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Research Paper

Estimation of Soil Loss from Watershed for Identifying High Risk Erosion Zones Using GIS

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ABSTRACT

Soil loss from watersheds significantly influences the fertility soils and natural environment and hence it is a serious concern across the globe. Soil conservation is the top priority in watershed management though it is impractical to completely control soil erosion from all parts of watershed and hence achieve soil conservation. As controlling soil erosion in watersheds at micro level is difficult, broad measures which are economical and feasible are recommended for soil conservation. In order to plan suitable conservation techniques, it is essential to prioritize watersheds based on vulnerability to soil erosion. For identifying suitable soil conservation methods, it is necessary to consider critical erosion zones, threats to lives and property, socio-economic constraints and local challenges. Assessment of soil erosion is very important for arriving at the prioritization of watersheds for soil conservation. This paper reports the findings of the study carried out on Janagoan Mandal in Warangal District with hell of GIS techniques. Estimation of soil loss from the watershed is estimated using Universal Soil Loss Equation (USLE). Using the data available with various agencies, average annual erosion is estimated by developing GIS maps for six major watershed parameters. The watershed has been divided into sub watersheds and prioritization study is carried out considering factors that influence soil erosion. Using GIS tool and Universal Soil Loss Equation (USLE), the soil loss from the watershed is estimated and high risk zones are demarked. Soil loss from 80% of the watershed area is in the range of 0 - 200 tons/ha/year, while the high risk zones of erosion are about 12% of the area. Watershed management practices are recommended to reduce the soil loss from the high risk zones.

Keywords : Soil erosion; Watershed; high risk erosion zones; USLE, GIS, Soil erodibility factor, Soil conservation factor.

INTRODUCTION

Watershed management essentially focuses on conservation of soil and water with a broader goal of conservation of natural resources. Since historic times, soil conservation is most critical task in watershed management. The effects of soil erosion are of major concern in developing countries, as agriculture exceedingly depends on inherent land properties and famers are not very successful in improving soil fertility by other methods. Uncontrolled soil erosion can result in reduction in crop yield or unproductive zones in watersheds. Literature reports, about 175 mha of land in India, contributing to 53% of its total geographical area is prone to soil erosion and other forms of land degradation. Erosion by wind and water contributes to 150 mha of land amounting to soil loss of 5,300 million tons per year. About 25 mha land is subjected to degradation by shifting cultivation, salinity, alkalinity, water logging, etc. Per capita arable land in India, which is around 0.17 ha in 1995 (Sebastian et al., 1995) reduced to 0.118 ha in

2016 (World Bank Development Indicators, 2016) and is expected to decrease to 0.09 ha by the year 2075 (Sebastian et al., 1995). To conserve the natural resources from the above threats, watershed management is practiced.

Land and water management plans should essentially focus on soil and water conservation techniques on watershed basis (Biswas and Desai, 2002). Soil loss and sediment yield from catchments is estimated by using Universal Soil Loss Equation (USLE), the Modified Universal Soil Loss Equation (MUSLE), or the Revised Universal Soil Loss Equation (RUSLE) (Jimmy and Herald, 1972; Umesh and Jain, 1997). Watersheds are to be regularly monitored, for planning judicious use and management of resources. For this comprehensive exercise of watershed management, remote sensing and GIS techniques are popularly used (Krishna et al., 1996; Solanke and Srivastava, 2005). For estimation of soil erosion in catchments, data integration is effectively carried out by GIS (Jain and Kothari, 2000). Watershed management in tropical regions is very important to improve the productivity of the soil and hence, socio-economic development in the watersheds. The watershed under study receives rainfall only in the monsoon season and is subjected to significant soil erosion and reduction in crop yields. The present study attempts to create GIS database of the watershed under study and use the same for prioritizing the sub watersheds considering the Morphometric parameters, soil loss, and runoff potential.

MATERIALS AND METHODS

The watershed considered for the study reported in this paper is located in the Jangaon mandal of Warangal district, Telangana state, India. The watershed is geographically located between North latitude 17 º 45' and 17º 55', East longitude 79º 5' and 79º 15'. The survey of India topo sheet 56 O/1 covers the entire area of the watershed which is about 6430 ha. The villages included in the watershed are Maddur, Kannaboinagudem, Venkriyala, Ashwaraopalle, and Hanmantapur. Topography of the watershed varies from almost flat terrain to steep hills. The average annual rainfall of this area is in the range of 700 - 850 mm. Almost 80% of this rainfall occurs during the months of June to October and is highly uneven both temporally and aerially. The temperature is highly variable depending on the seasons. The maximum temperature is about 40 - 45º C during the month of May, while the minimum temperature is 10-12º C during the month of December. The open pan evaporation is 20-40% of total rainfall during the summer. Wind velocity varies in the range of 20 to 30 km/hr. The soils of the watershed are formed through pedogenic process or transported soils.

A Standard False Colour Composite (FCC) of IRS –P6 LISS III data acquired on October 16, 2014 is used for land use/land cover mapping. Topographical Map no 56 0/1 of 1: 50000 scale is used as base map for geo-referencing and digitize contours. Rainfall data is obtained from Planning Commission Office, Warangal. Pedological data is obtained from Agriculture and Soil Department, Warangal. ARC GIS 9 Version 9.1 from the Environmental Systems Research Institute (ERSI), Redlands, CA, USA is used for creation of the GIS database of the watershed. In GIS both spatial and non-spatial data source can be integrated and a set of spatially registered data layers can be analyzed independently or in combination. The thematic maps required for the prioritization studies and soil erosion estimation are prepared by using GIS. Data inputting was done using ARC GIS software. The toposheets are scanned and all tics (tic is a registration or geographic control point for coverage) to be used as critical points are marked before scanning. Using the above vectorized output files are created. Vectorized files are used for generating topology and checked to reduce errors. Different layers are created and ids are created for various features. Digitized maps are created and suitable labeling is done.

The Universal Soil Loss Equation (USLE) estimates mean annual erosion from watersheds considering factors like rainfall, soil type, topography, crop and management practices (Chow, 1964). The USLE is also used for comparison of soil loss from similar fields with specific crop ad management systems to "tolerable soil loss" rates. Five factors, Rainfall and runoff factor (R), soil erodibility factor (K), steepness of field slope (S), length of slope (L), soil cover and management practice factor (C) and supporting conservation practice factor (P) are used to estimate soil loss from a field under consideration. The above factors are estimates of the specific condition that influences the extent of soil erosion. The form of the equation is

$$A = R \times K \times LS \times C \times P \tag{1.0}$$

where, A is the computed soil loss per unit area over a specified time it is usually expressed as tons/ha/year; **R** is rainfall and runoff factor by geographic location; **K** is soil erodibility factor; **S** is steepness of field slope; **L** is length of slope; **C** is soil cover and management practice factor; P is supporting conservation practice factor.

RESULTS AND DISCUSSION

The Universal Soil Loss Equation (USLE) (Bera, 2017) is used to estimate the soil loss from the watershed considered for the study. The model parameters for the watershed are estimated and GIS data base is created. USLE given in Eqn. (1) computes the annual average soil loss from the catchment.

Rainfall Erossivity Factor (R)

Soil loss greatly depends on the rainfall and the detachment power of the raindrops hitting the soil surface. Soil particles, thus detached are carried in the runoff. Erossivity factor is a statistical value calculated from annual rainfall using Eqn, (2) (Roose, 1975). Erossivity factor for the watershed for different years is presented in Table 1. The R value varies from 339.42 to 762.66 and the mean value is 450.

(2)

Table 1. Rainfall Erossivity Factor (R)

Year	R Value	Year	R Value
1990 - 91	614.67	1999 – 00	468.91
1991 – 92	393.43	2000 – 01	358.64
1992 – 93	367.29	2001 – 02	360.78
1993 – 94	391.07	2002 – 03	339.42
1994 – 95	475.31	2003 – 04	378.20
1995 – 96	363.08	2004 – 05	569.34
1996 – 97	403.32	2005 - 06	762.66
1998 - 99	468.06	2006 - 07	471.27

Soil Erodibility Factor (K)

Soil Erodibility Factor (K) quantifies the vulnerability of soil particles to detachment from land surface and flow with runoff during rainfall. Soil texture predominantly influences the K value but the other factors like structure, organic matter and permeability of soil also contribute little. Thus K value is soil loss (tons/acre/unit area) for specific soil in cultivated, continuous fallow with specific slope length of 72.6 ft and slope of 9%. Typical values of K for different types of soils if given in Table 2.

The soil map of Jangaon Mandal at a scale of 1:50000 is used to determine the K factor. K factor is dependent on the predominant soil type, soil texture, organic matter etc. These parameters are obtained from the soil description provided by the Department of Agriculture. A shape file for soil map is created and the map is digitized. The soil type is added as attribute to the vector file and based on the soil type K factor is assigned as another attribute. The values of K factor can be found from Table 2. Now the vector file is converted into raster and a map representing the K factors in the watershed is generated. The common soils found in the area under study are fine loamy soil and coarse loamy soil. The K factor map is given in Fig. 1.

Table 2 Typical values of Soil Erodibility Factor (K)

Textural Class	Average	< 2%	> 2%
Clay	0.22	0.24	0.21
Clay Loam	0.30	0.33	0.28
Coarse Sandy Loam	0.07	-	0.07
Fine Sand	0.08	0.09	0.06
Fine Sandy Loam	0.18	0.22	0.17
Heavy Clay	0.17	0.19	0.15
Loam	0.30	0.34	0.26
Loamy Fine Sand	0.11	0.15	0.09
Loamy Sand	0.04	0.05	0.04
Loamy Very Fine Sand	0.39	0.44	0.25
Sand	0.02	0.03	0.01
Sandy Clay Loam	0.20	-	0.20
Sandy Loam	0.13	0.14	0.12
Silt Loam	0.38	0.41	0.37
Silty Clay	0.26	0.27	0.26
Silty Clay Loam	0.32	0.35	0.30
Very Fine Sand	0.43	0.46	0.37
Very Fine Sandy Loam	0.35	0.41	0.33

Slope Length Steepness Factor (LS)

Slope length, L and steepness, S are parameters that influence the soil loss in the catchment. LS factor is combination of both the above parameters. The ratio of soil loss under specific field conditions and the standard slope length of 72.6 ft and slope of 9% is LS factor. LS factor is determined using Eqn. 3 (Tirkey et al., 2013). Steep slope results in higher erosion and flat slopes reduce erosion and hence soil loss from the area under consideration.

$$LS = (Flow\ accumulation \times (Cell\ size / 22.13)^{0.40} \times (sin\ slope / 0.0896)^{1.3} \tag{3}$$

where, flow accumulation is the number of cells contributing to flow into a given cell and cell size is the size of the cells being used in the grid based representation of the landscape. For a given area the slope gradient and length of the slope factors are dependent on the slope of the area. As the slope becomes steeper the runoff velocities increase resulting in high risk of erosion. Also, longer slopes drain larger areas increasing the runoff quantity and hence higher erosion. Erosion potential of specific area depends on lope and length of the slope.

To determine the LS factor, the slope map (Fig. 4) of the study area is prepared. Digital Elevation Model (DEM) (Fig. 3) is used for arriving at the slope map of the watershed. DEM is also used for preparation of Contour map (Fig. 2) of the watershed. Using the spatial analysis tool, slope map is generated giving DEM as input. From the DEM the flow direction and accumulation maps are generated. Using the slope map and flow accumulation maps the LS factor is determined using the Eqn. 3. The contour map, the DEM, the slope map and LS map of the watershed are shown in Fig. 2 to 5 respectively.

Cover Management Factor (C)

C is the vegetative cover and management factor which is the ratio of soil loss from cropped land to the corresponding clean - tilled land. Cover management factor is the ratio of soil loss from field plot with a prescribed crop and management system to soil loss from continuously fallow and tilled field plot. C factor is determined by identifying the type of crop and the tillage method adopted in the field. The C factor is assigned to the whole of the watershed by giving C factor values to each type of land use/land cover. Generally, the C factor ranges between 1 (no cover effect) and 0.001 (very strong cover effect resulting in no erosion) (Wang and Jiao, 1996). Typical values of C for different land uses are given in Table 3. The land use map of the watershed is prepared. Based on the land use/land cover the C factor is determined from the Table 3 and is assigned as an attribute to the land use shape file. After assigning C factor values, C factor is generated. The land use map of the watershed is shown in Fig. 6. The C factor map prepared for the watershed is in Fig. 7.

Table 3 Typical values of Cover Management Factor

Land use	C factor
Agriculture land	0.377
Open scrub	0.014
Barren land	0.8
Meadow	0.11
Dense forest	0.003
Moderately dense forest	0.005

The Conservation Factor (P)

The conservation factor (P) depends on the erosion management practices adopted in the specific plot. Depending on the soil management practices adopted in the field. The conservation factor ranges between 0 and 1. Soil management activities are influenced by slope. Wischmeier and Smith (1978) considered only two land uses (agricultural land and other land) in their study and arrived at P value. However, the agricultural land can be sub-divided in to six classes based on the slope percent to assign different P-value. In the present study, as conservation practices are not implemented, P factor is adopted as 1.

Preparation of Erosion Map

After compiling the watershed parameters in GIS layers, the parameters are used as input parameters in USLE equation for estimation of soil loss from watershed. The maps of K factor, C factor, and LS factor are integrated to generate a composite map. The K factor map, C factor map are converted into raster form. The raster calculator is used to calculate the soil erosion rate. The factors R, K, LS and C are multiplied to estimate the soil loss. Using GIS, the soil erosion in each pixel is identified. The erosion intensity map of the watershed is represented in Fig. 8. The annual average soil loss in the area is estimated to be 185 tons/ha/year. For want of physical estimates, the results obtained in the study could not be verified. However, low erosion rates were observed in areas with mild slopes indicating the correctness of the soil loss estimation. Also areas with grass on the slopes also resulted in less erosion. The watershed is divided into five zones with varying rate of soil erosion and the area coming under each zone is represented in Table 4.

From Table 4 and Fig. 8, it is perceived that majority of the watershed area is in the erosion zone of 0 – 200 tons/ha/year. Nearly 80 % of the watershed comes is in this zone. There are some areas where erosion intensity is very high. About 6.5 % of the area falls in the high erosion zone of 2501-5000 tons/ha/year and 31% falls in erosion zone 1001 - 2500. In watershed management proposals this high erosion zones has to be given special attention for control of soil erosion.

CONCLUSIONS

The use of GIS data for estimation of soil loss by USLE is demonstrated in this paper. The soil loss in the study area is estimated as 185 tons/ha/year. The erosion is in the range or 0 - 200 kg/ha/year is most parts of the watershed. However, soil loss is estimated from the other areas of the watershed. The land areas in Class 4 and 5 are high risk zones are highly prone to erosion and hence are subjected soil degradation. Demarcation of the watershed into high risk zones helps in planning watershed management activities and deciding the priority in which the plans are to be implemented. Suitable erosion mitigation measures are to be planned in the different zones and the impact of the adopted methods on reducing the soil loss needs to be monitored. Based on prioritization, watershed management activities can be proposed. Remote sensing and GIS in combination with USLE, can be effectively used as appropriate tool for watershed studies.

Table 4 Soil loss in the study area

Class	Rate (tons/ha/year)	Area (ha)	% of area	Soil Loss (tons/ha/year)	% of Soil Loss
1	0 - 200	5171.03	80.45	81.929	45.02
2	201 - 500	183.00	2.85	6.444	3.541
3	501 - 1000	274.00	4.26	24.658	13.55
4	1001 - 2500	379.00	5.89	56.298	30.93
5	2501 - 5000	420.00	6.53	12.641	6.947
	Total	6427.03	100	181.97	100

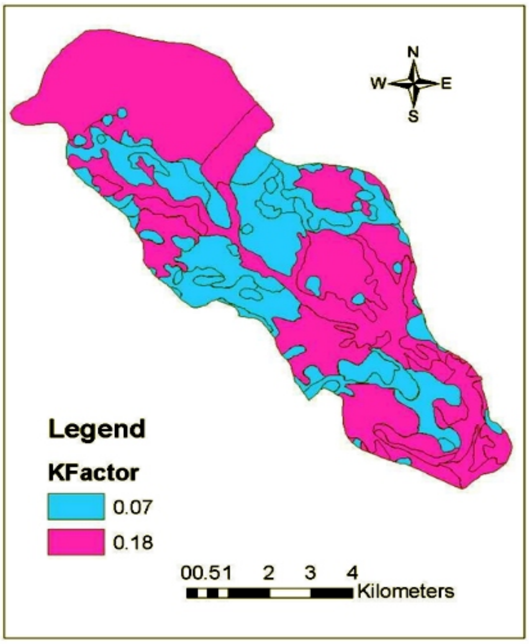

Fig. 1 K factor map

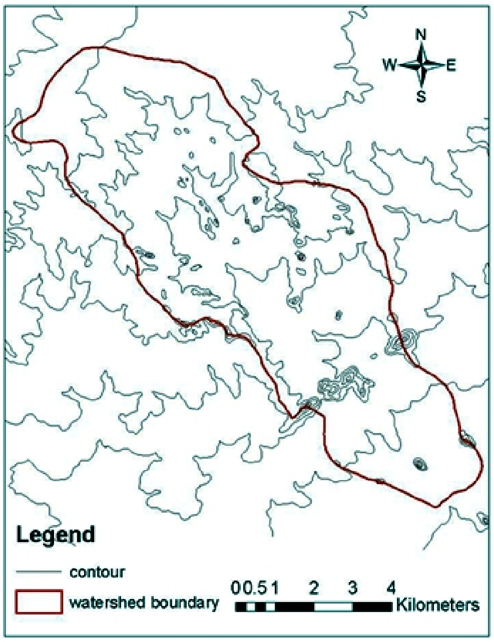

Fig. 2 Contour map

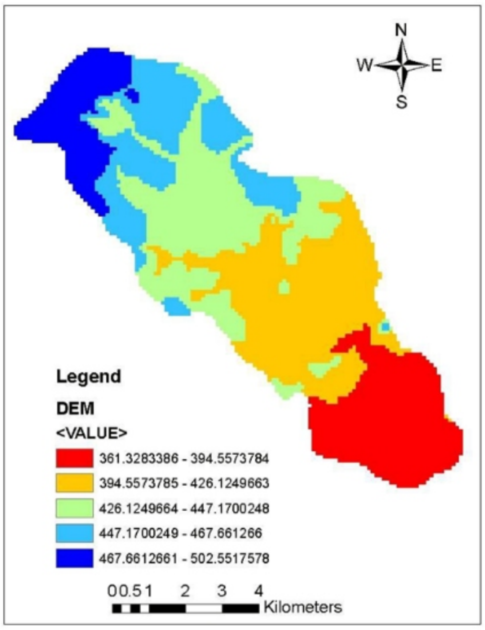

Fig. 3. Digital elevation model

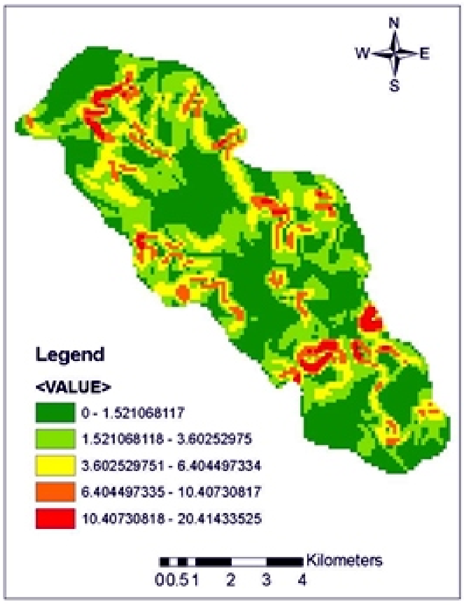

Fig. 4. Slope map

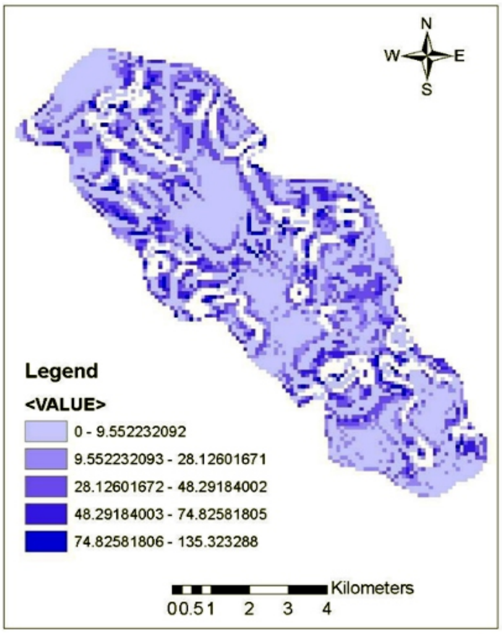

Fig. 5 Slope length steepness factor map

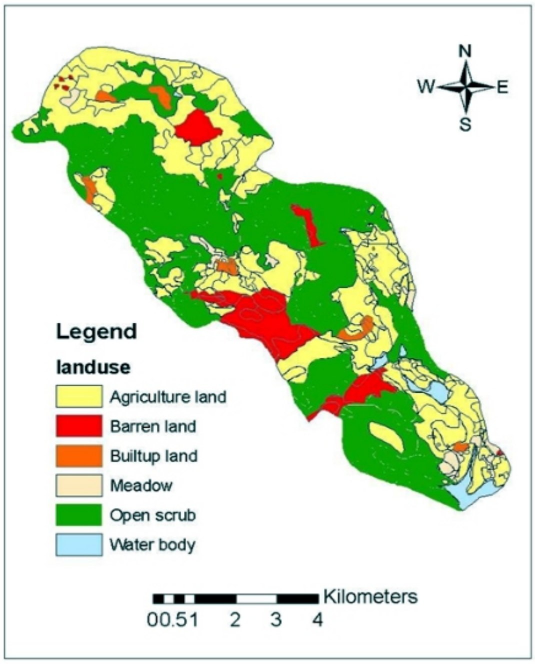

Fig. 6 Land use land cover map

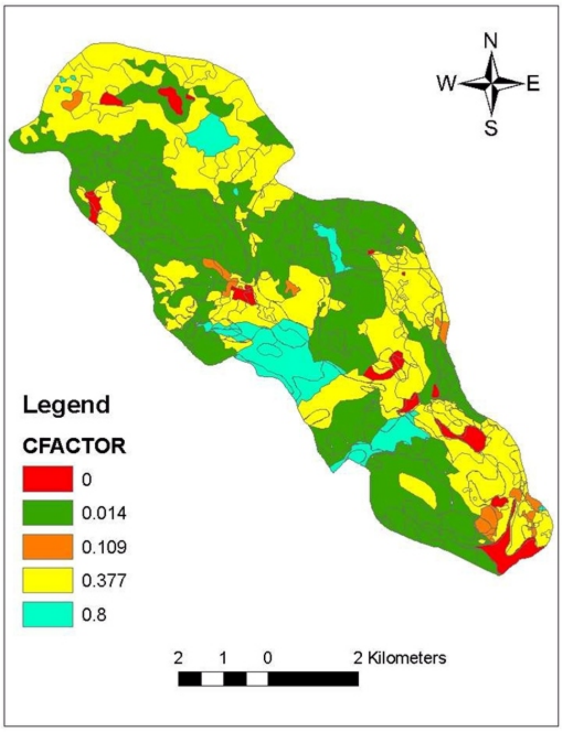

Fig.7 Cover management factor (C) map

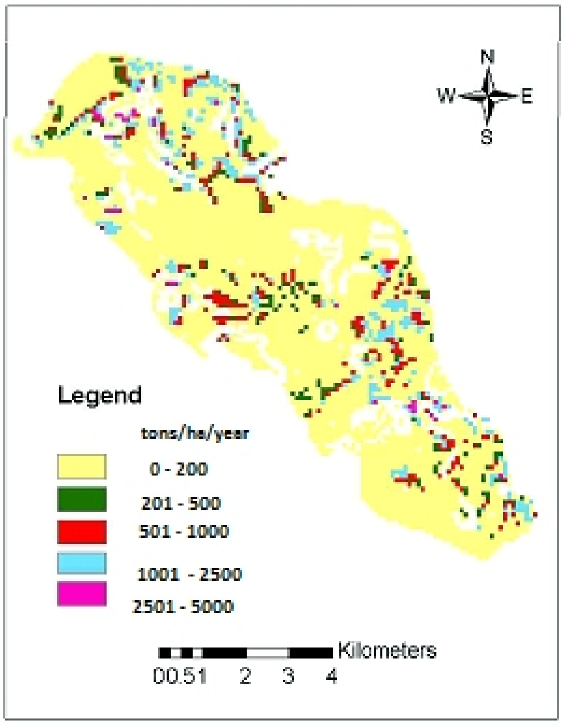

Fig. 8 Soil erosion map

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