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ESTIMATING SOIL LOSS FROM A WATERSHED IN WESTERN DECCAN, INDIA, USING REVISED UNIVERSAL SOIL LOSS EQUATION

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Abstract
USLE (Universal Soil Loss Equation) is the original and the most widely accepted soil loss estimation technique till date which has evolved from a design tool for conservation planning to a research methodology all across the globe. The equation has been revised and modified over the years and became a foundation for several new soil loss models developed all around the world. The equation has been revised as RUSLE by Renard et al. (1991) and is computed in GIS environment. The Revised equation is landuse independent which makes it a useful technique to apply in a variety of environment. The present paper is an attempt to estimate soil loss from a semi-arid watershed in Western Deccan, India by employing RUSLE. The region is a rocky terrain and sediments are restricted to only a few localities. The result indicates that the region is at the threshold of soil tolerance limit.

Keywords: USLE, RS, GIS, RUSLE, field study, modeling

1. Introduction

One of the most serious environmental issues of the 21st century is soil erosion and land degradation all over the world. The situation is graver in the densely populated tropical regions due to the intense climatic inputs (Sanchez et al., 2003) and the heavy pressure of population on land (Sinha – Joshi, 2012). The development of agriculture goes hand in hand with land degradation. More progress in the human activities only means more destruction of the natural resources upon which humans build a basis for survival (Pimentel, 1993). With more than 4 million hectares of land being identified as severely eroded, in India the rate of soil erosion is among the highest in the world.

The emergence of a soil loss estimate model called Universal Soil Loss Equation (USLE) by Wischmeier and Smith (1959) which claims that ‘Soil loss is the function of slope, climate, soil characteristics, ground cover and human activities’ in the form of A=RKLSCP, marked the beginning of a whole new paradigm of modeling in geomorphology. ‘A’ in the equation is the average annual soil loss from a plot; ‘R’ is the average annual rainfall as the erosion potential of rain storms (MJ $ha^{-1}mm\ h^{-1}$); ‘K’ is the average soil erodibility factor (tons $MJ^{-1}h\ mm^{-1}$) which is a function of soil textural and structural properties, permeability and organic matter content; and ‘LS’ is the slope length and gradient factor. Slope is one of the most important factors which influence the rates of soil erosion anywhere. As slope length increases, overland flow and flow velocity also steadily increase, leading to greater erosion forces on the soil surface, thus increasing soil erodibility (Wischmeier – Smith, 1978). The 'C' factor (cropping) plays a critical role in determining the rate of erosion and indicates the relative effectiveness of soil and crop management systems in preventing soil losses and the last factor 'P' is the management or conservation practices.

The equation that was originally formulated to apply in the small agricultural fields has been modified and revised by different scientists to suit different land use scenarios in the world. USLE evolved into MUSLE (Modified Universal Soil Loss Equation, Williams – Berndt, 1977); RUSLE (Revised Universal Soil Loss Equation, Renard et al., 1991); FUSLE (Universal Soil Loss Equation for Forests, Jin-Chi et al., 2008); and each had extended areas of application. At the same time a host of soil loss models, both empirical and physical, also originated in different areas of the world under different names. Almost all of these models have the foundation of USLE, but new variables have been added or the input parameters modified to arrive at the equation, depending on the application scenarios. Some of the most popularly applied models are EGEM (Ephemeral Gully Erosion Model, USDA-SCS 1992); ANSWERS (Areal Nonpoint Source Watershed Environment Response Simulation, Beasley et al. 1980; SWAT (Soil-Water Assessment Tool, Arnold et al. 1993); WEPP (Water Erosion Prediction Project, USDA-ARS, 1995; WaTEM (Water and Tilage Eroson Model, Van Oost et al., 2000); SEDEM (Sediment Delivery Model, Van Rompaey et al., 2001) etc. All these models have evolved out of the need to apply the equation in different situations and scale of the landscape.

The use of Geographic Information System (GIS) to compute soil losses became common in the last two decades. GIS provides a fast and efficient means of generating the input data required for these models. It also has the unique capability of representing watershed characteristics within a grid cell environment. The original USLE was designed basically for the agricultural fields and hence Wischmeier and Smith (1959) proposed a table for C factors, taking into consideration the type and stage of the crop grown in the field. The basis is that the root structure and the biomass of each crop differ, providing variations in ground cover and thus variations in the soil losses. P factor is based on the concept that soil loss from an agricultural field will be influenced by the type of conservation practices. In RS GIS environment, the original crop factor is obtained by calculating NDVI (Normalized Difference Vegetation Index), which indicates the health of the vegetation. C factor is also obtained from the classified landuse map of the area. P factor is also usually extracted from land use classified maps. The slope LS factor is obtained directly from a DEM.

The present paper has been designed to evaluate the soil loss from a riverine alluvial zone in the Western Deccan, India, using Revised Universal Soil Loss Equation. So far, there has been very little study that focuses on the soil loss from this part of the country. The reason is not very surprising because the Deccan Trap is a sediment starved rocky terrain. Rivers are confined within the rocky channels without the formation of floodplains. The occurrences of alluvium along the narrow banks of some rivers or colluvial deposits along some foothills do not go in proportion with the area. Therefore studies, that concern soil loss has been practically absent from this area. Large volume of literature are available that deals with rill and gully erosion from the central and northern part of India. But the scenario is different in Maharashtra which is a part of the Deccan Trap Region. Joshi (2014) and Joshi and Tambe (2010) calculated soil loss from a watershed in the region employing field techniques, such as, micro-profilometers, erosion pin and rainfall simulations. Except these studies, there has never been any report on soil erosion from this region. The previous studies were confined to small experimental sites and there has never been an attempt to estimate soil loss from a larger area. Due to the increasing population, every available patch of land is brought under agriculture or other uses in India which have put enormous burden on the natural landscapes. Field evidence indicates that the region has started showing an accelerated rate of soil erosion in the last two decades mainly due to anthropogenic activities.

2. Study Area

The study site is situated at about 160 km to the north of Pune, Maharashtra, along the Pune-Nashik Road (Fig. 1.). The average altitude of the region is 700 m MSL. The area is located in the semi-arid, rain shadow zone of the Western Ghats in Maharashtra and receives about 450-500 mm of rainfall per year. The region is predominantly covered by black cotton soil known locally as 'Regur'. Natural vegetation consists of the typical semi-arid acacias. Hillslopes reveal bare rocks without any natural vegetation, except in the areas where they were planted. Along the main Pravara River and a few of its tributaries, extensive badlands have been formed and presently, the region is undergoing massive land reclamation for agricultural uses.

3. Material and Method:

ASTER data with 30 m resolution and IRS (Indian Remote Sensing) LISS III imagery with 23.5 m ground resolution for the area were obtained for the analysis. The ASTER data was downloaded on 12th December 2012 (http://gdem.ersdac.jspacesystems.or.jp/) and a single scene multispectral LISS III image (path 095/row 059) for 30th November 2009 was also downloaded at the same time from the site http://bhuvan.nrsc.gov.in/data/download/index.php. The image covers an area of 171.45 km^2. Survey of India

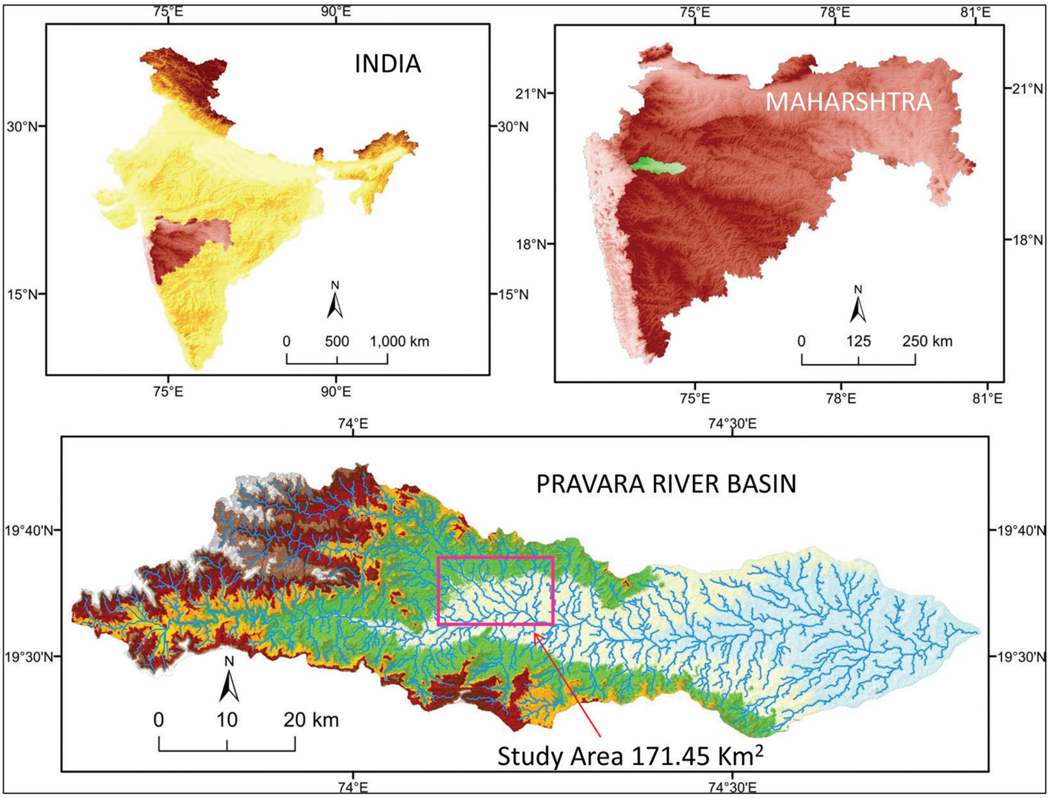

Fig. 1. Location map of the study area

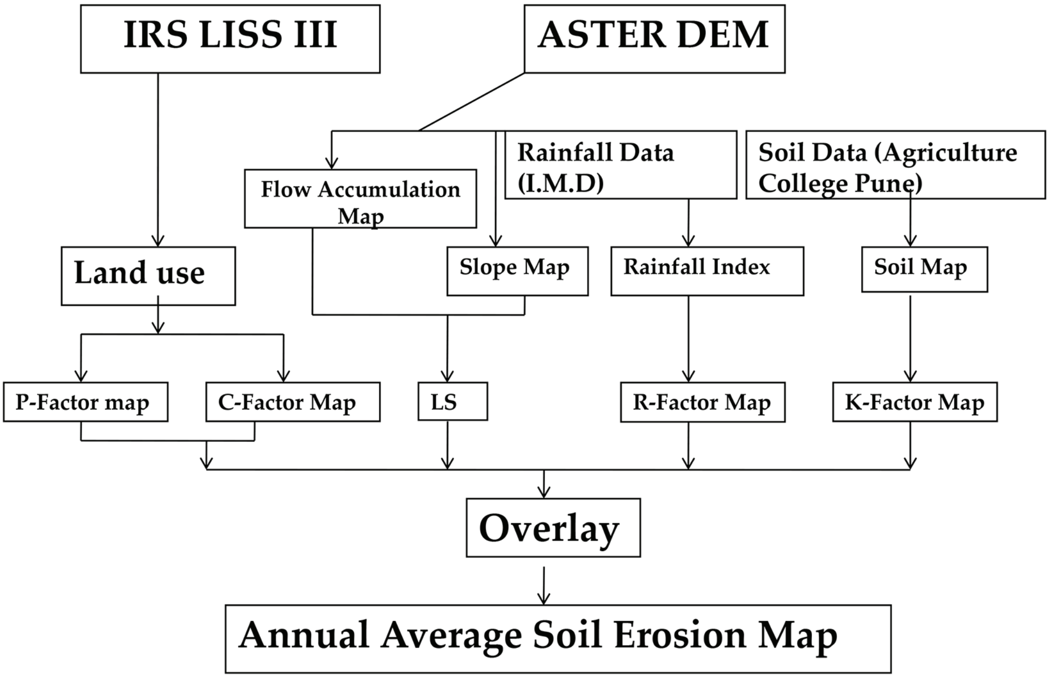

Fig. 2. Flow chart depicting methodology of USLE using RS and GIS

topographical map no. 47 I/2 were used to geo reference the image. These two imageries formed the base data for the analysis. The methodology adopted for this analysis is depicted in the flow chart shown in Fig. 2.

RUSLE is computed using the equation;

$$A = R.K.LS.C.P \quad (1)$$

Where,

A – is the potential long term average annual soil loss in tons/ac/yr^{-1}

R – is the erosion potential of rainstorms (MJ ha^{-1}mm h^{-1}),

K – is the soil erodibility factor,

LS – is the slope length-gradient factor,

C – is the crop factor,

P – is the conservation practice factor.

Rainfall Erosivity (R):

The amount, duration and intensity of the rainfall influence soil erosion greatly and hence rainfall factor has remained as the most important variable in this equation. According to Wischmeier and Smith (1959) one hundredth of the product of kinetic energy of the storm and the 30-minutes intensity which is expressed as EI30 is the most reliable single estimate of rainfall erosion potential. Annual total of storm EI value is the rainfall erosion-index. Based on the study of Ivory Coast (Côte d'Ivoire) and Burkina Faso, Roose (1975) computed that mean annual EI30 values can be approximated by the mean annual rainfall totals (mm) multiplied by 50. So he proposed the following formula for computation of R factor for USLE. He has used 0.5 as the general constant for multiplying the mean annual rainfall (Morgan, 1986).

Rainfall data from the year 1955 up to 2005 were obtained from the Indian Meteorological Department and R factor for the equation was computed using the following formula:

$$R = P * 0.5 \quad \text{(Roose, 1975)} \quad (2)$$

Where,

R – is the rainfall erosivity factor and

P – is the mean annual precipitation in mm.

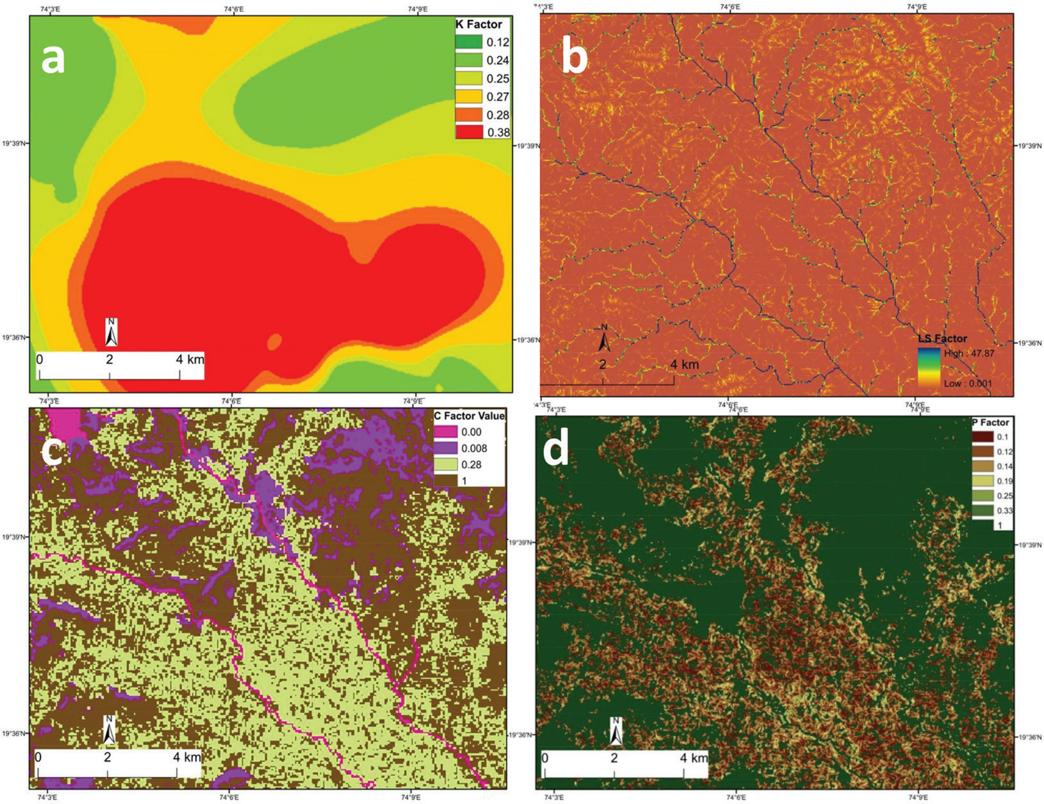

Fig. 3. a) K factor map b) LS factor map c) C factor map and d) P factor map

Rainfall data of the study site came from a single station in Sangamner Taluka, Ahamadnagar District of Maharashtra and hence a single value was generated. The same value has been assigned to all the pixels within the AOI to generate R factor map for the area in the study.

Soil Erodibility (K) Factor:

K is the average soil erodibility factor (tons $MJ^{-1} h\ mm^{-1}$), which is the resistance of the soil to both detachment and transport. Using the grain-size distribution, organic matter content, structure and permeability of the soil, K values can be estimated from the nomograph proposed by Wischmeier et al. (1971). Erodibility is generally less for both coarse texture (gravel) and very fine texture (clay) sediments. Fine sands and silts are very unstable and are in the category of easily erodible soils. When the organic matter content is high, the resistance of the sediments to detachment increases and greater permeability allows higher infiltration rates and hence reduces erodibility of soil.

Fifty-five sediment samples were collected from the field that spread over the entire area of study. The erodibility (K factors) for these samples has been estimated from the nomograph (Wischmeier et al., 1971). The input parameters were obtained by conducting textural analysis of samples by sieving and use of the Sedigraph. The organic content of the samples were detected from the Agriculture College of Pune and permeability were conducted from the Soiltech Engineering Pvt. Ltd, India. The structural codes were recorded during the field work. Table 1. shows the sediment parameters and the final K values for the fifty sites. The final K factor map was generated by interpolating these values using Arc GIS 9.3 and results have been presented in the Fig. 3a.

Slope gradient and length factor (LS):

In any given environment, the rate of soil erosion is greatly influenced by the slope of the area. The equation combines the slope length (L) and slope steepness (S) into a single index LS and therefore represent the slope length and the slope gradient factor. Steeper slopes permit higher velocity of overland flow which results in the increasing shear stresses on the soil particles. With the increase in the slope length, the length of the overland flow as well as flow velocity also increase steadily leading to greater erosion forces applied to the soil surface. The slope length in the USLE model is defined as the distance from the point of origin of overland flow to either where the slope decreases to the point that deposition begins, or to the point where runoff entered a well defined channel (Wischmeier – Smith, 1978). Slope length is defined as overland-flow path-length in RUSLE for its wider application (Renard et al., 1991). An overland flow path length is defined as distance from the origin of overland flow to where it enters a major concentrated flow area like an ephemeral gully, waterway, diversion, or stream (Renard et al., 1997). This definition helps in spatial prediction of topographic factor (LS) equation based on a digital elevation model (DEM) (Moore – Burch, 1986; Moore – Wilson, 1992; Desmet – Govers, 1996). Mitasova et al. (1996) replaced the slope length factor (LS) by the upslope contributing area in RUSLE model. Upslope contributing area can be approximated using flow accumulation. The merit of replacing the slope length by upslope area lies in the fact that the upslope area better reflects the impact of concentrated flow on increased erosion as normally witnessed in the hilly landscape. LS factor was obtained from ASTER DEM with 30 m resolution. The factor was computed using the raster calculator in ArcMap, employing the equation from Mitasova – Mitas (1999) and Tirkey et al. (2013).

LS=([Flow Accumulation]*Cell Size/22.13)0.6(Sin ([Slope of DEM]* 0.01745)/0.0896)1.3*1.4 (4)

The grids of flow accumulation correspond to the drainage in the catchment in a DEM. The values n=0.6 and m=1.3 were used in the present study for the maximum portion of watershed having slope upto 50 that is increasing gradually towards the hilly region in the upstream region of the watershed. The LS factor map of the region has been displayed in Fig. 3b.

Vegetation factor (C):

In a GIS environment, the original crop factor has been substituted by land cover factor which represents the effect of vegetation on the overall soil loss in any region. The land cover and management factor represent the effects of vegetation, management and erosion control practices on soil loss. The value of which ranges from 0 in water bodies to slightly greater than 1 in barren land (Toy et al., 2002), where there is no vegetation, root biomass, or other surface cover to resist erosive forces. The values are close to 1 for bare soils, 1 to 0.9 for root crops and tuber crops, 0.01 on grasslands and cover plants and 0.001 for forests (Roose, 1996).

A land use/cover classification was conducted from IRS LISS III imagery using ERDAS IMAGINE 9.2. Information related to different land use practices and types of crops grown in the fields have been obtained during a detailed field work conducted prior to the classification exercise. Several training samples were obtained for each land use class. The land use map of the region (2009) has been prepared by employing supervised classification using maximum likelihood algorithm and parallelepiped nonparametric rule method. Accuracy assessment was performed from a reference template margining the data with 200 randomly selected samples on the imagery, from which overall accuracy and Kappa statistics were derived with 96% accuracy. C factors for the present study were calculated using Table 2. In all, six site specific land use classes have been identified in the area and the values

Table 1-. Soil erodibility factor (k) data

Sample No	% Sl + vfs	% Sand	% OM	Str.Cod	Per.Cod	K value
1	26.46	33.23	0.41	3	1	0.10
2	27.37	29.84	0.41	3	2	0.125
3	34.24	27.97	0.52	3	2	0.170
4	44.44	33.21	0.63	3	2	0.290
5	58.20	24.12	0.82	3	2	0.390
6	44.28	23.44	0.68	3	3	0.295
7	42.90	31.80	1.07	3	2	0.250
8	36.77	31.41	1.36	3	2	0.175
9	11.74	29.60	0.87	3	2	0.06
10	36.53	33.46	0.89	3	2	0.20
11	45.61	22.07	0.90	2	4	0.26
12	50.60	28.77	0.90	2	4	0.36
13	49.27	26.53	0.89	2	4	0.32
14	53.23	20.91	1.36	3	3	0.33
15	54.23	20.94	1.23	3	3	0.33
16	38.44	31.28	1.09	3	2	0.20
17	55.54	27.64	1.38	3	3	0.39
18	36.73	31.61	1.36	3	2	0.19
19	43.82	26.9	0.27	3	2	0.27
20	46.29	45.29	1.28	3	1	0.29
21	31.93	27.06	0.71	3	2	0.16
22	66.15	18.40	1.25	2	4	0.42
23	57.22	18.53	1.23	2	4	0.34
24	48.05	27.17	1.23	3	3	0.30
25	65.92	2.37	1.25	1	6	0.39
26	27.37	29.84	0.41	3	2	0.125
27	44.44	33.21	0.63	3	2	0.290
28	11.74	29.60	0.87	3	2	0.06
29	57.22	18.53	1.23	2	4	0.34
30	36.73	31.61	1.36	3	2	0.19
31	46.29	45.29	1.28	3	1	0.29
32	54.23	20.94	1.23	3	3	0.33
33	43.82	26.9	0.27	3	2	0.27
34	58.20	24.12	0.82	3	2	0.390
35	36.77	31.41	1.36	3	2	0.175
36	45.61	22.07	0.90	2	4	0.26

Table 1. Soil erodibility factor (k) data

Sample No	% Sl + vfs	% Sand	% OM	Str.Cod	Per.Cod	K value
37	31.93	27.06	0.71	3	2	0.16
38	44.44	33.21	0.63	3	2	0.290
39	11.74	29.60	0.87	3	2	0.06
40	43.82	26.9	0.27	3	2	0.27
41	46.29	45.29	1.28	3	1	0.29
42	66.15	18.40	1.25	2	4	0.42
43	66.15	18.40	1.25	2	4	0.42
44	48.05	27.17	1.23	3	3	0.30
45	36.73	31.61	1.36	3	2	0.19
46	46.29	45.29	1.28	3	1	0.29
47	57.22	18.53	1.23	2	4	0.34
48	26.46	33.23	0.41	3	1	0.10
49	44.44	33.21	0.63	3	2	0.290
50	57.22	18.53	1.23	2	4	0.34
51	11.74	29.60	0.87	3	2	0.06
52	65.92	2.37	1.25	1	6	0.39
53	38.44	31.28	1.09	3	2	0.20
54	57.22	18.53	1.23	2	4	0.34
55	36.73	31.61	1.36	3	2	0.19

Table 2. C factors of the corresponding landuse classes (USDA-SCS, 1972; Tirkey et al., 2013; Rao, 1981)

Land use Class	C Factor
Settlement	1.0
Vacant land	1.0
Agriculture	0.28
Fallow land	1.0
Plantations	0.28
Dense forest	0.004

Table 3. Conservation Practice Factor (P) (Weischmeir – Smith, 1978)

Land use type	Slope %	P factor
Agriculture	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	All	1.00

of the corresponding land use classes were assigned from this table and the spatial distribution of the C value was prepared and is presented in Fig. 3c.

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 indicating the 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 a region (Table 3). Agricultural area is then further subdivided into six categories on the basis of slope percent to assign P values. This classification scheme has been adopted by many researchers while calculating USLE and

Table 4. Mean and range of each USLE parameter and final soil loss value of the whole area

	Maximum	Minimum	Mean	Standard Deviation
LS Factor	47.87	0.001	0.08	0.66
K Factor	0.38	0.120	0.26	0.03
C Value	1.00	0.00	0.63	0.39
P Value	1.00	0.10	0.69	0.41
FINAL SOIL LOSS	Maximum	Minimum	Mean	Standard Deviation
Annual Soil loss tons/ac/yr^{-1}	2016	0.001	2.278	24.15
Annual Soil loss kg/m^2/year	453.03	0.001	0.562	5.42

the same criteria has been adopted to assign P values in the present study also. A land use classification map with just the two criteria has been computed from the LISS III image. Using Arc Map the agricultural area has been draped on the slope categories as classified in the Table 3. and the final P values have been assigned using raster calculator. The P value map has been depicted in Fig. 3d.

The mean value and range of each input parameter of the equation generated from the remote sensing data has been demonstrated in the Table 4. The final soil loss map thus calculated has been presented in Fig. 4. and summarized in Table 4. It is evident from the table that C and P factors with 0.63 and 0.69 have emerged as the most important two variables to affect soil loss here and the average soil loss from the study area is 0.562 kg/m^2/year.

4. Discussion

The data presented above demonstrates that the average soil loss from the whole area is 2.278 t/ac/yr^{-1} or 0.562 kg/m^2/year. Any soil erosion studies throws light on how the land in question is coping with the environmental and/or anthropogenic stress on them, if any, and the most widely adapted methodology to evaluate this is to compare the soil loss value with the soil tolerance limits. Based on 80 years of research USDA, NRCS (2011) has published a most widely used threshold of soil tolerance limits. These are

<1 t/ac/yr^{-1}, ie below 0.247 kg/m^2/year - safe.

1-5 t/ac/yr^{-1}, ie 0.247-1.124 kg/m^2/year - at threshold.

>5 t/ac/yr^{-1}, ie 1.124 kg/m^2/year - high erosion beyond tolerance limits.

The area under investigation is at the threshold level of soil loss. The value of 0.562 kg/m^2/year is significant in this region considering the proportion of sediment available in the region. The region is a narrow alluvial tract along the banks of Pravara River which is intensively dissected by gullies to form “Badlands”. Joshi (2014) calculated soil loss from two badland catchments from the same area by employing erosion pin techniques in an earlier study and the soil loss were 3.58 kg/km^2/yr^{-1} and 1.52 kg/km^2/yr^{-1} respectively. This suggests that the soil loss value is much higher at individual sites within the present study area.

The reclamation of these badlands began not later than the year 2000 in this area, following the construction of some few big dams and several weirs on the river, thus making irrigation available to the farmers. Irrigation introduced the practice of agriculture in such inhospitable terrains for the first time in a big way and hence such badland slopes are largely being remodelled and levelled at many sites to grow variety

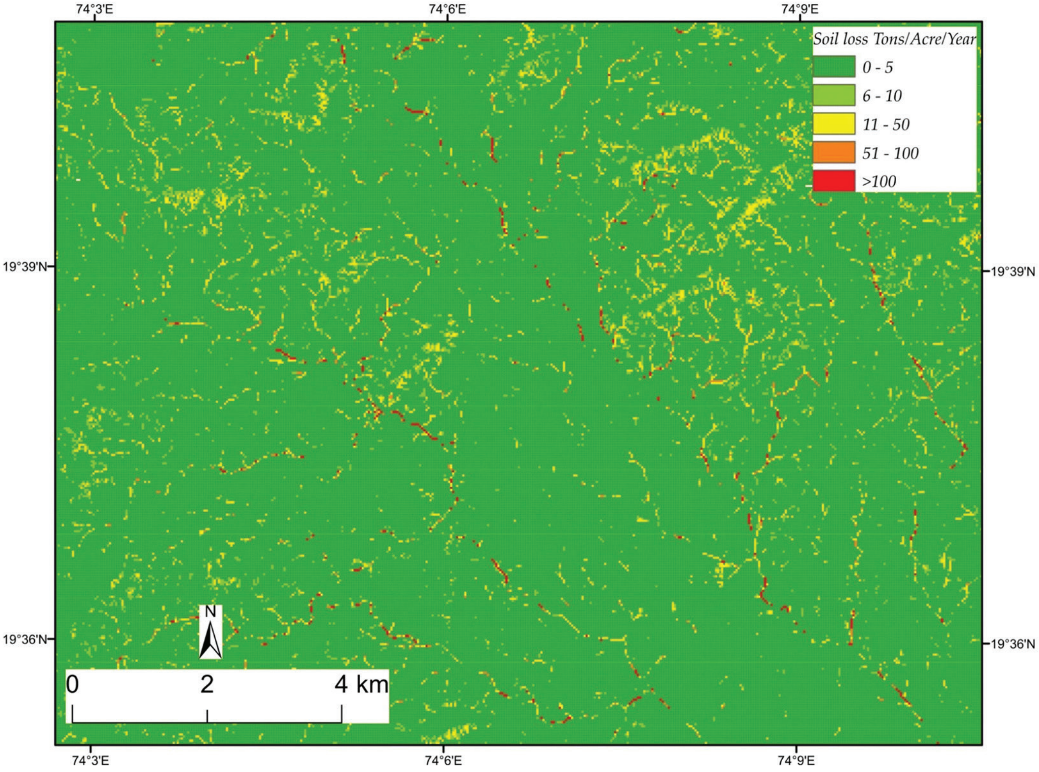

Fig. 4. – Final soil loss map

of crops. Such landforms are known to be dynamic landscapes and the rate of erosion is normally high. As exemplified by recent examples from all over the world, land use change is expected to have a greater impact on gully erosion than climate change. Last few decades have witnessed rapid land use changes to meet the demands of the growing population all over the world, especially in India. Wells – Andriamihaja (1993) blamed human for the initiation of the lavaka gullies in Madagascar. Remodelling of badlands to bring about agriculture and accelerated erosion has been distinctly reported by many investigators, such as, Clarke – Rendell 2000, Valcárcela et al 2003, Gábris et al 2003, Piccarreta et al. 2006 etc. Gallart (2012) found that ditches made by farmers to protect their fields from runoff gave rise to deep gullies and subsequently led to the development of badlands in those areas. Castaldi and Chiocchini (2012) reported that the cause of badland expansion along clayey drainage basins in Central Italy was due to the watershed disturbance.

All these studies suggest beyond the scope of any doubt that gully erosion is accelerated wherever humans interfere with the landscape. The present area under review is also currently undergoing similar situation.

5. Conclusion

Soil erosion is a phenomenon which affects large parts of India, especially in the last few decades due to rapid increase in the population and urbanization. The study reports soil loss from a deeply dissected riverine alluvial zone along the banks of Pravara River in Western Deccan, India, estimated using Revised Universal Soil Loss Equation. The area is characterized by an erosional landscape with very little sediment deposition unlike the northern parts of the country known as Indo Gangetic Plain where there are rich sediment depositions all along the region. This has resulted in the bulk of soil erosion studies being conducted in the alluvial plains in the north and there has been very little such type of studies in the Deccan Basaltic Region. The study area is a natural badland which is presently undergoing massive disturbances for the purpose of agriculture. Although USLE (Wischmeier – Smith, 1959) and RUSLE (Renard et al., 1991) empirical equations have been used widely all over the world, these techniques are fairly unexplored in these regions. Indian Remote Sensing Satellite LISS III multispectral image was used to classify landuse landcover to derive C and ASTR DEM was used to obtain LS factor. The input data for calculating erodibility K factor was obtained from the manually collected soil samples from the field. R factor map was generated from the 50 year rainfall data obtained from the Indian Meteorological Department. The main focus of the study is to assess whether the estimated soil loss is within the permissible limit or otherwise.

The study revealed two things, such as, C and P factors emerged as strong factors for the soil loss in the area and also that the estimated soil loss of 0.562 $kg/km^2/yr^{-1}$ in such a sediment starved region is beyond the tolerance limit of these sediments. 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. Though badland represents a dynamic landscape, it has been demonstrated from previous studies from all over the world that if they are left undisturbed, they are fairly stable. These badland slopes are covered by shrubs and grasses that provide protection to the surface most time of the year. Levelling these slopes for agriculture loosens the soil and promotes water erosion. Continued practice of the same activities will accelerate the soil erosion in the area. Taking into consideration the rapid growth of population and hence an equal demand for land, it is the need of time to prepare for a landuse practice which is more sustainable for the area for longer term benefit in the future.

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