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Assessing Vulnerability to Soil Erosion of a Watershed of Tons River Basin in Madhya Pradesh using Remote Sensing and GIS

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Abstract

Land and water are the two most valuable and vital resources essentially required not only for sustenance of life but also for the economic and social progress of a region. In India population pressure is increasing over the years which resulted in the scarcity of availability of land and water resources. Industrial expansion is also a need of the time, which requires infrastructural facilities; which intern forms a feed back resulting in further pressure on finite land and water resources. About 53 percent of the total area of India which is 172 m ha suffers from serious soil erosion and other forms of degradation. So, planning and management of land and water resources on a sustained basis without deterioration and with constant increase in productivity is the main stay in the mankind. Planning and management of natural resources requires hydrological data. In India, sediment yield data(hydrological data) are generally not collected for smaller watersheds and it becomes difficult to identify the most vulnerable area for erosion that can be treated on priority basis. In the present study remote sensing and GIS (Geographical Information System) technology were used to generate information regarding factors affecting soil erosion. These factors include soil type, vegetation, topography and various watershed properties such as drainage density, form factor etc. The present study is carried out in Kanhiya nala watershed of Gusuru river which is a tributary of Tons river basin in

Madhya Pradesh, India. The study area is divided into nine sub watersheds and different topology, vegetation, soil and morphology related indices are estimated separately for each sub watersheds. The integrated effect of all the parameter is evaluated to find different areas vulnerable to soil erosion. Two sub watersheds i.e. 1 and 8 were identified as very high susceptible to soil erosion.

Keywords: Vulnerability, Remote Sensing, Watershed, Soil erosion.

1. Introduction

Land and water resources are limited and their wide utilization is imperative, especially for countries like India, where the population pressure is increasingly continuous. Ironically, adequate emphasis has not been paid to conserve, develop and judiciously utilize these resources in many parts of the country. This is evident from the fact that 175 million ha of land in India constituting 53% of its total geographical area, suffers from such deleterious effects. It has been estimated that about 16.4 tones/ha of soil is detached annually in our country because of destruction (Singh, 2000).So, planning and managing of these natural resources in a sustainable manner have become an important issue, especially in land and water scarcity regions. The development of land and water resources on a sustainable basis without deterioration and with a constant increase in productivity is the mainstay of mankind. To overcome aforesaid conditions at the national level, an integrated watershed management considering crop production, soil and water conservation and management, reclamation of waste land and degraded lands is essential to increase overall efficiency of the watershed.

Sediment yield from a catchment is one of the main criteria for assessing the vulnerability of a watershed for soil erosion. However, this criterion requires continuous monitoring of sediment samples at the catchment outlet. Such data are hardly available in India for small watersheds. Although the sediment yield from large basins can be obtained from such observations, it is not possible to ascertain the vulnerability to soil erosion of small watersheds within a basin. Further, acquiring field data for generation of information on soil erosion has several inherent difficulties. Setting up discharge and sediment gauging station in a watershed to monitor spatial behavior is not practically feasible for number of reasons. A soil conservation program is an expensive and cumbersome process, carried out in steps starting from the most vulnerable (highest sediment producing) region. Therefore, there is a need to assign relative priorities to different region within a catchment.

The major factor responsible for soil erosion include rainfall, soil type, vegetation, topographic and morphological characteristics of the basin (Kothyari and Jain, 1997). Where there is a lack of data on rainfall, runoff and sediment yield the relative vulnerability of watersheds can be assessed with respect to time-independent factors (topography and morphology). With the advancement of remote sensing technique and data acquisition, it is now possible to generate and revise land use/land cover maps at the scale of even a few meters. The effect of land use and land cover can also be incorporated in such analysis. A geographic information system (GIS) is computer based system designed to store, process and analyze geo-referenced spatial data and their attributes. Using a GIS, the soil, topographic and morphometric analysis may be carried out efficiently and different layers of information can be integrated. Geographic information system (using traditional and remotely sensed data) have already proved to play a very important role in analyzing soil erosion and sediment yield, as evident from recent studies in the Indian Peninsula and other part of world (Jain and Kothiyari, 2000; Noorkaratnam, et al 2005, Kusre, et al 2010; Sharma et al 2013).

In the present study, digital analysis of remotely sensed data has been carried out to assess the land use land cover indices. Topographic, soil and morphometric indices have been generated in GIS using topographic information (contour and drainage) from Survey of India toposheets and soil information has been collected from National Bureau of Soil Survey and Land Use Planning (NBSSLUP). Finally, all the indices have been combined to prioritize different sub watersheds in the study area.

2. Materials and Method

2.1 Description of Study area

The study area Kanhiya nala watershed is a tributary of Gusuru river which lies within the Tons River catchment is situated between 80^0 31' 51.01" to 80^0 35’ 17.05 E longitude and 24^0 06' 29.23" to 24^0 11' 05.03" N latitude (Fig 1) with elevation range 480 to 620 m above Mean Sea Level (MSL) and extends a total area of 23.51 km^2. Kanhiya nala watershed situated in Satna District Madhya Pradesh, India.

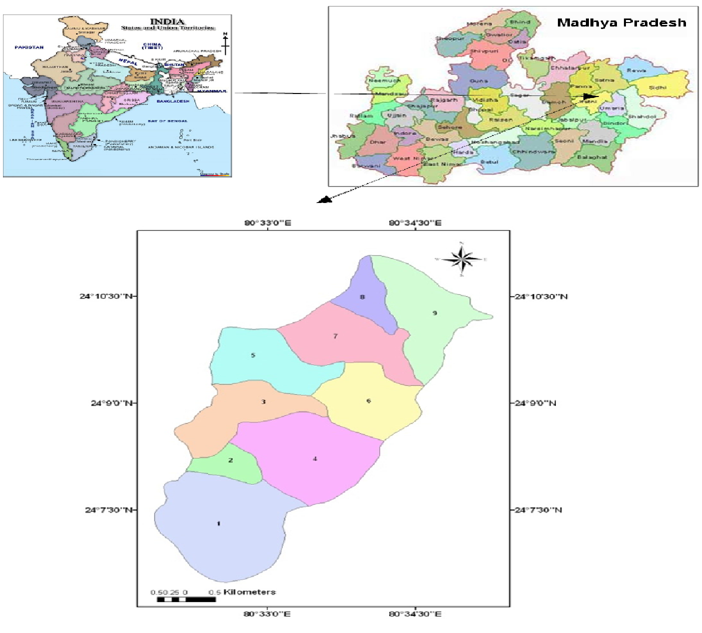

Figure 1: Location map of study area.

The study area belongs to Kymore Plateau and Satpura hills agroclimatic zone IV of M.P. which is earlier known as Rice-Wheat zones. It has a typical subtropical climate with hot dry summers and cool dry winters. Temperature extremes vary between the minimum of 4°C during December or January months to the maximum of 45°C in May or June. Average annual precipitation is 1100 mm, which is concentrated mostly between mid June to mid September with scattered winter rains during late December and January months.

2.2 Data used

Survey of India toposheets 63D/12 on 1:50000 scale was used for the preparation of base map, delineation of watershed and sub watersheds boundary, drainage and contour map. For preparation of land use/ land cover map remote sensing data of IRS-P6 (Resourcesat-I) sensor LISS III with spatial resolution of 23.5 m dated 25th October 2007 was used. For preparation of base map the toposheet was imported in EDRAS imagine 9.1 software. Further processing was done in Arc-GIS.

2.3 Assigning the Relative Vulnerability

In assessing the relative vulnerability of different sub watersheds to soil erosion, the major factors responsible for soil erosion was considered. The determination of the different factors is briefly discussed below.

2.3.1 Rainfall

The amount and intensity of rainfall affect the sediment yield from a basin. Rainfall is random metrological phenomenon. If a dense network of rain gauge stations and long-term rainfall data are available, then the effect of rainfall characteristics on soil erosion may be taken consideration. However, within small regions rainfall characteristics do not vary a large extent and can be assumed similar over a large time span.

2.3.2 Topography

One topographic feature that mostly influences the erosion process is the degree of slope. With the advent of GIS technique it is now possible to prepare the digital elevation model (DEM) of an area. Using the DEM, the elevation at each grid is calculated and this can be converted from raster to vector to get polygon map which gives the area under each contour i.e. area under the specified elevation and this information can be utilized for assessing the vulnerability to soil erosion.

2.3.3 Land use/ Land cover

Land use/ land cover have a major influence on soil erosion. Vegetation not only reduces the raindrop's capability to detach soil particles but also retard velocity of flowing water and significantly affects the erosion process. Land use/land cover map was generated with the help of IRS-P6 (Resourcesat-I) satellite data using unsupervised classification.

2.3.4 Soil

The physical properties of soil affect its infiltration capacity and the extent to which the soil can be detached, dispersed and transported. The properties which most influence erosion include soil structure and texture, organic matter content, moisture content, density (compactness), shear strength as well as chemical and biological characteristics (Sharma et al., 1990). To study the effect of soil condition in the watershed the soil erosion map prepared by NBSSLUP was used.

2.3.5 Morphology

The relationship between the morphology of streams and sediment yield has been considered important for many decades, especially when changes in morphology might somehow be linked to changes in sediment yield from the landscape. Important morphological characteristics of a watershed include drainage density, form factor, elongation ratio and circulatory ratio (Jain and Goel, 2002). Drainage density is defined as the quotient of the cumulative length of the streams to the total drainage area and is expressed in length per unit area (Choubey and Jain 1992). A higher drainage density represents a relative higher number of streams per unit area and thus a rapid storm response. It also represents conditions favorable for higher erosion from the catchment. The form factor is defined as the ratio of the basin area to the square of the basin length. The circulatory ratio is defined as the ratio between the area of the basin and the area of the circle having the same perimeter as that of the basin (Choubey and Jain, 1992). A higher circulatory ratio induces lesser erosion (Jain and Goel, 2002). The elongation ratio is the ratio between the diameter of circle having the same area (as that of basin) and the maximum length of the basin. A higher elongation ratio induces lesser erosion (Jain and Goel, 2002).

2.3.6 Relative Vulnerability of sub watersheds

To determine relative vulnerability of sub watersheds percent influence (weight) to each factor was given on its importance to the soil erosion. The four factors *viz.*, topographic information, land use/land cover, soil and morphology were considered to have equal influence in causing soil erosion (25 % each). In the study five point evaluation scales was considered to facilitate easy decision process. The area with minimum scale value was considered to be less prone to erosion and the sub watersheds with higher scale values were considered to be more prone to erosion. The weightage criteria indicate that the area within the watershed having (i) steeper slopes, (ii) lesser vegetation (iii) soil characteristics and (iv) morphometric parameters favoring erosion should be given higher priority for treatment measures.

3. Result and Discussion

First paragraph text. For assessing relative vulnerability of different sub watersheds considering three factors i.e. topographic information, land use/land cover and morphology, base map was prepared from toposheets and used to delineate the watershed and sub watersheds boundary. Fig 2 and 3 presents FCC (False Color

Composite) and drainage map of study area respectively. The drainage network was delineated from toposheets and then updated from satellite data. Contour map is shown in Fig 4 was used for further analysis. The generation and calculation of all factors used for assessing relative vulnerability is explained below.

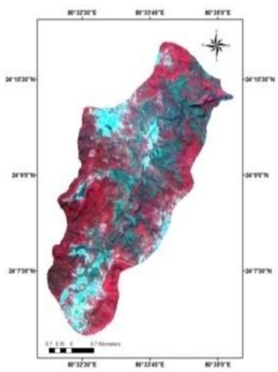

Fig. 2: FCC of study area

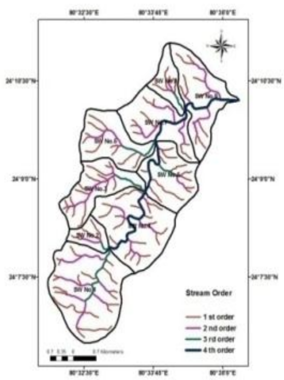

Fig. 3: Drainage map

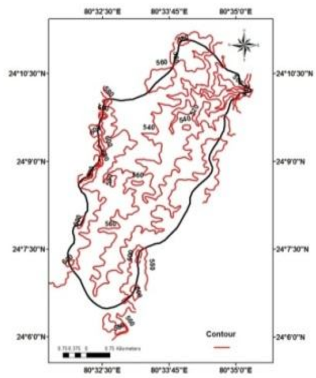

Fig. 4: Contour map

3.1 Topographic information

Topography map was prepared using digitized contour map which is used to prepare DEM (Fig 5). In the topographic map i.e. DEM, the map was classified based on their elevation ranges. The class with minimum elevation was given the minimum weightage as is expected to cause lesser erosion than the classes having higher elevation. The weightage were given on five point scales with one as areas with minimum erosion and five with maximum erosion.

In the present study, the elevation range varied from 480 to 620 m. The minimum weight 1 was given to the areas falling under elevation range 480 m to 526 m. The areas having elevation more than 579 m was assigned weight 5. The Table 1 shows the weightage given to each class and the area under each elevation class.

Table 1: Weights given to various elevation classes.

Elevation	**Weights**	**Area under each class (Km^2)**
480-526	1	0.82
526-549	2	2.28
549-565	3	14.82
565-579	4	4.96
579-620	5	0.63

In each sub watershed percentage area falling under erosion class 5 (highest erosion proneness class) was taken to determine vulnerability scale (Table 2).

Table 2: Sub watershed wise vulnerability scale based on elevation.

Sub watershed	Area of Sub watershed (Km^2)	Area under erosion class					Percentage of area falling under erosion class 5	Vulnerability Scale
		1	2	3	4	5		
SW 1	4.98			2.11	2.54	0.33	6.63	4
SW 2	0.78			0.30	0.47	0.01	1.03	2
SW 3	2.33			1.11	1.05	0.17	7.28	5
SW 4	3.95			3.59	0.37	0	0	1
SW 5	2.44		0.10	1.87	0.37	0.10	4.25	3
SW 6	2.44		0.21	2.23	0	0	0	1
SW 7	2.68		0.99	1.69	0	0	0	1
SW 8	0.99		0.14	0.75	0.11	0	0	1
SW 9	2.91	0.82	0.82	0.15	0.11	0	0	1

3.2 Land use/ land cover map

Land use/land cover obtained in the watershed (Fig 6) were water bodies (0.15 km^2), forest (20.31 km^2), fallow (1.42 km^2), and agriculture (1.62 km^2). The water bodies were given least weightage i.e. 2 as it always available at lower elevation. Agriculture land is more prone to erosion as more and more agricultural activities exposes the soil every time so due to rain action and rolling topography causes more erosion and considered highly erosion potential with an assigned weightage of 5. The weightage allotted to remaining land use classes are provided in Table 3 along with the area coverage under each class.

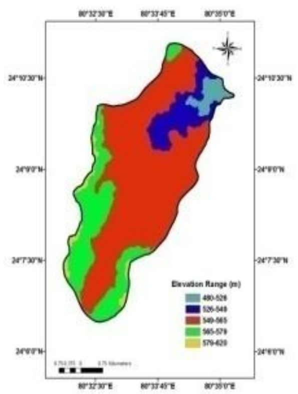

Figure 5: DEM of Study area

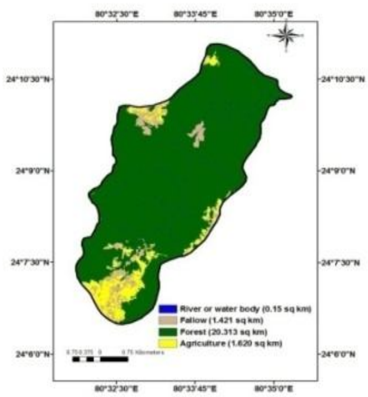

Figure 6: Land use / land cover map

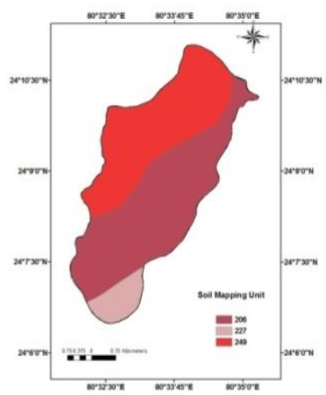

Figure 7: Soil map

Table 3: Weights given to various land use classes.

Type of land use	Weights	Area under each class (Km^2)
River or water body	2	0.15
Evergreen forest	3	20.31
Fallow land	4	1.42
Agriculture	5	1.62

In each sub watershed percentage area falling under erosion class 5 (highest erosion proneness class) was taken to determine vulnerability scale (Table 4).

Table 4: Sub watershed wise vulnerability scale based on Land use/land cover.

Sub watershed	Area of sub watershed (Km^2)	Area under erosion class					Percentage of area falling under erosion class 5	Vulnerability scale
		1	2	3	4	5		
SW 1	4.98		0.03	3.07	0.74	1.13	22.86	5
SW 2	0.78		0.01	0.77	0.01	0.01	0.12	1
SW 3	2.33		0.01	2.32	0.00	0.001	0.04	1
SW 4	3.95		0.02	3.62	0.11	0.20	5.23	3
SW 5	2.44		0.01	1.99	0.33	0.11	4.28	2
SW 6	2.44		0.02	2.35	0.05	0.02	0.98	1
SW 7	2.68		0.02	2.43	0.16	0.06	2.28	2
SW 8	0.99		0.01	0.89	0.02	0.07	6.81	4
SW 9	2.91		0.02	2.88	0.01	0.02	0.10	1

3.3 Soil

The soil map was obtained from the National Bureau of Soil Survey and Land Use Planning (NBSSLUP) presented in Fig 7. In the soil map the various soil types were mapped based on their characteristics. There are three soil series falling in the study area. The description of those is given as follows.

SMU 227- Slightly deep, well drained, loamy soil on gently sloping foot hill slopes with lower pediment with moderate erosion and slightly stony

SMU 249- Slightly deep, well drained, loamy soil on moderate slope, moderately sloping undulating plateau with severe erosion.

SMU 206- Shallow depth, well drained loamy soil on steeply sloping hills with escarpments, very severe erosion, moderately stony

These soils are also classified into categories as (i) moderate erosion (ii) severe erosion (iii) very severe erosion with assigned weightages of 3, 4 and 5 respectively. The details of categorization are provided in Table 5.

Table 5: Weights given to various Soil classes.

Mapping unit	Weights	Area under each class (Km^2)
SMU 227	3	1.59
SMU 249	4	9.88
SMU 206	5	12.04

(SMU refers to Soil Mapping Unit as indicated by NBSSLUP)

In each sub watershed percentage area falling under erosion class 5 (highest erosion proneness class) was taken to determine vulnerability scale (Table 6).

Table 6: Sub watershed wise vulnerability scale based on Soil.

Sub watershed	Area of sub watershed (Km^2)	Area under erosion class					Percentage of area falling under erosion class 5	Vulnerability Scale
		1	2	3	4	5		
SW 1	4.98			1.59		3.38	68.05	3
SW 2	0.78				0.04	0.73	94.81	4
SW 3	2.33				2.03	0.30	12.85	1
SW 4	3.95				0.26	3.70	93.50	4
SW 5	2.44				2.39	0.05	0.12	1
SW 6	2.44				0.08	2.36	96.72	4
SW 7	2.68				2.32	0.35	13.09	1
SW 8	0.99					0.99	100	5
SW 9	2.91				1.78	1.14	39.08	2

3.4 Estimation of Morphological parameters

For the estimation of morphological parameters, Survey of India toposheets was used. The drainage network was derived from the toposheets. All the maps were digitized and different thematic layers were generated for the contours and drainage pattern. The Strahler system (Strahler, 1964) was used for stream ordering. After networking, the lengths of streams of each order were evaluated separately for each sub watershed. Using this GIS database, the physical characteristics of the sub watersheds, such as drainage density (D_d), form factor (R_f), circulatory (R_c) ratio and elongation ratio (R_e) were estimated (Table 7).

Table 7: Estimated Morphological parameters.

Sub watersheds	D_d	R_f	R_c	R_e
SW 1	3.076	0.619	0.780	0.888
SW 2	3.725	0.442	0.671	0.750
SW 3	3.904	0.264	0.476	0.580
SW 4	3.169	0.720	0.800	0.958

SW 5	2.943	0.361	0.600	0.678
SW 6	3.493	0.544	0.749	0.833
SW 7	2.853	0.474	0.522	0.777
SW 8	3.190	0.262	0.484	0.578
SW 9	3.117	0.383	0.458	0.698

Based on the length of different order streams, drainage density was calculated for each sub watershed separately and among those sub watersheds relative vulnerability was determined. Further the highest rank value given to the sub watershed which has highest drainage density among the all comparison. The higher the drainage density, the higher will be the vulnerability to erosion and, hence, the greater the weight. Form factor, circulatory ratio and elongation ratio were calculated similarly for each sub watershed and highest rank value given to the sub watershed which has lowest value of these factors, among all comparison. Higher value of the form factor circulatory ratio and elongation ratio induces lesser erosion and higher values in these cases was assigned less weight.

The different weights obtained for each morphological parameter were averaged out and again divided into different classes (Table 8). Thus, a single weight was assigned for all the morphological parameters taken together. Weights were assigned to each range of average weight, assuming that higher morphological weight induces higher erosion.

Table 8: Weights to Morphological parameters.

Sub watersheds	**D_d**	**R_f**	**R_c**	**R_e**	**Average weight**	**Vulnerability scale**
SW 1	3	2	2	2	2.25	1
SW 2	8	5	4	5	5.50	3
SW 3	9	8	8	8	8.25	5
SW 4	5	1	1	1	2.0	1
SW 5	2	7	5	7	5.25	3
SW 6	7	3	3	3	4.0	2
SW 7	1	4	6	4	3.75	2
SW 8	6	9	7	9	7.75	5
SW 9	4	6	9	6	6.25	4

3.5 Relative Vulnerability of sub watersheds

To account for the integrated effects of all the four parameters considered in this study, the individual vulnerability scale of all the parameters were added together. Sub watershed with higher final vulnerability scale was considered to be most vulnerable to soil erosion. Thus, a sub watershed with a priority code 1 is highly vulnerable to soil erosion and must be given the highest priority for the purpose of basin treatment and for the adoption of soil conservation measures. Table 9 presents the relative prioritization status of the sub watersheds.

Table 9: Priority code derived for all the sub watersheds.

Sub watershed	Vulnerability scale				Sum of Vulnerability scale	Priority code
	Topography	Land use/land cover	Soil	Morphology		
SW 1	4	5	3	1	13	1
SW 2	2	1	4	3	10	3
SW 3	5	1	1	5	12	2
SW 4	1	3	4	1	9	3
SW 5	3	2	1	3	8	4
SW 6	1	1	4	2	8	4
SW 7	1	1	1	2	5	4
SW 8	1	2	5	5	13	1
SW 9	1	4	2	4	11	2

Table 10: Range of accumulated weights and the corresponding priority code.

Range of accumulated weights	Vulnerability	Code
> 12	Very High	1
11-12	High	2
9-10	Medium	3
< 9	Low	4

4. Conclusions

Investigation of basin with a view to planning soil conservation measures is an important aspect of basin management. Sediment yield data are generally not collected for smaller sub watersheds and it becomes difficult to identify the areas most vulnerable to erosion that should be treated on the basis of priority. An index based approach is suggested using the surface factors mostly responsible for soil erosion i.e. soil, topography, land use/land cover and various catchment properties such as drainage density, form factor, etc. With the advent of remote sensing data and GIS capabilities, it has become convenient to calculate indices for different basins such that their relative vulnerability to soil erosion can be as assessed.

A case study is presented of vulnerability assessment for the Kanhiya nala watershed lying in Tons river basin in Satna district of Madhya Pradesh, India. Sub watersheds with different soil erosion potential have been assessed with a view to adopting soil conservation measures. Sub watersheds 1 and 8 were classified as very high priority form the point of view of soil conservation. Similarly, sub watersheds 3 and 9 were classified as high priority. The major factors that contribute to soil erosion potential in these sub watersheds were analyzed. For the very high priority sub watersheds, it can be seen that all the factors apart from morphology in sub watershed 1 and soil and topography in sub watershed 8 are the dominant factors for soil erosion.

Of the High priority sub watersheds, sub watershed 3 is affected by all the factors except soil and land use/land cover, while morphology and land use/land cover plays dominant role in sub watershed 9. Therefore, if some conservation measures have been adopted in the catchment, or land-use practices have undergone some change, their impact on soil erosion may be analyzed using remote sensing technique.

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