

Estimation of Soil Erosion from Watershed using Remote Sensing and GIS

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Abstract – Remote sensing data and GIS techniques have been used to compute average annual soil erosion for the SA-13 watershed having area of 21,300 ha. Watershed SA - 13 of Ashti, Beed District of Maharashtra state (750 04' 55" to 750 16' 25" E longitude and 180 40' 11" to 180 56' 20" N latitude. Multidate satellite data of IRS P-6 LISS III of path 059 and row 096 with 23.5 m resolution was used. Different types of thematic maps viz., Administrative Boundary maps, Slope map, Land Use Land Cover map and rainfall maps were developed to estimate the different parameters required for the calculation of the soil erosion. Annual soil erosion was estimated using the Revised Universal Soil Loss Equation model. The watershed was divided into 15 sub-watersheds. The highest soil erosion of 9.97 t/ha/year was observed in micro-watershed number 4, whereas lowest soil erosion of 5.59 t/ha/year was observed in micro-watershed number 13. The average annual soil erosion from SA-13 watershed was found 8.2 tons/ha/year.

Keywords – GIS, Remote Sensing, RUSLE, Watershed.

I. INTRODUCTION

Soil erosion is a complex phenomenon as it is governed by various natural processes, and it, in turn, results in decrease of soil fertility and reduction of crop yields. India is one of the few countries in the world to have estimated the loss of topsoil due to erosion (Narayana and Babu, 1983). An estimated 329 Mha, constituting about 53% of the total geographical area suffers from deleterious effect of soil erosion with an annual average soil erosion rate of 16 t/ h/year (Dabral et al. 2008). The process of soil erosion involves detachment, transport and subsequent deposition (Meyer and Wischmeier, 1969). The consequence of soil erosion occur both on-site and off-site (Morgan, 1986). On site effects are particularly important on agricultural land, where the redistribution of soil within a field, the loss of soil from a field, the breakdown of soil structure and the decline in organic matter and nutrient result in a reduction of cultivable soil depth and decline in soil fertility. Erosion also reduces available soil moisture, resulting in more drought prone conditions. The net effect is a loss of productivity which, at first; restricts what can be grown and results in increased expenditure on fertilizers to maintain yields but later, ultimately leads to land abandonment. Off-site problems result from sedimentation downstream, which reduces the capacity of the rivers, enhance the risk of flooding, blocks irrigation canals and shortens the design life of reservoirs.

Several parametric models such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965), the Modified Universal Soil Loss Equation (MUSLE) (Williams, 1975), or the Revised Universal Soil Loss Equation (RUSLE) (Renard et al, 1991) are frequently used

for the estimation of surface erosion from catchment areas (Ferro and Minacapilli 1995; Ferro 1997; Kothyari and Jain, 1997; Ferro et al, 1998) were used to estimate soil erosion. The soil erosion depends on rainfall and geomorphological characteristics of catchment. Both of these parameters have large variability due to the spatial variation of rainfall and catchment heterogeneity. Remote Sensing and GIS techniques makes it possible to measure these hydrologic parameters on spatial scales. The use of Geographical Information System (GIS) and remote sensing methodology was found most suitable for the quantification of heterogeneity in the topographic and drainage features of a catchment (Shamsi, 1996; Roddaet al., 1999). Therefore in this study remote sensing and GIS technique were used to estimate average annual soil erosion for the watershed.

II. MATERIALS AND METHODS

1. Study Area

Watershed SA - 13 selected for the study was located in Ashti tahsil, Beed district of Maharashtra. Watershed SA - 13 spans from 750 04' 55" to 750 16' 25" E longitude and 180 40' 11" to 180 56' 20" N latitude occupying an area of about 21,300 ha (Fig 1). Survey of India toposheets numbering 47 N/1, 47 N/2 and 47 N/5 (1:50,000 scale) was used for watershed delineation. The elevation of the watershed ranges from 730 m above mean sea level at north-east border and gradually decreasing down to 575 m at the confluence of Sina and Talwar river. The maximum temperature of the study area was ranges between 400 C to 420 C and minimum temperature ranges between 120 C to 130 C and mean relative humidity was approximately 52.6 percent. The average rainfall of study area was 794 mm.

2. Data Used

2.1 Remote Sensing Data

Multi-date (8th Nov, 2005, 19th Jan, 2006 and 25th Apr, 2006) Indian Remote Sensing satellite data of IRS-P6, Resourcesat-1 of row 059 and path 096 with spatial resolution of 23.5m was used for the estimation of soil loss in the watershed study.

2.2 Climate Data

Daily rainfall data of Ashti rain gauge station for the years 1998 to 2005 was downloaded from Agriculture Department, Govt. of Maharashtra web site of <http://www.mahaagri.gov.in> and used to estimate the R-factor

III. METHODOLOGY

3.1 Soil Erosion by Revised Universal Soil Loss

Equation (RUSLE)

The average annual soil loss for SA-13 was estimated using RUSLE and the satellite data using remote sensing and GIS techniques. The detailed methodology is presented in the form of flow chart in figure 2. The empirical equation RUSLE was proposed by Renard et al. (1997) used to calculate average annual soil loss. The soil loss was calculated using following equation

$$A = R \times K \times L \times S \times C \times P$$

Where, A is gross amount of soil loss (t / ha / year), R is rainfall erosivity factor (MJ -mm /ha-hr-yr), K is soil erodibility factor (t-ha- hr/ ha-MJ- mm), L is slope length factor (dimensionless), S is slope steepness / gradient factor, C is cover management factor (dimensionless) and P is support practice factor (dimensionless)

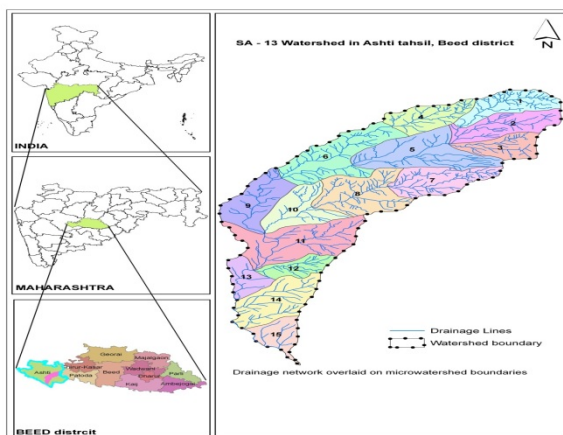


Fig.1. Location map of study area

Sub-watershed wise annual soil loss for SA-13 watershed was estimated by using raster calculator by using ERDAS Imagine and the maps were prepared in GIS.

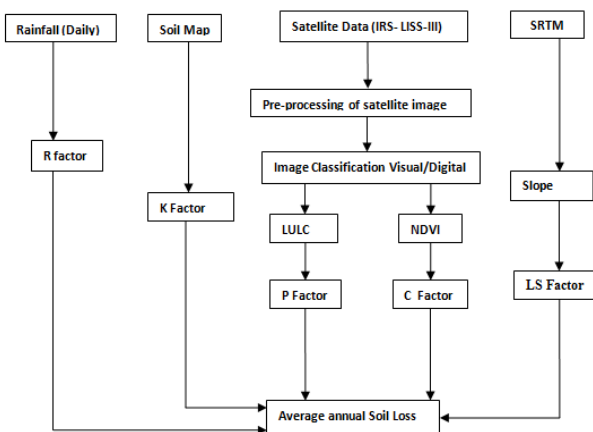


Fig.2. Flow Chart for Estimation of Annual Soil Loss

3.1.1 R-Factor (Rainfall Erosivity Factor)

R- factor is the rainfall erosivity factor which is based on rainfall data. The R-factor was calculated by using the formula by Ram Babuet. al. (2004)

$$R \text{ Factor} = 81.5 + [0.380 \times (R_n)]$$

Where, R-Factor is rainfall erosivity factor and Rn is average annual rainfall, mm

3.1.2 K-Factor (Soil Erodibility Factor)

The erodibility of a soil is an expression of its inherent resistance to particle detachment and transport by rainfall. The K-factor was calculated by using the formula by Atawoo and Heerasing (1997) given as below,

$$100K = (2.1 \times 10^4 \times (2 - OM) \times m^{1.14} + 3.25 \times (St - 2) + 2.5 \times (Pt - 3))$$

Where, K is soil erodibility (tons-yr/MJ-mm), OM is per cent organic matter, Pt is permeability code, St is soil structure code and M is a function of the primary particle size function given by M is percent silt and percent sand content

3.1.3 L and S Factor (Slope Length and Steepness Factor)

The L and S factor (topographic factor) accounts for the effect of topography on erosion in RUSLE method. The slope length factor (L) represents the effect of slope length on erosion, and the slope steepness factor (S) reflects the influence of slope gradient on erosion. The topographic factor in the present study was therefore computed by using the equation stated by Moore & Wilson (1992).

$$LS = (A_s / 22.13)^n \times (\sin \beta / 0.0896)^m$$

Where, As is the specific area (=Alb), defined as the upslope contributing area for an overland cell (A) per unit width normal to the flow direction (b), β is the slope gradient in degrees; n is 0.4; for 3 to 4 % slope, m is 1.3

The slope steepness factor S, is evaluated by relationship developed by McCool et al. (1987, 1993),

$$S = 10.8 \sin \theta + 0.03 \text{ for } S < 9\%$$

$$S = (\sin \theta / \sin 5.143)^{0.6} \text{ for } S \leq 9\%$$

$$\beta = (\sin \theta / 0.0896) / [3.0(\sin \theta)^{0.8} + 0.56]$$

Where, θ is slope angle

The combined topographic (LS) factor was computed rather than the individual slope length and slope angle factors. The inputs for the computation include the slope in percent and the slope length as a flow length.

3.1.4 C-Factor (Cover Management Factor)

C - Factor is calculated from NDVI. NDVI is a spectral ratio between near infrared (NIR) and red (R) reflectance. NDVI map was generated for the watershed to formulate the linear equation between NDVI and C-factor. The NDVI values less than zero indicates water and other non-vegetated features, so the negative values are not considered in preparing the C-factor equation. With these boundary conditions the regression equation for C factor was developed to estimate C-Factor based on following conditions.

$$C = 0 \quad \text{NDVI} \leq 0$$

$$C = -0.50 \text{ NDVI} + 1 \quad 0 < \text{NDVI} \leq 0.68$$

$$C = 0 \quad \text{NDVI} \geq 0.68$$

3.1.5 P-Factor (Support Practice Factor)

The P-factor represents the ratio of soil loss by a support practice to that of straight-row farming up and down the slope. The P-factor was assumed by using the Conservation practice of the study area and the value of P factor for strip cropping was taken as 0.37. (Stone and Hilborn, 2000).

IV. RESULTS AND DISCUSSION

Estimation of Soil Loss

The composite term RKLSCP represents the soil erosion potential of different grid cells in the unit t/ha/yr. The GIS database generated for the estimation of soil erosion such as R-factor, K factor, L and S factor, C factor and P factor has been multiplied using “Raster Calculator” in Spatial Analyst of ArcGIS to calculate soil loss. The different factors required for the estimation from soil erosion from the watershed were derived and presented in figure 3, 4, 5, 6. All the factor maps of R-factor, K factor, L and S factor and C factor were integrated to generate composite map of soil loss for the watershed. The soil erosion map of the watershed is given figure 7 and micro-watershed wise average soil erosion computed is presented in Table 2. The average annual soil erosion of the entire watershed was 8.2 t/ha/year. The highest soil erosion of 9.97 t/ha/year was observed in micro-watershed number 4, whereas lowest soil erosion of 5.59 t/ha/year was observed in micro-watershed number 13. The highest soil erosion was observed in areas of with upland topography with 30 degrees slope.

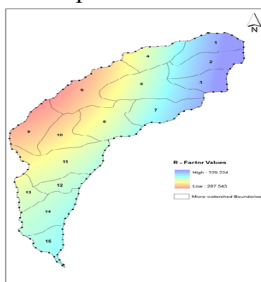


Fig.3. R- Factor

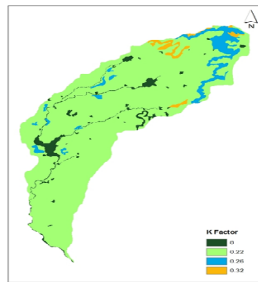


Fig.4. K- Factor

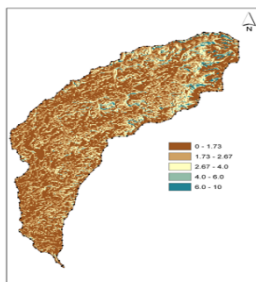


Fig.5. LS- Factor

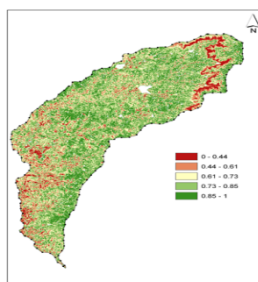


Fig.6. C- Factor

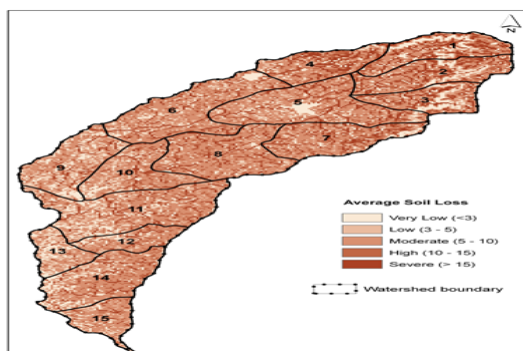


Fig.7. Soil erosion map showing the average annual soil loss

Table 1: Micro-watershed wise soil loss for the Year 2005

Micro-watershed	Rainfall (mm)	Soil loss (t/ha/year)
1	406.5	9.35
2	406.5	9.87
3	406.5	9.01
4	406.5	9.97
5	406.5	8.67
6	406.5	8.22
7	406.5	9.10
8	406.5	8.85
9	406.5	6.75
10	406.5	7.84
11	406.5	7.50
12	406.5	7.82
13	406.5	5.59
14	406.5	7.75
15	406.5	6.66
Annual Avg.	406.5	8.20

V. CONCLUSION

The average annual soil erosion for the watershed was 8.2 tons/ha/year with minimum soil erosion of 5.59 tons/ha/year for sub-watershed 13 and maximum soil erosion of 9.97 tons/ha/year for sub-watershed 4. This methodology can be applied to small basins. The application of remote sensing images and GIS tools are useful to approximate the land cover and potential soil erosion of the basin.

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