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Estimation of Soil loss by USLE Model using GIS and Remote Sensing techniques: A case study of Muhuri River Basin, Tripura, India

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Abstract

Soil erosion is a most severe environmental problem in humid sub-tropical hilly state Tripura. The present study is carried out on Muhuri river basin of Tripura state, North east India having an area of 614.54 Sq.km. In this paper, Universal Soil Loss Equation (USLE) model, with Geographic Information System (GIS) and Remote Sensing (RS) have been used to quantify the soil loss in the Muhuri river basin. Five essential parameters such as Runoff-rainfall erosivity factor (R), soil erodibility Factor (K), slope length and steepness (LS), cropping management factor (C), and support practice factor (P) have been used to estimate soil loss amount in the study area. All of these layers have been prepared in GIS and RS platform (Mainly Arc GIS 10.1) using various data sources and data preparation methods. In these study DEM and LISS satellite data have been used. The daily rainfall data (2001-2010) of 6 rain gauge stations have been used to predict the R factor. Soil erodibility (K) factor in Basin area ranged from 0.15 to 0.36. The spatial distribution map of soil loss of Muhuri river basin has been generated and classified into six categories according to intensity level of soil loss. The average annual predicted soil loss ranges between 0 to and 650 t/ha/y. Low soil loss areas (<25 t/ha/y) have been recorded under very densely forested areas and intensely plantation (mainly Rubber plantation) area. The high rate (>70 t/ha/y) of soil erosion was found along the main course of Muhuri River.

Keywords: Soil loss, erosion risk, USLE, GIS, remote sensing, Muhuri river.

Introduction

Soil erosion may be simply defined as the detachment and transportation of soil (Tideman, 1996). Natural or geological soil erosions do not occur at constant or consistent rates. Semi-arid and arid soils, which lack protective plant covers, may erode naturally at rates averaging 10-50 times greater than those for humid climate soils (Miller and Donahue, 1990). Asia has the highest soil erosion rate of 74 ton/acre/yr. (El-Swaify, 1997) and Asian rivers contribute about 80 % per cent of the total sediments delivered to the world oceans and amongst these Himalayan rivers are the major contributors (Stoddart, 1969). The soil erosion process is modified by biophysical environment comprising soil, climate, terrain, ground cover and interactions between them. Important terrain characteristics influencing the mechanism of soil erosion are slope, length, aspect and shape (Ganasri and Ramesh, 2016). Universal Soil Loss Equation (USLE) is the most widely applied empirical models for estimating the soil loss which was developed by Wischmeier and Smith (1965). Tripura is predominantly a small hilly state (Bera and Namasudra, 2016). Soil erosion is the common recurring phenomena of this state. Muhuri river basin lies in the southern- most part of the state. The

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catchment area of Muhuri river basin is 614.54 sq.km within Tripura and within Indian Territory the total length of the river is 59 km. The objective of the present study is to assess the amount of soil loss of Muhuri river basin by USLE method with the help of remote sensing and Geographical Information System techniques.

Material and Methods

Location of the study area

The Present study was conducted at Muhuri river basin in Tripura (Figure 1). Latitudinal and longitudinal extent of the basin are between 23°6'59" N to 23°25'16" N and 91°26'46"E to 91°44'35" E respectively. The maximum portion of Muhuri river basin lies in the South Tripura districts. It originates from the Deotamura hill range and there after it flow towards eastern direction, then enters into Bangladesh. The climate of the Muhuri river basin is under the influence of south west monsoon. The average annual rainfall is 335.27 cm and maximum humidity was noticed in the month of June.

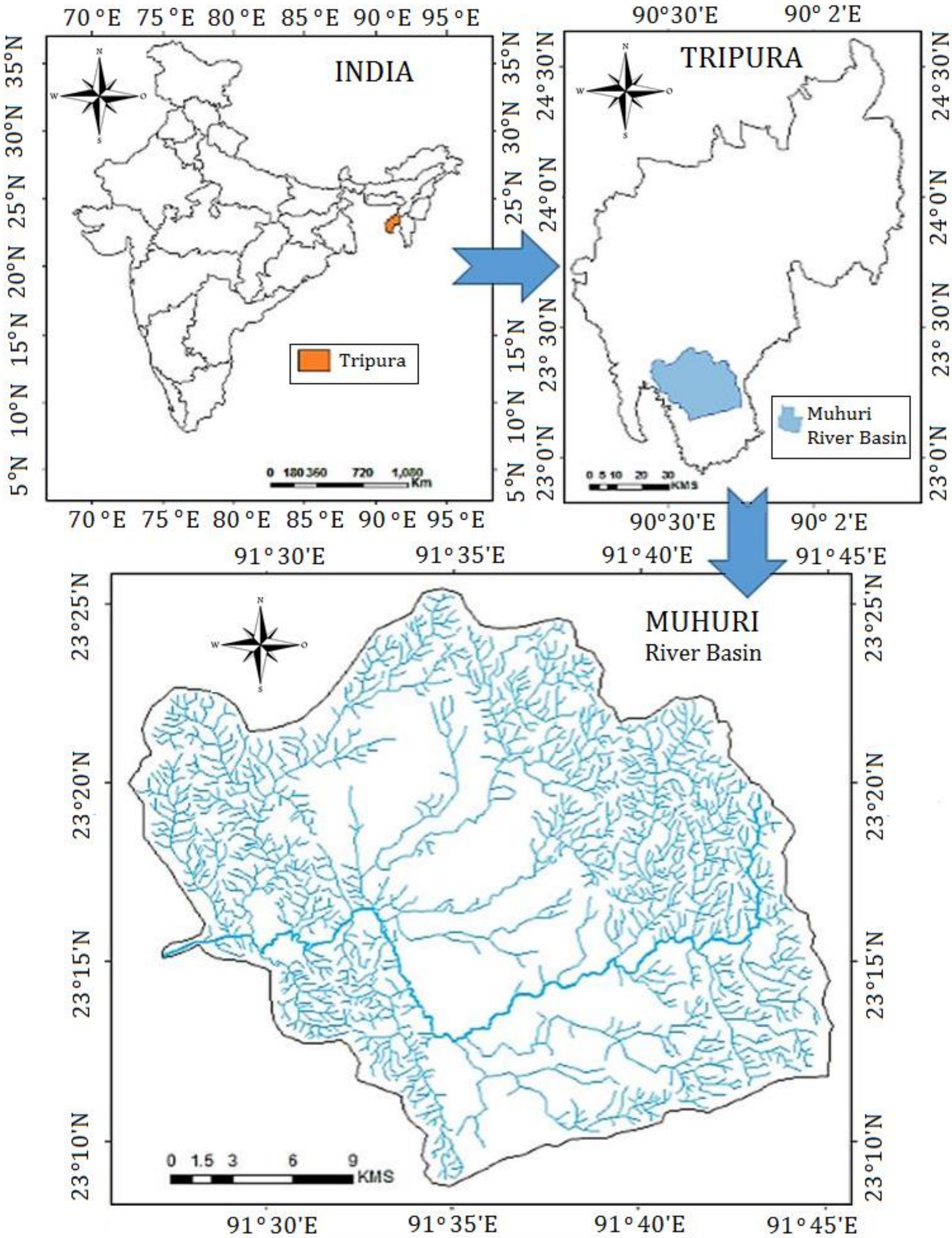

Figure 1. Location of the study area

Various types of materials have been used for the calculation of soil loss within the Study area. Those data are mainly, Rainfall data From Indian Meteorological Department (IMD), Soil Data from NBSS & LUP, ASTER DEM and LISS data.

The USLE soil loss equation is:

$$A = R \times K \times LS \times C \times P$$

Where, 'A' is the average annual soil loss; R is rainfall-runoff erosivity factor; K is Soil- erodibility factor; L is Slope-length factor; S, the slope-gradient factor; c, cropping-management factor and P is support practice factor.

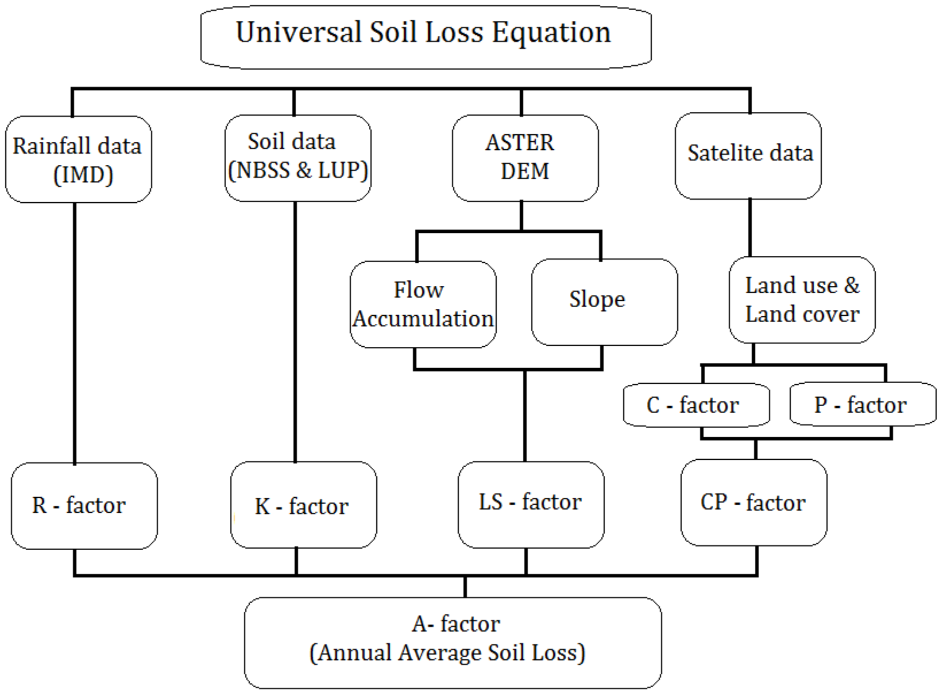

Figure 2. Methodological flow chart for the preparation of soil loss assessment map

Rainfall erosivity (R) factor

The erosivity factor of rainfall (R) is a function of the falling raindrop and the rainfall intensity, and is the product of kinetic energy of the raindrop and the 30-minute maximum rainfall intensity (Pandey et al., 2007). But in Indian context that kind of detailed meteorological data is less available. Therefore, G. Singh's (1981) empirical equation has been used for estimating annual and seasonal R factors in Indian context. The annual erosion index was as follows:

$$R_a = 79 + 0.363*P$$

Where, R_a is the average annual Rainfall erosivity factor (mt ha-cm^{-1}); and P is the Rainfall in mm. In the present study, R was computed by analyzing the rainfall data available from six rain-gauge stations (Udaipur, Amarpur, Belonia, Subroom, Bagafa and Sonamura) located in the Muhuri river basin and its adjoining area. Spatial distribution of R Factors data in the study area is estimated using inverse distance weighting (IDW) method of interpolation. In this IDW interpolation method, 10 years rainfall data for 6 rain gauge stations in and around the Muhuri river basin area were considered. The calculated R factor is given in Table 1.

Table 1. Average annual rainfall (mm) and calculated *R* value for the selected stations.

SL No.	Station	Average Annual (2001-2010)		SL No.	Station	Average Annual (2001-2010)	
		Rainfall (mm)	R-Factor			Rainfall (mm)	R-Factor
1	Udaipur	2220.46	885.03	4	Sabroom	2496.17	985.11
2	Amarpur	2144.88	857.59	5	Bogafa	2226.9	887.36
3	Belonia	2205.38	879.55	6	Sonamura	2072.71	831.39

Soil erodibility factor (K)

On the basis of the Geo-pedological map (Figure 4) of the National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Govt. of India, Soil erodibility index factor (K) values of different soil types of Muhuri river basin have been estimated and there after the soil erodibility map of the study area has been prepared by plotting the K values of each map unit. Here K factor is rated '0' to '0.36', where '0' indicates the vulnerability rate of soil erosion is less and '0.36' is the indication of high vulnerable rate of soil erosion by water. Based on salient characteristics of different soil types a detailed table has been prepared and calculated K values of surface soil was also computed.

Table 2. Geo-pedological characteristic and computed K values

Map unit	Relief type	Soil Taxonomy	K Value
LRSH1	Low relief Structural hills and ridges	Fine loamy Typic Dystrochrepts, coarse loamy Typic Udorthents, fine loamy Hapludalfs	0.24
LRSH2	Low relief Structural hills and ridges	FineTypic Dystrochrepts, Fine loamy Typic Dystrochrepts, Fine loamy Typic Paleudults	0.24
LRSH3	Low relief Structural hills and ridges	Fine loamy Typic Udorthents, Fine loamy Typic Haplumbrepts, Fine loamy Umbric Dystrochrepts	0.24
LRSH4	Low relief Structural hills and ridges	Loamy skeletal Umbric Dystrochrepts, Fine loamy Typic Dystrochrepts	0.24
LRSH5	Low relief Structural hills and ridges	Coarse loamy Typic Udorthents, Fine loamy Umbric Dystrochrepts, Fine loamy Typic Dystrochrepts	0.24
FTDH6	Flat topped Denudation hill	Fine loamy Typic kandiudalfs, Fine loamy Aquic Dystrochrepts, Fine Typic Dystrochrepts	0.15
UPLM7	Undulating plains with low mounds and narrow valleys	Fine loamy Typic Dystrochrepts, Fine loamy Typic Epiaquepts, Coarse loamy Typic Dystrochrepts	0.16
UPLM8	Undulating plains with low mounds and narrow valleys	Fine loamy Typic Dystrochrepts, Fine loamy Aquic Dystrochrepts, Fine loamy Oxyaquic Dystrochrepts	0.16
UPLM9	Undulating plains with low mounds and narrow valleys	Fine loamy Typic Dystrochrepts, Fine loamy Oxyaquic Dystrochrepts, Coarse loamy Typic Udorthents	0.16
UPLM10	Undulating plains with low mounds and narrow valleys	Fine Typic kandiudults, fine silty over sandy Aquic Dystrochrepts, Coarse loamy Typic Udorthents	0.16
IHV11	Inter hill valley	Fine loamy Aquic Dystrochrepts, Coarse loamy Fluventic Dystrochrepts	0.36
FP12	Flood plain	Fine Aquic Dystrochrepts, Fine Oxyaquic Dystrochrepts, Fine Aquic Dystrochrepts	0.34
FP13	Flood plain	Fine Typic Epiaquepts, Fine loamy Aeric Epiaquepts	0.34

Source: Through the review of literature (Ghosh et al. 2013) and NBSS and LUP, Bangalore

Topographic Erosivity Factor (LS)

Topographic Erosivity Factor (LS) has been considered as one of the most important model parameters in USLE analysis. When the slope length increases, the soil erosion by water also increases as due to the greater accumulation of surface runoff. Slope gradient and slope length factor is calculated from the flow accumulation and slope values. Finally the Topographic Erosivity Factor (LS) map has been derived using the following formula in ArcGIS spatial analysis raster calculator function.

LS = power (Flow Accumulation *cell size/22.13, 0.4) * power (sin(slope) * 0.01745) / 0.09, 1.4) * 1.4

Crop management factor (C) and conservation supporting practice factor (P)

Cropping management factor is be considered according to the USLE and RUSLE, with which cropping pattern determines the amount of erosion process (Vinay et al. 2015). C factor map was prepared on the basis of land use-land cover map of the study area. The land use land cover of the Muhuri river basin was classified with six major types of land use-land cover classes. Satellite image was processed for extracting these six land use-land cover classes using supervised classification method and there after the land use-land cover map was reclassified based on their estimated C-factor value for the generation of the Crop management factor (C) map.

During the field visit, it was found that soil conservation practice are not adopted in the area, so, for this study the P factor values are assumed as 1 for the entire Muhuri river basin. C and P factors are treated together as CP (biological erosivity) factor. The C factor and P factor were assigned as per Table 3.

Table 3. Computed CP values for Muhuri river basin area

Land-Use/Land Cover Class	C Factor	Researchers/Author/Source	P Factor value	CP Factor
Dense forest	0.008	Kumar and Kushwaha, (2013)		0.008
Forest plantation	0.02	Kumar and Kushwaha, (2013)		0.02
Moderately Dense forest	0.04	Ghosh et al.(2013)	1	0.04
Degraded forest	0.06	Ghosh et al.(2013)		0.06
Agricultural land	0.34	Devatha et al.(2015)		0.34
Fallow/ Wasteland	0.6	Biswal (2015)		0.6

Results and Discussion

Rainfall erosivity (R)

The annual average rainfall erosivity factor (*R*) for the years 2001 to 2010 was found to be in the range of 863.44 to 926.43 mt ha-cm^{-1}. Within the Muhuri river basin area the highest value (887.36 mt ha-cm^{-1}) of annual R factor was observed in Bagafa station when the total average annual rainfall was 2226.9 mm and the lowest value (879.55 mt ha-cm^{-1}) of annual R factor was found to be in Belonia meteorological station when the total rainfall was 2205.38 mm.

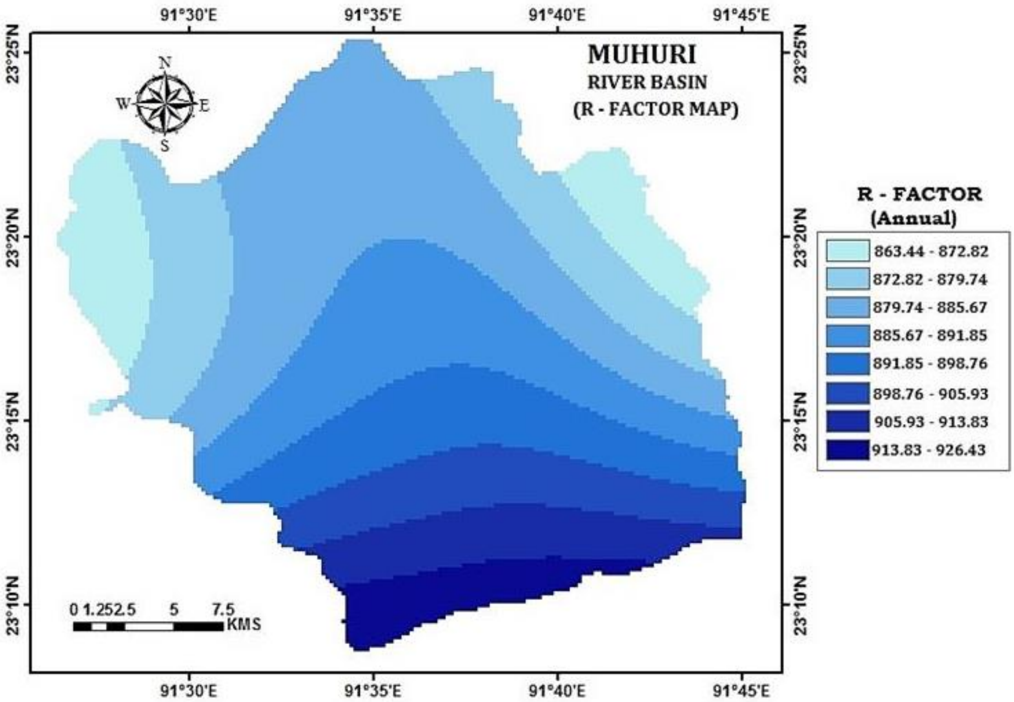

Figure 3. Spatial distribution of *R* factor

Soil erodibility (K)

Soil erodibility is an important index, which help to evaluate the soil vulnerability to erosion. Spatial distribution of surface soil K values in Muhuri river basin has shown in Figure 5 and Table 2. From the study (K factor map) it has been found that, In low relief areas like alluvial plains, an inter-hill valley and flood plains region, the K value is become significantly high which is ranges from 0.34 to 0.036. Soil erodibility of flood plain is comparatively high because soils texture of flood plains lying along Muhuri river course were generally loamy sand to sandy loam texture in nature and organic matter content was also very low, which making them more susceptible to erosion. In high relief area like structural hill and Denudation hill, the K value is comparatively less, it generally ranges from 0.24 to 0.15.

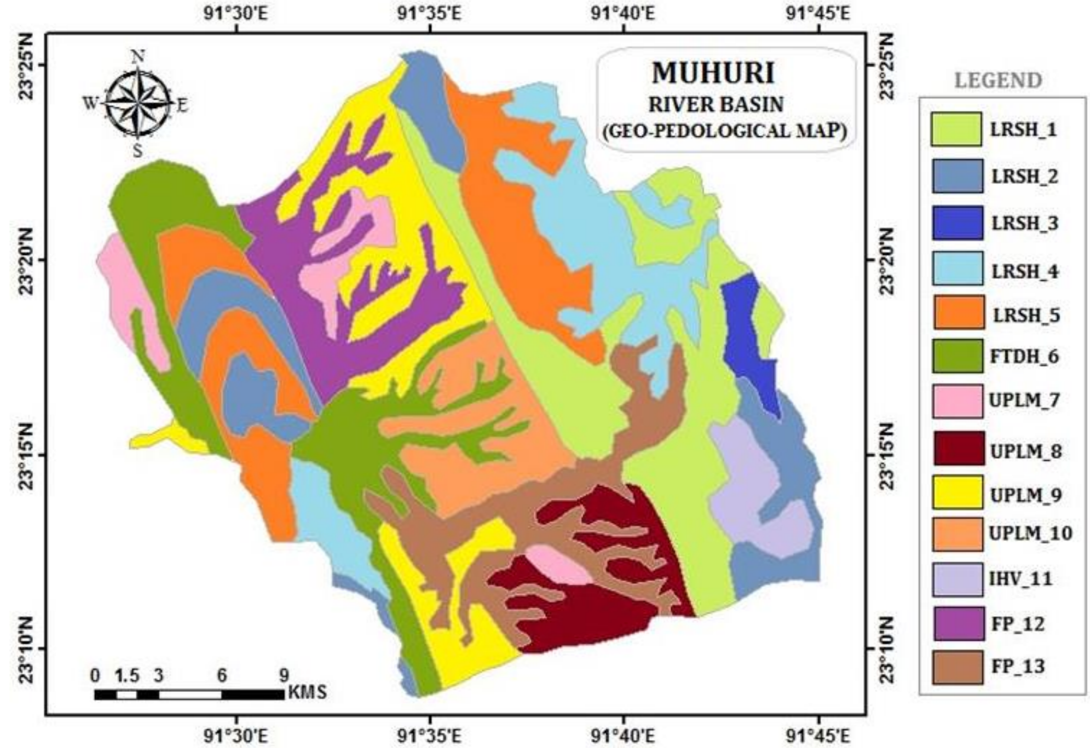

Figure 4. Geo-pedological map of Muhuri river Basin

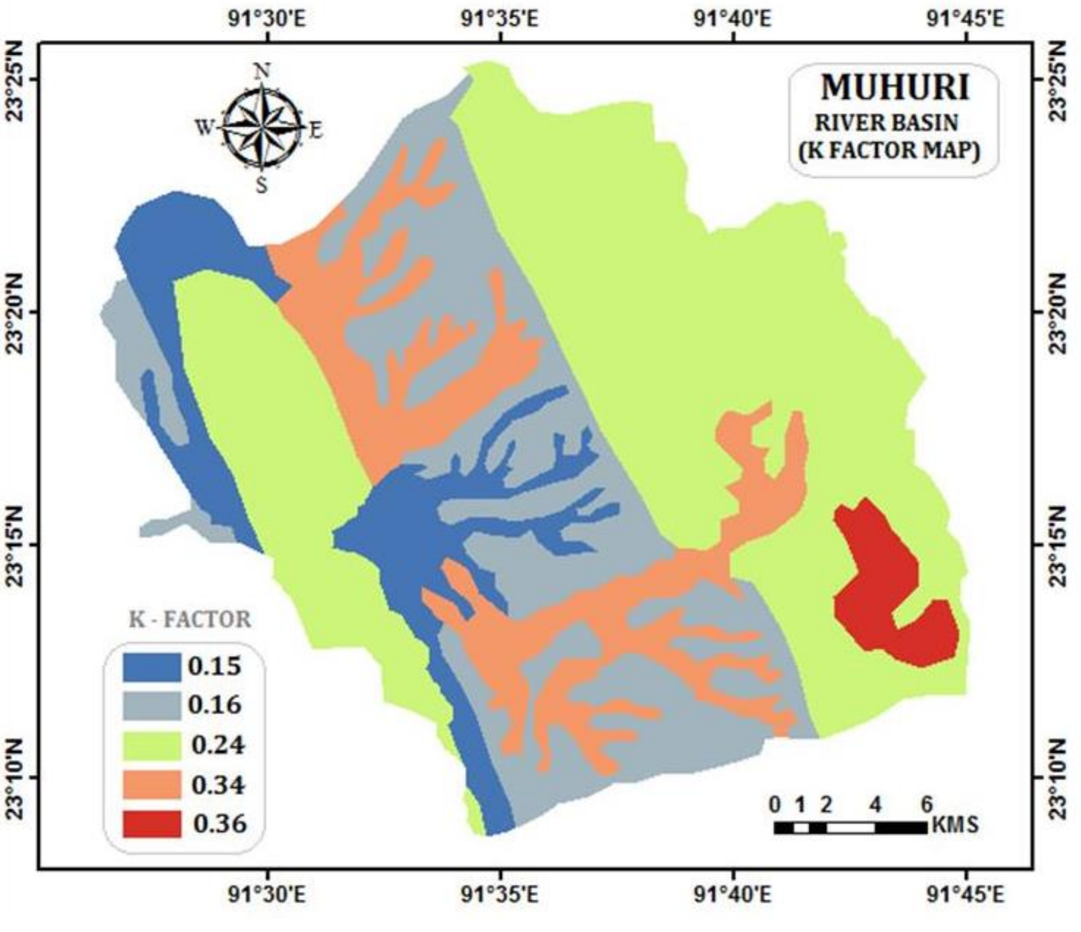

Figure 5. Spatial distribution of K factor of Muhuri river Basin

Topographic erosivity (LS Factor)

The slope length factor (L) and slope steepness factor (S) mainly reflect the effect of Topography on erosion (Yildirim, 2012). Slope length is defined as the horizontal distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition begins, or runoff is concentrated in a defined channel (Renard et al., 1997; Wischmeier and Smith, 1978). Slope steepness reflects the influence of slope gradient on erosion. In general, an increase in the L and/or S factor produces higher overland flow velocities and correspondingly greater erosion (Ozsoy et al., 2012) Topographic Erosivity factor (LS) factor of Muhuri river basin has been calculated by considering the flow accumulation and slope factor extracted from DEM. From the analysis, it is observed that the Topographic Erosivity factor in Muhuri river basin has been found to be in the range of 0 to 50 (Figure 6).

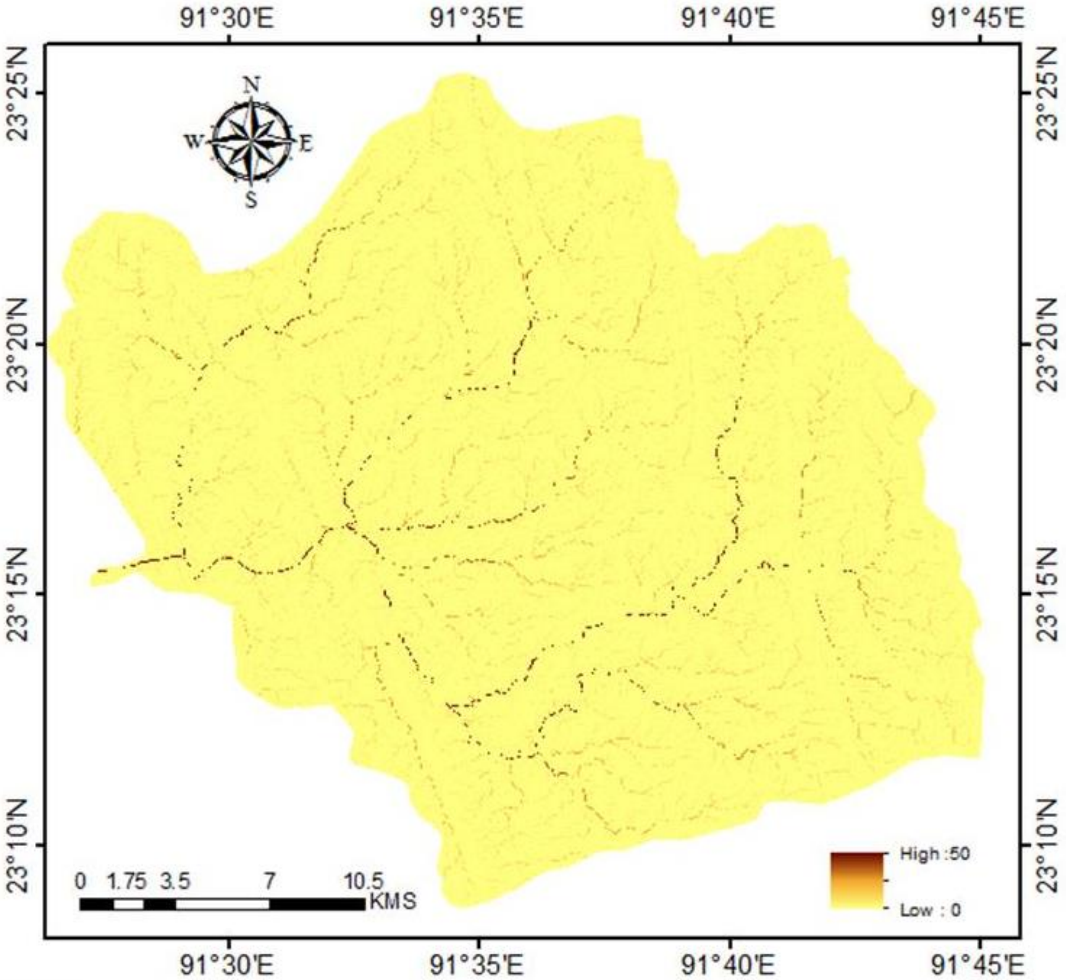

Figure 6. LS factor of Muhuri river Basin

C P factor

The cover management factor (C) is a crucial factor to the erosion because it is a readily managed condition to reduce erosion (Renard et al. 2011). Soil loss is very sensible to land cover in addition to relief (Chatterjee et al., 2014). In the present study area almost 65 % area is under dense and degraded forest. C factor is less significant when land use and land cover area comprises maximum percentage of natural vegetation and plantation crops. The value of which ranges from '0' in water bodies to slightly greater than '1' in barren land (Toy et al., 2002). The CP factor values in the study area vary from 0 to 0.6. The lower CP factor values (0.008-0.02) are mostly seen in the eastern most part of the basin where maximum potion of land use and land cover is dominated by dense forest and densely rubber plantation. However, the agricultural areas which occupy the central part of the basin have moderate CP factor values (Figure 7). The high CP factor value (0.34 – 0.6) was found along the main course of Muhuri River and the Waste land and barren land.

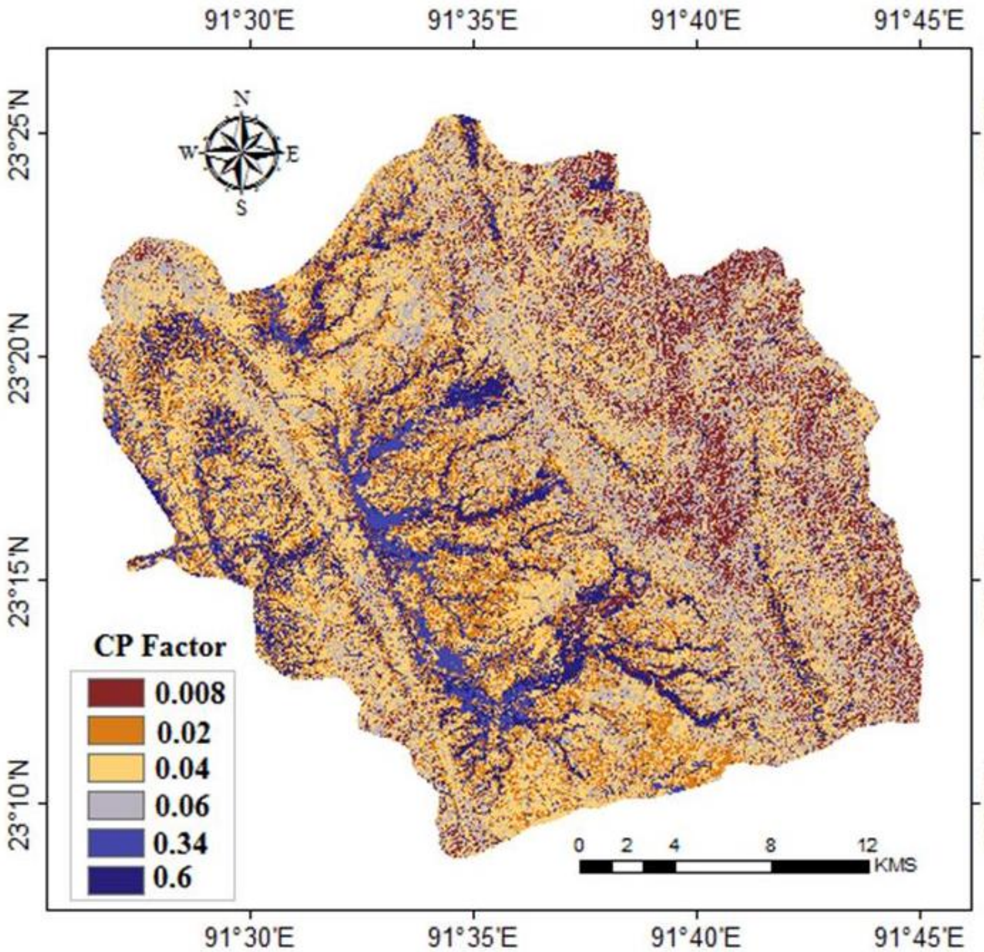

Figure 7. CP factor map of Muhuri river Basin

Average annual soil loss (A factor)

The average annual soil erosion potential (A) has been computed by multiplying the developed raster data from each factor (A= R K L S C P) of USLE analysis. The final 'A' factor map displays the average annual soil loss potential of the Muhuri river basin is shown in figure 8. Results shows that the study area has gentle slope so the erosion loss is obtained with low rate and it is within acceptable limit. Predicted average annual soil loss of Muhuri river basin has been classified into six erosion intensity classes (Table 4) to assess erosion potential severity. The average annual predicted soil loss ranges between 0 to and 650 t/ha/y. Negligible soil loss areas (<5 t/ha/y) have been recorded under very densely forested areas and low soil loss (5-10 t/ha/y) was found manly intensely plantation (mainly Rubber plantation) area and degraded forest area. Soil erosion rate was predicted moderately high (10-25 t/ha/y) for agriculture, which needs proper soil conservation measures to reduce erosion. The high rate (>70 t/ha/y) of soil erosion was found along the main stream and along the Lunga (valley) portion of the basin, because of moderate slope value and the high slope length and steepness factor. According to erosion risk classes it is observed that 80-90 % area is under negligible to slight class whereas only 20 -10 % area is under moderate to extremely high class.

Table 4. Different classes of soil erosion

Soil loss classes (t/ha/yr)	Erosion Intensity Type
0-5	Negligible Erosion
5-10	Low Erosion
10-25	Moderate Erosion
25-70	Moderately high Erosion
70-100	High Erosion
>100	Extremely high Erosion

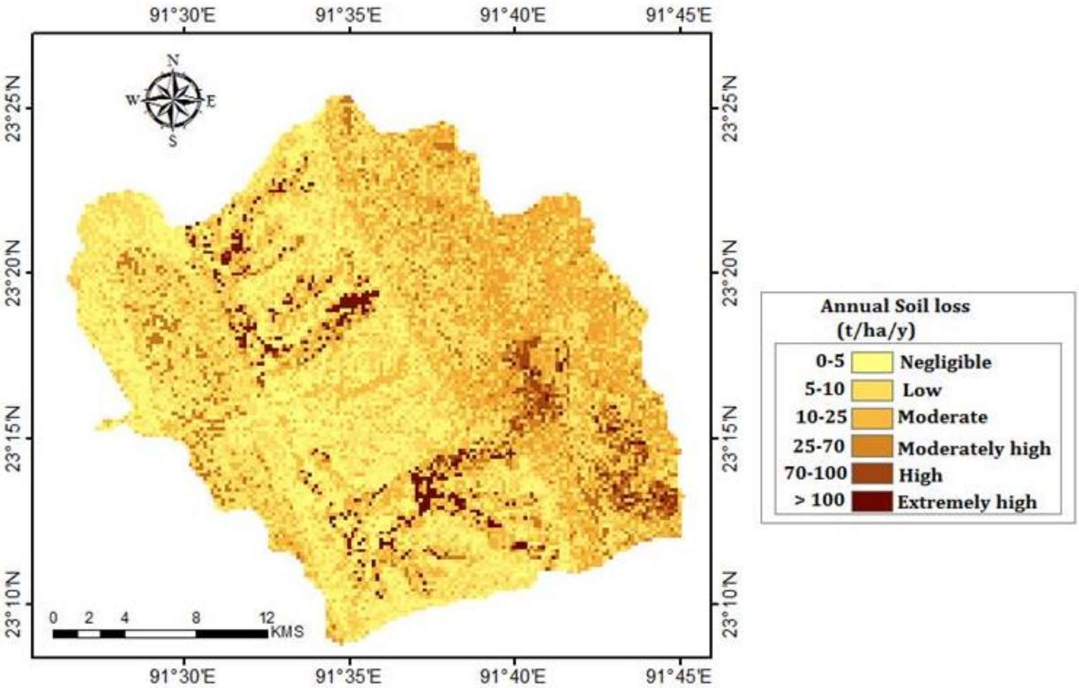

Figure 8. Spatial distribution of Average annual soil loss (A factor) map of Muhuri river Basin

Conclusion

The study was done to address and quantify the soil loss problem in Muhuri river basin of Tripura. Geographic Information System (GIS) and Remote Sensing are emerging most effective tools for analyzing spatial distributed information in a vast area now a days. The use of the USLE model integrated to GIS and RS is an effective tool than the time consuming conventional methods for assessing the soil loss vulnerability in a basin's scale. The all USLE parameter R, K, LS, C and P factor maps were combined together for creating the annual average soil loss map of the Muhuri river basin area. The output results shows that the LS factor varies from 0 to 50; CP value in the study area varies from 0.008 to 0.6 and K value is observe in between 0.15 to 0.36. Average annual soil loss risk in the study area is moderately high from the acceptable limit. The methods and the predicted amount of soil loss and its spatial distribution of the basin described in this study which are useful to formulate and further implement conservation program that will reduce soil loss from the basin.

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