Journal of Indian Geomorphology
Volume 6, 2018 ● ISSN 2320-0731
Indian Institute of Geomorphologists (IGI)

Application of RUSLE-3D Model to Predict Soil Loss from a Watershed in Western Deccan, Maharashtra

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Abstract: *Deccan volcanic province of exhibits a rocky terrain. Sediment layers are thin wherever they are present and confined along the narrow banks of the rivers and along some foot-slopes. The present study is an attempt to estimate soil loss from a watershed of the Tapi Basin in Western Deccan, by employing Revised Universal Soil Loss Equation-3D (RUSLE-3D) model in GIS platform. The area is a narrow alluvial zone where the banks are dissected by gullies to form badlands. These badlands have been levelled and reclaimed for agriculture in the last two decades. Availabilityof data poses a serious limitation in such studies in the area.Cartosat-I stereo images were used to create a DEM of 10 m resolution to obtain topographic LS factor and IRS LISS-4 multispectral images were used for calculating crop vegetation index C and conservation factor P. Soil classes identified by Soil and Landuse Survey of India was used as guideline and for each soil class andsamples were also collected from the field and analysed. Final K factor map was generated following the criteria suggested by earlier workers. The R value was generated using the EI_{30} data tablespublished for few stations of India and the rainfall of those stations were obtained from the Indian Meteorological Department. The result indicates that the area has annual sediment loss of 2.42 kg $m^{-2}year^{-1}$. Comparing this value with the tolerance limit reported from other studies indicate that the value is high, more so from theDeccan region that lacks a thick sedimentlayer in general.*

Introduction

Soil erosion may be defined as the detachment and transportation of soil (Tideman, 1996) and is a serious environmental issue all over the world. The situation is more serious in the densely populated tropical regions due to the heavy pressure of population on the land (Sinha and Joshi, 2012). Due to rapidly growingpopulation in India, every available piece of land has been brought under various economic activities, especially agriculture, which puts enormous pressure on the land. Due to improved technology and better availability of irrigation facilities in many states of India, even the inhospitable areas that were once left untouched, have now been reclaimed for agriculture.One such example is the rapid reclamation of badlands all overthe country. It is estimated that in India, out of the total reported geographical area of 329 million ha, about 169 million ha (51% of the total) are affected by soil degradation. About 127 million ha of land are subject to serious soil erosion and 40 million ha are degraded through gullying, ravine formation, shifting cultivation, water-logging, salinisation, increase in alkalinity, shifting of river courses, desertification etc. (Das, 2012). There are a few studies on soil erosion reported from the Indo-Gangetic plains of India. However, Deccan trappe basalt terrain is a stark contrast to the Indo-Gangetic plain as the region is completely rocky with very little sediment deposition. Sedimentlayers are thin and are found only at specific areas, such as, narrow belts along the river banks and at some foothills. Some of these alluvial tracks are deeply dissected by gullies to form badlands. It has been observed that over the last few decades, these badlands have been largely levelled for agriculture. So far, studies on soil erosion from these areas are very few. Joshi (2014) reported soil loss from a few catchments using field techniques, such as, micro-profilometer and erosion pin method. Based on the plot experiments by simulating rainfall, Joshi and Tambe (2010) established the soil loss under different landuse category in a small watershed in Maharashtra.The study of Joshi and Nagare (2010) demonstrated that land reclamation, vegetation clearance, excessive irrigation and introduction of new land use practices which are not suitable in the area have the increased the rates of land degradation, salinisation and soil erosion. Barring these studies of small areas, very few attempts have been made to generate data or establish any model of soil erosion on a watershed or basin from any part of the Deccan volcanic province. Hence, dearth of data is a serious problem in carrying out soil erosion studies in this area. Many parameters that are required for modelling soil erosion are not available in the desired format. Data are meager and patchy, be it for climatic, soil, slope or ground cover parameters.

Objectives

The objective of the present study is to generate data for the variables of the soil loss model RUSLE-3D in this regionand to calculate the amount of soil loss from a deeply disturbed watershed that is characterised by badland topography.

Universal Soil Loss Equation (USLE)

Many predictive equations have been developed to estimate soil loss from drainage basins. However, the most accepted, used, convenient and suitable technique for assessing soil loss from small areas, such as, hill slopes and fields is the USLE. Wischmeier and Smith, (1962) developed the USLE model to predict the long term average annual rate of erosion on a field slope based on the indices derived from rainfall pattern, soil type, topography, cropping system and management practices.

USLE is expressed as: A=R.K.LS.C.P

Where, A= Potential long term average annual soil loss in tons acre^{-1}year^{-1}, R= Rainfall erosivity factor, K= Soil erodibility factor, LS= Slope length-gradient factor, C= Crop factor, P= Conservation practice factor.

The equation that was originally formulated for small agricultural plots has been modified and revised by different authors to suite different landuse scenarios of the world. USLE thus transformed into Modified Universal Soil Loss Equation (MUSLE) (Williams and Berndt, 1977); Revised Universal Soil Loss Equation (RUSLE) (Renard *et al*., 1997) and Universal Soil Loss Equation for Forests (FUSLE) (Zhang Jin-Chi *et al*., 2008).

At about the same time there was an influx of newly formulated soil loss models, both empirical and field-based, but with foundations on the USLE. Some of the most popularly applied models are WEPP (Water Erosion Prediction Project, Flanagan and Nearing, 1995); EGEM (Ephemeral Gully Erosion Model, USDA-NRCS 1992); SWAT (Soil-Water Assessment Tool,Arnold *et al.*, 1993); WaTEM (Water and Tilage Eroson Model, Van Oost *et al*., 2000); SEDEM (Sediment Delivery Model, Van *et al.*, 2001); ANSWERS (Areal Non point Source Watershed Environment

Response Simulation, Beasley *et al.*, 1980); EPIC (Erosion-Productivity Impact Calculator,Williams *et. al*., 1982), etc. RUSLE and WEPP are hillslope erosion models, SEDEM is based on RUSLE but incorporates sediment transport, EPIC and SWAT and ANSWERS are watershed-scale models that are all based on USLE / RUSLE technique for erosion estimation and EGEM is an ephemeral gully model that does not include a hillslope component.In India, soil erosion studies are still in its infancy and no soil loss model has been evolved for the country yet.

RUSLE (Revised Universal Soil Loss Equation, (Renard *et al.*, 1997) is landuse independent and can be used in a variety of environments.RUSLE uses the same empirical principles as USLE but algorithms have been changed andnumerous improvements have been made, such as—computerisation of the technique, new and revised iso-erodent maps, time varying approach for soil erodibility factor, sub-factor approach for evaluating C factor, upslope contributing area for calculating LS factor and new P values. Later it evolved as computer models known as $RUSLE_1$ (text-based DOS version) and $RUSLE_2$ (empirical and process-based, in Windows environment). Even though $RUSLE_2$ model is considered as one of the best soil loss models so far that can be applied in variety of landuse and climatic conditions with reliable results,it is difficult to apply in India because there is no data bank and available data are of poor resolution. In spite of all the difficulties the present paper is an attempt to generate data to estimate soil loss from a riverine alluvial zone in the western Deccan, by employing RUSLE-3D (Revised Universal Soil Loss Equation, Mitasova*et al.*, 1996). Hence, focus is on generating site specific data for all the variables of RUSLE-3D model. Attempt will also be to improve data quality by adopting a few non-traditional techniques.

Study Area

The watershed under study is in the middle Tapi basin which is in the northern part of the Deccan plateau. More than 78% of the Tapi basin lies in the state of Maharashtra. The study area is located close to Yawaltown in the Jalgaon district of Maharashtra. The area of interest extends from 75° 24′ E to 75° 52′ E and from 20° 57′ N to 21°16′ N, covering an area of approximately 802 km^2 (Fig 1). River Tapi is the second largest west flowing

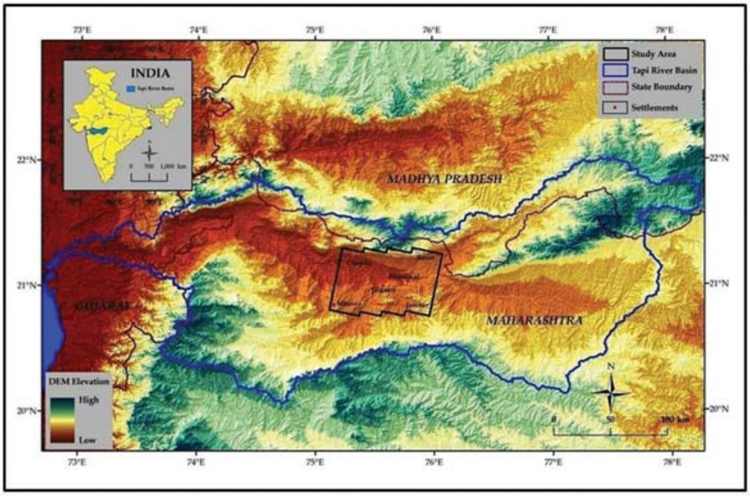

Figure 1. ASTER DEM of Tapi basin showing area of interest within the basin which is covered by 8 scenes of Cartosat images.

river in peninsular India. The area has an average altitude of 760 m ASL. It receives about 450–500 mm of rainfall per year and is located in the semi-arid, rain shadow zone of the Western Ghats in Maharashtra. Natural vegetation consists of thorny acacias that are typical of semi-arid regions. Hillslopes are mostly bare, except where planted.The banks along the Tapi in this stretch are subject to the past few decades, there are barely any natural slopes left in this area that are not disturbed by human activities. This may have increased the instability and promoted accelerated erosion. Few monitoring sites and experimental studies have indicated rapid soil loss from these areas (Joshi, 2014). Clearance of vegetation for the purpose of agriculture is not new in India and has been

Figure 2. View of the study area where natural badlands are levelled for agriculture

the processes of gullying and ravination, which have transformed a major part of the landscape into badland terrain. There are many pockets along the river banks where deeply dissected badlands are found. Such badlands along these parts of Trappeterrain have been attributed to lineament controlled block displacements (Joshi and Nagare 2013). Being located well above the local base level the streams are trying to reach equilibrium by eroding down the slopes. In in practice along the forested hillslopes for a long time. In the last few decades, agriculture has resulted in clearance of vegetation and encroachment in inhospitable areas as well. The area under investigation is a rocky terrain and sediments are thin wherever they are present. Some of these deposits have been deeply dissected bynetwork of gullies at many localities form badlands. The current trend is to reclaim these badlands wherever feasible. In recent times, these badlands are shrinking in size asthese areas are being levelled for agriculture.Some of these areas have been completely altered in the last twenty years. Figure 2 demonstrates some of the areas where natural badlands have been disturbed, levelled and brought under cultivation. These hummocky badlands do not provide suitable sites for any economic use and they are found mostly in semi-arid areas in Maharashtra covered by acacia which do not provide easy access to these lands. Under different schemes, Maharashtra government promoted irrigation facilities to the farmers and many weirs and dams have been constructed across the rivers and the tributaries in the last two decades. Availability of water for irrigation boosted the agriculture in these semiarid areas in the last twenty years and the need for more land for agriculture became apparent. The badland have the potential to be reasonably productive for agriculture if irrigation is provided. This has led to massive badland reclamation for agriculture and in few sites, there are no traces of the previous landscape. They have been completely wiped out.

Model Computation

RUSLE-3D is computed using the following equation:

$A_{(r)} = R * K * LS_{(r)} * C * P$............ Equation 1

Where:

$A_{(r)}$ = The average soil loss per year (t $ha^{-1}y^{-1}$)

R = Rainfall intensity factor

K = Soil erodibility factor

LS = Topographic length-slope factor

C = Land cover factor

P = Soil conservation factor

The data source and the methodology has been depicted in the flowchart (Fig. 3).

Rainfall Erosivity (R)

The erosivity factor is the product of

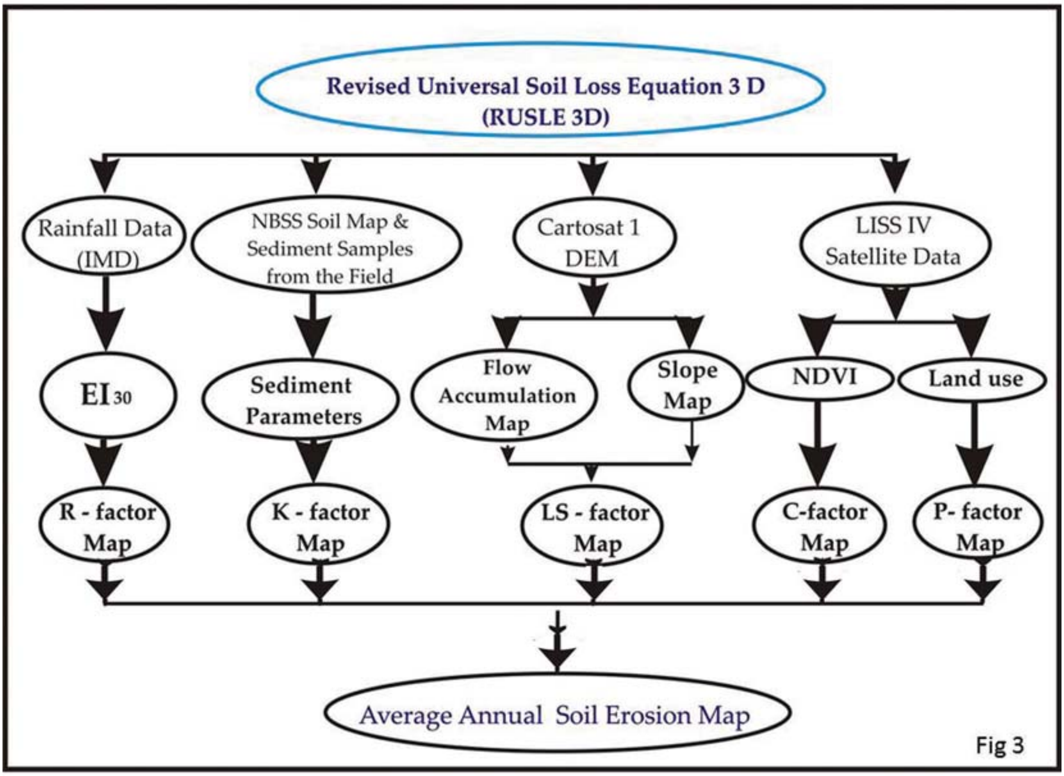

Figure 3. Flowchart of the data and methodology of RUSLE-3D

the kinetic energy of the raindrop and the maximum intensity of rainfall over duration of 30 minutes in a storm, a product known as the EI value.The kinetic energy of rainfall (E) is calculated by using the following formula (Wischemeier and Smith, 1978)

$E = \sum E_i$ .... Equation 2

$E_i = \sum(200 + 87 \log_{10} I_i) P_i$ ....Equation 3

Where:

E_i = kinetic energy of the i^{th} rain increment, Jm^{-2}

I_i = average intensity of rainfall intensity in the i^{th} increment, cmh^{-1}

P_i = depth of rainfall in the i^{th} increment, cm

Rainfall erosion index (EI) for a given rainstorm equals the product of total storm energy (E in hundreds of foot-tons $acre^{-1}$) and maximum 30 minute intensity (I_{30} in inches $hour^{-1}$). In other words $EI = E \times I_{30} = EI_{30}$. The average annual storm EI value in a particular location is the rainfall erosion index for that particular locality. The location value of this index is the rainfall factor, R in the USLE (Babu *et al.*, 1978). Thus $R = \sum_1^n EI_{30}$ where n is the number of storms in the year.The kinetic energy of storm can be computed in metric units by using the equation developed by Wischmeier and Mannering (1969) and Raghunath *et al.*, (1970):

KE = 210.3 + 89 Log I ....Equation 4

Where:

KE = kinetic energy in metric ton-meters $ha^{-1}cm^{-1}$.

I = Rainfall intensity in cm^{-hr}

R factor is obtained using the following equation;(Wischemeier and Smith,1978):

$R = \sum(E_i.I_{30})/ 100$ ....Equation 5

n=0

Where:

E_i = rainfall kinetic energy, $J.m^{-2}mm^{-1}$ where, $J = (kg.m^2).s^{-2}$

I_{30} = maximum intensity of rainfall during a continuous period of 30 min, mmh^{-1}

n = number of rainstorms $year^{-1}$

The rainfall data for any climatic study in Maharashtra is obtained from IMD, Pune that gives daily rainfall data for each district of the state. Rainfall intensity cannot be calculated from these data. Besides that, district wise rainfall is not always good enough coverage of the study area. Thus, while computing the R factor, there is a need to resort to other methods. A single work in this field in India was done by Babu *et al.*, (1978) who computed monthly, seasonal and annual erosion index values for 44 stations that spread across various rainfall zones in India. In the present study the author has used the average annual EI_{30} values of 16 stations located in the western and central zones of India which are adjacent to the present study site, from the table provided by Babu *et al.*, (1978) and prepared the average annual EI_{30} map of the state of Maharashtra in ArcGIS v.10.3 using spatial interpolation. In the same way, the average annual rainfall values of the same 16 stations were collected from the IMD and were used to generate the rainfall map of Maharashtra. Table 1 shows the average annual EI_{30} and rainfall values of the 16 such selected stations. These two maps were used as base maps and taking 400 random points in each of them the linear relationship between average annual EI_{30} and average annual rainfall was carried out for Maharashtra where the basin is located. The calculated regression equation is:

R = 134.6 + 0.204P, r = 0.96 .... Equation 6

Where:

R = Rainfall Factor and P = average annual rainfall in mm.

Rainfall data for the study has been collected from 15 gauging stations within Jalgaon district where the study area falls. Using the above relationship the R factors for the 15 stations were calculated for those stations and spatially interpolated in ArcGIS 10.3 to create the final R factor map of the study area as depicted in Fig. 4.

Table 1. Average Annual EI_{30} of Selected Stations

Sl. No.	Name	Avg. Annual EI_{30}	Avg. Annual Rainfall (mm)
1	Indore	413	945
2	Bhopal	464	1146
3	Jabalpur	511	1386
4	Punasa	380	981
5	Thikri	334	752
6	BagraTawa	514	1303
7	Nagpur	483	1092
8	Raipur	606	1385
9	Jugdalpur	534	1451
10	Bhuj	120	358
11	Veraval	533	710
12	Vasad	519	826
13	Nandurbar	245	767
14	Aurangabad	226	734
15	Mahabaleswar	1320	5761
16	Vengurla	1259	3223

Source : Babu *et al*. (1978)

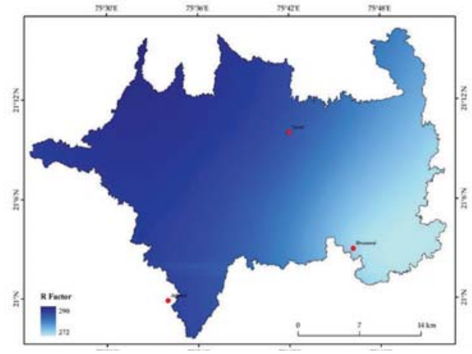

Figure 4. R factor map of the study area

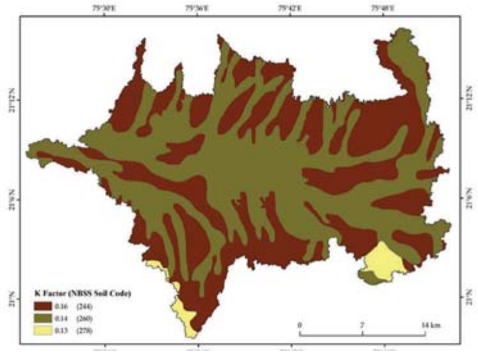

Figure 5. K factor map & NSSB Soil Code for the studied watershed

Soil Erodibility (K)

K is the average soil erodibility factor (t.h. $MJ^{-1}h\ mm^{-1}$), that is the resistance of the soil to both detachment and transport. The soil map of the state of Maharashtra, prepared by National Bureau of Soil Survey and Landuse Planning (NBSS & LUP) was used as the guideline to generate the K factor map for the study area.This map was digitised and the area of interest was clipped. The area is characterised by two major types of soil and a third category occupies a small area in the south. Each category has been given a soil code and descriptions are displayed in Table 2.

In the classification, the study area is characterised by three types of soil with the soil code no 244, 260, 278. Twenty two samples were collected from Soil code 260 and another twenty five samples were from soil code 244. Only 8 samples were collected from soil code 278, since it covers very small area. In all a total of 55 samples were collected

Table 2. Soil Codes and their description

Sl. No	Soil Code	Description
1	244	Slightly deep, moderately well drained, fine soil on very gently sloping plains and valleys with moderate erosion and moderate salinity. Associated with moderately deep, well drained, clayed, calcareous soil with moderate erosion.
2	260	Very deep, Moderately well drained, fine, calcareous soil on very gently sloping plains and valley with moderate erosion; and slight salinity; associated with slightly deep, well drained, fine soil with moderate erosion.
3	278	Very shallow, excessively drained, clayey soils on moderately steeply sloping undulating to rolling lands with mesas and buttes with severe erosion and strong stoniness; associate with very shallow, excessively drained, loamy soils with severe erosion and strong stoniness.

Table 3. K factor values of the three soil categories

Soil code	Sample	K Value	Soil Code	Sample No.	K Value	Soil Code	Sample No.	K Value
260	1	0.15	244	1	0.17	278	1	0.12
260	2	0.15	244	2	0.14	278	2	0.13
260	3	0.15	244	3	0.14	278	3	0.14
260	4	0.12	244	4	0.14	278	4	0.12
260	5	0.12	244	5	0.14	278	5	0.13
260	6	0.18	244	6	0.14	278	6	0.14
260	7	0.18	244	7	0.17	278	7	0.12
260	8	0.12	244	8	0.13	278	8	0.13
260	9	0.12	244	9	0.12			
260	10	0.12	244	10	0.17			
260	11	0.16	244	11	0.15			
260	12	0.16	244	12	0.17			
260	13	0.16	244	13	0.17			
260	14	0.13	244	14	0.14			
260	15	0.13	244	15	0.15			
260	16	0.13	244	16	0.15			
260	17	0.13	244	17	0.15			
260	18	0.14	244	18	0.15			
260	19	0.14	244	19	0.15			
260	20	0.14	244	20	0.15			
260	21	0.14	244	21	0.18			
260	22	0.14	244	22	0.17			
			244	23	0.17			
			244	24	0.17			
			244	25	0.17			

that spread over the entire study. For these samples, grain size, organic content and soil permeability were detected in the laboratory while the soil structure was recorded in the field at the sample sites. The erodibility (K factors) for these samples has been estimated using the equation (Schwab *et al.*, 1993);

$K = 2.8 \times 10^{-7} M^{1.14} (12 - a)\ 4.3 \times 10^{-3} \times (b^{-2}) \times 3.3 \times 10^{-3} (c^{-3})$ ………….Equation 7

Where:

M = Particle size parameter
a = organic matter content
b = soil structure code
c = soil permeability

Table 4. Mean, standard deviation and Coefficient of Variation of K values

Soil Code and Parameter	Soil Code 244	Soil Code 260	Soil Code 270
Mean	0.16	0.14	0.13
Standard Deviation	0.02	0.02	0.01
Coefficient of Variation	12.50%	14.29%	7.69%

Table 3 shows the sediment parameters and the final K values for the three soil categories. The mean, standard deviation and coefficient of variation of the K values for each soil category has been depicted in Table 4.

It is seen that the deviation from the mean which shows the internal variability or heterogeneity of the K factor within a particular soil category is very small as it is evident from the low coefficients of variation. Thus, it can be said that for each soil group the mean K value is a good representative of the overall K factor for that soil type. Therefore, the mean K values of 0.16, 0.14 and 0.13 have been used as K values for each of the soil codes of 244, 260 and 278 respectively, while calculating the soil loss from the study area. The final K factor map has been generated and demonstrated in Fig. 5.

Slope gradient and length factor (LS)

For the present study, the DEM was generated from IRS-P5 Cartosat I with 2.5 m spatial resolution and has fore-aft stereo capability designed to generate DEMs and ortho-images for terrain modelling and cadastral mapping. Eight Cartosat I stereo images were used to generate the DEM for the study area (Table 5).

Table 5. IRS Cartosat I images used to create DEM

Sl. No.	Path	Row	Date
1	524	299	12 Jan 2012
2	524	300	12 Jan 2012
3	525	299	31 Dec 2011
4	525	300	31 Dec 2011
5	526	299	18 Dec 2011
6	526	300	18 Dec 2011
7	527	299	30 Mar 2011
8	527	300	30 Mar 2011

The complete procedure of DEM extraction has been depicted in the flow chart (Fig.6)and the resultant Carto DEM of 10 m resolution has been shown in Fig. 7.In USLE equation, the slope length (L) and slope gradient (S) are combined into a single LS index.Wischmeier and Smith, (1978) defined slope length in the USLE model as the distance from the point of origin of overland flow to either the point where deposition begins, or to the point where runoff enters a well-defined channel.

A map showing the spatial distribution of slope was generated from the DEM for better understanding of the relation between slope and LS (Fig. 8). For wider application, in RUSLE, slope length is defined as path length of overland flow by Renard *et al.*, (1991), which is the distance from the origin

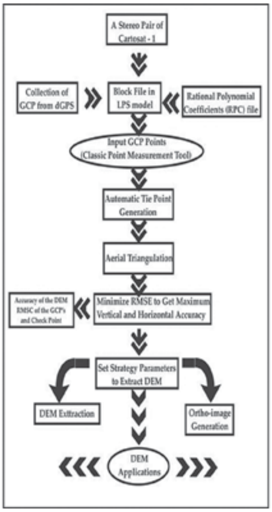

Figure 6. Flowchart showing DEM Creation from IRS Cartosat I

of overland flow to where it enters a major concentrated flow area, such as, a waterway, an ephemeral gully, a stream or a diversion. Moore and Burch (1986); Moore and Wilson (1992) and Desmet and Govers (1996) made spatial prediction of topographic factor (LS) based on DEM. In RUSLE-3D model the slope length factor (LS) is replaced by the up-slope contributing area by Mitasova *et al.*,(1996). Up-slope contributing area can be approximated using flow accumulation factor. The merit of replacing the slope length by up-slope area lies in the fact that the up-slope area better reflects the impact of concentrated flow on increased erosion as normally witnessed in the hilly landscape (Mitasova*et al.*, 1996). Following Mitasova *et al.* (1996) the slope length was replaced by the up-slope contributing area per unit width of cell spacing $A_{(r)}$ (m^2m^{-1}) in RUSLE-3D. The modified LS factor of a grid cell or at a point r = (x, y) is calculated as:

$$LS\,(r) = (m+1)\,[A(r)/22.13]^m[\sin \beta_{(r)}/0.09]^n \quad \text{......Equation 8}$$

Where:

β (r) is the land surface slope in degrees, m and n are constants equal to 0.6 and 1.3.

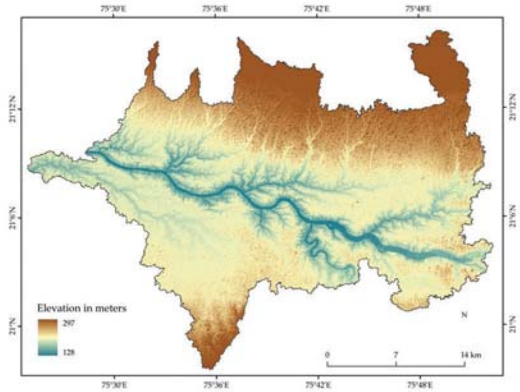

Figure 7. DEM Created from IRS Cartosat I

The equation was calculated using Spatial Analysis Tool in Arc GIS (version 10.3). Figure9 reveals LS factor distribution map showing different categories following the natural breaks. LS factor is the result of slope gradient and length factor on soil erosion.

A comparison of the slope map and LS factor map reveal that higher values of LS factor coincide with steeper slopes (S) where slope length factor (L) is low. Hoyos (2005) observed that highest slope length (L) factor

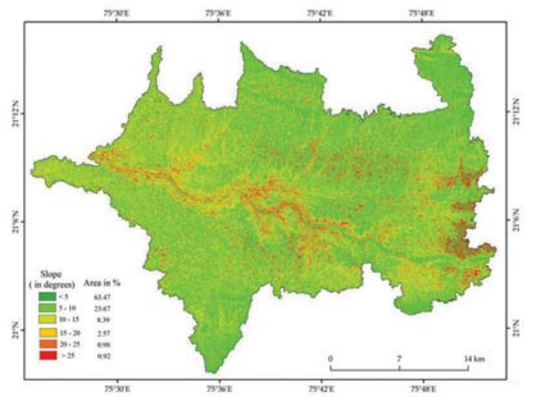

Figure 8. Slope map of study area

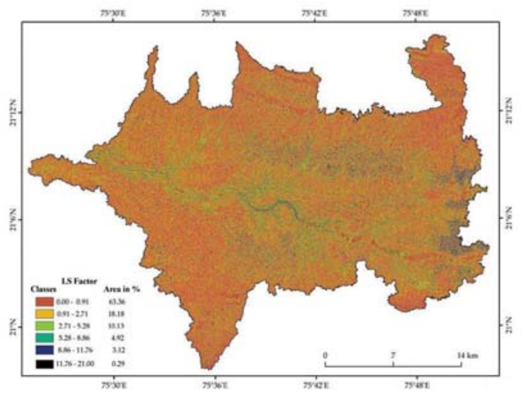

Figure 9. LS factor map of study area

occurs where overland flows accumulate at the base the convex ridges. It is clearly visible that areas of steeper slopes are showing higher LS values in the map, indicating the greater impact of slope steepness on LS. The Slope map (Fig. 8) demonstrates that 63.47% of the area lies under the 'gently undulating' category, having slope below 5°. The highest slope is of 25° and above, but that occupies a small area of less than 2% of the total area under investigation. Rest of the classes are in between these two extremes. The LS factor map (Fig. 9) displays that 63 % of the area with 0–0.91LS,falls along the floodplain of the river and the deeply dissected badland tracts occupy 15% of the area with LS value ranging from 2 to 5. Only 9% of the area is occupied by LS above 5 to 11 that depicts the surrounding higher hillocks.A small area of less than 0.3 % shows value above 11,whichis concentrated all along the riverbank, depicting the gorge cut by the river.All over there is strong evidence that topographic factor LS exercises a strong control in the erosion process in the watershed.

Vegetation factor (C)

Vegetation cover protects land surface from raindrop impacts and promotes infiltration and retards the rate of soil erosion.C values are commonly computed in GIS environment in association with land use classes as suggested by many workers (Toy *et al.*, 2002). Recently the Normalized Difference Vegetation Index (NDVI) is being popularised as another methodology to compute C value. NDVI is an important biophysical indicator to soil erosion (De Jong, 1994; De Jong *et al*., 1999; Tweddales*et al.*, 2000). The NDVI indicates the canopy cover and health of vegetation on any surface. The formula can be computed as;

NDVI = (NIR – red) / (NIR + red) ....Equation 9

Vegetation index, as the formula suggests, is the difference in the spectral reflectance between Near Infrared (NIR) band and red band in a multi spectral image. NDVI values range from –1.0 to 1.0. Higher values of NDVI indicate green vegetation and bare soils are represented by values which are closest to 0. Negative NDVI values are found over water bodies (Sader and Winne, 1992; Jasinski, 1990; Lillesand *et al*., 2004).Two scenes of IRS P6 LISS-IV and Resourcesat-1 multi spectral imageries of 5.8 m resolution, taken on 18.01.2016 and 11.02.2016 were used to derive NDVI values for the present study. NDVI of the basin is depicted in Fig 10a.

Equation for C for the study area was created based on regression correlation between NDVI and C factor as suggested by

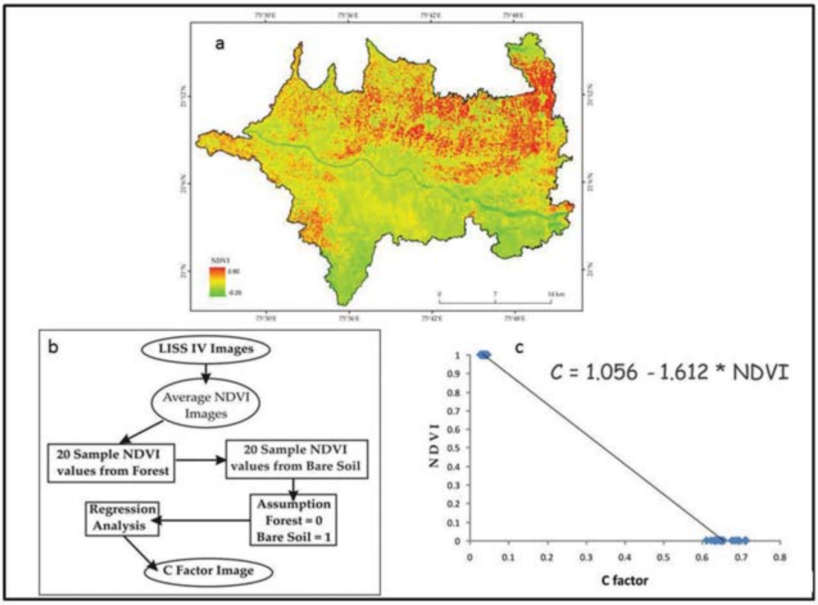

Figure 10. (a) NDVI map from IRS LISS IV; (b) Flowchart showing determination of C factor from the NDVI; (c) correlation between NDVI and C Factor.

Karaburun (2010). Areas with full vegetation cover as well as completely bare grounds are demarcated on the imageries. Google Earth image was also used for this demarcation. Twenty values of NDVI from the pixels with complete vegetation cover and another twenty values from pixels with completely bare ground have been randomly picked out for the analysis. C factor values range from 0 for well-protected soil to 1 for bare soil (Pierce *et al*., 1986). These C factor values have been used in the present regression analysis (Karaburun, 2010, Fig. 10b and 10c). The regression equation derived from the analysis is as follows:

C = 1.056 –1.612 × NDVI........Equation 10

The final C factormap was generated using the regressionequation in Spatial Analysttool of ArcGIS. The C factor map thus generated is given in Figure 11.

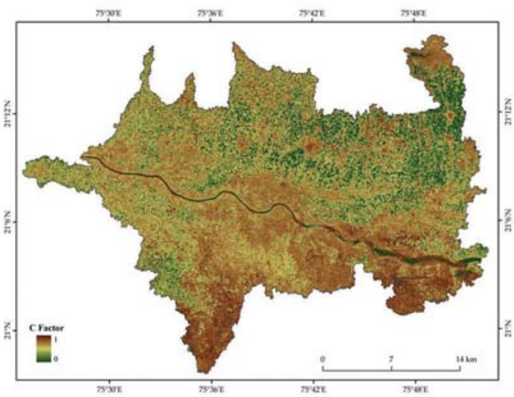

Figure 11. Factor map of the study area

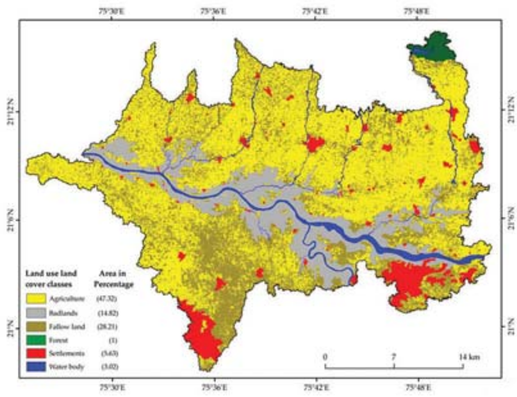

Figure 12. LS factor map of study area

Erosion Management Practice (P)

Conservation practice or erosion management factor is a factor of comparable importance while considering soil loss in any region. The P value ranges between 0 and 1 with the lower value of P indicates higher supporting practice. Wischmeier and Smith (1978) considered slope as well as two major land use classes, such as agricultural land and other, while determining the P value of the study area (Table 6, Figure 12). Agricultural area was then further subdivided into six classes on the basis of slope categories to assign the P values.

A landuse-landcover classification was performed on the two images of IRS LISS IV which were used to calculate NDVI. The map has been prepared by supervised classification using maximum likelihood algorithm and non-parametric parallelepiped rule method. The classified map is depicted in Figure 13 and reveals that nearly 75% of the area is under agriculture and fallow land.

From the classified map only the agricultural areas were extracted andusing Arc Map the agricultural area has been draped on the slope map. Using Spatial Analyst Reclassify toolthe final P values from the table have been assigned and the resultant map is presented in Figure 12. The mean

Table 6.Conservation practice factor (P) (Weischmeir and Smith, 1978)

Land use type	Slope %	P factor
Agricultural land use	0-5	0.10
	5-10	0.12
	10-20	0.14
	20-30	0.19
	30-50	0.25
	50-100	0.33
Other land use	All	1.00

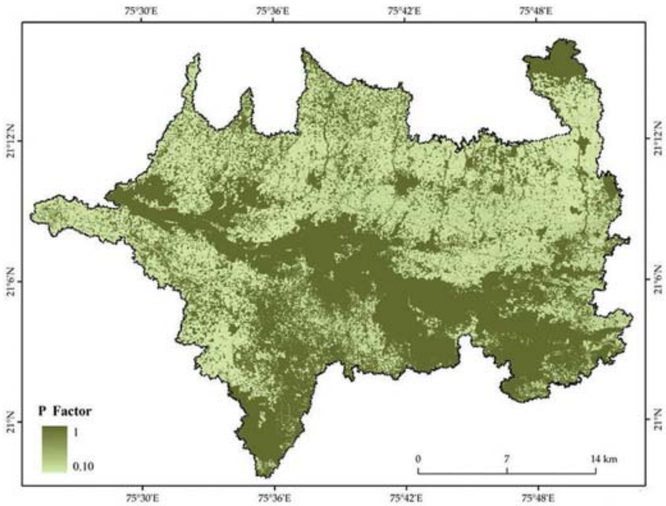

Figure 13 Landuse-landcover classified map of the study area from IRS LISS IV images

value and range of each input parameter of the equation generated from remote sensing in the study, such as R factor, C factor and K Factor. The estimated soil loss is 2.42 kg

Table 7.Mean and range of each RUSLE parameter and final soil loss value of the whole area

Factor	Maximum	Minimum	Mean	Standard Deviation
R Factor	290.14	271.75	283.12	5.13
K Factor	0.19	0.12	0.15	0.009
LS Factor	20.99	0.00	1.30	2.42
C Factor	1.00	0.00	0.63	0.22
P Factor	1.00	0.10	0.61	0.42
NDVI	0.6	–0.20	0.21	0.12
Annual Soil Loss (kg $m^{-2}yr^{-1}$)	24.80	0.00	2.42	4.99

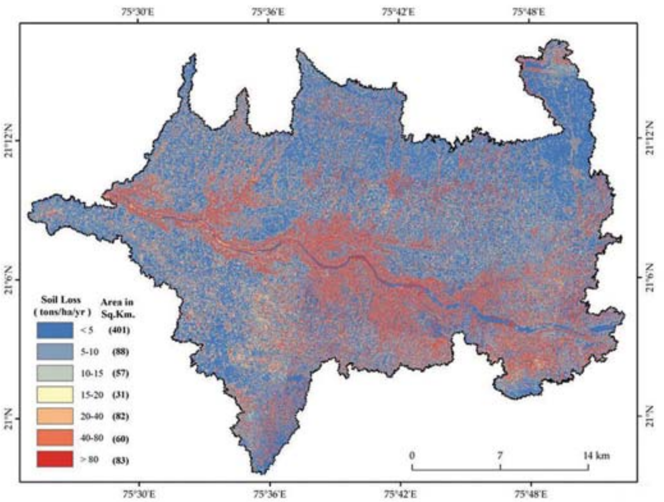

Figure 14 Final soil loss map of the study area

data has been demonstrated in the Table 7. The final soil loss map thus calculated has been presented in Figure14 and summarized in Table 7.

Conclusion

Soil loss from a deeply dissected riverine alluvial zone along the banks of Tapi river in western Deccan, India was estimated using RUSLE-3D Equation. In the study few site specific equations were generatedand applied $m^{-2}yr^{-1}$. Soil loss from two badland catchments from the same area were calculated by employing erosion pin technique in an earlier study which indicated the soil loss to be 3.58 kg $m^{-2}yr^{-1}$and 1.52 kg $m^{-2}yr^{-1}$ respectively (Joshi, 2014). This suggests that the soil loss values differ at individual sites within the study area. The Deccan trappe as a whole is characterised by rocky terrain. Sediments are patchy and thin. The soil loss of 2.42 kg $m^{-2}yr^{-1}$in such a sediment-starved region is a matter of concern. Currently, the region is undergoing extensive reclamation of badlands for agriculture. Last two decades have witnessed a complete transformation of the landscape in these areas. If the trend continues, it appears that there will be further acceleration of soil erosion from the area. Slope plays a very important role in the soil loss in the present study. The badlands in these areas are reported to bethe response of lineament-controlled block uplift (Joshi and Nagare, 2013) causing a drop in the local base level and inducing erosion and development of badlands. The gullies are vigorously eroding the bed to attain equilibrium.Hence, erosion is a process that will continue herewith or without human interference. Disturbance of the slope for agriculture will accelerate the erosion rate. Taking into consideration the rapid growth of population and an ever increasing demand for land, more site specific studies are recommended to prepare a suitable landuse for a sustainable future.

Acknowledgements

The paper is the outcome of a project funded by DST, New Delhi. Authors would also like to acknowledge the help from many students of the department like Sandeep Pawar, Gaurav Gamre, Debasree Sinha, Sadashiv Tukawanvar, Chandrakant Kadam, Prashant Shinde during the fieldwork. Thanks are due to the National Remote Sensing Agencies India for the satellite imageries provided for the study. Agriculture College, Pune, Soiltech Engineering Pvt. Ltd, National Bureau of Soil Survey, Nagpur and Indian Meteorological Department supported the study by making the data available on time.

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Date received : 9 March 2018
Date accepted after revision: 30 July 2018