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Preparation of Erosion Susceptibility Map of Dhaman Khadi Sub-Watershed in Eastern Gujarat Using ArcGIS Interface

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Abstract: An attempt has been made to model land degradation in term of water erosion of selected Dhaman Khadi sub-watershed (7710.64 ha.) in Eastern Gujarat, India through Revised Universal Soil Loss Equation using ArcGIS interface. The average erosivity of 30 years (1986-2015) annual rainfall using standard formula was estimated to be 480.63 MJ mm ha^{-1} hr^{-1} per year. The erodibility factor K was computed as 0.236 and 0.177 mt·hr MJ^{-1} mm^{-1} per unit R respectively for clay loam and clay soils using modified formula.. 20 m Digital Elevation Model was prepared from Toposheet No. F43N10 by using 'Topo to Raster' interpolation method. The slope length factor L was derived from DEM using Unit Stream Power Erosion and Deposition (USPED) Model. The raster layers of slope steepness factor for slope having < 9 % and ≥ 9 % was prepared separately to form final slope steepness factor map. Cover management factor map was derived based on cropping pattern for the various land cover categories of the study area. The standard conservation practice factor values for cross-sloped agricultural lands were assigned to the attribute table of the intersected map of LU/LC and slope maps to prepare the P factor map. Average gross soil erosion was minimum for evergreen forest while maximum for wasteland without scrub. Highest area covered by agricultural land (i. e. 41.54) of Dhaman Khadi sub-watershed having 33.28 tons/ha/yr gross soil erosion needs immediate treatment to prevent land degradation. Soil loss tolerance limit of study area was used to derive erosion susceptibility map in order to identify the priority of conservation programs. As all the factors of RUSLE was estimated precisely at sub-watershed level, the study could help for rapid and reliable planning of watershed development programs in combination with the use of RS and GIS technology.

Keywords: Eerosion risk area, GIS, Gross erosion, RUSLE, Sub-watershed

INTRODUCTION

Soil is the basis for food, feed, medicines, ecosystem services and fuel. Humans obtain more than 99.7% of their food from the soil and less than 0.3% from the oceans and other aquatic ecosystems (Pimentel, 2006). Soil supplies essential nutrients, water, oxygen and supports root system that our food producing plants need to grow and flourish. World is under the threshold of food insecurity especially in the developing countries. Worldwide 19.65 M km^2 areas are affected by human-induced soil degradation, mainly caused by water erosion (55.67 %), wind erosion (27.94 %), chemical degradation (12.16 %) and physical degradation (4.22 %), (Young and Orsini, 2015Among the major causes of soil degradation in India, water erosion is the most severe one which covers almost 68.39 % of the affected area resulting into the annual soil loss of about 5.3 billion tons through erosion (Maji *et al*., 2010). The process of assessing soil erosion using conventional methods is cumbersome, time-consuming and costly. The success of planning for watershed developmental activities depends on the quality and quantity of information available on physical/terrain parameters, climatic and socio-economic resources. In the present study an attempt has been made to measure and model the land degradation in term of water erosion and identify erosion susceptible area for the Dhaman Khadi sub-watershed in Eastern Gujarat using remote sensing and GIS techniques.

MATERIALS AND METHODS

Revised Universal Soil Loss Equation (RUSLE) was used to estimate soil loss from inter rill plus rill erosion for Dhaman Khadi sub-watershed in Eastern Gujarat near Dediapada region of Narmada District, Gujarat, India. The All India Soil and Land Use Survey has developed a hierarchical system of watershed delineation. Based on that, selected sub-watershed is given the number as 5D1A5c (Anonymous, 2014). The study area covers 7710.64 ha. RUSLE retains the structure of its predecessor, the Universal Soil Loss Equation

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(USLE, Wischmeier and Smith, 1978),

A = R x K x L x S x C x P (1)

Where,

A = Average gross soil erosion (mt/ha. per year); R = Rainfall Erosivity Factor (MJ mm $ha.^{-1}$ $hr.^{-1}$ per year); K = Soil Erodibility Factor (mt·hr. MJ^{-1} mm^{-1} per unit R); L= Slope Length Factor (dimensionless); S = Slope Steepness Factor (dimensionless); C = Crop/Cover Management Practice (dimensionless) and P = Support Practice Factor (dimensionless).

Rainfall erosivity factor (R): Relationship between rainfall erosivity index and annual rainfall was developed by Singh *et al.*, 1981 with the data available from various meteorological observatories of India and presented as eq. 1 was used for the study to estimate rainfall erosivity.

Y = 79 + 0.393 X (2)

Where, Y = Annual rainfall erosivity (MJ mm $ha.^{-1}$ $hr.^{-1}$ per year) and X = Average annual rainfall (mm)

Soil erodibility factor (K): Reclassified and modified formula for K factor given by Auerswald *et al.* (2014) as presented in eq. no. 3 to 8 was used to estimate K factor for study area.

For silt + very fine sand > 70 percent,

$K_1 = 1.75 \times 10^{-6} \times M^{1.14} + 0.0024$ (% silt + % very fine sand) + 0.16 (3)

For organic matter < 4 percent,

$K_2 = 100 - clay$ (4)

For $K_1 * K_2 > 0.2$,

$K_3 = 2.77 \times 10^{-6} \times M^{1.14} (12-a) + 0.043 (b-2) + 0.033 (c-3)$ (5)

For $K_1 * K_2 < 0.2$,

$K_3 = 0.091 - 0.34 * K1 * K2 + 1.79 * (K1 * K2)^2 + 0.24 * K1 * K2 * b + 0.033 (c-3)$ (6)

For rock fragment < 1.5 percent,

Soil Erodibility factor K = K3 (7)

For rock fragment > 1.5 percent,

Soil Erodibility factor K = K3 * [1.1- {exp (-0.024 x F_{rk}) – 0.06}] (8)

Where, F_{rk} = Rock fragment content (%)

To ascertain the soil texture analysis, samples from top 15 cm soil layer were collected from several locations that represents various land cover categories from the Dhaman Khadi Sub-watershed study area and finally 10 representative soil samples from clay soils and 8 representative soil samples for clay loam soils were prepared for laboratory analysis to estimate the soil physico-chemical properties i. e. soil texture, organic carbon and rock fragment.. Soil texture, organic carbon and rock fragment percent was estimated respectively using international pipette method, Walkley and Black's rapid titration method and sieve analysis technique (Jackson, 1973).

Slope length factor (L)

Digital elevation model (DEM): Three shape files were prepared separately for elevation points, contours and sub-watershed boundary using Toposheet no. F43N10. These 3 shape files were used to generate hydrologically corrected DEM of 20 m resolution (Fig. 1) using 'Topo to Raster' interpolation method. (Kumar and Kushwaha, 2013)

Unit stream power erosion and deposition (USPED) model: The cell wise slope length factor value was estimated based on USPED model described by Mitasova (1996) and as presented in Eq. (9).

$$L = (m+1)\left(\frac{\lambda_A}{22.1}\right)^m \quad (9)$$

Where, L is the slope length factor λ_A ; is the area of upland flow; 22.1 is the unit plot length and *m* is a variable exponent calculated from the ratio of rill-to-inter rill erosion, as described in equation no. 10. β dependent on slope was computed using eq. no. 11.

$$m = \frac{\beta}{1+\beta} \quad (10)$$

$$\beta = \frac{\sin\theta}{0.0896\,[3\,(\sin\theta)^{0.8} + 0.56]} \quad (11)$$

The DEM was used to derive the raster layers of slope (in degree), flow direction, flow accumulation, variable exponent and ultimately slope length factor map using raster calculator in ArcGIS interface.

Slope steepness factor (S): The equation no. 12 and 13 given by Mc Cool et al. (1987) have been used to

$$S = 10.8\sin\theta + 0.03 \quad \text{for slope gradient} < 9\% \quad (12)$$

$$S = 16.8\sin\theta - 0.50 \quad \text{for slope gradient} \geq 9\% \quad (13)$$

estimate and prepare the thematic map on slope steepness factor in ArcGIS interface. Where, S is the slope steepness factor and θ is the slope in degrees.

The raster layer of slope in degree (Fig. 2) was used to calculate the slope steepness factor by using both the formula (Eq. 12 and 13) separately for the area having > and ≥ 9 percent slopes. Attribute value of slope steepness for the resulting raster layers was transferred to the raster layer of slope in percent (Fig. 3) in order to get the final slope steepness factor map.

Vegetative cover factor (C): The study was carried out at sub-watershed level therefore supervised classification technique was selected to prepare land use / land cover map of study area from Landsat image (LC81480452014150LGN00) dated 6th Nov., 2014 using ERDAS IMAGINE 2013 Interface.

The C factors for agricultural land of the study area have been derived by using the crop wise C factor value given by Kurothe *et al.* (1991-92). The average area covered by different crops of the Dediapada block during last 3 years (Annual Progress Report, 2012-13, 2013-14 & 2014-15) was used to derive the weighted C factor value of 0.358. The C factor values presented by Singh *et al.* (1981) and Narain *et al.* (1994) for different land use as given Table 1 were used to derive the raster layer of C factor for the study area. The land use

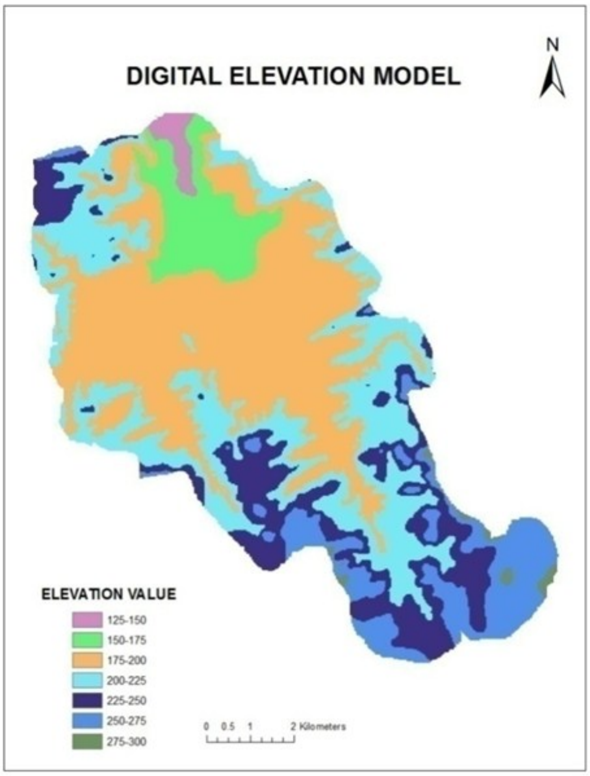

Fig. 1. *Digital elevation model of 5D1A5c.*

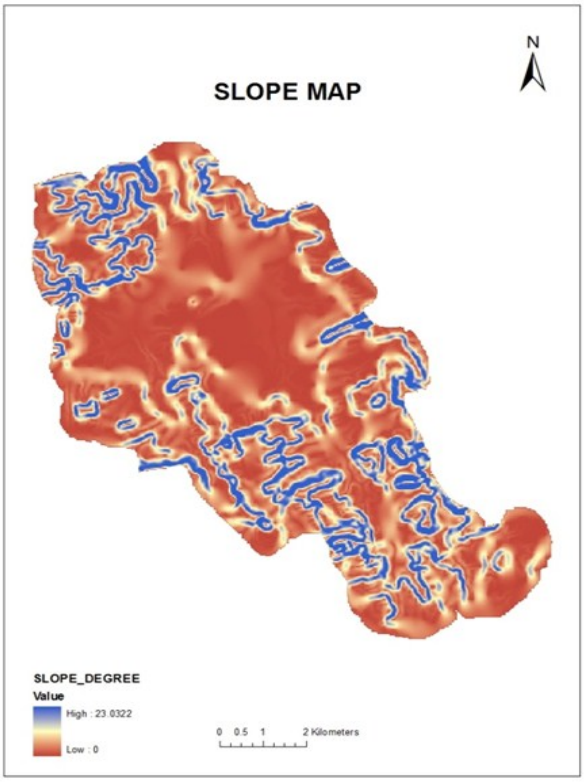

Fig. 2. *Slope Map of 5D1A5c in degree*.

Fig. 3. *Slope map of 5D1A5c in percent.*

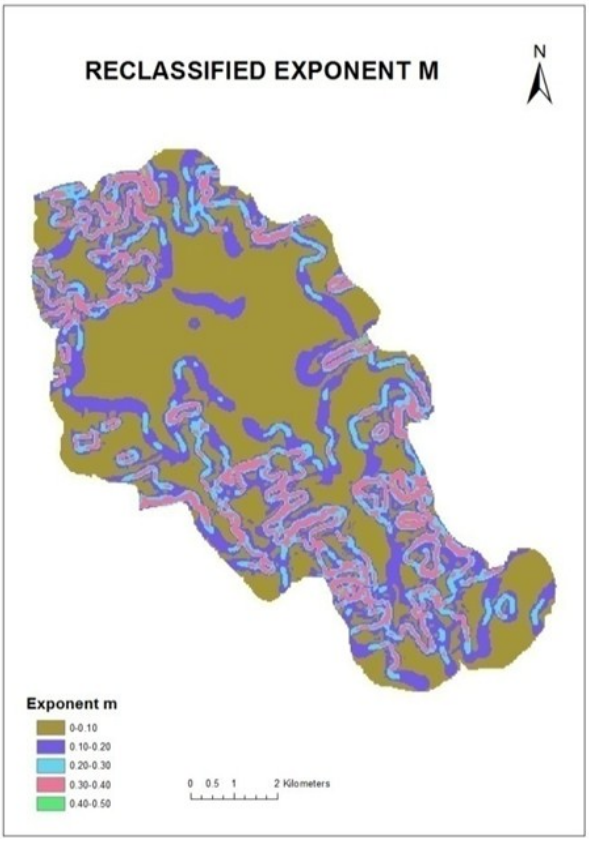

Fig. 4. *Reclassified exponent m map of 5D1A5c.*

Table 1. C factor values for various land.use / land cover class.

S. No.	Land Use / Land Cover	C Factor Value
1	Evergreen Forest	0.004
2	Mixed Forest	0.08
3	Deciduous Forest	0.4
4	Pasture	0.6
5	Low Density Resident	1.0

map was used to assign the cover management factor value as per the land use categories of the study area.

Support practice factor (P): The conservation efficiency of the conservation measures depends on slope and land use pattern. Information regarding conservation measures was obtained through field observations in the study area. All the agricultural lands are under cross slope farming while other lands do not have any type of conservative measures so P factor value was assigned as per recommendation given by Dhruvnarayan (2007) and presented in Table 2 in order to prepare conservation practice factor map.

Gross soil erosion estimation: The raster layers of RUSLE parameters i. e. K, L, S, C, P and computed rainfall erosivity factor (R) value was used to derive gross soil erosion map using raster calculator of spatial analyst tools in ArcGIS interface. The gross erosion map was re-classified based on erosion class given by Singh *et al.* (1992) by using reclassify tools of Spatial Analyst extension into ArcGIS interface.

Erosion susceptibility map: The priorities for soil conservation of the study area is identified based on erosion risk values of the study area. The erosion risk values were computed using gross erosion rate and soil loss tolerance limit of the study area i. e. 5 ton/ha./year (Anonymous 2008-09, ICAR Annual Report). Eq. 14 given by Sharda *et al.* (2013) was used to prepare erosion susceptibility map of the study area.

Erosion Risk = Gross Erosion Rate – Soil Loss Tolerance Limit (14)

Table 2. C factor values as per land cover class and land slope class.

S. No.	Land use / Land Cover	Slope (%)	P Factor Value
1	Agricultural Land	0 – 2	0.6
2		2 – 7	0.5
3		7 – 12	0.6
4		12 – 16	0.7
5		16 – 20	0.8
6		20 - 25	0.9
7		> 25	1.0
8	Other Land Use Pattern	-	1.0

RESULTS AND DISCUSSION

Average rainfall erosivity of last 30 years (1986-2015) is 480.63 MJ mm $ha.^{-1}$ $hr.^{-1}$ with an average annual rainfall of 1106 mm. All the analyzed soil samples have greater than 70 percent silt with less than 4 percent organic matters hence, eq. 3 and 4 were used to compute the values K_1 and K_2. As given in Table 3, 7 soil samples (viz. sample no.-6, 10, 12, 15, 16, 17 and 18) have the value of $K_1 \cdot K_2$ less than 0.2 therefore eq. 10 was used for the estimation of K factor, while, for other soil samples, (viz. sample no.-1 to 5, 7, 8, 9, 11 and 13) eq. 8 was used to estimate the K factor. The

Table 3. Soil erodibility factors of soil samples of selected sub-watershed.

Soil Type	Sample Number	K_1	K_2	K_1 x K_2	K_3	Rock Fragment (%)	K	Average K
Clay Loam Soil	1	0.029	8.95	0.261	0.29	11.30	0.23	0.236
	2	0.029	10.53	0.303	0.34	23.55	0.19	
	3	0.030	10.31	0.306	0.34	2.65	0.33	
	4	0.033	10.22	0.333	0.37	11.07	0.28	
	5	0.030	10.97	0.332	0.37	10.41	0.29	
	6	0.017	11.30	0.197	0.22	19.57	0.14	
	7	0.024	11.15	0.265	0.30	11.37	0.23	
Clay Soil	8	0.023	10.62	0.241	0.27	12.62	0.20	0.177
	9	0.023	9.96	0.233	0.30	31.02	0.14	
	10	0.018	11.08	0.196	0.25	8.99	0.21	
	11	0.020	10.37	0.208	0.27	12.79	0.20	
	12	0.018	10.68	0.193	0.25	8.72	0.21	
	13	0.020	10.45	0.208	0.27	14.18	0.20	
	14	0.020	10.84	0.215	0.28	17.96	0.18	
	15	0.017	10.10	0.175	0.24	18.58	0.15	
	16	0.011	10.91	0.124	0.20	4.41	0.19	
	17	0.009	10.09	0.089	0.18	7.59	0.16	
	18	0.011	10.81	0.114	0.20	12.61	0.15	

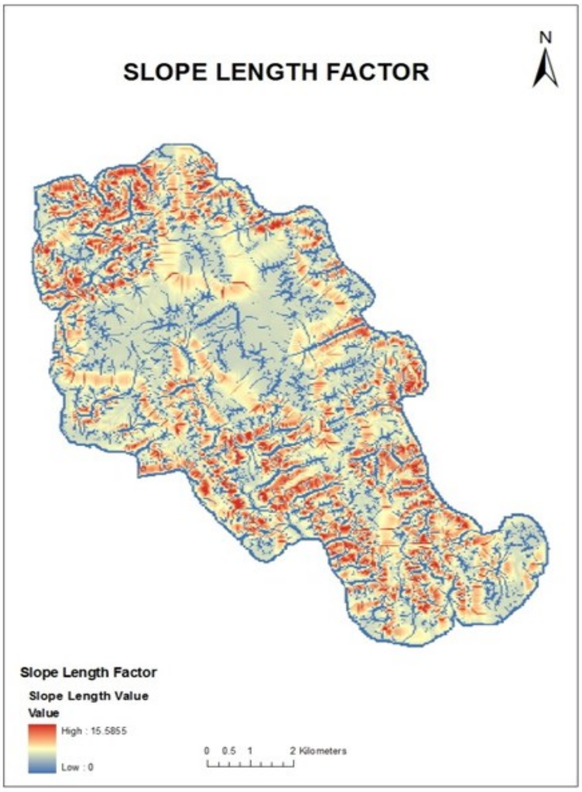

Fig. 5. *Slope length factor map.*

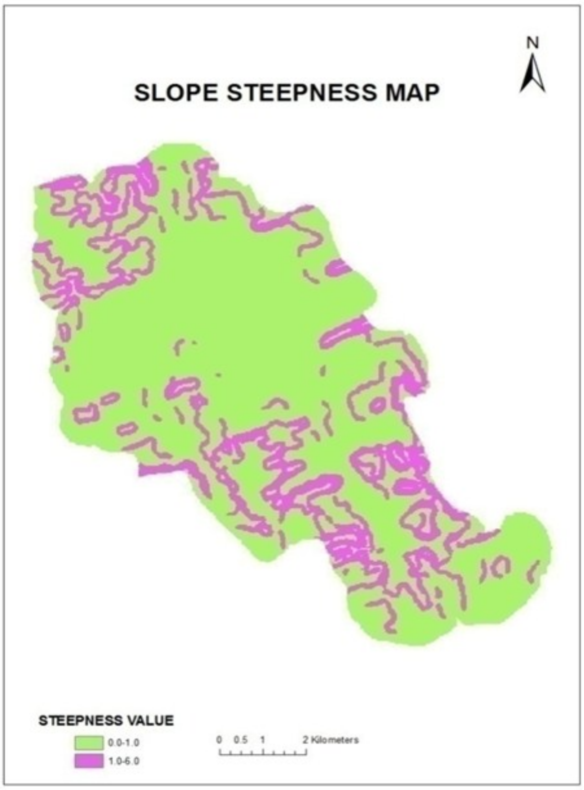

Fig. 6. *Slope steepness map.*

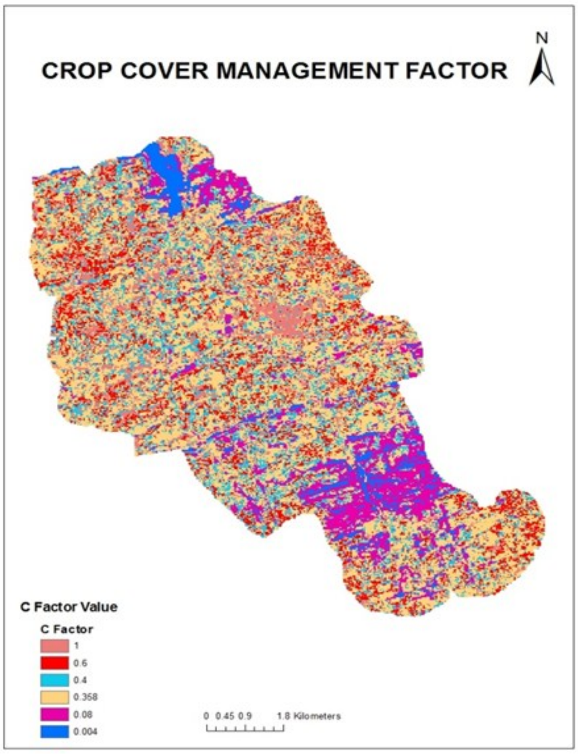

Fig. 7. *Cover management factor map.*

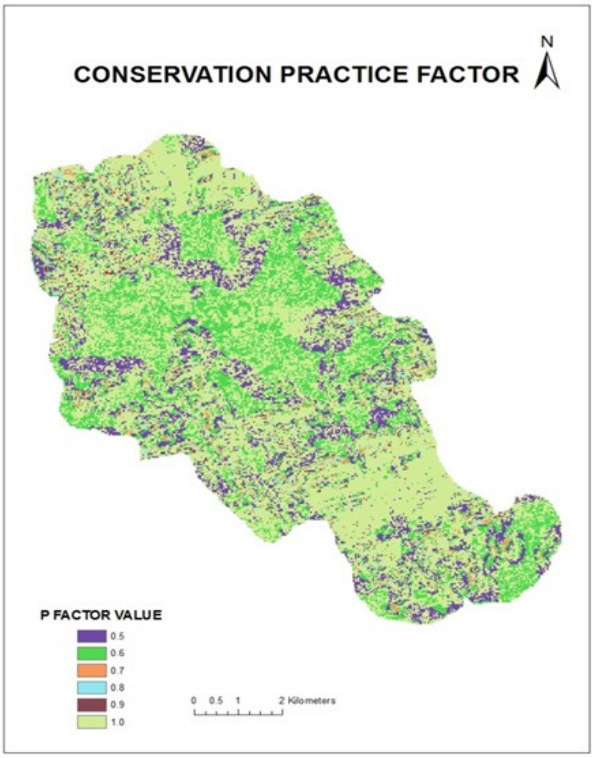

Fig. 8. *Conservation factor map.*

average erodibility of clay loam and clay soil was 0.236 and 0.177 mt·hr MJ^{-1} mm^{-1} per unit R respectively; the higher value in clay loam soils makes it more susceptible for erosion.

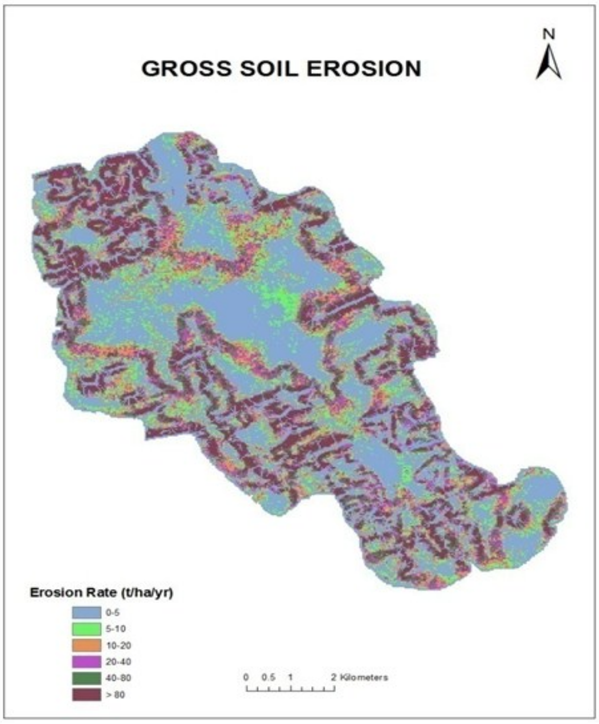

Fig. 9. *gross soil erosion map.*

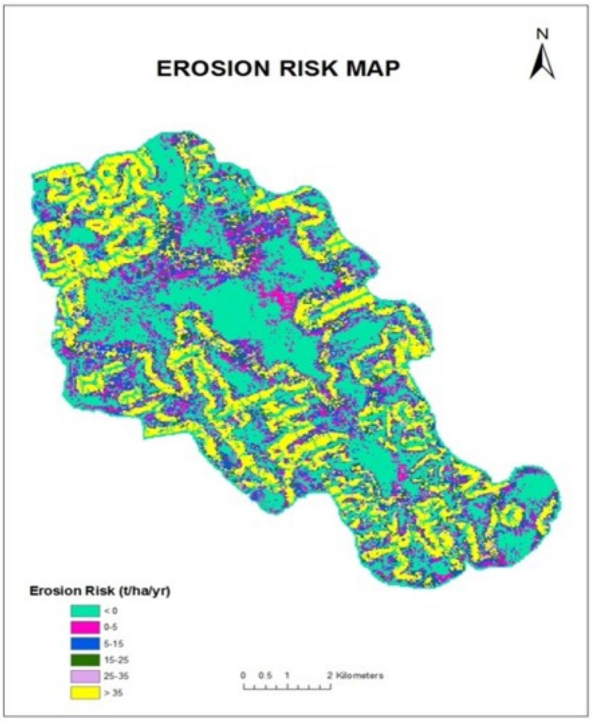

Fig. *10. Erosion risk map.*

Table 4. Gross soil erosion classes of selected sub-watershed.

S. No.	Erosion Class	Range (tons/ ha./yr)	Area (Ha.)
1	Slight	0 – 5	3278.99
2	Moderate	5 – 10	943.12
3	High	10 – 20	913.65
4	Very High	20 – 40	866.91
5	Severe	40 – 80	692.81
6	Very Severe	> 80	1015.16

The reclassified DEM (Fig. 1) indicates that the lowest and highest altitude values of study area are 139.39 m and 288.35 m respectively. It could be inferred that most of the area has an elevation difference of 125 m which makes the topography highly susceptible to erosion due to overland flow. The reclassified exponent value (Fig. 4) shows the 51.68 % area having less than 0.10 exponent values while only 0.14 % area having greater than 0.40 exponent values. The maximum value of exponent is 0.44. The values of slope length factor (L) ranges from 0 to 15.58 (Fig. 5) It could be inferred that when value of L was more than erosion was more, in steep areas, where as when it was less, in plain topography, erosion was less. Reclassified slope steepness map (Fig. 6) indicates that area having less than 9 percent slope has less than 1.0 of slope steepness value while for the area having greater than 9 percent slope, the slope steepness value ranges from 1.0 to 6.0. The cover management factor C map (Fig. 6) describes the land use/ land cover wise C factor values. The highest area covered by cultivated land

Table 5. Prioritization of erosion risk area of selected sub-watershed.

S. No.	Erosion Risk (ton/ha/ year)	Area (hectare)	Percent Area (%)	Erosion Risk Criteria	Priority Class
1	< 0	3278.99	42.53	Safe	6
2	0 to 5	943.12	12.23	Very less priority	5
3	5 to 15	913.65	11.85	Less priority	4
4	15 to 25	501.89	6.51	Medium priority	3
5	25 to 35	365.03	4.73	High priority	2
6	> 35	1707.97	22.15	Very high priority	1

(41.54 %) of sub-watershed has C values of 0.358 while lowest area covered by evergreen forest (4.05 %) has C value of 0.004 (Fig. 7). Fig. 8 depicts that only 0.33 % of total cultivated land has slope greater than 25 % therefore 99.67 % land having P factor values less than 1.0.

The reclassified gross erosion map (Fig. 9) and Table 4 indicate that highest area (42.53 %) comes under slight erosion class followed by very severe (13.17 %); moderate (12.23 %); high (11.85 %); very high (11.24 %) and severe (8.99 %) class.

Land use/land cover wise average gross soil erosion: Average gross soil erosion was lowest for evergreen forest (i.e. 5.16 tons/ha./yr) followed by mixed forest (i.e. 21.87 tons/ha./yr), agricultural land (i. e. 33.28 tons/ha./yr), deciduous forest (i. e. 45.75 tons/ha./yr), pasture (i. e. 51.42 tons/ha./yr) and highest for wasteland without scrub / low density residential area (i. e. 64.64 tons/ha./yr).

Highest area covered by agricultural land (i. e. 41.54 %) of selected sub-watershed having 33.28 tons/ha./yr gross soil erosion needs immediate soil conservation measures in order to reduce water erosion in cultivated land to sustain crop productivity.

Erosion susceptibility map: The erosion susceptibility map (Fig. 10) and Table 5 indicate that 42.53 % of study area is under safe zone while about 22.15 % area was under very high priority which needs immediate attention to prevent the land degradation.

Conclusion

In the present study, the RUSLE model adopted for estimating the average annual gross soil loss in the Dhaman Khadi sub-watershed. The raster layers of all the 5 parameters K, L, S, C and P and computed R value were multiplied using raster calculator to prepare gross soil erosion map in ArcGIS interface. Average annual erosion rate for study area was estimated as 39.25 tons/ha/yr. Average gross soil erosion was minimum for evergreen forest followed by mixed forest, agricultural land, deciduous forest, pasture and wasteland without scrub. The 42.53 % of the study area comes under safe zone which is maximum area of sub watershed, while 22.15 % area comes under very high priority zone. Therefore, if 22.15 % gets treated than total 66.68 % area of sub-watershed will come under safe zone. It is concluded that RUSLE in combination with RS & GIS techniques could be effectively used for estimating soil erosion and planning of development of sub-watersheds.

REFERENCES

Anonymous (2009). Soil Resource Inventory and Management. Soil and Water Productivity, DARE/ICAR Annual Report, pp 7-11.

Anonymous (2014). Watershed Atlas of India, Office of the Chief Soil Survey, Soil and Land Use Survey of India, Department of Agriculture and Co-operation, Ministry of Agriculture, Government of India, Aravali Printers & Publishers Pvt. Ltd., New Delhi, 2nd Edition, pp-107.

Anonymous (2012-13, 2013-14 & 2014-15). Annual Progress Report, Krushi Vigyan Kendra, Navsari Agricultural University, Dediapada.

Auerswald, K., Fiener, P., Martin, W. and Elhaus, D. (2014). Use and misuse of the K factor equation in soil erosion modeling: An alternative equation for determining USLE nomograph soil erodibility values. *Catena*, 118:220-225

Dhruvnarayan, V.V. (2007). Soil and water conservation research in India, Publications and Information Division, ICAR, New Delhi, pp 40-41

Jackson, M.L. (1973). Soil chemical analysis, prentice-hall of India Pvt. Ltd., New Delhi, India, pp 39-415

Kumar, S. and Kushwaha, S.P.S. (2013). Modelling soil erosion risk based on RUSLE-3D using GIS in a Shivalik sub-watershed. *J. Earth. Syst. Sci*., 122(2): 389 -398

Kurothe, R.S. (1991-92). Determination of 'C' and 'P' factors of USLE for important crops and management practices in vasad region. *Annual Report*, Central Soil and Water Conservation Research and Training Institute, Dehradun, pp 100-101

Maji, A.K., Obi Reddy, G.P. and Sarkar, D. (2010). Degraded and Wastelands of India: Status and Spatial Distribution. Indian Council of Agricultural Research, New Delhi, India, pp.23, 159

McCool, D.K., Brown, L.C., Foster, G.R., Mutchler, C.K. and Meyer, L.D. (1987). Revised slope steepness factor for the Universal Soil Loss Equation. *Transactions of the ASAE*, 30(5): 1387-1396

Mitasova, H., Hofierka, J., Zlocha, M. and Iverson, L. (1996). Modelling topographic potential for erosion and deposition using GIS. *Int. J. Geogr. Inf. Syst.,* 10(5): 629-641

Narain, P., Khybri, M.L., Tomar, H.P.S. and Sindhwal, N.S. (1994). Estimation of runoff, soil loss and USLE parameters for Doon Valley. *Indian journal of Soil Conservation*, 22(3):129-132

Pimentel, D. (2006). Soil Erosion: A food and environmental threat. *Environment, Development and Sustainability,* 8: 119–137

Sharda, V.N., Mandal, D. and Ojasvi P.R. (2013). Identification od soil erosion risk areas for conservation planning in different states of India. *Journal of Environmental Boilogy*, 34:219-226

Singh, G., Babu, R. and Chandra, S. (1981). Soil loss prediction research in India; *Tech. Bull. T-12/D-9,* Central Soil and Water Conservation Research and Training Institute, Dehradun, India.

Singh, G., Babu, R., Narain, P., Bhushan, L.S. and Abrol, I. P. (1992). Soil erosion rates in India. *J. Soil Water Conserv.,* 47(1): 97-99

Wischmeier, W.H. and Smith, D.D. (1978). Predicting rainfall erosion losses-A guide to conservation planning. USDA Handbook, 537, U.S. *Dep. Agric*., Washington, D.C.

Young, R. and Orsini, S. (2015). Soil degradation as big a threat to huminiy as climate change. Sustainable Food Trust, UK, pp 1-55