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THE IMPACT OF LAND USE DYNAMICS ON THE SOIL EROSION IN THE PANCHNOI RIVER BASIN, NORTHEAST INDIA

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Abstract: Land use (LU) dynamics and its relation to the accelerated soil erosion phenomenon in two broad geomorphic divisions of the Panchnoi River basin of Northeast India have studied. The present study was based on the Revised Universal Soil Loss Equation (RUSLE). To measure the impact of the LU dynamics on soil erosion, the basin was divided into two broad geomorphic divisions, i.e., plain zone and hilly zone, and the rate of soil erosion has been estimated separately for both of the geomorphic divisions. It has been found that in the plain zone, LU dynamics significantly accelerated soil erosion—from 0.52 ton/ha/yr in 1990 to 0.94 ton/ha/yr in 2015. Similarly, the vegetation density decreased significantly in the mountainous and hilly zone as the mean Normalized Difference Vegetation Index (NDVI) value changed from 0.45 in 1990 to 0.35 in 2015, which accelerated soil erosion from 12.06 ton/ha/yr to 18.30 ton/ha/yr from 1990 to 2015. The study indicates that soil erosion may give rise to a severe environmental as well as economic problem in the Panchnoi river basin, which may trigger issues related to the soil fertility of the basin area.

Keywords: soil erosion; RUSLE; LU dynamics; Panchnoi River basin (Northeast India)

Introduction

Soil is an essential natural component that supports all forms of terrestrial life and provides a foundation for its growth and development. Water-induced soil erosion is a natural phenomenon which accelerates through anthropogenic activities and may have severe impacts on land and environment qualities (Jaiswal, Thakuria, Borah, & Saikia, 2014; Kalita & Sarmah, 2016; Saha, 2003). Soil erosion leads to land degradation, and the excessive soil loss resulting from poor land management has inevitable implications on crop productivity and food security (Montgomery, 2007). The vast areas of land now under cultivation may become economically unproductive if the soil erosion continues unabated (Jain & Kothyari, 2000). In recent times, the problem of soil erosion proliferates due to unscientific use and overutilization of the natural resources by humans in the form of changing natural landscape to land-use. The conversion of land use, land cover (LULC) usually has an unintended consequence on the natural environment (Regmi, Saha, & Subedi, 2017), especially in the form of soil erosion (Abdulkareem, Pradhan, Sulaiman, & Jamil, 2017; Chalise, Kumar, & Kristiansen, 2019; Kumar, 2015; Ozsahin, Duru, & Eroglu, 2017).

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Several studies have been conducted with the aim to understand the soil dynamics since the mid of last century and many empirical and mathematical models for estimating soil erosion have been developed (Adinarayana, Gopal Rao, Rama Krishna, Venkatachalam, & Suri, 1999; D'Ambrosio, Di Gregorio, Gabriele, & Gaudio, 2001; Morgan, R., Morgan, & Finney, 1984; Renard, Foster, Weesies, McCool, & Yoder, 1997; Shen et al., 2003; Wischmeier & Smith, 1978). For the present study, the RUSLE model has been used to estimate soil erosion under different LULC set up. The RUSLE is an improved version of the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978), which includes more diverse databases (Renard et al., 1997). The RUSLE model was developed to predict water erosion in the form of soil loss, and it is to be used as a sophisticated medium for the assessment of soil erosion in river basins. For its accuracy and applicability, many researchers have used RUSLE in GIS platform to estimate soil loss from river basins, especially in India (Biswas & Pani, 2015; Jaiswal et al., 2014; Kalita & Sarmah, 2016; Kumar, 2015; Narayana Swamy, Inayathulla, & Shashisankar, 2017; Shinde, Tiwari, & Singh, 2010; Thomas, Joseph, & Thrivikramji, 2018).

India has a total geographical area of 329 million ha out of which 157 million ha (47.7%) has the land degradation problem (Singh & Panda, 2017). The average annual soil erosion in India is about 16 ton/ha or about 5 billion tons annually (Saroha, 2017). Water-induced soil erosion is one of the severe soil degradation problems in India, resulting in the loss of topsoil and terrain deformation. Like other parts of India, North Eastern Region of India is also facing a significant challenge on soil degradation because of a drastic land-use change without any conservation measures (Poręba & Prokop, 2011; Saha, Majumdar, & Das, 2015).

The present study focused on the effects of land-use changes in the soil erosion scenario of the Panchnoi river basin. The primary concern was to evaluate the role of different land use categories in soil erosion scenarios with particular stress to land-use changes and soil erosion. Besides this, the topographic impact on the geomorphic processes was also considered, and an effort has made to calculate the rate of soil erosion in two broad geomorphic divisions. The findings of this research can help land managers and decision-makers to tackle the on-site and off-site damages due to erosion by providing adequate information on the rates and determinants of soil loss.

Data and methodology

The Panchnoi river basin is located in the foothill region of the western part of the Arunachal Himalaya, where fluvial dynamism and soil erosion processes are accelerated by a torrential monsoonal downpour on the fragile geological setting. The Panchnoi River basin is a significant sub-basin of Brahmaputra. Its source is in Arunachal Himalayan ranges of northwestern Arunachal Pradesh and flows southward toward the Brahmaputra River. The rivers Deosini, Mainajulli, and Bhutimari are the major tributaries of this river. The river basin extends from 26°33'13" N to 27°04'29" N latitudes and 92°15'14" E to 92°24'01" E longitudes (Figure 1) with an area of 552.4 km^2, out of which 150.36 km^2 are in Arunachal Pradesh, and the rest is in Assam. The basin is located south of Arunachal Himalaya and its elevation varies from 55 m to 2,920 m above mean sea level (MSL), with general dip toward the south. The basin has a diverse geological composition ranging from Quaternary sediments (southern plains), Siwalik sediments, rocks of lower Gondwana group, and metasediments of Bomdila group (northern hills) (Geological Survey of India [GSI], 1974, 2010). The total length of the river from the source to the confluence is 75.50 km.

The basin has a diverse characteristic of high seismicity, flimsy geological base, seasonal weather variations, assorted physiography, rich biodiversity, and inimitable ethnic and cultural opus (Jaiswal et al., 2014). It experiences a sub-tropical humid climate, characterized by the southwest monsoons. The annual precipitation in this part of the world is an assorted one, and about 70% of rainfall occurs in the monsoon months (June–September), mostly in the form of torrential downpour, which leads to high soil erosion during this period (Kalita & Sarmah, 2016). There is also a deviation in the rainfall distribution pattern in the river basin. The lower reaches of the basin record comparatively low average rainfall (1,800 mm), whereas the upper reaches account higher precipitation (2,150 mm) (Jaiswal, 2014). The basin is covered by several natural vegetation types that include sub-alpine forests, meadows with coniferous and tropical evergreen trees, sub-tropical semi-evergreen trees and mixed deciduous trees (Jaiswal, 2013).

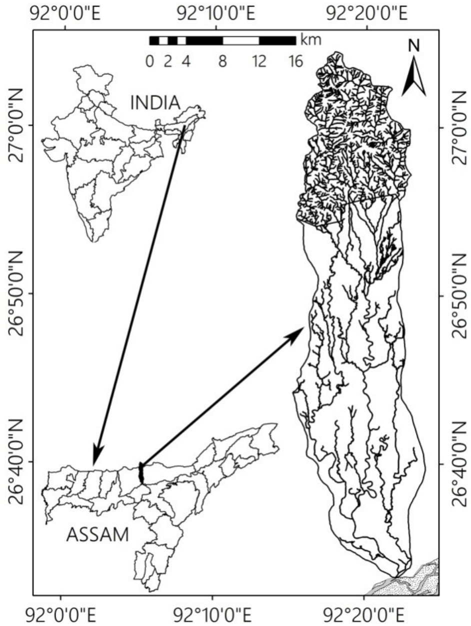

Figure 1. Study area.

To evaluate the impact of LU dynamics on soil erosion in the Panchnoi River basin, a diverse set of data from authentic sources have been used. The different sets of data used for the study with their sources are given in Table 1.

The methodology used in this study is the RUSLE, developed by the United States Department of Agriculture Natural Resource Conservation Service (Renard et al., 1997). RUSLE is an empirically based model used worldwide to estimate soil erosion from a per-unit area at an annual time scale (Renard & Foster, 1983). In this research study, RUSLE was used to evaluate the magnitude of soil erosion from the Panchnoi River Basin under the changing land use scenario in a GIS platform.

Different data sets that were necessary to estimate soil erosion in RUSLE were obtained from several sources, as given in Table 1. After collecting the data from the sources mentioned above (Table 1), separate GIS layers were prepared for each factor of RUSLE in raster format to estimate the soil erosion from the Panchnoi River Basin. The overall schematic flow of the methodology is given in Figure 2.

Table 1
Details of various data sets used in the present study

Type of data	Year	Author/Source	Title
Toposheets	1972	Survey of India (SOI)	83–A/8, B/5, and B/6 (1:50,000)
Thematic maps	1999	National Bureau of Soil Survey and Land Use Planning (NBSS & LUP), Nagpur	Soil map of Assam and Arunachal Pradesh
Rainfall Data	2016	Assam Water Resource Department	Rainfall data register of central Assam districts (1990–2015)
Rainfall Data	1990–2015	India Meteorological Department	Rainfall Data
Topography Data	2014	US Geological Survey Geological Survey, EarthExplorer website	Shuttle radar topographic mission 30m DEM
Remote Sensing data	1990, 2000, 2015	US Geological Survey Geological Survey, EarthExplorer website	LANDSAT TM, LANDSAT ETM
Remote Sensing data	2008	National Remote Sensing Agency (NRSA), Hyderabad	IRS P6 LISS III

The RUSLE model can predict erosion potential on a pixel-by-pixel basis, which is effective when attempting to identify the spatial pattern of soil erosion present in a region. The derivative equation of RUSLE is (Renard & Foster, 1983; Renard, Foster, Weesies, & Porter, 1991; Wischmeier & Smith, 1978):

$$A = R \cdot K \cdot LS \cdot C \cdot P \tag{1}$$

Where *A* is average soil loss in ton/ha/yr; *R* is the rainfall erosivity factor in MJmm/ha/yr; *K* is the soil erodibility factor in ton/MJmm/ha; *L* is the slope length factor (dimensionless); *S* is the slope steepness factor (dimensionless); *C* is the cover and management factor (dimensionless); *P* is the conservation practices factor (dimensionless).

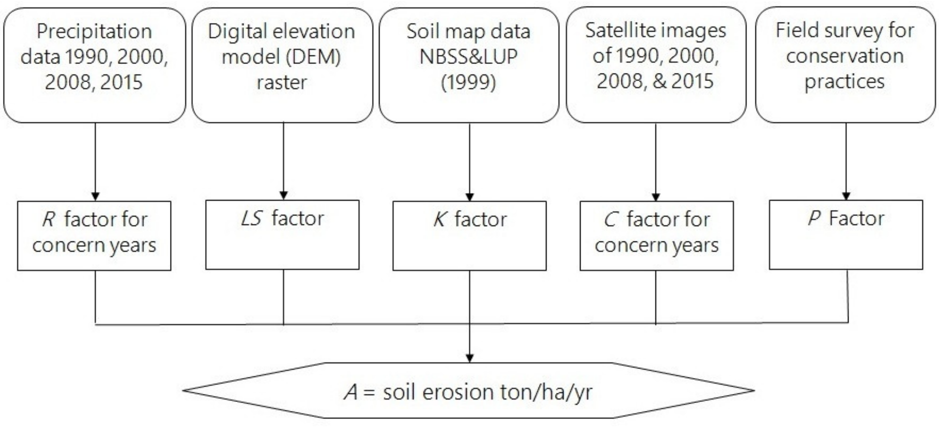

Figure 2. RUSLE methodology flow chart.

R factor

The rainfall-runoff erosivity factor (*R*) quantifies the effect of raindrop impact and reflects the amount and rate of runoff likely to be associated with rain. It is a numerical description of the ability of rainfall to erode soil (Wischmeier & Smith, 1978). Within the RUSLE, rainfall erosivity is usually estimated using the EI_{30} measurement (Renard et al., 1997). However, due to the lack of continuous pluviograph data in the study area, the Rainfall erosivity (*R*) is calculated by the following equation as given by Wischmeier and Smith (1978):

$$R = \sum_{i=1}^{12} 1.735 \cdot 10^{\left(1.5\left(\log\left(\frac{P_i^2}{P}\right)-0.8188\right)\right)} \tag{2}$$

Where P_i is the monthly amount of precipitation and P is the annual precipitation.

Table 2
Rain-gauge stations with annual precipitation

Rain gauge station	Latitude and longitude	Average annual precipitation (mm)
Tezpur	26°38'42" N and 92°47'01" E	2,161
Panbari tea estate	26°45'58" N and 92°29'05" E	1,960
Lambari tea estate	26°50'15" N and 92°15'45" E	2,165
Orang tea estate	26°43'30" N and 92°19'08" E	2,052
Mazbat tea estate	26°47'37" N and 92°17'06" E	2,186
Kawpati tea estate	26°34'56" N and 92°14'48" E	1,652
Chikanmati tea estate	26°37'11" N and 92°11'24" E	2,132
Tawang	27°40'30" N and 91°52'00" E	2,055
Bomdila	27°15'48" N and 92°25'24" E	2,174

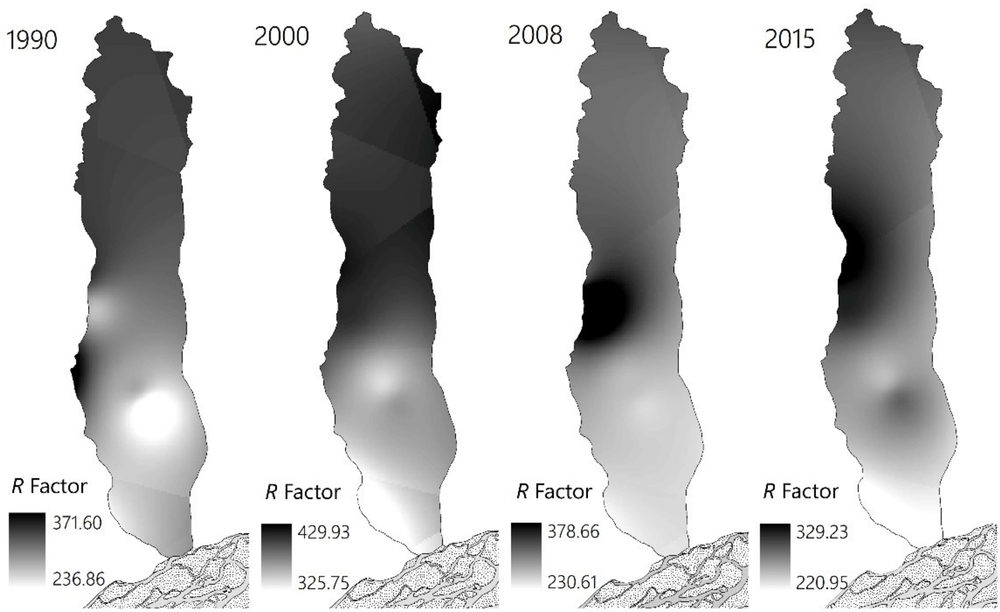

Figure 3. Rainfall-runoff erosivity factor (*R* factor).

To account for the spatial variability of the R factor, monthly rainfall data were collected from nine rain-gauge stations (Table 2), located within and adjacent to the Panchnoi River basin for the period 1990–2015. Most of the rain-gauge stations record only daily rainfall data, and no hourly precipitation information is available at the stations.

Therefore, the R values of different sites were calculated by using the equation mentioned above for the years 1990, 2000, 2008, and 2015. By using the R factor values of the mentioned rain-gauge stations (Table 2), a spatially distributed map of the R factor was generated by using spatial interpolation techniques of ArcGIS version 9.3 (2009) for the years 1990, 2000, 2008, and 2015 (Figure 3).

K factor

The soil erodibility is the inherent susceptibility of soils to erosion by rainwater and runoff and is a function of texture, structure, organic matter content, hydraulic properties of the soil (Blanco-Canqui & Lal, 2008; Pérez-Rodríguez, Marques, & Bienes, 2007). The erodibility of each soil group was calculated by using the following equation that was put forward by Sharpley and Williams (1976) in EPIC (Erosion productivity impact calculator):

$$K = \{0.2 + \exp[-0.0256SAN(1 - SIL/100]\}\cdot[SIL/(CLA+SIL)]^{0.3}\cdot\{1.0 - 0.025C/[C + \exp(3.72 - 2.95C)]\}\cdot\{1.0 - 0.7SN_1/[SN_1 + \exp(-5.51+22.9SN_1)]\} \tag{3}$$

Where SAN referred to the content of sand (%), SIL is the content of silt (%), CLA is the content of clay (%), C is organic carbon (%), and SN_1= 1−SAN/100. This equation results in a K factor with units of ton/MJmm/ha (Renard et al., 1997).

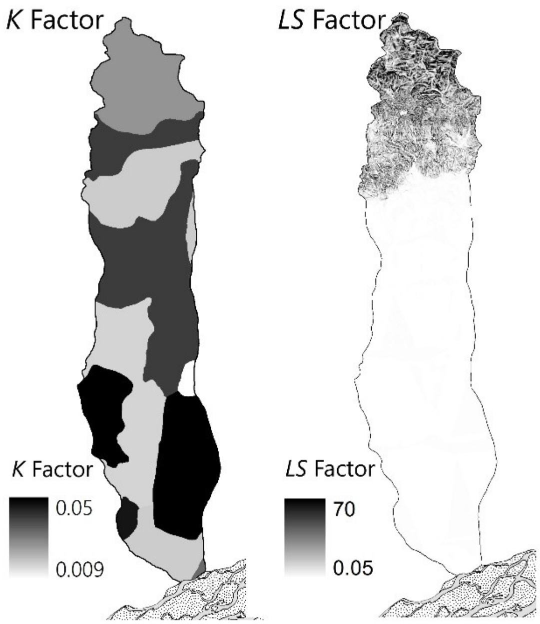

Figure 4. Soil erodibility factor (K factor) and topographic factor (LS factor) map.

Soil erodibility (*K*) was derived by using inherent soil properties, and the values were computed from the soil map data of Assam and Arunachal Pradesh (National Bureau of Soil Survey and Land Use Planning [NBSS & LUP], 1999) (Figure 4).

LS factor

The dimensionless *LS* (topographic) factor implies the influence of topography on soil erosion as a product of the slope length factor (*L*) and the slope steepness factor (*S*) (Thomas et al., 2018). They are crucial as higher slope regions always generate higher water velocity under the gravitational pull, and this phenomenon accelerates soil erosion. Therefore, it is essential to evaluate the effect of topography on soil erosion. Several empirical relationships capably evaluate the *L* and *S* factors. The present study used Moore and Burch (1986), and Moore and Wilson (1992) equation to calculate the *LS* factor of the basin:

$$LS = (AS/22.13)^{m} \cdot (\sin \lambda/0.09)^{n} \tag{4}$$

Where *AS* is upslope contributing area per unit width of the pixel spacing; λ is the slope angle (degrees), *m* and *n* are the exponents of slope parameters for slope length and gradient, and the typical values of *m* and *n* are 0.4–0.6 and 1.0–1.4, respectively.

Crop Cover Management Factor (C)

The *C* factor reflects the effect of land use, land cover (LULC) and management practices on soil erosion, and it is the factor used most often to compare the relative impacts of vegetation cover and management options on conservation tactics (Renard et al., 1997). This *C* factor has a close connection to land use and land cover types and also to anthropogenic interventions on the soil erosion processes. Vegetation cover protects the soil by dissipating the raindrop energy before reaching the soil surface (Karaburun, 2010). Traditionally, the *C* factor is computed from tables with experimental field survey data under natural rainfall (Almagro et al., 2019). Remote sensing images are used to estimate the *C* factor by incorporating vegetation indices, models such as the Normalized Difference Vegetation Index (NDVI) (Panagos et al., 2015). For the present study following NDVI- based equation (Rouse, Haas, Schell, & Deering, 1973) is used to calculate the *C* factor for different periods after van der Knijff, Jones, and Montanarella (2000):

$$C = \exp\left[\alpha\left(\frac{\mathrm{NDVI}}{\beta - \mathrm{NDVI}}\right)\right] \tag{5}$$

Where $\alpha = -2$, and $\beta = 1$, NDVI is a normalized difference vegetation index. The obtained results are presented in Figure 5.

Support practice factor (P)

The *P* factor is the ratio between soil erosion with a specific support practice and the corresponding erosion with upslope and downslope tillage. The support factor *P* represents how surface conditions such as contouring, tillage marks or terracing influence erosion—deposition processes when surface runoff occurs. These practices mainly affect erosion by regulating the flow pattern, direction of surface runoff and by reducing the amount and rate of runoff (Renard & Foster, 1983). Values for *P* are generally difficult to determine and are the least reliable of all the RUSLE factors (Renard et al., 1991). In the study area of the Panchnoi River basin, no supporting practice was witnessed. Thus, the value of *P* was taken as 1.

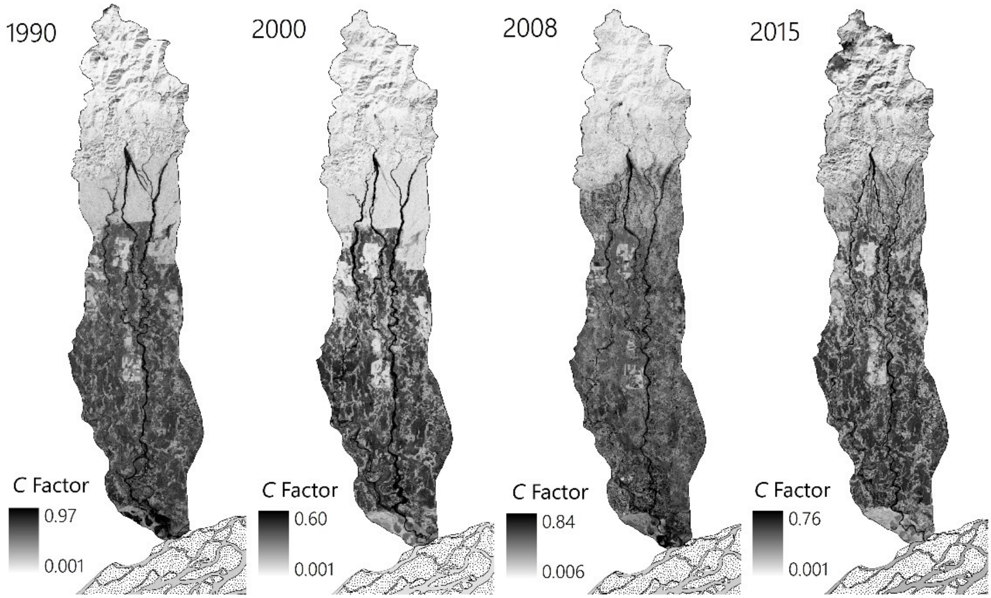

Figure 5. Crop cover management factor (*C* factor).

Results and discussion

The annual soil erosion of the Panchnoi River basin has been estimated for different periods by using RUSLE to estimate the impact of LU dynamics of the soil erosion phenomenon. Based on the integrated variables in RUSLE model, the annual soil erosion of the Panchnoi River basin for the years 1990, 2000, 2008, and 2015 was estimated; where the mean soil erosion for the respective years was estimated as 3.64, 4.35, 4.94, and 5.63 ton/ha/yr respectively. Both plain and hilly topography characterize the river basin, and the impact of this is visible in the soil erosion zonation map. To estimate the magnitude of soil erosion in different parts of the basin, we divided the basin area into six zones based on soil erosion sensitivity, ranging from a very low zone to severe soil erosion zone. Table 3 and Figure 6 show the area under different soil erosion sensitivity zones of the study area.

Most of the basin area falls under very low soil erosion zone (0–2 ton/ha/yr), but the area under very low zone decreases significantly from 1990 to 2015. Except for very low and moderate soil erosion zones, other soil erosion sensitivity zones, especially high, very high and severe soil erosion zones increase to some extent. The soil erosion sensitivity zonation (Figure 6) show that very low, low, and moderate soil erosion sensitivity zones mostly lie in the plain region, whereas high, very high, and severe soil erosion sensitivity lies in the mountain and hilly regions.

Table 3
The area under different soil erosion sensitivity zones

Soil Erosion in tons	Soil Erosion in ton/ha/yr	Area in percentage (%)			
		1990	2000	2008	2015
Very low	≥0 < 2	76.16	71.23	69.77	71.89
Low	≥2 < 5	8.10	11.14	9.07	8.25
Moderate	≥5 < 10	6.29	6.47	6.22	5.62
High	≥10 < 20	4.85	5.66	7.85	5.97
Very high	≥20 < 50	3.52	4.08	5.90	5.85
Severe	>50	1.09	1.41	1.19	2.42

Factors which play a significant role in the natural mechanism of soil erosion are the terrain conditions, soil types, rainfall pattern, and land use, and land cover scenario. The terrain conditions and soil types remain stagnant, whereas rainfall and land use land cover change over time. Therefore, it is crucial to access the dynamics of both factors. The data collected from IMD and water resource department of Assam show that annual rainfall in the Panchnoi River basin and the adjacent areas has a decreasing trend, where the average annual precipitation for the selected periods is 1989, 2228, 2079, and 2005 mm in 1990, 2000, 2008, and 2015, respectively. So, the increasing trend of soil erosion in the basin, i.e., 3.64, 4.35, 4.94, and 5.63 ton/ha/yr in the years 1990, 2000, 2008, and 2015, respectively, were caused by LU dynamics.

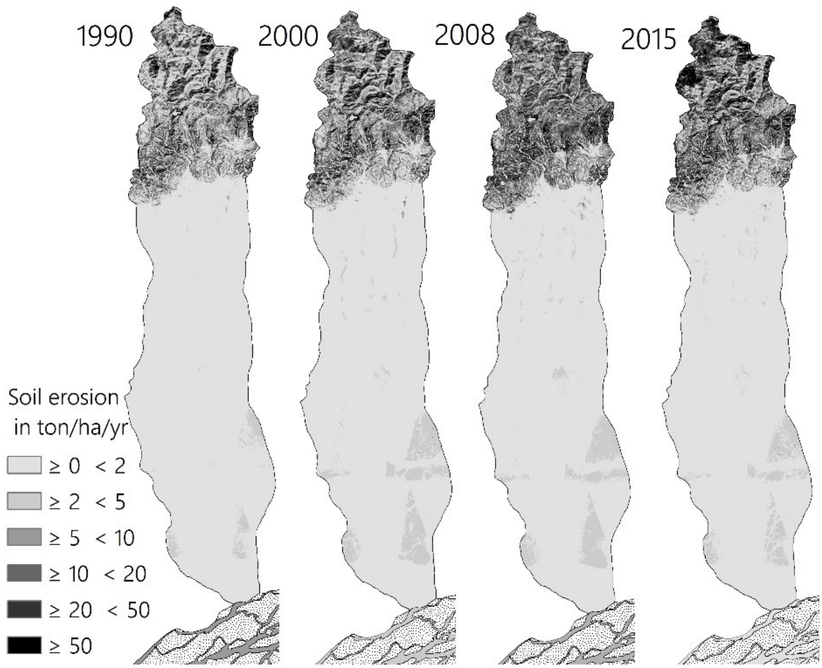

Figure 6. Soil erosion sensitivity zones in the Panchnoi River basin.

The terrain and vegetation characteristics of an area have a significant impact on soil erosion processes (Jaiswal et al., 2014; Sharma, Tiwari, & Bhadoria, 2011). To achieve our formulated goal here, we divided the whole basin into two broad halves based on topographic conditions; these are plain zone and hilly zone. These broad divisions were taken in order to get a clear picture of land use dynamics on soil erosion by balancing the terrain's effects. These geomorphic divisions were done based on slopes and elevation ranges. The geomorphic division which has a gentle surface with low slope (0.2–5°) and elevation ranges (57–250 m a.s.l.) were considered as a plain region, whereas the undulating terrain with high slope (≥5°) and elevation ranges (250–2920 m a.s.l.) were considered as a hilly region. The mean soil erosion from different land-use categories from the two broad physiographic divisions was estimated. It was found that the mean soil erosion in different land use categories increased substantially from 1990 to 2015 according to the changes observed in land use dynamics (Table 4 and 5).

Table 4
The Mean soil erosion (ton/ha/yr) in different land use, land cover categories in plains zone

LULC categories	1990		2000		2008		2015	
	Area in km^2	Soil erosion	Area in km^2	Soil erosion	Area in km^2	Soil erosion	Area in km^2	Soil erosion
Dense forest	74.81	0.21	72.71	0.42	11.93	0.35	7.54	0.34
Degraded forest	0.81	0.56	3.04	0.78	25.62	0.65	7.64	0.66
Agricultural land	200.81	0.61	184.21	1.18	214.73	0.98	232.40	1.09
Settlement	69.61	0.66	85.21	1.28	97.52	0.76	102.46	0.87
Tea Garden	22.56	0.23	26.03	0.28	26.42	0.28	27.40	0.24
Sand Bar	4.60	0.84	8.56	1.21	6.30	0.94	5.04	1.01
Grass land	16.42	0.51	12.29	0.69	10.72	0.62	10.45	0.65
Rivers	12.43	0.63	10.00	1.13	8.81	1.02	9.12	1.08
Plain zone	402.05	0.52	402.05	0.70	402.05	0.83	402.05	0.94

The accelerated mean soil erosion (Table 4 and 5) in different land-use categories of the physiographic divisions is the result of a change in the LU scenario in the basin area from 1990–2015. Both topographic divisions signify the role of slopes in soil erosion, and soil erosion in different land use categories increased significantly.

Table 5
The mean soil erosion (ton/ha/yr) in different land use, land covers in the hilly zone

LULC categories	1990		2000		2008		2015	
	Area in km^2	Soil erosion	Area in km^2	Soil erosion	Area in km^2	Soil erosion	Area in km^2	Soil erosion
Dense Forest	148.34	12.04	148.02	14.19	147.29	15.97	146.75	18.31
Degraded forest	0.04	26.74	0	N/A	0.45	17.88	0.87	18.98
Sand bar	0.11	14.92	0.09	14.99	0.19	16.88	0.18	16.78
Grass land	0.14	14.57	0.12	15.23	0.08	15.76	0.12	17.66
River	0.31	15.77	0.71	21.64	0.93	25.21	0.70	21.89
Agricultural land	0.00	0.00	0.00	0.00	0.00	0.00	0.32	5.54
Hilly zone	148.94	12.06	148.94	14.22	148.94	16.04	148.94	18.30

The major land-uses in the plain zone of the Panchnoi River basin are agricultural land, settlement, sand bar, grassland and the river itself. Forest covers and tea gardens act as a protective blanket. The decreasing trend of forest cover and the increasing trend of agricultural land and settlement area drastically increase the soil erosion probability in the region (Table 5). The mean soil erosions in this section were 0.52, 0.70, 0.83, and 0.94 ton/ha/yr in 1990, 2000, 2008, and 2015 respectively. The changes in the magnitude of soil erosion in this period from 1990 to 2015 were due to the changes in land-use practices in this zone.

In the hilly zone of the Panchnoi River basin, the probability of soil erosion is always higher than in the plain counterpart. Under the influence of topographic slope, soil erosion in this part is much higher, even in dense forest cover zones. Forest covers are hardly able to resist soil detachment and erosion. Although this section is mostly covered by forests (about 99%), the density gradually decreases, which is evident from NDVI analysis. The mean NDVI value of this section decreased from 0.45 in 1990 to 0.34 in 2015. Concerning the decreasing trend of forest density, the magnitude of mean soil erosion increased in this part—from 12.06 ton/ha/yr in 1990 to 18.30 ton/ha/yr in 2015. The decreasing vegetation thickness in this part significantly attributes to soil erosion. Soil erosion in this part also causes damage to the flood plain and low-lying area through sedimentation and riverbed aggradations. Riverbed aggradations take place in low-lying areas to reduce the water carrying capacity of the river, which ultimately causes severe flood situations. The findings of the study strongly suggest the impact of LU dynamics on the soil erosion phenomenon, which highlight the importance in the formulation of land use management strategies and conservation policies.

Conclusion

The study estimates soil erosion from the Panchnoi River basin located at the humid tropical monsoonal climatic regime. This study reveals the impact of LU dynamics on the soil erosion phenomenon in both of the geomorphic divisions. Here, we have found that, despite the decreasing rainfall trends in the study area, the mean soil erosion significantly increased from 3.64 to 5.63 ton/ha/yr in the study period (1990–2015). Considering both of the physiographic divisions, we have found that LULC in the plain area was significantly modified in the study period and that soil erosion almost doubled – from 0.52 ton/ha/yr (1990) to 0.94 ton/ha/year (2015) in this part.

On the other hand, in the hilly region, LU remained almost the same. Here the forest cover occupies 99% of the area, but the density of the forest cover decreased over time and so did the impact of this phenomenon observed in the soil erosion magnitude during this period. Soil erosion in the hill and mountainous part during this period increased from 12.06 ton/ha/yr (1990) to 18.30 ton/ha/yr (2015). The increase of human-induced land use and the decrease of natural land covers caused the increase in the soil erosion in the river basin. The findings of this study help to formulate land use management strategies for the conservation of soil and the environment.

References

Abdulkareem, J. H., Pradhan, B., Sulaiman, W. N. A., & Jamil, N. R. (2017). Prediction of spatial soil loss impacted by long-term land-use/land-cover change in a tropical watershed. *Geoscience Frontiers*, *10*(2), 389–403. https://doi.org/10.1016/j.gsf.2017.10.010

Adinarayana, J., Gopal Rao, K., Rama Krishna, N., Venkatachalam, P., & Suri, J. K. (1999). A rule-based soil erosion model for a hilly catchment. *Catena*, *37*(3–4), 309–318. https://doi.org/10.1016/S0341-8162(99)00023-5

Almagro, A., Thomé, T. C., Colman, C. B., Pereira, R. B., Marcato Junior, J., Rodrigues, D. B. B., & Oliveira, P. T. S. (2019). Improving cover and management factor (C-factor) estimation using remote sensing approaches for tropical regions. *International Soil and Water Conservation Research*, *7*(4), 325–334. https://doi.org/10.1016/j.iswcr.2019.08.005

ArcGIS (Version 9.3) [Computer software]. Retrieved from Environmental System Research Institute.

Assam Water Resource Department. (2016). *Rainfall data register of central Assam districts*. Mangaldoi, India: Assam Water Resource Department–Central Assam Investigation Division.

Biswas, S. S., & Pani, P. (2015). Estimation of soil erosion using RUSLE and GIS techniques: a case study of Barakar River basin, Jharkhand, India. *Modeling Earth System and Environment, 1*, 42. https://doi.org/10.1007/s40808-015-0040-3

Blanco-Canqui, H., & Lal, R. (2008). *Principles of Soil Conservation and Management*. https://doi.org/10.1007/978-1-4020-8709-7

Chalise, D., Kumar, L., & Kristiansen, P. (2019). Land Degradation by Soil Erosion in Nepal: A Review. *Soil Systems, 3*(1), 12. https://doi.org/10.3390/soilsystems3010012

D'Ambrosio, D., Di Gregorio, S., Gabriele, S., & Gaudio, R. (2001). A cellular, automata model for soil erosion by water. *Physics and Chemistry of the Earth, Part B: Hydrology, Oceans, and Atmosphere*, *26*(1), 33–39. https://doi.org/10.1016/S1464-1909(01)85011-5

Geological Survey of India. (1974). *Geology and mineral resources of the states of India, Misc. Publication 30.* New Delhi, India: Government of India.

Geological Survey of India. (2010). Geology and mineral resources of Arunachal Pradesh. Shillong, India: Government of India.

India Meteorological Department. (1991–2015). Rainfall data [Data file]. Retrieved from https://www.imdtvm.gov.in/index.php?

Jain, M. K., & Kothyari, U. C. (2000). Estimation of soil erosion and sediment yield using GIS. *Hydrological Science Journal*, *45*(5), 771–786. https://doi.org/10.1080/02626660009492376

Jaiswal, M. K. (2013). *Geospatial analysis of surface fluvial processes*. Saarbrücken, Germany: LAP Lambert Academic Publishing.

Jaiswal, M. K. (2014). Analysis of land-use land-cover impact on surface runoff in Panchnoi River Basin, North East India, using Geospatial tools. *Image–A research Journal, 3*, 15–25.

Jaiswal, M. K., Thakuria, G., Borah, A. C., & Saikia, R. (2014). Evaluation of parametric impact on soil loss of Panchnoi river basin, North-East India, using revised universal soil loss equation (RUSLE). *The Clarion International Multidisciplinary Journal*, *3*(1), 51–60.

Kalita, N., & Sarmah, R. (2016). Soil loss sensitivity in the Belsiri River basin using Universal Soil Loss Equation in GIS. *International Journal of Current Research*, *8*(3), 28831–28838. Retrieved from https://www.journalcra.com/sites/default/files/issue-pdf/13745.pdf

Karaburun, A. (2010). Estimation of C factor for soil erosion modelling using NDVI in Buyukcekmece watershed. *Ozean Journal of Applied Sciences, 3*(1), 77–85.

Kumar, S. (2015). Geospatial Approach in Assessing Impact of land use/land cover on soil erosion in a Himalayan watershed. In S. Bhan & S. Arora (Eds.), *Advances in Soil and Water Resource Management for Food and Livelihood Security in Changing Climate* (pp. 135–143). New Delhi, India: Soil conservation society of India.

Montgomery, D. R. (2007). Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences of the United States of America*, *104*(33), 13268–13272. https://doi.org/10.1073/pnas.0611508104

Moore, I. D., & Bruch, G. J. (1986). Modelling erosion and deposition: Topographic effect. *Transactions of American Society of Agriculture Engineering*, *29*(6), 1624–1630. http://dx.doi.org/10.13031/2013.30363

Moore, I. D., & Wilson, J. P. (1992). Length-slope factors for the revised universal soil loss equation: simplified method of estimation. *Journal of Soil and Water Conservation, 47*(5), 423–428.

Morgan, R. P. C., Morgan, D. D. V., & Finney, H. J. (1984). A predictive model for the assessment of erosion risk. *Journal of Agricultural Engineering and Resources, 30*, 245–253. https://doi.org/10.1016/S0021-8634(84)80025-6

Narayana Swamy, Y. A. N., Inayathulla, M., & Shashishankar, A. (2017). Spatial Estimation of Soil Erosion Using RUSLE, RS and GIS Techniques: A Case Study of T. G. Halli Watershed, Karnataka, India. *International Journal of Engineering Development and Research*, *5*(3), 1056–1063. Retrieved from https://www.ijedr.org/papers/IJEDR1703149.pdf

National bureau of soil survey and land use planning, India. (1999). Soil map of Assam and Arunachal Pradesh [Data file]. Retrieved from http://www.bhoomigeoportal-nbsslup.in/

National Remote Sensing Agency. (2008). IRS P6 LISS III [Data file]. Retrieved from https://bhuvan-app3.nrsc.gov.in/

Ozsahin, E., Duru, U., & Eroglu, I. (2018). Land Use and Land Cover Changes (LULCC), a Key to Understand Soil Erosion Intensities in the Maritsa Basin. *Water, 10*(3), 335. https://doi.org/10.3390/w10030335

Panagos, P., Borrelli, P., Meusburger, K., Alewell, C., Lugato, E., & Montanarella, L. (2015). Estimating the soil erosion cover-management factor at the European scale. *Land Use Policy, 48*, 38–50. http://dx.doi.org/10.1016/j.landusepol.2015.05.021

Pérez-Rodríguez, R., Marques, M. J., & Bienes, R. (2007). Spatial variability of the soil erodibility parameters and their relation with the soil map at subgroup level. *Science of Total Environment, 378*(1–2), 166–173. https://doi.org/10.1016/j.scitotenv.2007.01.044

Poręba, J. G., & Prokop, P. (2011). Estimation of Soil Erosion on cultivated fields on the hilly Meghalaya Plateau, North-East India. *Geochronometria, 38*(1), 77–84. https://doi.org/10.2478/s13386-011-0008-7

Regmi, R. R., Saha, S. K., & Subedi, D. S. (2017). Geospatial Analysis of Land Use Land Cover Change Modeling in Phewa Lake Watershed of Nepal by Using GEOMOD Model. *The Himalayan Physics*, 6/7, 65–72. https://doi.org/10.3126/hj.v6i0.18363

Renard, K. G., & Foster, G. R. (1983). Soil conservation: principles of erosion by water. In W. O. Willis & H. E. Dregne (Eds.), *Dryland Agriculture, Agronomy Monograph 23* (pp. 155–176). Madison, WI: American Society of Agronomy.

Renard, K. G., Foster, G. R., Weesies, G. A., & Porter, J. P. (1991). RUSLE: revised universal soil loss equation. *Journal of Soil and Water Conservation*, *46*(1), 30–33. Retrieved from https://www.tucson.ars.ag.gov/unit/publications/PDFfiles/775.pdf

Renard, K., Foster, G., Weesies, G., McCool, D., & Yoder, D. (1997). *Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Erosion Equation (RUSLE)* (USDA Agriculture Handbook 703). Washington, DC: U.S. Department of Agriculture.

Rouse, J. W., Haas, Jr. R. H., Schell, J. A., & Deering, D. W. (1973). *Monitoring the vernal advancement and retrogradation (green wave effect) of natural vegetation.* College Station, TX: Remote Sensing Centre, Texas A&M University.

Saha, S. K. (2003). Water and wind-induced soil erosion Assessment and Monitoring using Remote Sensing and GIS. In M. V. K. Sivakumar, P. S. Roy, K. Harmsen, & S. K. Saha (Eds.), *Satellite Remote Sensing and GIS Applications in Agricultural Meteorology* (pp. 315–330). Geneva, Switzerland: World Meteorological Organization.

Saha, R., Majumdar, B., & Das, K. (2015). *S*oil Conservation Management Practices for Fragile Ecosystem of Northeast India. In S. Bhan & S. Arora (Eds.), *Soil Conservation Management Practices* (pp. 1–8). New Delhi, India: Soil Conservation Society of India.

Saroha, J. (2017). Soil Erosion: Causes, Extent, and Management in India. *International Journal of Creative Research Thoughts*, *5*(4), 1321–1330. Retrieved from http://ijcrt.org/papers/IJCRT1704172.pdf

Sharma, A., Tiwari, K. N., & Bhadoria, P. B. S. (2011). Effects of land-use land cover change on soil erosion potential in an agricultural watershed. *Environmental Monitoring and Assessment*, *173*(1), 789–801. https://doi.org/10.1007/s10661-010-1423-6

Sharpley, A. N., & Williams, J. R. (1976). *EPIC – Erosion Productivity Impact Calculator: Model Documentation* (USDA Technical Bulletin Number 1768). Washington, DC: United States Department of Agriculture.

Shen, D. Y., Ma, A. N., Lin, H., Nie, X. H., Mao, S. J., Zhang, B., & Shi, J. J. (2003). A new approach for simulating water erosion on hill slopes. *International Journal of Remote Sensing*, *25*(9), 1791. https://doi.org/10.1080/01431160410001675514

Shinde, V., Tiwari, K. N., & Singh, M. (2010). Prioritization of micro watersheds based on soil erosion hazard using remote sensing and geographic information system. *International Journal of Water Resources and Environmental Engineering, 2*(3), 130–136.

Singh, G., & Panda, R. K. (2017). Grid-cell based assessment of soil erosion potential for identification of critical erosion-prone areas using USLE, GIS, and remote sensing: A case study in the Kapgari watershed, India. *International Soil and Water Conservation Research, 5*(3), 202–211. http://dx.doi.org/10.1016/j.iswcr.2017.05.006

Survey of India. (1972). Toposheets—83–A/8, B/5, B/6 [Data file]. Retrieved from http://soinakshe.uk.gov.in/searchbygeodata.aspx

Thomas, J., Joseph, S., & Thrivikramji, K. P. (2018). Assessment of soil erosion in a tropical mountain river basin of the southern Western Ghats, India using RUSLE and GIS. *Geoscience Frontiers*, *9*(3), 893–906. http://dx.doi.org/10.1016/j.gsf.2017.05.011

US Geological Survey. (1990). Landsat TM 7 band image [Data file]. Retrieved from https://earthexplorer.usgs.gov/

US Geological Survey. (2000). Landsat ETM 8 band image [Data file]. Retrieved from https://earthexplorer.usgs.gov/

US Geological Survey. (2014). SRTM 1 Arc-Second Global [Data file]. Retrieved from https://earthexplorer.usgs.gov/

US Geological Survey. (2015). Landsat ETM 8 band image [Data file]. Retrieved from https://earthexplorer.usgs.gov/

van der Knijff, J. M., Jones, R. J. A., & Montanarella, L. (2000). *Soil erosion risk assessment in Europe*. Brussels, Belgium: European Commission, European Soil Bureau, Joint Research Centre.

Wischmeier, W. H., & Smith, D. D. (1978). *Predicting Rainfall Erosion Losses–A Guide to Conservation Planning, (*Agricultural Handbook 537*)*. Washington, DC: U.S. Department of Agriculture.