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Soil Loss Assessment using Revised Universal Soil Loss Equation and GIS in an Agricultural Watershed in Assam

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Abstract: *This study is an attempt to assess soil loss sensitivity based on revised universal soil loss equation (RUSLE) and GIS in an agricultural watershed for the years 2009 and 2010. It has estimated that total soil loss from the basin is 30,886 ton, and 72,790 ton during the years 2009 and 2010 respectively. The average rate of soil loss from the catchment of the study area is estimated to be 2.12 t $ha^{-1}yr^{-1}$ and 5.28 t $ha^{-1}yr^{-1}$ in the years 2009 and 2010 respectively. If this rate of soil loss continued then there is most likelihood of occurring fluvial hazards like drainage congestion, flood, etc. in some areas of both side of the river particularly in downstream part of the watershed. This study also reveals that although high and extreme soil loss sensitivity areas occupied less area compared to other soil loss sensitivity zones, they are mainly distributed in the thickly populated and intensively cultivated areas which are also the economically rich regions of the study area. This high and extreme soil loss sensitivity has been adversely exerting great pressure on the rural economy and thus required to be noted as the priority areas in soil and water conservation planning and erosion control.*

Introduction

Research on surficial processes particularly action of water on land surface has gained importance worldwide. Soil erosion is a surficial process and may be defined as the detachment and transportation of individual soil particles by water in the overland flow path. Soil erosion and soil loss are not interchangeable terms. Soil loss is the net loss of sediment from the eroding portion of the overland-flow path which is deposited elsewhere in the depressions within the basin or catchments but not in the stream. According to UNEP (1982), about 20 million hectare in the world become uneconomical for cropping each year due to soil erosion and erosion induce degradation. Brown (1984) estimated that about 23 billion tons of soil from crops in the world is being lost every year. For example, the average annual soil loss of the Dikrong river basin is 51 t $ha^{-1}y^{-1}$ (Dabral *et al.* 2008). Study made by

Prasannakumar *et al.* (2011) on the Siruvani watershed using RUSLE found that rate of maximum soil loss is 14. 917 t $ha^{-1}yr^{-1}$ and about 5.76% (1,184 hectares) of the area comes under the severe soil erosion zone followed by the high-erosion zone (11. 50% of the total area). This study reveals that high soil erosion areas are attributed to the shifting cultivation, and forest degradation along with the combined effect of soil erodibility (K), slope length and slope steepness factor (LS), and cover and management factor (C) (Prasannakumar *et al.*, 2011). Sharma *et al.* (2011) found that the mean soil erosion potential of an agricultural watershed in India was increased slightly from 12.11 t $ha^{-1}yr^{-1}$ in the year 1989 to 13.21 t $ha^{-1}yr^{-1}$ in the year 2004 because of influence of land use and land cover change. Study made by Xu *et al.* (2011) on soil erosion change characteristics and soil loss using USLE in GIS environment for the Maotiao River watershed of China during 1973 to 2007 indicated that changes in land use within the watershed have significantly affected soil erosion. Spatial analysis revealed that the disappearance of forest patches from relatively flat areas, increase in wasteland in steep slope, and intensification of cultivation practice in relatively more erosion-prone soil were the main factors contributing towards the increased soil erosion potential of the watershed during the study period. Results indicated that transition of other land use land cover (LULC) categories to cropland was the most detrimental to watershed in terms of soil loss while forest acted as the most effective barrier to soil loss.

Study area

The study area is the Mora Dhansiri river basin which extends from 26°33'84" N to 26°53'49" N and 92°07'04" E to 92°16'05" E and covers an area of 151.87 km^2 (Fig.1). It is an agricultural watershed and tributary basin of the Jia Dhansiri river, which is one of the important right bank tributary rivers of the Brahmaputra river in India. The upper half of the basin falls in the piedmont region while the lower half occupies the younger

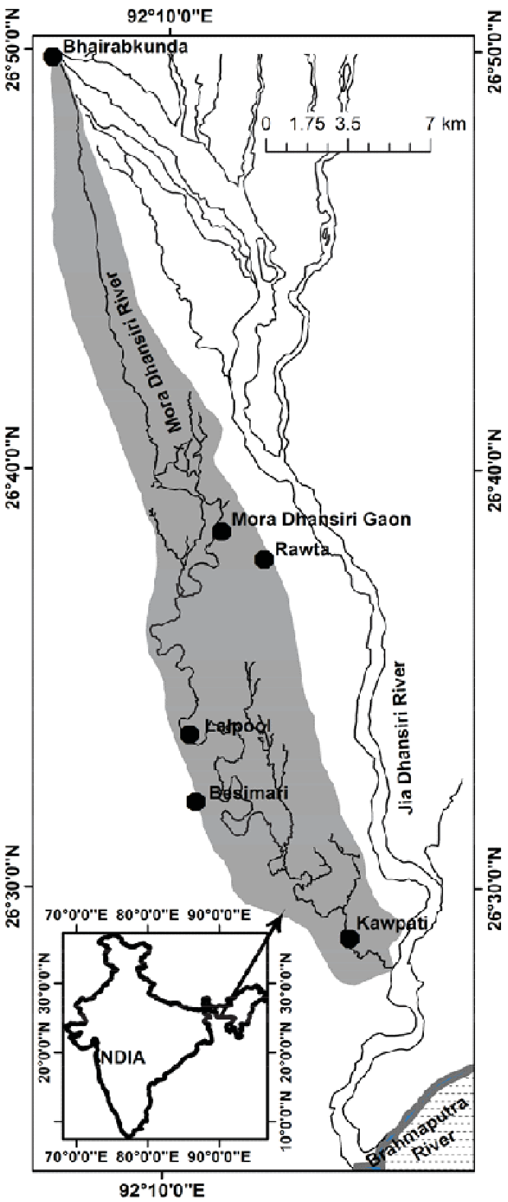

Figure 1. Location of the study area

floodplains of the northern Brahmaputra valley. It is basically fed by rainwater during summer monsoon season. In dry winter season, few bifurcated distributaries of the Jia Dhansiri river located in the piedmont region feeds the Mora Dhansiri river (Sarmah, 2012). Field observation reveal that the study area is characterised primarily by the presence of sand with admixtures of pebbles and boulders in its upper part, while alluvial soils, mostly silt and clay formed from recent river deposits, occur in the lower part. The area experiences a monsoon type of climate characterised by warm wet summers and cool dry winters. The basin receives 2,000 mm of rainfall (Sarmah, 2007). About 71% of the total rainfall is received in the monsoon months (May to October), of which 52% is derived in the months of June and July alone. The maximum temperature varies from 30° to 37 °C (Sarmah, 2007).

Methods and results

The study is based on Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997). The Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith (1978) is one of the most frequently used empirical soil loss model worldwide. It is later modified into the Revised Universal Soil Loss Equation (RUSLE) model by including improved means of computing soil erosion factors (Shi *et al.*, 2002). The RUSLE model can predict erosion potential on a pixel-by-pixel basis, which is effective for attempting to identify the spatial pattern of soil loss present in a region. GIS can then be used to isolate and query on these locations to identify the role of individual variables contributing to the observed erosion potential value (Shi *et al.*, 2002). RUSLE computes average annual soil loss from cover slopes (Renard *et al.*, 1997). The RUSLE is written as:

$$A = R.K.LS.C.P \qquad \ldots(1)$$

Where, A is the soil loss in t ha^{-1} over a particular period, usually yearly basis but sometimes it may calculate month or season basis; R is rainfall erosivity factor in MJ.mm ha^{-1}hr^{-1}; K is soil erodibility factor in t ha^{-1} /(MJ.mm); L is slope length factor (dimensionless); S is slope steepness factor (dimensionless); C is cover and management factor (dimensionless); and P is conservation practices factor (dimensionless). The raster based ArcInfo is useful to incorporate the values in RUSLE model for prediction of erosion potentiality pixel-by-pixel basis. This capability of GIS can reduce tedious labour to compute soil erosion from a significantly large area such as drainage basin. Study the P factor was not considered as there is no conservation practice found in the basin. Consequently, the equation used in the study becomes

$$A = R.K.LS.C \qquad \ldots(2)$$

In order to predict the rate of average soil loss in the Mora Dhansiri River basin, these four parameters of the RUSLE model are multiplied using the raster calculator function tool of the ArcInfo.

Result on assessment and mapping of single factor

INFLUENCE OF PRECIPITATION FACTOR (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 and Smith, 1978). The rainfall erosivity factor indicates the erosive force of a specific rainfall (Prasannakumar *et al.*, 2012). The relationship between rainfall erosivity and rainfall depth developed by Wischmeier and Smith (1978) and modified by Arnoldus (1980) has been used to translate the rainfall depth to rainfall erosivity. The calculation formula was as follows:

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5\log\frac{p_i}{p} - 0.8188\right)} \quad \ldots(3)$$

where R is rainfall erosivity value in MJ.mm $ha^{-1}yr^{-1}$, pi is the monthly rainfall in mm; and P is the annual rainfall in mm. R factor layer has been prepared in 10 meter grid cell in ArcInfo platform. In calculating R factor values, pi is considered for five months viz. June, July, August, September, and October; and for p, total precipitation of these five months is considered. Using this R factor equation, R factor values are calculated for the years 2009, and 2010. Using the R factor values, R factor layer maps have been prepared in 10 meter grid cell at Arcinfo platform for the two selected years and presented in Fig. 2a, and 2b.

INFLUENCE OF SOIL ERODIBILITY FACTOR (K FACTOR): In this study, the soil erodibility (K) values are computed from the soil map data prepared by the Department of Agriculture, Government of Assam, with description of soil texture and composition of the soil belts. Since K factor value is mainly related to soil texture, in computing soil erodibility factor, the equation for K inherited in RUSLE has not been used. The equation put forward by Sharply and Williams (1990) is used following EPIC (Erosion Productivity Impact Calculator), given as follows:

$$K = \{0.2+\exp[-0.0256SAN(1-SIL/100]\}\times[SIL/(CLA+SIL)]^{0.3}\times\{1.0-0.025C/[C+\exp(3.72-2.95C)]\}\times\{1.0-0.7SN_1/[SN_1+\exp(-5.51+22.9SN_1)]\} \quad \ldots(4)$$

Where, SAN is referred to the content of sand (%), SIL is the content of silt (%), CLA is content of clay (%), C is the organic carbon (%), and SN_1 = 1-SAN/100.

Using the above equation, the K factor values are calculated. Analog data of different soil categories have been converted into Arcinfo shapefile and attribute data of soil erodibility are assigned and converted this layer into raster format. Following this procedure, the K factor distribution map is prepared and presented in Fig. 3. Since K factor distribution map is prepared from soil class map, year wise maps are irrelevant and thus only one map is considered for the years 2009 and 2010.

LS FACTOR: Out of all factors instinctive in RUSLE the calculation of LS factor i.e. the degree of hypsography is quite difficult in a relatively large area. To assess the effect of topographic factor vs. soil erosion sensitivity in the present study area, the LS factor is computed with the help of Digital Elevation Model (DEM) generated in Arcinfo. The contour data were digitised from survey of India topological maps of 1:50000 scale for the study area. The DEM of the study area is prepared at 10 meter resolution and slope layer was derived from the same (Fig. 4). The original equation to calculate the LS factor was an empirical equation published in the USDA Agriculture Handbook No. 537 (Wischmeier and Smith, 1978). The equation has undergone some minor changes including the equation published by Moore and Burch in (1986a, b). Thus, here, the LS factor was determined using the following equation:

$$LS = (AS/22.13)^m * (\sin\lambda/0.09)^n \quad \ldots(5)$$

Where AS = Upslope contributing area per unit width of pixel spacing; λ=slope angle (degrees), m and n are exponent 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. Lower values of m and

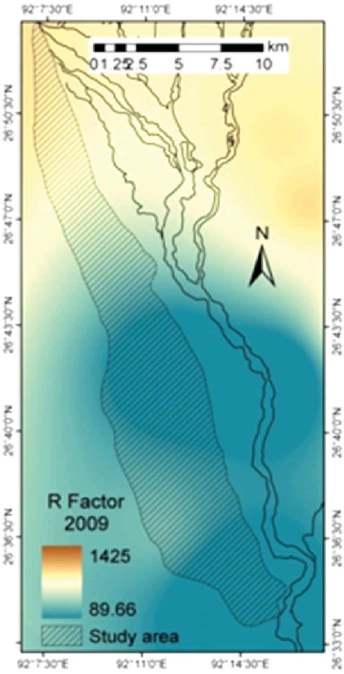

Figure 2a. R factor influencing layer for the year 2009

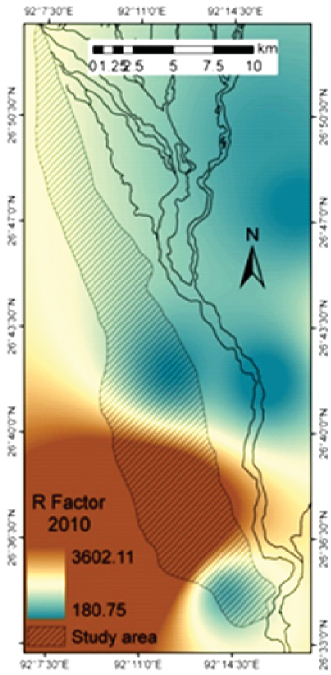

Figure 2b. R factor influencing layer for the year 2010

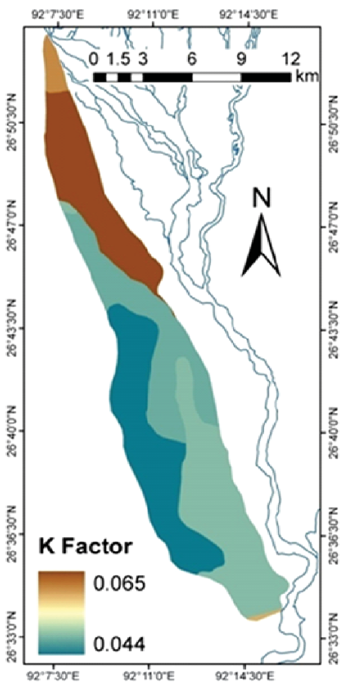

Figure 3. K factor influencing layer

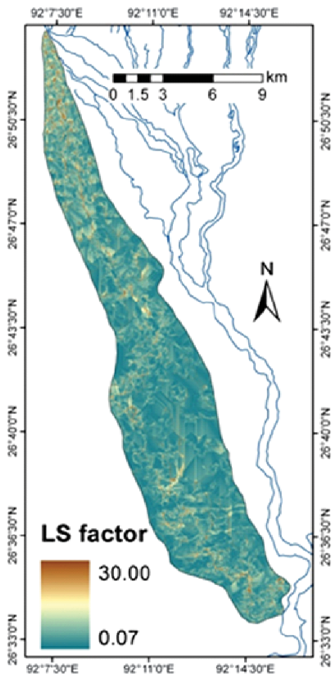

Figure 4. LS factor influencing layer

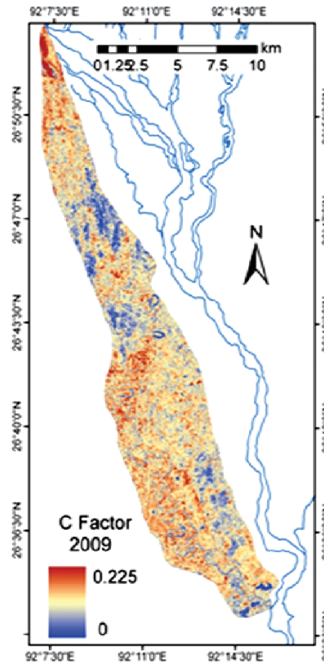

Figure 5a. C factor influencing layer for the year 2009

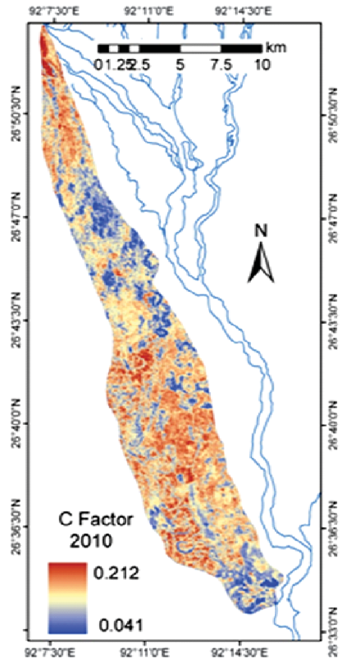

Figure 5b. C factor influencing layer for the year 2010

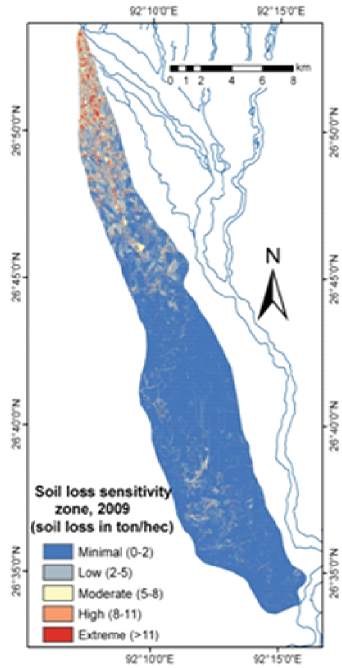

Figure 6a. Integrated assessment of sensitivity of soil loss for the year 2009

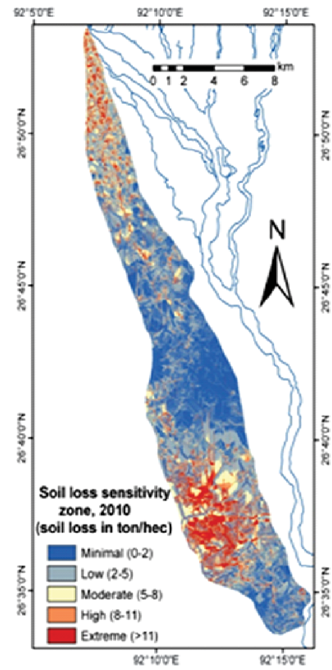

Figure 6b. Integrated assessment of sensitivity of soil loss for the year 2010

n are selected as 0.40 and 1.4 respectively. This selection is made considering the uneven character of the topography of the study area. In ArcInfo platform the equation is applied in the following form:

$$LS = (\text{Flow Accumulation grid}*(\text{cell size}/22.13)^{0.4} * (\text{Sin (Slope grid}*0.01745)/0.0896)^{1.4} \quad \ldots(6)$$

C FACTOR: One of the most influential parameters of RUSLE is C factor which represents land cover and land use practices. The C factor reflects natural and anthropogenic interventions on the processes of soil loss. According to Prasannakumar *et al.* (2012), the Normalised Difference Vegetation Index (NDVI) can be used as an indicator of the land vegetation vigor and health. In addition, Karydas *et al.* (2009) and Tian *et al.* (2009) state that due to the variety of the land cover patterns, satellite remote sensing data can act as an extremely important role to estimate the C-factor. This study uses the satellite images for the year 2009 and 2010 with the reflectance values in bands green, red and near-infrared, which were converted to NDVI for the corresponding years. The NDVI calculation formula can be represented as following:

$$NDVI=(rNIR-rRed)/(rNIR+rRed) \quad \ldots(7)$$

where rNIR is the reflectance value in near-infrared band; and rRed is the reflectance value in visible red band.

After calculation of NDVI, the C-factor can be estimated by applying the relationship used in Zhou *et al.* (2008) and Kouli *et al.* (2009):

$$C=\exp[-\alpha\{NDVI/(\beta-NDVI)\}] \quad \ldots(8)$$

where C is the calculated cover management factor; NDVI is the vegetation index, and α and β are two scaling factors.

Van der Knijff *et al.* (2000) suggest that by applying this relationship, better results can be obtained than using a linear relationship. They suggest the values for the two scaling factors α and β to be 2 and 1, respectively. Thus, in this study, the C factor values are computed with the help of satellite remote sensing data of IRS P6 imagery of 2008. With the help of this method, the C factor values of each and every pixel is calculated for various LULC categories. Using the calculated C factor values, C factor maps have been prepared in Arcinfo platform for the years 2009 and 2010 and presented in Fig. 5a and Fig. 5b respectively.

Integrated assessment of sensitivity of soil loss

The composite analysis of water induced soil loss from Mora Dhansiri river basin, reveals that rainfall (R factor), soil types (K factor), slope (LS factor), and LULC (C factor) have considerable influence in soil loss processes. Soil sensitivity maps are prepared in ArcInfo platform for the years 2009 and 2010 and are presented in Fig. 6a and Fig. 6b respectively. Soil sensitivity maps are prepared classifying the magnitude of soil loss in five different classes viz. minimal, low, moderate, high, and extreme. The classifying influences of RUSLE factors on sensitivity of soil loss in the year 2009 and 2010 are presented in Table 1 and Table 2 respectively.

Discussion

Sensitivity of soil loss in the Mora Dhansiri River catchment is found to be quite varying in nature in the years 2009 and 2010. Soil sensitivity maps (Fig. 6a and 6b) show considerable resemblance between physiography and soil loss sensitivity. This

Table 1. Classification of influences of RUSLE factors on sensitivity of soil loss in the year 2009

Soil loss sensitivity class	Soil loss class (t ha^{-1})	Classifying influences of RUSLE soil loss factors				Area in km^2
		R value	K value	LS value	Land cover / land use (C factor)	
Minimal	0 - 2	<500	<0.048	<1 Flat	Wastelands (grass lands, wetlands) <0.1300	118.25 (78%)
Low	2 - 5	500–700	0.044–0.052	1–3 Very low	Horticultural croplands, 0.1300-0.1425	20.99 (14%)
Moderate	5 - 8	700–900	0.052 - 0.056	3–5 Low	Agricultural lands (cash crop, tea gardens) 0.1425-0.1500	6.43 (4%)
High	8 - 11	>900	0.056 - 0.060	5–8 Moderate	Agricultural lands (summer vegetables) 0.1500-0.1575	2.16 (1%)
Extreme	<11	–	>0.060	>8 Gentle	Agricultural lands (grain cropland), >0.1575	3.86 (3%)

means the influence of various RUSLE factors have positive co-relationship with soil loss. It is evident in both the maps that upstream part of the basin which is characterised by high gradient (Fig. 4) and dissected topography shows high to extreme sensitivity (Table 1 and 2) of soil erosion. From canopy cover point of view, this region is mostly covered by grasslands which also prevent soil erosion. The middle downstream part of the basin, in most of the cases at the proximity of the river, which is characterised by high LS factor, drainage density and drainage frequency also shows high to extreme sensitivity (Fig. 6a and 6b) of soil erosion. This region is basically put to agricultural lands producing grain crops and summer vegetables (Table 1 and 2) which require high tillage during high runoff period catalysing rapid soil loss. The piedmont zone part covering almost upstream half of the basin shows minimal to low soil loss sensitivity (Fig. 6a and 6b) primarily because of coarse soil texture allowing rainwater to percolate fast reducing soil loss. This area is extensively used for raising horticultural crops and cash crops which require less tillage frequency and that too not in the high runoff period. Thick canopy cover of tea gardens, which are scatterdly existed in this area also attributable to low sensitivity of soil erosion in this area.

Significant difference in pattern of sensitivity of soil erosion is evident in the soil

Table 2. Classification of influences of RUSLE factors on sensitivity of soil loss in the year 2010

Soil loss sensitivity class	Soil loss class (t ha^{-1})	Classifying influences of RUSLE soil loss factors				Area in km^2
		R value	K value	LS value	Land cover / land use (C factor)	
Minimal	0 - 2	<1200	<0.048	<1 Flat	Wastelands (grass lands, wetlands) <0.1320	65.69 (43%)
Low	2 - 5	1200–1900	0.044–0.052	1–3 Very low	Horticultural croplands, 0.1320-0.1400	44.51 (29%)
Moderate	5 - 8	1900–2600	0.044 - 0.052	3–5 Low	Agricultural lands (Cash crop, Tea gardens) 0.1400-0.1500	19.13 (13%)
High	8 - 11	2600-3200	0.056 - 0.060	5–8 Moderate	Agricultural lands (summer vegetables) 0.1500-0.1650	7.39 (5%)
Extreme	<11	–	>0.060	>8 Gentle	Agricultural lands (grain cropland, wetlands) >0.1650	15.11 (10%)

loss sensitivity maps (Fig. 6a and 6b) prepared for the years. This difference is examined to be because of occurrence of high rainfall in the year 2010 compared to the year 2009, particularly during the ground saturated period. This fact is evident in the R factor maps presented in Fig. 2a and 2b. Since there is no water conservation practice in the study area and the ground is a gentle plain, rainfall plays vital role in soil loss sensitivity. Though there is difference in occurrence of rainfall in the years 2009 and 2010 piedmont region shows minimal to low sensitivity of soil erosion in both the years basically because of coarse soil texture characteristics.

This study estimates that total soil loss from the basin is 30,886 ton, and 72,790 ton during the years 2009 and 2010 respectively. The average rate of soil loss from the catchment of the study area is estimated to be 2.12 t $ha^{-1}yr^{-1}$ and 5.28 t $ha^{-1}yr^{-1}$ in the study years. The integrated assessment of soil loss from the basin evidences highest surface area i.e. 118 km^2 and 65 km^2 under minimal sensitivity class in the study years (Table 1 and 2). However, there is 45% decrease in surface area coverage in the minimal soil loss sensitivity class during 2009-10. But in all other soil sensitivity classes the area under them increases during the study period. The decrease of surface area coverage under the minimal soil sensitivity class in 2009 and increase of the same in other soil sensitivity in classes in 2010 is examined because of temporal distribution of rainfall. Though total rainfall from May to October were nearly same (2,588 mm in 2009 and 2,894 mm in 2010) temporal distribution of rainfall in terms of number of rainy days were different. Total number of rainy days in the years 2009 and 2010 were 62 and 88 respectively with an increase of 29%. It is found that rainfall pattern in terms of number of rainy days is more consistent in 2010 (CV=4.29) than in 2009 (CV=4.48). This comparative consistency in rainfall caused more soil loss in all areas other than the minimal soil sensitivity class, which mostly fall in piedmont zone, fine soil texture. Although there were consistency in rainfall in 2010, the minimal soil sensitivity class which mostly falling in piedmont zone could not yield more soil because of coarse soil texture.

Conclusion

This study estimated that total soil loss from the basin is 30,886 ton, and 72,790 ton during the years 2009 and 2010 respectively. The average rate of soil loss from the catchment of the study area is estimated to be 2.12

t $ha^{-1}yr^{-1}$ and 5.28 t $ha^{-1}yr^{-1}$ in the years 2009 and 2010 respectively. If this rate of soil loss continued then there is likelihood of fluvial hazards like drainage congestion, flood, etc. in some areas of both sides of the river particularly in the lower half of the basin. This study also reveals that although high and extreme soil loss sensitivity areas occupied less area compared to other zone, yet they are mainly distributed in the thickly populated and intensively cultivated areas which are also economically active and rich areas of the study area. This is exerting great pressure on the rural economy and thus required to be noted as the priority area in soil and water conservation planning and erosion control.

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