Soil Loss Mapping for Sustainable Development and Management of Land Resources in Warora Tehsil of Chandrapur District of Maharashtra: An Integrated Approach Using Remote Sensing and GIS

**M. S. S. Nagaraju · G. P. Obi Reddy · A. K. Maji ·
Rajeev Srivastava · P. Raja · A. K. Barthwal**

Abstract The study area is characterized by low and fluctuating rainfall pattern, thin soil cover, predominantly rain-fed farming with low productivity coupled with intensive mining activities, urbanization, deforestation, wastelands and unwise utilization of natural resources causing human induced environmental degradation and ecological imbalances, that warrant sustainable development and optimum management of land resources. Spatial information related to existing geology, land use/land cover, physiography, slope and soils has been derived through remote sensing, collateral data and field survey and used as inputs in a widely used erosion model (Universal Soil Loss Equation) in India to compute soil loss (t/ha/yr) in GIS. The study area has been delineated into very slight (<5 t/ha/yr), 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) soil erosion classes. The study indicate that 45.4 thousand ha. (13.7% of TGA) is under moderate, moderately severe, severe and very severe soil erosion categories. The physiographic unit wise analysis of soil loss in different landscapes have indicated the sensitive areas, that has helped to prioritize development and management plans for soil and water conservation measures and suitable interventions like afforestation, agroforestry, agri-horticulture, silvipasture systems which will result in the improvement of productivity of these lands, protect the environment from further degradation and for the ecological sustenance.

Keywords Land resources · Remote sensing · Soil erosion · Conservation · USLE · GIS

M. S. S. Nagaraju (✉) · A. K. Maji · R. Srivastava ·
A. K. Barthwal
Division of Remote Sensing Applications,
National Bureau of Soil Survey and Land Use Planning,
Amravati Road,
Nagpur 440010, India
e-mail: nraju@nbsslup.ernet.in

G. P. Obi Reddy
GIS Section,
National Bureau of Soil Survey and Land Use Planning,
Amravati Road,
Nagpur 440010, India

P. Raja
Division of Soil Resource Studies,
National Bureau of Soil Survey and Land Use Planning,
Amravati Road,
Nagpur 440010, India

Introduction

Increasing requirements of land and water by rapidly growing population has resulted in over exploitation of natural resources that has inflicted severe damage to soil environment. About 148.9 m. ha. representing 45.3% of the total geographical area (TGA) of the

country is affected by various forms of soil degradation by water, wind, chemical and physical agencies (Sehgal and Abrol 1994). Soil degradation and erosion are insidious processes, not readily apparent to farmers until the effects are severe and irreversible (Cleaver and Schrieber 1995) and a threat to long-term soil productivity (Narain 2008; Bhattacharyya et al. 2007). They deplete the soil of nutrients, diminish its moisture retention capacity, and reduce the depth of the rooting zone for annual crops. Deforestation, wastelands and indiscriminate usage of cultivable lands have collectively induced soil erosion resulted in ecological imbalances. The estimates indicated that the soil erosion has been taking place at an average rate of 16.35 tha^{-1}yr^{-1}, totaling an annual loss of 5,334 million tons (Dhruvanarayana and Ram Babu 1983). The magnitude of soil erosion depends largely on physiography, vegetative cover, slope gradient and inherent physical and chemical properties of soils. Since soil is the base for every production system and more than 90% of world's food production depends on soil (Venkatratnam and Manchanda 1997), thorough knowledge of their spatial distribution is a prerequisite in developing rational land use plans at different levels. Soil resource inventory provides an insight into the potentialities and limitations of soils for their optimum utilization (Devi and Kumar 2008).

Remote Sensing imagery provides information about various land utilization types in spatial format which is vital for erosion assessment (Saha and Singh 1991; Pandey et al. 1992). The potential utility of remote sensing data has been well recognized in mapping and assessing land attributes such as physiography, soils, land use/land cover (Solanke Preeti et al. 2005; Sarkar et al. 2006) and integration of these attributes to compute soil erosion (Potdar et al. 2003). The rapid evolution in satellite remote sensing in terms of spatial, spectral, radiometric and temporal resolutions of different sensors, the availability of data in digital format and spatial analysis in Geographic Information System (GIS) using an integrated approach has made possible the quantitative assessment of soil erosion and mapping (Skidmore et al. 1997).

The study area is enriched with mineral deposits such as coal and limestone. Intensive mining, deforestation and urbanization warrants explorative studies for sustainable development of the area. Besides, it is predominantly of rain-fed farming with soil erosion

problems and low productivity. Therefore, the present study aims at characterizing the land resources through remote sensing and other ancillary data and to integrate these informations in GIS to compute quantitative soil loss using USLE model for sustainable development.

Study Area

The study area is located between 19°57′ to 20°43′ N latitudes and 76°48′ to 79°36′E longitudes, covering an area of 332.85 thousand hectares (Fig. 1). Geology of the area (GSI 2001) is mainly of Deccan basalts followed by sandstone/lime stone of Lameta group of cretaceous period, laterites, and granite-gneiss. The elevation ranges from 200 to 370 m above MSL. The area is mainly drained by Wardha river with predominant dendritic pattern. The climate of the area is subtropical, dry sub-humid with ustic soil moisture and hyperthermic soil temperature regime. The mean annual rainfall is 1,349 mm. The natural vegetation comprises a wide variety of dry deciduous mixed tree species, shrubs and interspersed with grasses. The commonly occurring tree species are teak (*Tectona grandis*), Shivan (*Gmelina arboria*), Babul (*Acacia arabica*), Khair (*Acacia catechu*), Shevri (*Acacia nilotica*), Palas (*Butea monosperma*), Char (*Buchananea lanjan*), Ber (*Zizipus jujuba*), Mahua (*Madhuka indica*). A large percentage of cultivated land is mainly under kharif crops such as cotton (*Gossypium spp.*), soybean (*Glycine max*) and pigeonpea (*Cajanus cajan*). The dominant rabi crops of the area are linseed (*Linum usitatisimum*), sorghum (*Sorghum bicolor*), wheat (*Triticum aestivum*), maize (*Zea mays*) and gram (*Cicer arietinum*).

Materials and Methods

Landsat-7 Thematic Mapper (TM) digital data of February, 2004 with a spatial resolution of 30 m was used (Fig. 2). The satellite data was processed and geocoded in orthoengine module of Geomatica image processing software using topomaps (1:50,000) of Survey of India (SOI). For land use/land cover map preparation, the boundaries of notified forests were considered as reference, digitized and transferred as a layer from topomaps to the satellite image. The
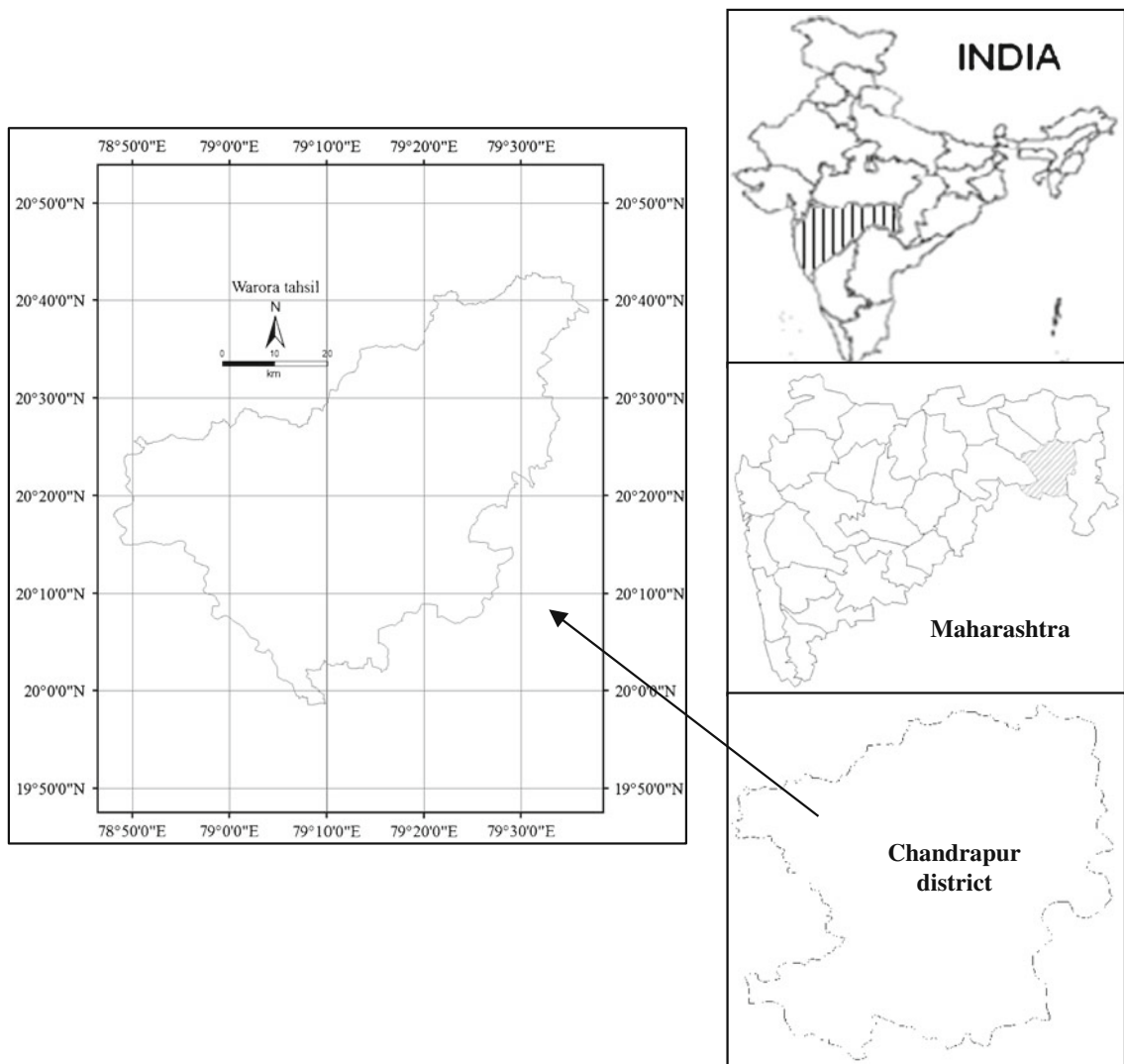
Fig. 1 Location map of study area

methodology followed for extraction of information from satellite data is essentially of standard visual interpretation based on tone, texture, pattern, shape and size (Lillesand and Kiefer 2002) for identification of various physiography and present land use/land cover as per Natural Resource Information System Standards (NRIS 2000). The slope map was generated using available contour information from the topomaps. Ground truth was carried out for better accuracy and finalization of maps. Physiography, slope and land use/land cover variations were considered for depicting the soil variability. Site (slope, erosion, stoniness etc.) and soil morphological characteristics (colour, texture, structure etc.) were

recorded in the standard format (Soil Survey Division 2000), representative soil samples were collected from each horizon of the soil pedons and analyzed for physical and chemical properties (Jackson 1967; Black et al. 1965) and soils were classified (Soil Survey Staff 1998) besides soil information available in the reports (NBSS&LUP 1993).

Soil erosion assessment was done using Universal Soil Loss Equation (USLE) model (Wischmeier and Smith 1978). It is designed in a way to enable the planners to predict the average rate of soil erosion for each feasible alternative combination of cropping system and management practices in association with a specified soil type, rainfall pattern and topography
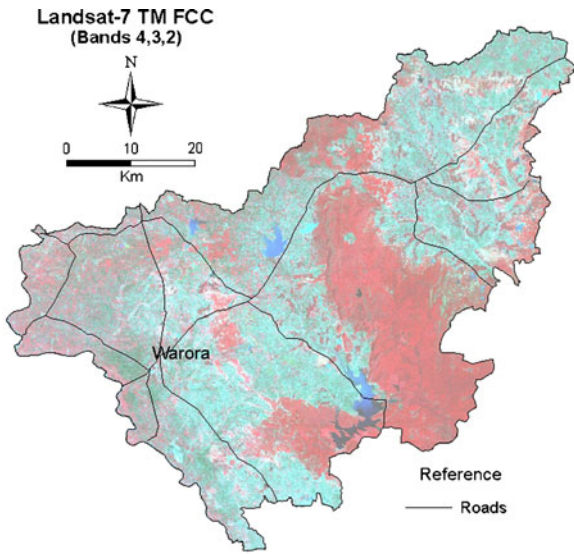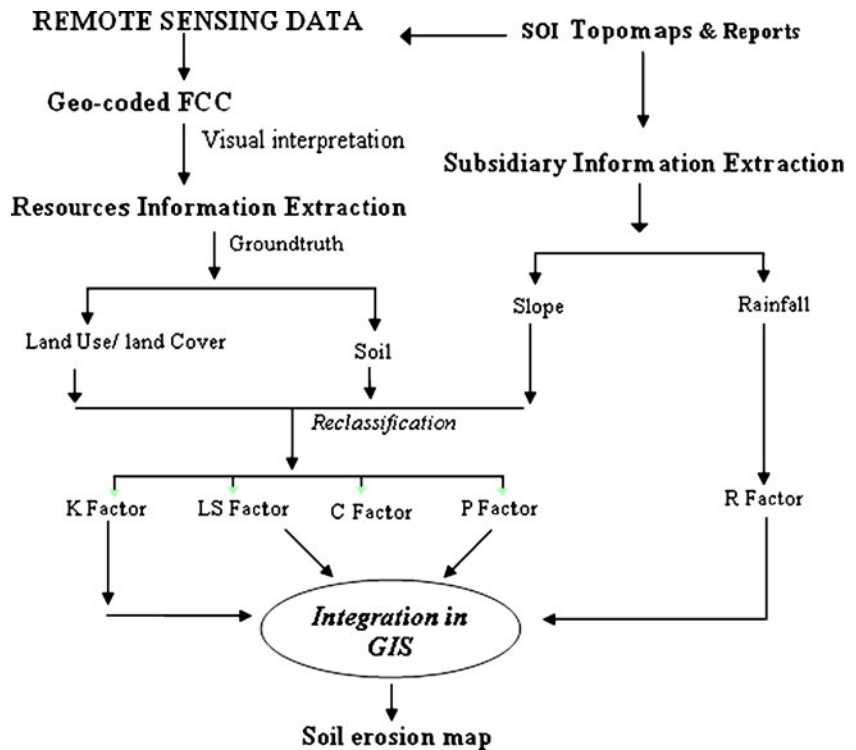
Fig. 2 Landsat-7 TM FCC of study area

over a long period of time. When these predicted soil losses are compared with given soil loss tolerance, the model provide a specific guidelines for effecting erosion control measures within specified limits. The model computes soil loss as the product of six major factors expressed as:

$$A = R. K. L. S. C. P$$

Where 'A' is average annual soil loss ($tha^{-1}yr^{-1}$); R, K, L, S, C, P are rainfall erosivity, soil erodibility, slope length, slope gradient, crop cover and management and conservation/support practice factors respectively.

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. In the absence of EI values, a value 483 representing the study area was taken as rainfall erosivity factor (Ram Babu et al. 1978). Soil erodibility (K) values for different soils were determined using soil erodibility nomograph (Wischmeier et al. 1971). The topographic factor (LS) is the expected ratio of soil loss per unit area from a field slope to that from a 22.13 m length of uniform 9% slope under otherwise identical condition. Even though the L and S factors can be determined separately, the procedure has been further simplified by combining the two as a single topographic factor and a nomograph has been developed (Wischmeier and Smith 1978). The slope length (m)

Fig. 3 Flow chart for the generation of soil erosion map

and gradient (per cent) from slope map has been matched with nomograph and a corresponding LS factor has been derived. The values of C and P were derived from the published literature (Singh et al. 1981; Karad et al. 1991). After estimating the different USLE factors, 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 soil erosion classes *viz.* very slight (<5 t/ha/yr), 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) as per Kurothe et al. (2001). The flow chart for generation of soil erosion map is presented in Fig. 3.

Database Generation Through GIS

Geographic Information System (GIS) is a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough and McDonnell 1998). The ArcGIS software ver. 9.3.1 was used for creation of spatial and attribute database, analysis and integration, reclassification and generation of various thematic maps. The line maps of the physiography, land use/land cover and slope were generated through digitization. These line maps were checked for digitization errors, topologies were cleaned, built and polygonized. Attributes were added in the attribute table for each theme and a spatial database was created. The attribute database of reclassified maps of USLE factors from soil, slope and land use/land cover and soil erosion were also generated.

Results and Discussion

Slope

The major slopes identified are very gently sloping (1%–3%), gently sloping (3%–8%), moderately sloping (8%–15%) and moderately steeply sloping (15%–30%) lands. The extent of area under different slope classes indicate that land with 1%–3% slope covers 58.1% and 3%–8% sloping land that covers 37.2% of TGA are mainly associated with cultivated lands. Moderately and moderately steeply sloping lands are generally associated with dense, moderately dense, degraded forest and wastelands with scrub.

Land Use/Land Cover

The land use/land cover classes identified are cultivated land, dense, moderately dense and degraded forest, wasteland with scrub, stony waste, habitation and water bodies. The area under different land utilization types indicate that cultivated land is the dominant land utilization type (63.9%) followed by moderately dense forest (25.1%), dense forest (4.1%), wasteland with scrub (3.0%) and degraded forest (1.2%). Stony waste, habitation and water bodies comprises 0.3, 1.7 and 7.1% respectively.

Physiography

Physiographically, the basaltic landscape (200–320 m above MSL) is characterized by gently sloping plateau, moderately sloping escarpments, gently sloping isolated mounds, very gently sloping to gently sloping undulating land, very gently sloping subdued plateau and upland, very gently to gently sloping interfluves and very gently sloping alluvial plain and valley. The area is under cultivation, moderately dense forest and wasteland with scrub. The laterite landscape (170–200 m above MSL) is characterized by very gently sloping interfluve, undulating land and valleys. The area is associated with moderately dense and degraded forest. The granite-gneiss landscape (200–370 m above MSL) is characterized by very gently sloping plateau top, moderately to moderately steeply sloping escarpments, moderately sloping isolated hills, very gently sloping to gently sloping subdued plateau and foot slopes, very gently sloping upland, very gently sloping to gently sloping undulating land, very gently sloping to gently sloping interfluves and very gently sloping valley. The area is under cultivation, moderately dense and degraded forest and wasteland with scrub. The sandstone/lime stone landscape (200–340 m above MSL) is characterized by very gently sloping plateau top, moderately sloping hilly terrain, moderately steeply sloping escarpment, very gently to gently sloping foot slopes, moderately sloping isolated hills, gently sloping isolated mounds, very gently sloping to gently sloping subdued plateau and undulating land, very gently sloping upland, very gently sloping to gently sloping interfluves and very gently sloping alluvial plain and valley. The area is under cultivation, dense, moderately dense and degraded forest and wasteland with scrub.

Table 1 Soils and soil erodibility (K) in relation to physiography in different landscapes

Mapping unit	Physiography	Soil series association	Soil classification (Sub-group level)	Soil erodibility (K)	Area ('000 ha)	Percent of total area
	Basaltic landscape					
1	Plateau top (Bpt)	Chincholi	Lithic Ustorthents	0.48	0.67	0.2
2	Escarpment (Bpe)	Chincholi	Lithic Ustorthents	0.48	0.51	0.15
3	Isolated mounds (Bim)	Chincholi	Lithic Ustorthents	0.48	0.21	0.06
4	Undulating land (Bn)	Girsawli-2 Kharwad-2	Vertic Haplustepts Typic Haplusterts	0.43	40.04	12.03
5	Subdued plateau (Bsp)	Kutbala-2	Vertic Haplustepts	0.48	2.08	0.63
6	Upland (Bu)	Kharwad-2 Girsawli-2	Typic Haplusterts Vertic Haplustepts	0.43	9.77	2.94
7	Interfluves (Bi)	Madheri Kartangadi	Typic Haplusterts Vertic Haplustepts	0.46	5.63	1.69
8	Alluvial plain (Bap)	Kartangadi Madheri	Typic Haplusterts Vertic Haplustepts	0.44	13.06	3.92
9	Broad valley (Bvb)	Panjurni Longadga	Typic Haplusterts Vertic Haplustepts	0.43	7.3	2.19
10	Narrow valley (Bnv)	Wandhali Girsawli-3	Vertic Haplustepts Typic Haplustepts	0.42	8.30	2.49
			Total area		87.57	26.3
	Granite-gneissic landscape					
11	Plateau top (Gpt)	Sondo	Lithic Ustorthents	0.53	0.2	0.06
12	Escarpment (Gpe)	Sondo	Lithic Ustorthents	0.53	0.47	0.14
13	Isolated hills (Gih)	Sondo	Lithic Ustorthents	0.53	0.28	0.09
14	Subdued plateau (Gsp)	Sondo	Lithic Ustorthents	0.53	1.27	0.38
15	Foot slopes (Gf)	Bhisi Khodi	Vertic Haplustepts Typic Plinthustalfs	0.52	6.32	1.9
16	Upland (Gu)	Hirapur Timram	Leptic Haplusterts Vertic Haplustepts	0.50	2.78	0.83
17	Undulating land (Gn)	Timram Hirapur	Vertic Haplustepts Leptic Haplusterts	0.52	42.19	12.67
18	Interfluves (Gi)	Pranhita Wainganga	Typic Haplusterts Vertic Haplustepts	0.52	8.53	2.56
19	Broad valley (Gvb)	Wainganga Pranhita	Vertic Haplustepts Typic Haplusterts	0.52	2.41	0.73
20	Narrow valley (Gvn)	Pranhita Wainganga	Typic Haplusterts Vertic Haplustepts	0.52	6.07	1.82
			Total area		70.52	21.18
	Lateritic landscape					
21	Interfluves (Li)	Lawari	Typic Haplustepts	0.58	1.84	0.55
22	Undulating land (Ln)	Saigatta Lohara	Typic Rhodustalfs Typic Haplustepts	0.54	5.43	1.63
23	Broad valley (Lvb)	Saigatta	Typic Rhodustalfs	0.53	0.21	0.06
24	Narrow valley (Lvn)	Saigatta	Typic Rhodustalfs	0.53	0.37	0.11
			Total area		7.85	2.35
	Sandstone/limestone landscape					
25	Plateau top (Spt)	Madnapur	Lithic Ustorthents	0.58	4.96	1.49

Table 1 (continued)

Mapping unit	Physiography	Soil series association	Soil classification (Sub-group level)	Soil erodibility (K)	Area ('000 ha)	Percent of total area
26	Hilly terrain (Sh)	Madnapur	Lithic Ustorthents	0.58	4.29	1.29
27	Escarpment (Spe)	Madnapur	Lithic Ustorthents	0.58	7.62	2.29
28	Foot slopes (Sf)	Khadsangi-3 Khadsangi-4	Lithic Ustorthents Typic Ustorthents	0.55	8.84	2.65
29	Isolated hills (Sih)	Madnapur	Lithic Ustorthents	0.58	0.67	0.2
30	Isolated mounds (Sim)	Madnapur	Lithic Ustorthents	0.58	0.19	0.06
31	Subdued plateau (Ssp)	Khadsangi-1 Khadsangi-2	Typic Haplustepts Lithic Haplustepts	0.48	3.42	1.03
32	Undulating land (Sn)	Tekepar Khadsangi-6	Typic Haplusterts Typic Ustorthents	0.53	91.02	27.35
33	Upland (Su)	Khadsangi-6 Tekepar	Typic Ustorthents Typic Haplusterts	0.56	9.61	2.89
34	Interfluves (Si)	Talodi gaonganna Karbada	Vertic Haplustepts Typic Haplustepts	0.58	11.39	3.42
35	Alluvial plain (Sap)	Talodi Tukum Manemohadi-1	Typic Haplustepts Typic Haplustepts	0.62	0.22	0.07
36	Broad valley (Svb)	Vihirgaon Manemohadi-2	Typic Haplustepts Typic Haplustepts	0.57	2.77	0.68
37	Narrow valley (Svn)	Kolara Karbada Rithi	Typic Haplustepts Typic Haplustepts	0.58	13.4	4.03
			Total area		158.4	47.45

Soil Characteristics

Physiography-soil relationship (Table 1) was established to map the soils of the area. Thirty five soil series were tentatively identified and mapped as soil series association in 37 physiographic units. The soils developed over basaltic landscape are shallow (Chincholi), moderately deep (Kutbala-2, Girsawli-2, Kartangadi, Longadga) to deep (Karwad-2, Madheri, Panjurni, Wandhali, Girsawli), clay texture with shrink-swell properties except for the soils of Chincholi (clay loam),

neutral to moderately alkaline (pH 6.5–8.3), medium to high organic carbon (0.7%–1.6%), non-saline, calcareous except for the soils of Chincholi which is non-calcareous with cation exchange capacity (CEC) ranges from 32.2 $cmol(p^+)kg^{-1}$ (Chincholi) to 64.3 $cmol(p^+)$ kg^{-1} (Kutbala-2). Soils developed over granite-gneiss landscape are shallow (Sondo), moderately deep (Bhisi, Wainganga) to deep (Timram, Hirapur, Khodi, Pranhita), sandy clay loam, silty clay loam to clay loam texture, strongly acidic to slightly alkaline (pH 5.1–

Table 2 Estimated values of LS factor under different slope classes

S. No.	Slope class and gradient	Estimated LS value
1	Moderately steeply sloping (15%–30%)	6.8
2	Moderately sloping (5%–10%)	2.4
3	Gently sloping (3%–8%)	0.4
4	Very gently sloping (1%–3%)	0.2

Table 3 Estimated values of C, P factors under different land utilization types

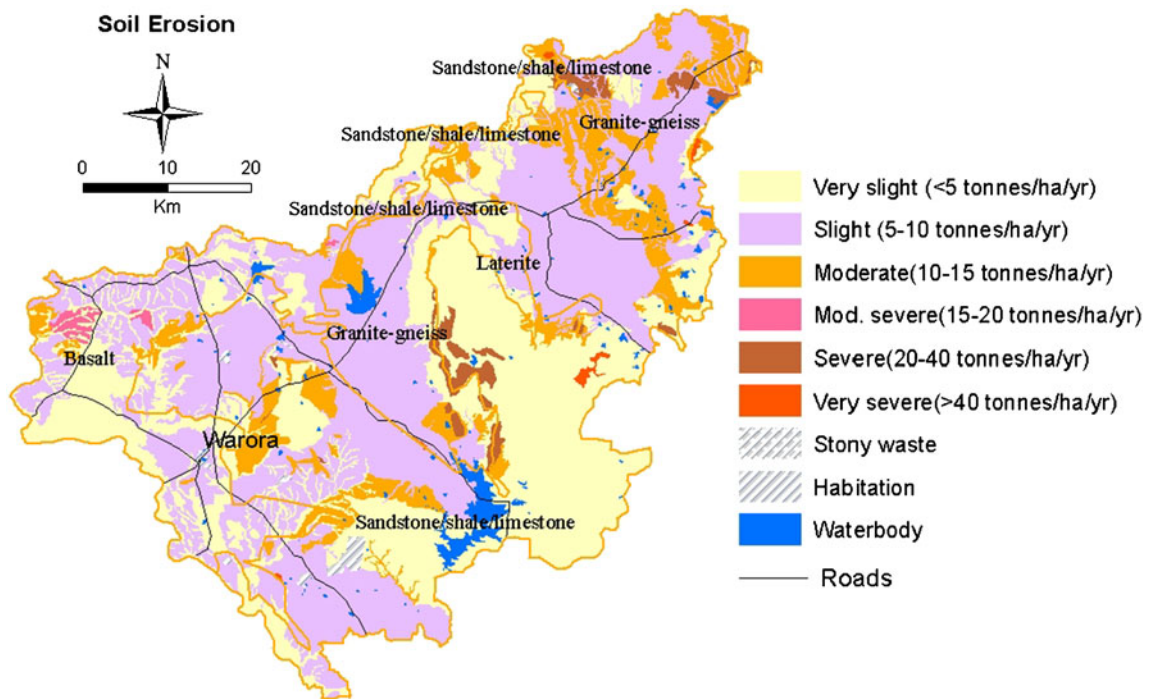| S. No.	Land utilization type	C value	P value
1	Moderately dense forest	0.02	1.0
2	Dense forest	0.01	1.0
3	Degraded forest	0.20	1.0
4	Cultivated	0.38	0.3
5	Wasteland with scrub	0.20	1.0

Fig. 4 Soil erosion in different landscapes

8.1), low to high in organic carbon (0.3%–1.5%), non-saline and non-calcareous. The CEC ranges from 12.4 cmol(p$^+$)kg^{-1} (Khodi) to 49.0 cmol(p$^+$)kg^{-1} (Wainganga). Soils of laterite landscape are moderately deep (Lawari) to deep (Saigatta, Lohara), sandy loam to sandy clay loam texture, moderately acidic to strongly alkaline (pH 5.8–8.8), medium to high in organic carbon (0.5%–1.1%), non-saline and non-calcareous with CEC ranges from 13.2 cmol(p$^+$)kg^{-1} (Lohara) to 18.0 cmol(p$^+$)kg^{-1} (Saigatta). Soils developed over sandstone/lime stone landscape are shallow (Madnapur), moderately shallow (Khadsangi-4, Khadsangi-6), moderately deep (Kolara, Manemohadi-2) to deep (Talodigaonganna, Karbada, Talodi Tukum, Manemohadi-1, Tekepar, Karbada Rithi, Vihirgaon); sandy loam, sandy clay loam to sandy clay texture, strongly acidic to strongly alkaline (pH 4.9–8.5), low to high organic carbon (0.1%–1.7%) with CEC ranges from 6.1 cmol(p$^+$)kg^{-1} (Khadsangi-2) to 75.7 cmol(p$^+$)kg^{-1} (Vihirgaon).

Estimation of USLE Factors

Rainfall Factor (R): The annual values of erosion index at any given location differ substantially from year to year. The estimated average annual erosion index (Kurothe et al. 2001) for Chandrapur area is 483. The same value has been used for the estimation of soil loss in Warora tehsil.

Soil Erodibility Factor (K): Since soil mapping unit is the association of soil series with dominant soils occupying 60% and sub-dominant soils occupying 40% area of the polygon, appropriate weightage (60% for dominant and 40% for sub-dominant) was given to different soil series in the association to prepare soil erodibility factor (K) map. The K value ranged from 0.42 to 0.48, 0.50 to 0.53, 0.53 to 0.58 and 0.48 to 0.62 in basaltic, granite-gneiss, laterite and sandstone/limestone landscapes respectively.

Slope Length and Gradient Factor (LS): The slope length and gradient factor (LS) determined for each physiographic unit of the area is presented in Table 2. The data indicate that higher LS values are associated with moderately steeply sloping (15%–30%) to moderately sloping (8%–15%) escarpment, isolated hills in granite-gneiss and hilly terrain, escarpment and isolated hills in sandstone/limestone landscapes. The low LS values are associated with very gently sloping (1%–3%) to gently sloping (3%–8%) lands in basalt, granite-gneiss, laterite and sandstone/limestone landscapes.

Crop Cover and Management Factor (C): The dominant crop cover is the cultivated land (cotton, soybean, paddy in *kharif*; wheat, gram, linseed and sunflower in *rabi*) followed by moderately dense forest cover. The data in Table 3 indicate that the C values varied from 0.01 to 0.38. Higher C values were observed under cultivation followed by wasteland with scrub. The lowest C values were observed under dense forest cover.

Conservation/Support Practice Factor (P): The data in Table 3 indicate that higher conservation/support practice factor values are observed with forest and wasteland with scrub as these land utilization types does not have effective conservation measures. The cultivated lands have low conservation/support practice factor value as these areas are covered with field bunds.

Soil Erosion

The analysis of soil erosion in different mapping units (Fig. 4) indicate that very slight erosion areas with 37.7% of TGA are associated with very gently sloping to gently sloping plateau, isolated mounds, undulating land, subdued plateau, interfluves, upland, alluvial plain, broad and narrow valley in basaltic landscape; subdued plateau, foot slope and undulating land in granite-gneissic landscape; interfluves, undulating land and narrow valley in lateritic landscape and foot slope, subdued plateau, undulating land, upland and narrow valley in sandstone/limestone landscape. These areas are under cultivation, dense, moderately dense forest. The slight erosion areas with 46% of TGA are associated with very gently sloping to gently sloping plateau top, isolated mounds, undulating land, subdued plateau, interfluves, upland and alluvial plain in basaltic landscape; subdued plateau, foot slope, upland, undulating land, interfluves and valleys in granite-gneissic landscape; interfluves, undulating land, and valleys in lateritic landscape and foot slope, subdued plateau, undulating land, upland, interfluves, valleys in sandstone/limestone landscape. These areas are mainly under cultivation and wasteland with scrub are in patches. The areas with moderate erosion covers 10.9% of TGA, are associated with moderate sloping, gently sloping and very gently sloping escarpments, isolated mounds, undulating land, subdued plateaus, inter-

fluves and broad valley in basaltic landscape; escarpments, isolated hills, foot slope, undulating land, interfluves and narrow valleys in granite-gneissic landscape; undulating land and narrow valley in lateritic landscape and escarpments, foot slope, isolated hills, undulating land, upland, interfluves, broad and narrow valley in sandstone/limestone landscape. These areas are mainly under cultivation, wasteland with scrub, moderately dense and degraded forest. The moderately severe eroded areas are confined to gently sloping undulating land in basaltic landscape. These areas are under degraded forest and wasteland with scrub. The severe to very severely eroded areas are associated with moderately sloping to moderately steeply sloping escarpments, isolated hills and hilly terrain in granite-gneissic and sandstone/limestone landscapes. These areas are under degraded forest and wasteland with scrub. The moderately severe, severe and very severe erosion constitute 0.5%, 2.0% and 0.3% of TGA respectively.

Soil and Water Conservation Measures

The hilly terrain, isolated hills, escarpments with moderate to moderately steeply slopes under degraded forest and wasteland with scrub are exposed to moderate to very severe erosion and can be brought under vegetative cover with reasonable efforts through afforestation programmes with suitable tree species. Mechanical measures like continuous contour trenches are to be taken up to conserve water and also to protect soil and plants. The subdued plateau top with very gentle slope is under cultivation and moderately dense forest with slight to moderate erosion. The cultivated lands need to be protected through proper field bunding. Afforestation programme has to be taken up in moderately dense forest areas to prevent soil loss. Isolated mounds with gentle slope are under cultivation, moderately dense forest and wasteland with scrub. The agricultural lands need to be protected through field bunding, contour cultivation, vegetative barriers across the slope and establishment of vegetative cover in forest and wasteland with scrubs are recommended. Undulating lands with substantial area (53.7%) are associated with very gently to gently sloping lands under cultivation, wasteland with scrubs and moderately dense forest with very slight, slight and moderate erosion. The areas under very slight to slight soil loss

need no immediate soil and water conservation measures as the soil loss is under tolerance limit of 4.5–11.2 t/ha/yr (Mannering 1981). The areas under moderate erosion require conservation measures such as proper field bunding and optimum vegetative cover to reduce soil loss. In wasteland with scrub, agro-forestry, agri-horticulture and silvipasture interventions are needed. Teak, Sivan, *Acacia spp.*, *Prosopis juliflora*, Palas and other suitable tree species should be planted. Horticultural crops like aonla, custard apple and ber are recommended. The interfluves, alluvial plain and valleys are on very gently sloping to gently sloping lands under cultivation, moderately dense and degraded forest with very slight, slight and moderate erosion. The areas under moderate erosion need soil and water conservation measures such as field bunding in cultivated areas and vegetative cover in forest areas with suitable species are recommended.

Conclusions

The spatial information on physiography, slope, present land use/land cover and soils derived through remote sensing and supportive data was utilized for estimation of various factors contributing to soil erosion using USLE model and integrated in GIS for the computation of quantitative soil loss by water erosion. The analysis of spatial database on soil erosion in different landscapes helps in prioritizing areas for soil and water conservation measures. Afforestation, agro-forestry, agri-horticulture interventions are suggested for sustainable development and management of natural resources, soil moisture conservation, water resources development, improving the crop productivity and preservation of eco-diversity. The spatial database generated in the present study will not only be useful to monitor the erosion processes, but also be useful for the estimation of soil loss using USLE model for appropriate management interventions.

References

Bhattacharyya, T., Ram Babu, Sarkar, D., Mandal, C., Dhyani, B. L., & Nagar, A. P. (2007). Soil loss and crop productivity model in humid subtropical India. *Current Science, 93*, 1397–1403.

Black, C. A., Evans, D. D., White, J. L., Ensmingel, L. E., & Clark, F. E. (Eds.) (1965). Methods of soil analysis, Part I. *Amer. Soc. Agron. Inc. Agron.* No. 9, Madison, Wisconsin, USA.

Burrough, P. A., & McDonnell, R. A. (1998). *Principles of geographical information systems*. New York: Oxford University Press.

Cleaver, K., & Schrieber, G. A. (1995). *Reversing the spiral: the population, agriculture and environment Nexus in Sub-Saharan Africa*. Washington DC: World Bank.

Devi, G. M. S., & Kumar, K. S. A. (2008). Remote sensing and GIS application for land quality assessment for coffee growing areas of Karnataka. *Journal of the Indian Society of Remote Sensing, 36*, 89–97.

Dhruvanarayana, V. V., & Ram Babu. (1983). Estimation of soil erosion in India. *Journal of Irrigation and Drainage Engineering, 109*, 419–434.

GSI (2001). Geology and minerals, District Resource Map, Chandrapur district, Geological Survey of India.

Jackson, M. L. (1967). *Soil chemical analysis*. New Delhi: Prentice Hall India Pvt. Ltd.

Karad, U. N., Gore, K. P., & Bhuibhar, B. W. (1991). Evaluation of some universal soil loss equation parameters for Parbhani (M.S.). *Indian Journal of Soil Conservation, 19*, 61–65.

Kurothe, R. S., Challa, O., Samra, J. S., & Velayutham, M. (2001). Assessment of soil erosion in Maharashtra. *Indian Journal of Soil Conservation, 29*, 133–137.

Lillesand, T. M., & Kiefer, R. W. (2002). *Remote sensing and image interpretation*. Singapore: Wiley.

Mannering, J. V. (1981). The use of soil tolerances as a strategy for soil conservation. In R. P. C. Morgan (Ed.), *Soil conservation: problems and prospects* (pp. 337–349). Chichester: Wiley.

Narain, P. (2008). Dryland management in arid ecosystem. *Journal of the Indian Society of Soil Science, 56*, 337–347.

NBSS&LUP (1993). Soils of Chandrapur district, Maharashtra. Soil Survey Report No. 525, National Bureau of Soil Survey and Land Use Planning, Nagpur.

NRIS (2000). *National (Natural) Resources Information System Node Design and Standards* (pp. 19–21). National Natural Resources Management System, ISRO Headquarters, Bangalore.

Pandey, L. M., Prasad, J., Saha, S. K., & Subramanyam, C. (1992). *Review of remote sensing applications to soils and agriculture*. Proceedings Silver Jubilee Seminar, IIRS, Dehradun.

Potdar, S. S., Srivastava, R., Nagaraju, M. S. S., Prasad, J., & Saxena, R. K. (2003). Mapping of erosional soil loss in Nanda-Khairi watershed of Nagpur district of Maharashtra using remotely sensed data and GIS techniques. *Agro-pedology, 13*, 10–18.

Ram Babu, Tejwani, K. G., Agarwal, M. C., & Chandra, S. (1978). *Rainfall erosion potential and iso-erodent map of India* (pp. 1–47). Dehradun 2: Central Soil and Water Conservation Research and Training Institute.

Saha, S. K., & Singh, B. M. (1991). Soil erosion assessment and mapping of Aglar River watershed (U.P.) using remote sensing technique. *Journal of the Indian Society of Remote Sensing, 19*, 67–76.

Sarkar, D., Gangopadhyay, S. K., & Sahoo, A. K. (2006). Soil resource appraisal towards land use planning using satellite remote sensing and GIS—a case study in Patloinala micro-watershed, district Purulia, West Bengal. *Journal of the Indian Society of Remote Sensing, 34*, 245–260.

Sehgal, J., & Abrol, I. P. (1994). *Soil degradation in India: Status and impact*. N. Delhi: Oxford and IBH Publishing Co. Pvt. Ltd.

Singh, G., Ram Babu, & Chandra, S. (1981). Soil loss prediction Research in India. Central Soil and Water Conservation Research and Training Institute, Dehradun, Bull No. T-1210-9.

Skidmore, A. K., Bijker, W., Schmidt, K., & Kumar, L. (1997). Use of remote sensing and GIS for sustainable land management. *ITC Journal* 302–315.

Soil Survey Division Staff (2000). Soil Survey Manual, USDA Handbook No. 18, Washington, DC.

Soil Survey Staff. (1998). *Keys to soil taxonomy* (8th ed.). Washington, DC: SCS, USDA.

Solanke Preeti, C., Srivastava, R., Prasad, J., Nagaraju, M. S. S., Saxena, R. K., & Barthwal, A. K. (2005). Application of remote sensing and GIS in watershed characterization and management. *Journal of the Indian Society of Remote Sensing, 33*, 239–244.

Venkatratnam, L., & Manchanda, M. L. (1997). Remote sensing in soil resource management. ISPRS workshop on application of remote sensing and GIS for sustainable development, National Remote Sensing Agency, Hyderabad.

Wischmeier, W. H., & Smith, D. D. (1978). Predicting rainfall erosion losses—a guide to conservation planning. Agricultural Handbook No. 537, USDA.

Wischmeier, W. H., Johnson, I. B., & Cross BV, A. (1971). Soil erodibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation, 26*, 189–193.