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Estimation of sediment yield using Remote Sensing (RS) and Geographic Information System (GIS) technique

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Abstract: *Sediment yield is the total amount of sediment particles reaches the watershed outlet due to erosion and deposition processes within a watershed.It causes removal of topsoil having higher amount of nutrient in upland areas and subsequent reduce of productivity of these areas and accumulation of sediment on plane land surface which is situated below the upland area. It affects on bed of river and lakes due to increase in sedimentation byreducing the capacity of river. It causes damage to coastal and marine ecosystems and human settlements.Hence,sediment yields are needed to estimate for studies of reservoir sedimentation, river morphology and soil and water conservation planning.*

The present study was based on estimation and comparison of sediment yield using Revised Universal Soil Loss Equation (RUSLE) for year 2002-03 and 2008-09. The observed sediment yield of the Sonwal watershed in 2002-03 was 5.88 t/ha/yr. However, it was found 10.22 t/ha/yr in 2008-09 with an increase of 4.34 t/ha/yr. The estimated sediment yield of the watershed for the year 2002-03 using RUSLE equation was found to be 6.07 t/ha/year with per cent change in observed and estimated sediment yield, 3.23.The estimated sediment yield of the watershed for the year 2008-09 was found to be 11.71 t/ha/year with per cent change in observed and estimated sediment yield, 14.58. The per cent change shows that the RUSLE equation gives accurate results for sediment yield estimation. Hence RUSLE equation is suitable for the Sonwal watershed for estimation of sediment yield. Also per cent increase of sediment yield in watershed from 2002-03 to 2008-09 shows that the watershed management programme is required for development of this watershed.

Keywords: RUSLE, Sediment Delivery Ratio, Sediment yield, RS, GIS, Normalized Vegetative Index

INTRODUCTION

Sediment yield is the total amount of sediment particles reaches the watershed outlet due to erosion and transport processes within a watershed basin. Sediment yield depends on erosion sediment delivery, topography, soil properties, vegetation, climate, drainage characteristics and land use pattern (Sekhar and Rao. 2002).

In India, 175 ha area (53 % of geographical area) is under serious degradation problem, in which effect of erosion covers 60 % cultivable area (Balakrishna 1986).The sediment problem occurs due to erosion. Hence, the erosion is mainly considered while estimating sediment yield. Soil loss and sediment yield are generally estimated by using RUSLE equation by using rainfall erosivity (*R*) using of rainfall data, soil erodibility (*K*) using soil map and soil properties, crop management factor (*C*) using satellite images, slope length factor (LS) using DEM and conservation practices (P) using satellite images and sediment Delivery Ratio (SDR) using empirical equation (Kamuludin et al. 2013),

The use of GIS model has been showed that the result of RUSLE equation for estimating soil loss

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and sediment yield was accurate (Arekhi*et al.* 2012,Kamaludin*et al.*, 2013, Lim *et al.*,2005, Maria Kouli*et al.2007,*Yoder &Lown 1995).

Present study is based on estimation of sediment yield using RUSLE method. The RUSLE method measures soil loss of watershed basin. This method is generally visualized by the factors such as rainfall erosivity factor (R), rainfall erodibility factor (K), length slope factor (LS), crop management factor (C) and support practice factor (P). After multiplying sediment delivery ratio to it, it gives sediment yield.

MATERIALS AND METHODS

Study Area

The study area of this research is Sonwal watershed, located in Shahadataluka of Nandurbar district, Maharashtra. The total area occupied by the watershed is 99.34 km^2. The location of watershed is 74° 53´ to 74°75´ N and 21°54´ to 21°62´ E and the average elevation is 455 m above sea level (Fig. 1). The Sonwal watershed is situated on Gomaitriburatory of Tapi River. It is one of the chief tributary of Tapi River and empties in it at Changdev in Prakasha in Nandurbar district. It originates in Satpura Mountain North Maharashtra and merge into the Tapi River. The maximum temperature of the region reaches is 48 °C and minimum temperature, of 9 ° C. Average rainfall of the watershed is 552 mm.

METHODOLOGY

RUSLE Equation

The Revised Universal Soil Loss Equation (RUSLE) computes soil loss with considering sheet and rill erosion from rainfall and the associated runoff for a landscape profile (Maria Kouli*et al.2007*). The soil erosion is calculated as follows

$$A = R.\ K.\ L.\ S.\ C.\ P \qquad (3)$$

Where,

A = Average soil loss per unit area by erosion (t ha^{-1} year^{-1}),
R = Rainfall erosivity factor (MJ mm ha^{-1} h^{-1} year^{-1}),
K = Soil erodibility factor (t h MJ^{-1} mm^{-1}),
L = Slope length factor,
S = Slope steepness factor,
C = Cover management factor,
P = Support practice factor.

As mentioned in Fig. 2, methodology for current research was used for year 2002-03 and 2008-09.

Figure 1: Location of study area

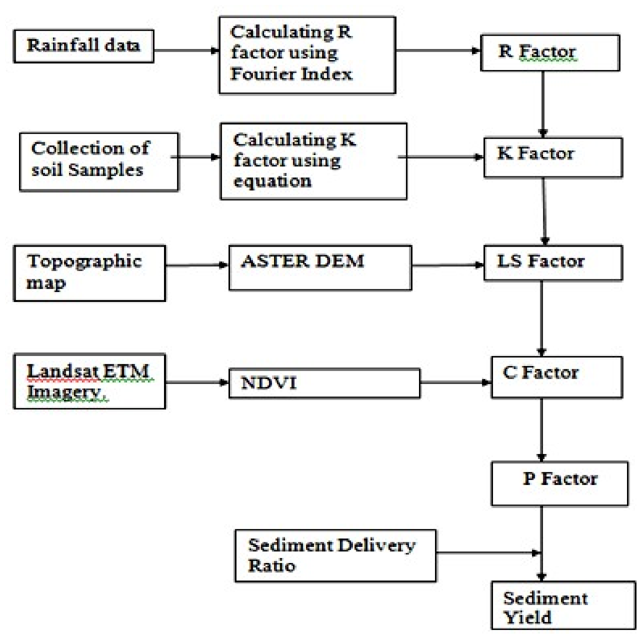

Figure 2: Flow chart of research work methodology for RUSLE equation

Rainfall erosivity factor (R)

Rainfall erosivity is rain ability responsible for erosion.Rainfall data for the year 2002-03 and 2008-09 was taken from Hydrology Project (Surface water) Water Resource Department, Govt. of Maharashtra, Nashik.

The Rainfall erosivity index was calculated by using Fournier index formula (Arekhi*et al.* 2012). Fournier index (F), is as follows:

$$F = \frac{\sum Pi^2}{\sum P} \quad (1)$$

Where,

P_i = Mean rainfall depth in mm of month i and

P = Mean annual rainfall in mm.

If F < 55, then

$$R - Factor = \frac{0.07397 \times F^{1.947}}{17.2} \quad (2)$$

If F > 55, then

$$R - Factor = \frac{\left((95.77) - (0.68 \times F) + \left(0.47 \times F^2\right)\right)}{17.2} \quad (3)$$

Soil erodibility factor (K)

The K values are usually estimated using the soil erodibilitynomograph method, which uses % silt, % sand and % clay to calculate K (Renard*et al.* 1997). The equation for K factor is

$$D_g = \exp\left(0.01 \times \sum f_i x ln(m_i)\right) \quad (4)$$

$$D_g = \exp\left(0.01 \times \sum f_i x ln\left(\frac{d_i + d_{i-1}}{2}\right)\right) \quad (5)$$

Where D_g = Geographical mean diameter

$$K = 7.594\left(0.0034 + 0.0405\exp\left(-0.5\left(\frac{\log D_g + 1.659}{0.7101}\right)^2\right)\right) \quad (6)$$

Where,

i = Particle sizes (sand, silt and clay), mm

D_g = Geometric mean particle diameter, mm

f_i = Primary particle size i, fraction,

m_i = Arithmetic mean of particle size limits for size i, mm.

In above equation, % silt, % sand and % clay were calculated by using International pipette method.

LS (Slope length & Slope gradient / steepness) factor (LS)

In this project,Advanced Spaceborn Thermal Emission and Reflection Digital Elevation Model (ASTER DEM) data of the study area with a cell size of 30 m wasdownloaded from *(http://glcf.umiacs.umd.edu/index.shtml)* website and is used after re-projecting it into Lambert Conical Conformal projection and clipping to study area boundary. In present study, the DEM imagery and Survey of India toposheet (1: 50,000) (Toposheet No. 46 K/10) were used to develop the slope map in degree which was further used for preparation of LS factor map.

LS-factor map was obtained from the DEM imagery of the region using "Arc GIS 9.3 / Arc View 3.2", based on the seminal work of Moore *et al.*1992 as follows (Lim *et al.* 2005):

$$LS = \left(\frac{A_s}{22.13}\right)^{0.4}\left(\frac{Sin\beta}{0.0896}\right)^{1.3} \quad (7)$$

Where,

A_S = Specific watersheds area (m^2/m)

β = Slope angle (radian).

Cover management factor (C)

On the basis of characteristic reflectance patterns, NDVI represents the distribution of vegetation and soil cover. NDVI for Landsat- 7 ETM is given by the following equation (Lin *et al.* 2002).

$$NDVI = \frac{NIR - R}{NIR + R} \quad (8)$$

Where,

NIR = Near Infrared.

R = Red bands.

Landsat 7 ETM imagery were used for this research work for year 2002-03 and 2008-09.The NDVI values are used to calculate the spectral ground-based data, showing the highest correlation with the above-ground biomass. The relationship between C and NDVI is as follows

$$C = \frac{(1 - NDVI)}{2} \quad (9)$$

Support practice factor (P)

It is the ratio of soil loss for a given conservation practices to the soil loss, obtained from up and down the slope.The conservation practice factor (P) is ranged from 0 to 1. In present study, P factor for no conservation practice was taken as P = 1 (Morgon, 1986).

Sediment deliver ratio (SDR)

The sediment delivery ratio is the ratio of sediment yield to total soil loss. It was calculated by formula

$$SDR = 0.51\ A^{-0.11} \quad (10)$$

Using the SDR value from equation (16) SY values is calculated using the formula developed by Wischmeier and Smith (1978) used by (Kamaludin*et al.* 2013) is as under:

$$SY = SDR \times SE \quad (11)$$

Where,

SY = Sediment yield (t ha^{-1} yr^{-1}),

SDR = Sediment delivery ratio, and

SE = Annual potential soil loss (*A*) (t ha^{-1} yr^{-1}).

RESULTS AND DISCUSSION

Sediment Yield Estimation Using Rusle Equation

R (Rainfall erosivity) factor

The value of R-factor for year 2002-03 was 250.49 MJ mm/ha/yrand for year 2008-09, 380.29 MJ mm/ha/yr.

K (Soil erodability) factor

From International pipette method, the values of sand, silt and clay in per cent were obtained as 36, 41 and 23 respectively. After putting the all above values and particle size ranges and their per cent content in soil, the value of K factor for study area obtained was 0.0467.

LS (Slope length& Slope gradient / steepness) factor

The LS factor was calculated by using DEM imagery. The flow direction map was obtained from the slope map. As depicted in Fig.3, the values of slope map ranged from 0 to 23. As depicted in Fig.4, the values of flow direction map ranged from 1 to 128. The flow accumulation map of study area was obtained from flow direction map. As shown in Fig. 5, the values of this map ranged from 0 to 7110.As mentioned in Fig. 6, LS factor value was obtained in the range of 0 to 4.837.

NDVI (Normalized Difference Vegetation Index)

The NDVI map was prepared by using NIR and IR band combination for two different years. As mentioned in Fig.7, the value of NDVI for year 2002-03 ranged from – 0.208 to 0.333. As mentioned in Fig. 8, the value of NDVI for year 2008-09 ranged from 0.013 to 0.531.

C (Cover management) factor

The value of C factor for year 2002-03 ranged from 0.333 to 0.604 (Fig. 9) and the value of C factor for year 2008-09 ranged from 0.235 to 0.494 (Fig. 10). The maximum C factor value for year 2002-03 was 0.60 and for year 2008-09 was 0.49.

P(Support practice)factor

The lower the P-factor value, the more effective the conservation practice is deemed to be at reducing soil erosion.Support practice factor for non conservation practice wastaken as 1(Morgon, 1986).

Sediment Delivered Ratio (SDR)

The equation of SDR was developed by Wischmeier and Smith (1978).After putting the value of area of the watershed (99.34 Km^2) in equation (16), the value of SDR is 0.3075

Sediment yield estimation using RUSLE equation

The Sediment yield was computed by multiplying the developed raster files for each factor ($A = R\ K\ L\ S\ C\ P$) in average annual soil erosion potential (A) and SDR. This was accomplished in ArcGIS by using the raster calculator tool. As indicated in Fig.11 and Fig. 12, the maximum sediment yield for year 2002-03 was 6.07t/ha/yr and for year 2008-09 was 11.71t/ha/yr.

CHANGE DETECTION IN SEDIMENT YIELD ESTIMATION USING RUSLE EQUATION

The sediment yield for the watershed for year 2002-03 using RUSLE equation was found to be 6.07 t/ha/year. The observed sediment yield for the watershed for year 2002-03 was 5.88 t/ha/yr. Per cent change in observed and estimated sediment yield was 3.23 (Table 2). The sediment yield for the watershed for year 2008-09 was found to be 11.71 t/ha/yr. The observed sediment yield for year 2008-09 was 10.22 t/ha/yr. Per cent change in observed and estimated sediment yield was 14.58. The sediment yield was increased from 2002-03 to 2008-09 by 5.64 t/ha/yr(Table 1).

CONCLUSION

The sediment yield using RUSLE equation shows the per cent change 3.23 and 14.58 for 2002-03 and

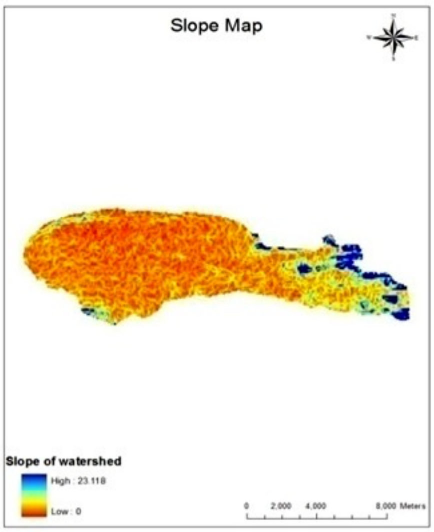

Figure 3: Slope map of Sonwal watershed in degree

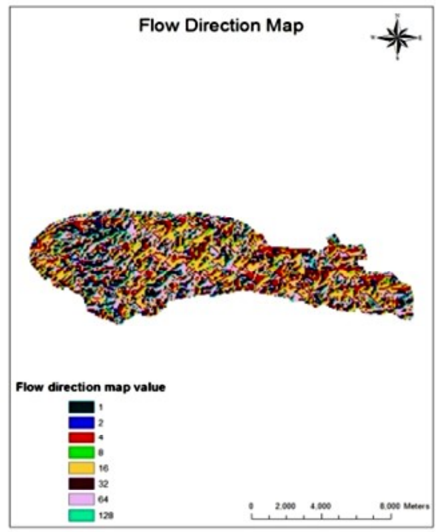

Figure 4: Flow direction map of Sonwal watershed

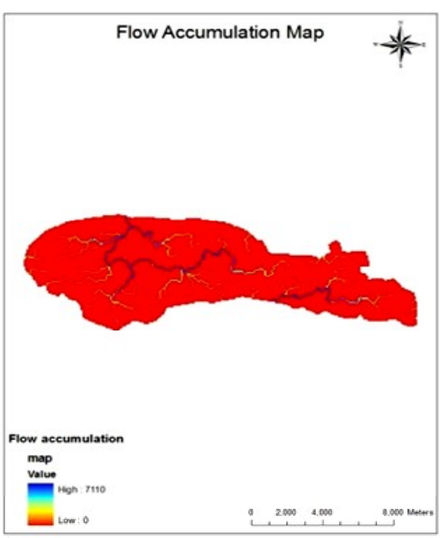

Figure 5: Flow accumulation map of Sonwal watershed

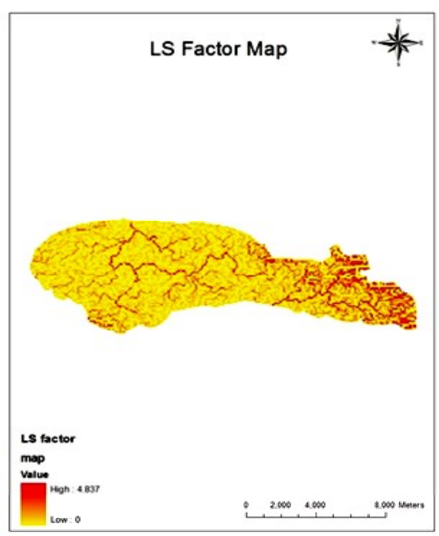

Figure 6: LS factor map of Sonwal watershed

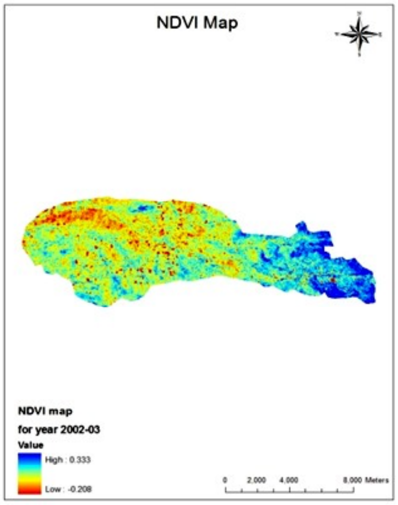

Figure 7: NDVI map of Sonwal watershed for year 2002-03

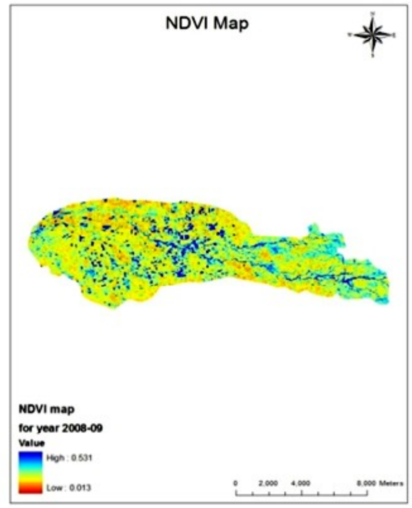

Figure 8: NDVI map of Sonwal watershed for year 2008-09

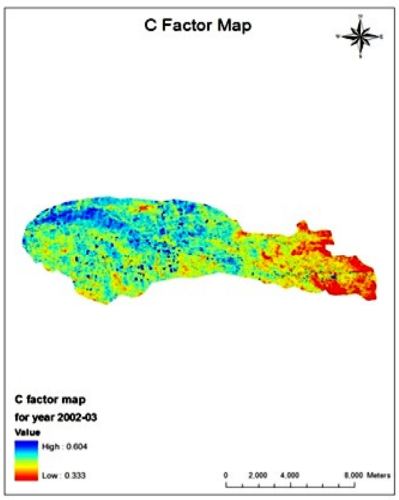

Figure 9: C factor map of Sonwal watershed for year 2002-03

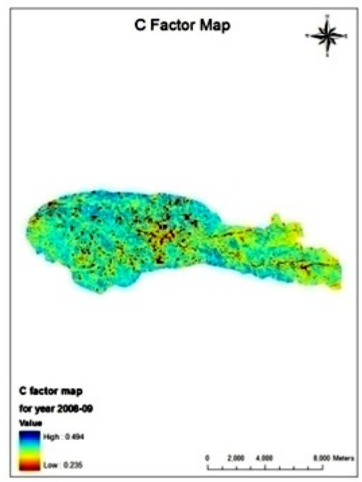

Figure 10: C factor map of Sonwal watershed for year 2008-09

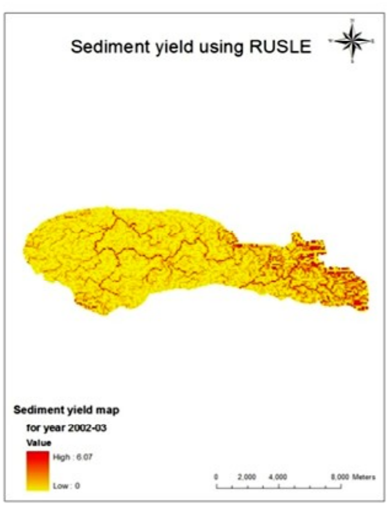

Figure 11: Sediment yield map of Sonwal watershed for year 2002-03 using RUSLE equationwatershed

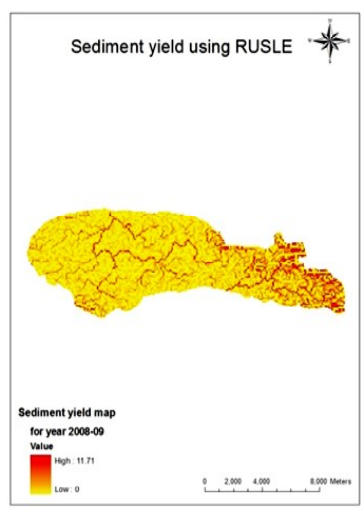

Figure 12: Sediment yield map of Sonwal for year 2008-09 using RUSLE equation

Table 1 Increase in sediment yield in 2008-09 over 2002-03 ofSonwal watershed using RUSLE equation.

Year 2002-03 Sediment yield (t/ha/ year)	Year 2008-09 Sediment yield (t/ha/ year)	Increase in Sediment yield in 2008-09 over 2002-03 (t/ha/year)
6.07	11.71	5.64

Table 2 Comparison of observed and estimated sediment yield for year 2002-03 and2008-09 of Sonwal watershed using RUSLE equation.

Year	Observed Sediment yield (t/ha/year)	Estimated Sediment yield (t/ha/year)	Per cent change in Sediment yield(%)
2002-03	5.88	6.40	3.23
2008-09	10.22	10.99	14.58

2008-09 respectively. The per cent change shows that the RUSLE equation gives accurate results for sediment yield estimation. Hence, RUSLE equation is suitable for the Sonwal watershed for estimation of sediment yield. Also per cent increase of sediment yield in watershed from 2002-03 to 2008-09 shows that the watershed program is required for development of Sonwal watershed.

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