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ORIGINAL ARTICLE

Assessment of soil loss by universal soil loss equation (USLE) model using GIS techniques: a case study of Gumti River Basin, Tripura, India

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Abstract   Soil loss is a serious environmental threat in humid sub-tropical State Tripura. The present study is carried out in Gumti River Basin of Tripura State, North East India having an area of 2492 km^2. Long term daily rainfall intensity is very high in this region and that's why sheet erosion of soil is common phenomena. Spatial distribution of soil loss in the study area was estimated by integrating five essential parameters of universal soil loss equation model in GIS mapping platform (mainly ArcGIS 10.1). Those five parameter are runoff–rainfall erosivity factor (R), soil erodibility factor (K), slope length and steepness (LS), cropping management factor (C), and support practice factor (P). In these study ASTER digital elevation model having 30 m resolution and LISS III image have been used for estimation of LS factor and C factor. The daily rainfall data (2001–2010) of seven rain gauge stations located in the Gumti River Basin and its adjoining area have been used to predict the R factor. Predicted average annual soil loss of the basin has been classified into five categories according to intensity level of soil loss. The high rate (>45 t ha^{-1} year^{-1}) of soil erosion was found along the main course of Gumti River, interhill valley portion and also the flood plain area of the basin, whereas low amount of soil loss (<10 t ha^{-1} year^{-1}) was found at densely forested areas and intensely plantation area of the basin.

Keyword   Soil loss · Erosion risk · USLE · GIS · Remotely sensed data · Gumti River

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Introduction

Soil erosion which may be called the 'creeping death of the soil is a worldwide problem (Rama Rao 1962; Tripathi and Singh 1993). 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). Soil erosion in India has a major effect on the agricultural sector, siltation of reservoirs, degradation of soils, etc. in the nation. One of the most widely applied empirical models for assessing the sheet and rill erosion is the universal soil loss equation (USLE), developed by Wischmeier and Smith in 1965 (Ganasri and Ramesh 2016). The GIS and remote sensing (RS) provide spatial input data to the model, while the USLE can be used to predict the sediment yield from the watershed. Although, GIS permits more effective and accurate application of the USLE model for small watersheds, most GIS-model applications are subject to data limitations (Fistikoglu and Harmancioglu 2002; Pandey et al. 2007). Digital elevation model (DEM) is one of the essential inputs required for soil erosion modelling, which can be created by analysis of stereoscopic optical and microwave (SAR) RS data (Kim 2006).

Geographically the Gumti Basin is lies in the lower middle part of Tripura. Mainly two broad physiographic divisions; hills and plains (undulating and flooded) are major topographical characteristics of Gumti River Basin (Bera and Namasudra 2016). The hilly part of study area was covered with dense and degraded forest cover. The whole basin is mainly composed of weathered sand stone, shale, mud stone, ferruginous sand stone and alluvium, which are significantly erosive in nature. The USLE is the best known and most widely used soil erosion model.

USLE was developed to estimate inter-rill soil losses over extended time periods. The limitation of this model is, that it does not estimate deposition, sediment yield, channel erosion, or gully erosion (Wischmeier and Smith 1965; Jain et al. 2001). The objective of the present study is to assess the amount of soil loss of Gumti River Basin by USLE method with the help of geographical information system techniques.

Location of the study area

The present study was conducted at Gumti River Basin in Tripura (Fig. 1). Latitudinal and longitudinal extent of the basin are between 23°17′46″ N to 23°47′45″ N and 91°14′43″ E to 91°59′29″ E, respectively. The maximum portion of the basin lies in the Gomati districts of Tripura. The catchment area of the basin is 2492 km^2 within Tripura and 77% area is under the hilly catchment portion and only 23% area is fall under the plains (Bera and Namasudra 2016). The climate of the study area is under the influence of south west monsoon and it is fully established by the last week of June or third week of July and heavy rainfall starts. The average annual rainfall is 335.27 mm and maximum humidity was noticed in the month of June.

Materials and methods

Different types of materials have been used for the calculation of soil loss within Gumti River Basin. Those data are mainly, rainfall data from Indian Meteorological Department, soil data from National Bureau of Soil Survey and Land Use Planning (NBSS and LUP), ASTER DEM (30 m resolution) and LISS III data.

The USLE soil loss equation is:

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

where 'A' is the computed soil loss per unit area, R is rainfall–runoff erosivity factor, K is soil-erodibility factor, L is slope-length factor, S is slope-gradient factor, c is cropping-management factor and P is support practice factor. Flow chart (Fig. 2) showing the methodology adopted in this study.

Rainfall erosivity factor (R)

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-min maximum rainfall intensity (Pandey et al. 2007). But in Indian context that kind of detailed meteorological data is less available. Therefore, Singh et al. (1981) empirical equation ('A1' and 'A2')

has been used for estimating annual and seasonal R factors in Indian context. The linear annual and seasonal (monsoon and non-monsoon) relationship to erosion index was as follows:

$$Ra = 79 + 0.363 * P, \tag{A1}$$

$$Rs = 50 + 0.389 * P, \tag{A2}$$

where Ra is the average annual rainfall erosivity factor (mt ha cm^{-1}), Rs is the average seasonal rainfall erosivity factor (mt ha cm^{-1}) and P is the rainfall (mm). In the present study, R was computed (Table 1) by analyzing the 10 years rainfall data available from seven rain-gauge stations (Udaipur, Amarpur, Sonamura, Teliamura, Bagafa, Bisalgarh and Chawmanu) located in the Gumti River Basin and its adjoining area. Out of such seven rain-gauge stations only Udaipur, Amarpur and Sonamura Stations are situated within the basin area and the rest are outside the boundary of the basin. Spatial distribution of R factors data (average annual rainfall erosivity and seasonal rainfall erosivity) in Gumti River Basin were estimated using inverse distance weighting method of interpolation.

Soil erodibility factor (K)

On the basis of the geo-pedological map (Fig. 3a) of the NBSS and LUP, Government of India, K values of different soil types of Gumti River Basin have been estimated from the nomo-graph (Wischmeier and Smith 1978) of USLE and there after a detailed table (Table 2) has been prepared and calculated K values of surface soil was also computed. K factor map of the study area has been prepared by plotting the K values of each map unit. The range of K factor of this study area is 0–0.36, where close to '0' indicates less vulnerability rate of soil erosion and close to '0.36' is the indication of high vulnerable rate of soil erosion.

Topographic erosivity factor (LS)

Topographic erosivity factor (LS) is the product of two subfactors which were slope length and slope steepness factors. Slope length factor (L) has been calculated on the basis of the following formula:

$$L = \left(\frac{\lambda}{22.13}\right)^m,$$

where 'L' is soil loss normalized to the 22.13 m long slope, 'm' is the variable slope-length exponent and the slope length 'λ' is the horizontal projection, not distance parallel to the soil surface (Wischmeier and Smith 1978).

$$m = \beta/(1 + \beta).$$

Values for the ratio 'β' of rill to inter-rill erosion for conditions when the soil is moderately susceptible to both rill and inter-rill erosion (McCool et al. 1989).
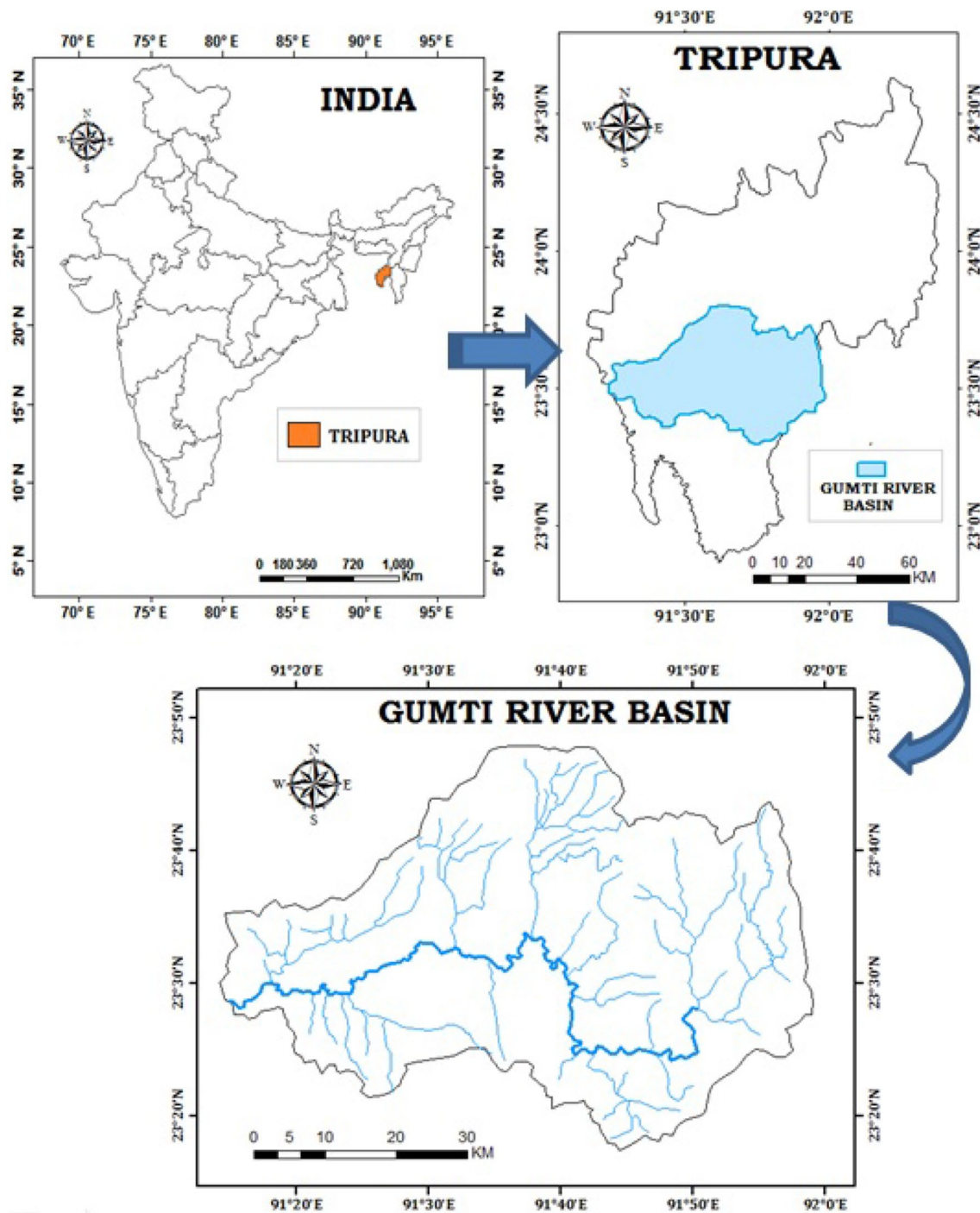
Fig. 1 Location of the study area

$$\beta = (\sin\theta / 0.0896) / \left[3.0(\sin\theta)^{0.8} + 0.56\right],$$
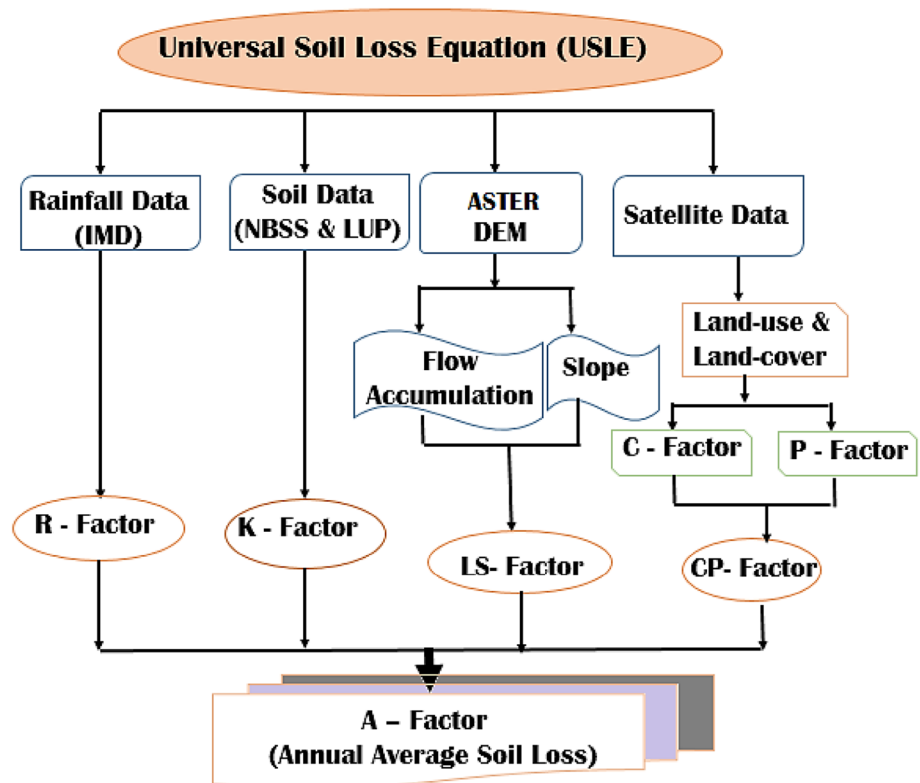
where θ is angle of the slope.

For slope length longer than 4 m, the slope steepness factor (S) is evaluated from following equations (McCool et al. 1987).

$$S = 10.8 \sin\theta + 0.03, \qquad s < 9\%$$

$$S = 16.8 \sin\theta - 0.05, \qquad s \geq 9\%$$

where 'S' represent slope steepness factor and θ stands for slope angle (°).

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

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

Stations	Average annual (2001–2010)		Average monsoon (2001–2010)		Average non-monsoon (2001–2010)	
	Rainfall (mm)	R-factors	Rainfall (mm)	R-factors	Rainfall (mm)	R-factors
Udaipur	2220.46	885.03	1341.71	571.93	826.61	371.55
Amarpur	2018.48	811.71	1282.66	548.95	694.68	320.23
Sonamura	2072.71	831.39	1311.08	560.01	719.41	329.85
Teliamura	1907.22	771.32	1130.61	489.80	736.63	336.55
Bagafa	2226.90	887.36	1421.09	620.80	748.46	341.15
Bisalgarh	2136.67	854.61	1332.87	568.49	774.26	351.19
Chawmanu	2142.86	856.86	1254.76	538.10	888.1	395.47

LS factor parameters was derived using RS data (ASTER DEM) and integrated in ArcGIS 10.1 environment with the help of following formula.

$$LS = power \ (flow \ accumulation \ * \ cell \ size/22.13, \ 0.4)$$
$$* \ power \ (sin \ (slope \ * \ 0.01745)/0.09, \ 1.4) \ * \ 1.4.$$

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

C and P factors are treated together as biological erosivity (CP) factor. C factor map has been prepared on the basis of land use–land cover map of the Gumti River Basin. The

land use–land cover of the study area have been classified with five (water bodies, dense forest area, degraded forest, built-up land and agriculture land) major types of land use–land cover classes with the help of supervised classification method and then it was reclassified based on their estimated C-factor value for the generation of the C factor map.

During the field visit at Gumti River Basin area, it was found that the farmers were not adopted any kind of conservation practice, so the P factor values was assumed as 1 for the entire basin area. The C factor and P factor values of study area were assigned as per Table 3.
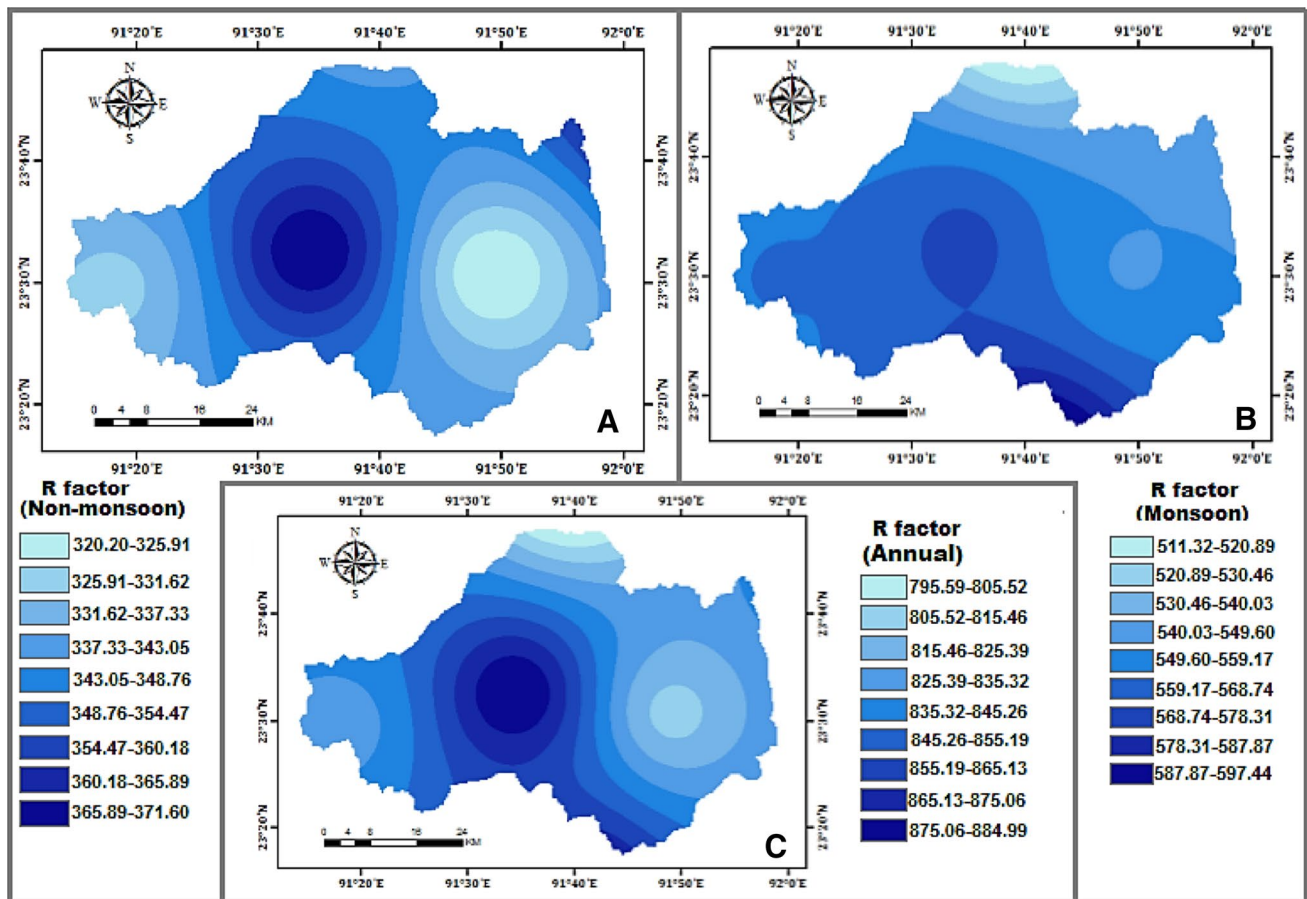
Fig. 3 Spatial distribution of *R* factor (**a** non-monsoon, **b** monsoon and **c** annual *R* factors)

Table 2 Geo-pedological characteristic and computed K values. *Source* through the review of literature (Ghosh et al. 2013) and NBSS and LUP, Bangalore

Map units	Relief types	Lithology	Dominant subgroups	K values
HSH 1	High relief structural hill	Weathered sandstone	Typic udorthents, typic dystrochrepts	0.09
MPR 2	Medium relief parallel ridge	Shale, silt stone	Typic udorthents, typic dystrochrepts	0.26
MPR 3	Medium relief parallel ridge	Shale, silt stone	Dystrochrepts, typic udorthents, typic haplumbrepts	0.26
MPR 4	Medium relief parallel ridge	Shale, silt stone	Dystrochrepts, lithic udorthents, typic haplumbrepts	0.26
MPR 5	Medium relief parallel ridge	Shale, silt stone	Typic dystrochrepts, typic udorthents	0.26
DH 6	Denudation hill	Weathered sandstone	Typic kandiudults, aquic dystrochrepts	0.16
FP 7	Flood plain	Alluvial	Aeric epiaquents, aquic dystrochrepts	0.34
AP 8	Alluvial plain	Alluvial	Fluventic dystrochrepts	0.28
IV 9	Interhill valley	Alluvial, sandstone	Typic dystrochrepts, typic haplumbrepts	0.36
IV 10	Interhill valley	Alluvial, sandstone	Umbric dystrochrepts, typic epiaquepts	0.36
IV 11	Interhill valley	Alluvial, sandstone	Typic dystrochrepts, typic hapludalfs	0.36
IV 12	Interhill valley	Alluvial, sandstone	Typic dystrochrepts, typic hapludalfs	0.36
UP 13	Undulating plains with low mounds	Weathered sandstone	Oxyaquic dystrochrepts, aquic udorthents	0.16

Table 3 Computed CP values for Gumti River Basin area

| Land-use/land cover class	C factors	Researchers/author/source	P factor value
Water bodies	0	Ghosh et al. (2013)	1
Dense forest	0.02	Ghosh et al. (2013)	
Degraded forest	0.04	Vinay et al. (2015)	
Build up land	0.09	Ganasri and Ramesh (2016)	
Agricultural land	0.58	Vinay et al. (2015)	

Result and discussion

Rainfall erosivity (R)

The rainfall erosivity index, R factor, in the USLE and RUSLE models, is an index of rainfall erosivity which is the potential ability of the rain to cause erosion (Irvem et al. 2007). The annual average rainfall erosivity factor (Ra) for the years 2001–2010 was found to be in the range of 771.32–887.36 mt ha cm^{-1} (Fig. 3). Within the Gumti River Basin area the highest value (885.03 mt ha cm^{-1}) of annual R factor was observed in Udaipur Station when the total average annual rainfall was 2220.46 mm and the lowest value (811.71 mt ha cm^{-1}) of annual R factor was found to be in Amarpur Meteorological Station when the total rainfall was 2018.48 mm. The average monsoon and non-monsoonal rainfall erosivity factor of these seven rain gauge stations is ranges from 489.80 to 620.80 and 320.23 to 395.47 mt ha cm^{-1}, respectively.

Soil erodibility (K)

Soil erodibility increases as the soil texture becomes finer. Fine loamy soils (silt loam) have higher proportion of silt and very fine sand, making them more susceptible to erosion. Organic matter in the soil influences the aggregation of soil particles into stable soil structure. Soils with less than 3.5% organic matter are considered to be erodible (Kumar and Kushwaha 2013; Evans 1980). Spatial distribution of surface soil K values in Gumti River Basin has shown in Fig. 4b and Table 2. From K factor map it has been found that high K value, ranges from 0.34 to 0.036, is generally found at low relief areas like flood plains and inter-hill valley region. Soils texture of flood plains lying along Gumti 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. Moderate K value (0.26–0.28) has been found at medium relief parallel ridge and alluvial plain in the basin. In high relief area
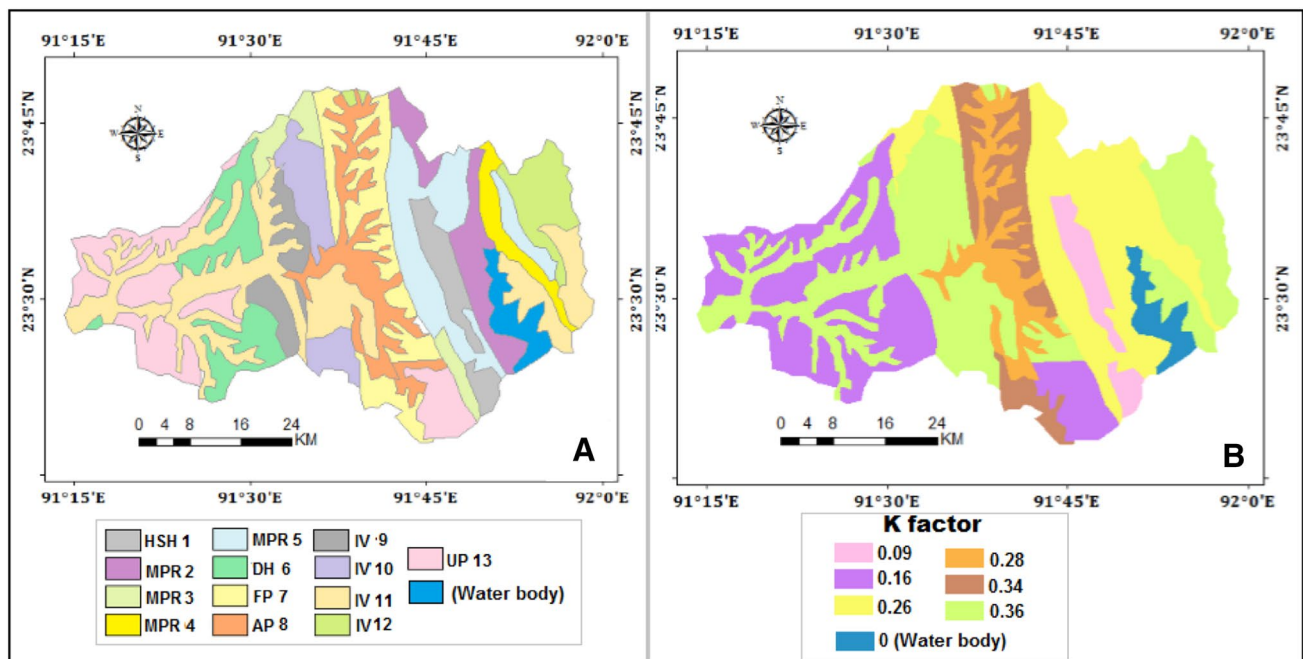
Fig. 4 a Geo-pedological map of the study area and **b** spatial distribution of k factor

like high relief structural hill, undulating plains with low mounds, the K value (0.09–0.16) is comparatively less.

Topographic erosivity (LS factor)

In using the USLE, the slope length was defined as beginning at the top of the hill slope where runoff starts, and extending down to where the sheet and rill flow reaches either a concentrated flow channel or a depositional area (Renard et al. 2011). Topographic erosivity factor (LS) factor was calculated by considering the flow accumulation and slope factor extracted from DEM. LS factor represents the influence of slope length (L) and slope steepness (S) on erosion process of surface soil. From the analysis, it is

observed that the topographic erosivity factor (Fig. 5) in Gumti River Basin has been found to be in the range of '0 to 47'.
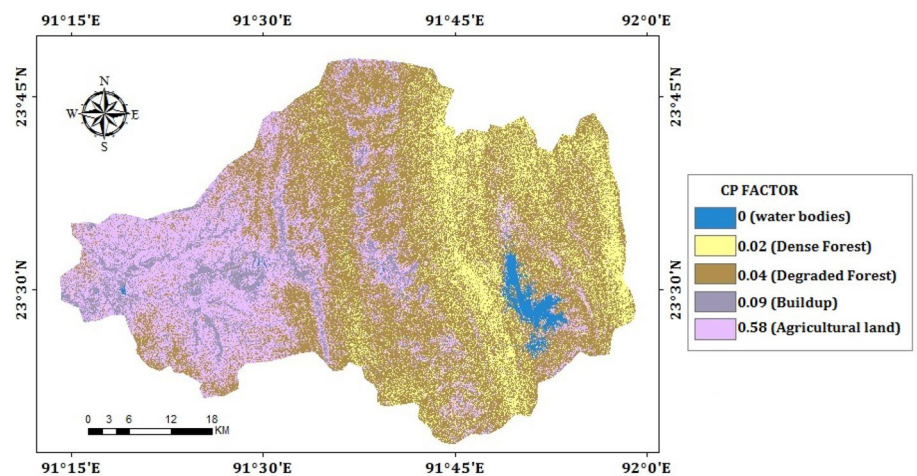
CP factor

In USLE, the C factor was described as providing a measure of how erosion from the current condition compares with that for the unit plot condition, which is considered as nearly worst-case (Renard et al. 2011). In Gumti River Basin area almost 68% 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 cover and plantation crops. The value of which
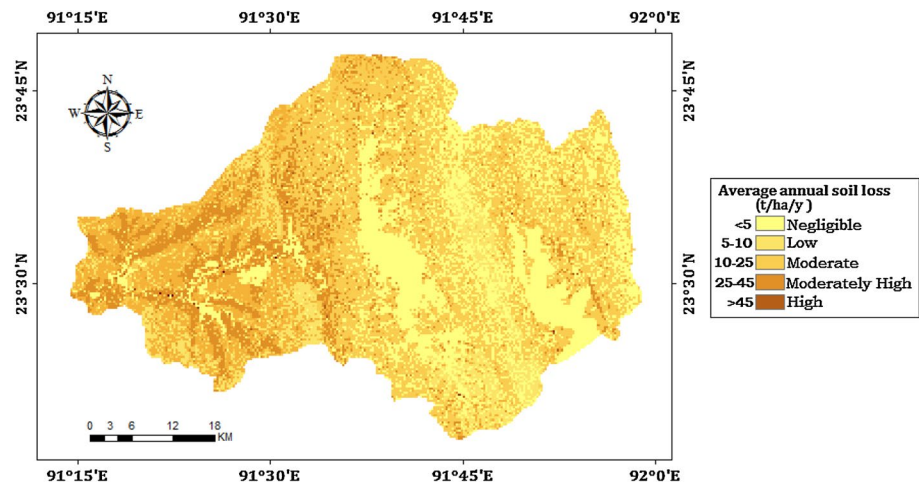

Fig. 5 LS factor map of Gumti River Basin
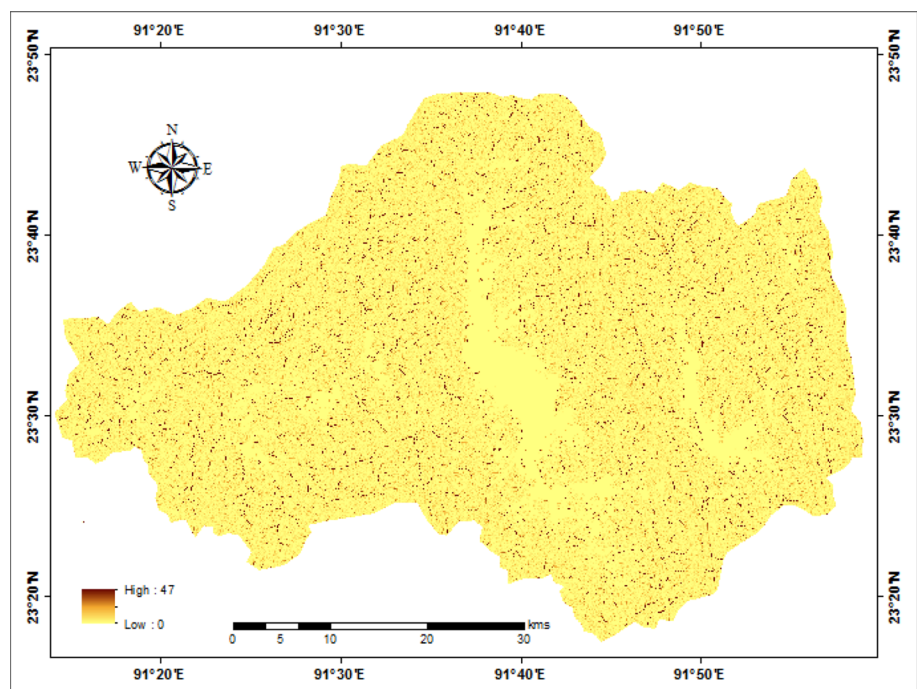
Fig. 6 CP factor map of the Gumti River Basin

Fig. 7 Average annual soil loss (A factor) map of Gumti River Basin

Table 4 Different classes of soil erosion

Soil loss classes (t ha^{-1} year^{-1})	Erosion intensity types
0–5	Negligible erosion
5–10	Low erosion
10–25	Moderate erosion
25–45	Moderately high erosion
>45	High erosion

ranges from '0' in water bodies to slightly greater than '1' in barren land (Toy et al. 2002). The CP factor values in the basin area vary from 0 to 0.58 and the lower CP factor values are seen in the eastern most part of the basin where maximum potion of land use and land cover is dominated by dense to moderately dense forest. However, the agricultural areas which occupy the western and central part of the basin have high CP factor values (Fig. 6).

Potential annual soil loss (A)

In Gumti River Basin, the average annual soil erosion (A) has been computed by multiplying the developed raster data from each factor (A = RKLSCP) of USLE analysis. The final 'A' factor map is shown in Fig. 7. Predicted average annual soil loss of the basin has been classified into five erosion intensity classes (Table 4) to assess soil loss potential severity. Results shows that major portion of soil loss is occurred along the main stream, interhill valley portion and also the flood plain area of the basin. According to erosion risk classes of study area it is observed that 35–40% area is under negligible to low class (0–10 t ha^{-1} year^{-1}) whereas only 5–10% area is under high erosion class (>45 t ha^{-1} year^{-1}) and rest of the area falls under the moderate soil erosion class.

Conclusion

Reliable and updated information on watershed soil erosion is an essential prerequisite for prioritization of watershed as well as formulation of appropriate management programs, which are key components for sustainable development (Pandey et al. 2007). Gumti River Basin in the hilly State Tripura is a forest dominated area and primarily agricultural dependent area. The output results shows that the R factor varies from 795 to 884 (mt ha cm^{-1}), K value is observe in between 0.09 and 0.36, LS factor varies from 0 to 47, CP value in the study area varies from 0.008 to 0.58. Average annual soil loss risk in the Gumti River Basin is moderately high from the acceptable limit. The rate of soil erosion has been changed mainly due to the changing of land use and land cover pattern since the rain fall has changed only with slightly. The study proves that USLE model for soil erosion in combination with RS and GIS is an efficient tool to handle huge volume data needed for basin area soil loss studies. However, there is a need to have direct field measurements data of soil loss in the Gumti River Basin and also the sub basin area to confirm and validate the results of USLE prediction for soil loss.

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