Photonirvachak
Journal of the Indian Society of Remote Sensing, Vol. 30, No. 4, 2002

Assessment of Soil Erosion Using Remote Sensing and GIS in Nagpur District, Maharashtra For Prioritisation and Delineation of Conservation Units

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ABSTRACT

In the present study, soil loss in Nagpur district of Maharashtra is predicted employing USLE method and adopting integrated analysis in GIS to prioritise the tahsils for soil conservation and for delineation of suitable conservation units. Remote sensing techniques are applied to delineate the land cover of the district and to arrive at annual cover factors. Results indicate that potential soil loss of very slight to slight (>5-10 tons/ha/year) exist in the valleys in north western, northern and in the plains of central and eastern parts of the district. Moderate to moderately severe erosion rates (10 to 20 tones/ha/year) is noticed in the south-eastern and some central parts. Severe, very severe and extremely severe erosion types (20 to 80 tons/ha/year) are noticed in the northern, western, southwestern and southern parts of the district. The average soil loss is estimated to be 23.1 and 15.5 tons/ha/yr under potential and actual conditions respectively. Slight, moderate, moderately severe and extremely severe potential erosion covering about 41 per cent area of the district is reduced to negligible and very slight rates of actual erosion under the influence of present land cover leading to a reduction of 7421.2 tones of potential soil loss. Priority rating of the tahsils is evaluated from the area weighted mean quantum of soil loss. Multi-criteria overlay analysis with the parameters of soil erosion, slope, soil depth, land cover and surface texture with rating for the constituent classes has resulted in delineation of nine conservation units. Appropriate agronomic and mechanical practices are suggested in the identified units for minimizing the erosion hazard.

Introduction

Soil erosion is of vital concern in landscape and conservation management. In Indian conditions climatic factor (rainfall) of water erosion is the major agent of soil loss. Accurate assessment of various contributory factors is needed for estimation of soil erosion spatially and for the identification of critical risk zones. Soil erosion processes involve a water phase and

Recd. 29 July, 2002; in final form 5 Oct., 2002

a sediment phase. The detachment of soil particles by raindrop impact and their transportation by overland flow may be called the potential erosion which is modified by the action of biological agents such as land cover, crop management and conservation practice to give the actual erosion (Requier, 1980; Hamer, 1981). Erosion assessment techniques are helpful for the evaluation of agricultural impacts on soil and water resources. Long-term average soil loss can be predicted by several established empirical models such as Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978), RUSLE (Renard *et al.*, 1991), Water Erosion Prediction Project (WEPP) watershed model (Ascough *et al.*, 1997) etc. However, these site specific estimates are not applicable to large and heterogeneous areas. Spatial representation of data is needed for understanding the ecological processes, which is enabled by Geographical Information Systems (GIS) (Bouma, 1989). GIS has been widely employed for evaluation of spatial phenomena through integration of various land surface data (Saraf and Choudhury, 1998).

Assessment of soil erosion for a large area such as a district is complicated through observed data points, however, it can be deduced by deterministic relationship of complex factors such as rainfall erosivity, soil erodibility, slope and land use/ land cover. Soil resource information generated through systematic field surveys and analysis (Challa *et al.*, 1995; Anonymous, 1990) are helpful to generate critical factors to estimate soil erosion quantitatively. Remote sensing techniques are highly helpful in interpreting spatio-temporal factors such as land cover to understand the influence of biological factors on soil loss of an area. The biological agents represent the effect of plant canopy, soil cover and biomass that control the erosion. Generalisation and quantification of these effects over an area are often difficult and complicated. Remote Sensing and GIS techniques have been proved to be of immense help in land cover mapping (Khoram and John, 1991; Roy *et al.*, 1991).

In the present study an attempt is made to estimate the potential and actual soil loss in Nagpur district of Maharashtra by Universal Soil Loss Equation (USLE) and adopting the integrated analysis of spatial data in GIS. The tahsils of the district are prioritised based on the estimated quantum of soil loss and soil conservation units are delineated based on the erosion and site characteristics by multi-criteria analysis in GIS.

Study Area

Nagpur district is situated in the eastern part of the state of Maharashtra. It is located between 78° 15′ to 79° 40′ longitude and 20° 35′ to 21° 45′ latitude and has a total geographical area of 10032.5 sq km. The district has 13 administrative tahsils and is characterised by 6 physiographic units, viz., hills and ridges in north eastern part, isolated hillocks, upper plateau, lower plateau in the western part, moderately undulating alluvial plains in the southern parts and gently sloping alluvial plains in the eastern parts. The elevation ranges from 300 to 600 meters above mean sea level (a.m.s.l). Climatically the district falls under tropical dry sub-humid with a mean annual rainfall of 1200 mm.

Methodology

The rate of soil loss is estimated by Universal Soil Loss Equation:

$$A = R \times K \times L \times S \times C \times P \quad \dots (1)$$

where A is the average annual soil loss from sheet and rill erosion caused by rainfall and associated overland flow (tons/ha/year), R is the rainfall erosivity, K is the soil erodibility, L is the slope length factor, S is the slope steepness factor, C is the cover-management factor and P is the support practice factor respectively. Spatial data base for the above factors are derived from different sources and integrated in GIS. As intensity measurements of rainfall are very limited in the district, R is calculated from average monthly rainfall of about 10 rain gauge

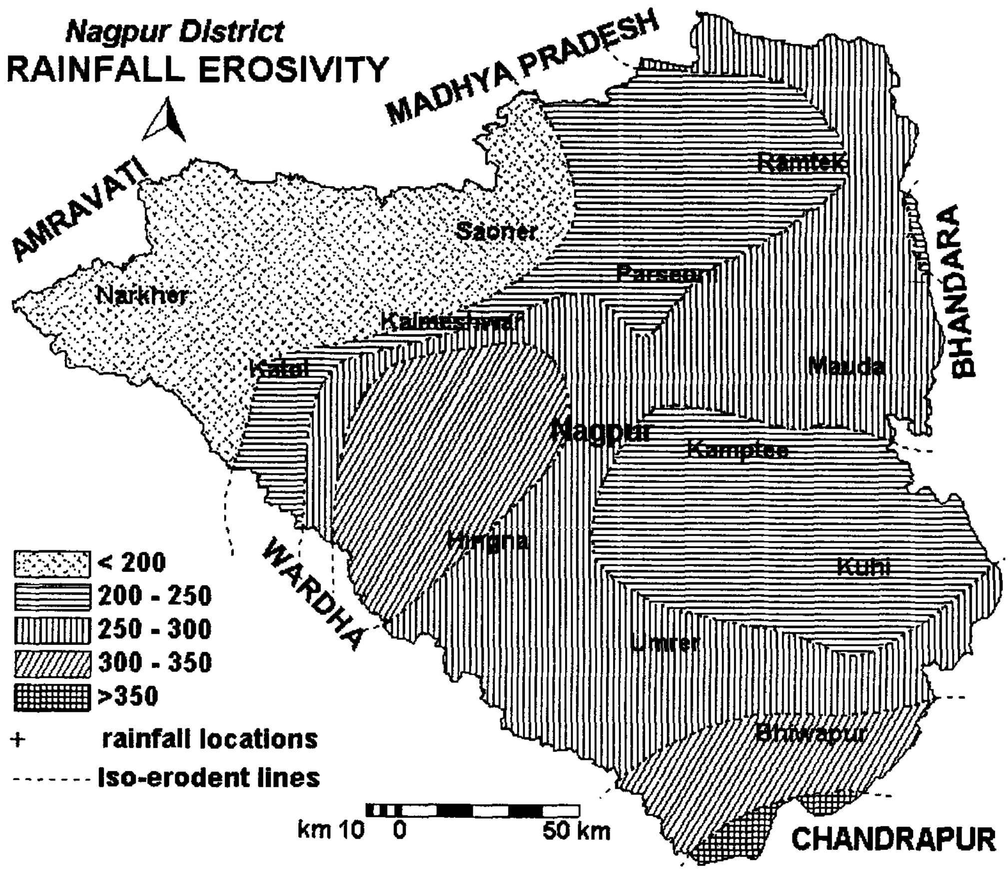

Fig.1. Iso-Erodent map of Nagpur District

stations spread in the study area (IMD, 1971) by Fournier's Index (Fournier, 1960).

$$R = \sum_{i=1}^{12} pi^2/P \quad \text{.... (2)}$$

p, P are the monthly and annual precipitation respectively. The rainfall data is interpolated using SPANS GIS by trend surface to calculate R spatially. Soil erodibility factor (K) is calculated using the data on soil properties (Wischmeier and Smith, 1978) from the relationship

$$K=1.2917\,[(2.1\times 10^{-4}\, M^{1.14}(12-a)+3.25(b-2)+2.5(C-3)]/100 \quad \text{.... (3)}$$

where M=(%silt+very fine sand)(100-%clay) 'a' is percent organic matter, 'b' is the soil structure code used in soil classification and 'c' is the permeability class. The physical and chemical data of different soil series of Nagpur district (Anonymous, 1990) are used for the estimation of soil erodibility. Weighted mean of soil organic matter, per cent of silt, very fine sand and clay are calculated for the depth of the profile which is then averaged in proportion to the area coverage of each constituent soil series of a particular mapping unit (Table 1).

The topographic factors i.e., slope gradient and length of slope significantly influence soil

Table 1. Physical, Chemical properties and estimated K-factor values of different soil series of Nagpur district

Soil Series	*O.C (%)*	*Organic Matter (%)*	*Very fine Sand (%)*	*Silt (%)*	*Clay (%)*	*Soil Structure code (b)*	*Profile Permeability class (c)*	*Particle Size M*	*Soil Erodibility K*
Malegaon	0.58	0.9976	5.41	24.95	60.76	4	5	1191.33	0.19
Muserkhapa	0.46	0.7912	5.41	26.9	60.8	4	5	1266.55	0.20
Yenwa	0.86	1.4792	25	20.5	34.6	4	3	2975.70	0.27
Pardi	0.05	0.086	5.7	23.2	19.9	2	2	2314.89	0.15
Chankapur	0.675	1.161	6.2	27.55	55.8	4	4	1491.75	0.18
Karla	0.52	0.8944	4.84	24.8	63.6	4	5	1078.90	0.18
Ramtek	0.62	1.0664	4.69	13.42	26.1	2	1	1338.33	0.03
Semda	0.4	0.688	14.7	10.84	23.96	3	2	1942.06	0.14
Sewadoli	0.53	0.9116	7.58	22.83	30.9	3	2	2101.33	0.15
Mangarli	0.48	0.8256	4.9	19.1	29.93	4	2	1681.68	0.15
Gunjepar	0.5	0.86	16.94	13.96	34.96	4	4	2009.74	0.23
Devadipar	0.35	0.602	11.94	19	33.1	4	3	2069.89	0.21
Rongha	1	1.72	6.52	20.87	24.02	3	2	2081.09	0.14
Bagbori	0.44	0.7568	10.12	15.03	41.4	3	5	1473.79	0.18
Borgaon	0.73	1.2556	3.71	20.27	27.5	4	3	1738.55	0.18
Khapri	0.71	1.2212	7.86	9.76	48.21	4	4	912.54	0.14
Panjra	0.58	0.9976	6.04	33.86	46.16	4	4	2148.22	0.24
Linga	0.41	0.7052	7.9	16.5	68.7	4	5	763.72	0.16
Aroli	0.19	0.3268	10.97	24.23	38.6	3	4	2161.28	0.21
Kirnapur	0.25	0.43	3.86	23.88	57.6	2	4	1176.18	0.10
Gaimukh	0.47	0.8084	6.83	13.87	33.88	2	4	1368.68	0.11
Wadhona	0.14	0.2408	6.16	27.8	34.19	4	3	2234.91	0.23
Jam	0.39	0.6708	14.15	20.1	32.85	3	4	2299.89	0.22
Sur	0.16	0.2752	3.22	15.16	19	3	2	1488.78	0.11

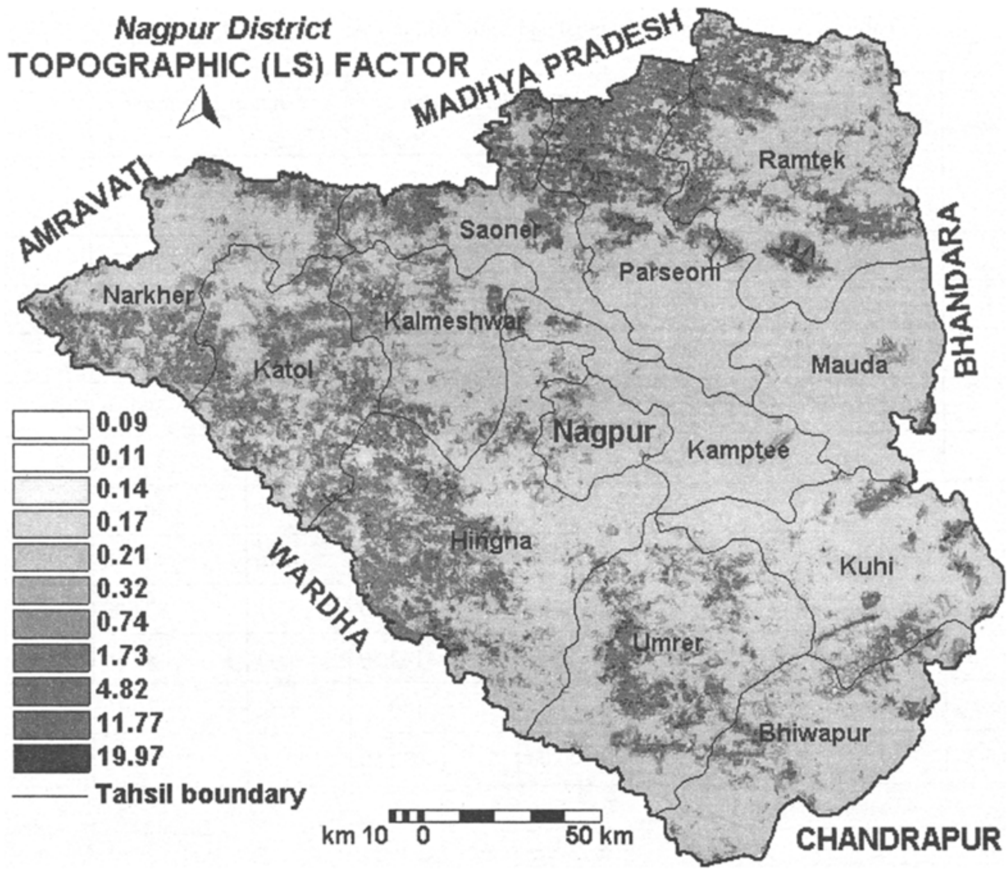

Fig. 2. Topographic factor (LS-factor) of Nagpur District

erosion by surface water movement. The slope of the study area was derived from the digital elevation model generated from contours at 20-m interval. Slope length in meters (L) is calculated from the slope steepness in percentage (S) following the relation (Desmet and Govers, 1996) developed for use in GIS for complex topographical conditions

$$L=158-2.92\times S \quad \text{.... (4)}$$

The LS factor is calculated using the empirical equation (Wischmeier and Smith, 1978) from slope length and slope percent.

$$LS = (L/22.13)^m(0.065+0.045S+0.0065S^2) \text{ ...(5)}$$

where 'm' is an exponent varying between 0.2 to 0.6 depending on the percent slope.

The IRS-1D digital data of path and row (99/57, 110/57) for the periods of November 1999 and March 2000 are used to interpret the land cover of the study area. The satellite data were co-registered to Survey of India (SOI) toposheets at 1:50,000 scale in polyconic projection using image to image registration algorithm with EASI/PACE image analysis system. The false colour composite (FCC) was prepared from green, red and near infra-red

Table 2. Area of different potential and actual soil erosion rates in Nagpur district

Sl.No	*Erosion Class (Tons/ha/year)*	*Potential Erosion*		*Actual Erosion*		*Change (%)*
		Area(%)	*Area(sq km)*	*Area(%)*	*Area(sq km)*	
1	Negligible (<2)	-	-	23.94	2401.70	23.94
2	Very slight (2-5)	14.03	1407.70	30.68	3077.70	16.65
3	Slight (5-10)	43.17	4331.00	15.09	1513.70	-28.08
4	Moderate (10-15)	10.56	1059.80	6.78	680.10	-3.78
5	Moderately severe (15-20)	3.41	342.20	2.31	232.20	-1.10
6	Severe (20-40)	5.58	559.40	5.01	503.10	-0.57
7	Very severe (40-80)	5.65	566.40	4.76	477.50	-0.89
8	Extremely severe (>80)	14.89	1493.40	8.71	874.00	-6.18
9	Water bodies	1.42	142.50	1.42	142.50	0.00
10	Builtup area	1.30	130.10	1.30	130.10	0.00
Total		100.00	10032.50	100.00	10032.50	-

(NIR) spectral bands (bands 2,3 and 4). The major land cover classes were generated by digitally classifying satellite data of Novmber 1999 (*kharif*) and March 2000 (*rabi*) seasons data using Maximum Likelihood Classification algorithm. The training sets are identified for each land cover class based on field knowledge of the study area. The C-factor values for natural vegetation are followed from USLE lookup table for different cover types. The P-factor for main conservation practices are computed from the slope and crop cover. The area under agriculture has bunding and terracing for irrigation and field boundaries. The slope of the agricultural area varies between 1 and 5 per cent. P factor values for slope values below 5 per cent with field bunding (Singh *et al.*, 1981) are used. Based on the degree of erosion and the site conditions nine conservation measures are evaluated using multi-criteria overlay in GIS considering potential erosion, slope, soil depth, land cover and surface texture in decreasing order of their weightage.

Results and Discussion

USLE Parameters

Rainfall erosivity of the district ranges from 150 in the northwestern parts to 400 in the eastern and southeastern parts (Fig. 1) with major area (83% of TGA) under R factor of 150 to 300. The plains have an elevation of about 200 to 400 m a.m.s.l, uplands have 400 to 500 m, hills and ridges in the north and western parts have altitude between 500 to 623 m. The slope length varies between 75 to 158 m and Topographic factor of the district ranges from 0.17 to 19.97 (Fig. 2). Major area has LS factor of 0.17, the hilly areas in the western parts have LS factor

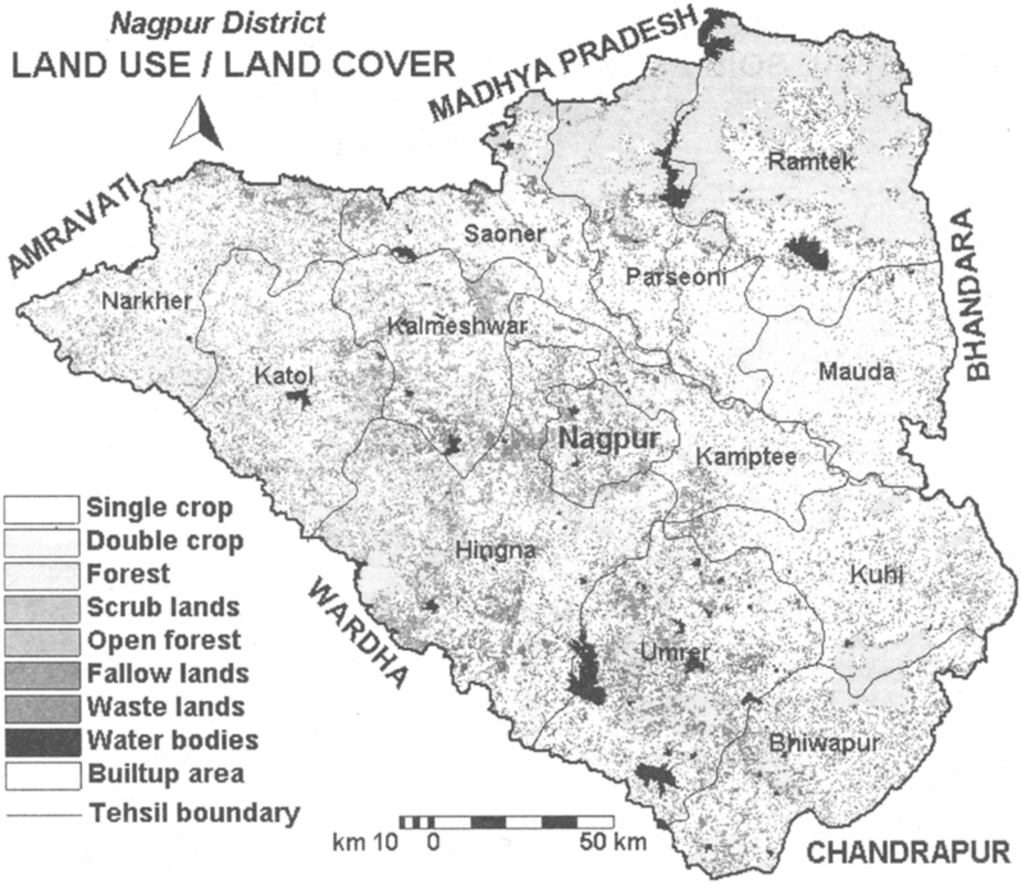

Fig. 3. Land use / land cover map of Nagpur District

ranging from 4.8 to 19.97.

The district has 24 soil series occurring in 42 soil mapping units (Table 1). The hilly areas in the northeast with forest cover have organic matter >1.25. The K-factor of the district varies from 0.19 to 0.25. The plateaus of the western part with clay to clay loam soils, low organic matter content (<0.5) have moderate to high erodibility. The hilly areas in the northern parts with sandy clay loam to sandy loam soils and high organic matter content (0.6 to 1.20) have very high erodibility. The areas with alluvial soils having clayey texture have very high erodibility (K>0.2). The central parts covering Kamptee, Nagpur, Parseoni and northern parts of Ramtek, Kuhi tahsils have very low soil erodibility.

From the land cover of the district classified from IRS data (Fig. 3) it is seen that about 45% of TGA is under croplands. The single cropped area (30% of TGA) is distributed in the northern, central, southern and eastern parts in the tahsils of Kuhi, Bhiwapur, Umrer, Kamptee, Hingna, Parseoni, Saoner and Kalmeshwar. The double cropped area (15% of TGA) is noticed in Maunda, Saoner, Hingna and Katol tahsils.

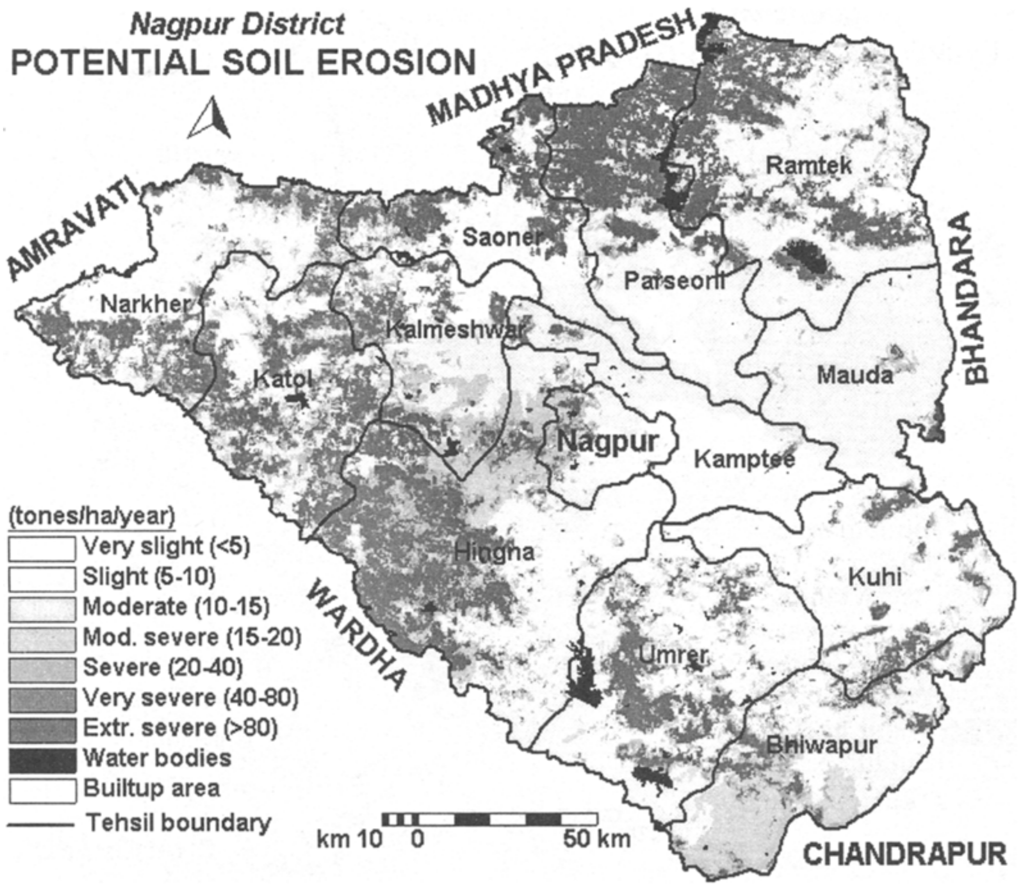

Fig. 4. Potential soil erosion of Nagpur District

Dense and open forests of deciduous nature prevail in northern, northwestern, south eastern, south western and western parts mostly on hilly areas. Ramtek, Parseoni tahsils have highest area under forests followed by Kuhi, Hingna, Katol and Narkher tahsils covering about 16% of TGA. Scrublands are found on the peripherals of dense forest in the central, western and north western parts. Fallow lands are distributed in the western, eastern parts in Kuhi, Katol and Narkher tahsils. Wastelands are distributed in isolated patches in the district. Considering annual average cover conditions of different types the cover factor ranges between 0.4 and 1.0 with major area (50% of TGA) having a value of 0.45 to 0.50. The P-factor is taken as 0.5 for level lands with double cropping, 0.60 for gently sloping single cropped areas, 0.70 for steep to very steeply sloping lands with forest vegetation, 0.75 to 0.80 for open forests and scrub lands under strong to very steep slopes, 0.90 for fallows and wastelands with very poor management conditions.

Predicted Soil loss

Analysis reveals that very slight to slight erosion (>5 to 10 tones/ha/year) is observed in the valleys in north western, northern parts and

Table 3. Priority rating for soil erosion of different tahsils in Nagpur District.

Tahsil	*Quantum of Soil loss in tones*									*Priority rating*
	Negligi-ble	*Slight*	*Very Slight*	*Moderate*	*Moderately Severe*	*Severe*	*Very Severe*	*Extremely severe*	*Weighted mean*	
Bhiwapur	216.6	954.1	1130.2	1362.5	421.7	699	1206	2240	11.62	9
Hingna	362.4	1325.8	1769.2	1405	873.2	2943	5274	18424	28.30	1
Kalmeshwar	291.2	623	559.5	747.5	227.5	1026	1374	3136	15.12	8
Kamptee	531.2	557.5	360.7	88.7	17.5	204	216	552	5.14	13
Katol	302	555.4	726	822.5	602	2205	3210	8984	27.47	2
Kuhi	459.2	1204	787.5	566.2	21	738	1140	1704	8.61	11
Maunda	198.6	1394.7	813.7	91.2	47.2	72	120	576	5.34	12
Nagpur	136.4	236.9	181.5	237.5	115.5	225	354	360	9.28	10
Narkher	572.4	553	457.5	630	327.2	1464	2760	5312	18.05	5
Parseoni	332	868	794.2	576.2	115.5	1473	3816	9592	25.63	3
Ramtek	745	1018.8	1437	865	187.2	1917	4452	7536	16.92	7
Saoner	382.8	415.1	444	280	306.2	1071	2652	4544	20.64	4
Umrer	273	1062.9	1887.7	827.5	801.5	1056	2058	6920	17.04	6
Total	4802.8	10769.5	11349	8500	4063.5	15093	28632	69880		

in the plains of central and eastern parts of the district in association with a rainfall erosivity of < 200 to 300, low to moderate soil erodibility (0.11 to 0.19) and level to moderately sloping lands (Fig. 4). Very slight to slight predicted potential soil loss is noticed in north western parts of Narkher, southern and central parts of Saoner, southern parts of Parseoni, central and eastern parts of Ramtek, central parts of Kalmeshwar, eastern parts of Hingna, major area of Kamptee, Maunda, Kuhi, Bihawapur and Umrer tahsils. Moderate to moderately severe erosion (10 to 20 tones/ha/year) is noticed in southern parts of Bhiwapur, north-eastern parts of Hingna, southern parts of Kalmeshwar and traces in Ramtek and Umrer tahsils.This erosion class is noticed in association with a rainfall erosivity of 300 to 350, moderate to high soil erodibility (0.20 to 0.22) and level to moderately sloping lands. Severe, very severe and extremely severe erosion types (20 to >80 tones/ha/year) are noticed in northern, western, south western and southern parts of the district in association with very high rainfall erosivity (300 to >350), very high soil erodibility (0.25) and strongly to very steeply sloping lands. Very severe erosion is observed in a few pockets covering an area of 5.68% (Table 2). Extremely severe soil erosion (>80 tones/ha/year) is observed in a major area of Hingna, Parseoni, Ramtek, Katol tahsils and in marginal areas in Narkher, Saoner, Umrer, Bhiwapur, Kuhi and Kalmeshwar tahsils in association with hilly areas.

The average potential soil loss of the district is estimated to be 23.1 tones/ha/year. Majority of the area in the district is under very slight, slight, moderate and extremely severe erosion classes covering an area of about 14.03, 43.17, 10.56 and 14.89 per cent respectively (Table 2). About 57% of TGA come under slight and very slight potential soil loss. About 25% of TGA is

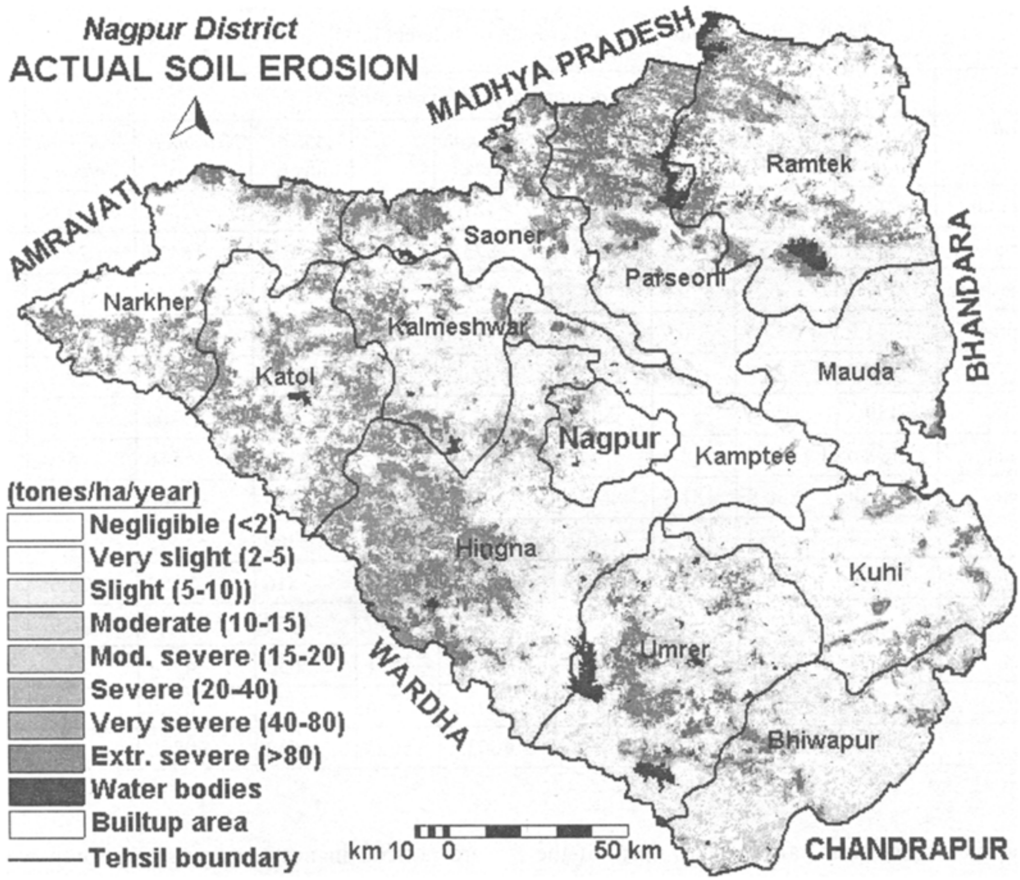

Fig. 5. Actual soil erosion of Nagpur District

estimated to be under the threat of severe to extremely severe potential soil loss which needs attention for proper land management.

The actual soil loss is computed by multiplying the potential soil loss, C-factor and P-factors. While there is no much reduction of soil loss from potential to actual conditions in hills and ridges of the northern, north-eastern and south-western parts, a significant decrement is observed in the cultivated lands (Fig. 5). Negligible, very slight and slight erosion are noticed in north-western, central, north-eastern and south-eastern parts of the district in association with single crop, double crop grown areas and forest areas. Moderate to severe soil erosion is observed in association with scrub lands and fallow lands in central, eastern and southeastern parts. Severe to very severe erosion is observed in association with scrubs, open forests and steep to very steep lands in the northern part of the district. Extremely severe erosion is noticed in association with scrublands, deciduous forests and pastures and very steep sloping lands occurring in north and southwestern parts of the district. The average actual soil loss of the district is estimated to be 15.5 tones/ha/year. An increment of 23.9, 16.7 per cent in the area occurred in the negligible and very slight erosion classes respectively from

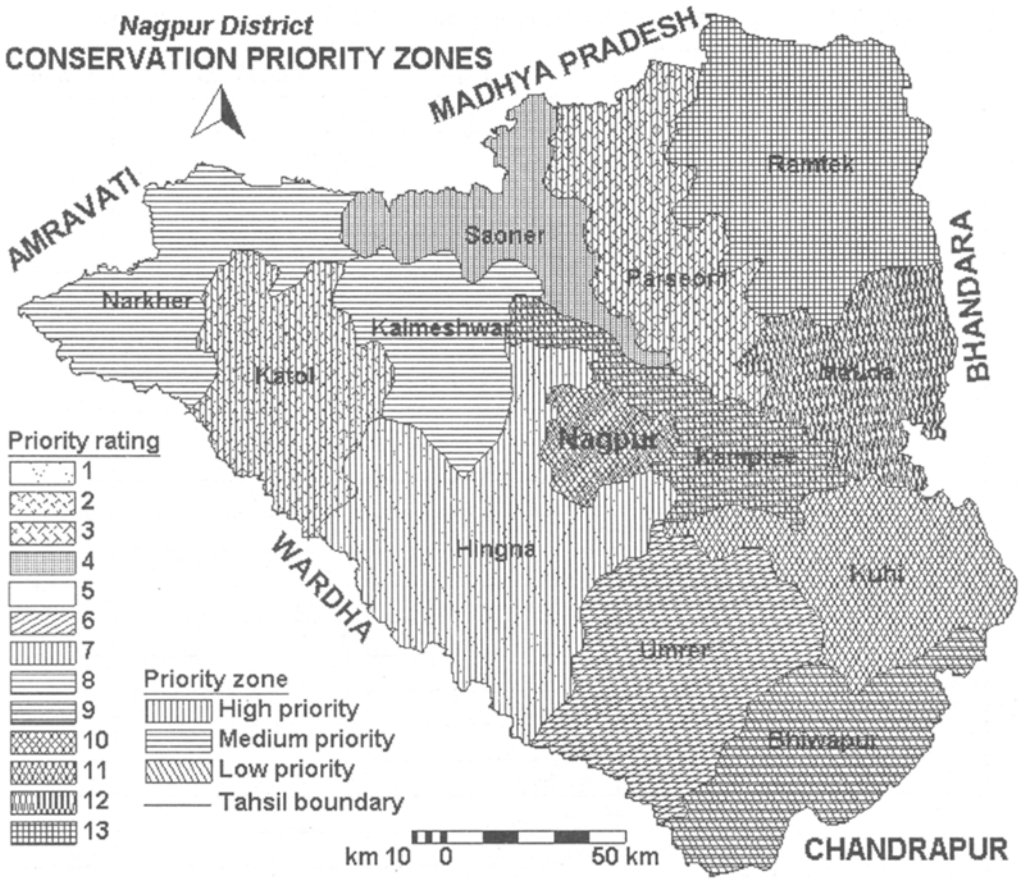

Fig. 6. Priority ratings of the tahsils for soil conservation

potential to actual conditions. On the other hand a decrease of 28.0, 3.8, 1.1, 0.57, 0.89 and 6.2 per cent in the area occurred in moderate, moderately severe, severe, very severe and extremely severe classes respectively from potential to actual conditions. The change of area under moderately severe, severe and very severe erosion classes is negligible. About 40 per cent of area under slight, moderate, moderately severe and extremely severe of potential erosion are redistributed in negligible and very slight classes of actual erosion (Table 2, Fig. 5). The quantum of potential soil loss is estimated to be 225475.75 tones and the quantum of actual soil loss is estimated to be 151354.58 tones for the district. There is a reduction of 74121.17 tones of soil loss from potential to actual conditions considering the present land use.

Prioritization of Tahsils

The priority rating of the tahsils is evaluated based on calculating the quantum of soil loss under each erosion class and by computing the area-weighted mean for each tahsil (Fig. 6, Table 3). The tahsils of Hingna, Katol, Parseoni and Saoner come under high priority with a mean soil erosion of ≥ 20.5 tones/ha and associated with

Table 4. Weightage for the themes and rating considered for classes in overlay analysis

02	*Theme*	*Weightage*	*Layer Class*	*Class Value*	*Rating*
1	Potential Erosion (tons/ha/yr)	30%	Very slight	<5	1.0
			Slight	5-10	1.5
			Moderate	10-15	2.5
			Moderately severe	15-20	4.0
			Severe	20-40	5.5
			Very severe	40-80	7.5
			Extremely severe	>80	9.0
2	Slope (%)	25%	Level to nearly level	0-1	1.5
			Very gentle	1-3	2.5
			Gentle	3-5	4
			Moderately sloping	5-10	5
			Strongly sloping	10-15	6.5
			Steep	15-30	7.0
			Very steep	>30	9.0
3.	Soil depth (cm)	20%	Very shallow	10-25	9.0
			Shallow	25-50	7.5
			Moderately shallow	50-75	5.5
			Moderately deep	75-100	4.5
			Deep	100-150	3.0
			Very deep	>150	1.5
4.	Land cover	15%	Single crop		1.0
			Double crop		1.5
			Forest		2.5
			Scrubland		4.0
			Open forest		5.5
			Fallow land		7.5
			Wasteland		9.0
5.	Surface Texture	10%	Clay		1.0
			Clay loam		3.0
			Sandy clay loam		5.0
			Sandy loam		7.0
			Gravelly sandy clay loam		9.0

strong to very steep sloping lands, moderately shallo w to very shallow soils, clay to clay loam texture, soil erodibility of 0.16 to 0.24, single crop, forests, scrub lands and wastelands. The tahsils of Narkher, Umrer, Ramtek and Kalmeshwar come under medium priority with a mean soil erosion ranging between 20 to 15 tones/ha and associated with very gentle to steep lands, very shallow to deep soils, sandy loam, sandy clay loam and clayey texture, forest,

Table 5. Site characteristics and suggested soil conservation measures in identified units

Sl.No	***Potential Erosion***	***Slope***	***Soil depth***	***Texture***	***Land Use/ Land cover***	***Suggested Control measures***
C9	Extremely severe	Very steep	Extremely shallow to very shallow	Gravelly sandy clay loam, sandy clay loam	Open forest, fallow lands, waste lands	Bench trenching, gully control structures, afforestation.
C8	Extremely severe	Very steep to steep	Very shallow to shallow	Sandy clay loam, clay loam	Open forest, scrub lands, waste lands	Gully control structures, rock fill structures, afforestation.
C7	Extremely severe to very severe	Steep, strongly sloping	Shallow	Sandy laom, clay loam	Open forest, scrub lands, fallow lands, single cropped area	Afforestation, rockfill structures, drainage channel diversion, graded bunding.
C6	Very severe, Severe	Moderate	Shallow, moderately shallow	Clay loam	Open forest, Scrub lands, forest lands, single cropped area.	Afforestation, Horticulture practices.
C5	Severe, Moderately severe	Moderate, gentle	Shallow, moderately deep	Clay loam	Fallow lands, Wastelands and open forest	Graded bunding, land leveling, land mulching, vegetative hedges.
C4	Moderate, Moderately severe	Gentle, Very gentle	Moderately deep, deep	Clay loam, clay	Fallow, Wastelands, Single crop	Diversion of drainage channels, grassland development, residue cover, intercropping etc.
C3	Moderate, slight	Very gentle	Moderately deep, deep	Clay	Wastelands, single crops	Contour strip cropping, inter cropping, vegetative bunding.
C2	Moderate, slight	Very gentle, level to nearly level	Deep, Very deep	Clay	Single crop, double crop, wastelands	Contour cultivation, Strip cropping, Contour strip cropping.
C1	Slight	Level to nearly level	Deep, Very deep	Clay	Single crop, double crop	Negligible.

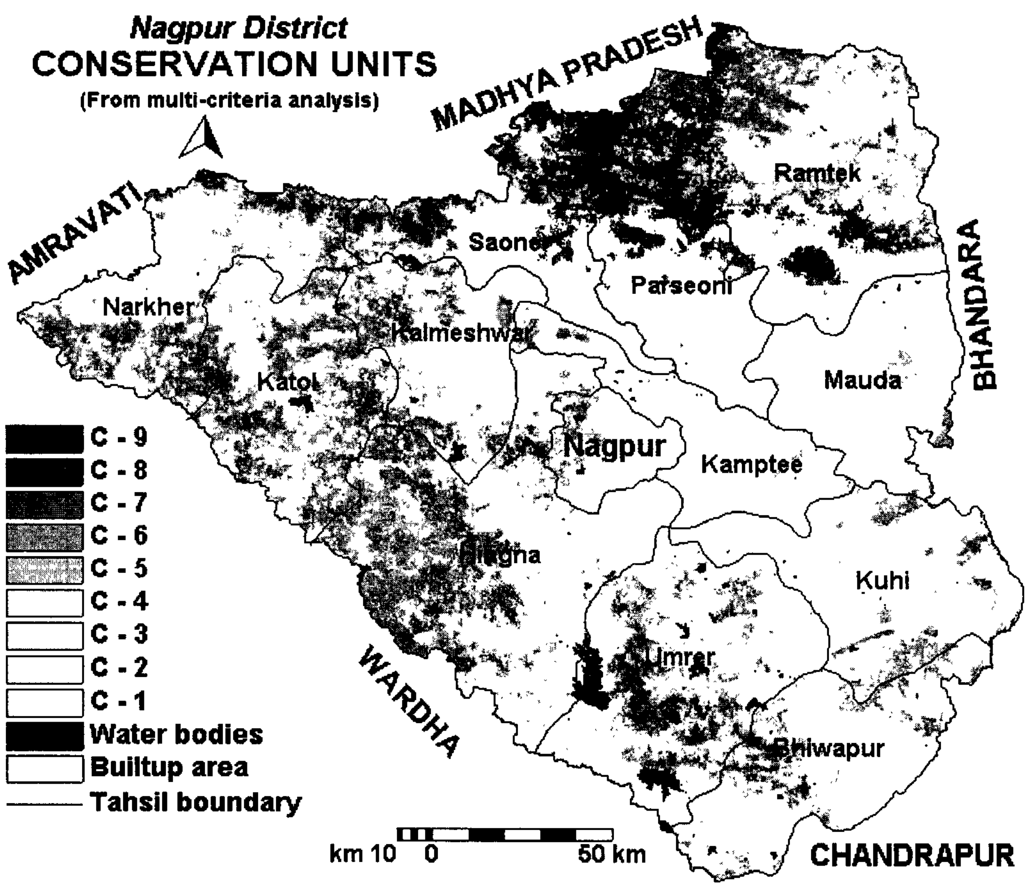

Fig. 7. Soil Conservation Units of Nagpur District

wastelands, single cropped area and scrub lands. The tahsils of Bhiwapur, Nagpur, Kuhi and Kamptee come under low priority with a mean soil loss of 15 to 5 tones/ha and associated with level to gently sloping lands, moderately deep to very deep soils, clay to sandy clay loam texture and single, double cropped area.

Soil Conservation Units

The degree of erosion and site conditions is considered to evaluate and identify conservation units. The site characteristics constitute slope, soil depth, and soil texture and land cover. The degree of erosion in combination with different site characteristics leads to different conservation priorities and practices. A weighted multi-criteria overlay analysis is performed using GIS considering the above parameters for the delineation of units for different conservation practices. Status of erosion is given highest weightage (30%) followed by slope (25%), land cover (15%) and texture (10%). Within each layer a rating from 1.0 to 9.0 is assigned to the classes in the increasing order of their qualitative importance for erosion (Table 4). Nine conservation units (C1 to C9) are delineated (Fig. 7) which are identified with different conservation measures. The units are validated with field information. Agronomic measures such as contour cultivation, strip cropping, contour strip cropping, vegetative bunding, residue cover, horticultural practices are appropriate in C1, C2, C3, C4 and C6 units which have slight to moderately severe erosion, level to moderate slope, moderate to deep soils, clay to clay loam texture, single and double crop, open forest and fallow lands (Table 5). Mechanical measures such as graded bunding, land leveling, rock fill structures, drainage channel diversion, bench trenching, graded bunding and gully control structures are suggested in C7, C8, C9 units having extremely severe erosion, very steep slopes, shallow to extremely shallow soils. The unit C5 is suggested with both agronomic and mechanical measures.

Conclusions

The soil erosion assessment technique used in the present study is helpful to evaluate the influence of different land cover and soil management factors in quantitative estimations of soil loss of the district. The remotely sensed data has been found to be highly valuable in the delineation of land cover with greater precision of type and extent and to evaluate the appropriate annual cover factors. Implementation of Universal Soil Loss Equation using integration procedures of GIS enabled the prediction of potential and actual soil loss rates and in the identification of units for suitable protection measures. The mean soil loss rate is estimated to be 23.1 and 15.5 tones/ha/year respectively under potential and actual conditions respectively. Nine units with unique combinations of soil erosion and site characteristics are identified for conservation using multi-criteria analysis in GIS. Suitable agronomic and mechanical measures are suggested for soil conservation based on the above characteristics in each unit.

Acknowledgements

The authors are grateful to Dr K.S. Gajbhiye, Director, National Bureau of Soil Survey and Land Use Planning for support and encouragement of the study. The authors are thankful to Dr. M.S.S. Naga Raju for guidance in the interpretation of soil data used in the study. Our grateful thanks are due to the anonymous reviewers for their valuable comments and suggestions.

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