Chapter 5
Effect of Land Use/Land Cover Change on Soil Loss in the Tropical River Catchment of Northeast India

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Abstract Soil erosion becomes a common problem in tropical river basins like the Muhuri River basin where intensity of rainfall as well as degradation of forest, unscientific agricultural activities and excessive jhoom cultivation are more pronounced. It accelerates the rate of sediment deposition in the river which disturbs natural condition of the channel. Therefore, the present research aims to assess the spatio-temporal change of soil erosion status owing to land use/land cover change (LULC) in the Muhuri River basin. This study used land sat imageries of 1986 (TM) and 2019 (OLI) along with supervised classification technique to estimate the LULC change. Moreover, the model of Universal Soil Loss Equation (USLE) was applied to assess the soil erosion. The whole work was processed and computed under the geo-processing tool of ArcGIS 10.1. The result revealed that during the period 1986–2019, the area under dense forest, open forest, degraded forest, jhoom cultivation and water body were reduced by 92.05, 68.63, 5.05, 25.29 and 25.64%, respectively, while the extent of the agricultural land, rubber plantation, settlement and barren land increased by 14.47, 1600.39, 95.36 and 197.33%, respectively. As a result, the range of average annual soil loss of the Muhuri River was increased from 0 to 101.06 t ha^{-1} year^{-1} (during 1986) to 0 to 110.08 t ha^{-1} year^{-1} (during 2019). Obviously, the mean rate of soil erosion is associated with the LULC change of the study area, and therefore, in case of degraded forest, agricultural land, rubber plantation and jhoom cultivation, the mean soil loss was increased by 2.37, 1.22, 1.50 and 1.32 t ha^{-1} year^{-1} correspondingly within the study period (1986–2019). Therefore, the findings of the research illustrate that declined natural forest cover along with increased settled area, barren land, agricultural land and existence of shifting cultivation increases the soil erosion potential in the river basin over the study period. Thus, there is a need of sustainable maintenance of watershed resources to control the sediment influx into the river.

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5.1   Introduction

Soil erosion is a natural phenomenon ensuing from detachment of the top soil due to some natural agents (wind and water) and anthropogenic activities (overgrazing, deforestation, forest fire, etc.). According to Angima et al. (2003), about 85% of land and degradation occurs owing to soil erosion, and Pandey et al. (2009) opined that LULC change is the main component for this. Since the last century, soil erosion expanded via anthropogenic activities becomes the most important environmental hassle all over the globe (Sharma et al., 2011). In India, almost 113.3 million hectare of land is affected by soil erosion and almost 5334 million tonnes of soil is being removed yearly owing to different reasons (Narayan & Babu, 1983), and almost 7.5% areas (0.20 million km^2) are effected by intense bank erosion (Ahmad et al., 2020). According to Bhattacharyya et al. (2016), inappropriate agricultural practices are mostly responsible for the soil erosion in India, which has reduced the soil fertility and created an effect on the food and livelihood security of the farmers. Generally, soil erosion is regulated by the nature of topography, soil properties, forest cover, land use, etc. Moreover, a group of aspects like slope steepness, heavy rainfall after long dry period, improper LULC pattern (e.g., degraded forest) and ecological disaster (e.g., shifting cultivation) along with some inherent characteristics of soil profile, such as thin upper layer and less organic content, make it more prone to erosion (Ganasri & Ramesh, 2016).

Nowadays, declining forest cover, growing settled area and inappropriate agricultural practice have accelerated soil erosion in the river catchments significantly. Intense soil erosion amplifies sedimentation in the channel bed and reservoir as well as affects floodplain morphology and its ecological functioning (Asselman & Middelkoop, 1995; Verstraeten & Poesen, 2002; Richards et al., 2002). Therefore, watershed management becomes an important task to the planners. To evaluate the annual soil loss and sediment yield of a river basin or a watershed and to recognize the erosion prospective zone at regional, as well as global scale, various models were used (Pandey et al., 2007; Dabral et al., 2008) among which USLE became widely accepted throughout the world (Wischmeier & Smith, 1978). The RS and GIS techniques are extensively used for its cost effectiveness and better accuracy to soil erosion estimation and its spatial distribution in broader areas (Shit et al., 2015; Phinzi et al., 2020). The USLE model associated with GIS provides a fruitful and better accuracy result than the traditional methods (Roy, 2019) and also helps for mapping the priority-wise erosion prone areas (Girmay et al., 2020; López-García et al., 2020; Fiener et al., 2020; Delgado, 2020). On the other hand, use of temporal satellite images to study the relation among the change of LULC and soil erosion becomes widespread in modern research (Jordan et al., 2005). Apparently, LULC change and its effects on the soil erosion potential in addition with sediment

transport rate were studied by many researchers at temporal scale (Sharma et al., 2011; Esa et al., 2018; Huang et al., 2020).

The present research pursuits to estimate the amount of soil loss due to LULC change using USLE model with the useful resource of the GIS medhod. Through this study the contribution of each LULC element on soil erosion was justified. Moreover, the spatio-temporal analysis of soil erosion over the whole basin was supportive to identify the most affected part of the basin and useful for the engineers and the planners for formulating important action plans.

5.2 Regional Setting

The Muhuri River basin consists of three Rural Development Blocks and is located in the southern part of Tripura (Fig. 5.1). It lies among 23°10′ N to 23°25′ N latitude and 91°26′ E to 91°46′ E longitude occupied about 701.72 km^2 surface area. The River Muhuri originates from the Baramura-Deotamura hill range and enters Bangladesh after flowing for 53.3 km within Tripura. The basin experiences moist humid climate with medium to high rainfall (1500–2000 mm). Here the average summer temperature varies from 25° to 29 °C, whereas the winter temperature from 19 to 24 °C.

The western part of the basin is bounded by Bangladesh. Its total population is estimated to be more than 1,80,000 among which the immigrated Bengalese dominate over the indigenous community. The area is most densely populated with a density of 256 persons/km^2. Here majority of the tribal population live in the hilly part and there is predominance of Bengalese in the plain part.

5.3 Materials and Methods

Identification of LULC Change Map

The study of LULC change detection and its evaluation was accomplished by adopting a series of steps and processes which includes collection of satellite images, pre-processing, supervised classification using maximum likelihood algorithm and post classification comparison. In an effort to identify the changes in LULC of the study area, the researcher used the TM (Thematic Mapper) satellite image of 1986 as the base year and OLI (Operational Land Imager) image of 2019 as the current year. All the Landsat images were downloaded from the United States Geological Survey (USGS) website. The collected raw imageries were processed in ArcGIS 10.1. The image pre-processing was performed for contrast enhancement of the satellite images so that the pixel values can be distributed uniformly to avoid the radiometric distortion, and thus reliability of the pixels' brightness value increases. On the other hand, supervised classification technique with maximum likelihood algorithm was
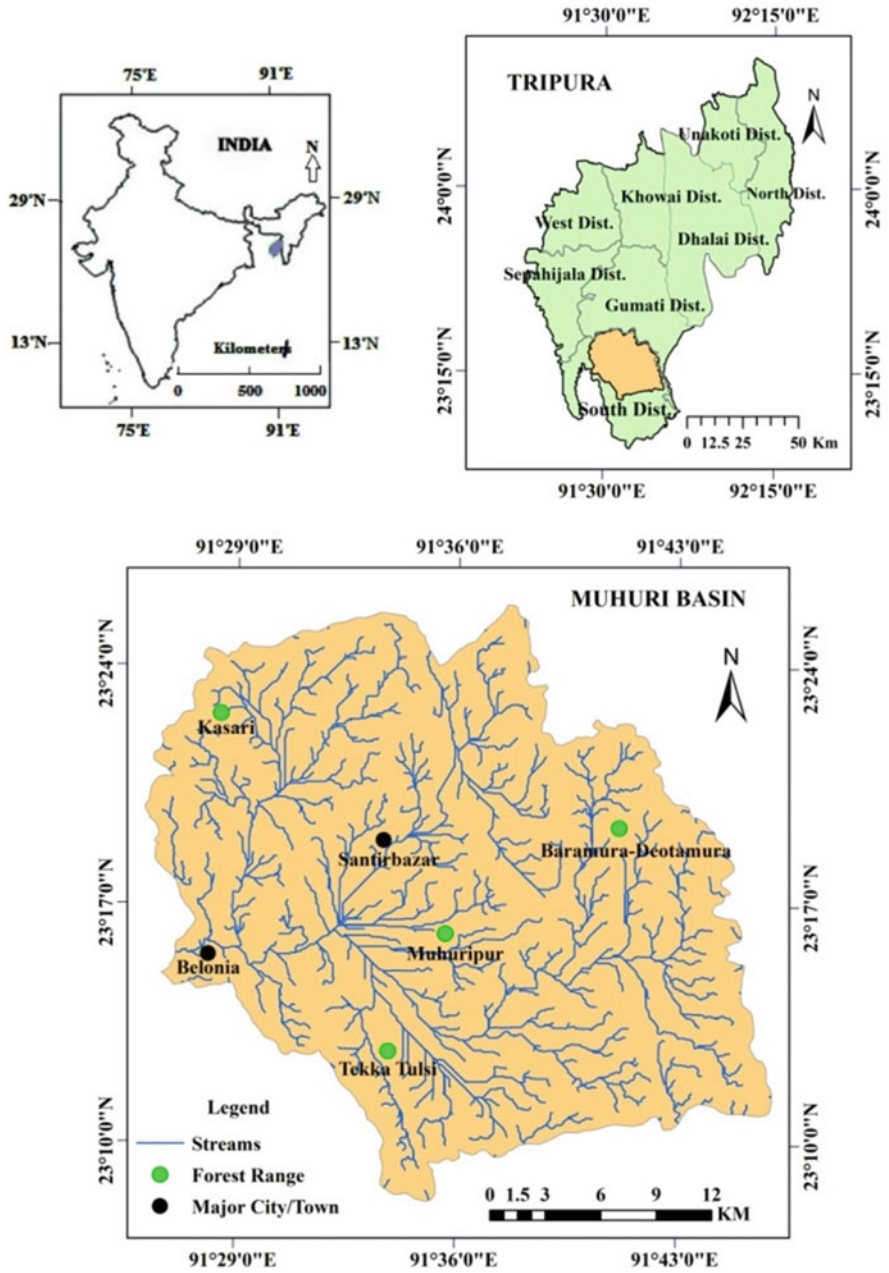
Fig. 5.1 Location map of the study area

used to prepare the LULC map from the collected imageries (Debnath et al., 2017a, b), and accuracy of the classified maps was assessed after field verification. Post classification comparison was completed to identify the changes of the LULC classes.

Confusion matrix was used for classification accuracy where producer's accuracy, user's accuracy, overall accuracy (Eq. 5.1) and Kappa accuracy (Eq. 5.2) were calculated using this matrix table (Congalton, 1991). These were calculated using the following formula:

$$\text{Overall accuracy} = \frac{\sum_{i=1}^{r} x_{ii}}{N} \times 100 \tag{5.1}$$

$$\text{Kappa accuracy} = \frac{N\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} (x_{i+} * x_{+i})}{N^2 - \sum_{i=1}^{r} (x_{i+} * x_{+i})} \tag{5.2}$$

where r is regarded as the number of rows in the matrix, x_{ii} expresses the total number of correctly classified pixels in row i and column i, x_{i+} and x_{+i} are the marginal totals of row i and column i, respectively, and N is the total number of pixels in the matrix table.

Estimation of Soil Loss Using USLE

USLE is an experimental Equation (Eq. 5.3) which predicts and estimates average annual soil loss from a particular area and its spatial distribution (Ahmed et al., 2017). The result of USLE equation depends on the five major factors which are expressed by the following equation:

$$A = (R \times K \times LS \times C \times P) \tag{5.3}$$

where A represents the mean annual soil loss in ton ha^{-1} $year^{-1}$, R is regarded as rainfall-runoff erosivity factor, K expresses the soil-erodibility factor, LS is the slope length and gradient factor, C is the crop-management factor and P is the support practice factor. All the factors were integrated in GIS environment to calculate the soil loss from the study area.

For estimation of soil loss of the Muhuri River basin for the years 1986 and 2019, the Landsat TM 1986 and Landsat OLI 2019 were used to prepare the LULC maps. These maps were utilized as crop management factor (C) and support practice factor (P) maps. Rainfall data of Belonia, Bokafa, Sabroom, Sonamura and Amarpur rain gauge stations were collected for 10 years' period (for 1986, data of 1976–1985 and for 2019, data of 2009–2018) to prepare the rainfall erosivity factor map (R). Whereas, so as to estimate the soil erodibility factor (K) map, the soil map of the

NBSS and LUP (1996) of 1:250,000 scale was used as the base map. Aster DEM of 30 m resolution was used to produce the slope length and gradient factor (LS) map.

Development of Database

Rainfall-Runoff Erosivity Factor (R)

Rainfall-runoff erosivity factor is one of the essential factors that influence soil erosion significantly. The R factor usually depicts the erosive power of rainfall at a particular place on account of the amount and intensity of rain (Uddin et al., 2016). It is computed (Eq. 5.4) with the help of the storm kinetic energy and the maximum 30 min rainfall intensity and facilitates to identify the effect of rain drop over a piece of land. As in the present study area such kind of meteorological data is unavailable, therefore, in this case the Rainfall erosivity factor was calculated using the formula

$$Ra = 79 + 0.363 \times P \qquad (5.4)$$

where Ra is the annual R factor and P is Rainfall in mm. R factor data of these five rain gauge stations were processed using the ArcGIS software. In order to prepare the map Interpolation method was applied using the IDW tool.

Soil Erodibility Factor (K)

The soil erodibility factor refers to the quantitative analysis of the intrinsic erodibility strength of a specific sort of soil. It is normally measured on susceptibility to detachment of soil particles from land surface and flowing through runoff. The K factor ranges between 0 and 1, where 0 (zero) means minimal prone to erosion, while 1 signifies highly prone to erosion through water. The soil properties that influence K factor are soil texture like sand, silt and clay, organic matter, soil structure, and its permeability. Here the soil erodibility factor was evaluated with the help of soil erodibility nomograph which is depends on Geo-pedological Map of the NBSS and LUP, 1996 Govt. of India (Wischmeier & Smith, 1978).

Slope Length and Gradient Factor (LS)

Slope length (L) and slope gradient (S) factor is also known as topographic erosivity factor. Generally, with the steepening of slope, soil erosion also augmented due to increasing velocity of the surface runoff towards downhill direction (Pradeep et al., 2015).

The Aster DEM for the study area was used to compute the topographic erosivity factor using the ArcGIS and Arc Hydro extension tool. The algorithm (Eq. 5.5) used

by Moore and Burch (1986) was applied to derive the soil erosion weightage for topographic factor as given below:

$$LS = \left[\left(\text{Flow accumulation} \times \frac{\text{Cell size}}{22.13} \right) 0.4 \times \left(\frac{\sin \text{slope}}{0.0896} \right) 1.3 \right] \qquad (5.5)$$

where flow accumulation denotes the accumulated upslope contributing area for a specified cell, cell size = size of grid cell (30 m for the present research work) and sin slope = sin value of slope angle in degree.

Crop Management Factor (C)

This factor depends on the nature of LULC of an area. The C factor is especially used to reflect the erosion rate as the effect of cropping and other management. Moreover, this factor is highly related with canopy cover of a particular place. In general, soil erosion reduces in consequence with the growth of canopy cover (Shit et al., 2013). The land cover interrupts rainfall, permits penetration and decreases the kinetic energy of rainfall over the land surface. For the present study, Landsat TM, 1986, and Landsat OLI, 2019, were used to generate the C factor maps.

Support Practice Factor (P)

This factor usually reflects the ratio of soil loss from a particular practice to the corresponding loss with straight row ploughing up and down slope (Dabral et al., 2008). The higher value of P factor indicates the application of effective soil conservation measures (Prasannakumar et al., 2011). During field verification, it was observed that the soil conservation techniques were adopted in the agricultural fields only. As a result, the researcher considered agricultural and non-agricultural land separately and assigned the P value of 0.28 and 1.0 respectively (Fig. 5.5). These values were used in other literatures also by Pandey et al. (2009) and Ahmed et al. (2017).

5.4 Result and Discussion

LULC Change (1986–2019)

The present observation shows that in the year 1986 about 5.90, 28.59 and 46.87% areas of the basin were occupied by dense forest, open forest and degraded forest, respectively, whereas, 9.99, 1.46, 1.71, 3.41, 1.94 and 0.11% areas were under agriculture, rubber plantation, jhoom cultivation, settlement, water body and barren

Table 5.1 Areas under different LULC categories in the Muhuri River basin

LULC Classes	1986		2019		1986–2019	
	Area (km^2)	Area (%)	Area (km^2)	Area (%)	Changed area (km^2)	Changed area (%)
Dense forest	41.4	5.90	3.29	0.47	−38.11	−92.05
Open forest	200.63	28.59	62.93	8.97	−137.7	−68.63
Degraded forest	328.92	46.87	312.3	44.50	−16.62	−5.05
Agricultural land	70.14	10	80.29	11.44	10.15	14.47
Rubber plantation	*10.28*	*1.46*	*174.8*	*24.91*	*164.52*	*1600.39*
Jhoom cultivation	12.02	1.71	8.98	1.28	−3.04	−25.29
Settlement	23.93	3.41	46.75	6.66	22.82	95.36
Water body	13.65	1.95	10.15	1.45	−3.5	−25.64
Barren land	0.75	0.11	2.23	0.32	1.48	197.33
Total	701.72		701.72			

land, respectively. Again, in the year 2019 about 0.47, 8.97 and 44.50% areas were under dense forest, open forest and degraded forest, respectively. On the other hand, 11.44, 24.91, 1.28, 6.66, 1.45 and 0.32% areas were occupied by agriculture, rubber plantation, jhoom cultivation, settlement, water body and barren land, respectively (Table 5.1).

The temporal data sets of LULC of the study area indicate some considerable changes between the base year and the current year which were inflated by human, as well as natural factors. During the 1986–2019 periods of 33 years, the areas under dense forest, open forest and degraded forest were decreased by 92.05, 68.63 and 5.05%, respectively, whereas areas under rubber plantation and agriculture were increased significantly by 1600.39 and 14.47%, respectively. Moreover, area under shifting cultivation was decreased by 25.29% and settled area increased appreciably by 95.36% with reduction in water body by 25.64% (Table 5.1). During this period, the basin experienced a significant increase in barren land by 197.33%.

Rainfall Erosivity Factor (R)

In order to compare rainfall erosivity (R) of the years 1986 and 2019, the mean rainfall of the periods 1976–1985 and 2009–2018, respectively, were used. The R factor values of the year 1986 ranged between 843.69 and 987.28 MJ mm ha^{-1} h^{-1} year^{-1}, whereas during the year 2019, it became 786.55 and 892.15 MJ mm ha^{-1} h^{-1} year^{-1} within the Muhuri basin (Table 5.2).

Table 5.2 Average annual rainfall and R value of the selected stations

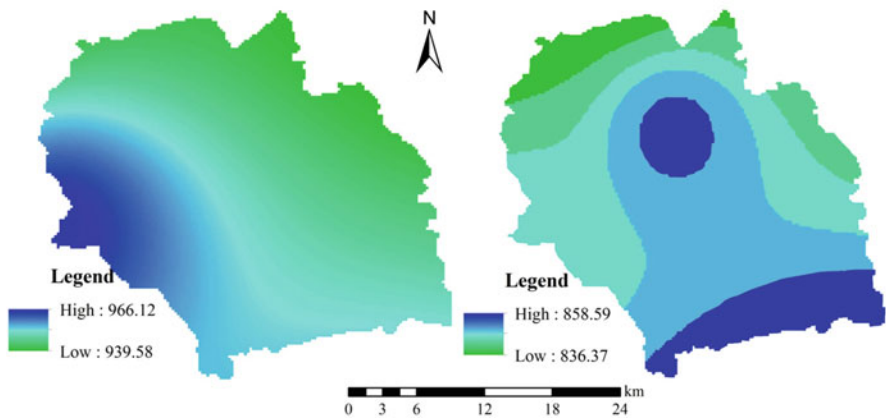| Station	Average annual (1976–1985)		Average annual (2009–2018)	
	Rainfall (mm)	R-factor	Rainfall (mm)	R-factor
Matabari	2407.44	952.9	1949.18	795.2
Amarpur	2390.75	946.84	2048.22	786.55
Belonia	2476.62	978.01	2110.03	822.5
Sabroom	2502.15	987.28	2240.09	844.94
Bokafa	N.A.	N.A.	2129.18	892.15
Sonamura	2106.58	843.69	1972.98	851.89

Fig. 5.2 Spatial distribution of R factor in the Muhuri River Basin for the years 1986 and 2019

The spatial distribution of R factor of 1986 indicates the concentration of highest R value in the western part and lowest value in the extreme northern part of the basin, whereas in the year 2019, it was observed in the central and the extreme northwestern portions of the basin, respectively (Fig. 5.2).

Soil Erodibility Factor (K)

Soil type varies according to the topographic and lithologic characters of the concerned area. The K value of each soil type of the study area was derived from the work of Ghosh et al. (2013), which was calculated using the nomograph (Wischmeier & Smith, 1978) of USLE (Table 5.3).

Higher the amount of K value more erosion prone is the area and vice versa. The highest K value (0.36) was observed in the central part of the basin in the soils of inter-hill valley, whereas the lowest value (0.16) was observed in the central and the

Table 5.3 K value of the study area according to the geo-pedological characteristics

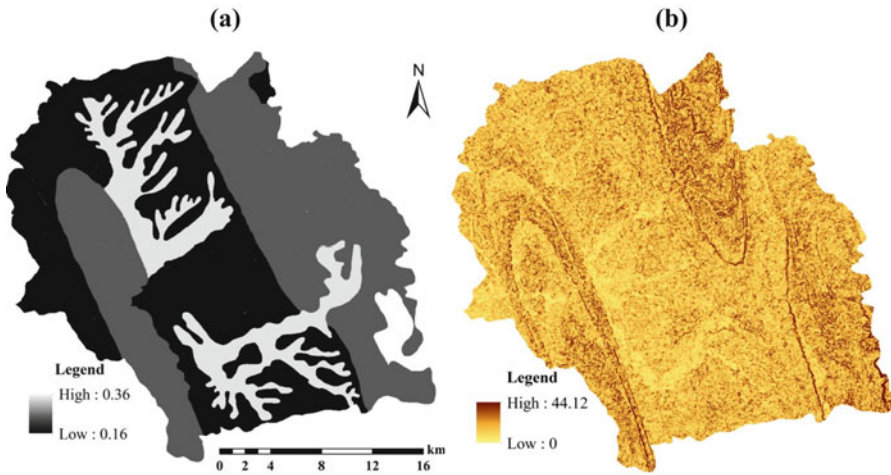| Soil type	K factor
Soils of low relief structural hills and ridges	0.24
Soils of undulating plains with low mounds and narrow valleys	0.16
Soils of inter hill valleys	0.36
Soils of flood plains	0.34

Fig. 5.3 Spatial distribution of (**a**) K and (**b**) LS in the Muhuri River basin

northwestern parts of the basin in the soils of undulating plains with low mounds and narrow valleys (Fig. 5.3a).

Slope Length and Gradient Factor (LS)

The LS value of the present study ranged between 0 to 44.02. Higher value was found in the upper and the lower catchments of the basin due to the presence of the Baramura-Deotamura hill range and the TekkaTulsi hill, respectively, whereas the minimum value was observed in the central part of the basin over the flood plains and inter-hill valleys (Fig. 5.3b).

Crop Management Factor (C)

The C values of the study area ranged between 0 to 1 (Table 5.4). The lower value was observed in the eastern part of the basin due to the presence of forest cover

LULC class	C value	Source
Dense forest	0.004	Dabral et al. (2008)
Open forest	0.008	Dabral et al. (2008)
Degraded forest	0.008	Dabral et al. (2008)
Agricultural land	0.28	Dabral et al. (2008)
Rubber plantation	0.20	Sujaul et al. (2012)
Shifting cultivation	0.33	Dabral et al. (2008)
Settlement	1.00	Dabral et al. (2008)
Water body	0.00	Ganasri and Ramesh (2016)
Barren land	0.18	Pandey et al. (2007)

Table 5.4 C value of different LULC classes of the basin
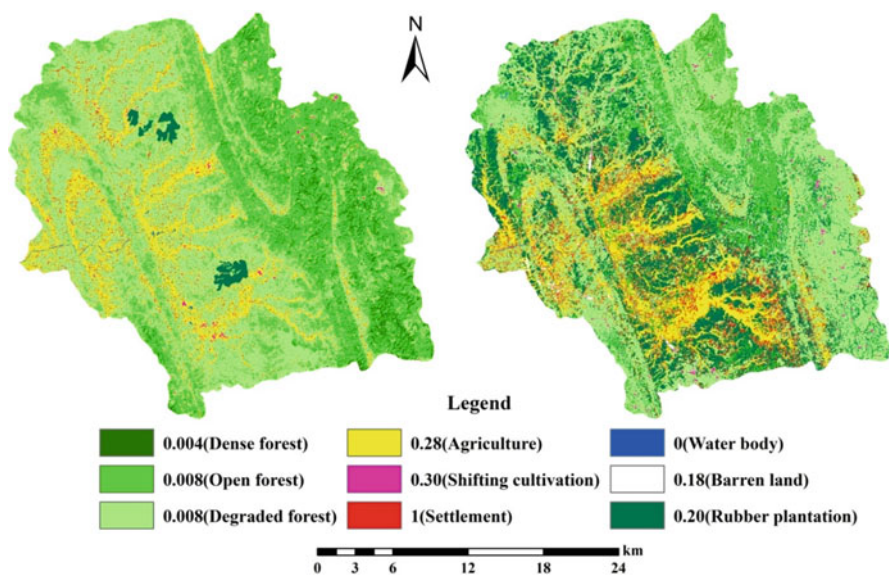
Fig. 5.4 Spatial distribution of C in the Muhuri River basin for the years 1986 and 2019

whereas the central and the western parts demonstrated higher values for the presence of agricultural land, settlement and rubber plantation. However, the occurrence of higher C value in the year 2019 in comparison to the year 1986 was due to the active interference of rubber plantation (Fig. 5.4).

Support Practice Factor (P)

Contour cultivation, strip cropping and terrace system are the most essential conservation practices revealed in the USLE. During field verification, only bundings in the agricultural lands was observed which was ineffective. Therefore, the *P* value was set to 0.28 for paddy fields and 1 for rest of the areas (Fig. 5.5).
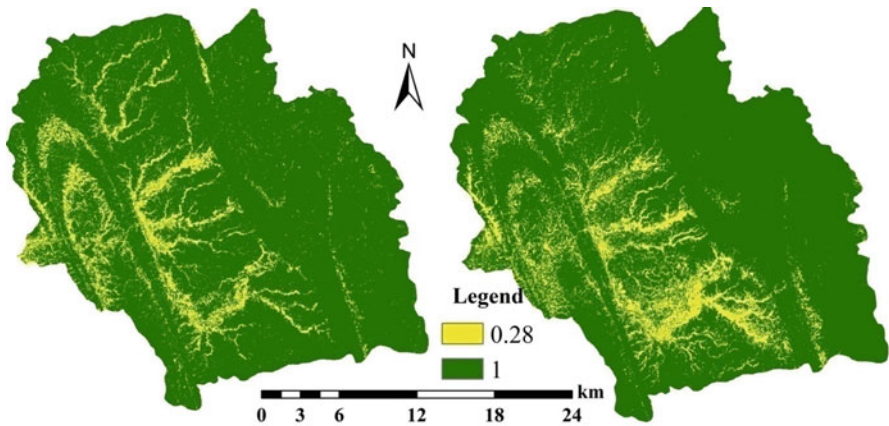
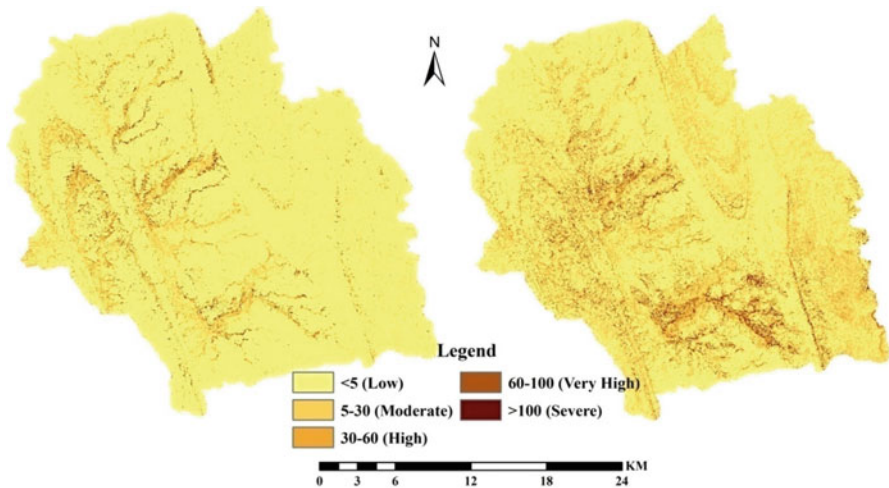**Fig. 5.5** Spatial distribution of P factor in the study area

Fig. 5.6 Spatial distribution of annual soil loss of the study area for 1986 and 2019

Spatial and Temporal Features of Soil Erosion in the Muhuri River Basin During 1986 and 2019

Present study shows that during the year 1986 and 2019, the average annual soil loss from the basin was between 0 to 101.06 t ha^{-1} year^{-1} and 0 to 110.08 t ha^{-1} year^{-1}, respectively (Fig. 5.6). The amount of annual soil loss has been categorised into five classes, such as low, medium, high, very high and severe. During 1986 and 2019, about 82.58 and 51.58% areas were under low soil erosion class, respectively (Table 5.5), where high vegetal cover in comparison to the open forests was found.

Table 5.5 Category-wise areas under soil erosion during 1986 and 2019

Average annual soil loss (t ha^{-1} year^{-1})	Erosion class	1986		2019		Change (1986–2019)	
		Area (ha.)	Area (%)	Area (ha.)	Area (%)	Area (ha.)	Area (%)
<5	Low	57,713.06	82.58	36,044.69	51.58	−21,668.37	−37.54
5–30	Moderate	7532.75	10.78	26,498.11	37.92	18,965.36	251.77
30–60	High	3071.7	4.39	4636.08	6.63	1564.38	50.93
60–100	Very high	1239.89	1.77	1903.94	2.72	525.79	42.41
>100	Severe	323.89	0.46	799.17	1.14	475.28	145.74

In these years, about 10.78 and 37.92% of the basin experienced moderate soil loss, 4.39 and 6.63% areas high soil loss, 1.77 and 2.72% very high and 0.46 and 1.14% areas severe soil loss (>100 t ha^{-1} year^{-1}), respectively.

During the periods 1986–2019, the areas under low soil loss were decreased to 37.54%. On contrary, the areas under moderate, high, very high and severe soil loss were significantly increased to 251.77, 50.93, 42.41 and 145.74%, respectively (Table 5.5). The central portion of the basin was mostly occupied by agricultural lands and settlements but very recently rubber plantation was flourished vigorously in this part (Fig. 5.6).

Such factors boosted the status of soil erosion in that part of the basin. As we know that the hilly parts of the basin are mainly affected by the traditional jhooming practised by the indigenous people and that's why the degraded forests still remain in high altitudes which ultimately become responsible for increasing soil erosion in that part.

Analysis of Relation Between Mean Soil Loss and LULC

Within the study period of 1986 to 2019, about 92.05, 68.63 and 5.05% areas under dense forest, open forest and degraded forest were decreased, respectively, whereas, agricultural land, area under rubber plantation, settled area and area under barren land were increased to 14.47, 1600.39, 95.36 and 197.33%, respectively.

The authors observed a relation between the LULC change and the rate of mean soil loss in the Muhuri River basin during the periods 1986–2019. With modification of the land cover, the erosion rate was changed significantly. The rate of mean soil loss in the areas under degraded forest, agriculture, rubber plantation, jhoom cultivation and settlement were 0.25, 11.02, 0.71, 3.55 and 12.85 t ha^{-1} year^{-1}, respectively, during the year 1986 and became 2.62, 12.24, 2.21, 4.87 and 13.25 t ha^{-1} year^{-1}, respectively, during 2019. On contrary, during 1986, the rate of mean soil loss from the areas under dense forest and open forest were 0.01 and 0.02 t ha^{-1} year^{-1}, respectively, but with decrease in areal coverage the soil loss became absent during 2019. In case of degraded forest, agricultural land, rubber

Table 5.6 LULC-wise mean annual soil loss of the study area

	1986		2019		1986–2019	Mean soil loss ($t\ ha^{-1}\ year^{-1}$)		
LULC	Area (ha)	Area (%)	Area (ha)	Area (%)	Change (%)	1986	2019	Change
Dense forest	4140	5.90	329	0.47	−92.05	0.01	0	−0.01
Open forest	20,063	28.59	6293	8.97	−68.63	0.02	0	−0.02
Degraded forest	32,892	46.87	3123	44.50	−5.05	0.25	2.62	2.37
Agricultural land	7014	9.99	8029	11.44	14.47	11.02	12.24	1.22
Rubber plantation	1028	1.46	1748	24.91	1600.39	0.71	2.21	1.50
Shifting cultivation	1202	1.71	898	1.28	−25.29	3.55	4.87	1.32
Settlement	2393	3.41	4675	6.66	95.36	12.85	13.25	0.40
Water body	1365	1.94	1015	1.45	−25.64	0	0	0
Barren land	75	0.11	223	0.32	197.33	1.71	2.39	0.68
Total	70,172	100	70,172	100				

plantation, jhoom cultivation, settlement and barren land the mean soil erosion was increased by 2.37, 1.22, 1.5, 1.32, 0.4 and 0.68 $t\ ha^{-1}\ year^{-1}$, respectively, whereas in case of dense forest and open forest, it was decreased considerably (Table 5.6).

Within the study period, all categories of soil erosion illustrated decreasing trend in case of the dense and open forests as areal coverage declined significantly. Again, in case of the degraded forest, the percentage of all erosion classes, except moderate and high class, were declined (Table 5.7). Although agricultural lands are of gentle slope but the absence of proper conservation practice augmented moderate, high and very high classes of erosion (Table 5.7). Rubber plantation was newly introduced in the study area and mainly found on moderate and steep slopes. Since it's a profit benefit income source, therefore, the area under rubber plantation increased significantly within the basin. During the year 1986, the area under rubber plantation was only 1.46%, whereas it became 24.91% in the year 2019. As a result, all categories of soil erosion except severe class were increased. However, despite decline in shifting cultivation by 25.29% areas under erosion classes were increased.

The settled areas which have considerable uncovered surface were revealed as most vulnerable to erosion. The areas under settlement were increased by 95.36% within the study period with increasing population pressure. Consequently, the areas under moderate, high, very high and severe erosion were augmented by 199.24, 215.20, 93.05 and 54.84%, respectively (Table 5.7). On the other hand, the barren lands were free from high, very high and severe erosion in both the years, while the susceptibility to low and moderate erosion were increased by 242.86 and 100%, respectively, with increasing the barren land from 0.11 to 0.32%. A clear relation between LULC change and amount of mean soil loss was evident in the study area. Growing anthropogenic activities had already altered the natural forest cover into

Table 5.7 Actual and changed area under different LULC classes with erosion status

Area (km²)

Soil erosion class	Dense forest		Open forest		Degraded forest		Agricultural land		Rubber plantation		Shifting cultivation		Settlement		Water body		Barren land	
	1986	2019	1986	2019	1986	2019	1986	2019	1986	2019	1986	2019	1986	2019	1986	2019	1986	2019
Low	40.65	3.27	194.43	63.33	339.93	229.82	15.91	13.12	7.56	139.8	2.4	2.53	8.76	5.57	0.0	0.0	0.56	1.92
Moderate	0.46	0.0	10.61	0.0	1.95	76.44	17.37	23.88	0.23	29.23	1.05	2.67	3.92	11.73	0.0	0.0	0.13	0.26
High	0.05	0.0	0.93	0.0	2.15	7.46	15.53	24.73	0.03	2.49	0.32	1.07	4.87	15.35	0.0	0.0	0.01	0.01
Very high	0.01	0.0	0.03	0.0	1.18	0.1	7.63	12.58	0.01	0.03	0.05	0.06	3.02	5.83	0.0	0.0	0.0	0.0
Severe	0.0	0.0	0.01	0.0	0.57	0.0	3.22	2.41	0.0	0.0	0.02	0.04	1.55	2.4	0.0	0.0	0.0	0.0

Changed area

| Soil erosion class	Dense forest		Open forest		Degraded forest		Agricultural land		Rubber plantation		Shifting cultivation		Settlement		Water body		Barren land	
	km²	%	km²	%	km²	%	km²	%	km²	%	km²	%	km²	%	km²	%	km²	%
Low	−37.38	−91.96	−131.1	−67.43	−110.11	−32.39	−2.79	−17.54	132.24	1749.21	0.13	5.42	−3.19	−36.42	0.0	0.0	1.36	242.86
Moderate	−0.46	−100	−10.61	−100	74.49	3820	6.51	37.48	29	12608.7	1.62	154.29	7.81	199.24	0.0	0.0	0.13	100
High	−0.05	−100	−0.93	−100	5.31	246.98	9.2	59.24	2.46	8200	0.75	234.36	10.48	215.20	0.0	0.0	0.0	0.0
Very high	−0.01	−100	−0.03	−100	−1.08	−91.53	4.95	64.88	0.02	200	0.01	20	2.81	93.05	0.0	0.0	0.0	0.0
Severe	0.0	0.0	−0.01	−100	−0.57	−100	−0.81	−25.16	0.0	0.0	0.02	100	0.85	54.84	0.0	0.0	0.0	0.0
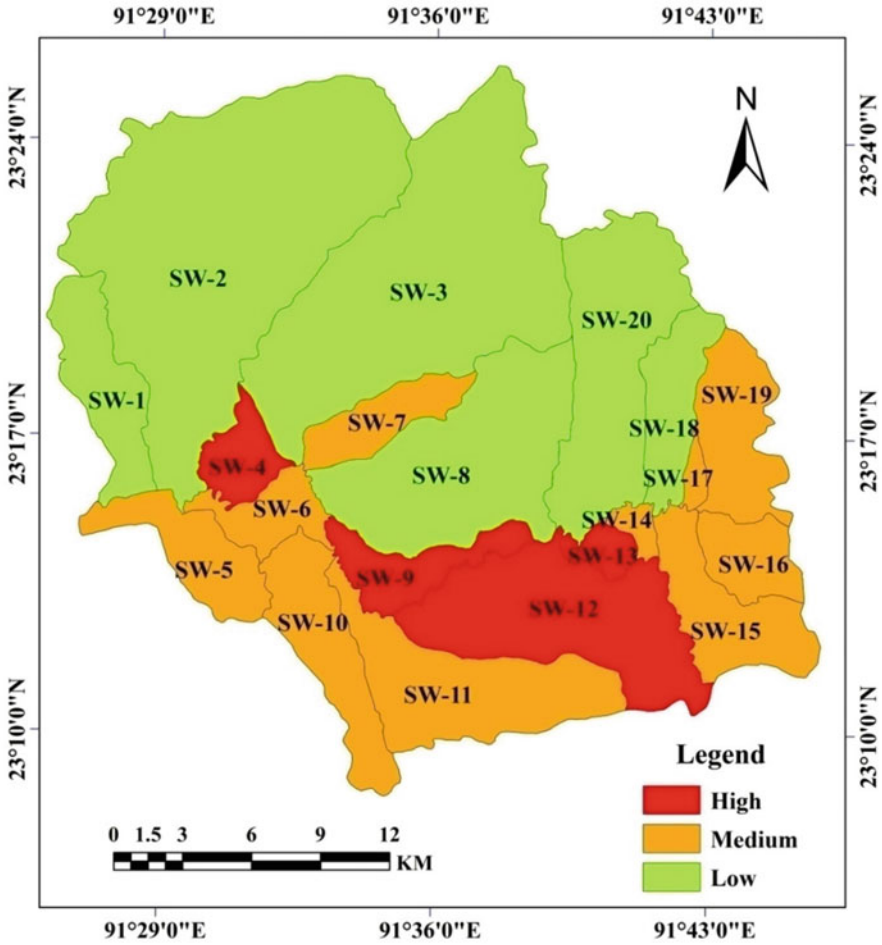
Fig. 5.7 Priority-wise sub-watersheds (SW) for control of soil erosion

degraded forest, as a result, areas under dense and open forests were decreased in the hilly areas and degraded forests still maintained higher position in the study area in general and in the hilly part in particular (Debnath et al., 2017a, b). Therefore, the combination of steep slope and degraded forest had accelerated the moderate, high and very high rate of soil loss in the hilly areas, although shifting cultivation had also contributed to moderate to severe erosion in the hilly part.

Rubber plantation was recognised as a substitute monoculture practice in the forest areas, mainly in the tilla lands with moderate to steep slope. Since the owners collect latex regularly and there is a chance of forest fire in plantation during dry season from the flushing leaves (Fig. 5.7a), the owners always try to keep the floor clean by clearing the secondary growth and removing the flushing leaves from the floor (Fig. 5.7b). Thus, the plantation floors always remain barren which promote

soil erosion, especially during the monsoon season. According to Wu et al. (2001), conversion of tropical forests to rubber monoculture increases the rate of soil erosion significantly. The central and the western parts of the basin were occupied by rubber plantation and gradually extended towards the hilly part leading to widespread moderate to very high erosion. In addition, moderate to steep slopes in the plantation areas favour runoff when rainfall intensity becomes high. Therefore, the barren ground surfaces of the plantations experience soil loss. The increased demand for agricultural land owing to the growing population in the study area had consequent upon the clearing of forest lands.

During field verification, it was observed that the farmers became conscious about soil fertility and its importance in high yield. As a result, the area under severe erosion class was slightly decreased, but moderate, high and very high erosion class still persist in the central part of the basin. Prolonged dry period followed by high intensity rainfall contributes high risk of soil erosion in the settled areas. The area under current fallow increases during dry season on account of shortage of irrigation water and contributes to high erosion.

The assessment of soil erosion using satellite images and GIS technique becomes the most important means for evaluation and monitoring of the past and present scenario of a macro- as well as a micro-geographical area in repetitive timescale coverage. Obviously, the mean rate of soil erosion is related with the nature of LULC.

The major changes identified in the river basin were due to the introduction of monoculture activity and decrease of natural forest cover. The significant increase in soil erosion had accelerated sedimentation process in downstream of the Muhuri River.

Prioritization of the Sub-watersheds (SW) for the Management

Identification of the priority areas of the entire Muhuri River basin is crucial for taking decision on soil and water conservation with the forest management programme (Fig. 5.7). For this purpose, the researcher has considered the actual amount of erosion, change of the erosion amount within the period 1986 to 2019 due to LULC change and LULC-wise estimated erosion. In the present study, 18 SW of the Muhuri River basin have been prioritized into three classes: low, medium and high based on mean soil loss from them measured through USLE model (Table 5.8).

Low priority level: The sub-watersheds 1, 2, 3, 8, 18 and 20 come under low priority level class where mean soil loss ranges between 2.43 to 4.40 t ha^{-1} year^{-1}. Hence, it's indicating that these watersheds do not need instantaneous measurement to reduce the soil erosion.

Medium priority level: The sub-watersheds with the mean soil erosion range of 4.40–6.50 t ha^{-1} year^{-1}come under the medium priority level. The sub-watersheds 5, 6, 7, 10, 11, 14, 15, 16, 17 and 19 have come under this category. There is need of

Table 5.8 Priority ranking of SW on the basis of mean soil loss

Code of sub-watershed	Soil loss (t ha^{-1} year^{-1})		
	Mean	SD	Category
SW-1	3.08	3.61	Low
SW-2	3.35	4.33	Low
SW-3	4.02	5.24	Low
SW-4	7.07	7.58	High
SW-5	4.88	5.3	Medium
SW-6	5	5.42	Medium
SW-7	5.48	7.05	Medium
SW-8	3.73	4.32	Low
SW-9	6.90	7.20	High
SW-10	4.98	5.74	Medium
SW-11	4.41	5.7	Medium
SW-12	7.4	8.22	High
SW-13	7.7	9.87	High
SW-14	4.97	6.32	Medium
SW-15	5.11	5.5	Medium
SW-16	5.72	5.34	Medium
SW-17	4.17	2.61	Medium
SW-18	3.87	3.34	Low
SW-19	4.45	3.99	Medium
SW-20	2.43	2.96	Low

proper attention in order to check these sub-watersheds from conversion to the successive priority level.

High priority level: Four sub-watersheds i.e., SW-4, 9, 12 and 13 have given under high priority level due to high mean soil loss of more than 6.50 t ha^{-1} year^{-1}. Hence, immediate action plan should be needed in these watersheds to minimize the soil erosion.

The study of the LULC map shows that the SW having agriculture and settlement come under high, as well as medium category. All other sub-watersheds except SW-15, 16, 17 and 19 come under the high and medium priority level, mainly the zone of rubber plantation, which have spontaneous soil erosion, whereas those remaining sub-watersheds, located in the hilly areas and mostly under shifting cultivation, have ultimately achieved the medium priority level in the soil and water conservation map.

Strategies of Soil Conservation

In order to reduce the intensity of the soil erosion in the Muhuri River basin, few alternative strategies has been suggested in the present study. Since the study area is situated in the hilly part of NorthEast India; therefore shifting cultivation is mostly

dominated in the upper catchment. This unscientific way of cultivation recognised as a vital factor for the soil erosion. Thus, terrace cultivation is recognised as a most effective conservation technique in the hilly part, which will reduce the surface runoff along with velocity of the rain water and reduced the soil erosion. According to Guo et al. (2019) and Dai et al. (2018), contour ridge tillage and cross ridge tillage are the most important techniques to reduce the soil erosion in the hilly region compare to the down slope tillage. The experimental study of Sharma et al. (2017) and Dai et al. (2018) suggested that intercropping and mulching practices can be a another techniques to reduce the soil erosion in the farm land of the hilly region.

Moreover, construction of check dams in the streams of the hilly parts can be effective measures to reduce the supply of eroded materials to the main channel which will reduce the problem of flood hazard in the lower parts of the basin. Identification of the suitable areas of the afforestation using the modern geospatial techniques like GIS and remote sensing and implementation of the proper afforestation programme can be a important measures in this watershed. This technique will increase the forest areas and reduce the soil erosion of the study area.

5.5 Conclusion

The role of human activities behind LULC change during last 33 years which led to change the soil erosion potential, i.e., either positive or negative have been revealed in the present study. Very limited parts of the watershed have protective land cover while most of the parts, mainly hilly areas, were affected by deforestation; tilla and plain areas are experienced by infrastructure and related land degradation which inherently enlarged the risk of the soil erosion. Obviously, the mean rate of soil erosion is associated with the LULC change of the study area, and therefore, in case of degraded forest, agricultural land, rubber plantation and jhoom cultivation, the mean soil loss was increased by 2.37, 1.22, 1.50 and 1.32 t ha^{-1} year^{-1} correspondingly within the study period (1986–2019). The main reasons for such increase of soil erosion potential in the river basin over the study period were decreased natural forest cover, increased settled area, barren land, agricultural land and existence of shifting cultivation. However, this enhanced erosion accelerated sedimentation problem in downstream of the Muhuri River.

The study illustrated that the conversion of forest land into rubber plantation became a common phenomenon in the basin which eliminated the effective impediment to soil erosion. Hence, there is a need of management through proper programme implementation. Recently in order to develop jhum areas, a number of integrated approaches of mixed land use system become most suitable in the hilly part. The approaches include promotion of modern agriculture, intercropping diversification with local preference, jhum fallow management, tree farming, floriculture, agroforestry, watershed management, etc. (Jamir et al., 2004; Verma et al., 2017). Growth of vegetal cover on the barren surfaces and degraded forests is necessary to reduce the soil erosion potential of the river basin. Moreover, there is scope of further

study within this study area where priority of sub-watershed and afforestation programme related researches could be carried out in order to facilitate the management plan.

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