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Estimation of Runoff and Soil Erosion for Vishwamitri River Watershed, Western India Using RS and GIS

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Abstract: A watershed is an area covering all the land that contributes water after rainfall occurs to a common point. Watershed management programme is mainly for conservation and development of natural resources. Remote Sensing and Geographic Information System (GIS) are emerging very powerful tools for analyzing spatial distributed information. In these study satellite images of IRS-P6 LISS-III images have been used. Heavy runoff and soil erosion are two severe problems of watershed development. In the present study, SCS Curve Number (CN) is used to estimate the runoff and USLE equations are used to measure the soil loss from the study watershed. The present study is carried out on Vishwamitri river watershed, Panchmahal& Vadodara districts of Gujarat State, India having an area of 1185 Sq.km. The geographical location of the area lies between 22°00' and 22° 45' of north latitude and 73 ° 00' and 73 ° 45' of east longitude. The daily rainfall data of 5 rain gauge stations (1990-2013) was collected and used to predict the daily runoff from the watershed using SCS-CN method and GIS. The analysis shows that for the study period 1990-2013, minimum and maximum values of (a) yearly computed average rainfall are 336.28 mm and 2170.2 mm and (b) yearly computed average runoff are 49.49 mm and 800.19 mm respectively. All five parameters of USLE equation for soil loss viz. R, K, LS, C, and P were estimated. Watershed based analysis for erosion shows that two sub watersheds coded as SW1 & SW2 are experiencing very severe soil erosion conditions whereas remaining two sub watersheds coded as SW3 & SW4 are subjected to moderate soil erosion conditions. The average computed annual soil loss from study watersheds is 60.65 ton /ha/year.

Keywords: GIS, Watershed, SCS-CN, USLE

1. Introduction

A watershed is the area covering all the land that contributes runoff water to a common point. It is a natural physiographic or ecological unit composed of interrelated parts and functions. Each watershed has different characteristics like size, shape, slope, geology, soil, geomorphology, land use, vegetation. In India the availability of accurate information on runoff is scarce. The soil conservation service curve number (SCS-CN method) also known as hydrologic soil group method was used, this method is a versatile and popular for quick runoff estimation and is relatively easy to use with minimum data and it gives adequate results (Chatterjee et al 2001; Gupta & Panigrahy 2008).

Soil is the top layer of the earth's surface that is capable of sustaining life. Therefore, soil is very important to farmers, who depend on soil to provide abundant, healthy crops each year. In India a total of 1 750 000 km^2 out of the total land area of 3 280 000 km^2 is prone to soil erosion. Thus about 53% of the total land area of India is prone to erosion (Narayana & Ram Babu, 1983).Soil erosion is one of the biggest global environmental hazards causing severe land degradation.

Population explosion, deforestation, unsustainable agricultural cultivation, and overgrazing are among the main factors causing soil erosion hazards (FAO, 1990; Reusing et al., 2000). Universal Soil Loss Equation (USLE) are the most popular empirically based models used globally for erosion prediction and control and has been tested in many agricultural watersheds in the world.

Remote sensing and GIS techniques have become valuable tools specially when assessing erosion at larger scales due to the amount of data needed and the greater area coverage. For this reason use of these techniques has been widely adopted.

2. Study Area

The study area is located between 22° 00’ and 22° 45’of North Latitude and 73°00’ and 73°45’ of East Longitude in Panchmahal and Vadodara districts, in Gujarat State.

The climate of Vishwamitri river watershed is semi-arid and sub-tropical having a temperature range of 21° to 41°C in summer and 7° to 29°C in winter. Most of rainfall is received during the mid-June to early October.

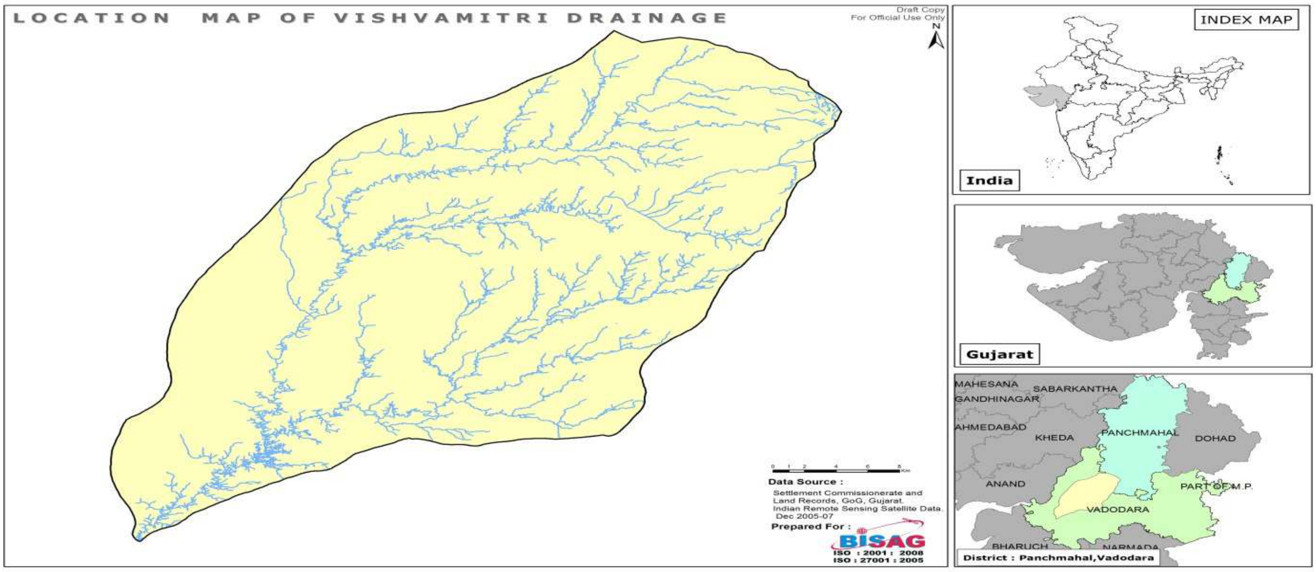


Fig. 1. *Location map of study area.*

The annual rainfall varies from 850 to 1000 mm out of which about 80% occurs during Southwest monsoon season. The watershed has dendrite drainage pattern. The total geographical area of the watershed is 1185 km^2.

The topography of the area is generally flat to gently sloping, with the elevation ranges from 829 m to 13 m above mean sea level. Five rainguage stations covers entire watershed namely Halol, Wadala tank, Vadodara, Waghodia, Pilol.

3. Methodology for Runoff Calculation

3.1. Soil Conservation Service (SCS) Method

In the early 1950s, the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) (then named the Soil Conservation Service (SCS)) developed a method for estimating runoff from rainfall. The SCS curve number method isbased on the water balance equation and two fundamental hypotheses which are stated as,

1) Ratio of the actual direct runoff to the potential runoff is equal to the ratio of the actual infiltration to the potential infiltration,
2) The amount of initial abstraction is some fraction of the potential infiltration (Handbook of hydrology, 1972).

$$\frac{Q}{(P-Ia)} = \frac{F}{S} \quad (1)$$

$$F = (P - Ia) - Q \quad (2)$$

Substituting eq. (2) in eq. (1) and by solving;

$$Q = \frac{(P-Ia)^2}{(P-Ia)+S} \quad (3)$$

Where, Q = Actual runoff (mm), P = rainfall (mm), Ia = initial abstraction, which represents all the losses before the runoff begins and is given by the empirical equation.

$$Ia = 0.2\ S \quad (4)$$

Substituting eq. (4) in eq. (3); the eq. (3) becomes

$$Q = \frac{(P-0.2S)^2}{(P+0.8\ S)} \text{For } P > Ia\ (0.2S) \quad (5)$$

S = the potential infiltration after the runoff begins given by following equation.

$$S = \frac{25400}{CN} - 254 \quad (6)$$

Where, CN is Curve Number.

The CN (dimensionless number ranging from 0 to 100) is determined from a table, based on land cover, HSG, and AMC. Although, SCS method is originally designed for use in watersheds of 15 km^2, it has been modified for application to larger watersheds by weighing curve numbers with respect to watershed/land cover area. The equation of weighted curve number is Given Below.

$$CNw = \frac{\sum(CNi * Ai)}{A} \quad (7)$$

Where CNw is the weighted curve number; CN_i is the curve number from 1 to any number N; A_i is the area with curve number CN_i; and A the total area of the watershed.

3.2. Data Used

In present study daily rainfall data from five rain gauge stations for the year of 1990-2013 (24 years) data were collected from the State Water Data Centre (SWDC), Gandhinagar, Gujarat.

Various thematic maps such as Land Use map, Soil map, Slope map and LISS-III satellite image of year 2013 was collected from BISAG, Gandhinagar, Gujarat. (If possible Put Fig-2(a) & (b) below this section).

3.3. Antecedent Soil Moisture Condition (AMC)

Antecedent Moisture Condition (AMC) refers to the water content present in the soil at a given time. It is very important factor for determine final CN value.

SCS developed three antecedent soil-moisture conditions (I, II, III,) according to soil conditions and rainfall limits for dormant and growing seasons.

In present study average condition (AMC-II) is taken for determine CN value for study area.

3.4. Hydrologic Soil Group Condition (HSG)

SCS developed soil classification system that consists of four groups, which are identified as A, B, C, and D according to their minimum infiltration rate.

CN values were determined from HSG and AMC of the watershed. For present study, average condition (AMC II) is selected foe study area. Runoff curve numbers for (AMC II) for hydrologic soil cover are shown in Table 1.

Table 1. *Runoff curve numbers (AMC II) for hydrologic soil covers (Ref-TR 55, 1986).*

Land use	Hydrologic Soil Group			
	A	B	C	D
Agriculture (without Kharif)	72	81	88	91
Double Crop	62	71	88	91
Plantation	45	53	67	72
Commercial	89	92	94	95
Industrial	81	88	91	93
Urban	89	92	94	95
Village	72	82	87	91
Land with scrub	36	60	73	79
Land without scrub	45	66	77	83
Scrub forest	33	47	64	67
Canal	100	100	100	100
River	97	97	97	97
Reservoir	100	100	100	100
Prosophis	61	70	74	78
Quarry	71	87	89	91

3.5. Weighted Area Curve Number

Different layers of land use/Land Cover, Soil, HSG were added in Attribute table using union tool in ArcGIS 9.3.

The result obtained from union attribute was used to compute Weighted area curve Number of the study area. Calculated value of CN is 88.14 (taking CN=88) in Table 2.

Table 2. *Calculation of Weighted Curve Number for AMC II.*

Land use	Soil type	CN	Area in km2	(%)of Area	(%)of Area*CN	(WCN)
Agriculture	C	88	883.26	74.54	6559.23	
	D	91	47.89	4.04	367.73	
Buit up	C	94	119.51	10.08	947.99	
	D	95	2.31	0.194	18.50	
Waste land	C	77	49.90	4.211	324.27	
	D	83	1.60	0.135	11.23	
Forest	C	77	3.2	0.2695	20.75	88.14
	D	83	0.140	0.011	0.977	
Water bodies	C	100	34.96	2.95	294.98	
	D	100	1.72	0.15	14.54	
Others	C	74	38.53	3.25	240.59	
	D	78	1.99	0.17	13.11	

3.6. Calculation of Runoff

In Present study, Calculation of Runoff was done using Eqn.5 for which Potential maximum Retention (S) is 34.64 and Initial abstraction Ia is 6.93.

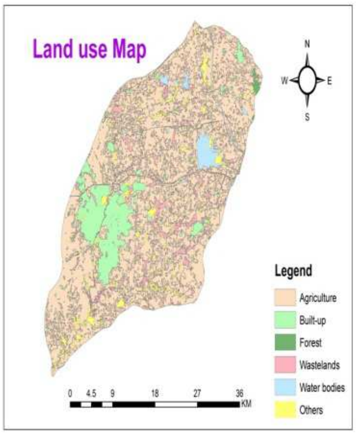
The following procedure was used to calculate the surface runoff:

1). Deciding Antecedent Moisture Condition (AMC-II) as taken here.

2). Preparation of land use/land cover (Fig-2-a) & soil map (Fig-2-b) using satellite images.

3). Preparation of the hydrological soil group layer from available soil map.

4). Integrating HSG and LU/LC maps in GIS environment and estimate CN (Table-2).



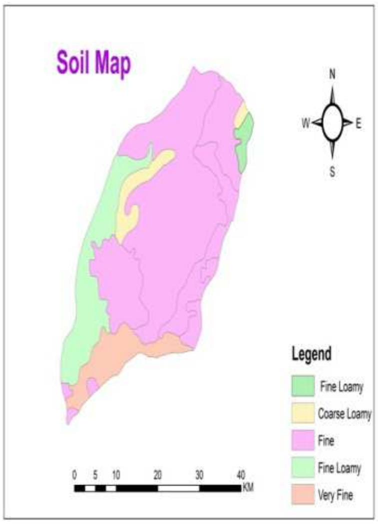


Figure 2. *(a) Land Use map; (b) Soil Map.*

5). Calculate potential maximum retention (S) using Eqn.6 & Initial Abstraction(Ia) using Eqn.4

6). Calculation of daily, monthly & annually runoff using eq.5

In Present study average rainfall and average runoff for the period of (1990-2013) shows increasing over the Vishwamitri River Watershed shows in Fig.3

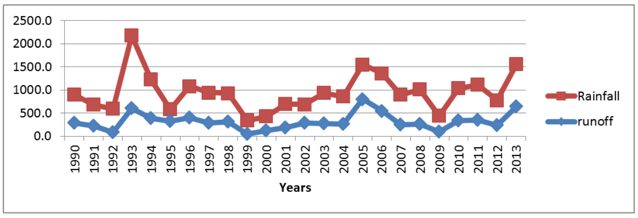


Fig. 3. *Average annual rainfall vs Annual runoff.*

Table 3. *Average Rainfall-Runoff of Vishwamitri River Watershed.*

Year	Rainfall(mm)	Runoff (mm)
1990	898.7	288.1
1991	676.7	223.6
1992	594.9	91.9
1993	2170.2	603.5
1994	1220	390.4
1995	582.62	332.01
1996	1078.9	407.7
1997	939.7	294
1998	928.33	315.71
1999	336.28	49.49
2000	431.7	126.3
2001	691.9	185.2
2002	687.5	291.8
2003	934.9	281.2
2004	854.8	261.2
2005	1547.96	800.19
2006	1357.3	548.6
2007	899	252.2
2008	1012	261.1
2009	437.38	99.25
2010	1036.6	340.2
2011	1106.1	350.1
2012	775.08	242.06
2013	1555	639.7

4. Methodology for Soil Erosion

4.1. Universal Soil Loss Equation

The Universal Soil Loss Equation (USLE) an Empirical model for predicting the annual soil loss caused by rainfall was developed by Wischmeier and Smith (1965).

The Universal Soil Loss Equation (USLE) widely applied at watershed scale to predict the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, and topography. Crop system and management practices (Williams and Berndt,1972, 1977).

The universal Soil Loss Equation is defined as,

$$A=R*K*LS*C*P \tag{8}$$

Where,
A= Annual computed Soil Loss (ton/ha/year)
R=Rainfall Erosivity factor
K=Soil Erodibility factor
LS= Slope-length factor
C= Crop management factor
P= Supporting Practice management factor

In present study, calculation of Soil Erosion using USLE based on Sub watershed level. Vishwamitri river watershed has four sub watersheds given in Figure 4.

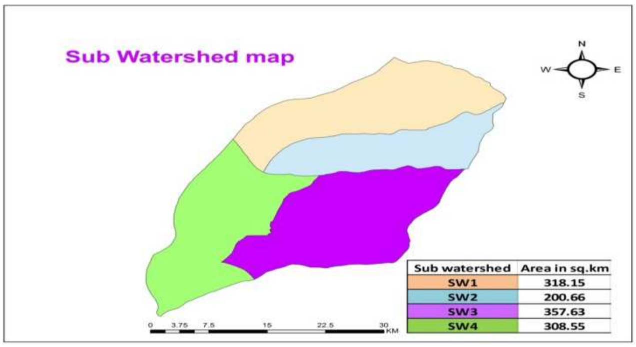


Fig. 4. *Sub watershed map.*

4.2. Rainfall Erositivity Factor (R-Factor)

Soil erosion is closely related to rainfall through the combined effect of detachment by raindrops striking the soil surface and by the runoff. According to USLE method, soil loss from the cultivated field is directly proportional to a rain storm parameter, if other factors remain constant. Rain-erosivity (*R*) is calculated as a product of storm kinetic energy (*E*) and the maximum 30 minutes rain fall intensity. This relationship helps to quantify the impact of rain drop over a piece of land and the rate of runoff associated with the rain. But In present area that kind of detailed meteorological data is not available for all the stations in the study area. The R factor was determined using formula given below (Chaudhry and Nayak, 2003).

$$R_a=79+0.363*X_a \tag{9}$$

Where,
R_a = Annual R factor,

X_a= Average Annual Rainfall in mm.

In present study, Rainfall data for 5 rain gauge stations have available for estimating the R factor, such as Halol, Wadala Tank, Vadodara, Waghodia, Pilol. All five rainguage stations are situated within the watershed boundary.

The average annual rainfall erosivity (R_a) was calculated using rainfall data of above rain gauge stations for the years (1990-2013).

***Table 4.** Average Annual Rainfall Erositivity factor.*

Station Name	Average Annual Rainfall (1990-2013)		
	Rainfall in mm	R-factor	(R_a=79+0.363*X_a)
Halol	1062.55	464.71	
Wadala Tank	677.18	324.82	
Vadodara	1020.48	449.43	
Waghodia	867.70	393.97	
Pilol	869.28	394.55	

In present study R factor is used by Sub watershed approach. As Vishwamitri river watershed has 4 sub watersheds. So the calculated value for sub watershed is given below in table 5.

***Table 5.** Calculated R- factor.*

Sub watershed	Rainguage Stations	Calculated R-factor
SW1	Halol, Wadala tank	627.12
SW2	Halol, Wadala tank, Waghodia	920.85
SW3	Waghodia, Vadodara, Pilol	974.92
SW4	Vadodara	449.43

4.3. Soil Erodibility (K) Factor

Soil Erodibility factor represents the soil susceptibility to detachment and transport of soil particles under an amount of runoff for specific rainfall. The K factor is rated mainly scale from 0 to 1, where 0 is for least susceptibility soil for erosion and 1 is for High susceptibility soil for erosion by water.

***Table 6.** K- factor values for different textures(Ref- stewert et.al-1975).*

Textural class	Organic matter Content (%)		
	0.5	2	4
Fine sand	0.16	0.14	0.1
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.1	0.08
Loamy Very fine sand	0.44	0.38	0.3
Sandy loam	0.27	0.24	0.19
Very fine sandy loam	0.47	0.41	0.33
Silt loam	0.48	0.42	0.33
Clay loam	0.28	0.25	0.21
Silt clay loam	0.37	0.32	0.26
Silty Clay	0.25	0.23	0.19

In Present study consists of soil texture classes namely as 1) Course loamy 2) Fine sand 3) Fine loamy. From above texture of classes, organic matter content normally varies from (1.5 to 2.6 %- taken 2 %). K values for different soil textures has defined by the stewert et.al (1975) which is given in table 6.

***Table 7.** Calculated average value of K- factor for different sub watershed.*

Sr.no	Sub watershed	Calculated K-factor
1	SW1	0.26
2	SW2	0.25
3	SW3	0.28
4	SW4	0.26

4.4. Slope Length & Steepness (LS) Factor

The slope length and slope steepness can be used in a single index, which expresses the ratio of soil loss as defined by Wischmeier (1978).

$$LS = (X/22.1)^{m} * (0.065 + 0.045\ S + 0.0065\ S)^2 \quad (10)$$

X = slope length (m or km);

S = slope gradient (%)

Slope value was derived from Digital Elevation Model (DEM) of vishwamitri river watershed.

The values of X and S were derived from DEM. To calculate the slope length (X) value, Flow Accumulation was derived from the DEM after conducting Fill and Flow Direction processes by using Arc Hydro tool in ArcGIS 9.3.

$$\text{Slope Length } (X) = (\text{Flow accumulation} * \text{Cell value}) \quad (11)$$

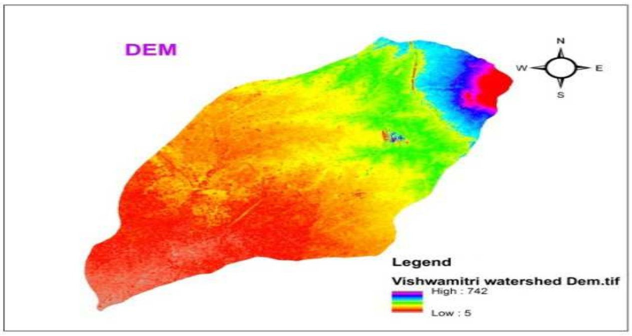
By substituting X value, LS equation will be:

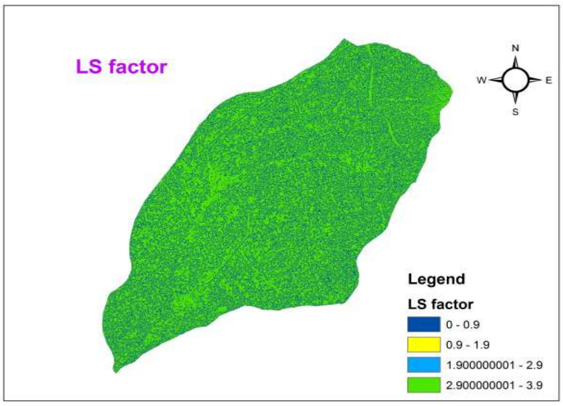
$$LS = (\text{Flow accumulation}*\text{Cell value} /22.1)\ m\ (0.065 + 0.045\ S + 0.0065\ S^{\wedge}2) \quad (12)$$

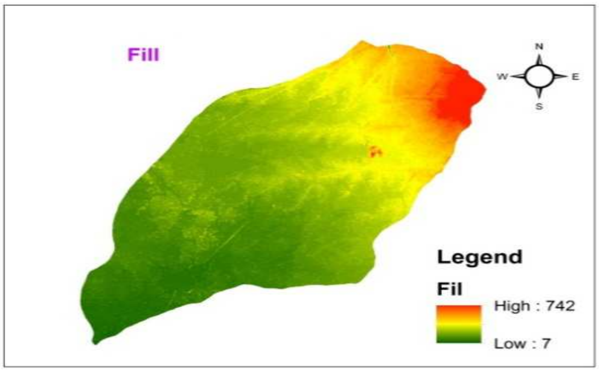
Moreover slope (%) also directly derived from the DEM using ArcGIS 9.3.

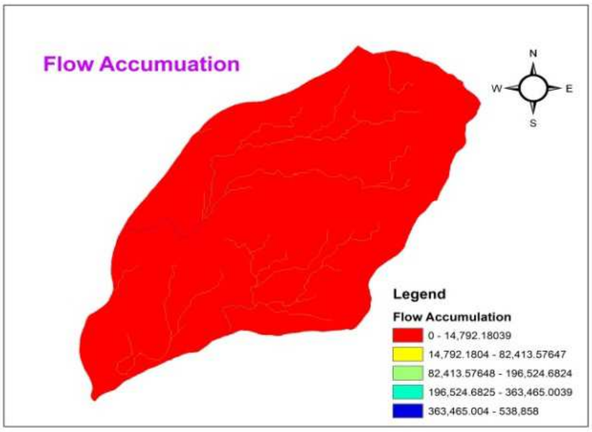
***Table 8.** M value.*

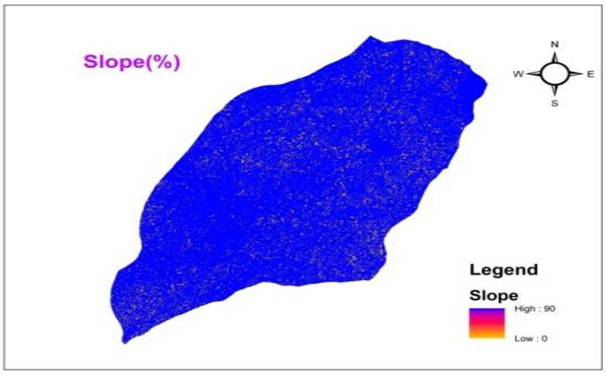
Slope (%)	1 < Slope (%)	1<Slope(%) ≤3	3 < Slope (%)< 5	Slope (%) ≥ 5
m - value	0.2	0.3	0.4	0.5











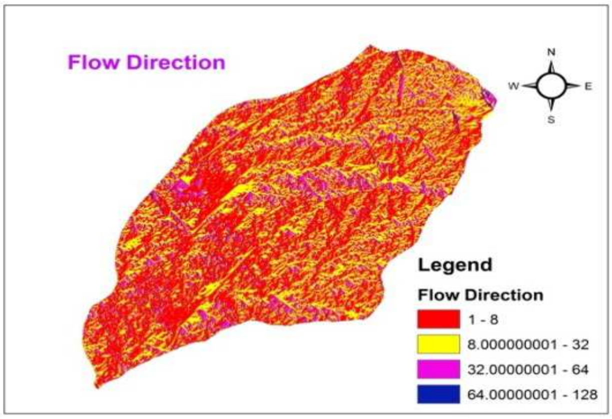


Fig. 5. *Procedure for LS factor Calculation.*

The value of m varies from 0.2 –0.5 depending of the slope as shown in table 8 (Wischmeier and Smith, 1978) which is used for above LS calculation. The result of the analysis is shown in figure (5).LS factor is calculated using Raster Calculator in Arc GIS software. Step by step procedure will describe below.

4.5. Procedure for LS factor Using ArcGIS 9.3

1) In ArcGIS 9.3 check in extension that Arc Hydro tool is marked or not. Mark Arc Hydro tool is used for calculation of LS factor.
2) Click on Terrain Preprocessing then click on DEM manipulation click on Fill sinks. It will fill automatically. After fill successfully a new map is generated.
3) Now, Slope map is created using DEM.
4) Calculate Using Raster calculator plot the below equation.

Again click on Terrain Preprocessing then click on Flow Direction. It will automatically give flow direction and a new map is generated.

Again click on Terrain Preprocessing then click on Flow Accumulation. It will accumulate flow and a new map is generated.

LS= (("Fac"*25/22.1)^0.2)*(0.065+0.045*"Slope" +0.0065*("Slope"*"Slope"))(13)

After following above procedure to calculate LS factor using Arc Hydro tool in Arc GIS the final result shows the value of LS factor in given Table 9.

Table 9. *Calculated LS factor values.*

Sr.no	Sub watershed	Calculated LS factor
1	SW1	3.43
2	SW2	3.41
3	SW3	0.12
4	SW4	0.29

4.6. Crop Management (C) Factor

The crop management factor is used to reflect the effect of cropping and management purpose on erosion rates. It represents the ratio of soil loss under a given crop to that of the Base soil (Morgan, 1994).

It is considered the second major factor (after topography) controlling soil erosion. An increase in cover factor indicates a decrease in exposed soil, and thus an increase potential soil loss.

The C factor is calculated depending upon different land use types as per below Table 10 (Wischmeier and Smith 1978).

Table 10. *C- factor values for different land use/ land cover.*

Land use	Sub Land use	C-factor
Agriculture	Current Fallow	0.6
	Kharif + Rabi (Double cropped)	0.6
	Kharif Crop	0.5
	Plantations	0.5
Buit up	Commercial	0.2
	Industrial	0.2
	Towns/cities (Urban)	0.2
	Villages (Rural)	0.2
Forest	Scrub Forest	0.02
Others	Prosophis	0.15
	Quarry	0.15
Waste land	Land with Scrub	0.95
	Land without Scrub	0.8
Water bodies	Canal	0
	Lakes / Ponds	0
	Reservoirs	0
	River	0

In present study, for vishwamitri river watershed C factor is calculated depending upon different land use types. Each land use/ land cover has a value varies from 0 to 0.95 as per below in Table 11.

Table 11. *Average values of C- factor for Sub watershed.*

Sr.no	Sub watershed	Calculated C-factor
1	SW1	0.30
2	SW2	0.31
3	SW3	0.34
4	SW4	0.31

4.7. Conservation Practice (P) Factor

Conservation practice factor (P) in USLE expresses the effect of conservation practices that reduce the amount and rate of runoff, which reduces soil erosion.

It is the ratio of soil loss with a support practice on croplands to the corresponding loss with up & down slope (Renard et.al., 1997).

Table 12. *Conservation Practice (P) factor on different slope gradient.*

Sr.no	Slope percentage (%)	P factor
1	0 - 1 %	0.6
2	1 - 3 %	0.6
3	3 - 5 %	0.5
4	5 - 10 %	0.5
5	10 - 15 %	0.7
6	15 - 35 %	1

It includes different types of agricultural management practices such as: Strip cropping, Contour farming, and terracing etc.

In present study, P factor is derived from the land use/land cover type map. Each value of P was assigned to each land use/land cover type and slope. The value of P –factor ranges from 0 to 1, in which highest value is assigned to areas with no conservation practices. The lower the P value, the more effective the conservation practices.

In vishwamitri river sub watershed slope percentage (%) is varies up to 35 %. As value of P factor was calculated for each sub watershed in Table 13.

Table 13. *Average conservation practice (P) factor for sub watershed.*

Sr.no	Sub watershed	Calculated P-factor
1	SW1	0.58
2	SW2	0.58
3	SW3	0.60
4	SW4	0.60

4.8. Procedure for Using USLE

1) Determine the R factor using available Rainguage station data which covers watershed (Table 5).
2) Based on the soil texture, determine the K value (Table 7). If there is more than one soil type in a field is present and the soil textures are not very different, use the soil type that represents the majority of the field.
3) Divide the field into sections of uniform slope gradient and length. Assign an LS value to each section using Arc Hydro tool in Arc GIS interface (Table 9).
4) Choose the crop type factor and tillage method factor for the crop to be grown. Multiply these two factors together to obtain the C factor (Table 11).
5) Select the P factor based on the support practice used (Table 13).
6) Multiply above all 5 factors to calculate Annual soil erosion (Ton/ha/year) (Table 14).

Table 14. *Annual Soil Erosion for different sub watershed.*

Sub watershed	R-factor	K-factor	LS-Factor	C-factor	P-factor	Annual Soil Erosion (ton/ha/year)
SW1	627.12	0.26	3.43	0.3	0.58	97.31
SW2	920.85	0.25	3.14	0.31	0.58	129.97
SW3	974.92	0.28	0.12	0.34	0.6	6.68
SW4	449.43	0.26	0.29	0.31	0.6	6.30
			Total Annual Soil Erosion			240.27

4.9. Soil Erosion Calculation

In this study, A Quantitative assessment of vishwamitri river watershed is taken place using USLE. All five parameters of Universal Soil Loss Equation (USLE) are calculated for each four sub watershed. After calculation of all five parameters of USLE, annual soil erosion of vishwamitri river watershed is 240.27 ton /ha/year as shown in Table-14.

As per the different class group category given by the Rambabu& Narayan for erosion by water in India is given in Table 15.

Table 15. *Different classes of soil erosion by water in India(Ref- Rambabu& Narayan)*

Sr.no	Soil erosion class group	Soil erosion range(ton/ha/year)
1	Slight	0-5
2	Moderate	5-10
3	High	10-20
4	Very High	20-40
5	Severe	40-80
6	Very Severe	>80

5. Conclusion

Vishwamitri river watershed consists of different Land uses/covers. About 79 % of the area is cover by Agricultural land, 10 % area is built up, 3 % area is cover by water bodies and remaining 8 % area is wastelands, quarries etc.

The computed values of minimum and maximum (a) Yearly average rainfall are 336.28 mm and 2170.2 mm respectively and (b) Yearly average runoff are 49.49 mm and 800.19 mm respectively.

The soil losses estimated using Universal Soil Loss Equation (USLE) has been carried out for Vishwamitri River Watershed. After calculation of the five parameters of USLE for the all four sub watersheds, it is found that two sub watersheds coded as SW1 & SW2 are subjected to very severe conditions of erosion (given in Table-16) and needs some watershed treatment to control the high rate of erosion.

Table 16. *Classes of soil erosion & prioritization vishwamitri watershed.*

Sub watershed	Annual Soil Erosion	Class group	Priority
SW1	97.31	Very Severe	2
SW2	129.97	Very Severe	1
SW3	6.68	Moderate	3
SW4	6.3	Moderate	4

The other two sub watersheds coded as SW3 & SW4 are subjected to moderate conditions of erosion. The annual computed soil loss from the whole Vishwamitri river watershed is 240.27 ton /ha/year.

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