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Estimation of sediment delivery ratio at sub-watershed level using revised and modified USLE

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ABSTRACT

The success of planning for watershed developmental activities depends on the quality and quantity of information available of natural resources. The process of assessing soil erosion using conventional methods is cumbersome, time-consuming and costly therefore, in the present study, an attempt has been made to estimate sediment delivery ratio at sub-watershed level using RUSLE and SWAT Model. The raster layers of K, L, S, C, P factors and computed R factor value was used to derive gross soil erosion map of study area using raster calculator of spatial analyst tools in ArcGIS interface. The MUSLE was used to route and estimate the sediment yield at watershed outlet using SWAT model. Highest area covered by agricultural land (i. e. 41.54) of study area having 33.28 tons/ha/yr gross soil erosion needs immediate treatment of soil conservation in order to reduce water erosion. The average gross soil erosion rate for study area was estimated as 39.25 tons/ha/yr whereas, the sediment yield by SWAT was estimated to be 22.78 tons/ha./year. The estimated sediment delivery ratio indicates that 58 per cent of eroded soils go out of the watershed which reduces the soil depth and fertility of land on site and reaches Karjan reservoir thus reducing the water storage capacity of reservoir each year.

Key words: MUSLE, RUSLE, Sediment Delivery Ratio, Sediment Yield, SWAT.

INTRODUCTION

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). Although the soil has evolved through millions of years of weathering and is sustaining various forms of terrestrial life, its management has become an essential component of strategy for sustenance of ever-increasing population and development pressure (NAAS, 2012). Indiscriminate use and mismanagement led to soil degradation which is an important global issue causing adverse impact on agricultural productivity and environmental quality and ultimately quality of human life. Soil degradation is a further strong driver of climate change through its current and anticipated effects on land use and management. Water erosion is the most dominant degraded process in Gujarat, affecting about 43% of the total area (Anonymous, 2008-09). The success of planning for developmental activities depends on the quality and quantity of information available on both natural and socio-economic resources. The process of assessing soil erosion using conventional methods is cumbersome, time-consuming and costly therefore, in the present study, an attempt has been made to estimate gross erosion, sediment yield and sediment delivery ratio due to water erosion for the study area using remote sensing and GIS techniques

MATERIALS AND METHODS

Study Area: The Sub-watershed 5D1A5c falling in Dediapada Taluka having 7710.64 ha catchment area was selected for precise estimation of sediment delivery ratio. The sub watershed lies between 73^0 31' 52.63" and 73^0 38' 58.02" East longitude and 21^0 33' 23.83" and 21^0 40' 14.18" North latitude.

Gross soil erosion: Revised Universal Soil Loss Equation (RUSLE) was used to estimate gross soil loss using ArcGIS 10.2 interface. The cell wise values of RUSLE parameters were derived separately to estimate gross soil erosion as described below.

Rainfall Erosivity Factor (R): Relationship between rainfall erosivity index and annual rainfall was developed by Singh *et al.* in 1981 presented as eq. 1 was used for the study to estimate average annual rainfall erosivity for 30 years (1986-2015).

$$Y = 79 + 0.393\ X \quad (1)$$

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 by Auerswald *et al.* (2014) based on silt, organic matter and rock fragment of soil sample as presented in eq. no. 2 to 6 was used to estimate K factor.

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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 (2)

For organic matter < 4 percent, K_2=100–clay (3)

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) (4)

For $K_1 * K_2 < 0.2$,

$K_3 = 0.091\text{-}0.34 * K1 * K2 + 1.79 * (K1 * K2)^2 + 0.24 * K1 * K2 * b + 0.033 (c-3)$ (5)

For rock fragment > 1.5 percent,

Soil Erodibility factor $K = K3 * [1.1 - \{\exp(-0.024 \times F_{rk}) - 0.06\}]$ (6)

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

Soil texture, organic carbon and rock fragment per cent from 10 representative soil samples from clay soils and 8 representative soil samples for clay loam soils was estimated respectively using international pipette method, Walkley and Black's rapid titration method and sieve analysis technique.

Slope length factor (L): These 3 shape files for elevation points, contours and sub-watershed boundary digitized from Toposheet no. F43N10 were used to generate 20 m resolution DEM (Fig. 1) using 'Topo to Raster' interpolation method. The DEM was used to derive the raster layer of variable exponent m and ultimately slope length factor map in ArcGIS interface using Unit Stream Power Erosion and Deposition (USPED) Model presented in eq. 7.

L = Float (m +1) · Power (flow accumulation * DEM cell size/ 22.13, m) (7)

Where, L is the slope length factor; λ_A is the area of upland flow; 22.1 is the unit plot length and is a variable exponent calculated from the ratio of rill-to-inter rill erosion.

Slope steepness factor (S): The equation no. 8 and 9 given by Mc Cool *et al.* (1987) has been used to estimate and prepare the thematic map on slope steepness factor in ArcGIS interface.

$s = 10.8 \sin\theta + 0.03$ for slope gradient ≤9% (8)

$s = 16.8 \sin\theta - 0.05$ for slope gradient >9% (9)

Where, S is the slope steepness factor and is the slope in degrees (Fig. 2).

Vegetative cover factor (C): The C factors for agricultural land have been derived by using the crop wise C factor value

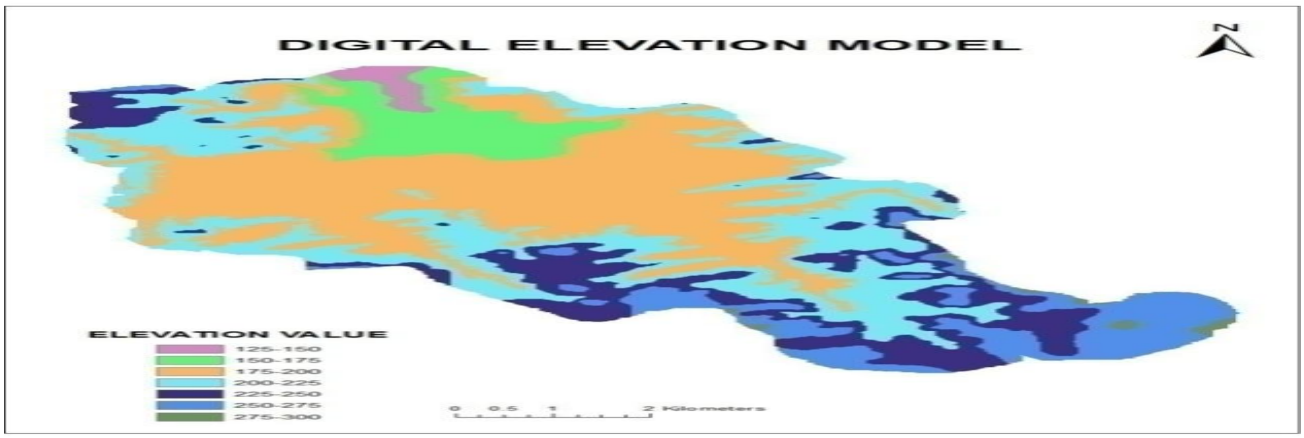

Fig 1: Digital elevation model

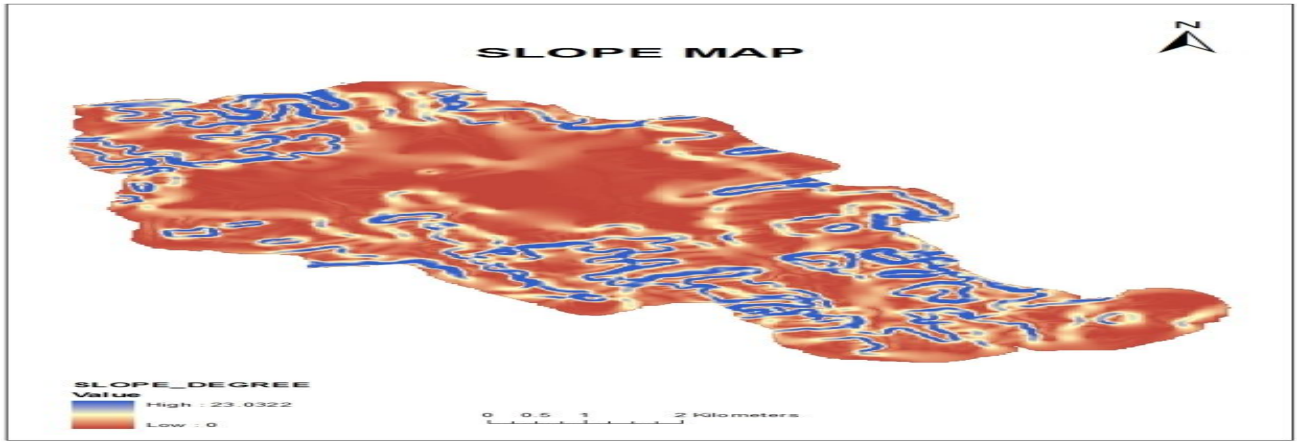

Fig 2: Slope in degree

given by Kurothe *et. al.* (1991-92) while C factor values for forest lands and wastelands presented by Singh *et al.* (1981) and Narain *et al*. (1994) were used to derive the C factor. The land use map derived from Landsat image (LC81480452014150LGN00) dated 6th Nov., 2014 by supervised classification techniques was used to assign the cover management factor value as per the land use categories of the study area.

Support practice factor (P): All the agricultural lands are under cross slope farming while other lands do not have any type of conservative measures therefore P factor values for agricultural land for 0-2 %; 2-7 %; 7-12 %; 12-16 % 16-20 % and 20-25 % slope classes were assigned as 0.6, 0.5, 0.6, 0.7, 0.8 and 0.9 respectiely as given by Dhruvnarayan (2007) in order to prepare conservation practice factor map.

Gross soil erosion estimation: The raster layers of K, L, S, C, P factors and computed R factor value was used to derive gross soil erosion map using raster calculator of spatial analyst tools in ArcGIS interface.

Sediment yield: Modified Universal Soil Loss Equation (MUSLE) was used to estimate sediment yield using Soil & Water Assessment Tool (SWAT) version 2012. The various database details required to run and estimate sediment yield by MUSLE using SWAT model is described below.

Soil and land cover database details: The Soil physic-chemical properties and land cover details derived for estimation of soil erodibility factor and vegetative cover factor were used as input in SWAT model respectively.

Weather database details: The daily weather parameters such as rainfall, temperature, relative humidity, wind speed and solar radiation were collected from State Water Data Center, Gandhinagar and used in SWAT model in order to generate the weather generator database. The pcp SWAT and *dew02.exe* program were used to estimate various rainfall and relative humidity parameters respectively while temperature, wind velocity and solar radiation related parameters were estimated using pivot table properties of Microsoft excel (Table 1 and 2).

Model calibration: Manual Calibration helper was used to replace USLE_P value for 0-2, 2-7, 7-12 and 12-25 percent slope classes with 0.6, 0.5, 0.6 and 0.8 respectively for agricultural land in order to calibrate swat model.

RESULTS AND DISCUSSION

Gross soil erosion: Average annual rainfall erosivity was estimated as 480.63 MJ mm ha^{-1} hr^{-1} with an average annual rainfall of 1106 mm. The average erodibility of clay loam and clay soil was 0.236 and 0.177 respectively. The values of slope length factor (L) ranges from 0 to 15.58 (Fig. 3) Reclassified slope steepness factor map (Fig. 4) indicates that area having less than 9 percent slope has less than 1.0 of slope steepness value while for the area having greater

Table 1: Statistical parameters of daily rainfall

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan.	0.47	0.40	29.40	0.00	0.50	0.07
Feb.	0.57	0.58	29.10	0.00	0.00	0.03
Mar.	0.20	0.20	30.50	0.00	0.00	0.03
Apr.	0.73	0.73	30.00	0.00	0.00	0.03
May.	6.17	3.36	21.33	0.00	0.50	0.20
Jun.	159.05	15.68	4.66	0.16	0.57	8.17
Jul.	414.40	30.28	6.93	0.37	0.79	20.53
Aug.	311.97	20.91	4.79	0.40	0.75	20.03
Sep.	186.73	16.02	4.58	0.20	0.64	11.57
Oct.	23.50	5.49	10.21	0.03	0.41	1.53
Nov.	1.87	0.95	20.41	0.01	0.00	0.20
Dec.	0.77	0.75	30.50	0.00	0.00	0.03

Table 2: Statistical parameters of temperature, wind velocity and solar radiation

Month	TMPMX	TMPMN	TMPSTDMX	TMPSTDMN	WD	SR
Jan.	30.30	14.14	2.42	2.66	2.66	20.43
Feb.	32.85	15.38	2.69	2.92	2.73	23.63
Mar.	37.34	18.39	2.74	2.45	3.13	25.51
Apr.	40.42	21.96	2.23	2.18	4.03	25.83
May.	41.05	25.49	2.19	1.50	4.15	21.75
Jun.	36.32	26.10	4.49	1.27	3.88	15.43
Jul.	29.63	24.26	3.23	0.93	3.42	13.64
Aug.	28.07	23.18	2.50	1.44	2.63	16.96
Sep.	30.17	22.34	2.97	1.58	2.12	19.92
Oct.	33.34	20.04	2.69	2.43	2.28	18.29
Nov.	32.61	17.92	1.94	2.54	2.57	17.15
Dec.	30.46	15.18	2.26	2.78	2.77	17.77

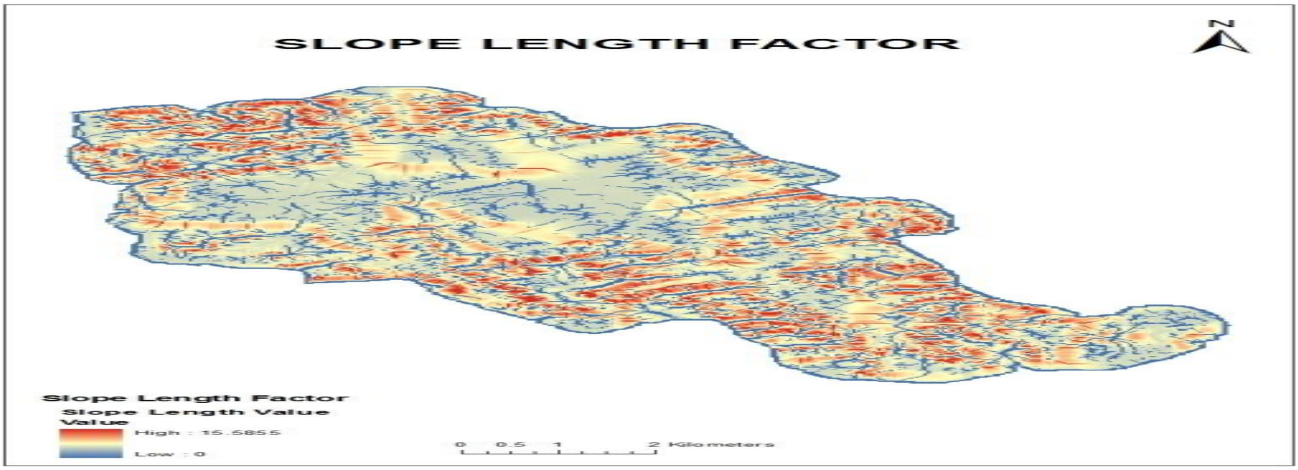

Fig 3: Slope length factor map



Fig 4: Slope steepness map

than 9 percent slope, the slope steepness value ranges from 1.0 to 6.0. The cover management factor C map (Fig. 5) depicts that highest area covered by cultivated land (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. The average gross soil erosion rate was estimated as 39.25 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 (Fig. 6) needs immediate treatment of soil conservation in order to reduce water erosion in cultivated land to sustain crop productivity.

Sediment yield: The model was re-run after the calibration. The sediment yield was estimated as 22.78 tons/ha/yr (Fig. 7) by calibrated SWAT Model. The surface runoff was remaining constant before and after the calibration of SWAT Model using USLE_P values.

Sediment delivery ratio: Sediment delivery ratio was estimated by taking ratio of gross erosion estimated from RUSLE (i. e. 39.25 tons/ha/yr) with sediment yield estimated from SWAT simulation (22.78 ton/ha./year). The sediment delivery ratio was computed as 0.58. This ratio indicates that about 58 percent of eroded soils go out of the watershed which reduces the soil depth and fertility of land on site and reaches Karjan reservoir thus reducing the capacity of water storage each year.

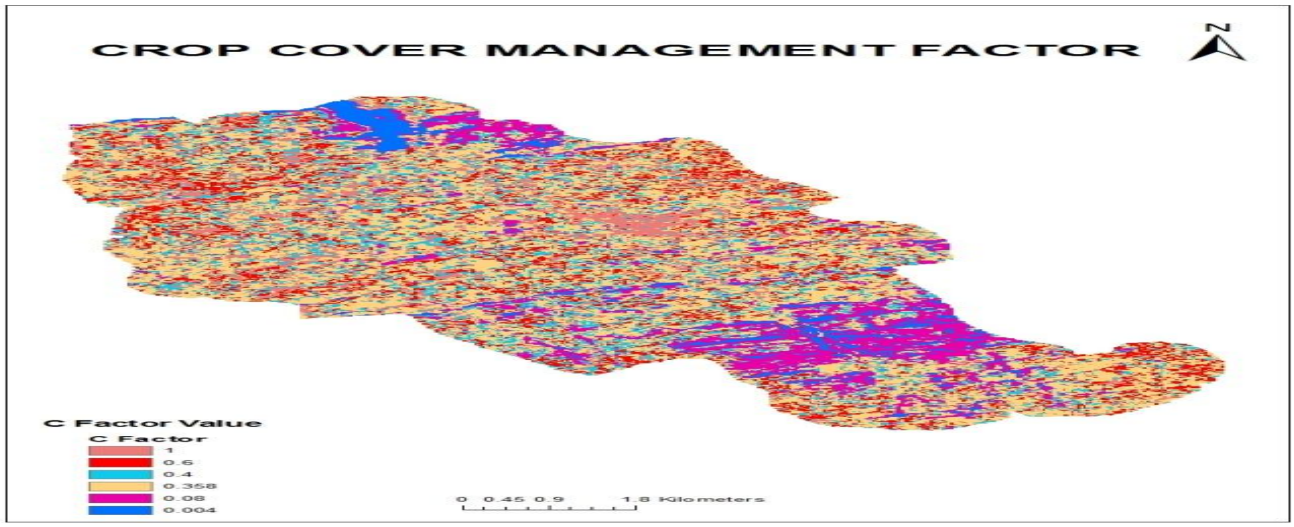

Fig 5: Cover management factor map

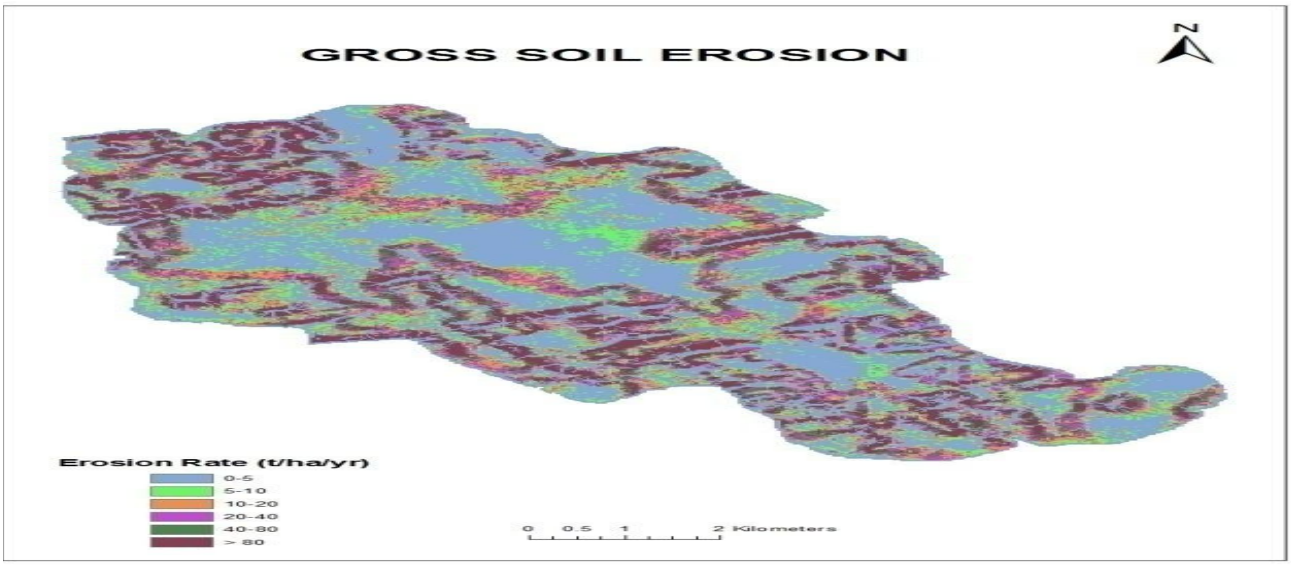

Fig. 6: Gross soil erosion map



Fig 7: Gross soil erosion map

REFERENCES

Anonymous, (2008-09.) Soil Resource Inventory and Management. *Soil and Water Productivity*, DARE/ICAR Annual Report, pp. 7-11.

NAAS (2012.) Sustaining agricultural productivity through Integrated Soil Management. Policy Paper No. 56, National Academy of Agricultural Sciences, New Delhi, pp. 24.

Anonymous, (2014.) Watershed Atlas of India, Soil and Land Use Survey of India, Ministry of Agriculture, Government of India, Aravali Printers & Publishers Pvt. Ltd., New Delhi, pp 107.

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, 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

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, 100-101.

Liersch, S. (2003.) The Program pcpSTAT: user's manual. *Berlin, August 2003*.

Liersch, S. (2003.)The Programs dew.exe and dew02.exe: user's manual.[*http://www. brc. tamus. edu/swat/pcpSTAT. zip*.].

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 L. Iverson (1996.) Modelling topographic potential for erosion and deposition using GIS. *International Journal of Geographical Information Systems*. **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.

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. *Journal of Soil and Water Conservation*, **47**(1): 97-99.