



# Soil erosion estimation using RUSLE and GIS techniques—a study of a plateau fringe region of tropical environment

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## Abstract

This paper tries to understand the soil erosion characteristics in a tropical plateau fringe region by the use of Revised Universal Soil Loss Equation (RUSLE). Soil loss estimation is an important phenomenon to understand the land degradation. An integrated method needs to be adopted in tropical plateau fringe region to estimate the soil loss. RUSLE has been adopted for the present study. The river in the basin under consideration sees its origin from a plateau top region and flows through the plateau fringe region of eastern Chotanagpur plateau, India. The present study area reflects undulated plateau fringe landform with gently sloping dissected plateau topography. The different factors like, rainfall erosivity factor ( $R$ ), soil erodibility factor ( $K$ ), topographic factor ( $LS$ ), crop and management factor ( $C$ ), and support and practice factor ( $P$ ) have been enumerated using field and remote sensing data. Each factors result has also been verified with previous literature. All factors have been multiplied in GIS environment to estimate soil loss. High-magnitude soil loss region ( $> 10 \text{ t ha}^{-1} \text{ year}^{-1}$ ) covers 4.88% of the total area and extends up to the upper reaches of the watershed. Topographic and soil factors best represent this loss. Low-magnitude soil loss region ( $< 2.5 \text{ t ha}^{-1} \text{ year}^{-1}$ ) in the lower reaches of the watershed is a result of successful land management activity. Soil erosion is dominated process of land degradation in the upper reaches of the watershed and estimation of soil loss is an important input for land-use land-cover management. The study also inferred that RUSLE soil erosion model could be effectively used in tropical plateau fringe environment.

**Keywords** Tropical plateau fringe · RUSLE · Soil loss estimation · Land degradation · Chotanagpur plateau · Plateau topography · Land-use land-cover management

## Introduction

Water-induced soil erosion has been accepted to have the most intensified effect in the process of land degradation. Soil erosion has ceased to remain a natural phenomenon exclusively lately; as it has been seen to be heavily human-induced in microregional scale, depending upon the size and activities of the population that resides in it. Since mid-twentieth century, farmers have had to double their food output to feed the ever-growing population. Man-land ratios of lower-middle income countries have also been seen to have enlarged considerably since the recent growth spurt post decolonisation. In addition to those above, intensified deforestation, clearing and burning of grassland, rangeland

grazing, and overexploitation of timber resources, to state a few of the causes, result in landfall vulnerable to agents of erosion (water, wind etc.). The loss of soil productivity using loss of soil fertility, degradation of natural resources and biodiversity is defined as land degradation (Thiombiano and Tourino-Soto 2007). Land degradation and soil degradation are more or less synonymous. Land degradation causes poor crop production leads people to poverty (Nkonya et al. 2015). Modern-day human civilisation has performed poorly in conserving the pristine natural condition. Hence, the cumulative negative anthropogenic effect on landscape has induced largescale land degradation. Degradation encompasses deforestation (tropical and temperate) and dryland desertification (Moussa et al. 2016). Almost 75% of the dry land in the world faces the problem of severe desertification (Gibbs and Salmon 2015). The areal coverage of land degradation is extensive worldwide, covering approximately 23% of the total earth terrestrial land. Land degradation has been seen to increase by 5–10 million ha annually affecting 1.5 billion people as a result of this (Fitzpatrick 2012).

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The major noted factors or causes of land degradation in tropical world are unsuitable land use and inappropriate land management practice, for example, cultivation on steep slopes (Pulido and Bocco 2014). Other factors include clearing of vegetation cover, soil types, topography, pollution, drought and flood, unsuitable agriculture practice, urban expansion or habitat alteration, agriculture expansion, and habitat destruction. The inappropriate land management with unsuitable land-use practice is the major cause of land degradation in developing country. The other factors are overgrazing, agricultural activities, overexploitation of vegetation, lowering of water table, water logging, soil fertility decline, salinisation, etc. (McGregor 1989). Land-population-poverty is the causal nexus of land degradation. The different processes of land degradation worldwide are vegetal degradation, water erosion, wind erosion, salinity/alkalinity, frost heaving, frost shattering, mass movement, deforestation, water logging, manmade, etc. (ISRO 2007). Water erosion, wind erosion, soil degradation regarding physical, chemical, biological and nutritional are the major types of soil degradation. Waterlogging, groundwater fluctuation, salinisation and deforestation are the important major types of soil degradation in the tropical climate regions of the world. Gully erosion is the major process of soil degradation in tropical environment (Pan and Wen 2014). The major process of soil degradation worldwide is soil nutrients loss (Oldeman and Van Engelen 1993). The soil erosion, salinisation, and alkalization, acidity, soil organic carbon losses, nutrient imbalance, pollution/contamination by toxic substances and soil sealing and capping are the major processes of soil degradation in the tropical world (Lal et al. 1989). Wind erosion, water erosion and decline in soil nutrient, organic matter, and structure are the common types of soil degradation in these areas. In addition to this, coastal erosion, mass movement, salt-affected soil, reduced agricultural yield and desertification are also common expressions of soil degradation. Two billion ha out of the five billion ha of degraded land suffers from the soil degradation (Bready and Well 2005). The deterioration of physical and chemical properties of soil leads to soil degradation. Erosion caused most (~85%) soil degradation processes. Out of two billion ha of degraded land, 56% is caused by water erosion (Bready and Well 2005).

Vegetal degradation (36%), water erosion (27%) and wind erosion (22%) are the major processes of soil degradation in India (NRSC 2011). According to different sources,  $16.6 \text{ t ha}^{-1}$  of soil falls prey to erosion annually in India, of which rivers cause 29%. Soil erosion is a considerably important process of soil degradation amongst the other processes of degradation like soil structural or chemical degradation (Lal 2001). Areas prone to vegetal degradation are present in almost all morpho-climatic regions of India. Areas prone to wind erosion are present in western Thar Desert areas where the speed and direction of wind are constant throughout the years. Areas prone to water erosion are noticeable in areas

where annual rainfall exceeds 150 cm; regions of active influence of Indian monsoon. N-E plateau areas (Meghalaya plateau), Western Ghat mountain areas, and large river basin areas (like Ganga, Sindh, and Godavari) serve as good examples exhibiting water erosion (ISRO 2007; ISRO 2016). The eastern Chotanagpur plateau located in the Eastern part of India is geographically unique because of its tropical plateau fringe landscape characteristics. Largely it comes under the Ganga river basin area. Eastern Chotanagpur plateau region has been studied to be amongst one of the most vulnerable areas in India to large scale water-related soil erosion (NRSC 2011). The soil cover of the area comprises mostly of water eroded laterite. Granite gneiss geological formations, undulating plateau morphology with occasional hills, less soil profile development causes soil degradation (Mahala 2017). Presently, continuous agriculture expansion, high groundwater extraction and irrigation expansion aids soil erosion. The area has extensively become prone to erosion due to deforestation, continuous uncovering the land as well as poor management practices. Degraded laterite scape is more vulnerable to erosion (Jha and Kapat 2009). Presence of laterite soil over undulating plateau and high slope river banks create favorable conditions for erosion (Ghosh and Maji 2011). During heavy monsoon rainfall, occasional rills and gullies are seen to develop in laterite areas (Shit and Maity, 2012b). High iron (Fe) and aluminium (Al) content in surface laterite are seen to cause infertility. Leaching processes of  $\text{SiO}_2$  cause high potentiality of erosion in such environment (Ghosh and Guchhait 2015). Continuous groundwater extraction causes water stress condition in soils of these areas (Mondal 2012). Recent climatic variability pattern increases the vulnerability of land to degradation (Chaudhary et al. 2012). Different studies have been conducted in the tropical plateau fringe areas or of Chotanagpur plateau to understand the phenomena of water-related soil erosion. Present literatures largely observe water erosion to be the major process of land degradation in the Chotanagpur plateau area. Gully formation facilitated by water erosion is the prominent erosional feature in this area (Ghosh and Guchhait 2017). Severely degraded land covers more than 10% of some districts in this region (Gupta et al. 1998). Kothyari et al. (2002) have used GIS-based method in their study, and have identified sediment source areas as well as predicted the total sediment discharge from a Chotanagpur plateau catchment area. The study uses ILWIS-GIS packages for catchment discretisation and evaluating topographic characteristics of catchment (Jain and Kothyari 2000). The catchment of Chotanagpur plateau has been found more vulnerable to soil erosion amongst other catchments of the study. Four types of typical Alfisols occupy the Chotanagpur area. They develop in old alluvium underlain by granite-gneiss. The soils found can be typified under sandy loam to loam with coarse texture and good water drainage, which are found to be more prone to water erosion. Broadly the soil comes under 'Ultic

PaleustalFs' and 'Rhodic PaleustalFs' (Sarkar et al. 2001). The studies of Roy et al. (2008) found the loss of soil organic carbon and related deforestation to be the major factor responsible for soil erosion in plateau fringe Chotanagpur area. Mining is also responsible for degradation of land in plateau areas (Sahu and Dash 2011). The study of Chakraborty and Chatterjee (2008), have used MUSLE to get the amount of soil erosion and run off potentiality in a part of Chotanagpur plateau. The study found alteration of land from forest area to other land-use types to be the major factor responsible for soil erosion. Many studies find specific characteristics of Chotanagpur plateau responsible for high soil erosion like, multicyclic laterite cover, short period of heavy rainfall, thin grass cover, low values of Constant of Channel Maintenance (CCE), etc. (Ghosh and Maji, 2011). The studies of Jha and Kapat, 2009 identified aberrant weather, crusting, drought, water erosion, and NPK deficiency as the major responsible factors for soil degradation in Chotanagpur plateau fringe areas. Some studies attributed climate change and relative increase in precipitation to soil erosion in Chotanagpur plateau (Chaudhary et al. 2012). Climate change and relative increase in rainfall intensity is a popularly believed fact about the tropical environment. Acceleration in soil detachment causes high rate of soil erosion in tropical plateau areas. Various studies found gully head retreat to be the major erosional landform in lateritic Chotanagpur plateau areas (Shit and Maity, 2012a; Shit et al. 2013). Studies suggest soil erosion factor ( $K$ ) and slope length factor ( $LS$ ) to be the most important variables characterising upper basin soil erosion. Support-practice factor, on the other hand, is the most important variable for the lower basin areas of Chotanagpur plateau (Parveen and Kumar 2012; Tirkey et al. 2013). Study conducted by Chatterjee et al. (2013) used USLE model to find out trends of soil erosion in the upper parts of Subarnarekha basin, a part of Chotanagpur plateau. The study found increase in the rate of erosion from  $40 \text{ t ha}^{-1} \text{ year}^{-1}$  to  $50 \text{ t ha}^{-1} \text{ year}^{-1}$  in a 10-year time gap period. Identifying factors for increase in soil erosion vulnerability are deforestation and increase in built-up areas. The study of Lenka et al. (2014) found Chotanagpur plateau fringe area of West Bengal to be a major vulnerable soil erosion area after examining the different factors of soil erosion. The study conducted by Gulati and Rai (2014) have used primary field survey to estimate the amount of soil loss as well as its economic value. It found that on an average 590 kg of macro-nutrients is lost during monsoon season per hectare area. The studies used RUSLE model to identify the major factors responsible for soil erosion in plateau fringe environment; revealing the fact that  $LS$  factor (landform and slope factor) is the major responsible factor behind soil erosion. Undulating plateau and slant areas provide potential energy to runoff responsible for erosion (Biswas and Pani 2015). Plateau proper areas or upper basin areas of plateau fringe environment have characteristics like coarse soil texture, low

organic matter and undulating landform. All the aforementioned characteristics assist in raising the rate of soil erosion (Shit et al. 2015). Lower reaches of the basin have lesser potentiality of soil erosion due to increased clay content in soil along with smooth gradient landscape (Samanta et al. 2016).

Different models can estimate soil erosion in a river basin where soil detachment, transport, and deposition can be mathematically predicted. The Water Erosion Prediction Project (WEPP) used by USDA is based on mathematical simulation. The processes leading to soil erosion is the fundamental mechanism of WEPP (Bready and Well 2005). It takes into account rainfall, soil, topography, vegetation and management of a site with the amount of soil to be lost. The Soil and Water Assessment Tool (SWAT) developed in the 1990s is a conceptual and continuous time-based model. The different components comprise of weather, hydrology, erosion/sedimentation, plant growth, nutrients, pesticides, agricultural management, stream routing and pond/reservoir routing (Arnold and Fohrer 2005). The Modified SWAT 2000 includes solar radiation, relative humidity, wind speed, potential evapotranspiration (ET), bacteria transport routines and urban routines. Different studies have expressed its advantage for the flexibility and development it provides (Arnold and Fohrer 2005). Its suitability is enhanced in the mountain environment. The Limburg Soil Erosion Model (LISEM) is a physical-based model which premises on raster geographical information system. The incorporated processes are soil, overland flow, channel flow, detachment by rainfall, through fall, detachment by overland flow and transport capacity of the flow. The main advantages of the model are its incorporation facilities, easy applicability in large catchments, user-friendliness, by avoiding the conversion routines, and applicability on remotely sensed data (Roo and Wesseling 1996). Due to the unavailability of the specified data, this model has not been taken into account for the current study area. The Chemical Runoff and Erosion from Agriculture Management Systems (CREAMS) evaluates the water quality of a basin. This method has however been criticised for being incapable during storm and is ideally not intended for basin scale studies, hence making the model less usable (Roo and Wesseling 1996). The European Soil Erosion Model [EUROSEM] can be used for predicting soil erosion by water in small catchment (Morgan et al. 1998). The Morgan, Morgan and Finny (MMF) can be used to predict soil erosion of a watershed in mountain environment. However, requirement of very specific data makes it unsuitable for the present study. Modified Pacific Southwest Inter-Agency Committee (PSIAC) however, includes the factors of surface geology, topography, climate, runoff, surface erosion, ground cover, land use and gully erosion in their study (Heshmati et al. 2012). Universal Soil Loss Equation (USLE) is a widely used soil erosion prediction model throughout the tropical climatic areas of the world, where

rainfall-runoff erosivity is the prominent factor causing erosion. The RUSLE is the modification of the USLE model formulated in the 1980s. Believed to estimate soil erosion more accurately, the RUSLE model has been successfully computerised. Rainfall erosivity factor ( $R$ ), soil erodibility factor ( $K$ ), slope factor ( $LS$ ), cover and management factor ( $C$ ) and practice factor ( $P$ ) have been multiplied in GIS environment to predict soil erosion potentiality through this model. Through the long-term breakpoint precipitation, the  $R$  factor has been determined.  $K$  factor evaluates the inherent erodibility of a given type of soil. Slope-length relationship has been evaluated through  $LS$  factor. The  $C$  factor is important because it covers the condition of land use which can be managed to reduce soil erosion. The least reliable factor of RUSLE named by  $P$  represents the surface conditions which affect flow hydraulics (Lane et al. 1992). The different individual factors of RUSLE dominate in different morpho-climatic settings. Different studies identified  $LS$  factor as the most dominant factor deriving soil erosion characteristics in tropical mountain environment. The model also provides an important soil conservation tool which is accessible and readily transferable in similar environment (Kalambukattu and Kumar 2017; Millwarda and Merseyb, 1999). Study of Lu et al. (2004) used RUSLE model to explore the importance of different factors in tropical Brazilian Amazonia. They found rainfall-runoff erosivity ( $R$ ) and support practice factor ( $P$ ) were not in use because of lack of ample human habitation due to unfavourable climatic condition. The results indicate most successional and mature forests are at a very low erosion risk while pasture and cropland areas are the most vulnerable to erosion. The study also found RUSLE to be an important erosion measurement tool. The Revised Universal Soil Loss Equation (RUSLE) is a widely used model in basin scale studies of tropical environment (Bhattarai and Dutta 2007; Bhandari et al. 2015). Different studies used RUSLE in Brazilian tropical environment found fruitful conclusions (Beskow et al. 2009). Study of Pandey and Chowdary (2007), found RUSLE to be an accurate model in estimating basin scale sediment yield from Karso watershed of Hazaribagh (a part of tropical Chotanagpur plateau in India). Few studies modify RUSLE factors with the application of AHP (Analytical Hierarchy Process) to estimate an accurate amount of basin scale soil erosion (Rahman et al. 2009). Studies have conducted attempting to estimate soil erosion in semiarid environment through the use of RUSLE model. But it suffers from overestimation or underestimation problems (Vaezi et al. 2010; Imani et al. 2014). High resolution remotely sensed data (like, Quick Bird) successfully utilises the RUSLE/USLE model to estimate erosion in temperate environments (Meusburger et al. 2010). RUSLE model has been successfully applied in tropical Africa where soil erosion is the primary degrading processes. Cropland areas of tropical eastern Africa are characterised as sites of major soil erosion

(Adugna et al. 2015). Studies also found, RUSLE to be a useful model to predict soil erosion potentiality of different land-use categories in Mediterranean Europe. Olive orchards and vineyard lands are most vulnerable to erosion in these climatic areas (Ferreira et al. 2015). RUSLE applied in tropical Mexico found slope ( $LS$ ) and cover management ( $C$ ) to be the factors most responsible for soil erosion (González-Morales et al. 2017). This model satisfactorily fits in for use in tropical environments while being easily computable (Millwarda and Merseyb 1999; Cunha et al. 2017).

Soil erosion forms major process of land degradation in eastern Chotanagpur plateau. The present study of soil erosion estimation has been taken up in a selected watershed of eastern Chotanagpur plateau. The RUSLE soil erosion model suggests a distinct river basin as an aerial unit to estimate soil erosion (Zhang et al. 2016; Pan and Wen 2014). The Kangsabati river basin forms a well-defined geomorphological unit in the tropical plateau fringe environment of eastern Chotanagpur plateau, India. It flows through different geomorphological units including undulating plateau areas in the upper reaches to the lateritic tracts in the middle-lower reaches. The soil in the upper reach is characterised by low soil profile development, low organic matter content and high silica content as well as undulating plateau topography. Agriculture practices are also limited to the lower part of the basin. The region faces drought in the upper reaches of the basin where groundwater level is very deep. So, it is important to characterise the soil erosion factors as well as erosion potentiality in that semi-drought prone plateau proper areas. The middle and lower reaches of the basin, characterised by thick laterite cover with primary laterite developed in upslope areas are prone to erosion. In addition to this, factors like recent deforestation and agricultural expansion attributed to increase in population enhances soil erosion in the lower part of the plateau fringe. It is pertinent to evaluate these factors in that part of the plateau fringe. Agricultural practice is observed throughout the basin. Therefore it is important to estimate the soil erosion and factors behind it in different land-use practice zones. However, the evaluation of soil erosion characteristics in these types of tropical plateau fringe environment has not been conducted earlier. Estimation of soil erosion potentiality helps build suitable water harvesting structure which provides water in dry season as well as reducing soil erosion. RUSLE also provides erosion control practice ( $P$ ) and computation of cover management ( $C$ ) which otherwise deduces the effect of vegetation. There is scanty information available to understand soil erosion factor and potentiality in such a fragile plateau fringe region of tropical environment. A detailed study would give insights into how soil erosion has created vulnerability, given the natural settings. The present study is an effort to understand the different factors leading to soil erosion in tropical plateau fringe environment. In such types of regions different physical and management settings



give rise to specific characteristics of land. Soil erosion potentiality is thus the result of different factors acting upon it. The paper also attempts to map soil erosion risk in the basin. Also, to provide a tool for soil conservation strategies, it becomes necessary to estimate soil erosion. In this regard, remote sensing and GIS enable manipulation to provide sufficient measures. Therefore, this work attempts to understand the different factors of soil erosion in a tropical plateau fringe region. This study also strives to estimate the soil erosion potentiality and vulnerability in a tropical plateau fringe environment.

## Location and description of study area

The selected basin for the present study namely “Kangsabati River” (locally known as Kasai River) originates from the Ajodhya hills of Purulia district is a part of eastern Chotanagpur plateau in India (Fig. 1). It flows through the eastern Chotanagpur plateau in an eastward direction. Basin falls under the Purulia, Bankura and Paschim Medinipur districts of West Bengal state, India. The total area of Kangsabati Basin falls entirely in the eastern Chotanagpur plateau. Out of 22,472 km<sup>2</sup> area of Purulia, Bankura, and Paschim Medinipur district, Kangsabati basin covers 6592 km<sup>2</sup>. The immature soil profile (Less in organic matter), less vegetal cover, weak soil profile development in the upper reaches of the basin, especially in Purulia district, accounts for a bulk of soil erosion which is eventually drained through the river (Dolui et al. 2014). Granite-gneiss geological formation, undulating plateau upland, occasionally hilly terrain and sub-humid climatic characteristics make the upper part of the basin area or the western part more prone to soil erosion. The middle part of the basin is characterised by transitional plateau-plain geological formations, lateritic soil cover in undulating sloping surface (Sarkar et al. 2014). Recent agricultural expansion and related deforestation have hastened the process of soil erosion, high soil erosion with rill and gully formation (Ghosh 2015). Reduction of vegetal cover, transformation of forest land to agricultural land, enhances the vulnerability of soil to erode, which ultimately flows through Kangsabati basin. The plain topography characterises the lower reach of the Kangsabati basin. Agricultural expansion, deforestation and related groundwater exploitation pose major threat of soil erosion (Mondal 2012).

## Database and methods

The RUSLE models have been suggested for soil erosion assessment since the second half of the nineteenth century. Such models include the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith in 1978 and Modified Universal Soil Loss Equation (MUSLE) developed

by Williams in 1978. The updated RUSLE model was developed by Renard et al. in 1991 and updated from time to time (Jain and Kothyari 2000). The USLE model has been widely used since the 1970s (Bready and Well 2005). The factors (*R*, *K*, *LS*, *C*, and *P*) are quantified in USLE model. To create an erosion prediction tool the basic USLE model was updated and computerised called RUSLE. The RUSLE soil erosion model uses the same factors of USLE with better defined and interrelationship, enabling it to calculate soil erosion estimation more or less accurately (Bready and Well 2005). RUSLE model has better flexibility in modelling of erosion potentiality (Lu et al. 2004). The different model’s results have large variations due to the changes in the catchment scale and input requirements. Though the RUSLE model has not shown the real picture of sediment yield, it can give an approximate estimation of soil loss. The RUSLE model is widely used for its simplicity in respect of data availability (Jain and Kothyari 2000). With RUSLE model river sedimentation, valley-side soil loss can also be accessed. RUSLE helps carry out estimation of soil loss through long range of environmental settings (Beskow et al. 2009). RUSLE can be applied to individual field, basin and areal units (Pandey and Chowdary 2007).

## Generation of thematic maps for RUSLE model

The RUSLE model has been used to predict soil loss of Kangsabati river basin, located in a tropical plateau fringe region. Renard KG (1991) described this model with the following equation;

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

where ‘*A*’ is average annual soil loss per unit of area (t ha<sup>-1</sup> year<sup>-1</sup>), ‘*R*’, rainfall-runoff erosive factor (MJ mm ha<sup>-1</sup> h<sup>-1</sup> year<sup>-1</sup> and ‘*K*’ the soil erodibility factor (t ha MJ<sup>-1</sup> mm<sup>-1</sup>). ‘*LS*’ is the topographic factor (dimensionless) which includes slope length factor (dimensionless) and slope steepness factor (dimensionless). ‘*C*’ is the cover- management factor (dimensionless), and ‘*P*’ is the support practice factor. For different factors, Raster Kriging (*R*, *K*, *LS* factors) and Raster Weightage (*C*, *P* factors) maps have been generated.

## Rainfall erosivity factor

The driving forces for sheet and rill erosion are represented by rainfall erosive factor or ‘*R*’ factor. It takes into account the intensity and seasonal distribution of rainfall. Intense rain with large drop size results in cumulating of greater kinetic energy, thus permitting the detachment of soil particles. The high intense rainfall caused high runoff leads to high sheet and rill erosion. High magnitude of rain causes higher runoff; which

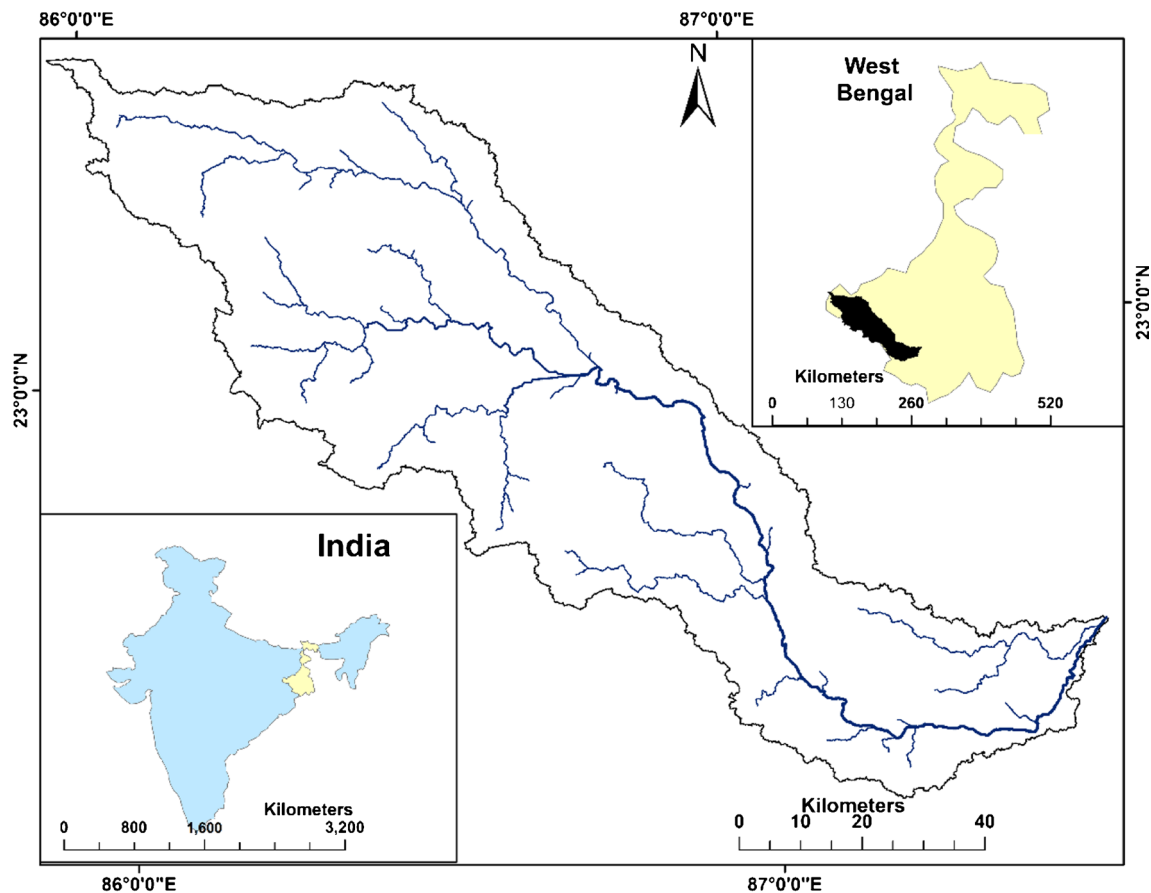


Fig. 1 Location map Kangsabati river basin

ultimately results in greater soil erosion. ‘*R*’ factor has been estimated using the equation developed by Renard and Freimund in 1994. Different authors have used the equation for plateau fringe regions (Beskow et al. 2009;

Shit et al. 2015), while, many other studies have used different ‘*R*’ factor equations (Rahman et al. 2009; Prasannakumar et al. 2012). The average monthly erosivity (Eli) equation has been computed as follows:

$$Eli = \frac{125.92 \times (ri^2/P)^{0.603} + 111.173(ri^2/P)^{0.691} + 68.73 \times (ri^2/P)^{0.841}}{3} \quad (1)$$

where ‘Eli’ is the average monthly erosivity ( $\text{MJ mm ha}^{-1} \text{h}^{-1}$ ) for the month of *i*. ‘*r*’ is the average monthly rainfall for the month of *i* and ‘*P*’ is the mean annual precipitation (mm).

The average monthly and annual rainfall data of Indian Meteorological Department (IMD) for 1965 to 2010 has been used for rainfall erosivity calculation. Data of three stations (Purulia, Bankura and Paschim Medinipore) of IMD have been used in the present study. These three stations are situated within Kangsabati basin, the present study area. The annual rainfall erosivity has been derived by summing up the monthly erosivity values for each station (Table 1). Arc GIS (version 10.1) has been used for locating the rainfall erosivity factor values within Kangsabati basin. With these point location,

the ‘Kriging raster’ of rainfall erosivity (*R*) has been generated. The spatial distribution of ‘*R*’ values has been extracted through this raster.

#### Soil erodibility factor

Soil erodibility factor (*K*) is the inherent vulnerability of the soil to get eroded. The values of ‘*K*’ assigned to a particular soil represent the amount of soil loss per unit of erosive energy. The two most significant soil characteristics which control the erosivity of soil are infiltration capacity and soil structure (Bready and Well 2005). Soil characterised by high infiltration causes low

**Table 1** Mean annual rainfall-runoff erosivity factor ( $R$ ) of three rainfall station of IMD in Kangsabati river basin

Rainfall gauging station	Latitude and Longitude	R (MJ mm ha <sup>1</sup> h <sup>1</sup> )
Purulia	23° 15' 13" N 86° 22' 23" E	8295.67
Bankura	22° 54'54" N 86° 45' 00" E	8885.20
Paschim Medinipore	22° 26' 07" N 87° 10' 42" E	8417.60

overland flow, which leads to less erosion. Therefore the ' $K$ ' values are notably lower. Soils having compact structure are susceptible to erosion. RUSLE also takes into account soil organic matter and soil texture considering seasonality. The increasing base content tends to high values of ' $K$ ', including a high content of silt and very fine sand. The greater the organic matter, lesser is the soil susceptibility to erosion. The soil erodibility equation ( $K$ ) is:

$$100 K = 2.1M1.1410^{-4}(12-a) + 3.25(b-2) + 2.5(c-3) \quad (2)$$

where ' $M$ ' = particle size parameter, (percent silt + percent very fine sand) (100 – percent clay), ' $a$ ' = percent organic matter, ' $b$ ' = soil structure code used in soil classification and ' $c$ ' = soil permeability class.

The different values of ' $K$ ' have been derived for different soil types based on texture, structure, organic matter, and permeability. For different soil classes different ' $K$ ' values were assigned in different studies by scholars (Beskow et al. 2009; Kothayari and Jain 1997; Bhattarai and Dutta 2007). The soil erodibility factor has been estimated using soil type data and field soil test. The soil data for the present study have been derived with the help of district-level maps prepared by the National Bureau of Soil Survey and Land-use Planning (NBSS and LUP), ICAR, India and National Atlas and Thematic Mapping Organisation (NATMO), Kolkata, India, respectively. The different ' $K$ ' values for the different soil types of Purulia, Bankura, and Paschim Medinipore located in the Kangsabati basin have been assigned concerning distinct soil texture, structure, organic matter and permeability, respectively (Table 2). The corresponding ' $K$ ' values have been

assigned following different studies carried out in India (Jain and Kothayari, 2000) (Pandey and Chowdary 2007; Shit et al. 2015; Kothayari and Jain 1997; Tirkey et al. 2013).

The whole of the Kangsabati basin has been divided into 72 equal rectangles of 100 km<sup>2</sup> each. Within each of the rectangles particular ' $K$ ' values have been assigned to a particular type of soil. Kinging raster has been created aided with these ' $K$ ' values. The spatial distribution of soil erodibility factor ( $K$ ) has been extracted from this raster.

### Topographic factor

The topographic factor (LS) is considered in RUSLE model for capturing the impact of topography on soil erosion (Ganasri and Ramesh 2015). The two important factors; topography-slope length ( $L$ ) and slope steepness ( $S$ ) are employed to generate the runoff which leads soil erosion (Beskow et al. 2009). The topographic (LS) factor represents the length and steepness characteristics of slope which affects soil erosion. It is expressed as a unitless ratio. The numerator constitutes soil loss from the area, and a standard plot of 22-m length and 9% slope form the denominator. The concentration of runoff is proportional to the slope length (Bready and Well 2005).

' $L$ ' factor values may be expressed as

$$L = \left( \frac{\lambda}{22.1} \right)^m \quad (3)$$

where ' $L$ ' is the slope length factor,  $\lambda$  = contributing slope length (m.), ' $m$ ' is the variable slope length exponent that varies based on slope steepness. The values of ' $m$ ' are considered at 0.3 for slope less than 3%, 0.4 for slope 4% and 0.5 for slope greater than 5% (Pandey and Chowdary 2007).

The slope steepness ( $S$ ) is calculated from the equation given by McCool in 1987 are

**Table 2**  $K$  factor values of soil of Kangsabati river basin

Soil textural class	$K$ factor values	Soil textural class	$K$ factor values
Fine sandy loam	0.72	Silt	0.75
Very fine sandy loam	0.92	Silt loam	0.94
Silty clay	0.51	Loamy sand	0.22
Silty clay loam	0.72	Sandy loam	0.54
Sandy clay loam	0.55	Ultisols	0.27

$$S = 10.8\sin\theta + 0.03 \text{ when slope is } 9\% \quad (4)$$

$$S = 16.8\sin\theta - 0.05 \text{ when slope is } \geq 9\% \quad (5)$$

where 'S' = slope steepness factor (dimensionless).

For 'LS' calculation, the whole area of Kangsabati basin is divided into 75 grids of 100 km<sup>2</sup> each in Arc GIS (version 10.1). Aster DEM data have been used for 'LS' calculation. For each grid, the slope length (m) has been measured. Percentage value of slope has been derived from DEM data for each grid in Arc GIS 10.1. Degree of slope ( $\theta$ ) has also been also measured for the same. Finally, the 'L' and 'S' values have been multiplied using raster calculator. The spatially distributed topographic 'LS' values have been extracted using the multiplied 'LS' raster.

### Cover and management factor

The cover and management factor (C) or land cover and land-use factor exerts great control over soil erosion. If other physical factors remain constant, it is only the 'C' factor which controls soil erosion of any region. Temporally speaking, it is this 'C' factor which is susceptible to frequent changes. In the absence of other perpetuating physical factors, the land will remain under dense forest cover, thus controlling soil erosion. Vis-a-vis, intensive agriculture itself plays an important contributing role in prolonged soil erosion; other physical factors remaining constant. As land-use and land-cover changes are more frequent, It is thus pertinent to assign values for different land-use land-cover types.

The values above vary from '0' to '1' for different land-use land-cover (LULC) types depending upon different geographic locations ('0' representing less vulnerability to '1' representing high vulnerability). Different scholars worldwide have made attempts at assigning values to different LULC categories. The United State Department of Agriculture (USDA) national resource conservation service has given values of '0.40' to scrubland and '0.03' to rotated crop field (Bready and Well 2005). Most studies have assigned values of '0.007' to pasture and '0.290' for agricultural land (Beskow et al. 2009). Prasannakumar et al. (2012) have given the value of '0' for all types of water bodies and wetland. In the Indian scenario, however, different authors have assigned values like, '0.28' (agricultural land), '0.18' (wasteland), '1' (settlement/built-up area) and '0.006' (vegetation) (Pandey and Chowdary 2007).

For land-use and land-cover classification, multispectral image of Landsat-8 (ETM, 2015) has been used. The optical satellite imagery used has a resolution equal to 23 m. ERDAS IMAGINE 2014 Software has been used for layer-stack and mosaic functions. Agriculture land, built-up area, barren land, river and water body, sandy area and vegetation cover, respectively constituted the classes for land-use and land-cover classification in the AOI layer. An accuracy assessment then

**Table 3** C factor values of different land-use categories of Kangsabati river basin

Land-use categories	C factor values
Agriculture land unirrigated	0.28
Agriculture land irrigated	0.28
Barren land/agriculture fallow	1.0
Built-up area	0.002
River and water body	0.0
Sandy area	0.0
Vegetation cover	0.004
Wet land	0.00

chases this entire process. The different 'C' factor values (Table 3) have been assigned through Arc GIS (10.1) and finally 'C' raster has been created.

### Support practice factor

In some areas, rate of erosion is determined by the different existing management practices like tillage practice, construction work, bush cover, residues management, management of vegetation cover etc. This support factor determines the values of 'P' in the RUSLE model. The 'P' factor, in fact, is the ratio of soil loss by a given support practice to the corresponding loss if rows crops are planted up and down the slope (Pulido and Bocco 2014). Contour tillage, strip cropping and terrace systems are the different support practice factors.

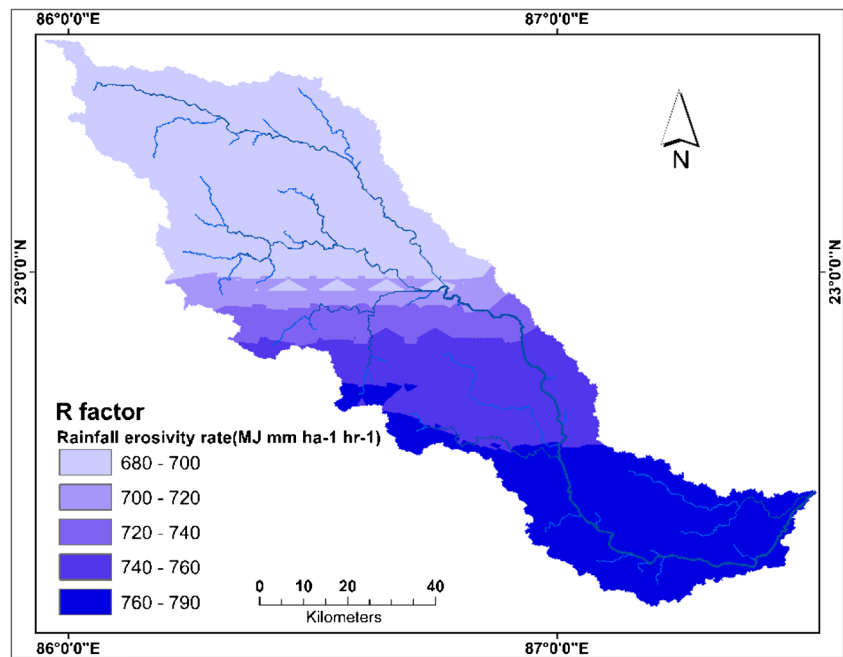
Similar to the 'C' factor, 'P' factor also varies from '0' (practices) to '1' (no practices) (Table 4). Most studies have assigned P values of '0.60' (contour cropping) '0.30' (strip cropping) on landscapes of 1–2% slope, 0.70 (contour cropping), 0.35(strip cropping) for 13–16% slope and 0.90 and 0.45 for 21–25% of slope, respectively (Bready and Well 2005). Pandey and Chowdary, 2007, in their study of the Jharkhand basin, have assigned 'P' values of '0.28' (paddy field) and 1 (non-paddy field). Such arbitration is supported by the fact that Paddy is the dominantly grown crop in the

**Table 4** P factor values of different land-use categories of Kangsabati river basin

Land-use categories	P factor values
Agriculture land unirrigated	0.28
Agriculture land irrigated	0.28
Barren land/agriculture follow	1.00
Built-up area	1.00
River and water body	1.00
Sandy area	1.00
Vegetation cover	1.10
Wet land	1.00



**Fig. 2** Rainfall erodibility (*R*) factor map of Kangsabati river basin



region under question. Jain et al. 2001 have assigned the highest ‘*P*’ value of 0.8 to open scrub, degraded Sal forest and the lowest value (0) to snow and river (Jain et al. 2001).

For the different support practice factors, the LULC classification of Kangsabati basin has been carried out through the supervised classification method. The Area of Interest (AOI) layer creation followed by accuracy assessment has been carried out by ‘ERDAS IMAGINE 2014’. The ‘*P*’ values have been assigned for different classes by ‘Arc GIS 10.1’ software, finally creating the ‘*P*’ raster. Soil erosion through RUSLE model has been generated by multiplying the five factors (*R*, *K*, *LS*, *C* and *P*). Float function in the Raster Calculator tool of ‘Arc GIS 10.1’ has been used in the multiplication of the parametric raster datasets.

### Results and discussion

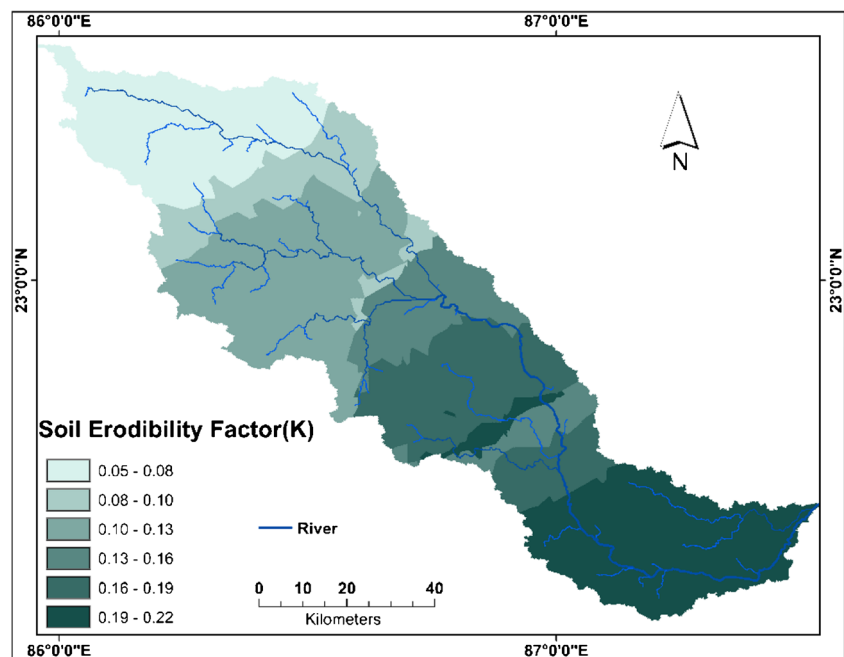
Plateau fringe areas of tropical environment have unique characteristics of soil loss. The present study attempts at capturing these characteristics. Old Gondwana geological formation, undulating plateau upland, occasional hills and sloping river banks are the common morphological characteristics of plateau fringe landscape. Intense seasonal rainfall and alternating dry and wet conditions of the tropical climate cause high soil erosion in lateritic upland areas of plateau fringes worldwide. Increasing population pressure leads to uncovering of lands in these tropical developing countries, increasing the soil erosion potentiality. The river Kangsabati or Kasai which originates from the eastern flanks of Chotanagpur plateau is the major

river basin of the study area. Dissected hillocks, undulating tropical plateau fringe topography characterised by vast open land, immature bare soil with low organic matter content, high silica content, account for the characteristics of a true plateau in the upper reach of Kangsabati basin. The topographic factor (*LS*) is the dominant factor for soil erosion in this part of the basin. The middle basin represents the characteristic dissected lateritic tract with high rill and gully erosion and highly acidic soil accompanied with high leaching processes and low organic matter content. This plateau fringe region is characterised by high seasonal fluctuation of groundwater level and human-induced land-use and land-cover changes. Soil erodibility factor (*K*), cover management factor (*C*) and support practice factor (*P*) are the major driving forces behind soil erosion in this part of the basin. In the lower section, river Kangshabati enters into plain lands where large agricultural field (*C*) and intense pressure on land have been identified as factors driving soil erosion.

**Table 5** Area under different rainfall erosivity values (*R*) of Kangsabati river basin

Rainfall erosivity rate (MJ mm ha <sup>1</sup> h <sup>1</sup> )	Area (km <sup>2</sup> )
680–700	2841
700–720	404
720–740	490
740–760	1155
760–960	1702

**Fig. 3** Soil erodibility ( $K$ ) factor map of Kangsabati river basin



### Spatial distribution of soil erosion factors in a tropical plateau fringe basin

#### Spatial distribution of rainfall erosivity factor

The rainfall erosivity factor ( $R$ ) provides the kinetic energy for detachment of soil from aggregate, which eventually flows down the river. Within rainfall erosivity rate ( $R$ ) the intensity and seasonality of rainfall have been taken into account. Short-spanned high intensity rainfall events result in high detachment rate in soil. In tropical environments, high-intensity rainfall occurs in monsoon season. Long spells of dry season and abrupt high frequency intense rainfall events induce high detachment rates of soil. Continuous alteration of dry and wet period causes relative variations in moisture stress, affecting the process of soil erosion in the present study area environment.

In Kangsabati basin, high ' $R$ ' values ( $780 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$ ) are seen in the lower reaches of the basin (Paschim Medinipore), thus fostering high soil erosion susceptibility in the region (Fig. 2). Comparatively, lower values are shown in upper reaches of the basin ( $690 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$ ) provoking

lower susceptibility to soil erosion. Middle reaches of the basin shows the medium values around ( $730 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$ ). The  $R$  values of middle and lower basin indicate typical humid type climate. The upper portion, however, shows a semi-humid-type climate. Large portion of the basin lies under the region characterised by high rainfall erosivity rate ( $740\text{--}780 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$ ).

Around 30% of the basin area represents rainfall erosivity rate  $> 750 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$  rendering the soil susceptible to the risk of erosion (Table 5). Eastern part of the basin (Paschim Medinipore district) is categorised under tropical humid type climate. Year-long high-intensity rainfall renders the soil prone to experience high rates of soil erosion in this part of the basin. The middle basin is characterised by medium rainfall erosivity ( $720\text{--}750 \text{ MJ mm ha}^{-1}$ ). Contrasted to the upper part, middle part of the basin shows lower rainfall erosivity. Large sections of basin area in the western part show the erosivity  $> 700 \text{ MJ mm ha}^{-1} \text{ h}^{-1}$ , representing low rainfall erosive potentiality. This part of the basin is situated in Purulia district which is a well rainfed district of India.

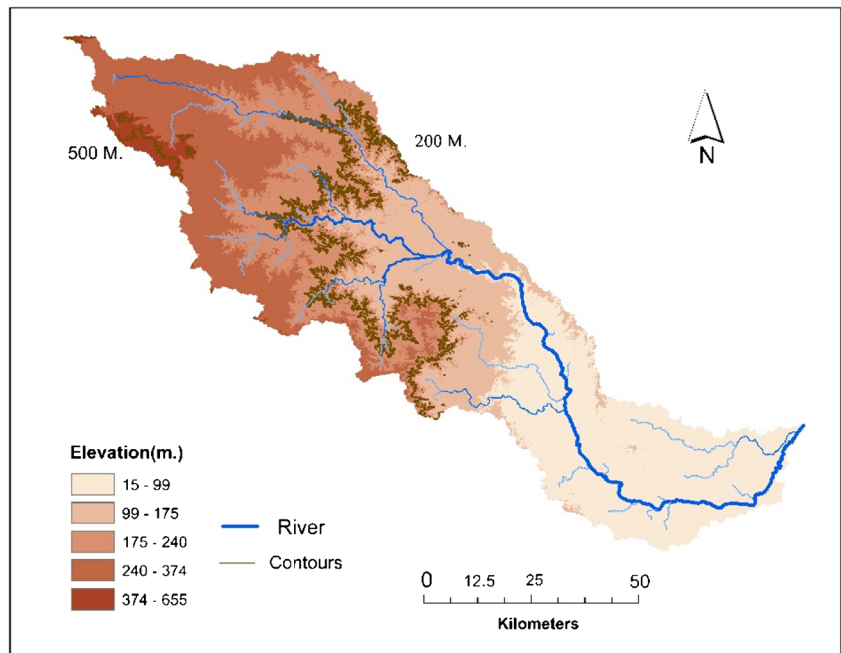
#### Spatial distribution of soil erodibility factor

The inherent characteristics of soil form an important parameter in controlling erosion. Pedosphere (soil cover of the earth) falls under the category of 'transitional zone' considering the other spheres of the planet. This is so because soil is the result of interaction of various physical and biological factors over a period. Soil characteristics experience variations frequently across space. The different physical (texture, structure) chemical (PH, CEC, BEC elementals), biological and mineralogical characteristics of soil are known to control erosion and vice

**Table 6** Area under different soil erodibility ( $K$ ) values of Kangsabati river basin

Soil erodibility factor ( $K$ )	Area ( $\text{km}^2$ )
0.06–0.08	1176
0.08–0.10	641
0.10–0.13	1461
0.54–0.55	748
0.55–0.56	1154
0.56–0.63	1410

**Fig. 4** Elevation map of Kangsabati river basin



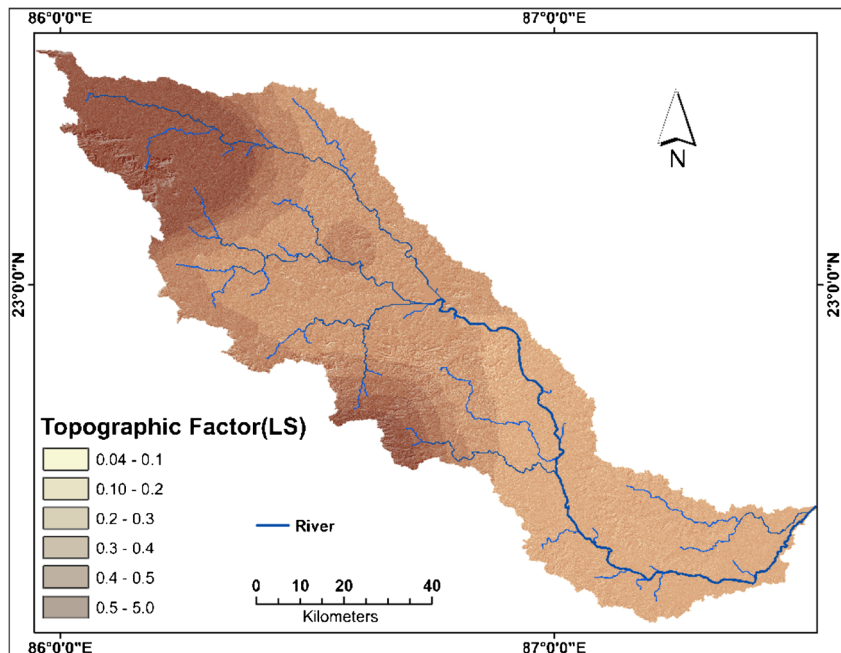
versa. Different physical properties, like high silica content, low clay content, poor soil structure, lower permeability and high overland flow are the general characteristics of soil in tropical plateau region. The four important parameters were taken into account in the RUSLE model according to the specific soil characteristics of the study area. These are soil texture, structure, organic matter and permeability.

In Kangsabati, basin high ‘K’ values (more prone to erosion) are exhibited in the lower reaches of the basin (Fig. 3). Main soil types of the region are fine loamy-type ustifluvents, loamy-type haplustalfs, fine loamy-type orchaqualfs and silt

clay (along river tracks). The characteristics of the soils (high silt content and low organic matter) make the area vulnerable to erosion. The upper section of the basin in Purulia district is largely covered by gravelly sand-sandy (high permeable), sandy loam (less organic matter), sandy loam-sandy clay loam (riverside soil), loam-silt clay loam (dissected patches).

Less developed soil, high permeability, coarse structure, make soil in the upper reaches of the basin less vulnerable to soil erosion. Fine sandy loam covers the middle part of the basin to clay-loam (along river course), sandy-loam (far from river course) and coarse loamy

**Fig. 5** The topographic factor map (LS) of Kangsabati river basin



**Table 7** Area under different topographic factor (LS) of Kangsabati river basin

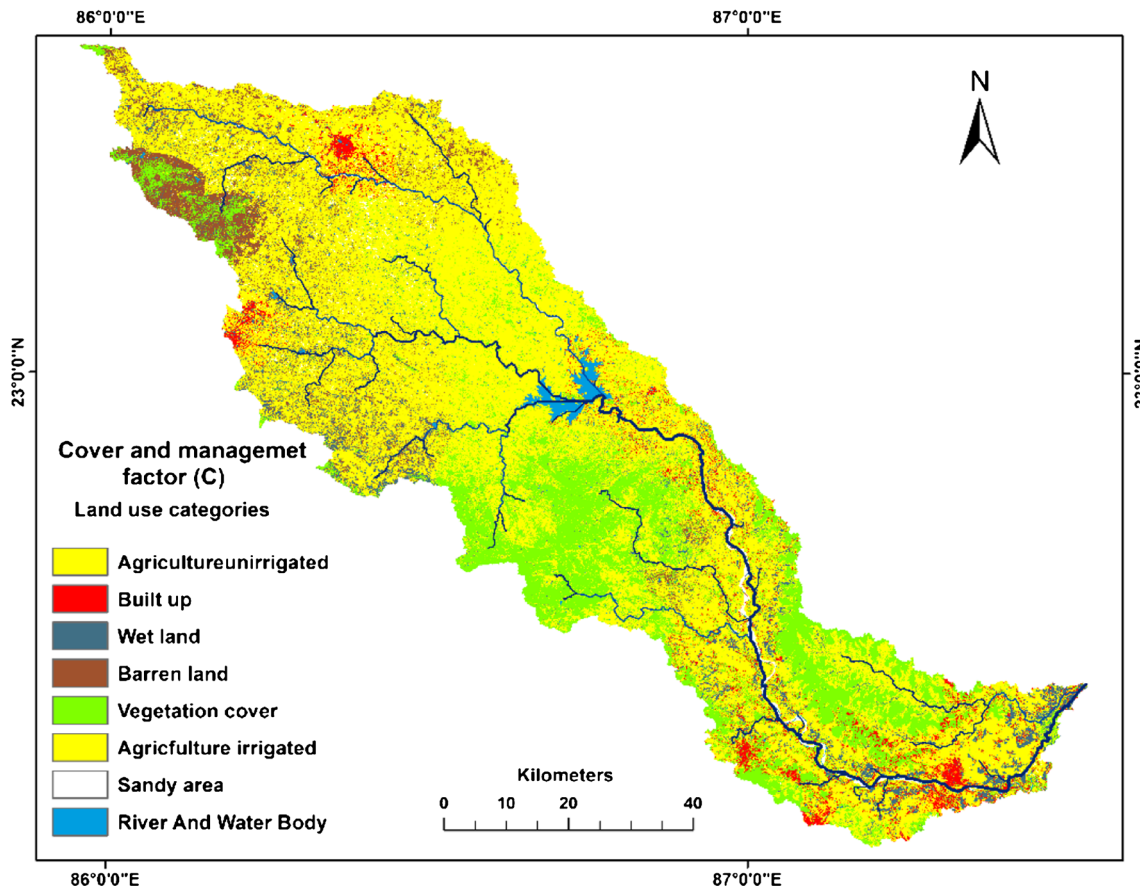
LS factor	Area (km <sup>2</sup> )
0.04–0.10	2125
0.10–0.20	2138
0.20–0.30	813
0.30–0.40	251
0.40–0.50	206
0.50–5.0	1059

types (dissected areas). The mature structure, moderate to less organic matter content, high infiltrative capacity and lower silica content makes the middle parts of Kangsabati basin less vulnerable to soil erosion. Nearly 40% of basin area exhibit high ‘K’ values (> 0.55) mostly distributed in the middle and lower portions of the basin which is prone to high erodibility (Table 6). Rapid urbanisation and expansion of population have built up high pressure on the agricultural lands. Extensive irrigation and excessive use of fertiliser to enhance agricultural output has led to serious soil degradation. The strength and structure of soil are lost in this process. Different factors like deforestation, loss of organic matter content in soil, low mulch cover, large open field, high crop rotation frequency, high tillage

**Table 8** Area under different land-use categories (C factor) of Kangsabati river basin

Cover and management factor	Total area (km <sup>2</sup> )	C value
Agriculture land	4078	0.28
Barren land	338	1.00
Built-up land	235	0.002
River and water body	90	0.000
Sandy area	78	0.000
Vegetation cover	1224	0.004
Wet land	308	0.000

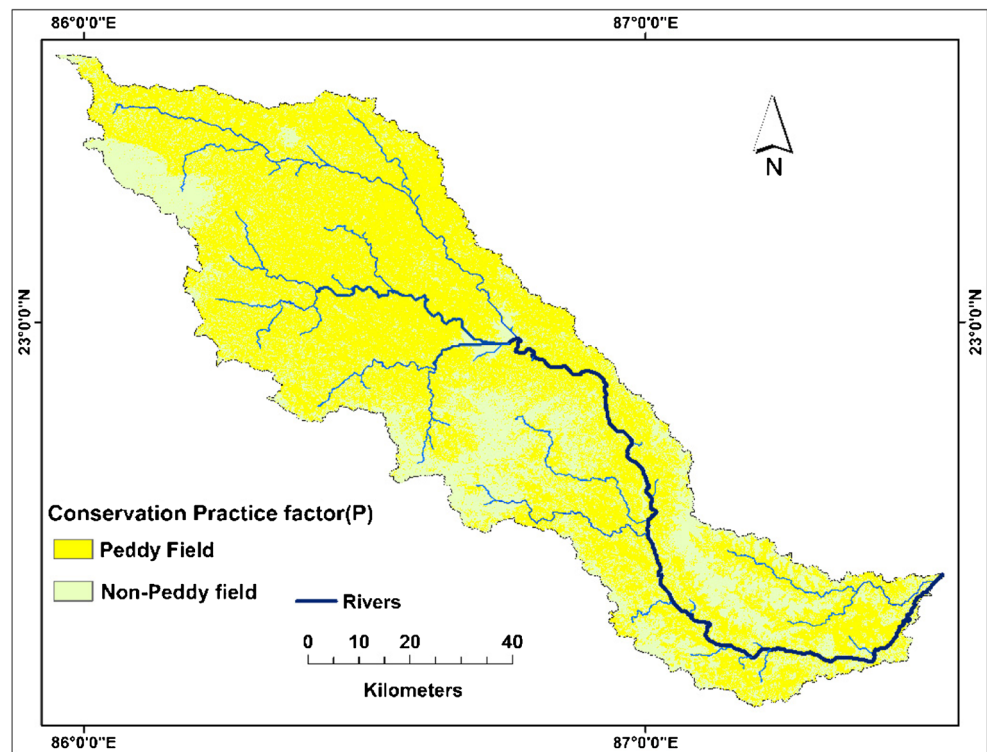
practice, and unscientific way of land management makes the land vulnerable to various erosional agents. Laterite soil covers large parts of Kangsabati basin. The soil observes its genesis through the process of intense leaching (eluviation of clay materials to the lower profile and concentration of Si and Fe in the upper profile of soil). Low organic matter content renders the soil vulnerable to soil erosion. The intense gully and rill erosion has been seen in the lateritic tracts of Kangsabati basin. Other factors like topography, slope and rainfall aid these erosion processes.



**Fig. 6** The cover and management factor (C) map of Kangsabati river basin



**Fig. 7** Support practice factor (*P*) map of Kangsabati river basin



**Spatial distribution of topographic factor**

The topographic or the regional undulation of an area defines the potentiality of the soil cover to erode. The Erosional agent (in this case water), upon interaction with gravity due to the presence of undulations, gets kinetic energy to perform its erosive process. The tropical plateau exhibits topographic characteristics like gently sloping uplands, undulating upland, dissected highland, pediments and medium slope, which enhance soil erosion potentiality.

In Kangsabati river basin, the elevation ranges from 15 m at the mouth, to 655 m near Ajodhya hills of Chotanagpur plateau (Fig. 4). The 200-m contour intersects the basin at the middle. More than 60% of the basin area exhibits elevation greater than 200 m. High absolute and relief values, dissected plateau, small hillocks and undulating topography characterises the upper portion of Kangsabati basin. Contrastingly, undulating and isolated hillocks are replaced by lateritic caps in the middle reach of the basin. The range in elevation is also noticeably lower than in the upper reach. Vast plain land and lateritic tract characterise the lower part of basin. The 100-m contour passes through this region.

**Table 9** Area under different support practice factor (*P*) of Kangsabati river basin

<i>P</i> factor	Area (km <sup>2</sup> )
0.28	4087
1.00	2505

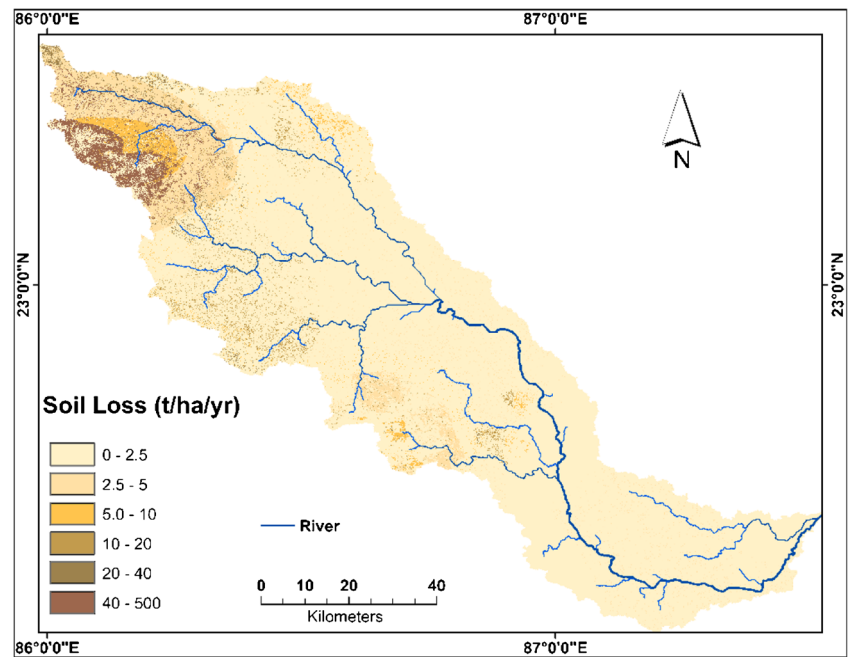
The topographic factor (LS) shows typical distribution pattern in the basin (Fig. 5). The upper basin area shows high ‘LS’ factor values (> 0.4) (Table 7). Presence of massive dissected plateau and isolated hillock has to these high values. Most of Purulia district falls under this category. Therefore, the high LS factor values indicate at prolonged soil erosion in this area. Moderate ‘LS’ factor values have been observed in large tracts in the middle basin where transitional slopes are the prominent causes of soil erosion. The lower part of the basin shows the plain to near plain type slope characteristics (<0.2) indicating lower soil erosion. Out of 6592 km<sup>2</sup> basin area, < 20% observes ‘LS’ scores between 0.4 to 5 ‘LS’, indicating towards medium levels of soil loss. Soil near Ajodhya hills with ‘LS’ score above 3.0 are prone to soil loss.

**Spatial distribution of cover and management factor**

In the static physical condition, it is the cover and management factor which exerts control on soil erosion. Cover and management factor controls soil surface openness to physical processes of erosion. Population growth is mainly concentrated in the tropical developing countries. The uncovering of lands via general conversion of forest land to pasture, agricultural and built-up land is prominent in the tropical developing world. Soil cover faces the brunt of intense erosion through all of these uncovering processes.

Eight types of soil cover and management classes have been identified in Kangsabati river basin (Fig. 6). Lowest

**Fig. 8** The soil loss map of Kangsabati river basin



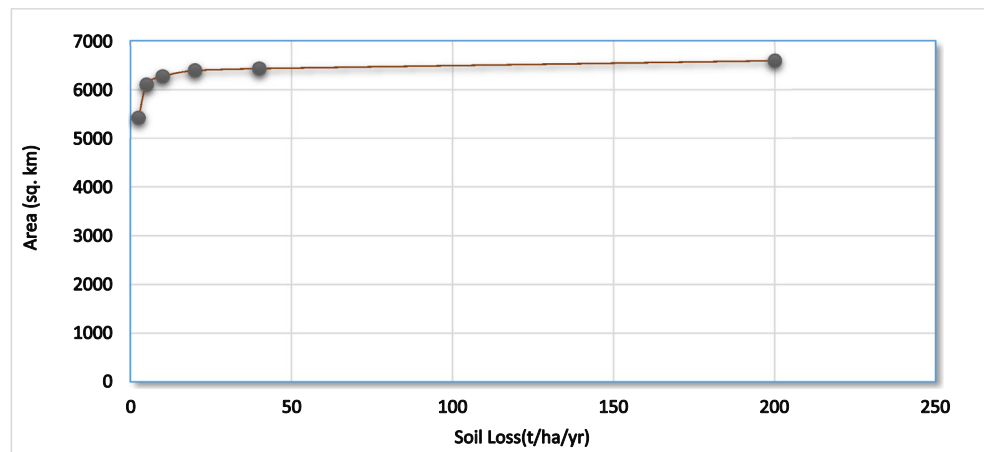
value has been assigned to water body which has no contribution to erosion by virtue of lacking any soil cover. Highest value has been assigned to barren land which has the highest potentiality to get eroded (Table 8). The land-use land-cover (LULC) map of Kangsabati basin shows the dominance of agricultural land in the basin. Agricultural practice in the region has amplified the soil erosion potentiality. Agricultural land occupies 4000 km<sup>2</sup> out of 7000 km<sup>2</sup> area. The built-up land is evenly distributed in the basin. Built-up land effectively decreases soil erosion but affects the inherent soil structure negatively. Built-up land covers 235 km<sup>2</sup> area in the basin. Barren land and agriculture fallow exhibit greater potentiality to soil erosion due to human induced unfavourable soil characteristics (lack of trees and plants to hold on to soil aggregate). Therefore, highest value has been assigned (1.0) to this class of land use. The upper part of Kangsabati basin mostly

exhibits barren land, prone to erosion. The various types of vegetation covering the basin (1224 km<sup>2</sup> area) have been assigned a low value (0.002). High vegetation density in the upper reaches of the basin indicates amounts to lesser soil erosion. The river along with other water bodies, wetlands, and sandy areas cover about 500 km<sup>2</sup>. This area has no contribution to erosion. Therefore, '0' value has been assigned to this class.

**Spatial distribution of support practice factor**

It is the ratio of soil loss in a given support practice to the corresponding loss if row crops are planted in up and down of the slope (Bready and Well 2005). Practice factor controls the erosion processes. Therefore, 'P' values range according to with practices adopted in different places. In tropical plateau areas

**Fig. 9** The cumulative soil loss areas of Kangsabati river basin



**Table 10** Average rate of soil loss of the Kangsabati river basin

Erosion class	Rate of soil loss (t ha <sup>-1</sup> year <sup>-1</sup> )	Area (ha)	% of total Area
Slight	< 2.5	5421	82.23
Moderate	2.6–5.0	681	10.33
High	5.1–10.0	169	02.56
Very high	> 10.0	321	04.88

paddy is mostly cultivated crops. The paddy is extensively harvested in monsoon season only. Other season and rest of areas have not experienced any significant conservation practice.

In Kangsabati basin area, not any significant practice factor (contour cropping, strip cropping) has been adopted by the peoples (Fig. 7). The traditional subsistence agriculture gives some amount of support to soil from erosional vulnerability of the basin. In upper reaches of the basin where earlier high topographic factor makes the region high vulnerable to erosion and adding to this no support practice makes the region prone to erosion (Table 9). By contrast to this, the lower portion of the basin which have high intensity of cropping have improved support to less soil erosion. Contrastingly, the lower part of the basin, which exhibits intensive agricultural activity but, improved support practices, slows down soil erosion.

### Estimation of spatial distribution of soil erosion in a tropical plateau fringe basin

The revised universal soil loss (RUSLE), based on empirical factors, can estimate the soil erosion rate based on rainfall pattern (intensity and seasonality), soil type, topography, crop management and practice. Based on the aforementioned factors, different raster has been created for each factor in GIS environment. Using float tool actual ( $R$ ,  $K$ ,  $LS$ ) and potential ( $R$ ,  $K$ ,  $LS$ ,  $C$ ,  $P$ ), soil loss has been estimated for tropical plateau fringe Kangsabati basin.

The actual soil loss estimates in the basin range from 1 to 200 t ha<sup>-1</sup> year<sup>-1</sup> (Figs. 8 and 9). From these soil loss values (t ha<sup>-1</sup> year<sup>-1</sup>), the different soil loss area has been estimated (slight < 2.5 t ha<sup>-1</sup> year<sup>-1</sup>, moderate 2.6–5.0 t ha<sup>-1</sup> year<sup>-1</sup>, high 5.0–10 t ha<sup>-1</sup> year<sup>-1</sup> and very high > 10 t ha<sup>-1</sup> year<sup>-1</sup>) within the basin (Table 10). Lower reaches of the basin, characterised by plateau fringe plain type topography, experiences lower levels of soil loss (Fig. 8) (Table 10). Tropical humid rainfall characteristic to this part of the basin, adds up to high rainfall erosivity factor ( $R$ ). High percentage of clay and organic matter content in the soil manifests into lower soil erodibility ( $K$ ). This region, characteristically low in elevation, is demarcated by the 200-m contour. This topography ranging from near plain to plain with low slope contributes to binds the ‘ $LS$ ’ value to less than 0.2. The area under agriculture field (irrigated and unirrigated) ( $C$  value = 0.28), and forest area ( $C$  value = 0.04) in the plateau fringe plain regions helps bind soil loss. The higher percentage of agricultural land to total land makes the support factor comparatively better ( $P$  value of agriculture land is 0.28). The soil is less vulnerable to erosion due to absence of barren land and fewer undulating topographic characteristics in the plateau fringe plain region (Fig. 10).

The middle reaches of the basin which is dominated by tropical plateau fringe characteristics experience moderate soil loss (2.6–5.0 t ha<sup>-1</sup> year<sup>-1</sup>) (Fig. 8) (Table 10). This part of the basin is mostly distributed in the dissected areas of the Bankura and Paschim Medinipore districts in Chotanagpur plateau. The characteristic tropical sub-humid rainfall makes the area moderately prone to soil erosion from rainfall erosivity factor ( $R$ ). Laterite soil developed in the undulating plateau region with active leaching is prone to soil erosion by virtue of the soil erodibility factor ( $K$ ). The plateau fringe undulating elevated (200–300 m.) areas are classified to this class of soil erosion. The dissected plateau exhibit moderate ‘ $LS$ ’ factor values ranging from 0.2–0.3. Agricultural fields (both Irrigated and unirrigated) cover a large area in the plateau plain region compared to the plateau fringe region. In this region the ‘ $P$ ’ values are greater than 0.28. Deforestation

**Fig. 10** Types of soil erosion. Rill erosion in barren land, gully erosion in Riverside of Kangsabati river basin



and stripping the land of its soil cover makes the soil vulnerable to erosional agents. Conservation practices ( $P$ ) are also seen to be faltering because monsoonal paddy cultivation only dominates the area.

The upper reaches of the basin is the part of a proper tropical plateau. This region has experienced high soil loss rates ( $> 5.1 \text{ t ha}^{-1} \text{ year}^{-1}$ ) (Fig. 8) (Table 10). The upper reaches of the basin shows semi-arid characteristics due to low rainfall and remoteness from moisture source. Extensive dry spell increases the soil moisture stress. Sudden rainfall in monsoon after prolonged dry winter increases the prospect of rainfall erosivity ( $R$ ). The likelihood of deep soil profile development in the tropical plateau proper environment is meagre along with low water holding capacity, therefore ultimately increasing the soil erodibility value ( $K$ ) in the upper basin region. These parts of tropical plateau proper have high relative relief (300–500 m), greater length of slope, which ultimately increases the percentage value and steepness ( $\theta$ ) of slope. High percentage of barren land is one of the causal factors of elevated rates of soil loss in this region. Aforementioned factors, therefore, contribute to greater 'LS' values ( $> 0.3$ ). Degraded vegetation cover, limited agricultural land and presence of barren land in plateau proper environment give rise to decreased cover management practices ( $C$ ). Vast stretches of land in the upper part of the river basin have not experienced any support practice measures ( $P$ ). Plateau proper type of environment does not support extensive agricultural practice. Thus the absence of support practices ( $P$ ) renders this region vulnerable to erosion.

## Conclusion

The purpose of the current study is to characterise soil erosion in tropical plateau fringe areas. Empirical models like RUSLE need minimum resources in working out an estimate of soil erosion with readily available resources. RUSLE was developed in the USA first but it proves its applicability throughout the different morpho-climatic areas. It is most widely known and easily applicable. Land degradation through soil erosion is a worldwide phenomenon. Soil erosion estimation in the plateau fringe region is itself a challenging task. The study reveals that the upper reaches of the basin plateau proper is prone to high rates of erosion ( $> 5 \text{ t ha}^{-1} \text{ year}^{-1}$ ). Upper reach is representative of true tropical plateau characteristics like undulating upland, high relative relief and extensively sloping surface. The tropical plateau fringe characteristics dominate most of the middle course of the basin. Dissected plateau with extensively sloping surface, lateritic caps over undulating uplands and ruggedness are the general characteristics of the middle part of the basin. Deforestation and uncovering of lands cause degradation of land. Moderate rates soil erosion is experienced in the middle part of the basin (2.5–

$5 \text{ t ha}^{-1} \text{ year}^{-1}$ ). The lower reaches of basin catalogued under humid plateau fringe plain conditions; represent characteristics like tropical humid climatic conditions and high rainfall erosivity. High percentage of clay content and high organic matter content decreases the soil erodibility. Topographically, this area is considered as plain land with sloping surface in the plateau fringe. Extensive agriculture and some amount of support practice help lower soil erosion rates ( $< 2.5 \text{ t ha}^{-1} \text{ year}^{-1}$ ). Study finds high amount of soil loss all over the basin. Amongst the different land-use types, croplands face major risk of soil erosion. It can be concluded that upper reaches of basin are prone to erosion due to topographic factor. The lower reaches face rapid land-use land cover change rendering the soil prone to erosion.

Tropical plateau fringe has definite characteristics of soil erosion which is reflected from the present study. Moreover, most of the studies have been conducted in definite or homogeneous morpho-climatic regions. The present study, however tries to evaluate different soil erosion factors as well as erosion vulnerability in a heterogeneous tropical plateau fringe region. The factors and vulnerability are different in different parts of the plateau fringe. The topographic factors (like, undulation, slope) dominate soil erosion in the upper parts of plateau or plateau proper areas; whereas, cover management and support practice factors are dominate the in middle-lower basin or plateau fringe region. The study evaluates these characteristics of soil erosion in tropical plateau fringe region.

Geographic information system also proves to be a convenient tool for estimation of soil loss, given the vast array of digital resources present in the current age. The study used GIS tool to quantify soil erosion potentiality. The results have been calibrated for different factors. Soil erosion factors have been generated and integrated spatially to understand the soil erosion characteristics.

A comprehensive watershed and development plan can be undertaken following the findings of the study. The algorithms used in this study can be used in similar morpho-climatic and agro-climatic areas of the world. Long-term predictability of soil and nutrient loss can be estimated using the result. Estimation of vulnerability to erosion can entail intensive management or corrective measures.

There are some questions which may spurt up on the reliability and validity of the input data for the present study. For ' $K$ ' factor, the primary soil analysis result (soil texture, organic matter) has been used. The soil structure and estimated permeability may result in  $d$  errors. The insight into micro regional topographic variations is inaccessible due to the utilisation of Aster DEM data with spatial resolution of 30 m. The land-use and land-cover classification are standardised through field check for this study. The small-scale regional support practice measures have been eliminated to count broad regional practices. The present results should be useful in determining land-use strategies with careful consideration of certain



physical and human controls. Notwithstanding inherent shortcomings, the estimation of soil loss of any area is indispensable for management practices and future planning.

## References

- Adugna A, Abegaz A, Cerdà A (2015) Soil erosion assessment and control in Northeast Wollega, Ethiopia. *Solid Earth Discuss* 7(4):3511–3540
- Arnold JG, Fohrer N (2005) SWAT2000: current capabilities and research opportunities in applied watershed modelling. *Hydrol Process* 19: 563–572
- Beskow S, Mello CR, Norton LD, Curi N, Viola MR, Avanzi JC (2009) Soil erosion prediction in the Grande River Basin Brazil using distributed. *Catena* 79(1):49–59
- Bhandari KP, Aryal J, Damsawasi R (2015) A geospatial approach to assessing soil erosion in a watershed by integrating socio-economic determinants and the RUSLE model. *Nat Hazards* 75(1):321–342
- Bhattarai R, Dutta D (2007) Estimation of Soil Erosion and Sediment Yield Using GIS. *Water Resource Management* 21:1635–1647
- Biswas SS, Pani P (2015) Estimation of soil erosion using RUSLE and GIS techniques: a case study of Barakar River basin, Jharkhand, India. *Model Earth Syst Environ* 1(42):1–13
- Bready NC, Well RR (2005) *The nature and properties of soil*. Singapore, Pearson Prentice Hall
- Chakrabarty A, Chatterjee S (2008) IRS-LISS-IV data for cadastral level infrastructure mapping and land degradation study at PPSF Project Site-Ajodhya Hills, Purulia. *Indian Journal of Geography and Environment* 10:38–46
- Chatterjee S, Krishna AP, Sharma AP (2013) Geospatial assessment of soil erosion vulnerability at watershed level in some sections of the Upper Subarnarekha river basin, Jharkhand, India. *Environ Earth Sci* 71(1):357–374
- Choudhary JS, Shukla G, Prabhakar CS, Maurya S, Das B, Kumar S (2012) Assessment of local perceptions of climate change and coping strategies in Chotanagpur Plateau of Eastern India. *J Prod Agric* 3(1):8–15
- Cunha ER, Bacani VM, Panachuki E (2017) Modeling soil erosion using RUSLE and GIS in a watershed occupied by rural settlement in the Brazilian Cerrado. *Nat Hazards* 85(2):851–868
- Dolui G, Chatterjee S, Das Chatterjee N (2014) The importance of non-timber forest products in tribal livelihood: a case study of Santal community in Purulia District, West Bengal. *Indian Journal of Geography and Environment* 13:110–120
- Ferreira V, Panagopoulos T, Cakula A, Andrade R, Arvela A (2015) Predicting soil erosion after land use changes for irrigated agriculture in a large reservoir of southern Portugal. *Procedia* 4:40–49
- Fitzpatrick RW (2012) Land degradation processes. In: Mc Vicar TR, Li Rui WJ, Fitzpatrick RW, Liu C (eds) *Regional water and soil assessment for managing sustainable agriculture in china and australia*. ACIAR, Canberra, pp 119–129
- Ganasri BP, Ramesh H (2015) Assessment of soil erosion by RUSLE model using remote sensing and GIS—a case study of Nethravathi Basin. *Geosci Front* 7(6):1–9
- Ghosh D (2015) Mapping and monitoring of the impact of gully erosion in the district of Medinipur (West), West Bengal, India. *International Journal of Novel Research in Humanity and. Soc Sci* 2(4):73–89
- Ghosh S, Guchhait SK (2015) Characterization and evolution of laterites in West Bengal: implication on the Geology of Northwest Bengal Basin. *Transaction* 37(1):93–119
- Ghosh S, Guchhait SK (2017) Estimation of geomorphic threshold in permanent gullies of lateritic terrain in Birbhum, West Bengal India. *Curr Sci* 113(3):478–485
- Ghosh S, Maji T (2011) PedoGeomorphic analysis of soil loss in the lateritic region of Rampurhat I block of Birbhum district, West Bengal and Shikaripara block of Dumka district. *Jharkhand. International Journal of Environmental Sciences* 1(7):1734–1751
- Gibbs HK, Salmon JM (2015) Mapping the world's degraded lands. *Applied Geography* 57:12–21
- González-Morales BS, Mayer A, Ramírez-Marcial N (2017) Assessment of soil erosion vulnerability in the heavily populated and ecologically fragile communities in Motozintla De Mendoza, Chiapas, Mexico. *Solid Earth Discuss* 1–24.
- Gulati A, Rai SC (2014) Cost estimation of soil erosion and nutrient loss from a watershed of the Chotanagpur Plateau, India. *Research Communications* 107(4):670–674
- Gupta SK, Ahmed M, Hussain M, Pandey AS, Singh P, Saini KM, Das SN (1998) Inventory of degraded lands of Palamau District, Bihar—a remote sensing approach. *J Ind Soc Remote Sens* 26(4):161–168
- Heshmati M, Arifin A, Shamshuddin J, Majid NM (2012) Predicting N, P, K and organic carbon depletion in soils using MPSIAC model at the Merek catchment, Iran. *Geoderma* 175–176:64–77
- Imani R, Ghasemeh H, Mirzavand M (2014) Determining and mapping soil erodibility factor (case study: Yamchi Watershed in Northwest of Iran). *Open Journal of Soil Science* 4:168–173
- Indian Space Research Organisation (2007) *Desertification and land degradation Atlas of India*. Government of India, Space Application Center. <https://www.isro.gov.in/desertification-and-land-degradation-atlas-released>
- Indian Space Research Organisation (2016) *Desertification and land degradation Atlas of India*. Government of India, Space Application Center. <https://www.isro.gov.in/desertification-and-land-degradation-atlas-released>
- Jain MK, Kothiyari UC (2000) Estimation of soil erosion and sediment yield using GIS. *Hydrological Sciences Journal* 45(5):771–786
- Jain SK, Kumar S, Varghese J (2001) Estimation of soil erosion for a Himalayan watershed using GIS technique. *Water Resour Manag* 15(1):41–54
- Jha VC, Kapat S (2009) Degraded lateritic soilscape and land use in Birbhum district, West Bengal, India. *Sociedade & Natureza* 21(2):141–158
- Kalambukattu JG, Kumar S (2017) Modelling soil erosion risk in a mountainous watershed of Mid-Himalaya by integrating RUSLE model with GIS. *Eurasian J Soil Sci* 6(2):1–15
- Kothiyari UC, Jain SK (1997) Sediment yield estimation using GIS. *Hydrological. Science* 6:833–843
- Kothiyari UC, Jain MK, Raju KG (2002) Estimation of temporal variation of sediment yield using GIS/estimation. *Hydrological Sciences Journal* 47(5):693–706
- Lal R (2001) Soil degradation by erosion. *Land Degrad Dev* 12(6):519–539
- Lal R, Hall GF, Miller FP (1989) Soil degradation: I. Basic processes. *Land Degradation & Development* 1(1):51–69
- Lane LJ, Renard KG, Foster GR, Laften JM (1992) Development and application of modern soil erosion prediction technology. *Aust J Soil Res* 30:893–912
- Lenka NK, Mandal D, Sudhishri S (2014) Permissible soil loss limits for different physiographic regions of West Bengal. *Research Communications* 107(4):665–670
- Lu D, Li G, Valladares GS, Batistella M (2004) Mapping soil erosion risk in Rondonia, Brazilian Amazonia: using RUSLE, remote sensing and GIS. *Land Degrad Dev* 15:499–512
- Mahala A (2017) Processes and status of land degradation in a plateau fringe region of tropical environment. *Environ Prog* 4:663–682
- McGregor D (1989) Land degradation: problems and policies. *Land Degrad Dev* 1(1):71–72

- Meusburger K, Konz N, Schaub N, Alewell C (2010) Soil erosion modelled with USLE and PESERA using Quick Bird derived vegetation parameters in an alpine catchment. *Int J Appl Earth Obs Geoinf* 12(3):208–215
- Millward AA, Mersey JE (1999) Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. *Catena* 38(2): 109–129
- Mondal S (2012) Remote sensing and GIS based ground water potential mapping of Kangshabati irrigation command area, West Bengal. *Geography & Natural Disasters* 1(1):1–8
- Morgan RP, Quinton JN, Smith RE, Govers G, Poesen JW, Auerswald K, Styczen ME (1998) The European Soil Erosion Model (EUROSEM): a dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surf Process Landf* 23:527–544
- Moussa B, Nkonya E, Meyer S, Kato E, Johnson T, Hawkins J (2016) Economics of Land Degradation and Improvement in Niger. In: Nkonya E, Mirzabaev A, Von Braun J (eds) *Economics of land degradation and improvement—a global assessment for sustainable development*. Springer, Bonn, pp 499–539
- National Remote Sensing Center (2011) *Wastelands Atlas of India*. NRSC, ISRO, GOI: Hyderabad. [http://dolr.nic.in/dolr/wasteland\\_atlas.asp](http://dolr.nic.in/dolr/wasteland_atlas.asp)
- Nkonya E, Anderson W, Kato E, Koo J, Mirzabaev A, Brau JV, Meyer S (2015) Global Cost of Land Degradation. In: Nkonya E, Mirzabaev A, Braun J (eds) *Economics of land degradation and improvement—a global assessment for sustainable development*. Springer, Bonn, pp 117–165
- Oldeman LR, Van Engelen VW (1993) A world soils and terrain digital database (SOTER)—an improved assessment of land resources. *Geoderma* 60(1–4):309–325
- Pan J, Wen Y (2014) Estimation of soil erosion using RUSLE in Caijiamiaio watershed. *China Nat Hazards* 71(3):2187–2205
- Pandey A, Chowdary VM (2007) Identification of critical erosion prone areas in the small agricultural watershed using USLE. GIS and remote sensing. *Water Resource Management* 21:729–746
- Parveen R, Kumar U (2012) Integrated approach of Universal Soil Loss Equation (USLE) and geographical information system (GIS) for soil loss risk assessment in upper South Koel Basin Jharkhand. *J Geogr Inf Syst* 4:588–596
- Prasannakumar V, Vijith H, Abinod S, Geetha N (2012) Estimation of soil erosion risk within a small mountainous sub-watershed in Kerala, India, using Revised Universal Soil Loss Equation (RUSLE) and geo-information technology. *Geosci Front* 3(2):209–215
- Pulido J, Bocco G (2014) Local perception of land degradation in developing countries: a simplified analytical framework of driving forces, processes, indicators and coping strategies. *Living Rev* 8: 4–21
- Rahman M, Shi ZH, Chongfa C (2009) Soil erosion hazard evaluation—an integrated use of remote sensing, GIS and statistical approaches with biophysical parameters towards management strategies. *Ecol Model* 220:1724–1734
- Renard KG, Foster GR, Weesles GA, Porter JP (1991) Revised universal soil loss equation. *J Soil Water Conserv* 46(1):30–33
- Roo AP, Wesseling CG (1996) Lisem: a single-event physically based hydrological and soil erosion model for drainage basins: theory, input and output. *Hydrol Process* 10:1107–1117
- Roy PK, Samal NR, Roy PM, Mazumdar A (2008) Soil carbon and nutrient accumulation under forest plantations in Jharkhand State of India. *Clean – Soil. Air, Water* 38(8):706–712
- Sahu DB, Dash E (2011) Land degradation due to mining in India and its mitigation measures. *Second International Conference on Environmental Science and Technology*, Singapore, pp 1–5
- Samanta RK, Bhunia GS, Shit PK (2016) Spatial modelling of soil erosion susceptibility mapping in lower basin of Subarnarekha river (India) based on geospatial techniques. *Model Earth Syst Environ* 2(99):1–13
- Sarkar D, Gangopadhyay SK, Velayutham M (2001) Soil toposequence relationship and classification in lower outlier of Chhotanagpur plateau. *Agropedology* 11:29–36
- Sarkar D, Mandal D, Halder A (2014) Soil maturity assessment along a toposequence in Chotanagpur Plateau, West Bengal using inorganic soil phosphorus based weathering index, soil taxonomy and other chemical indices: A comparative study. *Agropedology* 24(1):82–94
- Shit PK, Maity R (2012a) Rill hydraulics—an experimental study on gully basin in lateritic upland of Paschim Medinipur, West Bengal, India. *Journal of Geography and Geology* 4(4):1–11
- Shit PK, Maity RK (2012b) Mechanism of gully-head retreat—A study at Ganganir Danga, Paschim Medinipore, West Bengal. *Ethiopian Journal of Environmental Studies and Management* 5(4):332–342
- Shit PK, Bhunia GS, Maity R (2013) Assessment of factors affecting ephemeral gully development in Badland Topography: a case study at Garbheta Badland (Pashchim Medinipur, West Bengal, India). *Int J Geosci* 4:461–470
- Shit PK, Nandi AS, Bhunia GS (2015) Soil erosion risk mapping using RUSLE model on jhargram sub-division at West Bengal in India. *Model Earth Syst Environ*. 1(28):1–12
- Thiombiano L, Tourino-Soto I (2007) Status and trends in land degradation in Africa. In: Sivakumar MV, Ndiang’ui N (eds) *Climate and Land Degradation*. Springer, Berlin, pp 33–53
- Tirkey AS, Pandey AC, Nathawat MS (2013) Use of satellite data, GIS and RUSLE for estimation of average annual soil loss in Daltonganj Watershed of Jharkhand (India). *Journal of Remote Sensing Technology* 1(1):20–30
- Vaezi AR, Bahrami HA, Sadeghi SH, Mahdian MH (2010) Spatial variability of soil erodibility factor (K) of the USLE in North West of Iran. *J Agr Sci Tech*. 12:241–252
- Zhang L, Bai KZ, Wang MJ, Karthikeyan R (2016) Basin-scale spatial soil erosion variability: Pingshuo opencast mine site in Shanxi Province. *Loess Plateau of China Nat Hazards* 80(2):1213–1230