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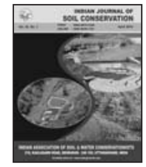

Geospatial assessment of erosional behaviour of a watershed in Angara block of Ranchi district, Jharkhand

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ABSTRACT

Soil erosion assessment was carried out in Dumar Kocha watershed of Ranchi district in Jharkhand state to understand the erosional behavior geospatially using Universal Soil Loss Equation (USLE). It was observed that average annual soil erosion for the watershed ranged from slight (<5 t $ha^{-1}yr^{-1}$) to very severe (>80 t $ha^{-1}yr^{-1}$). This was further observed that the watershed areas covered by slight, moderate, high, very high, severe and very severe erosion potential zones were 67, 12.42, 10.98, 3.82, 5.14 and 1.21% of the watershed, respectively. Spatial analysis using remote sensing and geographic information system (GIS) indicated high soil erosion rates in central portion of the watershed, which could be attributed to the severe terrain modifications, inappropriate agricultural practices and forest degradations. Since the areas which are sensitive to soil loss could be demarcated, outcome of the study has the potential to serve as a valuable resource for better land management. Geoinformatics based analysis of erosion behavior in this region at watershed level can help manage natural resources better. Results thus obtained should further help in assessment of appropriate indicators to work upon for conserving water and soil through watershed management and land use planning.

1. INTRODUCTION

Jharkhand state suffers from varying degrees of soil erosion problems (Krishna and Hemrom, 2008; Chatterjee *et al.,* 2013). Such soil degradation processes lead to deterioration of healthy ecosystems of the watersheds. Watershed characteristics refer to the biophysical and socio-economic features prevalent in a watershed (Krishna, 1996) and can broadly be categorized as climate, geology, physiographic properties of soils and land use and land cover (LULC) conditions. Overexploitation of natural resources for meeting growing demand for food, fuel and fodder of increasing population leads to LULC changes within the watersheds (Sharma *et al.*, 1998). Conditions of LULC are considered to be greatly related to the erosion conditions and LULC changes in turn, depend on local and regional climatic conditions and climate change impacts as well. Watershed characteristics are required to be identified for better management and planning (Krishna and Rai, 1996). Information on drivers of LULC changes and nature, extent, magnitude and temporal aspects of soil degradation are the prerequisites for taking up suitable mitigation measures (Joshi and Krishna, 2000).

Space-acquired multi-spectral remote sensing data with synoptic view of a fairly large region at regular intervals offer immense potential for generating above mentioned information on degraded soils in a cost-effective manner. Remote sensing (RS) alongwith GIS provides the best methodological toolset to investigate soil erosion (Landi *et al.*, 2011). There is considerable potential for the use of GIS technology as an aid to soil erosion inventory with reference to soil erosion modeling and erosion hazard assessment (Shinde *et al.*, 2011). Soil erosion is a natural process in which earth materials are entrained and transported across a given surface (Kouli *et al.*, 2009).

Analysis of such problems for the watershed under study was carried out using geospatial techniques coupled with Universal Soil Loss Equation (USLE) to understand soil erosion behavior. USLE allows the computation of the average annual soil loss and its spatial distribution in the watershed. USLE predicts soil loss for a given site as a product of six major erosion factors whose values at a particular location can be expressed numerically (Dabral *et al.*, 2008). Inventory of degree of soil erosion sensitivity was generated through LULC change based spatio-temporal inputs to USLE.

Thus, annual soil erosion rates and soil erosion potential as erosion severity classes of the watershed were determined. Soil and nutrient losses have also been identified as important factors controlling net primary productivity. Therefore, characterizing spatial variability and distribution of soil and nutrient loss in relation to the site conditions and other variables is critical for predicting the ecosystem processes (Mushtak *et al.,* 2005). Sustainable management of land and water resources warrants formulation of effective and appropriate erosion prevention measures, which in turn, rely on soil erosion rate (Kumar *et al.*, 2011).

2. MATERIALS AND METHODS

Study Area

Dumar Kocha watershed lies between 23º2'35″N to 23º26'10″N latitudes and 85º30'30″E to 85º36'38″E longitudes (Fig.1) in Angara administrative block of Ranchi district in Jharkhand state. This watershed covering an area of 48 square kilometers falls within the Subarnrekha river basin. Average temperature of the area varies from 21ºC to 38ºC and 10ºC to 24ºC during the summer and winter, respectively. The annual rainfall received in this area varies between 1100 to about 1400 mm. Ranchi district has

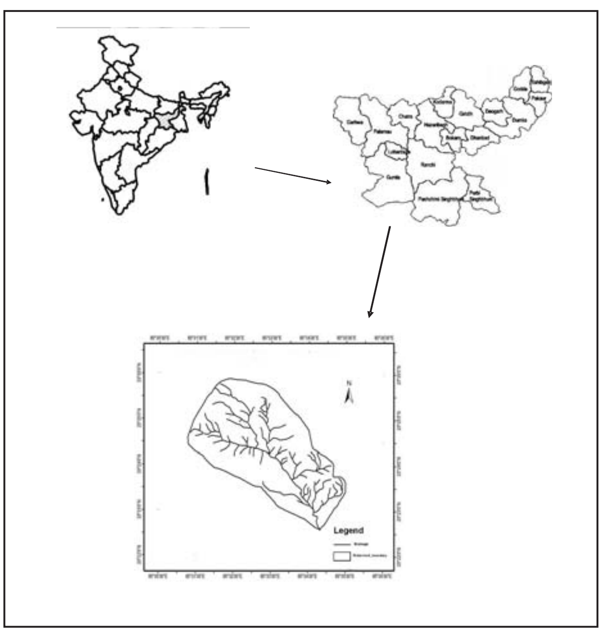

Fig. 1. (a) Location map of Dumar Kocha watershed in Ranchi district of Jharkhand

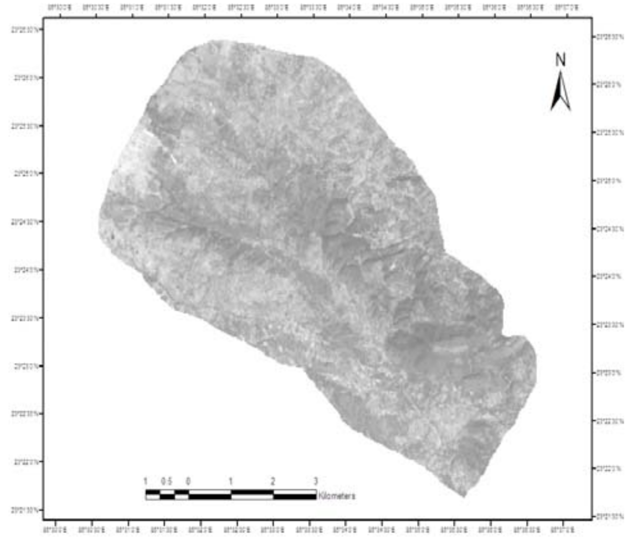

Fig. 1. (b) IRS 1C LISSIII False Color Composite (FCC showing the watershed area

presence of soil orders such as *Alfisols* as the dominant soils followed by *Inceptisols* and *Entisols* as per the inventories of National Bureau of Soil Survey and Land Use Planning (NBSS & LUP) and Birsa Agricutural University (BAU), Kanke, Ranchi.

Thematic Details

Survey of India topographic map no. 73E/11 of the watershed area on a scale of 1:50,000 was used for location details such as contours, drainage, ridgelines of the watershed for delineation and locations. Digital image processing of satellite data was performed using ERDAS Imagine software version 9.1. GIS based thematic layers were generated using ARC Info software version 9.1. Significant thematic layers include contour map, drainage map, landuse/land cover map and other relevant data sets of the study area. Indian Remote Sensing Satellite (IRS 1C) LISSIII digital data of the year 2004 with a spatial resolution of 23.5 m was used for assessment of land use/land cover (LULC) and corresponding normalised difference vegetation index (NDVI) parameters. Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) satellite data based digital elevation model (DEM) was generated and used for deriving topography related relevant details of the study area.

Soil Erosion Estimation Using Universal Soil Loss Equation (USLE)

Universal Soil Loss Equation (USLE) is an empirical method for soil erosion quantification considering different contributing factors (Wischmeier & Smith, 1978). This method provides long-term average annual soil loss using GIS (Khosrowpanah *et al.*, 2007). USLE model parameters were derived as follows:

$$A = R \times K \times LS \times C \times P \quad \text{..............} 1$$

Where, A = Mean annual soil loss; R = Rainfall erosivity factor; K = Soil erodibility factor; LS = Topographic factor; C = Crop management factor; and P = Conservation practice factor.

Rainfall Erosivity Factor (R)

Rainfall erosivity or the R factor represents the input that drives the sheet and rill erosion process, and differences in R values represent differences in erosivity of the climate. R factor quantifies the effect of rainfall impact and the rate of runoff likely to be associated with the precipitation events. It can be calculated for the Indian condition (Singh *et al.*, 1992; Solanki and Singh, 1996) by equation 2 as follows:

$$R=79+0.363r \qquad \text{......... 2}$$

Where, r is mean of annual rainfall amount in mm and R in MJ $ha^{-1}mm^{-1}yr^{-1}$.

Rainfall data recorded on monthly basis was used to work out the mean of annual rainfall for one of the representative years 2004 of the decade. This was further cross-checked with the rainfall records for the years 1990 1999 representing the previous decade. Rainfall data was obtained from the Department of Agricultural Physics and Meteorology, Birsa Agricultural University (BAU), Kanke for the rainfall stations in the vicinity of Ranchi area applicable to this watershed.

Soil Erodibility Factor (K)

K factor represents the soil susceptibility to erosion, the sediment transportability and the run-off quantity and rate (González, 2004). K factor is a measure of the inherent characterisctics of a given soil under the standard condition of the unit USLE plot maintained in continuous fallow. Values for K typically range from about 0.10 to 0.45 (t MJ-1mm-1) with high-sand and high-clay content soils having the lower values and high-silt content soils having the higher values. Because of a wide range, there may be possible effects on the erosion in varying degrees. Much attention is required to be given to the ground cover without considering the effects within the soil, such as those associated with root mass and tillage. For example, 30% cover after plantation is the criterion frequently used for conservation tillage. A 30% plantation cover reduces the soil loss by about 72%. K factor was calculated from the formula (Wischmeier & Smith. 1978):

$$100\,K = 2.1\,M^{1.14}\,(10^{-4})(12 - a)+3.25\,(b - 2) + 2.5\,(c - 3) \qquad \text{....3}$$

Where, M = (percent si + percent vfs) x (100 - percent clay); a = percent organic matter; b = soil-structure code used in soil classification; and c = profile-permeability class, si = silt and vfs = very fine sand.

Soil erodibility or the K factor for the study area was calculated from the NBSS & LUP soil map and information on the soil types obtained from the Department of Agricultural Physics and Meteorology, Birsa Agricultural University (BAU), Kanke, Ranchi. After adding the attribute of K factor, the shape file was converted into grid in the ARC GIS in its spatial analyst extension.

Slope Length and Steepness Factor (LS)

Slope length and steepness factor (LS) also known as topographic factor signifies the expected ratio of soil loss per unit area from a field slope to that from a 22.2 m (equivalent to 72.6 ft) length of uniform 9 percent slope under otherwise identical conditions. The modified topographic (LS) factor was determined using ASTER DEM whose spatial resolution was set to 20 m for this study. This resolution is near to the spatial resolution of IRS1C LISS III satellite data used for land use and land cover maps. LS factor was calculated using spatial analyst module of raster calculator in the ARC GIS using the modified formula in the raster form:

$$LS = \sqrt{L/22}(0.065+0.045*S+0.0065*s^2) \qquad \text{........ 5}$$

Where, L = slope length (m) fixed to 20 m; and S = slope steepness (radians).

With the incorporation of DEM into GIS, the slope gradient (S) and slope length (L) are determined accurately and combined to form the topographic factor LS. Map for LS factor was created from DEM along with calculation of a slope (grid radian) first for obtaining a value of LS in each pixel.

Cover and Management Factor (C)

The cover and management factor (C) was calculated from land use and land cover map of the study area generated from supervised classification of the satellite data using maximum likelihood classifier technique in ERDAS IMAGINE. NDVI was also used for better inferences of the land use and land cover classes coupled with ground truth validation. The accuracy assessment was carried out by GPS points collected during field observations. Such an accuracy assessment was carried out for better results. C factor was derived from already available experimental values given by USDA-SCS (1972) and Rao (1981). The values of C factor thus obtained are shown in Table 1.

Table:1
C and P factor values for different land use/land cover classes

Sl. No.	Land Use/Land Cover Classes	C factor value	P factor value
1.	Rural built-up	1.0	1.0
2.	Rocky/stony waste	1.0	1.0
3.	Crop land	0.28	1.0
4.	Fallow land	1.0	0.28
5.	Plantation	0.28	0.28
6.	Dense/open forest	0.004	1.0
7.	Degraded forest	0.008	1.0
8.	Scrub land	0.7	1.0
9.	Land without scrub	0.18	1.0
10.	Stream/water body	0	1.0

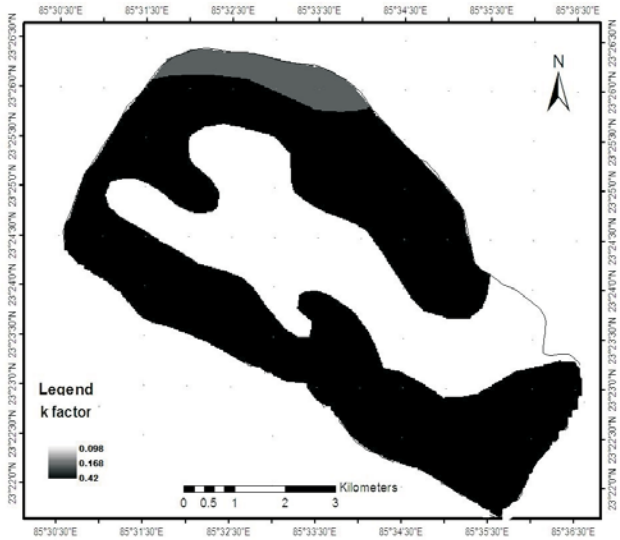

Fig. 2. GIS generated K factor map of the study area

Table:2
(a) Soil structure and
b) permeability classes and code assignments

Sl.No.	(a) Soil structure	Code
1.	Very fine	1
2.	Fine	2
3.	Medium	3
4.	Coarse	4
5.	Very coarse	5
6.	Gravelly	6
Sl.No.	(b) Soil permeability	Code
1.	Rapid	1
2	Rapid to moderate	2
3	Moderate	3
4	Moderate to slow	4
5	Slow	5
6	Very slow	6

(Classes after USDA, 1972)

Conservation Practice Factor (P)

Conservation practice factor (P) is considered as the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope cultivation. For this study area, conservation practice factor value varies from 0.28 to 1 (Table 1) as per the land use/land cover classes based on USDA-SCS (1972), Rao (1981) and Singh *et al.* (1992). Fallow land and plantations were assigned value of 0.28 whereas all other land use and land cover classes were assigned value of 1 for conservation practice factor as per the conservation practices associated with such classes.

3. RESULTS AND DISCUSSION

Based on the annual rainfall of 1200.3 mm recorded for the year 2004 as one of the representative years of the last decade was used for calculation of the rainfall erosivity factor. Thus, the calculated R factor value found was 514.70 MJ $ha^{-1}mm^{-1}yr^{-1}$ for the said year of reference for this study. Considering the soil structure and corresponding permeability classes after USDA, 1972 and their respective code assignments (Table 2), K Factor was determined for the study area. It ranged from 0.098 to 0.42 (t $MJ^{-1}mm^{-1}$) and is presented in Table 3 which shows the considered soil characteristics as well. Corresponding K factor spatial distribution map was generated through GIS for the study area (Fig. 2). Topographic factor (LS) could be determined from the ASTER DEM with suitable modifications considering slope length (L) = 20 m and the slope (S) grid in radians. In USLE, slope length was calculated as grid using raster calculator of ArcGIS 9.1 by the equation 4. LS was found to be within the value range of 0 to 7.38063 and thus, spatial distribution of this factor was derived (Fig. 3).

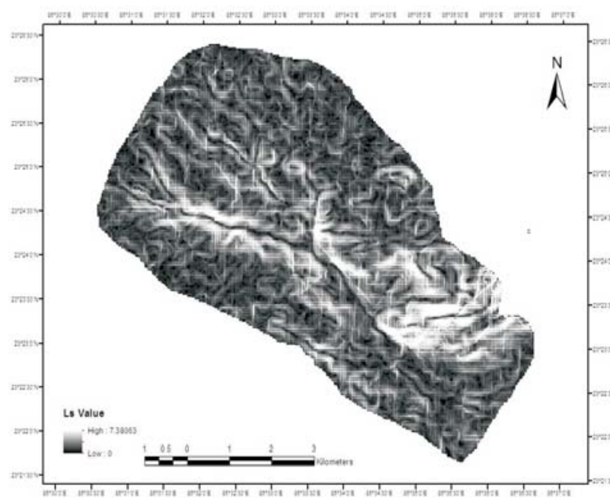

Fig. 3. LS factor map of the study area

Cover management factor (C) was computed based on land use and land cover classification by supervised classification. Land use/land cover was classified into different classes according to their spectral characteristics and image interpretation techniques (Dabral *et al.*, 2008). Land use/land cover map thus derived is shown in the Fig. 4 and the maximum likelihood classification report of the same is shown in Table 4. C factor for different land use/land cover classes was derived from already available experimental values and its interplotation in the raster form for spatial analysis. Thus, the C factor map was created for the watershed (Fig. 5). Conservation practice factor (P) depicts the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope cultivation. Simulating and visualising such practices in different land use and land cover, values of 0.28 and 1 respective classes were assigned (after Rao, 1981 and Singh *et al.,* 1992). The spatial interpolation map was prepared to represent P factor according to the values of land use/land cover conditions (Fig. 6).

Table:3
Soil series groups and erodibility parameters for USLE

Soil	*Organic Matter (a)	*Very fine sandy (%)	*Sand (%)	*Silt (%)	*Clay (%)	Soil Structure Code (b)	Profile permeability class (c)	Particle size (M)	K factor (tonMJ^{-1}mm^{-1})
Coarse loamy	0.30	7.56	43.28	42.13	14.59	2	2	2191.62	0.0986
Sandy loamy	0.04	43.2	62.18	24.45	13.37	5	1	2386.79	0.168
Sandy clay loam	0.34	5.24	61.79	12.98	25.23	2	2	2484.68	0.42

*Source: Birsa Agricultural University, Kanke, Ranchi

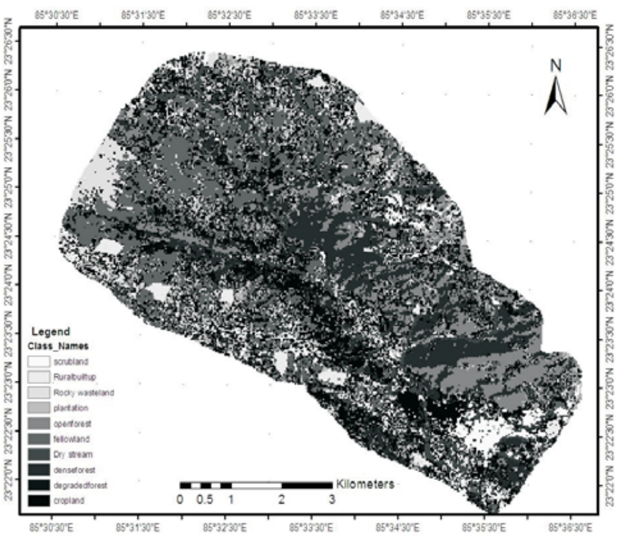

Fig. 4. Land use/land cover map of the study area

Table: 4
Land use/land cover of the watershed based on supervised maximum likelihood classification

S.No.	Land use/land cover	Area (sq km)	Area (%)
1.	Rural built-up	2.58	5.351
2.	Dense forest	5.23	10.848
3.	Open forest	4.31	8.94
4.	Degraded forest	6.43	13.337
5.	Scrub land	4.94	10.246
6.	Plantation	4.56	9.458
7.	Crop land	11.06	22.941
8.	Fallow land (current)	3.82	7.923
9.	Rocky/stony Waste	1.79	3.712
10.	Stream	3.49	7.239
	Total	48.21	100%

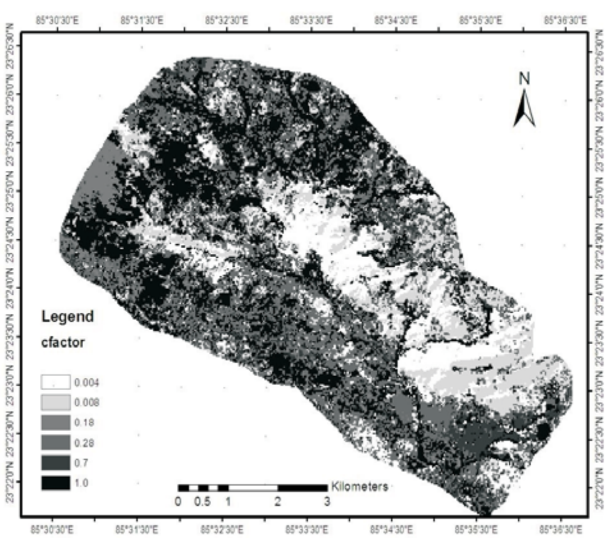

Fig. 5. C factor map of the study area

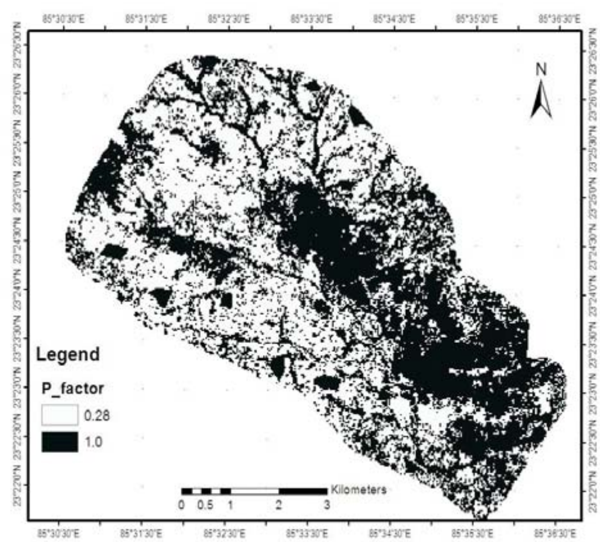

Fig. 6. P factor map of the study area

Table:5
Spatial extent of the areas under different soil erosion sensitivity classes

Sl. No.	Erosion range (t $ha^{-1}yr^{-1}$)	Erosion sensitivity classes	Area (sq km)	Area (%)
1	<5	Slight	32.54541	67.507
2	5-10	Moderate	5.98859	12.421
3	10-20	High	5.29407	10.981
4	20-40	Very high	1.84329	3.823
5	40-80	Severe	2.47991	5.143
6	>80	Very severe	0.05873	1.21
		Total	48.21	100

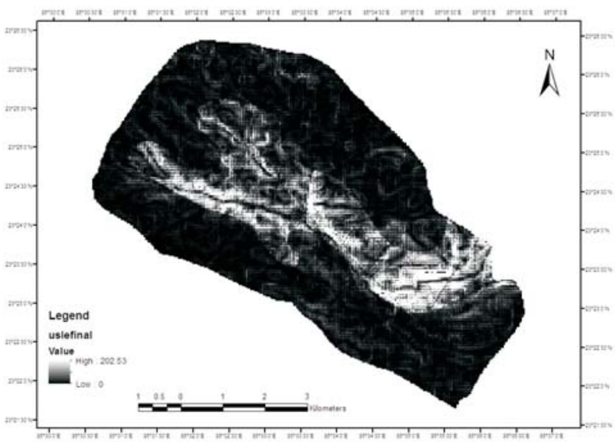

Fig. 7. Soil erosion map of the study area

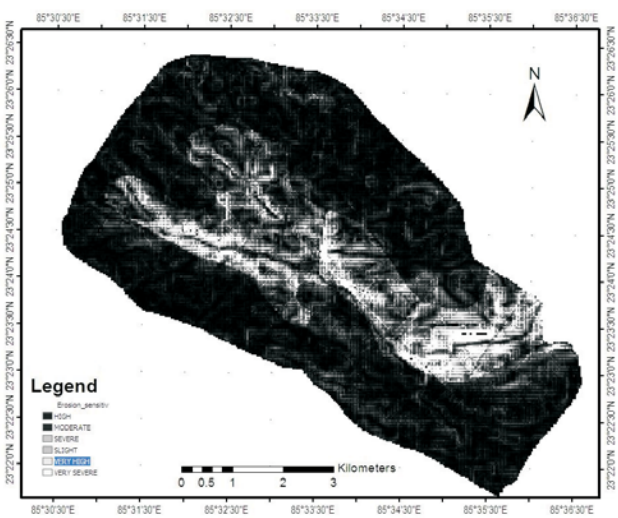

Fig. 8. Erosion sensitivity map of the study area

Estimated Annual Soil Erosion Rate (A)

Based on the derived values, five potential and actual soil erosion-controlling data layers R, K, LS, C and P were integrated within the raster calculator option of the ARC GIS Spatial Analyst. This led to the creation of soil loss map giving the annual soil loss rate per hectare which could be categorized into various zones giving rise to soil erosion sensitivity zone map of the area. The estimated average annual soil loss of the watershed is shown in Fig. 7. Use of USLE allowed the quantitative assessment of the average annual soil loss with a view to know the spatial distribution of erosion rate of the watershed. Using the quantitative details generated on the annual average erosion rate, an erosion sensitivity map was prepared for the watershed (Fig.8). This basically used the erosion sensitivity categorisation in terms of slight, moderate, high, very high, severe and very severe classes (Table 5). The average annual soil erosion rates for Dumar kocha watershed was found to be ranging from a minimum of <5 t $ha^{-1}yr^{-1}$ to >80 t $ha^{-1}yr^{-1}$. About 67.5% of the watershed area was found to be under slight to moderate erosion classes. Areas covered by moderate to high, very high, severe and very severe erosion potential zones were 12.421, 10.981, 3.823, 5.143 and 1.21% of the watershed, respectively.

4. CONCLUSIONS

Spatial variation of erosion severity of the Dumar kocha watershed in the Angara block of Ranchi district was worked upon and mapped using geospatial techniques. This took into account the behavior of different land use/land cover (LULC) classes with respect to erosion as well as other inherent biophysical factors of the watershed. Land use/land cover characteristics depend to a great extent on the local and regional climates as well as global climate change influences. Annual soil erosion rates within the watershed were determined using USLE. Spatial analysis indicated high soil erosion rate in the central portion of the watershed which can be attributed to the terrain modifications, inappropriate agricultural practices and forest degradation along with the combined effects of other biophysical factors. Creation of database through conventional methods is time consuming, tedious and difficult to handle. In this study, remote sensing and GIS were utilized generation of USLE factors. Since the areas that are vulnerable to water and soil loss could be demarcated using the potential soil erosion map, the outcome of the study can serve as a valuable resource for decision makers for better management. These results can also serve as significant information input to implement the water and soil conservation, management and land use planning.

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