic matter content of the soil, its permeability and profile structure. It varies from 0.7 for the most fragile soil to 0.01 for the most firm soil. It is measured on bare reference plots 22.2 m long on 9% slopes, tilled in the direction of the slope and having received no organic matter for three years (http://www.grr.ulaval.ca). It quantifies the cohesive character of a soil type and its resistance to dislodging and transport (particle size and density dependent) due to raindrop impact and overland flow shear forces. K is a function of complex interaction of a substantial number of its physical and chemical properties. A simpler method to forecast K was presented by Wischmeier et al. which includes the particle size of the soil, organic matter content, soil structure and profile permeability (Wischmeier et.al.).

The Topographic Factor (L & S)

SL, the topographical factor, depends on both the length and gradient of the slope. Value varies from 0.1 to 5 in the regular farming lands, and may reach up to 20 in hilly areas. The slope length and slope steepness can be used in a single index, which expresses the ratio of soil loss as defined by (Wischmeier and Smith 1978).

$$LS = (\lambda/22.1)^{.5} * (0.065 + 0.045\,G + 0.0065G^2) \quad (4)$$

Where λ = slope length (m) and G = percentage slope gradient. Slope percentage layer was derived from digital elevation model (DEM) of the study area and slope length was assumed to be fixed for each pixel (100 m). The values of G and λ will be derived from DEM.

Cropping Management Factor (C)

The plant cover factor, C, is a simple relation between erosion on bare soil and erosion observed under a cropping system. It is the ratio of soil loss from land cropped under specified conditions to corresponding loss under tilled, continuous fallow conditions. It measures the combined effect of vegetation cover and management variables. It varies from 1 on bare soil to 0.001 under forest, 0.02 under grasslands and cover plants, and 1 to 0.9 under root and tuber crops.

Conservation Practice Factor (P)

The conservation practice factor, P, is the ratio of soil support practice to the corresponding loss with up and down slope culture. Practices induced in this term are contouring, terracing (alternate crops on a given slope established on the contour), strip cropping. P is a factor that takes account of specific erosion control practices such as contour tilling or, contour ridging or mounding. Value varies from 1 on bare soil with no erosion control to about 0.25 with tied ridging on a gentle slope.

Application of ILWIS GIS Tool

The Integrated Land and Water Information System (ILWIS) has the capability of analyzing the Remote Sensing (RS) data as well as Geographic Information System (GIS). ILWIS multiplies the map by overlaying these maps one over another. Hence it becomes very essential for all maps to be rasterized with same pixel size. All the factors required for soil erosion estimation as given in the equation 1 were calculated using ILWIS GIS software and stored as thematic maps in raster format. These maps were then multiplied together to generate the soil erosion map using Map Calculation operation .The approach is made to observe how severe the specific area is by generating a classified map of various erosion class such as 0-10, 10-20, 10-20, 20-40, 40-80, 80-120, >120 etc. The sensitivity analysis will also been done by assigning the barren land as forest cover, agricultural land with good management practices, etc. to see the changes in the quantity of soil erosion from the catchment area. The analysis is helpful for planning the watershed management practices, such as afforestation, contour bunding, gully plugging, etc. Histogram of Erosion map can be used in calculating the total soil erosion of the catchment. The histogram provides total number of pixels falling in each erosion intensity, the number of pixels can be multiplied with the corresponding mid value of erosion intensity to get the total soil loss.

DATA PROCESSING & PARAMETER ESTIMATION

Base Map

A base map was generated by importing and thus digitizing the Survey of India (SOI) toposheet no. 64H as reference map for all other purposes. The watershed boundary was marked on the basis of the contours and the drainage lines available on the SOI topographic map. Drainage network and water bodies were included in the base map. Total geographical area of the reservoir catchment is 3832.62sq. Km. including 143.00 sq. km. water spread area. Therefore, the land surface considered for estimation of soil erosion remains 3689.62 sq. km..

Rainfall Map

The seasonal rainfall data for this catchment were obtained from State Water Data Centre of Water Resources Department, Raipur. The Thiessen Polygon map was prepared in GIS platform using the eight raingauge stations covering the entire watershed area. Each polygons were assigned the R-factor values computed by using the equation 3 and stored as raster map. For Ravishankar Sagar reservoir 8 rain gauge stations falls so thiessen polygon map was made and seasonal rainfall index of each polygon was calculated manually. Table 1 shows the Rainfall Factors corresponding to the rainfall observed in the catchment area.

Table-1: Rainfall factor (R)

S.No.	Rain gauge stations	Rainfall index
1	Birgudi	470.99
2	Charama	441.74
3	Dhamtari	419.81
4	Dudhawa	530.40
5	Gangrel	443.03
6	Kanker	526.70
7	Khajravand	517.23
8	Mahaud	511.75
9	Murumsilli	531.67

Soil Map

The organic matter (O.M.) contents in these soils are reported about 2%. K values was determined based on locally measured soil properties and using soil erodibility factor monograph for great soil groups in India. These values were annual averaged corresponding to homogeneous different soil groups as shown in Fig.2. K values for study area are shown in Table 2.

Table-2: Spatial distribution of soil erodibility factor (K)

S. No.	Texture class	K value	No. of pixel	Area(KM^2)
1	Water bodies	0	8954	89.54
2	Sand	0.05	69629	696.29
3	Loamy Sand	0.10	4855	48.55
4	Sandy Clay	0.13	49708	497.08
5	Fine Sand	0.16	73627	736.27
6	Loamy fine Sand	0.20	13261	132.61

7	Sandy Loam	0.24	80548	805.48
8	Clay Loam	0.25	33349	333.49
9	Fine Sandy Loam	0.28	44897	448.97
10	Loam	0.30	1057	10.57
11	Loamy Very Fine Sand	0.38	562	5.62

Topography Map
Digital Elevation Model (DEM) of the 20°0’0” N 81°0’0” E to 21°0’0” N 82°0’0” E was downloaded from authorized website of USGS earth explorer. The DEM available in the site is of 60 m pixel size. The DEM map was then filtered to derive the dx and dy value map. Based on these maps, slope percentage map was computed by using the formulae 100*hyp(dx,dy)/Pix size (Fig.3). Slope length factor map was generated by using the equation no. 4.

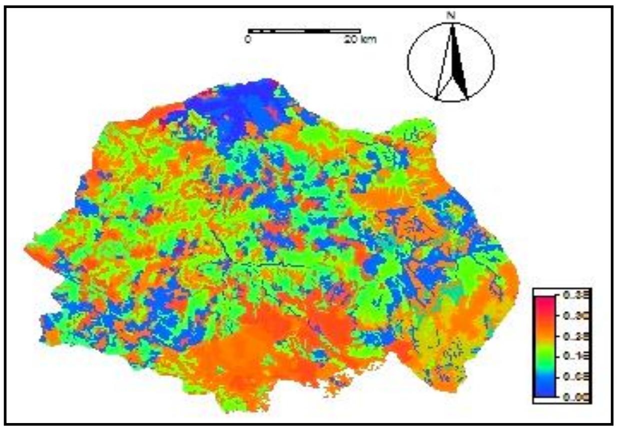

Fig. 2: K factor Map

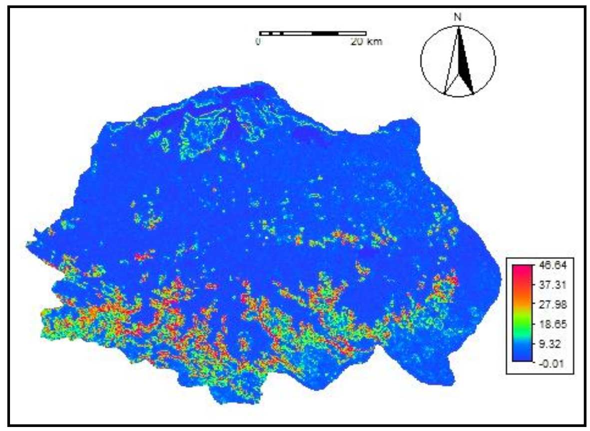

Fig. 3: Slope map

Land Use Map
Land use map was obtained from Chhattisgarh Council of Science and Technology. The map so obtained was in vector format. It was also cross checked form the map downloaded from www.*bhuvan.gov.in*. The map was classified in various land-use classes and then was rasterised and resampled. The land use classes include Agriculture, barren/grazing lands, forest and shrubs/bushes, settlements, water bodies and mining activity.
The land use map thus classified from satellite data is shown in the following Fig.4 and spatial distribution of all the five land use classes is given in the Table 3.

Table-3: Land use distribution in Ravishankar Sagar catchment and ‘C’ factor

S. No.	Land use class	No. of pixels	Area in sq.Km	C factor
1	Agriculture	159611	1596.11	0.28
2	Barren Land	12964	129.64	0.75
3	Forests	168184	1681.84	0.05
4	Mining activity	2537	25.37	1.00
5	Shrubs land	16448	164.48	0.15
6	Settlement	1961	19.61	0.25
7	Water-body	21231	212.31	0.00

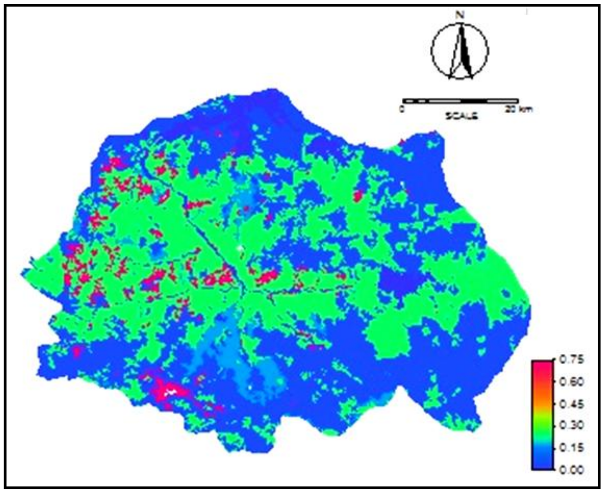

Fig. 6: C-factor Map

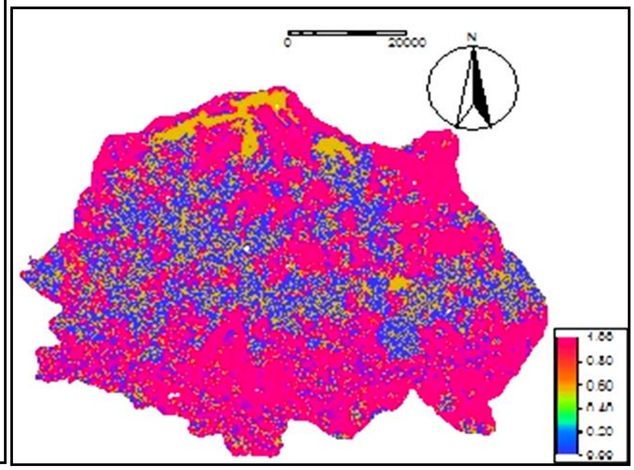

Fig. 7: P-factor map

Conservation Practice Factor (P)

The classified slope map slope class was attributed to P factor values to create a raster map of conservation practices factor. The non-agricultural lands (forest, shrubs/bushes and barren/grazing land) were assigned value 1.0 for P factor.

RESULTS AND DISCUSSION

Estimation of Expected Soil Erosion

The various maps having the values of factors responsible for soil erosion, i.e. R, K, LS, C and P were brought in the form of raster maps as affirmed previously to obtain the soil loss. Multiplying the R, K and LS maps gave the potential soil erosion of the catchment. The expected soil loss map ‘USLE’ was obtained by multiplying all the six factor maps. The USLE map was again classified into distinct group of erosion intensities to create the classified expected soil loss and the result has been presented in Table 4.

Table-4: Distribution of soil erosion class in Ravishankar Sagar catchment

Class	**Soil erosion (tonnes/ha/yr)**	**No. of pix**	**Area (Sq.km.)**	**% Area**
Slight	0 to 10	287113	2871.13	82.15
Moderate	10 to 20	27890	27.89	00.80
High	20 to 40	23345	233.45	06.68
Very High	40 to 80	13783	137.83	03.94
Severe	80 to 120	8233	82.33	02.35
Very Severe	> 120	14246	142.46	04.07

By this assessment it can be clearly observed that almost 4 % of the catchment is prone to very severe erosion condition and 2.3 % is under severe erosion situation.

The quantity of actual soil erosion calculated by USLE model comes out to be 8.72 Million tones/year. This value can be converted in terms of volume by dividing the same with the specific gravity of the sediment load, i.e. 1.1 tones/m^3. Thus, the soil erosion from the Ravishankar catchment will be 7.9 Mm^3/year

CONCLUSIONS

- Erosion is product of rainfall erosivity (the R factor); and the resistance of the environment, which comprises K, the soil erodibility; LS, the topographical factor; C, the plant cover and farming techniques and P, the management or control practices.
- The model is valid only for sheet erosion as the source of energy is rain; so it is not applicable to linear or mass erosion. Since it is a multiplier, if any one factor tends to zero, erosion will tend toward zero.
- The effect on erosion of slope combined with plant cover and the effect of soil type on slope are not taken into account.
- Soil erosion can be controlled effectively if it is predicted accurately under alternate management strategies and practices.

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