Estimation of Soil Erosion and Nutrient Loss by USLE Model for Ratnagiri District

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Abstract

Soil erosion is the common land degradation problem in the worldwide, and also is one of the most critical environmental hazards of recent times. A large area suffers from soil erosion, which in turn, reduces productivity. Assessment of soil erosion is expensive and intensively long exercise. A number of parametric models have been developed to forecast soil erosion, yet Universal Soil Loss Equation (USLE) model is most widely used empirical formula for estimating annual soil loss from agricultural basins. In the present study USLE model has been used for estimation of soil loss for Ratnagiri district of Konkan region of Maharashtra. Parameters of model were estimated from available data using RS and GIS tools. The average annual predicted soil loss by USLE from Ratnagiri district was estimated as 43.61 t $ha^{-1}yr^{-1}$ before adoption of soil and water conservation measures. More than 80 percent of area from Ratnagiri district comes under severe (20-40 t $ha^{-1}yr^{-1}$) to extremely severe (>80 t $hqa^{-1}yr^{-1}$) erosion classes. This is indicate to adept soil and water conservation measures on watershed for sustainable development of soil and water. An estimated nutrient loss of N, P_2O_5, K_2O and OC of Ratnagiri were found as 8.9 g $kg^{-1}yr^{-1}$, 0.13 g $kg^{-1}yr^{-1}$, 5.8 g $kg^{-1}yr^{-1}$ and 638.94 kg $ha^{-1}yr^{-1}$, respectively before adoption of conservation measures. It proves that urgent need of adoption of conservation measures is required.

Keywords: Soil erosion, USLE, Nutrient loss, RS and GIS.

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Introduction

Erosion is a natural geological phenomenon resulting from removal of topsoil by natural agencies like wind and water, some human intervention can significantly increase erosion rates. It is a major agricultural problem and a major global environmental issue. It is generally associated with agricultural practices, leading to decline in soil fertility, bringing in a series of negative environmental impacts and has become a threat to sustainable agricultural production and water quality in many countries (Lal *et.al,* 1998). In India, the problems of land degradation are prevalent in many forms. In many parts of the country, unchecked soil erosion and associated land degradation has made vast areas economically unproductive (GOI 2009).

Soil erosion is the process of detachment and transportation of surface soil particles from original location and accumulation of it to new depositional area. Soil erosion as "soil cancer" is a complex process and its multiple obvious hidden social and environmental impacts is an increasing threat for the human existence (Ownegh and Nohtani 2004).

Soil degradation by accelerated erosion is a serious problem and will remain so during the 21st century and its severity and environmental impacts are debatable (Lal 2001). Soil erosion on cultivated lands has received much concern since it is considered to be one of the most critical forms of degradation (Montgomery 2007)

In recent years, soil degradation has reached alarming proportions in many parts of the world, especially in the tropics and sub-tropics. The estimates suggest that globally about 24 BT(Billion Tonne) of soil is lost annually through water erosion in excess of the natural rate of soil regeneration. According to FAO, about 18 percent of the arable lands in the world could be lost for ever if no measures are taken to preserve them. About 30–50 percent of the world's arable lands are substantially degraded due to soil erosion, which directly affects rural livelihood (Mandal and Sharda 2011).

In India, about 53 percent of the total land area is prone to erosion and has been estimated that about 5,334 MT of soil is being detached annually due to various reasons (Narayana and Babu 1983). Soil degradation in India is estimated to be occurring on 147 Mha of land, including 94 Mha from water erosion, 16 Mha from acidification, 14 Mha from flooding, 9 Mha from wind erosion, 6 Mha from salinity and 7 Mha from a combination of factors (Bhattacharyya *et al* 2015).Maharashtra is also facing similar level of severity in soil erosion. The quantity of soil erosion per year in Maharashtra is 773.5 MT and 94 percent of that erosion is water induced (Durbude 2015).

Estimating the soil loss risk and its spatial distribution are the one of the key factors for successful erosion assessment. Spatial and quantitative information on soil erosion on a regional scale contributes to conservation planning, erosion control and management of the environment. Identification of erosion prone areas and quantitative estimation of soil loss rates with sufficient accuracy are of extreme importance for designing and implementing appropriate erosion control or soil and water conservation practices (Shi *et al* 2004). Researchers have developed many predictive models that estimate soil loss and identify areas where conservation measures will have the greatest impact on reducing soil loss for soil erosion assessments (Angima *et al* 2003).

A number of parametric models have been developed to forecast soil erosion at drainage basins. Universal Soil Loss Equation i. e. USLE (Wischmeier and Smith 1978) is the most popular empirically based model used globally for erosion prediction and control. The various factors of USLE are rainfall erosivity factor (R), soil erodibility factor (K), length and steepness of slope factor (LS), vegetation and crop cover factor (C) and conservation practice factor (P).

Soil loss leads to loss of vital soil nutrients and organic matter which also needs to be quantified. Loss of major nutrients *viz*., nitrogen, phosphorous and potassium along with soil carbon would be of concern. Soil organic carbon is the critical component of soil resource base. The role of soil organic carbon in the formation of stable soil aggregates has major implication for air-water balance and surface strength of soil.

This kind of study is very essential in Konkan region of Maharashtra due to extreme weather conditions and huge loss of soil through runoff. It is part of Western Ghats which comes under one of 34 world biodiversity hotspots (Myers *et al* 2000). So also Ratnagiri district is ecologically sensitive region where natural resources need to be protected with maximum care.The application of Remote Sensing and GIS is most suitable technique for coastal resource management. GIS based analysis gives better results and effective strategies for the mitigation of such affected coastal zones. However, due to hilly terrain of Sahyadri ranges, data availability or accessibility is scare.

The Remote Sensing (RS) and GIS techniques have become valuable tools specially when assessing erosion at larger scales due to the amount of data needed and the greater area coverage (Parveen and Kumar 2012). With the advance of Remote Sensing technique it becomes possible to measure hydrologic parameters on spatial scales while Geographic Information System (GIS) integrates the spatial and analytical functionality for spatially distributed data. The combined use of GIS and erosion models, such as USLE/RUSLE, has been proved to be an effective approach for estimating the magnitude and spatial distribution of erosion. The present study explains the estimation of actual soil loss and nutrients loss of Ratnagiri district.

Materials and Methods

Study area: Ratnagiri district lies between $15^0$40' and 18°5' N latitude and $73^0$5' and $73^0$55' E longitude. Ratnagiri district is a coastal district of Maharashtra state, situated on the Western Coast of India. The total geographical area of Ratnagiri district is 8,461 km^2. Average annual rainfall of Ratnagiri district is 3,591 mm. Sahyadri hills surrounds it in the east and the Arabian Sea in the west. It comprises of nine tehsils, namely Mandngad, Dapoli, Khed, Chiplun, Guhagar, Sangmeshwar, Ratnagiri, Lanja and Rajapur. The soil of the district is mainly lateritic. and the main cereal crops grown are Rice, finger millet, Lablab bean, Horse gram, Red gram, Red cow pea and Seasame beans. In horticulture, Mango, Cashew, Coconut, Arecanut, Jack fruit, Kokum and Banana form the main crops. A rapid increase in the area of cultivation of Horticulture in general and Mango and Cashew in particular.

Soil erosion USLE (Universal Soil Loss Equation)

The USLE (Universal Soil Loss Equation) was proposed for estimating sheet and rill erosion losses from cultivated fields. This empirical equation, based on a large mass of field data, computes sheet and rill erosion as annual average soil loss (t $ha^{-1}yr^{-1}$) using the values representing the four major types of factors affecting erosion. These factors are climatic, soil, topographic, land use and management.

In the present study an attempt has been made to estimate the actual soil loss in study area through Universal Soil Loss Equation (USLE) and by the integrated analysis of spatial data in GIS.

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

where, A is computed soil loss (t $ha^{-1}yr^{-1}$), R is the rainfall erosivity factor (MJ mm ha^{-1} $hr^{-1}yr^{-1}$), K is the soil erodibility factor (t ha hr ha^{-1} MJ mm), L is the slope length factor (m), S is the slope steepness factor, C is the crop cover management factor, and P the conservation practice factor.

Rainfall erosivity factor (R)

R is long term annual average of the product of total kinetic energy and the maximum intensity in 30 minutes in mm per hour (Wischmeierand Smith 1978). Rainfall erosivity estimation using rainfall data with long-time intervals have been attempted by several workers for different regions of the world. Using the data for storms from several rain gauge stations located in different zones, linear relationships were established between average annual rainfall and EI_{30} values for different zones of India.

In the present study the daily precipitation and EI_{30} data of Wakawali station were used for regression analysis (Yadavand Mhatre 2005) and regression equation was obtained for computing the daily erosivity index from trade line of graph. The following equation implies the correlation between daily Erosivity Index and daily rainfall.

$$Y = \alpha X^{b} \quad \dots\dots(2)$$

where, Y is daily erosivity index and x is daily precipitation. The equation found was power in nature where a and b are constants. Hence Equatic 2 has been used in the present study to compute R factor values for five stations using daily rainfall data for 28 years. These values were assigned to respective polygons in thiessen polygon to get rainfall erosivity (R) map.

Soil erodibility factor (K)

The soil erodibility factor, K, relates to the rate at which different soils erode due to inherent soil properties. Soil erodibility is a measure of the total effect of a particular combination of soil properties on the soil loss. However, it is different than the actual soil loss because latter depends other factors, such as rainfall, slope, crop cover, etc. The K factor was computed for each soil type of study area with the help of data obtained from soil analysis regarding soil texture, structure, permeability and organic matter content. An algebraic approximation of the monograph that includes soil parameters such as texture, structure, permeability and organic matter content is proposed by the equation (Wischmeierand Smith 1978 and Renard *et al* 1997)

$$K = \left\{\frac{[2.1 \times 10^{-4} M^{1.14}(12 - a) + 3.25(b - 2) + 2.5(c - 3)]}{100}\right\} \times 0.1317 \quad \dots\dots(3)$$

where, K= soil erodibility factor (t ha hr ha^{-1} MJ mm),

b= structure of the soil,

M= (% silt + 0.7 * % sand) * (100 - % clay),

c= permeability of the soil,

a= organic matter content(a=organic carbon * 1.724).

In the present study the different soil parameters such as sand, silt, clay and organic carbon were collected from previous work (Thawakar 2014) at Dr. B.S.K.K.V., Dapoli. Based on these data parameters erodibility estimation (Eqn. 3) were determined by using various relationships among the soil characteristics. These K factor values were assigned to the different location of study area in ArcGIS 10.2 to get soil erodibility (K) map.

Topographic factor (LS)

Topographic factor (LS) in USLE accounts for the effect of topography on sheet and rill erosion. The two parameters that constitute the topographic factor are slope gradient (S) and slope length factor (L) and can be estimated from a digital elevation model (DEM).

The relationship between the slope steepness in percentages (Sp) and slope length in meters (L) were used to generate slope length map. It is given by

$$L = 0.4 \times Sp + 40 \quad \ldots\ldots(4)$$

where, L = Slope length in meters and Sp = Slope steepness in percentage. By applying this equation the resultant map was prepared for slope length.

Although L and S factors were determined separately, the procedure has been further simplified by combining the L and S factors together and considering the two as a single topographic factor (LS) (Wischmeier and Smith 1965). Combined LS factor layer was generated as

I. For slopes up to 21 percent, the equation was modified (Wischmeier and Smith 1978) was used which is,

$$LS1 = \left(\frac{L}{22.1}\right)(65.41\, sin^2\theta + 4.56\, sin\theta + 0.065) \quad \ldots\ldots(5)$$

where, LS1 is the slope length and gradient factor and θ is angle of the slope.

II. For slope steepness of 21 % or more, the equation used, which is given by

$$LS2 = \left(\frac{L}{22.1}\right)^{0.7} (6.432 \sin(\theta^{0.79})\,(cos\theta)) \quad \ldots\ldots(6)$$

where, LS2 is the slope length and gradient factor, θ is angle of the slope and L is slope length in meters. Digital elevation model (DEM) of the study area was prepared using SRTM data.

A slope map was created from the DEM, based on the slope map, slope length (L) and slope gradient(S) maps and finally a layer of LS factor was generated for Ratnagiri district.

Crop cover and management factor (C)

The C factors are related to the land use and land cover. The cover and management factor (C) reflects the effect of cropping and management practices on soil erosion rates. The land use and land cover map of study area was used for analysing the C-value. LANDSAT-7 images (ftp.glcf.umd.edu) Path No. 147, Row No. 48 and 49, February 2004 were used for preparation of land use land cover map. Crop cover data of study area was collected from the District Superintedent Agriculture Office, Ratnagiri, Maharashtra to obtain the crop cover management factor (C). The land use/cover classification of the study area was carried out using supervised classification (maximum likelihood classification). Classification was carried out for five land use classes: agriculture, forest, waterbody, barren land and urban area. Crop management factors were assigned for different land use patterns as shown in Table 1.

Conservation practice factor (P)

The conservation practice factor (P) in USLE is defined as the ratio of soil loss with a specific conservation practice to the corresponding soil loss due to up and down practice. The P factor accounts for the practices that reduce the erosion potential of the runoff by their influence on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil. The supporting mechanical practices include the effects of contouring, strip cropping, or terracing. The P factor depends on the conservation measure applied to

Table 1: Land use/land cover and C value

Land use/land cover	C value
Forest (Rasool et al 2014)	0.040
Barren land (Rasool et al 2014)	0.034
Built-up (Rasool et al 2014)	0.024
Horticultural crops (Pal and Samanta 2011)	0.100
Oilseeds (Panagos 2015)	0.280
Rice (Panagos 2015)	0.150

the study area. P factor was assigned as 1 for the study area as it was untreated.

Estimation of Nutrient loss

The nutrient losses were calculated by for each tehsil of Ratnagiri district by available value of nutrient for that tehsil multiplied by soil loss of that tehsil. Therefore, organic carbon, Nitrogen, Phosphorous, Potassium was obtained from soil series information (Table 3) (Joshi, 2012 and Sonawane 2013).

Results and Discussion

Rainfall erosivity factor (R)

In the present study the relationship between daily rainfall and erosivity factor R data of Wakawali station were used for regression analysis and regression equation was obtained which has been used to compute R factor for five stations of Ratnagiri district using daily rainfall of 28 year (1984-2011). The equation found was power in nature and the coefficient of determination obtained was 0.7624 with value of a as 0.3339 and value of b as 1.50. It was observed that average annual erosivity for Hedvi, Karak, Poynar, Dapoli and Wakawali stations were 10,001.93, 10,837.42, 9,734.62, 10,285.58 and 10,117.86 MJ mm $ha^{-1}hr^{-1}yr^{-1}$ respectively. Hence, the average annual erosivity obtained for Ratnagiri district was 10,195.48 MJ mm $ha^{-1}hr^{-1}yr^{-1}$.These values were assigned to respective polygons in thiessen polygon to get rainfall erosivity (R) map. Using these annual erosivity values, R-map of study area was prepared (Figure 1). Erosivity of Ratnagiri district is very high due to very high intensity and high amount of rainfall. Therefore, erosivity is one of the major factors influencing soil erosion of the district.

Table 2: Area under different classes of soil erosion before conservation measures

Soil erosion class	Soil loss (t $ha^{-1}yr^{-1}$)	Area (ha)	Percent area
Slight	0-5	10868.86	1.30
Moderate	5-10	34641.46	4.14
Moderately severe	10-20	95689.16	11.42
Severe	20-40	390953.6	46.67
Very severe	40-80	186843.2	22.31
Extremely severe	>80	118677.4	14.17

(Joshi 2012; Sonawane 2013)

Table 3: Tehsil wise available nutrients in soils of Ratnagiri district

Sr. No.	Tehsil Name	N kg ha^{-1}	P_2O_5 kg ha^{-1}	K_2O kg ha^{-1}	OC g kg^{-1}
1.	Dapoli	419.93	5.62	258.73	14.21
2.	Khed	444.80	5.76	236.10	15.22
3.	Ratnagiri	513.54	4.69	229.01	15.13
4.	Lanja	512.00	6.81	289.69	15.14
5.	Chiplun	335.55	5.61	250.30	14.65
6.	Rajapur	304.19	5.71	266.78	14.01
7.	Guhagar	344.96	6.14	259.39	15.14
8.	Mandangad	324.58	5.85	252.67	14.66
9.	Sangmeshwar	319.87	5.59	260.06	13.70

(Joshi 2012; Sonawane 2013)

Soil erodibility factor (K)

The different soil parameters such as sand, silt, clay and organic carbon were collected from previous work (Thawakar 2014) carried out at Dr. B.S.K.K.V., Dapoli. Soil erodibility factors were computed for 45 villages of Ratnagiri district (using Equation 3). These K factor values were assigned to the different locations of study area in ArcGIS 10.2 to get soil erodibility (K) map. Soil erodibility was observed higher in patches and increasing towards coastal side.Accordingly K factor map of Ratnagiri district was prepared (Figure 2).Soil erodibility factor for different villages of Ratnagiri district were found in the range of 0.0346 to 0.0636 t ha hr ha^{-1} MJ mm.

Topographic factor (LS)

The topographic factors slope gradient and slope length significantly influence soil erosion. A slope map was created from the DEM, based on slope length (L) and slope gradient(S) maps and finally a layer of LS factor was generated. LS factor map of Ratnagiri district was generated in ArcGIS 10.2 (Figure 3).The values of LS factor for study area was found in the range of 1.953 to 4.393. Major portion of Ratnagiri district was covered by LS factor ranging between 2 to 3 (85.42 percent), followed by 1 to 2 (14.25 percent) and 3 to 4 (0.34 percent). Very small portion of the study area was covered by LS factor more than 4 (0.001 percent).

Crop cover and management factor (C)

LANDSAT-7 images used for preparation of land use land cover map. The land use/cover classification of the study area was carried out using supervised classification (maximum likelihood classification). Classification was carried out for five land use classes: forest, waterbody, agriculture, barren land and urban area were 2,99,097.6 ha, 11,240.52 ha, 1,20,437.4 ha, 2,13,621.4 ha and 2,01678.8 ha respectively. Crop management factor (C) values for study area ranged from 0.024 to 0.12. C factor values for different land cover class were shown in Table 1, as per C factor map of Ratnagiri district (Figure 4).

Conservation practice factor (P)

The conservation practice factor (P) was considered as 1 for whole Ratnagiri district as it was untreated, without any conservation measures. So the relative soil loss reduction would be estimated, if conservation measures are adopted in future.

Average Annual Soil Loss using USLE

The average annual soil loss for study area was calculated by annual average R (based on annual average rainfall data of 1984-2011), K, LS, C and P factors. All the layers viz. R, K, LS, C and P were generated in GIS and were overlaid to obtain the product, which gave average annual soil loss of the Ratnagiri district. Classification of study area was done into six classes as slight, moderate, high, very high, severe, and very severe (Singh 1992). Estimated average annual soil loss from Ratnagiri district was 43.61 t $ha^{-1}yr^{-1}$ (Figure 5). Highest percent of area was found under the severe soil erosion class (46.67 percent), followed by very severe soil erosion class (22.31 percent), extremely severe soil erosion class (14.17 percent), moderately severe soil erosion class (11.42 percent), moderate soil erosion class (4.14 percent) and slight soil erosion class (1.30 percent) before recommendation of soil and water conservation measures (Table 2). It showed that more than 80 percent of area comes under severe to extremely severe erosion class which was major cause of concern. This proves an urgent need of soil and water conservation measures in the watershed for the sustainable management of natural resources. Tehsil wise area under different classes of soil erosion before conservation measures of Ratnagiri district as shown in Table 4.

Table 4: Area by tehsils under different classes of soil erosion before conservation measures of Ratnagiri district.

	Area under each Soil erosion class (t $ha^{-1}yr^{-1}$) ha					
Tehsil	Slight (0-5)	Moderate (5-10)	Moderately severe (10-20)	Severe (20-40)	Very severe (40-80)	Extremely severe (>80)
Chiplun	1349.74	3897.35	17159.93	55256.10	14991.76	17265.24
Dapoli	993.94	3826.9	10544.24	48534.29	13203.93	13140.35
Guhagar	2057.04	3383.2	7681.69	37282.31	8747.092	10468.58
Khed	2063.6	4596.36	10018.91	40749.54	26270.26	18830.17
Lanja	969.14	2393.76	6578.55	29444.00	26889.00	9101.03
Mandangad	848.91	2878.45	5500.32	20950.24	6963.95	8175.01
Rajapur	1448.08	2466.54	13178.83	57621.95	31986.23	14739.04
Ratnagiri	1318.58	1773.65	10882.5	54893.18	14971.56	10231.25
Sangameshwar	637.078	5469.13	14144.089	46233.55	42822.96	16716.74

Table 5: Loss of nutrients before soil and water conservation measures.

Sr. No.	Tehsil Name	N g kg^{-1}	P_2O_5 g kg^{-1}	K_2O g kg^{-1}	O.C. kg ha^{-1}
1	Dapoli	10.10	0.13	6.22	590.71
2	Khed	9.36	0.12	4.96	723.102
3	Ratnagiri	12.89	0.11	5.74	602.77
4	Lanja	10.65	0.14	6.02	727.47
5	Chiplun	8.06	0.13	6.01	609.44
6	Rajapur	6.91	0.12	6.06	616.16
7	Guhagar	8.46	0.15	6.36	616.65
8	Mandangad	7.46	0.13	5.81	637.27
9	Sangmeshwar	6.85	0.11	5.57	639.51

Estimation of nutrient loss

The loss of nutrients with soil loss before adoption of measures was given in Table 5. Estimated nutrients loss of N, P_2O_5, K_2O and OC of Ratnagiri were found as 8.975 g $kg^{-1}yr^{-1}$, 0.13 g $kg^{-1}yr^{-1}$, 5.867 g $kg^{-1}yr^{-1}$ and 638.94 kg $ha^{-1}yr^{-1}$, respectively. This whole nutrient was not lost completely from Ratnagiri district. But major portion of it was displaced from its original position and deposited in other fields along with soil. Some portion which moves with stream flow was lost completely. However, this study gave the insight about movement of soil loss and nutrient from Ratnagiri district.

Conclusions

In the present study, the soil loss was estimated by USLE: The average annual erosivity factor for Ratnagiri district was 10195.48 MJ mm ha^{-1} hr^{-1} yr^{-1}. The K factor, LS factor and C factor for different location of Ratnagiri district was found in the range of 0.0346 to 0.0636 t ha hr ha^{-1} MJ mm. 1.95 to 4.39 and 0.024 to 0.12 respectively.

An average annual predicted soil loss from Ratnagiri district was 43.60 t $ha^{-1}yr^{-1}$ before adoption soil and water conservation measures. It was observed that about 1.30 percent area was under slight erosion class, 1.46 percent area was under moderate erosion class, 1.21 percent area was under moderately severe erosion class, 57.62 percent area was under severe erosion class, 24.24 percent area was under very severe erosion class and 14.17 percent area was under extremely severe erosion class of Ratnagiri district before soil and water conservation measures. More than 80 percent of are from Ratnagiri district comes under severe (20-40 t $ha^{-1}yr^{-1}$) to extremely severe (>80 t $ha^{-1}yr^{-1}$) erosion classes. Estimated nutrients loss of N, P_2O_5, K_2O and OC of Ratnagiri were found as 8.975 g $kg^{-1}yr^{-1}$, 0.13 g $kg^{-1}yr^{-1}$, 5.867 g $kg^{-1}yr^{-1}$ and 638.94 kg $ha^{-1}yr^{-1}$, respectively.

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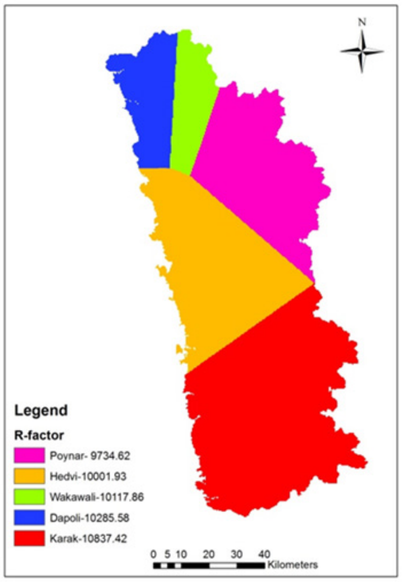

Figure 1. Rainfall Erosivity map of Ratnagiri district

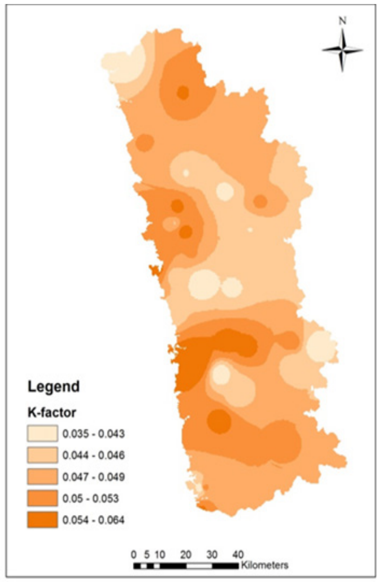

Figure 2. Soil erodibility map of Ratnagiri district

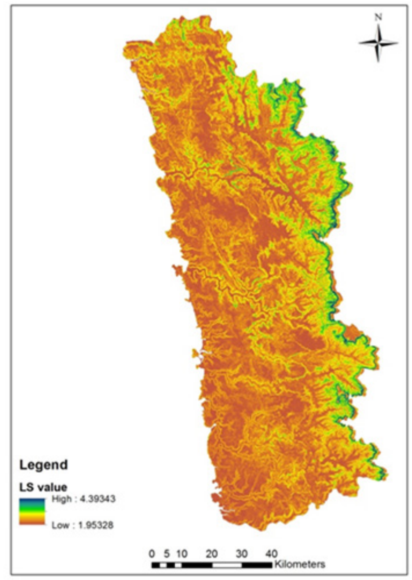

Figure 3. Topographic factor map of Ratnagiri district

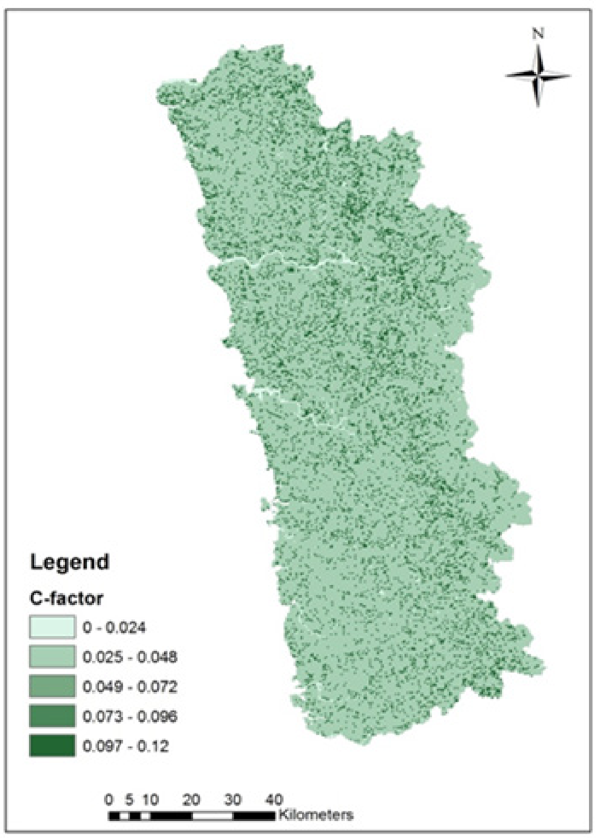

Figure 4. Crop cover management map of Ratnagiri district

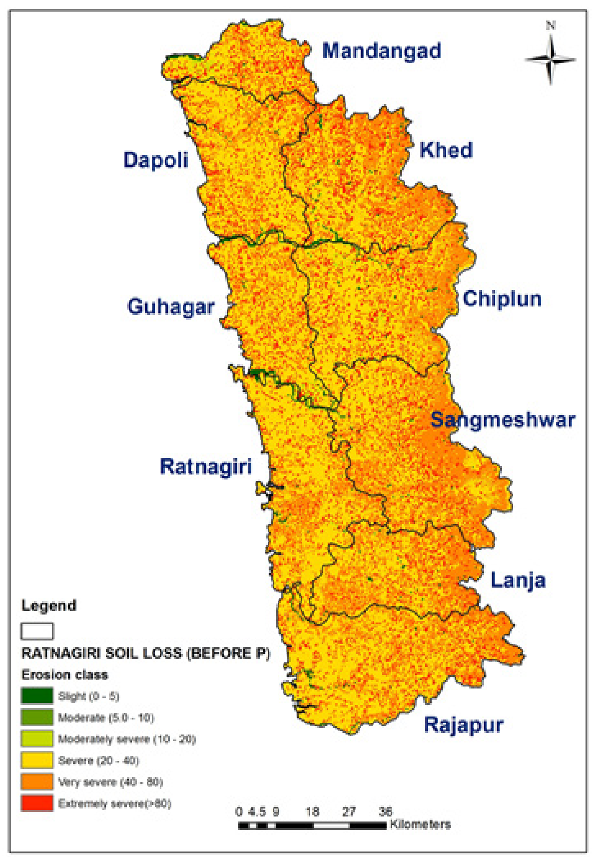

Figure 5. Average annual soil loss map of Ratnagiri district before conservation measures

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