Mapping of erosional soil loss in Ridhora watershed of Nagpur district of Maharashtra using remotely sensed data and GIS techniques

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Abstract : A study was taken up to map the erosional soil loss in Ridhora watershed of Nagpur district of Maharashtra using geo-coded false colour composites (FCC) of IRS-P6 (LISS- III and IV) data of *kharif* and *rabi* seasons. The data related to soil, slope length and steepness, crop management and conservation measures were derived from satellite data, toposheet and ground truth survey and used as inputs in USLE Model for assessment of erosional soil loss. The soil erosion map prepared by the integration of USLE factors revealed three soil erosion classes. Nearly 32.48 per cent area of the watershed was under slight erosion with soil loss of <5 t/ha/yr. The moderately slight erosion (5-10 t/ha/yr) and moderately severe erosion (15-20 t/ha/yr) class covered 25.44 and 40.63 per cent area, respectively. Based on the erosion classes appropriate conservation measures have been suggested.

Additional key words : *Watershed characteristics, erosional soil loss, remote sensing and GIS*

Introduction

Information on spatial distribution of degraded/eroded lands and areas prone to degradation/ soil erosion is needed for formulation of conservation plan for development of an area. Mapping of such areas by conventional technique is time consuming and consistent set of ground measurements are needed. Satellite remote sensing provides scientific input for faster and precise mapping of natural resources (Saxena *et al.* 2000; Bodhankar *et al.* 2002) and degraded/ eroded lands (Skidmore *et al.* 1997) and also facilitates for quick evaluation of vegetation status vital for erosion assessment. Several models have been developed to predict soil erosion but USLE model of Wischmeier and Smith (1978) is most frequently used in India (Sharma *et al.* 2003 ; Potdar *et al.* 2003). Through present paper, an attempt has been made for mapping the erosional soil loss in Ridhora watershed of Nagpur district, Maharashtra using remote sensing and GIS techniques .

Materials and methods

Study Area

The Ridhora watershed is located between 21°10' to 21°14' N latitude and 78°33' to 78°38' E longitude in Katol tahsil of Nagpur district, Maharashtra. The elevation ranges from 420 to 540 m above the mean sea level and covers an area of 2482.59 ha. Physiographically, the area consists of pediment, plateau top, lower valley, upper valley, isolated hillocks and escarpment. Ridhora nala drains the area. The climate is sub tropical subhumid (dry). The mean annual temperature is 26.6 °C associated with mean annual rainfall of 1051.5 mm. The area qualifies for

'Ustic' soil moisture regime and *'Hyperthermic'* soil temperature regime. The natural vegetation comprises dry deciduous tree species, shrubs interspersed with grasses. Commonly occurring species of tree and grasses are Teak *(Tectona grandis)*, babul *(Acacia spp.)*, palas *(Butea frondosa)*, charoli *(Buchanania latifolia)*, ber *(Zizyphus jujuba)*, anjan *(Hardwicia binata)* and kans *(Saccharum spontaneum)*. Sorghum *(Sorghum bicolor)*, soybean *(Glycine max)*, cotton *(Gossypium spp.)* pigeonpea *(Cajanus cajan)*, and groundnut *(Arachis hypogae L.)* are major *kharif crops* whereas wheat *(Triticum aestivum)* and chickpea *(Cicer arietinum)* are important *rabi* crops raised on residual moisture or under irrigation. Mandarin *(Citrus reticulata)* is main fruit crop in the watershed.

Methodology

Geocoded false colour composites (FCC) of IRS-P6 (LISS-III and IV) data of two seasons *(kharif* and *rabi)* were visually interpreted in conjunction with Survey of India (SOI) toposheet 55 K/12 (1:50,000 scale) and subsequently ground-truth observations were collected to derive spatial information related to existing land use/land cover, physiography and soils. Soil samples (horizon-wise) collected from pedons representing different physiographic units were analyzed for relevant physical and chemical properties following standard procedures. Slope map was prepared using contour information available on SOI toposheet.

Soil erosion assessment and mapping

Soil erosion assessment in the watershed was made using Universal Soil Loss Equation (Wischmeier and Smith 1978). The universal soil loss equation (USLE) is an erosion model designed to predict average soil losses from specific tracts of land in specified land use/land cover management systems over long period of time. It computes soil loss as the product of six major factors whose value can be expressed numerically. Erosion variables reflected by these factors vary considerably about their means with the intensity of rainstorms, but the effects of these random fluctuations tend to average out over extended periods. The soil loss equation is represented by

$$A = R \times K \times L \times S \times C \times P$$

Where,

A = average annual soil loss (t ha^{-1} yr^{-1}),

R = the rainfall erosivity factor,

K = soil erodibility factor (t ha^{-1} per unit of R),

L = the slope length factor,

S = the slope steepness factor,

C = the cover and management factor and

P = conservation practice factor

The maps of soil, slope and land use/land cover were re-classified to generate soil erodibility (K), slope length and steepness (LS) and crop management and conservation (CP) maps. These maps were integrated under GIS environment using ArcGIS software to compute soil loss and to generate soil erosion map. The procedure adopted for derivation of different factors of USLE was as fallows.

Rainfall erosivity factor(R): The rainfall erosivity factor (R) in the universal soil loss equation is the number of rainfall erosion index units (EI_{30}) for a particular location. The monthly, seasonal and annual Erosion Index values for Nagpur area have been calculated (Ram Babu *et al.* 1978).

Soil erodibility factor (K): The soil erodibility factor indicates the rate at which different soils erode. The K values of different soils vary because of differences in soil properties such as texture, structure, permeability and organic matter content. Direct measurements of K values are quite expensive and time consuming. In the present study, K values for different soils were determined using soil erodibility monograph (Wischmeier *et al.* 1971).

Topographic factor (LS): Soil erosion is expected to increase with slope gradient (S) and slope length (L). The topographic factor (LS) has been calculated using the nomograph (Wischmeier and Smith 1978).

Crop management and conservation factor (CP): The crop management factor (C) is the expected ratio of soil loss from land cropped under specified conditions to soil loss from clean tilled fallow on identical soil and slope and under same rainfall (Singh *et al.* 1981). This factor is the most complicated because there is almost infinite number of ways of managing the growing crops. In the present study, the values of C for different land use classes were extracted from the published literature (Karad *et al.* 1991; Kurothe *et al.* 2001).

The soil conservation factor (P) in the universal soil loss equation is the ratio of soil loss with specific supporting practices to the corresponding soil loss with up and down cultivation. The most important of these supporting practices are contour cultivation, strip cropping, terrace system, bunding and waterways for the disposal of excess rainfall. Common practices adopted in the study area are contour cultivation and field bunding.

The maps were digitized and processed under GIS environment using Arc. GIS 9.3 version software. The maps of soil erodibility (K), slope length and steepness (LS) and crop management and conservation (CP) were integrated under GIS to compute the soil loss and to generate soil erosion map.

Results and discussion

Land use/ Land cover

The present land use/land cover data indicate agricultural crop lands (single crop and double crop land), notified forests (dense , moderately dense and degraded forest) , scrub land and habitation.

Slope

Five slope classes *viz.* (a) very gently sloping (1-3 % slope) covering an area of 1094.25 ha, (b) gently sloping (3-8 % slope) occupying an area of 988.65 ha, (c) moderately gently sloping (8-15 %) covering an area of 240.75 ha and (d) moderately steeply sloping (15-30 %) occupying an area of 122.82 ha have been derived.

Table 1. Estimated value of soil erodibility factor (K) for different soil series

Landform	Soil series	Silt+Very fine sand (0.002-0.1 mm)	Sand (0.1-2mm)	Org. matter (%)	Structure	Permea-bility	K value
Plateau top	Kokarda - 1	39.08	22.91	1.63	Blocky	Moderate	0.40
	Kachari Sawanga - 1	23.75	13.60	1.14	Blocky	Moderate	0.32
Escarpment	Kokarda - 2	30.17	21.29	2.38	Blocky	Rapid	0.42
	Mendhe pathar	46.56	20.87	1.23	Blocky	Rapid	0.32
Isolated hillocks	Kachari Sawanga - 2	46.10	16.01	0.86	Blocky	Moderate	0.37
	Bhiwari - 1	47.49	12.69	1.61	Blocky	Moderate	0.30
Pediment	Ridhora - 1	37.61	24.45	1.20	Blocky	Moderate	0.22
	Subkund -1	44.96	15.29	2.05	Blocky	Moderate	0.30
Upper valley	Kachari Sawanga -3	33.90	11.84	1.31	Blocky	Moderate	0.34
	Bhiwari - 2	31.19	14.39	1.02	Blocky	Moderate	0.30
Lower vally	Ridhora - 2	24.87	35.03	1.25	Blocky	Moderate	0.28
	Subkund - 2	38.22	21.08	1.30	Blocky	Moderate	0.28

Physiography-soils

Based on visual interpretation of satellite data and ground truth survey, six major physiographic units i.e. pediment, plateau top, lower valley, upper valley, isolated hillocks and escarpment were identified and delineated. Twelve soil series (Kokarda-1, Kachari Sawanga-1, Kokarda-2, Mendhe Pathar, Kachari Sawanga-2, Bhiwari-1, Ridhora-1, Subkund-1, Bhiwari-2, Ridhora-2 and Subkund-2) were identified in different physiographic units and mapped as soil series association (Table 1).

Rainfall factor (R)

The total geographical area of the watershed of the is only 2482.59 ha which is quite small and hence it was assumed that there would not be much variation in the rainfall distribution pattern in the watershed. Ram Babu *et al.* (1978) estimated the erosion index of Nagpur area based on rainfall distribution pattern and reported annual rainfall erosion index value 483 for the area. The same index value has been used for the estimation of soil loss in the present study.

Soil erodibility factor (K)

The physiography-soil map was utilized to generate information on soil erodibility factor (K) and preparation of soil erodibility map. The soil erodibility factor was determined for each soil unit using soil erodibility nomograph (Wischmeier *et al.* 1971). The soil erodibilty factor (K) for different soil series are presented in table 1 and map in figure 1. Soil units where two soil series occur in association, average soil erodibility index was computed after assigning 60 per cent weightage to the dominant soil and 40 per cent to the sub-dominant soil.

Slope length and steepness factor (LS)

The LS factor for each physiographic units were determined based on degree and length of slope using monograph developed by Wischmeier and Smith (1978). The data (Table 2 and Fig. 2) indicates that escarpment slopes have the highest LS values because of steep slopes and lower alluvial plain had lowest LS value because of field bundings.

Crop cover and management factor (CP)

The 'C and T" values used for different land utilization types were extracted from published literature (Singh *et al.* 1981; Karad *et al.* 1991; Kurothe *et al.* 2001). The CP values for different land

Table 2. Estimated value of slope factor (LS) for different soil series

Sr.No.	Soil series	Physiography	Slope Class (%)	Estimated LS value
1.	Kokarda - 1	Plateau top	1 – 3	0.28
2.	Kachari Sawanga - 1	Plateau top	1 -3	0.20
3.	Kokarda - 2	Escarpment	8 – 15	2.10
4.	Mendhe pathar	Escarpment	15 – 30	6.60
5.	Kachari Sawanga - 2	Isolated hillocks	8 – 15	2.10
6.	Bhiwari - 1	Isolated hillocks	8-15	1.70
7.	Ridhora - 1	Pediment	3 - 8	0.88
8.	Subkund -1	pediment	3 - 8	0.88
9.	Kachari Sawanga -3	Upper valley	1 - 3	0.28
10.	Bhiwari - 2	Upper valley	1-3	0.28
11.	Ridhora - 2	Lower valley	1-3	0.20
12.	Subkund - 2	Lower valley	1-3	0.20

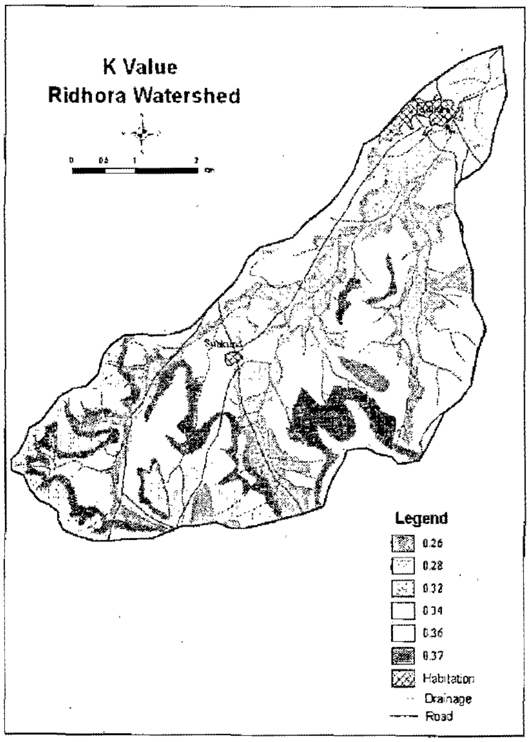

Fig. 1 : Soil erodibility factor (K) for Ridhora watershed

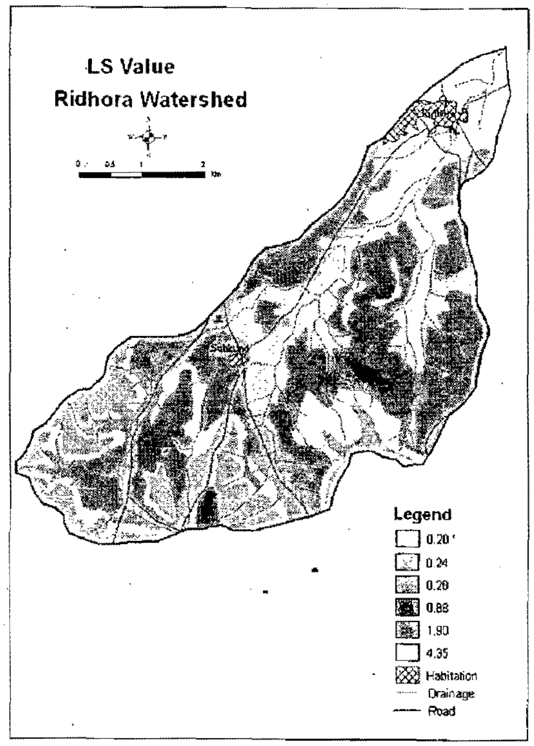

Fig. 2 : Soil slope factor (LS) for Ridhora watershed

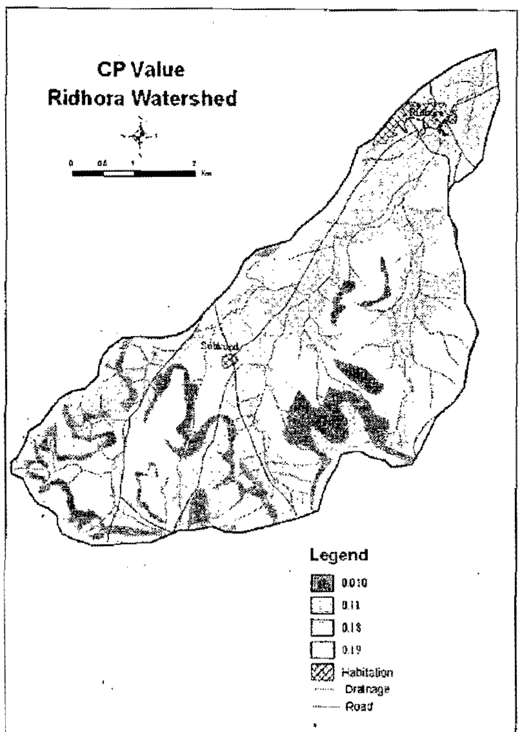

Fig. 3 : Soil conservation and management

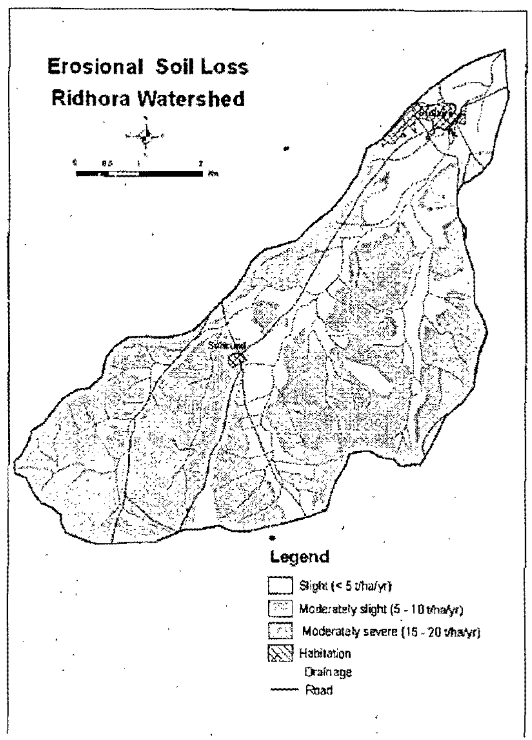

Fig. 4 : Soil loss due to various factors of erosion (CP) factor for Ridhora watershed

Table 3. Estimated value of conservation(C) and management (P) factor for different soil series

S. No.	Soil series	**Land utilization type**	C value	P value	CP value
1.	Kokarda - 1	Single crop	0.35	0.50	0.18
2.	Kachari Sawanga - 1	Single crop	0.35	0.50	0.18
3.	Kokarda - 2	Moderately dense forest	0.01	1.00	0.01
4.	Mendhe pathar	Moderately dense forest	0.01	1.00	0.01
5.	Kachari Sawanga - 2	Moderately dense forest	0.01	1.00	0.01
6.	Bhiwari - 1	Moderately dense forest	0.01	1.00	0.01
7.	Ridhora - 1	Single crop	0.35	0.50	0.18
8.	Subkund -1	Scrub land	0.20	1.00	0.20
9.	Kachari Sawanga -3	Double crop	0.38	0.30	0.11
10.	Bhiwari - 2	Double crop	0.38	0.30	0.11
11.	Ridhora - 2	Double crop	0.38	0.30	0.11
12.	Subkund - 2	Double crop	0.38	0.30	0.11

utilization type in the watershed have been given in table 3 and map in figure 3. The dominant crop cover under the single crop is cotton, whereas in double cropland sorghum/soybean is taken during *kharif* followed by wheat/gram during *rabi* season. Hence the 'C' value for cotton and sorghum/soybean were considered for assessment of soil loss under single and double crop land respectively. Since no prominent conservation measures are followed in forest and scrub land areas and hence they were assigned 'P' value as 1. Under agricultural land, the double crop land had very good bunding as compared to single crop and fallow land hence the 'P' value of 0.3 was assigned to double crop land and 0.5 to single crop and fallow land.

Table 4. Soil loss estimation due to different factors of erosion for different soil series

Sr. No.	Soil series	R value	K value	LS value	C value	P value	Soil loss (tonnes/ha/yr)
1	Kokarda - 1	483.0	0.40	0.28	0.35	0.50	9.74
2	Kachari Sawanga - 1	483.0	0.32	0.20	0.35	0.50	5.56
3	Kokarda - 2	483.0	0.42	2.10	0.01	1.00	5.26
4	Mendhe pathar	483.0	0.32	6.60	0.01	1.00	10.20
5	Kachari Sawanga - 2	483.0	0.37	2.10	0.01	1.00	3.75
6	Bhiwari - 1	483.0	0.30	1.70	0.01	1.00	2.46
7	Ridhora - 1	483.0	0.22	0.88	0.35	0.50	16.83
8	Subkund -1	483.0	0.30	0.88	0.20	1.00	20.30
9	Kachari Sawanga -3	483.0	0.34	0.28	0.38	0.30	5.06
10	Bhiwari - 2	483.0	0.30	0.28	0.38	0.30	4.96
11	Ridhora - 2	483.0	0.28	0.20	0.38	0.30	2.87
12	Subkund - 2	483.0	0.28	0.20	0.38	0.30	2.98

Table 5. Extent and distribution of erosion classes on the basis of soil loss

Sr. No.	Erosion class on the basis of soil loss	Soil loss (t/ha/yr)	Area (ha)	% of TGA
1.	Slight	< 5	806.33	32.48
2.	Moderately slight	5 -10	631.49	25.44
3.	Moderately severe	15 - 20	1008.65	40.63
4.	Habitation	-	36.12	1.45
	Total		**2482.59**	**100.00**

Soil erosion mapping

After estimating the different USLE factors (R, K, LS and CP), the total soil loss (A) was estimated by multiplying all the factors. Based on estimated soil loss (t/ ha/yr), the area was grouped under different erosion classes *viz.* slight (<5 t/ha/yr), moderately slight (5-10 t/ha/yr), moderate (10-15 t/ha/yr), moderately severe (15-20 t/ha/yr), severe (20-40 t/ha/yr) and very severe (>40 t/ha/yr). (Kurothe *et al.* 2001). Total erosion in each series shown in table 4 and the area under different soil erosion class is shown in table 5 and map in figure 4. Nearly 32.48 per cent area of the watershed in under slight erosion having soil loss less than 5t/ha/yr. These areas, as such, require no special treatment for soil conservation as the soil loss from these areas are near the tolerable limit of 4.5 t/ha/yr (Mannering 1981). Moderately slight erosion cover about 25.44 per cent area. These areas require conservation practices such as proper field bunding and optimum vegetative cover to reduce the soil loss. The moderately severe class comprises 40.63 per cent area of the total watershed. These areas need special soil conservation measures to check soil degradation depending upon the soil-site characteristics and land utilization type. On the basis of this study, some soil and water conservation measures should be adopted. Natural regeneration of forest species in the moderately dense forest and afforestation in degraded forest areas should be taken up to reduce the runoff and soil erosion from isolated hollocks and escarpments. Based on soil characteristics, physiography, land use/land cover and soil erosion class, the drain-line treatments *viz.* gully plugging, check dams spillways and other suitable engineering structures should be taken up to conserve rain water and soil loss. The foot slope and alluvial plains which are mostly under cultivation, field treatments such as vegetative bunds, strip cropping, mulching and ploughing across the slope are suggested. Green manuring and FYM should be encouraged to increase the productivity of these soils. Climatically adapted fast growing tree species should be planted on wasteland with or without scrub lands to check the soil erosion.

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