

# An assessment to prioritise the critical erosion-prone sub-watersheds for soil conservation in the Gumti basin of Tripura, North-East India

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**Abstract** Erosion-induced land degradation problem has emerged as a serious environmental issue across the world. Assessment of this problem through modelling can generate valuable quantitative information for the planners to identify priority areas for proper soil conservation measures. The Gumti River basin of Tripura falls under humid tropical climate and experiences soil erosion for a prolonged period which has turned into a major environmental issue. Increased sediment supply through top soil erosion is one of the major reasons for reduced navigability of this river. Thus, the present study is an attempt to prioritize the sub-watersheds of the Gumti basin by estimating soil loss through the USLE (Universal Soil Loss Equation) model. For that purpose, five parameters of the USLE model were processed, computed and overlaid in a GIS environment. The result shows that potential mean annual soil loss of the Gumti basin ranges between 0.03 and 114.08 t ha<sup>-1</sup> year<sup>-1</sup>. The resultant values of soil loss were classified into five categories considering the minimum and maximum values. It has been identified that low, moderate, high, very high and severe soil loss categories occupy 68.71, 8.94, 5.86, 5.02 and 11.47% of the basin respectively. Moreover, it has been recognised that sub-watersheds like SW7, SW8, SW12, SW21, SW24 and SW29 fall

under very high priority class for which mitigation measures are essential. Therefore, the present study recommends mitigation measures through terrace cultivation, as an alternative of shifting cultivation in the hilly areas and through construction of check dams at the appropriate sites of the erosion prone sub-watersheds. Moreover, proper afforestation programmes that have been implemented successfully in other parts of Tripura through the Japan International Cooperation Agency, Joint Forest Management, and National Afforestation Programme should be initiated in the highly erosion-prone areas of the Gumti River basin.

**Keywords** Gumti basin · Geographical information system · Universal soil loss equation · Sub-watershed · Soil loss

## Introduction

The process of soil erosion is regarded as the detachment of productive surface soil, and its transportation and accumulation in a distant place which results in the exposure of subsurface soil (Jain et al. 2001). It is considered to be one of the major environmental issues in both the developing and developed countries of the world. Although the problem persisted on the earth for a longer period, it has become severe in recent times due to increased man-environment interactions (Rasool et al. 2014). Alteration of land cover through expansion of agricultural land and large-

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scale deforestation is acting as a key driver behind the acceleration of soil erosion (Karamage et al. 2016; Lee et al. 2017). Estimation shows that about 5334 metric tonnes of soil is being removed annually from India itself (Narayan and Babu, 1983) and sheet erosion is considered as the most serious problem of India (Tideman 1996).

Soil is considered as a basic resource in maintaining the productivity of any landscape (Gashaw et al. 2017). The rate of erosion of this valuable resource is largely governed by various factors like rainfall, runoff, slope, land cover, and the presence or absence of conservation measures (Solanki and Singh 1996). The balance among such factors is highly influenced by different anthropogenic activities like mining, urbanization, deforestation, and unscientific agricultural practices. Erosion reduces soil fertility, water quality, and crop production (Kartic et al. 2014) which threatens food security. Moreover, maximum portion of the detached particles generated through soil erosion are ultimately added to the river. Consequently, the river bed rises and accelerates the probability of flood hazard. Thus, quantitative information on spatial distribution of erosion induced soil loss is very much essential in prioritizing the areas which require more attention for conservation practices. According to Prasannakumar et al. (2012), the whole watershed environment can be managed appropriately through information at the sub-watershed level. But the traditional field-based method is not effective to monitor and estimate the spatial pattern of soil loss due to the high cost and time involved in it (Chen et al. 2011; Kumar and Kushwaha 2013; Ganasri and Ramesh 2016). In order to overcome this problem, different countries across the world have adopted various models like Universal Soil Loss Equation (Wischmeier and Smith 1965, 1978), Revised Universal Soil Loss Equation (Renard et al. 1991), European Soil Erosion Model (Morgan et al. 1998), Erosion Productivity Impact Calculator (Williams et al. 1990), Water Erosion Prediction Project (Flanagan and Nearing 1995) and EROSION-3D (Schmidt et al. 1999). Among these, the USLE/RUSLE model is functional worldwide in estimating spatial distribution of soil loss for its better accuracy, cost-effectiveness and suitability with GIS application (Millward and Mersey 1999; Jain and Kothiyari 2000; Fernandez et al. 2003; Lu et al. 2004; Erdogan et al. 2007).

The Gumti basin, the largest river basin of Tripura, is experiencing large-scale land degradation due

to increased population pressure. River Gumti was once used as a trade route between India and Bangladesh. But nowadays, the navigability of the river is diminishing alarmingly due to the decrease in water depth. The influx of extra sediment through accelerated soil erosion is considered to be the main reason behind such problem. Moreover, the storage capacity of the Dumbur Reservoir located in the upper course of the Gumti River is depleting due to gradual siltation. Consequently, backflow from this reservoir often flooded the surrounding areas (Majumder et al. 2015). Thus, proper addressing of these problems through identification and conservation of erosion-prone areas of the sub-watersheds is the need of the hour. Therefore, the objective of the present study is to prioritize sub-watersheds of the Gumti basin for soil conservation on the basis of calculated mean annual soil loss using the Universal Soil Loss Equation (USLE) model in the GIS environment as the rate of soil erosion can be estimated with better accuracy through the application of RS and GIS techniques (Sidhu et al. 1998; Sharma et al. 2001; Mani and Chatterjee 2003; Yoshino and Ishioka 2005; Nagaraju et al. 2011; Demirci and Karaburun 2012).

## Study area

Gumti, the longest (180 km) and largest river of Tripura, is formed of the union of two tributaries, namely Raima and Sarma. Its basin is located between 23° 19' N to 23° 47' N latitude and 91° 15' E to 91° 58' E longitude covering an area of 2250 km<sup>2</sup> within the Indian Territory (Fig. 1). The basin is characterised by Dupitila, Tipam, and Surma and recent geological formations. It falls under tropical monsoon climate where pre-monsoon, monsoon and post-monsoon seasons have pronounced influence. The mean maximum and minimum temperatures remain about 35 and 10.4 °C respectively. Most of the rainfall (70–80%) occurs during monsoon in the months of June to October. Dumbur Hydel Power Project, the only hydroelectricity generation station of Tripura, is located on this river. Phyto-geographically, the study area is characterised by savannah woodland, scrub forest and deciduous forest, a part of which has been declared as reserved forest. About 53.87% (2011 Census) workforce of the study area are engaged in agriculture and allied activities.

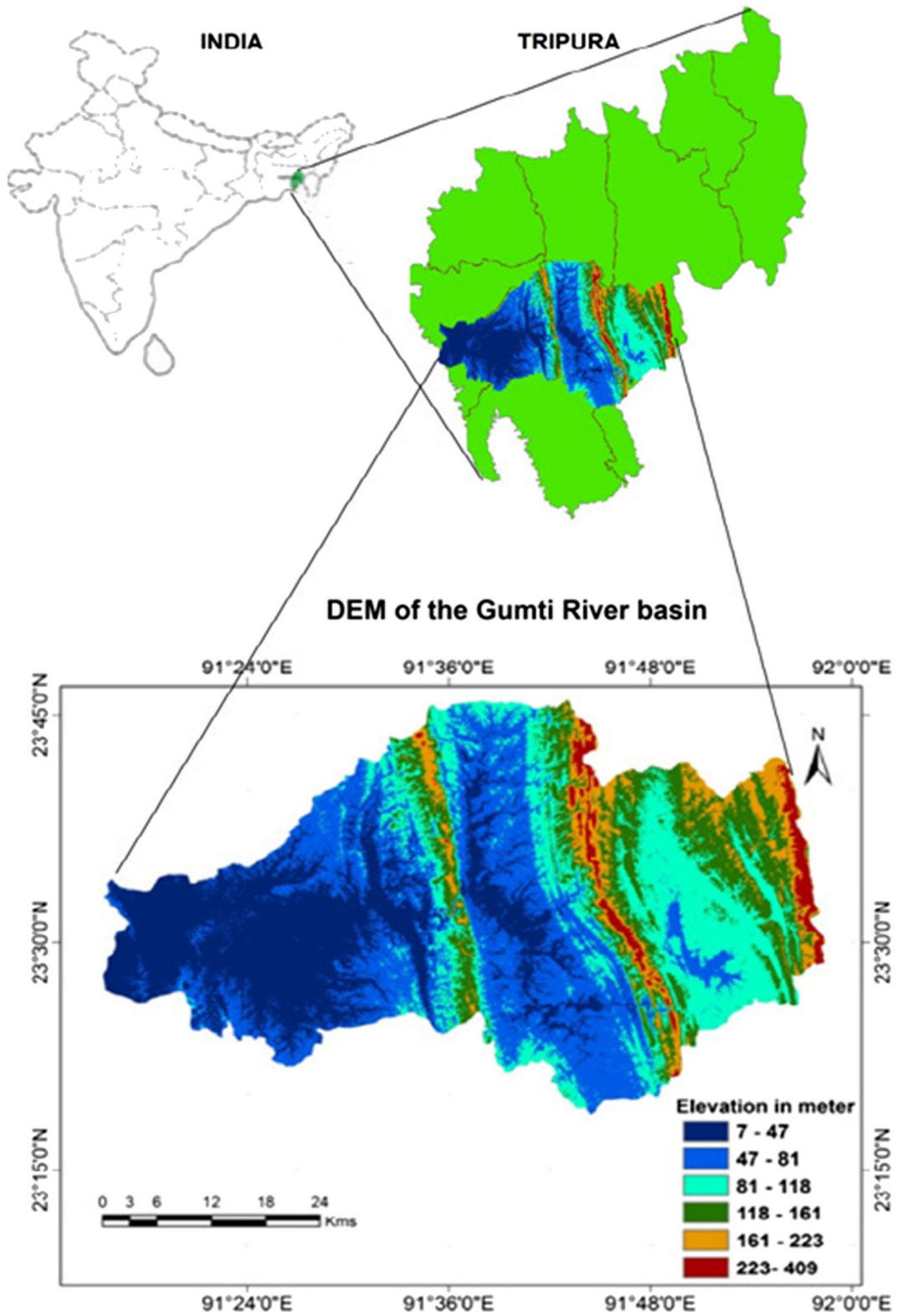


Fig. 1 Location of the study area

## Materials and methods

### Data sources and processing

In the present study, LANDSAT 8 satellite imagery, acquired on March 2016, was used for preparation of land use/land cover map. This latest version of LANDSAT series uses two sensors, i.e. Operational Land Imager and the Thermal Infrared Sensor for better spectral and radiometric characteristics. Supervised classification by maximum likelihood algorithm along with ground truth verification method was applied to prepare the LULC map which became the basis of C and P factor maps. For preparation of soil erodibility factor map, the soil map of Tripura State from NBSS and LUP (National Bureau of Soil Survey and Land Use Planning) was geo-referenced, the soil map of the Gumti basin was extracted and the vector layer of different soil classes was generated. Rainfall data of different meteorological stations were collected from the Department of Agriculture, Govt. of Tripura. The LS factor map was prepared by using Aster DEM of 30 m resolution. All the raster datasets were reprojected using UTM Zone 46N. The grid cells of all the base maps were of  $30\text{ m} \times 30\text{ m}$  as this procedure is very much effective to create uniform spatial environment for GIS analysis (Bhadur 2009; Prasannakumar et al. 2012; Farhan et al. 2013).

### Description of the model

Universal Soil Loss Equation (USLE) is an empirical equation used to predict and calculate mean annual soil loss of a given area. Its result varies from area to area depending on five major factors which have been discussed in the present study. The equation of USLE is expressed as

$$A = R.K.LS.C.P$$

where A denotes computed average annual soil loss ( $\text{t}^{-1}\text{ ha}^{-1}\text{ year}$ ), R is the rainfall erosivity factor ( $\text{MJ mm}^{-1}\text{ ha}^{-1}\text{ h}^{-1}\text{ year}^{-1}$ ), K is the soil erodibility factor ( $\text{t MJ}^{-1}\text{ year}^{-1}\text{ ha}^{-1}\text{ h}^{-1}\text{ mm}^{-1}$ ), LS (dimensionless) is the topographical factor (slope length and slope steepness factor), C (dimensionless) is the crop management factor and P (dimensionless) is the conservation practice factor. Finally, the amount of soil loss was calculated by integrating all these factors in GIS environment (Fig. 2).

### Rainfall erosivity factor (R)

This factor quantifies the erosive force of rain which depends on its amount, intensity and duration. It expresses the capability of rain to erode (Lal 1990). Erosivity of rainfall is considered to be the most important factor of USLE as it plays the key role in detachment of soil and formation of gullies. In the original equation of USLE model, data on kinetic force of storm and

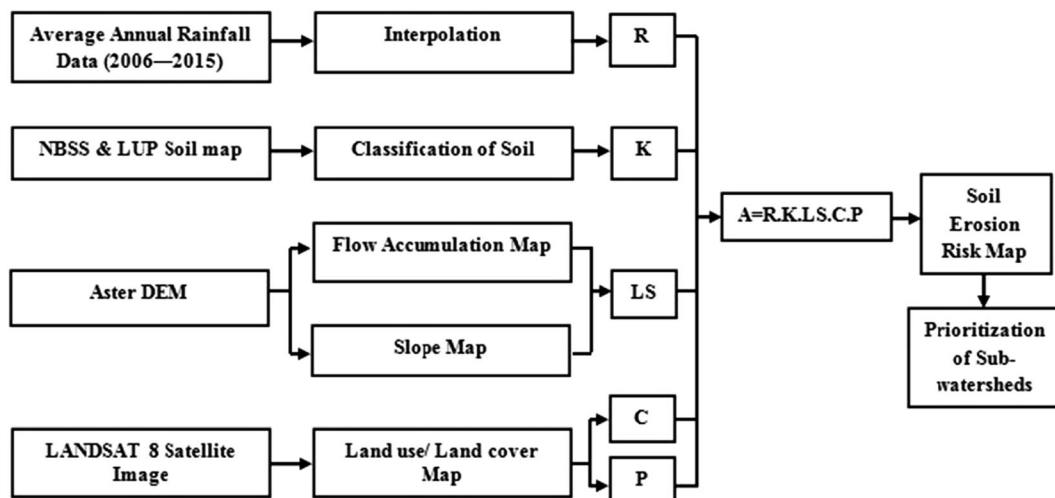


Fig. 2 Flow chart showing methodology of the present study

intensity of rainfall in 30 min are used to calculate the R factor. But for the study area, these data are unavailable and therefore, linear equation, suggested by Singh et al. (1981), was applied to compute rainfall erosivity. This linear relationship between rainfall erosivity ( $R_a$ ) and annual rainfall (P) was developed on the basis of data collected from 45 rain gauge stations located in different zones of India. This equation had already been applied by many Indian scholars to estimate rainfall erosivity (Jain et al. 2010; Ghosh et al. 2013; Parveen and Kumar 2012; Ahamad and Verma 2013; Dutta et al. 2015; Tiwary et al. 2015; Bhat et al. 2017). It is expressed as

$$R_a = 79 + 0.363 \times P$$

Here,  $R_a$  = R factor on annual basis, P = Rainfall in millimeters.

For the present purpose, average rainfall data for 10 years (2006–2015) of Amarpur, Udaipur and Sonamura rain gauge stations were considered to calculate the R factor (Table 1). Moreover, for better accuracy, rainfall data of the neighbouring Chhamanu, Teliamura, Bishalgarh and Belonia stations were also considered. All data were interpolated in ArcGIS using the IDW (inverse distance weighting) method. The resolution of the generated map was set as 30 m to keep it identical with other maps used in the present study. Figure 3 represents the spatial distribution of the R factor over the Gumti basin.

#### Soil erodibility factor (K)

The susceptibility of soil to erosion through runoff is determined by its erodibility (Parveen and Kumar 2012). Factor K is controlled by the inherent

**Table 1** Average annual rainfall and respective R values at different rain gauge stations

Sl. no.	Rain gauge station	Average annual rainfall (mm) (2006–2015)	R factor value
1	Chhamanu	2017.60	811.39
2	Teliamura	1880.00	761.44
3	Bishalgarh	1734.82	708.74
4	Sonamura	2025.37	814.21
5	Matabari	2017.77	811.45
6	Amarpur	2095.05	839.50
7	Belonia	2161.19	863.51

characteristics of soil like texture, structure, porosity and organic matter content. Generally, clayey soils are resistant to erosion for its cohesiveness. On the other hand, non-cohesive soils containing large quantity of silt and fine sand are highly erodible (Prasannakumar et al. 2011). Other factors like topography, steepness of slope and anthropogenic disturbances also affect this factor directly or indirectly. For the present study, the vector layer of the Gumti basin was overlaid on the geo-referenced soil map of Tripura prepared by NBSS and LUP and was cropped using clipping tool of ArcGIS 10.1 software. Subsequently, vector layers of different soil types which fall within the Gumti basin were prepared through digitization and converted to raster format after assigning a K value to each of them.

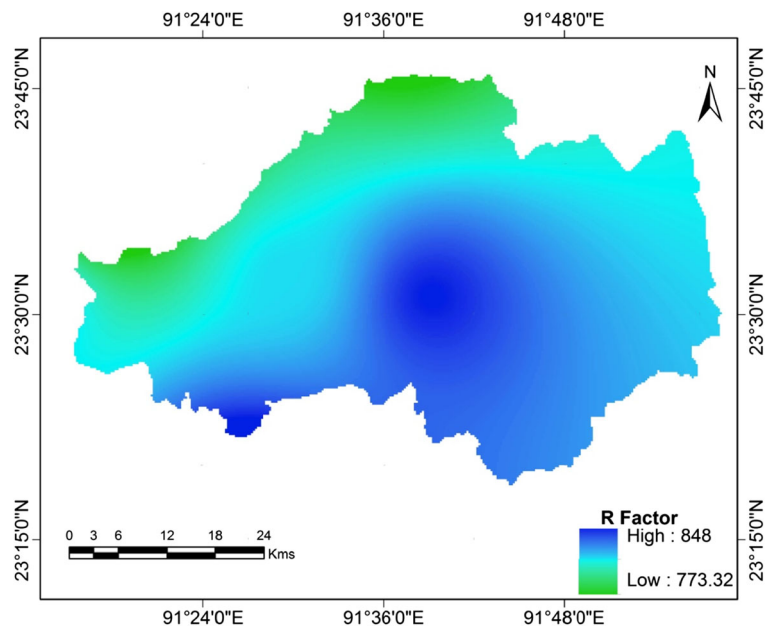
Based on different physiographic units of the basin, different soil types were identified as (i) soils of the high relief structural hills ( $K = 0.09$ ), (ii) soils of the medium relief parallel ridges ( $K = 0.26$ ), (iii) soils of the flat-topped denudation hills ( $K = 0.16$ ), (iv) soils of the undulating plains with low mounds ( $K = 0.16$ ), (v) soils of the inter-hill valleys ( $K = 0.36$ ) and (vi) floodplains ( $K = 0.34$ ). The K values of respective soils were considered following Ghosh et al. (2013) who estimated it using the nomograph suggested by Wischmeier and Smith (1978). The spatial distribution of the K factor over the Gumti basin is presented in Fig. 4.

#### Slope length and slope steepness factor (LS)

Slope length (L) and slope steepness (S) factors reflect the role of topography in controlling the rate of soil erosion of an area (Naqvi et al. 2013). Slope length generally controls the detachment of soil and generation of sediment whereas steepness rules the motion of these sediments through rainfall-induced runoff (Pradeep et al. 2015). In general, as slope steepness increases, soil erosion also gets momentum in response to the cumulative progress in velocity of surface runoff in downhill direction. For the present study, Aster DEM was used to derive the LS factor map using Spatial Analysis tool of ArcGIS 10.1 software. Aster DEM was selected as its spatial resolution (30 m) closely matches with the resolution of LANDSAT 8 imagery. Primarily, slope map and flow accumulation map were generated from Aster DEM using hydro extension of Spatial



**Fig. 3** Spatial distribution of rainfall erosivity in the Gumti River basin



Analysis tool. Both the maps were then used in raster calculator of ArcGIS to prepare LS factor map of the Gumti basin following the formula suggested by Moore and Burch (1986a, b) (Fig. 5).

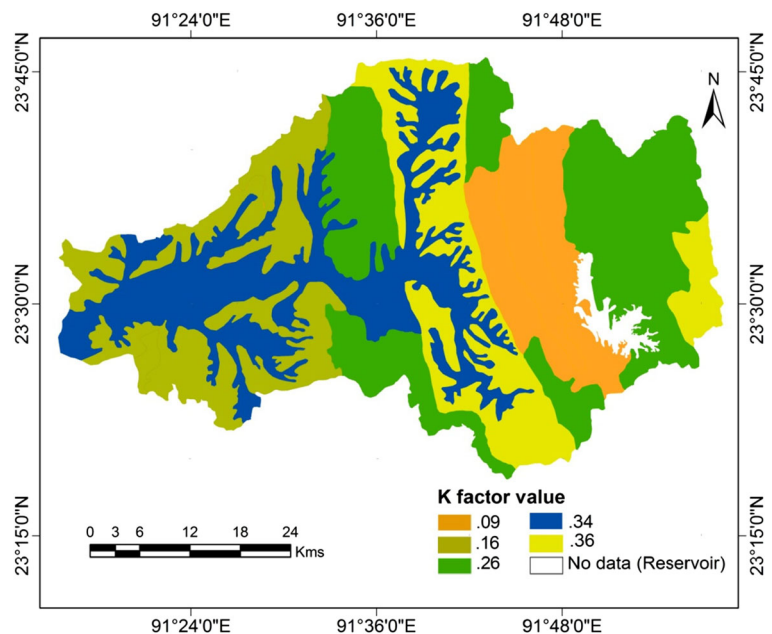
$$LS = (Flow\ accumulation \times Cell\ size / 22.13)^{0.4} \times (\sin\ slope / 0.0896)^{1.3}$$

Here, LS is the combination of the factors of slope length and steepness, Cell size means the size of cells of different grids (for the present study cell size is 30 m) and Sin slope means the Sin value of the slope angle in degrees.

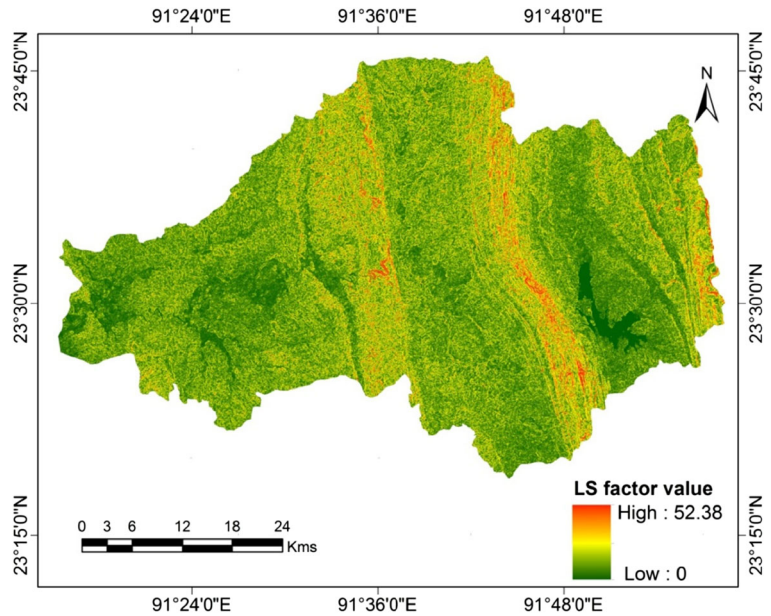
Crop management factor (C)

Factor of crop management depends on the nature of land use/land cover (LULC) of any area. It is defined as

**Fig. 4** Spatial distribution of soil erodibility in the Gumti River basin



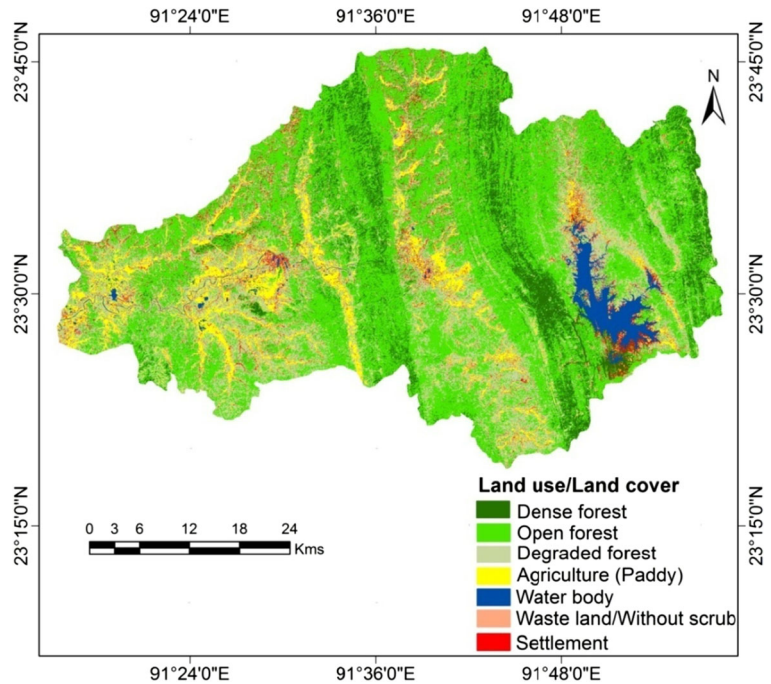
**Fig. 5** Spatial distribution of slope length and steepness in the Gumti basin



the ratio of soil loss from a land under crop to corresponding loss from bare tilled fallow land under the same condition (Wischmeier and Smith 1978). The crop management factor is highly influenced by the canopy cover of any area. With increase in vegetal cover, the rate of soil erosion tends to decrease (Shit et al. 2013; Jiang et al. 2015). High C value means more susceptible to erosion due to lesser protection against direct impact of rain drops.

For the present purpose, a supervised classification technique was applied to prepare the LULC map using LANDSAT 8 imagery (discussed earlier). The Gumti basin was divided into seven LULC classes namely (i) Dense forest, (ii) Open forest, (iii) Degraded forest, (iv) Agriculture (paddy field), (v) Waste land with/without scrub, (vi) Water body and (vii) Settlement (Fig. 6). Maximum portion (44.83%) of the study area falls under open forest class (Table 2). The raster land use map was

**Fig. 6** Land use/land cover map of the Gumti River basin as in March 2016



**Table 2** Land use/land cover statistics of the Gumti River basin

Sl. no.	Land use/land cover classes	Area (km <sup>2</sup> )	Area (%)
1	Dense forest	296.10	13.16
2	Open forest	1008.67	44.83
3	Degraded forest	541.13	24.05
4	Agriculture (paddy field)	270.90	12.04
5	Waste land with/without scrub	10.35	0.46
6	Water body	56.25	2.5
7	Settlement	66.6	2.96

converted into polygon form using ArcGIS conversion tool. The C value was then allotted to the polygon of each LULC class (Table 3) which was taken from previous literatures (USDA 1972; Rao 1981; Pandey et al. 2009). After assigning C values, the whole polygon map was reconverted to the raster form to generate the C factor map of the Gumti basin (Fig. 7).

#### Conservation practice factor (P)

The P factor refers to the ratio of soil loss from a field with definite supporting practice to that where upslope and downslope cultivation is practiced (Wischmeier and Smith 1978; Dabral et al. 2008). Factor P signifies the conservation measures that have been taken up in any area to reduce runoff-induced soil erosion. The lower value of P indicates the presence of effective conservation measures against soil loss (Yue-Qing et al. 2008; Prasannakumar et al. 2011; Shit et al. 2015).

The most important conservation practices mentioned in the USLE model are contour farming, strip cropping and terrace system which decrease the velocity of runoff. In the study area, only bunds along paddy fields are observed which are not at all effective in

**Table 3** C factor for different land use/land cover classes

Sl. no.	Land use/land cover classes	C factor value
1	Dense forest	0.004
2	Open forest	0.008
3	Degraded forest	0.008
4	Agriculture (paddy field)	0.28
5	Waste land with/without scrub	0.18
6	Settlement	1

Source: USDA (1972), Rao (1981), Pandey et al. (2009)

reducing soil erosion. Other areas are lacking in any conservation measures to reduce soil erosion. Therefore, the whole land use/land cover map was converted into polygon form and except the polygon of agricultural land, all other polygons were merged together to divide the whole Gumti basin into two land use classes i.e. agricultural land and non-agricultural land. The P value of 0.28 was assigned to the former and 1.0 to the later (Fig. 8), as used in other literatures (Rao 1981; Pandey et al. 2009; Biswas and Pani 2015).

## Results and discussion

### USLE factors

The values of rainfall erosivity (R) within the Gumti basin ranges between 773.32 and 848 MJ mm<sup>-1</sup> ha<sup>-1</sup> h<sup>-1</sup> year<sup>-1</sup> with maximum concentration in the central part and minimum in the extreme northern and north-eastern parts of the basin (Fig. 3). In general, the value of the R factor shows an increasing trend towards the centre from all directions of the basin. Variability in average annual rainfall over the Gumti basin and its surrounding areas has greatly influenced the overall distribution of the R factor.

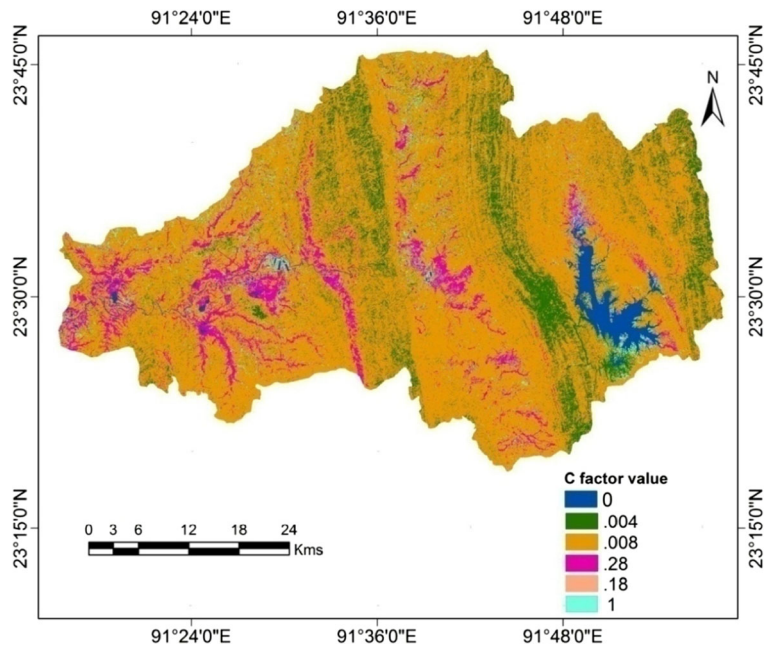
Distribution of soil erodibility over the Gumti basin is extremely uneven due to the diverse lithological characteristics. The lowest (0.09) and highest (0.36) values were observed along the Atharamura hill range and in the synclinal valley between the Atharamura and the Baramura-Deotamura hill ranges respectively. Higher K value of any soil type indicates that the soil is more susceptible to erosion (Kumar and Kushwaha 2013).

The slope length and slope steepness factor (LS) value of the Gumti basin ranges between 0 and 52.38 (Fig. 5). High values are found in the central and eastern parts of the basin where the Baramura-Deotamura, Atharamura (Central part) and Longtarai (Eastern part) hill ranges are present (Fig. 5). These areas are characterised by alternate ridge and vale topography where length and steepness of slopes are more. On the contrary, low LS values are observed in the flood plain characterised by a gentle slope present in the lower course of the river (from Maharani up to Srimantapur). Thus, the areas characterised by higher LS value with exposed surface have the possibilities to wear away more easily than the areas with lower values.

The overall land use/land cover map of the Gumti basin reveals that a maximum portion (44.83%) of the



**Fig. 7** Spatial distribution of crop management in the Gumti River basin

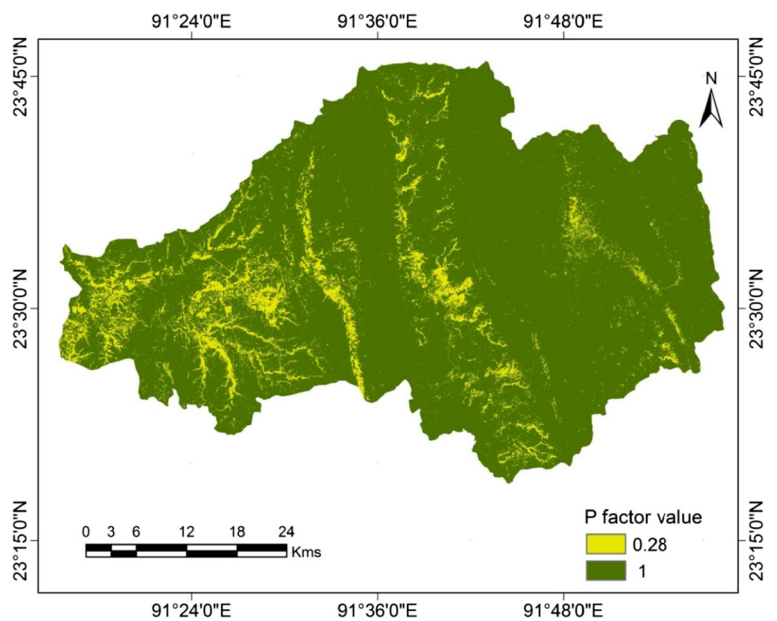


study area falls under open forest class (Table 2). Variation in land use/land cover pattern seems to have influenced the overall distribution of the C factor. Spatial distribution of the C value reveals that moderate (0.28) to very high (1.0) value prevails in the central and western parts of the Gumti basin. High C value leads to an

increase in the vulnerability of soil erosion as it indicates an unprotected nature of the surface area (Prasannakumar et al. 2011).

The lower value of the P factor reveals that effective conservation measures have been taken to reduce erosion which is highly lacking in the study area. Its spatial

**Fig. 8** Spatial distribution of conservation practices in the Gumti basin



**Table 4** Percentage of area under different soil erosion classes

Average annual soil loss ( $t^{-1} h^{-1} year^{-1}$ )	Erosion class	Area coverage ( $km^2$ )	Area in percentage
< 8	Low	1546	68.71
8–30	Moderate	201.15	8.94
30–71	High	131.85	5.86
71–103	Very high	112.95	5.02
> 103	Severe	258	11.47

distribution indicates lower value (0.28) in the central and western parts of the basin, and remaining areas with higher values i.e. conservation measures are lacking.

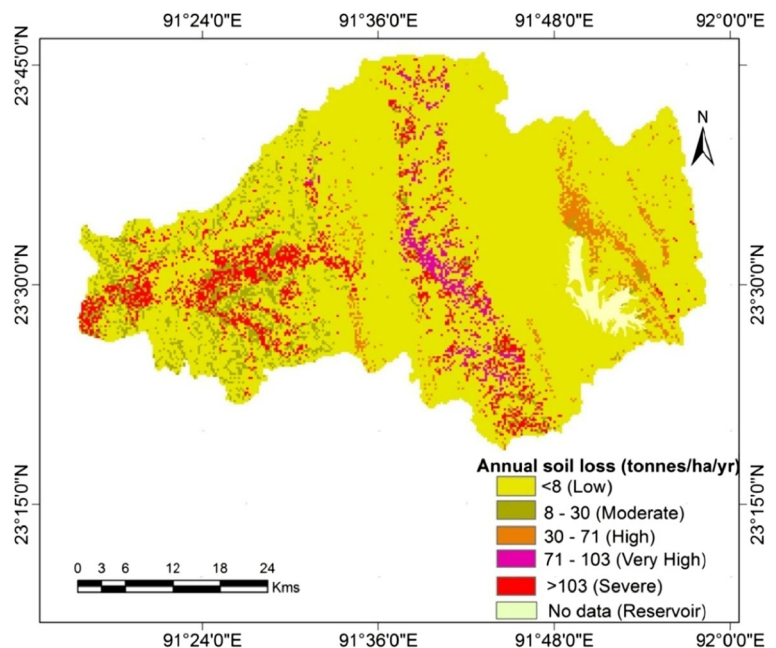
#### Average annual soil loss of the Gumti basin

The dimension of erosion in any area is governed by the interaction of different factors like topography, soil, climate, natural vegetation, land use/land cover and various development efforts. The present study was an attempt to measure the amount of soil loss in the Gumti basin using the USLE model within GIS environment. The result shows that the potential mean annual soil loss in the Gumti basin ranges from 0.03 to 114.08  $t ha^{-1} year^{-1}$ . The researchers have categorised the amount of soil loss into five erosion classes following different studies conducted in India regarding soil

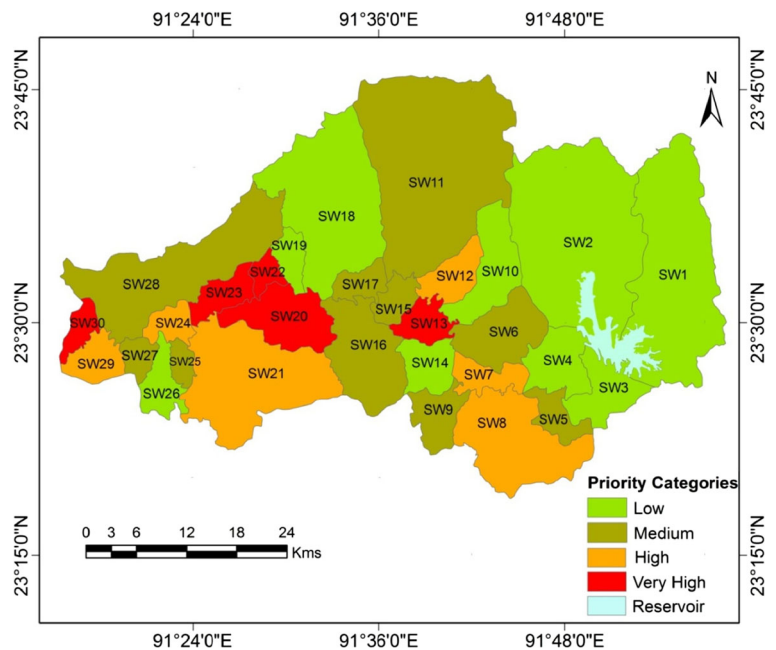
erosion (Prasannakumar et al. 2011; Kartic et al. 2014; Saini et al. 2015; Khare et al. 2017).

The major portion of the basin (68.71%) falls under low soil erosion risk category ( $< 8 t ha^{-1} year^{-1}$ ) (Table 4). The areas having high vegetal cover show low vulnerability to soil erosion that are located mainly in the north-eastern and extreme eastern parts of the Gumti basin. At the same time, 11.47% of the basin experiences severe soil loss of  $> 103 t ha^{-1} year^{-1}$  which are observed in central and western parts of the basin (Fig. 9). The central section of the basin is characterised by high value of rainfall erosivity and soil erodibility as discussed earlier. Moreover, this portion of the basin is dominated by inter-hill valleys where agriculture is practiced in the relatively sloppy areas. The combined effect of all the factors leads to high rate of soil erosion. The western part of the basin is characterised by the presence of residual hills and valleys, locally called as “tilla and lunga,” surrounded by flood plains. This part is known as the “granary of Tripura” and experiences high population pressure. Consequently, large-scale expansion of agricultural land has been taking place over the last few decades through deforestation activities which have led to severe soil erosion. Therefore, proper management strategies are required to be implemented in the central and western parts of the Gumti basin for effective soil conservation on an urgent basis. Other classes like

**Fig. 9** Spatial distribution of average annual soil loss in the Gumti River basin



**Fig. 10** Prioritization of sub-watersheds on the basis of mean annual soil loss



moderate, high and very high erosion occupy 8.94, 5.86 and 5.02% of the basin respectively (Table 4).

Prioritization of sub-watersheds on the basis of mean annual soil loss

The concept of prioritization plays a vital role in identification of areas which require more attention in respect to soil erosion (Kanth and Hassan 2010; Naqvi et al. 2012). It is very much effective for the application of proper planning and management programme in the adverse erosion-prone areas. For the present purpose, 30 sub-watersheds of the Gumti River basin have been categorised under four priority classes on the basis of mean annual soil loss which are (i) low ( $< 10 \text{ t ha}^{-1} \text{ year}^{-1}$ ), (ii) medium ( $10\text{--}20 \text{ t ha}^{-1} \text{ year}^{-1}$ ), (iii) high ( $20\text{--}30 \text{ t ha}^{-1} \text{ year}^{-1}$ ) and (iv) very high ( $> 30 \text{ t ha}^{-1} \text{ year}^{-1}$ ) (Fig. 10 and Table 6).

1. Low priority class

The SW1 to SW5, SW10, SW14, SW18, SW19 and SW26 fall under low priority class. Mean soil loss in these sub-watersheds ranges between 1.50 and  $9.21 \text{ t ha}^{-1} \text{ year}^{-1}$  (Table 5). These areas do not require immediate action plan towards reduction of soil erosion. The reasons behind such low mean soil loss are basically the presence of high canopy cover and less depletion of natural resources.

2. Medium priority class

The sub-watersheds with  $10 \text{ to } 20 \text{ t h}^{-1} \text{ year}^{-1}$  soil loss fall under this category. The watersheds SW6, SW9, SW11 and SW15 to SW17, SW25, SW27 and SW28 are considered under medium priority class (Table 6).

3. High priority class

Six sub-watersheds, namely SW7, SW8, SW12, SW21, SW24 and SW29 are characterised by a high priority class of mean annual soil loss among which the highest ( $29.8 \text{ t ha}^{-1} \text{ year}^{-1}$ ) loss has been reported from SW12 (Table 5). Proper attention is required to prevent these sub-watersheds from downgrading to very high priority class.

4. Very high priority class

The very high priority sub-watersheds include SW13, SW20, SW22, SW23 and SW30 (Table 6). Mean soil loss from these areas remains  $> 30 \text{ t ha}^{-1} \text{ year}^{-1}$  which is due to the occurrence of high rainfall (as observed in the R factor map) and overexploitation of natural resources.

**Table 5** Priority ranking of sub-watersheds on the basis of mean soil loss

Sub-watershed	Mean soil loss (tonnes ha <sup>-1</sup> year <sup>-1</sup> )	Priority
SW 1	7.62	23
SW 2	6.9	27
SW 3	1.5	30
SW 4	2.38	29
SW 5	6.88	28
SW 6	16.10	13
SW 7	26.24	8
SW 8	24.93	9
SW 9	13.17	16
SW 10	9.21	21
SW 11	10.16	20
SW 12	29.8	6
SW 13	33.27	5
SW 14	6.96	26
SW 15	12.51	17
SW 16	11.04	19
SW 17	11.48	18
SW 18	7.24	24
SW 19	8.40	22
SW 20	34.64	2
SW 21	20.40	11
SW 22	34.41	3
SW 23	44.66	1
SW 24	22.33	10
SW 25	14.54	14
SW 26	7.08	25
SW 27	13.89	15
SW 28	16.72	12
SW 29	26.81	7
SW 30	33.70	4

Therefore, immediate action is necessary in these sub-watersheds to diminish the amount of soil loss.

#### Suggestive measures to reduce soil erosion

In the present study, three measures have been suggested to reduce the intensity of soil erosion from the Gumti basin. The suggested measures are based on different local environmental issues, available resources and economic condition of the State.

**Table 6** Priority categories of different sub-watersheds

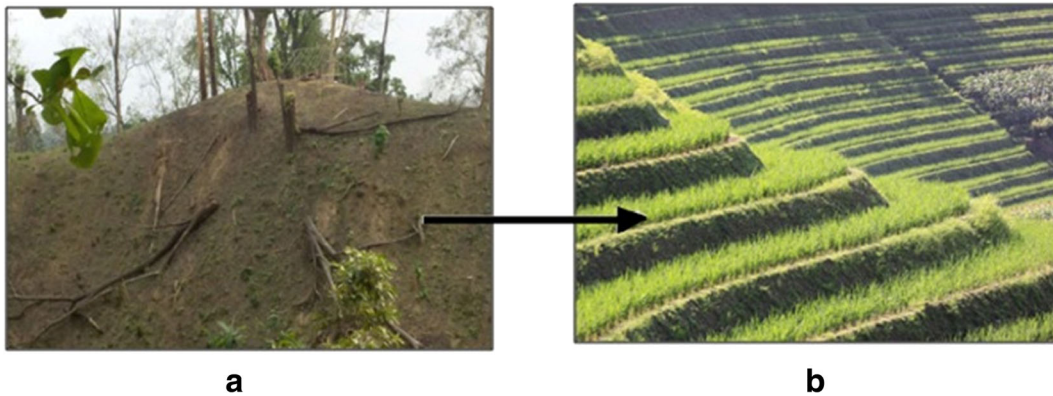
Priority categories	Mean soil loss (tonnes ha <sup>-1</sup> year <sup>-1</sup> )	Sub-watersheds	Number of sub-watersheds
Low	< 10	SW 1, SW 2, SW 3, SW 4, SW5, SW 10, SW 14, SW 18, SW 19, SW 26	10
Medium	10–20	SW 6, SW 9, SW 11, SW 15, SW 16, SW 17, SW 25, SW 27, SW 28	9
High	20–30	SW 7, SW 8, SW 12, SW 21, SW 24, SW 29	6
Very high	> 30	SW 13, SW 20, SW 22, SW 23, SW 30	5

#### 1. Scientific way of agricultural practice:

The hilly parts of the Gumti basin is dominated by shifting cultivation, locally called jhum cultivation, which is considered unscientific as in this process trees and vegetation are completely cleared up to prepare the land for cultivation (Plate 1a). Subsequently, during heavy shower the land becomes vulnerable to erosion. Thus, in the present study terrace cultivation has been suggested as a substitute of jhum cultivation. In terracing, level-floored benches are being prepared on the steep hill slopes (Plate 1b). The leveled floor is then being used for growing crops. Such step-like structure can be very much effective in decreasing soil erosion because the flow velocity of rain water is reduced while moving through such structure in downslope direction.

#### 2. Construction of check dams

Check dams should be constructed in the hilly parts of the streams that have their ultimate confluence with the Gumti River. The streams draining SW13, SW20, SW22, SW23 and SW30 should be given first priority for such construction as these are under very high erosion risk category. Construction of check dams can be very effective in reducing the supply of eroded materials to the main channel which, in turn, will minimize the problem of flood hazard.



**Plate 1** **a** Area under jhum cultivation at Amarpur within the Gumti basin. **b** Terrace cultivation suggested as an alternative to jhum cultivation

### 3. Implementation of proper afforestation programmes

Proper afforestation can remarkably reduce the intensity of soil erosion as trees not only bind the soil but also protect it from the direct impact of raindrops. Afforestation programmes like Japan International Cooperation Agency (JICA) project, Joint Forest Management (JFM) Programme and National Afforestation Programme (NAP) are running successfully in other parts of Tripura, which can also be initiated in the severe erosion-prone watersheds. Bamboo plantation is also recommended for its suitability under the geo-environmental condition of Tripura State.

### Conclusion

Soil erosion is a major environmental issue for the Gumti River basin as the eroded soils are directly or indirectly added to the river and thus hampered its navigability. Increased human pressure over the basin has resulted in the expansion of agricultural land by means of deforestation which, along with high rainfall, acts as a key factor for soil loss. The study reveals that the potential mean annual soil loss from the Gumti basin ranges between 0.03 and 114.08 t ha<sup>-1</sup> year<sup>-1</sup>. Moreover, about 5.02 and 11.47% areas of this basin fall under very high and severe soil loss categories. The five sub-watersheds fall under high priority class require immediate attention. The information derived from the present study can be very much effective for adaptation of proper management strategies and conservation measures on a micro level to reduce soil erosion in the Gumti

basin in the coming future. In Tripura, the estimation of soil loss, especially at the sub-watershed level, is lacking and therefore further studies are necessary as soil erosion is a burning environmental issue of the modern era.

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