SOIL EROSION AND SEDIMENT YIELD MODELING USING REMOTE SENSING AND GIS TECHNIQUES

[1]DR. MANJULAVANI K, [2]PRATHYUSHA B, [3]RAMESH M

[1,2,3] Centre for Spatial Information Technology, JNTUH, Hyderabad, India
E-mail: [1]ronilekha@gmail.com, [2]prathyusha.basani@gmail.com, [3]rameshmadipally37@gmail.com

Abstract- Soil erosion and sediment yield is a crucial problem in agriculture lands, watersheds and reservoirs. As soil conditions and internal connectivity play extremely important role in controlling water movement of a watershed, the study of the relationships among soil mechanics and watershed hydrology leads to a better understanding for proper decisions making. Hence, remote sensing and GIS techniques are applied due to the hold of great premises for the assessment and conservation of natural resources of surface soil. In the present study, the Madikonda watershed, Warangal district, Telangana State, India has been selected as the study area and satellite data from IRS LISS IV is used to estimate annual average soil erosion and the sediment yield.

Keywords- Soil erosion, sediment yield, Remote sensing and GIS.

I. INTRODUCTION

Soil erosion and sedimentation by water involves the processes of detachment, transportation, and deposition of sediment by raindrop impact and flowing water [9]. The sedimentation is defined as the ratio of the sediment yield at a given stream cross section to the gross erosion from the watershed upstream from the measuring point. Soil loss is defined as the amount of soil lost in a specified time period over an area of land which has experienced net soil loss. There are several possible methodologies for creating an erosion map based on the collection of distributed field observations, on an assessment of factors, and combinations of factors, which influence erosion rates and primarily on a modeling approach [7]. Most studies of soil erosion at the large scale have followed two general approaches: (1) evaluation by the regional erosion factors or available models; (2) evaluating soil loss by extrapolating from plot and micro-catchment scales to catchments, watersheds and regional scales [10]. Both of the approaches have the substantial obstacle of spatial heterogeneity at the large scale. The use of remote sensing and geographical information system (GIS) techniques makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas. In general, remote-sensing data were primarily used to develop the cover-management factor image through land-cover classifications, while GIS tools were used for derivation of the topographic factor from DEM, data interpolation of sample plots, and calculation of soil erosion loss [5]. The Universal Soil Loss Equation (USLE) model was suggested first based on the concept of the separation and transport of particles from rainfall in order to calculate the amount of soil erosion in agricultural areas. Universal soil loss equation (USLE) is the standard soil loss prediction model [6]. RUSLE model is a set of mathematical equations that estimates average annual soil loss. This is a technology for estimating soil loss from most undisturbed lands experiencing overland flow, from lands undergoing disturbance, and from newly or established reclaimed lands [8]. Strength of RUSLE is that it was developed by a group of nationally-recognized scientists and soil conservationists experienced with erosional processes [2]. The soil loss computed by RUSLE is the amount of sediment lost from a landscape profile described by the user. In the year 2000, Simple methods such as the USLE, the MUSLE, or the RUSLE are frequently used for the estimation of surface erosion and sediment yield from catchment areas [4]. In the year 2005, annual soil loss rates are estimated using the Universal Soil Loss Equation (USLE) that has been used for five decades all over the world [3]. In the year 2006, A GIS-based method has been applied for the determination of soil erosion and sediment yield in a small watershed in Mun River basin, Thailand. The gross soil erosion in each cell was calculated using Universal Soil Loss Equation (USLE) by carefully determining its various parameters [1]. In 2012, a qualitative Soil erosion model has been developed using weighted sum tool of ArcGIS, where raster's of all the factors given as input were assigned equal weightage and were later reclassified into five soil erosion classes [5].

II. STUDY AREA AND DATASETS

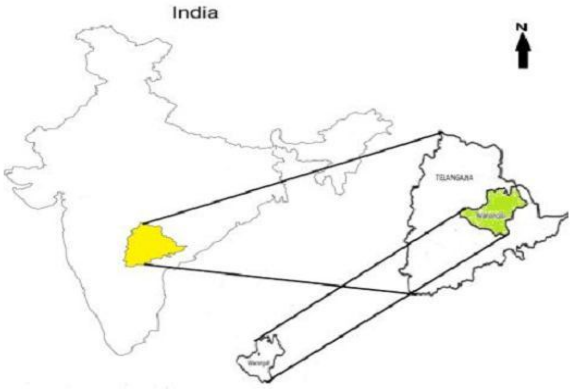


Figure 1. Study area

2.1 Study area: Madikonda watershed of Warangal district in Telangana state, India has been selected as study area. The geographical location of this watershed is in between North latitudes 17° 45′-18° 00′ and East longitude 79° 15′ -79° 30′. The selected watershed has an area of 35.9sq.km with an altitude of 524.28 m. Rainfall of this area is around 82.5cm (June to September). The drainage of the study area is mostly dendritic in nature. The location map of the watershed is shown in Figure 1.

2.2 Datasets: The spatial data of study area constitutes the toposheet of 56 O/5 from Survey of India and IRS LISS IV image from NRSC-Bhuvan. Non spatial data contains the annual rainfall and soil parameters. The rainfall of 12 years from 2002 to 2013 is collected and field survey has been carried out to collect soil samples at six locations, out of which five falling inside and one outside of the watershed area.

III. METHODOLOGY

The land use land cover (LU/LC) map was prepared from the LISS IV satellite data which provided accurate mapping of different LU/LC categories due to its high spatial resolution. The LU/LC map was used for preparing the land cover and management factor (C-factor) map. The values of C-factor were assigned to the different land use land cover classes in the study area which were estimated. The P-factor map was also prepared using the land use land cover map of the watershed and the values of P-factor were assigned to the different features based on the soil conservation practices taken up in the study area referring to previous studies. To estimate the soil erosion and the spatial distribution of different soil erosion zones in the Madikonda watershed, raster calculator was used. The methodology flowchart is shown in figure 2.

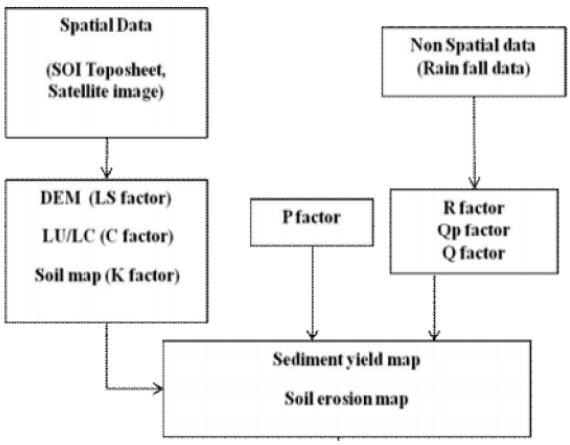


Figure 2. Flow chart of soil erosion and sediment yield estimation

3.1 RUSLE Parameter Estimation: RUSLE developed by Wischmeier and smith, 1965, is used to predict the average annual erosion on field slopes using equation 1

$$A = R.K.L.S.C.P \quad \ldots Eq\,(1)$$

Where A = computed spatial average soil loss and temporal average soil loss per unit of Area, expressed in ton× acre-1× yr-1; R = rainfall-runoff erosivity factor (100ft×ton×acre-1×yr-1); K = soil erodibility factor; L = slope length factor; S = slope steepness factor; C = cover management factor; P = support practice factor.

3.1.1 Rainfall-Runoff Erosivity Factor (R): Rainfall erosivity factor (R) is given by:

$$R = \frac{1}{n}[\Sigma_{j=1}^{n}\Sigma_{k=1}^{m}(E)(I_{30_K})] \quad \ldots Eq\,(2)$$

Where R = rainfall-runoff erosivity factor—the rainfall erosion index plus a factor for any significant runoff from snowmelt (100ft×ton×acre-1×yr-1), E = the total storm kinetic energy in hundreds of ft-tons per acre, I30 = the maximum 30-minute rainfall intensity, j= the counter for each year used to produce the average, k= the counter for the number of storms in a year, m= the number of storms n each year and n= the number of years used to obtain the average R.

3.1.2 Slope Length and Steepness Factor (LS): The effect of topography on soil erosion is accounted for by the LS factor in RUSLE, which combines the effects of a slope length factor, L, and a slope steepness factor, S. In general, as slope length (L) increases, total soil erosion and soil erosion per unit area increase due to the progressive accumulation of runoff in the down slope direction. As the slope steepness (S) increases, the velocity and erosivity of runoff increase. For cropping land, L is evaluated by the equations used in RUSLE with $L = (\frac{X_h}{72.6})^m$ …Eq (3)

Where, X_h = the horizontal slope length in ft, m = a variable slope length exponent.

RUSLE has six parameters, which are rainfall erosivity (R), soil erodibility (K), slope length and steepness (LS), cover management (C), and support practice factor (P). In the Madikonda watershed, the annual average R values range from 180mm to 109.118mm based on the location of rainfall stations. Based on the soil classification and organic matter, soil erodibility (K) is estimated and varies from 0.48 to 0.54. Slope length and steepness (LS) is predicted using the DEM and Arc info AML. LS values range from 0 to 188.13. The cover management factor (C) is calculated based on the C factor of NIAST (2003), Wischmeier and Smith (1987). Forested area C value is estimated using a "Trial and Error method" from the relationship between the annual soil losses and various sediment delivery ratio models. The determined C value for forested area was 0.03. C values range from 0 to 0.37. The support practice factor (P) is calculated according to the cultivating method and slope. The support practice factor (P) is assumed as 1.

3.2 MUSLE Parameter Estimation: The MUSLE is used in this study given by

$$Y = 11.8(Q q_p)^{0.56} K.C.P.LS \quad ..Eq\ (4)$$

Where, Y is the sediment yield on a given day (ton), Qs is the surface runoff (mm), qp is the peak runoff rate (m^3/s), A area is area (km^2),

3.2.1 Peak runoff rate q_p :

$$q_p = \frac{ci.A_{area}}{3.6} \quad \ldots \text{Eq (5)}$$

Where, q_p is the peak runoff rate (m^3/s), A_{area} is area (km^2), c is the runoff coefficient, i is the rainfall, Intensity (mm/hr) and 3.6 is a unit conversion factor.

3.2.2 Strom runoff rate (Q):

The rational method is described by the formula

$$Q = 0.28.C.I.A \quad ...Eq(6)$$

Where, Q= storm runoff rate [m^3/sec], C = Runoff coefficient, I = Rainfall intensity [mm/hr], A = Drainage area [km^2].

IV. RESULTS AND DISCUSSION

4.1 Thematic map preparation: The Digital Elevation Model, Land Use / Land Cover and soil maps are prepared in GIS environment from the spatial data and used to derive the K, LS and C factors.

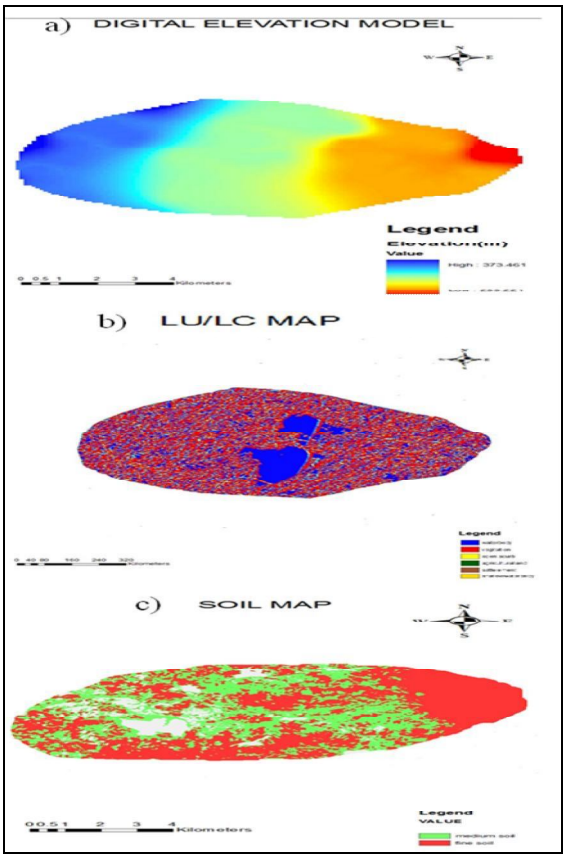


Figure 3. Thematic maps from spatial data

4.2 Estimation of Soil Erosion Using RUSLE

4.2.1 Rainfall Runoff Erosivity Factor(R):

The values of rain fall data is shown in table 1.

Table1: Values of rainfall, I_{30}, E_{30}.

YEAR	RAIN FALL (mm)	I_{30}	STROM E_{30}
2002-03	33-6	16.8	4.737
2003-04	20.34	10.17	2.664
2004-05	63.48	31.74	9.172
2005-06	99.19	49.595	14.377
2006-07	79.01	39.505	11.452
2007-08	84.341	42.170	12.22
2008-09	80.86	40.43	11.72
2009-10	64.95	32.475	9.404
2010-11	93.35	46.675	13.46
2011-12	60.91	30.45	8.800
2012-13	77.13	38.56	11.17

4.2.2 Soil Erodibility Factor (K): For calculation of K factor organic matter content test, permeability test, soil tests have been carried out. The classification of soil is done from the results of wet sieve analysis and hydrometer test. By observing the test results for six samples, soil permeability is assumed moderate. The values for organic matter content is 0.05%, soil structure is 2 and permeability is 3, K factor has been calculated for medium soil is 0.054 t ha h ha^{-1} $MJ^{-1}mm^{-1}$ and for fine soil it is 0.049 t ha h ha^{-1} $MJ^{-1}mm^{-1}$.

4.2.3 Slope Length and Steepness Factor (LS): Watershed will be a major factor in soil erosion potential, with steep slopes being more susceptible to soil loss. The topographic factors like slope length and slope steepness are derived from DEM.

4.2.4 Cover/ Cropping Management Factor (C): This cover management factor represents the effects of plants, soil biomass and disturbing activities on erosion. The LU/LC map has been prepared using IRS LISS IV image. Table 2 gives the value of C factor corresponding to the different type of land use land cover present in the watershed. Figure 4 is showing the C factor map of watershed.

Table 2: C factor values for LU/LC

Land use /Land Cover	C Factor
Shallow water body	0.01
Water body	0.01
Vegetation	0.3
Settlement	0.5
Open scrub	0.14
Agricultural land	0.2

4.2.5 Conservation Practice Factor (P): The present study area has not been applied for conservation as the area does not comprise of steep slope. For the present watershed the value of P factor has been assumed as one.

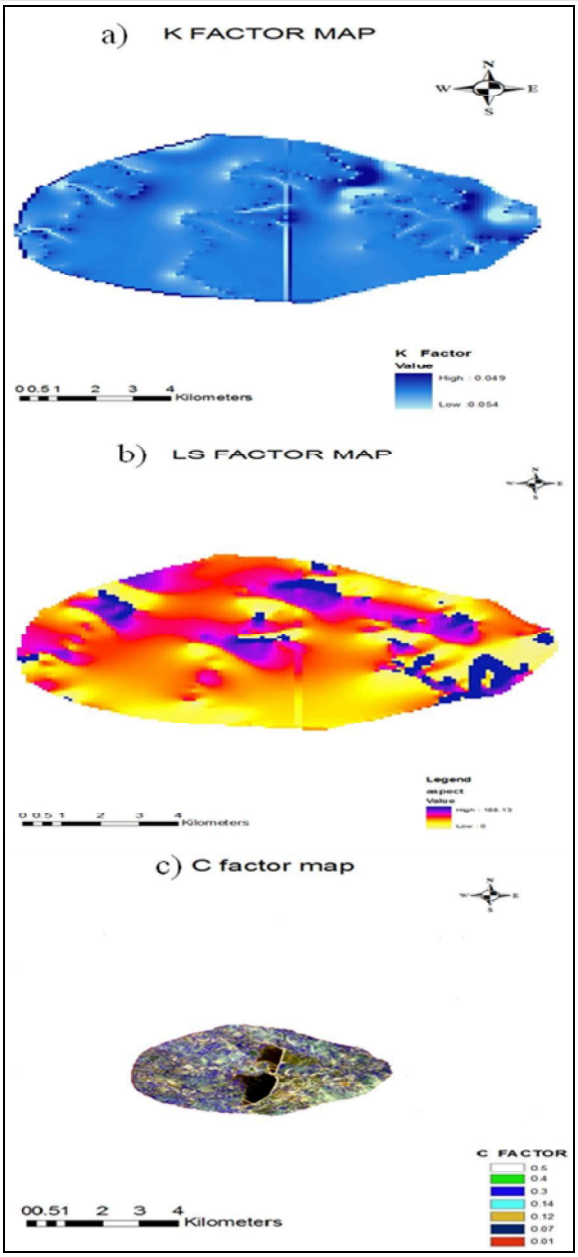


Figure 4. Factors derived from a) DEM, b) LULC and c) soil data

4.3 Derivation of Soil Erosion Map and Sediment Yield: The soil erosion map has been obtained by multiplying the six factors in GIS environment. In the watershed maximum soil erosion is occurring at the inlets of the tanks. From figure 5a), the portion of watershed covered by scrubs where density of vegetation is very less has moderate soil erosion and it may be due to lack of water. This portion may be prone to wind erosion. The portion of the watershed covered with the agricultural lands and dense vegetation have less soil erosion. The open scrub portion of watershed where streams are not present has the minimum soil erosion. MUSLE given in equation (4) has been used to estimate the sediment yield for the watershed. Peak runoff rate (q_p) and runoff volume (Q) required for estimation of sediment yield have been calculated using the equation (5) and (6).The value estimated for runoff volume is 7433.598 cubic meter and the value of peak runoff rate is 14.356 cubic meter per second. The estimated parameters and the factors are multiplied to get sediment yield of the watershed. The sediment yield for each sub watershed has been derived by using the raster layers created for sub watershed polygons as in figure 5b).

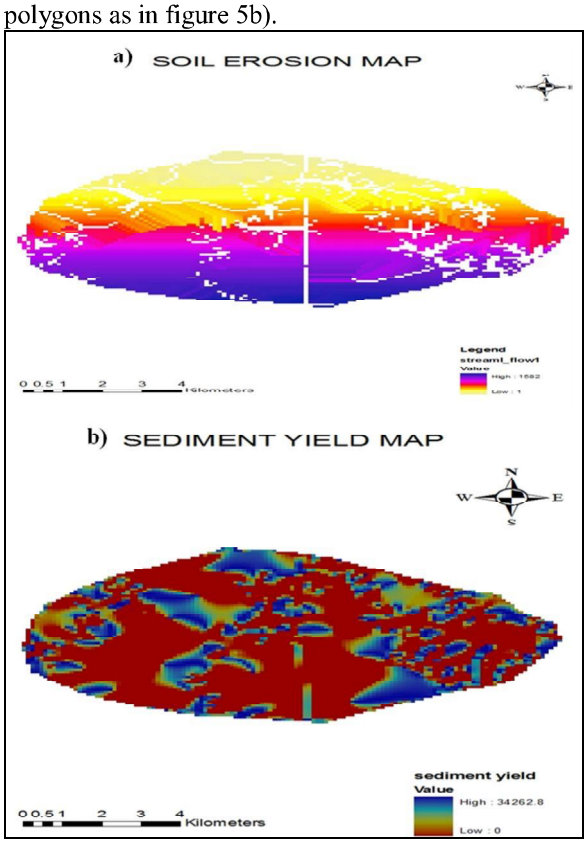


Figure 5. Soil erosion and Sediment yield of Madikonda watershed

CONCLUSIONS

The following conclusions are drawn from the output images of soil erosion and sedimentation yield model of study area. The Madikonda watershed is subjected to frequent erosion along the stream lines and it is coming to a total of 1582 tonnes/ha/yr at the inlet of tanks. The estimated sediment yield of the Madikonda watershed is 34226.8 tonnes. As the present watershed has not been subjected to conservation practices, plantation and row cropping are recommended to prevent soil erosion. From soil erosion map it is seen that 30% of watershed has soil erosion.

REFERENCES

[1]. Al-Soufi R., "Soil erosion and sediment transport in the Mekong basin", International Proceedings of 2nd APHW conference, Singapore, 2004, pp 47–56

[2]. Angima S.D., Stott D.E., O'Neill M.K., Ong C.K., Weesies G.A., "Soil erosion prediction using RUSLE for central Kenyan highland conditions", Agriculture Ecosystems and Environment, 2010, 97, pp 295–308

[3]. Arnold J.G., Srinivasan R., Muttiah R.S., Williams J.R., "Large area hydrologic modeling and assessment part I: model development", Journal of American Water Resources Association, 1998, 34 (1), pp73– 89

[4]. Atkinson E., "Methods for assessing sediment delivery in river systems", Hydrology Science Journal, 1995, 40(2), pp 273-280.

[5]. Bartsch K.P., Mietgroet H.V., Boettinger J., Dobrowolski J.P., "Using empirical erosion models and GIS to determine erosion at Camp William, Utah". Journal of Soil & Water Conservation, 2012, 57(1), pp: 29–37

[6]. Band L.E., "Topographic partition of watersheds with digital elevation models", Water Resource Research. 2002, 22, pp: 15–24.

[7]. Jain S.K, Kumar S., and Varghese J., "Estimation of Soil Erosion for a Himalayan watershed using GIS technique," Water Resource Management, 2013, 15, pp. 41–54,

[8]. Renard, K., Foster, G., Weesies, G., McCool, D. and Yoder, D. "Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE)", USDA Agriculture Handbook , 1997, 703, 384 p

[9]. Wischmeier, W.H. and D.D. Smith, "Predicting rainfall erosion losses - a guide to conservation planning", Agriculture Handbook No. 537. U.S. Department of Agriculture, Washington, DC.1996

[10]. Zhang .W, Y. Xie, B. Liu, "Rainfall erosivity estimation using daily rainfall amounts," Scientia Geographica Sinica, 2002, 22(6), pp: 705-711

★★★