Indian Journal of Agricultural Sciences **84** (1): 18–23, January 2014/Article

Estimation of soil erosion and crop suitability for a watershed through remote sensing and GIS approach

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Received: 31 March 2012; Revised accepted: 17 December 2013

ABSTRACT

Present study is in Patani micro-watershed situated in Satna District of Madhya Pradesh where soil erosion and crop suitability were estimated with Remote Sensing and GIS. The annual soil erosion potential was estimated using Universal Soil Loss Equation and suitable crops for particular watershed was suggested. The average rainfall erosivity factor (R), erodibility factor (K), highest and lowest value of slope length factor (LS), highest and lowest values of crop management factor (C), highest and lowest values of conservation factor (P) have been calculated. Average soil erosion rate of the watershed was estimated to be 8 tonnes/ha/yr. About 13.95% of the watershed area was found to be under slight erosion, 82.21% under the moderate erosion, high and severe erosion found in only 0.01% and remaining area was under very high erosion. Analysis shows that Patani micro-watershed is suitable for crops like maize, mustard, and greengram with minor limitations of soil and land characteristics.

Key words : Crop suitability, GIS, Remote Sensing, Soil erosion, USLE

Soil erosion is one of the most serious environmental problems in the world. Today soil erosion threatens agricultural and natural environment. It is very distressing that at a time when agricultural efforts are focused on increasing food production, soil degradation is increasing worldwide. Serious soil erosion is occurring in most of the world's major agricultural regions and the problem is growing as more marginal land is brought into production. Study on global soil loss has indicated that soil loss rate in the US is 16 tonnes/ha/yr; in Europe it ranges between 10 – 20 tonnes/ha/yr, while in Asia, Africa and South America between 20 to 40 tonnes/ha/yr (Pimentel 1986). Majority of the developing countries suffer from varying degree of soil erosion and degradation mainly due to rapid rate of deforestation, poor irrigation and drainage practices, inadequate soil conservation, steep slopes and overgrazing. An estimated 175 Mha of land in India, constituting about 53% of the total geographical area (329 Mha), suffers from deleterious effect of soil erosion and other forms of land degradation. Active erosion caused by water and wind alone accounts for 150 Mha of land, which amounts to a loss of about 5.3 MT of sub-soil per year. In addition, remaining 25 Mha land have been degraded due to ravine, gullies, shifting cultivation, salinity, alkalinity, and water logging (Reddy 1999). Land evaluation using scientific procedures is essential to assess the potentials and constraints of a given piece of land for agricultural needs (Rossiter 1996). Martin and Saha (2007) obtained soil data from soil resources inventory, land and climatic were derived from the RS satellite data and were integrated in GIS environment to obtained the soil erosion using USLE model.

GIS linked with simple erosion models provide tools for evaluation of vegetation management and rate of soil loss estimation at both local and watershed levels and planning of prevention practices (Thomas *et al*. 2010). Recent studies (Pandey *et al*. 2007, Sharma *et al*. 2001, Khan *et al*. 2001, Sidhu *et al*. 1998) revealed that Remote Sensing and GIS techniques are of great use in characterization and prioritization of watershed areas. The technology of remote sensing and GIS is gaining importance as a powerful tool in the management of information in agriculture, natural resources assessment, environmental protection and conservation (Javed *et al*. 2009). GIS with Remote Sensing has proved to be an effective tool in planning for micro watershed development (Sharma 2003). GIS plays an important role in the LUP approaches and taking decision to select the most suitable land use plan for the study area

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(Trung *et al*. 2006). Adinarayana *et al*. (1995) compiled a treatment-oriented land use planning scheme for hilly watershed in the Western Ghats region of India using a GIS. Martin and Saha (2009) coupled the Remote Sensing data with soil survey information and integrated in GIS environment to assess crop suitability for various soil and biophysical conditions. Alansi *et al*. (2009) studied for Bernam watershed located in Selangor state of Malaysia which is subjected to rapid land-use changes to residential and agriculture. The study on land use changes and their effects on runoff and sediment patterns for the watershed level suggested that it is essential in water resource planning and management. Jain *et al*. (2010) used Remote Sensing and GIS techniques for derivation of spatial information, catchment discretization, data processing, etc. for the Himalayan Chaukhutia Watershed (India). Erosion models often deal with great amounts of spatial data like topography, soil and land use, which can be easily handled by GIS. Looking to the aforementioned problem a study was planned with the specific objective of estimation of the spatial variation of soil erosion using Remote Sensing and GIS technique for Patani micro-watershed of Madhya Pradesh and recommendation of the suitable crop for the selected sub-watershed on the basis of soil erosion and slope.

MATERIALS AND METHODS

The study area is situated in Satna district, Madhya Pradesh. The Patani Nala micro-watershed is a part of Chakra Nala milli-watershed and encompasses an area of 731 hactares. The Patani micro-watershed lies between 24° 53' 30" to 24° 53' 45" N latitude and 80° 46' 15" to 80°45' 45" E longitude. It comes under the toposheets no. 63 D/9 and 63 D/13 of SOI. The average annual rainfall of the study area is 944 mm. Rainfall through South West monsoon starts from middle of June and ends in third week of September. South West monsoon contributes about 90 percent of total rainfall whereas the rest is received from the North-East monsoon in winter. The area experiences have cold and hot air during winter and summer respectively. Temperature in the district varies from 5°C to 45°C. The study area falls in Vindhyan Hills, categorized under agro-climatic zone 4th, known as Kymore Plateau and Satpura Hills. Geologically the study area comprises sandstone, shale, gneiss, quartz and carboniferous rocks.

The data have been collected both from primary and secondary data sources. The primary data collected are Survey of India (SOI) Toposheets at a scale of 1:50,000 (Toposheet No. 63 D/9 and 63 D/13) and Remote sensing data (IRS-P6, LISS-III, Sensor) used for the analysis was procured from National Remote Sensing Centre (NRSC) Hyderabad. Soil map used in the study was obtained from National Bureau of Soil Survey and Land use Planning (NBSSLUP 1998).

Initially base map has been prepared from toposheet. The topographic maps were geographically corrected having specifications of coordinate- Lat/long, projection- Polyconic, datum- India, Nepal 1975 and spheroid name- Everest. The geographical precision was tested by comparing the Root Mean Square Error (RMSE) with their theoretical coordinate kept within one pixel. Contours were digitized as per toposheet at contour interval of 20m with particular ID number. The contours were used for generation of digital elevation model (DEM) which represents spatial variation in altitude. Slope is an important factor for understanding the nature of terrain and drainage features of watershed. The runoff characteristics and soil erosion of the command area are controlled by the degree of slope. The flow diagram for generation of DEM is presented in Fig 1.

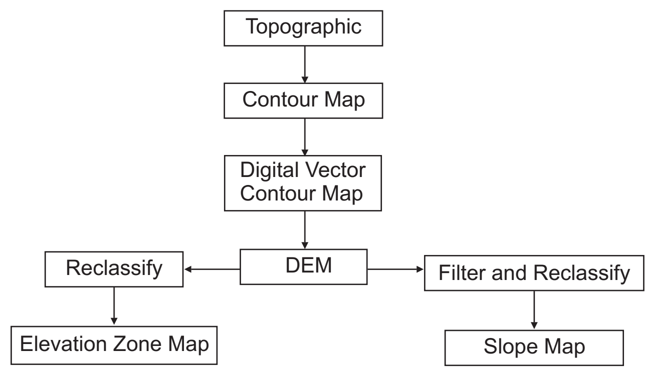

Fig 1 Flow diagram for generation of DEM and slope map using GIS

The resource map of land use/land cover was prepared by visual interpretation of satellite imagery of the area using data obtained from IRS-P6 Sensor LISS-III for 19 Oct 2008. Unsupervised classification of the satellite data was carried out. Categories of the type of land use/land cover available in the watershed are open land, agricultural land, forest, wasteland and water bodies. Area under different classes of land use/ land cover in the watershed is presented in Table 1.

After analysis of drainage map, it is found that the Patani watershed has 28, 8, 3 and 1 numbers of 1st, 2nd, 3rd and 4th order stream, respectively. The drainage pattern of the watershed is classified as sub-dendrite. The detailed methodology for estimation of soil erosion using RS and GIS technique is presented in Fig 2.

The universal soil loss equation was used to determine

Table 1 Area under different classes of land use/ land cover in the watershed

Land use/ land cover class	Area (ha)	Percent area
Forest	507	69.35
Wasteland	15	0.02
Agriculture	131	17.92
Open land	68	0.09
Water bodies	10	0.01

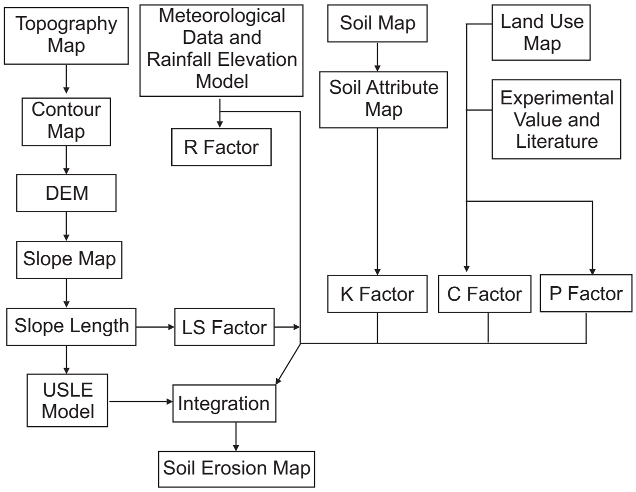

Fig 2 Methodology for estimation of soil erosion by the USLE model

the average annual soil loss and its spatial distribution on the watershed. The USLE predicts soil loss for a given site as a product of six major erosion factors (Equation 1), whose values at a particular location can be expressed numerically. The USLE is suitable for predicting long-term averages and the soil erosion is estimated as follows (Wischmeier and Smith 1960).

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

Where, A is average annual soil loss rate (tonnes/ha/year), R is rainfall erosivity factor (MJ mm/ha/h/year), K is soil erodibility factor (tonnes/ha/MJ/mm), LS is topographic factor, C is crop management factor, and P is conservation management practice factor.

The rainfall erosivity factor is generally taken as EI_{30} index described by (Wischmeier and Smith 1978). Estimation of EI_{30} index requires rainfall record from automatic rain gauge. Since, such rainfall records are not available; rainfall erosivity factor has been adopted 498 from ISO erodent map of India (Das 2000). Almost all soil types are categorized to moderate erodibility values (K = 0.3). Derivations of topographic factors (L and S) were performed by computing slope length and gradient respectively, combined (LS) factor for the micro-watersheds was computed as per slope map generated from the DEM of study area. Fig 3 presented the spatial variation of LS factor in the watershed, which varies from 0.11 to 8.24. It is the expected ratio of soil loss per unit area from a field slope to that from a 22.13 m length of uniform 9 percent slope continuously in clean-tilted fallow. Although, L and S factors can be 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 for the micro-watersheds was computed using the slope map generated from the DEM of study area.

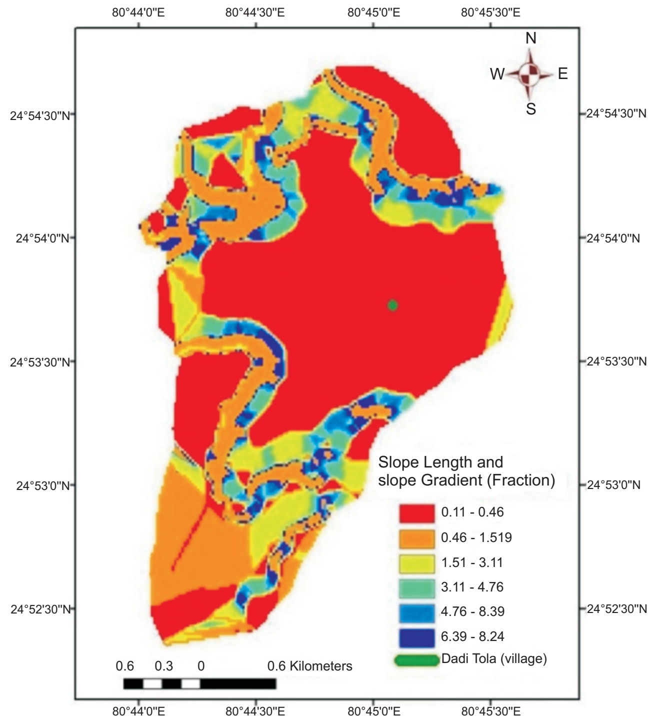

Fig 3 Spatial variation of combined LS factor in study area

Combined LS Factor Layer was generated as: For slopes up to 21 %, the equation modified by Wischmeier and Smith (1978) has been used-

$$LSI = \left(\frac{l}{22.1}\right) (65.41 \sin^2 \theta + 4.56 \sin \theta + 0.05) \quad (2)$$

where,

LS1 = slope length and gradient factor for slope up to 21 percent

θ = angle of the slope

l = slope length in m.

The relationship between the slope steepness in percentage (S_p) and slope length in meters (l) was used to generate slope length map. The relationship is expressed as-

$$L = 0.4 \times S_p + 40 \quad (3)$$

For slope steepness of 21% or more-

$$LS2 = \left(\frac{l}{22.1}\right)^{0.7} [6.432 \times \sin (\theta^{0.79}) \times \cos \theta] \quad (4)$$

where, LS2 = slope length and gradient factor and θ is angle of the slope.

Two layers separately for LS1 and LS2 were prepared and a final map of topographic factor (LS) was generated using following logical operation in map calculation function. LS = if (Slope < 21, LS1, LS2).

The land use/land cover map was derived from the satellite images served as a guiding tool in the allocation of C and P factors for different land use classes. The Crop management factor and Conservation practice factor maps were also generated with the help of land use/land cover map to develop the soil erosion potential. The C factor values were the representative values for allocating the USLE land cover and management factors corresponding to each crop/ vegetation condition, values were assigned 0.004, 0.28, 0.28 for forest, agricultural land and water body respectively (USDA-SCS 1972, Rao 1981).Conservation practice factor (P) depends on land use/ land cover information of the study area. P factor is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope cultivation. In the present study area no major conservation practice is adopted by the farmers. Therefore, the value of P factor were assigned as 0.28 for agricultural and 1 for remaining classes as suggested by USDA-SCS, 1972; Rao, 1981. Crop suitability criteria for crop under soil and land quality have been adopted which is proposed by Martin and Saha (2009) (Table 2).

RESULTS AND DISCUSSION

Suitable plan for watershed is essential for development of agricultural production through suitable crop selection and appropriate management practices. The estimates of soil erosion helps in prioritization of erosion control measures in the planning and management of watershed. In this study soil erosion potential mapping of watershed has been carried out using Universal Soil Loss Equation (USLE), Remote Sensing and GIS techniques.

Soil erosion potential mapping

The soil erosion potential of the watershed varies from 0 to 246 tonnes/ha/yr. The highest (value) soil erosion was observed from the agricultural land. A map has been generated for soil erosion classes as shown in Fig 4. The maximum area (601 ha) is falling under the class of moderate erosion, 102 ha area comes under slight erosion and very small area comes under severe rate of soil erosion. 86.04% area of the watershed having soil erosion potential more than 5 tonnes/ ha/yr. In this study it is found that the agricultural land having higher amount of soil erosion, there is a need to adopt cultivation with suitable crops and suitable soil conservation measures. The average erosion rate from the watershed is 8.0 tonnes/ha/year. Thus, this watershed can be categorised with moderate erosion potential. The tolerance limit for soil erosion varies with soil depth and other conditions. Majority of watershed area is having soil erosion more than 5 tonnes/ha/ yr. Thus, there is a need to protect the existing forest cover carefully. The catchment must be kept under meaningful vegetation, and immediate introduction of conservation treatment is necessary in the study area.

Suitability plan for crops in patani watershed

In this study, only 27.5 % land was found under cultivation and 72.5 % land was under other land use\land

Table 2 Criteria and rating of soil and land quality for land utilization

Soil and land quality	Suitability classes	Paddy	Wheat	Maize	Mustard
Texture	S1	CL	L	SL	SL
	S2	SL	SL	L	CL
	S3	Coarse SL	LS	CL	SC
	N	S	Fragmental	S	S
Soil depth	S1	Deep	Very deep	Deep	Deep
	S2	Moderate	deep	Moderate deep	Moderate deep
	S3	Shallow	Mod deep	Shallow	Shallow
	N	Very shallow	Shallow	Very shallow	Very shallow
Drainage	S1	Imperfectly to poor	Well drained	Well drained	Well drained
	S2	Moderate	Mod. well drained	Mod. well drained	Mod. well drained
	S3	Well drained	Imperfectly drained	Imperfectly drained	Imperfectly drained
	N	Somewhat excessively drained	Poorly drained	Poorly drained	Poorly drained
Slope	S1	Level	Flat to level	Nearly level	Nearly level
	S2	Very gentle	Gentle slope	Mod sloping	Very gentle
	S3	Gentle	Moderate slope	Moderate steep	Moderate to strong
	N	Moderate	Steep to very steep	Steep to very steep	Steep sloping
Erosion	S1	None	Slight	None	Very low
	S2	Slight	Moderate	Slight	Low
	S3	Moderate	High	Moderate	Moderate
	N	Severe	Severe	Severe	Severe

Note: SL, Sandy loam; CL, Clay loam; L, Loam; LS, Loamy sand; S, Sand, S1, Highly suitable; S2, Moderately suitable; S3, Marginally suitable and N, Not suitable

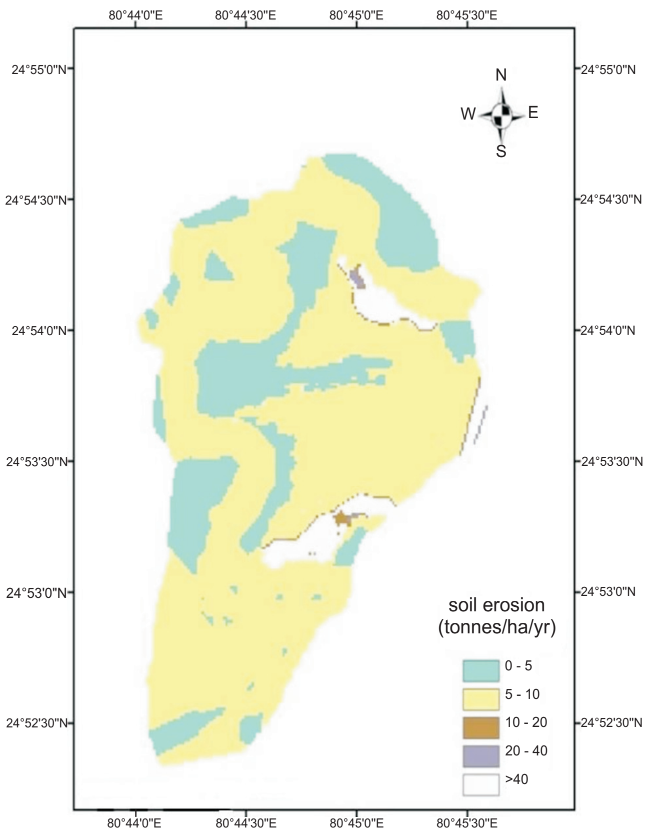

Fig 4 Spatial variation of soil erosion potential on Patani watershed

Table 3 Area under various classes of soil erosion in the watershed

Rate of soil erosion (tonnes/ha/yr)	Category	Area (ha)	Area %
0-5	Slight	102	13.950
5-10	Moderate	601	82.220
10-20	High	8	0.010
20-40	Very High	6	0.008
>40	Severe	14	0.020

cover classes of watershed. Table 4 provides the soil and land characteristics of cultivable land of study area. Crop suitability analysis on the basis of Table 4 (by imposing selection criteria of Martin and Saha (2009) clearly demonstrated that the watershed area was not highly suitable for paddy (because of existing soil depth, texture, drainage and erosion has not in favourable condition except slope), wheat (texture and soil depth has not fulfilled the selection criteria) and sugarcane (only drainage in favour) cultivation. Soil and land characteristics showed major limitations for cultivation of paddy, wheat and sugarcane. Cultivation of maize, mustard, and greengram can be encouraged with minor limitations. The total area suitable for maize, mustard and greengram are 169 ha, 169 ha and 175 ha, respectively and is presented in

Table 4 Soil and land characteristics in the watershed

Land	Texture	Soil Depth	Drainage	Slope	Erosion
Cultivable land	Loamy soil Sandy loam	Shallow	Well drained	Nearly level Gentle slope	Slight Moderate

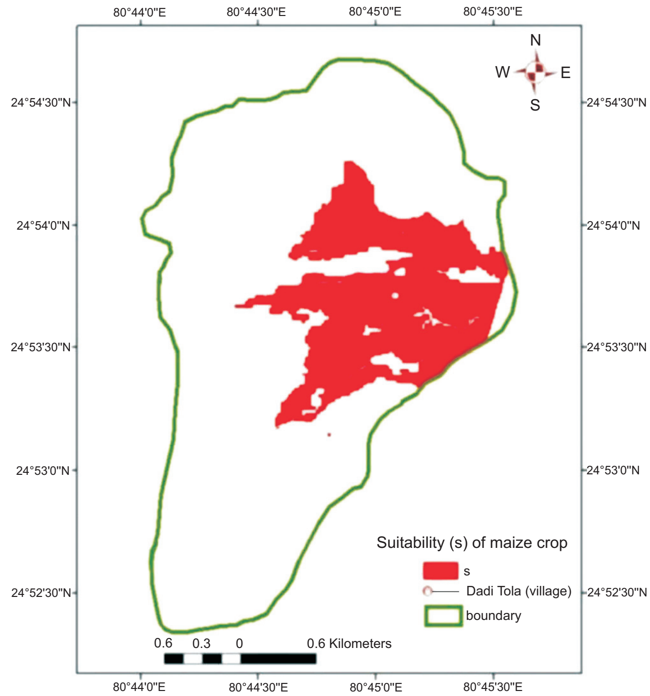

Fig 5 Suitability map for maize in the study area

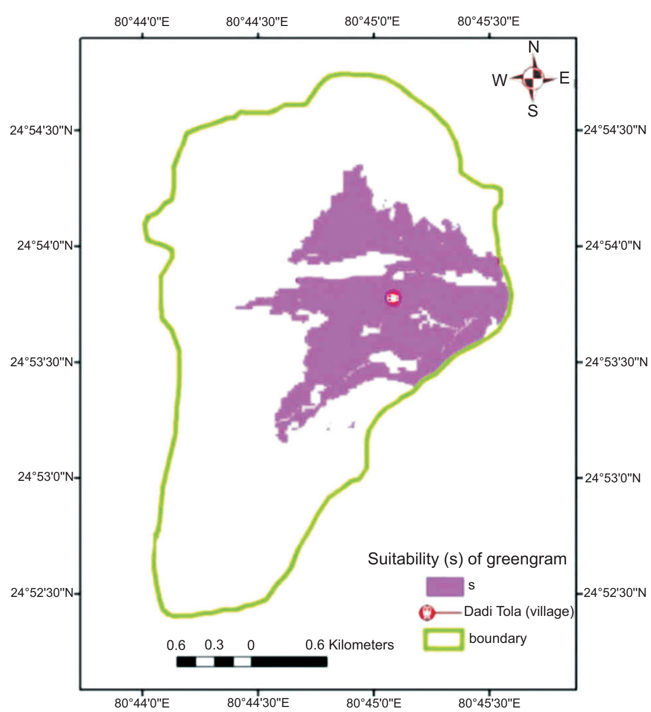

Fig 6 Suitability map for greengram in the study area

Fig. 5, 6. Suggested crop must be taken up within the watershed to improve the yield, soil fertility and soil conservation point of view.

CONCLUSION

Estimation of average annual soil erosion on micro-watershed basis was made using USLE with the help of Remote Sensing and GIS to know the spatial distribution, potential of soil erosion and the crop suitability over the Patani Nala micro-watershed. The use of GIS and remote sensing data enabled the determination of the spatial distribution of the USLE parameters. Various thematic maps and crop suitability maps were prepared using remote sensing and GIS technology for the present study satisfactorily. Annual average soil erosion for Patani Nala micro-watershed was 8 tonnes/ha/yr. The highest and lowest value of slope length factor (LS) is 0.46 and 0.11, respectively for the watershed. Based on annual average soil erosion and land characteristics of Patani micro watersheds, proposed crops are; maize, mustard, and greengram. It was found that agricultural land of the watershed is not suitable for paddy and wheat cultivation. There is a need to adopt suitable soil conservation management practices to control the soil erosion in those areas having high, very high and sever rate of erosion, and those areas having moderate rate of soil erosion was identified and can be controlled by suitable vegetative cover. Suggested crop in the present study will be helpful to increase the agricultural production, and also will be beneficial to control the soil erosion. Hence, remote sensing and GIS technology can be used as an alternative to conventional method of soil loss estimation of micro watershed for implementing soil conservation practices and to suggest crop suitability.

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