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Integrated framework for soil and water conservation in Kosi River Basin

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ABSTRACT

Soil loss through erosion and its subsequent deposition is considered as an important challenge for watersheds. In this paper, attempt has been made to integrate the Revised Universal Soil Loss Equation, rainfall climatology from merged IMD gauge-TRMM (1998–2015) and soil hydraulic parameters to delineate the highly susceptible zones of the Kosi River Basin (KRB), Bihar, India for soil erosion assessment and watershed prioritization. The soil hydraulic parameters are calculated by using the ROSETTA model. Afterwards, the analytical hierarchy process based on multi-criteria evaluation method (AHP-MCE) was employed to assign the weighting to each factor (Soil erosion, Compound Factor, Field Capacity) depending on their erosion potential. Weighted overlay analysis is then performed to generate the watershed prioritization map for soil and water conservation. The overall findings suggest that the sub-watersheds 5, 8 and 7 required utmost attention and conservative measures because of their high erodibility characteristics.

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Morphometric analysis; Kosi River Basin; RUSLE; ROSETTA; AHP-MCE

1. Introduction

The soil loss through soil erosion is a natural process and it involves the detachment, transport and subsequent deposition of soil particles (Jain et al. 2001). From decades, soil erosion remains a major natural hazard all over the world. Soil erosion causes deterioration of soil health, change in the drainage characteristics, degradation of the inland water quality and creates siltation problems in reservoirs and dams (Efthimiou et al. 2014). It often threatens the agricultural yield and food security and also alters the biodiversity in the region. Although soil erosion process is mainly controlled by the level of technological advancement, slope, topography, climatic conditions, land use, land cover and soil types of the particular area, it is also influenced by the human activities like agricultural practices, deforestation, urbanisation etc. (Ganasri and Ramesh 2016). Therefore, our prime

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concern is to provide better plan for the management and development of watershed for soil and water conservation.

In this context, there are many physically based simulation models developed in the last few decades for the estimation of soil erosion, such as WEEP (Water Erosion Prediction Project Soil Loss), SWAT (Soil and Water Analysis Tool), and EUROSEM (European Soil Erosion Model). The empirical models namely Universal Soil Loss Equation (USLE), and Revised Universal Soil Loss Equation (RUSLE) were originally developed for sheet and rill erosion at agricultural plot scale. These conceptual models play an important role and having unique characteristics as well as limits (Merritt et al. 2003). However, compared to the other models, RUSLE is a robust and widely used model all over the world (Biswas and Pani 2015; Pandey et al. 2007; Parveen and Kumar 2012;Efthimiou et al. 2014; Uddin et al. 2016; Vaezi et al. 2010) for estimating the soil loss in basin due to its simple model structure and easy integration within GIS framework (Ganasri and Ramesh 2016; Prasannakumar et al. 2011).

The morphometric analysis provide the quantitative characteristic of basin to provide better understanding of the hydrological process occurring in the basin (Magesh et al. 2013; Strahler 1964; Rama 2014). Further, in developing any modelling framework, along with the soil's physical properties the drainage morphometry of a basin is considered to be a highly influential component (Rai et al. 2017; Patel et al. 2015). On the other hand, soil field capacity is considered to be a vital parameter in estimating the water holding capacity of a soil, which needs soil physical properties such as soil texture, porosity/bulk density, organic matter etc (Srivastava et al. 2013; Garg and Gupta 2015).

The present study focused on the Kosi River Basin (KRB), Bihar, India, to evaluate the soil erosion by using the RUSLE model, in integration with the field capacity and morphometric parameter through AHP-MCE. This approach provides a new way to effectively manage and plan soil and water resources in a cost effective manner. In this context, the first objective of this study is to calculate morphometric parameters to prioritize sub-watersheds. The second objective is focused on estimating the soil erosion susceptible zones by RUSLE model, estimated field capacity and morphometric analysis with the help of the state of the art AHP-MCE technique. Finally, a prioritized map of the region is developed that need urgent conservative practices.

2. Study area

The river Kosi also known as the 'Sorrow of Bihar' is one of the major tributaries of river Ganga. It originates at an altitude of 7000 m from Himalayas and meets the river Ganga near Kursela, in district Katihar of Bihar. The river kosi can be divided into two parts– upper catchment which lies in the Tibet and Nepal comprises of about 80% of the total catchment area and lower catchment which has quite different characteristics compared to the upper one and covers 20% of the total catchment area. The study is carried out in part of the lower catchment of the Kosi, which, geographically, lies between 86° 20′ to 87° 10′ East and 25° 30′ to 26° 30′ North and covers an area of 4062 km^2 in Bihar (Figure 1). The lowest temperature can be observed in December–January with an average minimum of 8–10 °C and maximum of 24–25 °C. The highest temperature can be observed in the months of April to June with an average minimum of 23–25 °C and maximum of 35–38 °C. The entire lower area of the basin can be considered as a large inland delta formed by the huge sandy deposit and the main type of soil types are mostly sand, silty clay loam and loam. The basin is characterised by general slope from north to south and being steeper in the north and flatter in the south. From the past records, it is

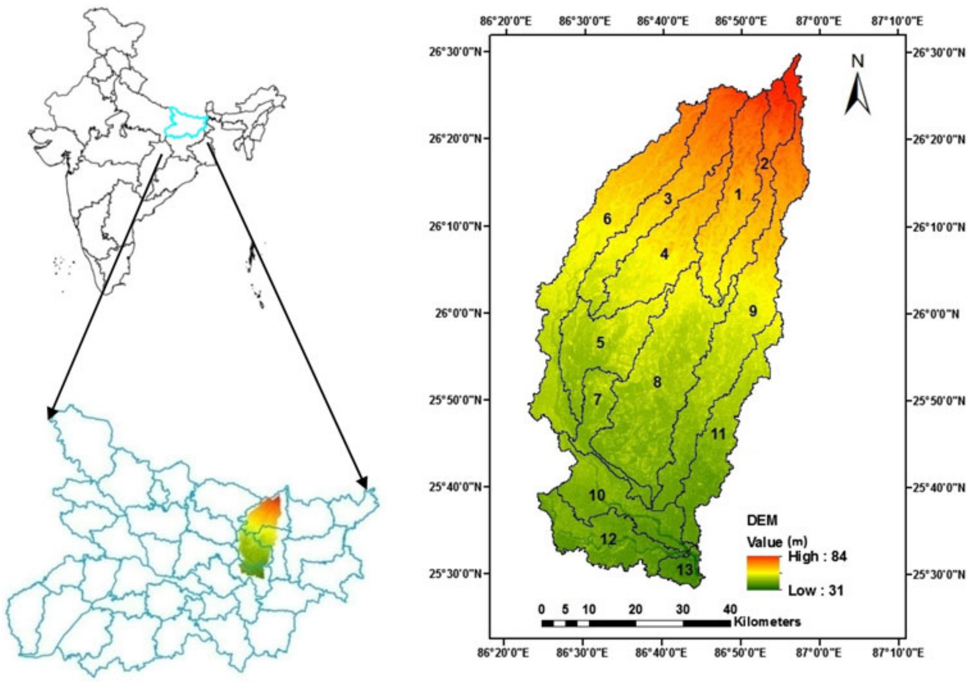

Figure 1. Geographical location map of Kosi River Basin.

revealed that the river has laterally shifted westward about 150 km in last 200 years (Bapalu and Sinha 2005; Gole and Chitale 1966; Wells and Dorr 1987) and this shifting has caused extensive damage to local inhabitants, their livelihood, infrastructure and property. The high intense rainfall of 1200–2000 mm is evident in the most parts of the basin (Sinha and Friend 1994), and considered as main driver for most of the soil erosion processes and are responsible for high amount of sediment load in the Kosi basin.

3. Materials and methodology

In this current study, several input datasets are prepared for soil erosion modelling such as morphometric parameters, soil hydraulic parameters and RUSLE factor. DEM is used for slope map and are projected to Universe Transverse Mercator projection (Zone 45 North), WGS-1984. The TRMM-IMD merged rainfall datasets 1998–2015 are utilized in understanding the spatial distribution of rainfall. The detailed methodology is shown in Figure 2 and discussed in below sub section.

3.1. SRTM DEM

The National Aeronautics and Space Administration (NASA) Shuttle Radar Topographic Mission (SRTM) has provided digital elevation data (DEMs) for over 80% of the globe. It is developed in collaboration between NASA and National Geospatial Intelligence Agency (NGA) for topographic analysis. The SRTM data is available at both 3 arc second (approx. 90m) and 1 arc second (approx. 90m). The SRTM dataset (90m) was downloaded from http://www.cgiarcsi.org for topographic analysis of the study area. The pre-processing of DEM was performed followed by post processing. DEM fills, flow direction and flow accumulation was calculated for individual pixel using Arc Hydro tool of ArcGIS10.1. The altitude of the DEM varies from 31 to 84 meters.

3.2. Soil type

The soil map (90 m) of the KRB obtained from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) soil series map, published by National Remote Sensing Centre (NRSC) Hyderabad, India (NRSC 2016b), and downloaded from http://gisserver.civil.iitd.ac.in/grbmp/metadata.aspx. The information about various soil types, texture and size, organic carbon, bulk density plays a significant role in the hydrological processes and calculation of soil hydraulic parameters.

3.3. Land use land cover

The land use and land cover map contain information about the different type of land use pattern existing in the KRB and, is collected from National Bureau of Soil Survey and Land Use Planning (NBSS&LUP). Agricultural crop lands, current fallow lands, grass lands, urban and water bodies are the main types of land use land cover in KRB. It has the resolution of 56 m and used for estimation of support practice factor (P) required in the RUSLE model.

3.4. TRMM

The Tropical Rainfall Measuring Mission (TRMM) is a combined U.S.-Japan satellite mission to study rainfall. The dataset has a resolution of $0.25^\circ \times 0.25^\circ$ and the spatial coverage from 50° S to 50° N latitudes. The daily TRMM rainfall data from 1998–2015 was downloaded from the http://neo.sci.gsfc.nasa.gov website and used for the rainfall distribution of the KRB. This rainfall distribution map is used in estimation of Rainfall erosivity factor (R) of the RUSLE model.

3.5. Morphometric analysis and prioritization

Morphometric analysis is an effective tool for evaluating the drainage network, stream gradient, shape of basin etc. Thus, the basic, linear and shape parameters are estimated for the KRB. The Strahler's (1964) method of ordering the stream was applied, owing to its simplicity and wide application. The morphometric characteristics of 13 sub watersheds were calculated. The formula and method used for the analysis of various morphometric parameters are shown in Table 1.

3.6. Revised universal soil loss equation (RUSLE) model

RUSLE computes the average annual erosion in tons/acre/year caused by the rainfall and associated overland flow for conservation measure rather than the precise quantitative estimation. USLE is an empirical model, developed in 1965 by Wischmeier and Smith, and later computerised and updated by a group of scientist and now subsequently known

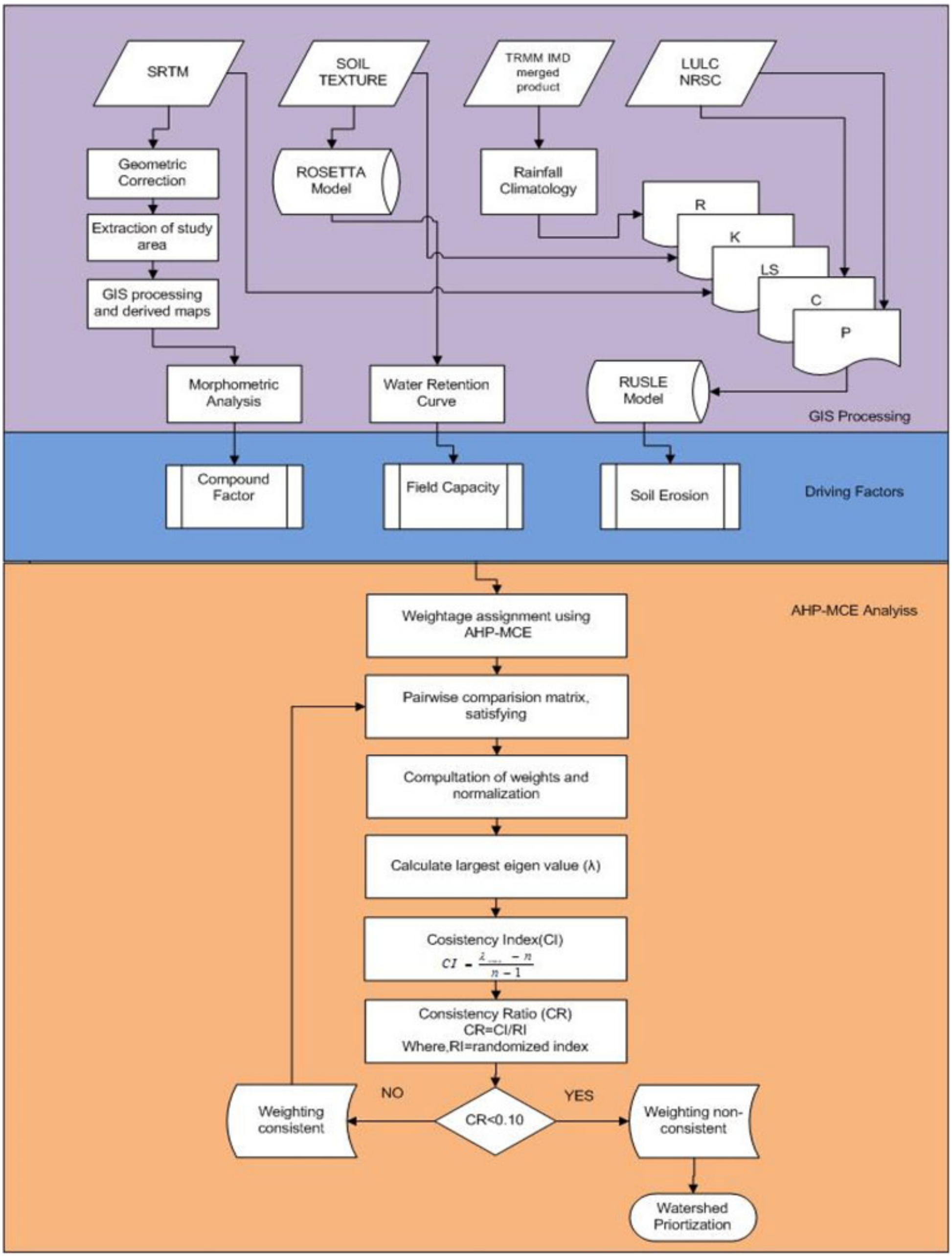

Figure 2. Flowchart of the Methodology.

as RUSLE (Agarwal et al. 2016). RUSLE is the update of USLE and is the function of five key input factors: rainfall erosivity, soil erosivity, slope length and steepness, cover management and support management. It is very simple model and can be easily integrated with GIS. It can be used for cropland, rangeland, mine land, disturbed forest land, reclaimed land, waste disposal sites, landfills, and other land use types wherever rainfall and overland flow are the main causes for soil erosion. The RUSLE Equation (1) can be expressed as follows:

$$A = R \times K \times LS \times C \times P \quad (1)$$

where, A: Computed Average Annual Soil Loss (t $ha^{-1} yr^{-1}$); R: Rainfall-Runoff Erosivity factor (MJ.mm ha^{-1} h^{-1}); K: Soil Erodibility Factor (ton h $MJ^{-1} ha^{-1} mm^{-1}$); L: Slope Length, Factor (dimensionless); S: Slope Steepness Factor (dimensionless); C: Land Cover-Management Factor (dimensionless); P: Conservation Practice (dimensionless). All the input factors are discussed in the following subsections.

3.6.1. Rainfall-runoff erosivity (R) factor

Rainfall runoff erosivity (R) factor represents the effect of raindrop impact, and it varies with the rate of associated runoff. It is defined as the long-term average of the product of total rainfall energy and the maximum 30 min intensity for the storm events (Wischmeier and Smith 1978). The scarcity of the detailed rainfall energy and the corresponding intensity data, limit the estimation of R factor. To overcome this problem, the simplified version of the modified Fournier Index (Arnoldus 1980) was applied for calculation of this factor. The merged IMD-TRMM (0.25 × 0.25) daily grided precipitation data, from 1998 to 2015 is used to estimate the R factor. Further, the spatial distribution of the R-factor is estimated using IDW (Inverse Distance Weighted) interpolation method. The modified Fournier Index is shown in Equation (2):

$$F = \sum_{i=1}^{12} \frac{(P_i)^2}{P} \quad (2)$$

where, *P*i represent the mean rainfall depth (mm) of the I month and P for mean-annual rainfall (mm).

3.6.2. Soil erodibility factor (K)

The Soil erodibility (K) represents the vulnerability of soils to erosion by rain water and its associated runoff. Soil texture, structure, organic matter and permeability of the soil are the key factors which influence the K- factor. The soil erodibility factor was calculated using the equation given by Sharpley and Williams (Sharpley and Williams 1990), which determine the K factor, as a function of complex interaction of percent of sand, silt, clay and organic carbon in the soil. The values K-factor lies between 0 to 1, where 0 represents less susceptibility to erosion and 1 for higher susceptibility. The K- factor was calculated using the following equations:

$$K = A \times B \times C \times D \times 0.1317 \quad (3)$$

where,

$$A = 0.2 + 0.3 \exp(-0.0256 \times SAN(1 - SIL/100) \quad (4)$$

$$B = \left[\frac{SIL}{CLA + SIL}\right]^{0.3} \quad (5)$$

$$C = \left[1.0 - \frac{0.25 \times C}{C \times \exp[(3.72 - 2.95 \times C)]}\right] \quad (6)$$

$$D = \left[1.0 - \frac{0.70 \times SN1}{SN1 + \exp[(-5.41 + 22.9 \times SN1)]}\right] \quad (7)$$

where, SAN, SIL and CLA represent the percent of sand, silt and clay respectively; C is the organic carbon content and SN1 is the sand content subtracted from 1 and divided by 100.

3.6.3. Topographic factor (LS)

Topographic factor (LS) is the ratio of soil under the given condition to the standard plot conditions that has a slope length of 23.6 m and steepness of 9%. Generally, the LS factor represents impact of topography on soil erosion. The SRTM DEM with resolution of 90 m as employed for the estimation of slope and flow accumulation of the KRB. Afterwards both slope steepness and slope length were estimated by the following equation with the help raster calculator tool of Arc GIS 10.1 which gives the detailed spatial distribution of the values of LS factor (Figure 3) given in equation (8).

$$\mathrm{LS} = (\text{flow accumulation} \times \text{cell size}/22.13)^{0.4} \times (\sin\ \text{slope}/0.0896)^{1.3} \tag{8}$$

Where, the LS is the collective slope length and steepness factor, flow accumulation is the total accumulated upslope area contributed to a cell, and cell size is the size of each pixel inside the image (90 m) and sin slope represent the slope degree values in sin form.

3.6.4. Cover and management factor (C)

This parameter reflects the management practices types and their effect on soil erosion. It is defined as the ratio of soil loss from the land cropped under specific condition to the corresponding loss from clean-tilled, continuous fallow (Wischmeier and Smith 1978). As the C-factor mainly depends on the type of vegetation, stage of vegetation growth and their cover percentage, it is useful to extract the information regarding the land cover type of the basin. The Normalized Difference Vegetation Index (NDVI) is used as one of the most widely used remote sensing derived indicator for the vegetative condition. Hence, in this case the MODIS estimated NDVI image of monsoon season from 2000–2015 of the KRB was downloaded and processed to represent the vegetation condition. In general, values of vegetative area contain more than 0.1, whereas less than 0.1 represent sparse or thin vegetation cover and non-photosynthetic materials like water bodies and barren lands. Afterwards, the mean NDVI estimated to solve the NDVI based equation for assessment of C-factor. This NDVI based equation for assessment of C-factor was successfully used by many researchers previously (Kouli et al. 2009; Pradeep et al. 2015) and can be expressed as;

$$C = \exp\left[-\alpha \frac{NDVI}{(\beta - NDVI)}\right] \tag{9}$$

where, α and β were unit less parameters that determine the shape of the curve relating to NDVI and C-factor and their corresponding values of 2 for α and 1 for β giving better results (Van der Knijff et al. 2000).

3.6.5. Support practice factor (P)

P-factor is considered as the support factor which indicates the effect of different control practices on soil loss from the basin. Contouring along the slope, strip cropping, terracing etc. are the main types of erosion control practices used in field to reduce soil loss against erosion by either changing the drainage structure or by reducing the runoff

Table 1. Morphometric parameters estimated for Kosi River Basin.

S. No.	Parameters	Formula	References
1	Stream order (u)	Hierarchical rank	(Strahler 1964)
2	Number of streams (Nu)	Total number of stream segment of the order u	(Strahler 1957)
3	Stream length (L_u)	Total length of the stream segment of particular order	(Horton 1945)
4	Stream frequency (Fu)	$Fu =$ Where $=$ Total number of stream of all order $A =$ Area of the river basin(Km^2)	(Horton 1932)
5	Length of overland flow (Lo)	$Lo = \times Dd$ Where, $Dd =$ Drainage density of basin	(Horton 1945)
6	Bifurcation ration (Rb)	$Rb =$ Where $=$ total number of stream segments of the order 'u' $=$ number of stream segments of the next higher order	(Schumm 1956)
7	Drainage density (Dd)	$Dd =$ Where, $=$ total length of the stream segments of all orders $A =$ Area of the river basin or grid (Km^2)	(Horton 1932)
8	Texture ratio (T)	$T =$ Where $=$ Total number of stream of all order $A =$ Area of the river basin(Km2)	(Horton 1945)
9	Elongation ratio (Re)	$Re = D/L = 1.128/L$ Where, $D =$ Diameter of a circle of the same area (A) as the basin $A =$ Area of the basin (Km^2) $L =$ Basin length (Km)	(Schumm 1956)
10	Circularity ratio (Rc)	$Rc = 4\pi A/$ Where, $A =$ Area of the basin (Km^2) $P =$ Perimeter (Km)	(Strahler 1964)
11	Form factor (Rf)	$Rf = A/$ Where, $A =$ Area of the basin (Km^2) $=$Basin length (Km)	(Horton 1945)
12	Shape factor (Bs)	$Bs = /A$ Where, $=$ Basin length (Km) $A =$ Area of the basin (Km^2)	(Horton 1932)
13	Basin length (Lb)	$Lb = 1.312\times$ Where, Lb=Length of basin(Km) $A =$ Area of the basin (Km^2)	(Ratnam et al. 2005)
14	Compactness constant (Cc)	$Cc = 0.2821P/$ Where, $Cc =$ Compactness Constant $A =$ Area of the basin (Km^2) $P =$ Perimeter of the basin (Km)	(Horton 1945)

potential to soil loss and erosion by decreasing the velocity of water. The P-factor is defined as the ratio of soil under a given support practice to that of straight-row farming up and down the slope (without any supporting practices) (Renard 1997). In general, P-factor represented by values that lies between 0 to 1, where the uppermost value is allotted to areas which have no conservation practices and vice-versa. In this study, the Land use land cover obtained from NRSC (NRSC 2016a) was used for the P-factor estimation.

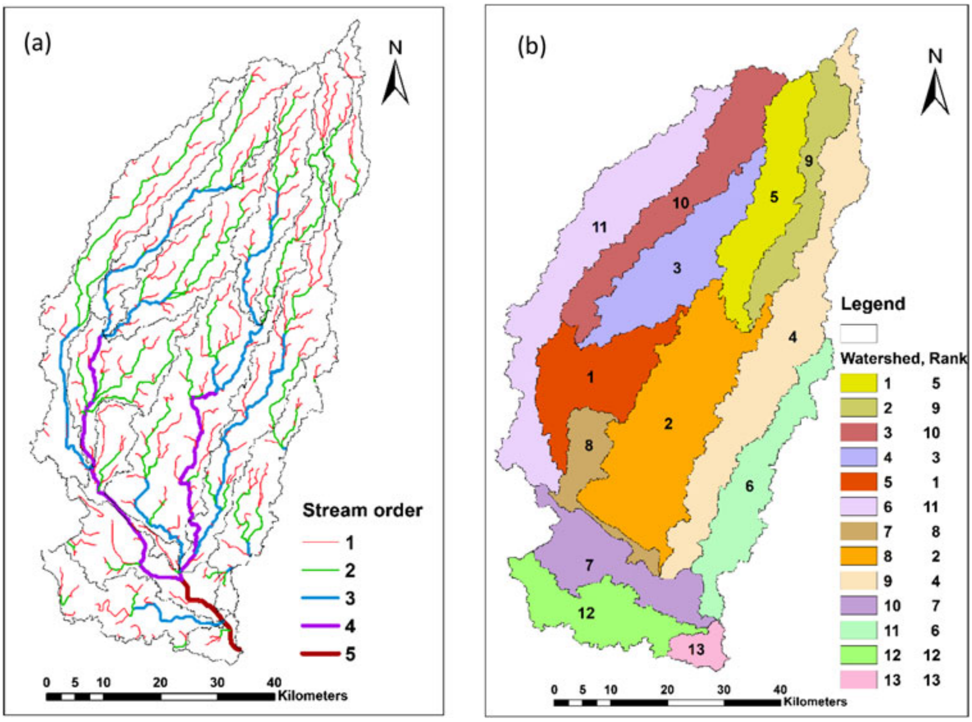

Figure 3. (a) Drainage order (b) Prioritization of sub-watersheds from Compound factor.

3.7. ROSETTA model

The estimation of soil hydraulic parameters is a time taking procedure although they play a vital role in water management studies. Therefore, some simple method is needed for soil hydraulic parameters calculation and to use with the simulation model. Among them ROSETTA is commonly used to assess the unsaturated hydraulic parameters from the basic soil properties such as soil texture, organic matter and bulk density, which is based on the PedoTransfer Functions (PTFs). In this study also the soil hydraulic parameters were calculated by using the ROSETTA model, supported by neural network bootstrap method (Schaap et al. 2001). ROSETTA model is capable to predict water retention curves and can provide both saturated and unsaturated hydraulic conductivity parameters (Van Genuchten 1980). Soil textural class such as sand, silt and clay percentages were used to simulate ROSETTA model and water retention curve. The values at −33 and −1500 kPa were used to estimate the field capacity of soil types of KRB. The Van Genuchten water retention function is given in Equation (10):

$$\theta(h) = \theta(h) + \frac{\theta_s - \theta_r}{\left(1 + (\alpha h)^n\right)^m} \tag{10}$$

where, θ_r and θ_s are the residual and saturated water content respectively, α is the scaling parameter, n is the curve shape factor and m is an empirical constant and these can be related to n by:

$$m = 1 - {}^{1}/_{n} \text{ for n } > 1$$

3.8. Multi-Criteria evaluation (MCE) and weighting assignment

As soil erosion is the very complex process and involves interaction of different factors, it is crucial to provide weighting to all the factors for an improved soil erosion prediction. In the present study, the AHP, introduced by Saaty and Vargas (Saaty and Vargas 1980), based on MCE was used to assign weighting to each factors. It involves the pair wise comparison of each factors, relative to its importance, on a rating scale from 1 to 9, where 1 indicates lowest contribution towards soil erosion, while 9 is for extremely important factor (Srivastava et al. 2012). Then the step involves calculation of normalized matrix, which is based on summing the numbers in each column, and then each entry in the column is later divided by the column value to get the normalized score.

The priorities of the criteria can be estimated by the principal eigenvector 'e' of the matrix 'M', as expressed in Equation (11).

$$M_e = \lambda_{\max} e \tag{11}$$

where, $\lambda_{\max}$ is the largest eigen value of the matrix 'M' and the eigen vector 'e'.

Then to make sure that the original preference rating is consistent, CR (consistency ratio) was calculated. Generally, a CR of 0.1 or below is considered as acceptable and any higher value indicate inconsistency and therefore need re-examination. The CR and consistency index (CI) can be estimated by Equations (12 and 13);

$$CR = \frac{CI}{RI} \tag{12}$$

$$CI = \frac{(\lambda_{\max} - n)}{(n-1)} \tag{13}$$

Where, RI: Random Inconsistency, n: number of variables.

4. Results and discussions

4.1. Morphometric analysis

Morphometric analysis is a quantitative process, which constitute the measurement of configurations of earth surface, shape and dimensions of landforms (Patel et al. 2013). The morphometric parameters considered here includes basic parameters, linear parameters and shape parameters. Further details about the different equations applied for the analysis of morphometric parameters are given in Table 1.

4.1.1. Basic parameters

The main basic parameters are considered for this work for morphometric analysis includes drainage area, perimeter, stream order, stream length and basin length.

4.1.1.1. Drainage area (A) and perimeter (P). Drainage area is the most important morphometric parameters of any watershed and it is used to estimate the total volume of runoff and sediment load. Results showed that the sub-watershed 8 has the maximum area of 598.21 km^2 while the sub-watershed 13 has the minimum area of 51.54 km^2. The basin perimeter can be defined as the length of the line that defines the surface divide of the basin. In the present case, the maximum value of 376 km is found for sub-watershed 9, whereas the minimum of 51.08 km is calculated for sub-watershed 13.

Table 2. Stream order of Kosi River Basin.

Sub-Watershed	First order	Second order	Third order	Fourth order	Fifth order	Total number of streams
1	22	11	10	0	0	43
2	12	9	0	0	0	21
3	20	10	11	0	0	41
4	23	12	9	0	0	44
5	21	13	1	8	0	43
6	24	11	5	0	0	40
7	8	2	0	4	0	14
8	40	18	13	8	0	79
9	37	16	14	3	0	70
10	19	7	0	6	2	34
11	23	15	5	0	0	43
12	16	5	2	0	0	23
13	3	2	0	0	2	7

4.1.1.2. Stream order (Nu). Hierarchical position of the streams within the drainage basin can be defined through analysis of stream order. In this research work, stream order analysis is performed by using the Strahler's method in which the first order streams does not consist of any tributaries, and the confluence of the two first order streams formed the second order streams and so on. However, as the stream order increases the total number of streams of the particular order decreases. The overall analysis indicates that the KRB is a fifth order drainage basin and having total number of 502 streams, sprawl over 4021.41 km^2 area (Figure 3(a)). Among the 13 sub-watersheds, the sub-watershed 8 has the maximum number of streams of 79 followed by 70 in sub-watershed 9, while the sub-watershed number-13 has lowest number of streams of 7. Further details about the number of streams in each order are given in Table 2

4.1.1.3. Stream length and Basin length (Lb). Stream length can be computed by adding all the stream lengths of a particular order. Generally, steep slope indicate the smaller stream length, whereas the more flatly or gradient slopes reflect the larger stream length. As per the results, sub-watershed 8 has the maximum stream length of about 268.60 km while the minimum of 15.52 km is obtained in case of sub-watershed 13. Basin length can be defined as the distance measured along the main channel from the watershed outlet to the basin divide. It is an important factor in estimation of various morphometric analyses and, is proportional to drainage area. As per the result, the basin length of sub-watersheds varies from 49.5 km (sub-watershed 8) to 12.3 km (sub-watershed 13).

4.1.2. Linear parameters

4.1.2.1. Bifurcation ratio. Bifurcation ratio (Rb) is the ratio between the number streams of a given order to number of streams of the next higher order. It is a dimensionless parameter which reflects the degree of distribution of stream network of the watershed (Mesa 2006; Soni 2016) and is highly influenced by the geological characteristics of the drainage basin. The higher bifurcation ratio of a basin reveals a strong structural control on the drainage pattern and vice-versa. In KRB, the maximum Rb ratio of 4.9 found in sub-watershed 5, whereas the minimum of 1.2 in sub-watershed 13, which indicates low structural control on the basin drainage pattern. Table 3 shows the list of sub-watersheds and their corresponding bifurcation ratio.

4.1.2.2. Drainage density and frequency. Drainage density (Dd) is the ratio of the total length of the streams of the watershed to the total area of that particular watershed.

Table 3. Analysed morphometric parameters.

Sub-watershed	A (km^2)	P (km)	L (km)	Rb (km)	T	Fu	Dd	Lo	Rf	Bs	Re	Rc	Cc
1	274.32	177.80	31.83	1.55	0.12	0.16	0.47	0.23	0.27	3.69	0.59	0.11	2.07
2	203.42	182.75	26.86	1.33	0.07	0.10	0.60	0.30	0.28	3.55	0.60	0.08	2.52
3	333.61	228.87	35.57	1.46	0.09	0.12	0.46	0.23	0.26	3.79	0.58	0.08	2.38
4	317.81	180.27	34.61	1.63	0.13	0.14	0.49	0.24	0.27	3.77	0.58	0.12	1.93
5	286.79	169.31	32.65	4.91	0.12	0.15	0.51	0.26	0.27	3.72	0.59	0.13	1.92
6	514.93	318.83	45.52	2.19	0.08	0.08	0.36	0.18	0.25	4.02	0.56	0.06	2.59
7	127.53	144.22	20.60	2.25	0.06	0.11	0.54	0.27	0.30	3.33	0.62	0.08	2.59
8	598.21	253.62	49.57	1.74	0.16	0.13	0.46	0.23	0.24	4.11	0.56	0.12	1.89
9	568.29	376.80	48.14	2.71	0.10	0.12	0.47	0.24	0.25	4.08	0.56	0.05	2.90
10	238.96	166.13	29.43	1.91	0.11	0.14	0.40	0.20	0.28	3.63	0.59	0.11	2.09
11	269.91	207.49	31.54	2.27	0.11	0.16	0.37	0.18	0.27	3.69	0.59	0.08	2.44
12	236.09	168.08	29.23	2.85	0.10	0.10	0.33	0.16	0.28	3.62	0.59	0.11	2.13
13	51.54	51.08	12.32	1.25	0.06	0.14	0.30	0.15	0.34	2.94	0.66	0.25	1.54

High Dd of basin indicates impermeable surface, thin vegetation and steep slope while low Dd values reflects the permeable surface, dense vegetation and flat relief. As per the result the Dd values ranges from 0.6 to 0.29 which indicates permeable sub-surface material with low to intermediate drainage and relief.

Stream frequency is the ratio of the total number of streams of all orders to the total area of the basin. Generally, it is the lithology of a watershed, which primarily influences the stream frequency of any basin. The higher values of stream frequency are generally associated with the higher runoff and steeper slope, which indicate a high chance of the occurrence of flood in these areas. As per the result, stream frequency of various sub-watersheds of the KRB ranges between 0.158 and 0.05 and further details are shown in Table 3.

4.1.2.3. Length of overland flow and texture ratio. Length of overland flow (Lo) is the length of the water flow over the ground before it combines with the main stream and, is also expressed as half of reciprocal of the drainage density (Horton 1945). The lower the value of Lo, the faster the runoff from the streams (Rama 2014). In present case, the value of Lo varies from 0.3 to 0.14 with the mean value of 0.22, which indicate ground slope with moderate infiltration and runoff. Texture ratio (T) is defined as the ratio of first order streams segments to the perimeter of the basin (Horton 1932). Further, T of a basin is mainly influenced by the lithology, infiltration capacity and relief of the terrain. The higher value of the texture can increase dissection, which leads to more erosion and vice-versa. The values of texture ratio ranges between 0.158 and 0.05 and reflect low erosivity.

4.1.3. Shape parameters

4.1.3.1. Shape factor. Shape factor (Bs) is the ratio of square of basin length to the area of that basin. It reflects the shape irregularity of the drainage basin and, is inversely correlated with the form factor. In KRB, shape factor ranges from 2.9 to 4.10, which indicates the elongated shape of the basin. Form factor (Rf) is the ratio between the area of the basin to the square of that basin length and it varies from 0 to 1, however in general the values are found below 0.79 (for a perfectly circular basin) (Chopra et al. 2005). Lower value of form factor is associated with the increase in elongated shape of the basin. It may cause a lower peak flow for longer duration of time, while the higher value indicates more circular shape basin with higher peak flow in short interval of time. In present case, the values of form factor varies from 0.24 to 0.33, which indicates a high elongated shape of the basin and thus may take longer time duration for getting a peak flow.

Table 4. Calculation of compound factor and prioritized ranks.

Sub-Watershed	Rb	Dd	Fu	T	Lo	Rf	Bs	Re	Rc	Cc	Compound factor	Prioritised rank
1	10	6	2	4	6	7	7	7	9	5	6.5	5
2	12	1	11	11	1	11	3	11	3	10	7.4	9
3	11	8	9	9	8	4	10	4	6	8	7.7	10
4	9	4	5	2	4	5	9	5	11	4	5.8	3
5	1	3	3	3	3	6	8	6	12	3	4.9	1
6	6	11	13	10	11	3	11	3	2	12	8.2	11
7	5	2	10	13	2	12	2	12	4	11	7.3	8
8	8	7	7	1	7	1	13	1	10	2	5.4	2
9	3	5	8	7	5	2	12	2	1	13	6.0	4
10	7	9	4	5	9	9	5	9	8	6	7.1	7
11	4	10	1	6	10	8	6	8	5	9	6.7	6
12	2	12	12	8	12	10	4	10	7	7	8.3	12
13	13	13	6	12	13	13	1	13	13	1	9.7	13

4.1.3.2. Elongation ratio (Re). It is the ratio of diameter of a circle of the same area as the basin to the maximum basin length (Schumm 1956) and considered as one of the important parameter in understanding the assessment of basin shape. According to Strahler, these values range between 0.6 and 1.0 for a broad range of climatic and geological conditions (Strahler 1964). Lower value of this factor is associated with the elongated shape of the basin. In the present case, the values of elongation ratio lies between 0.55 and 0.65, which reflect the elongated shape of the sub-basins.

4.1.4. Compactness coefficient and circulatory ratio

Compactness coefficient (Cc) can be expressed as, basin perimeter divided by the circumference of a circle to the same area of that basin. It is quite opposite (inversely related) to the elongation ratio of a basin and is responsible for high erosions in the basin. Low value of compactness coefficient can be linked with the high elongated shape of the basin and hence less erosion. On the other hand, higher values indicate less elongated of the basin and therefore high erosion in the basin. It is observed that the values of compactness coefficient exhibit a variation from 2.89 to 1.535 as shown in Table 3.

Circularity ratio (Rc) is the ratio between the basin areas to the area of a circle having the same circumference as the perimeter of that basin. It is equivalent to 1 when the basin is perfectly circular, and it is lies between 0.4-0.5 when the shape is elongated and permeable. As per the calculations, the maximum circularity ratio can be seen in case of sub-watershed 13 (0.248) while the minimum is obtained for the sub-watershed 9 (0.05), which reflects the highly elongated shape of the basins.

4.1.5. Compound factor and prioritized ranks

In present case, a compound factor is used for the prioritization of sub-watershed in the KRB. For this, both shape and linear parameters are taken into consideration. Linear parameters are directly correlated to the erosion (higher the value, more will be the erodibility), whereas as in the case of shape parameters it follows an inverse trend. First, individual rank is assigned to both linear and shape parameters according to their parameters values and afterwards a compound factor is calculated by summing up all the parameters ranking divided by the number of parameters. From the final compound factor results, the first rank is assigned to the lower most value, and the last rank to the higher most value. In the present case, sub-watershed 5 was ranked first (4.9), followed by sub-watersheds 8 and 4 with second and third ranks, respectively. On the other hand, the

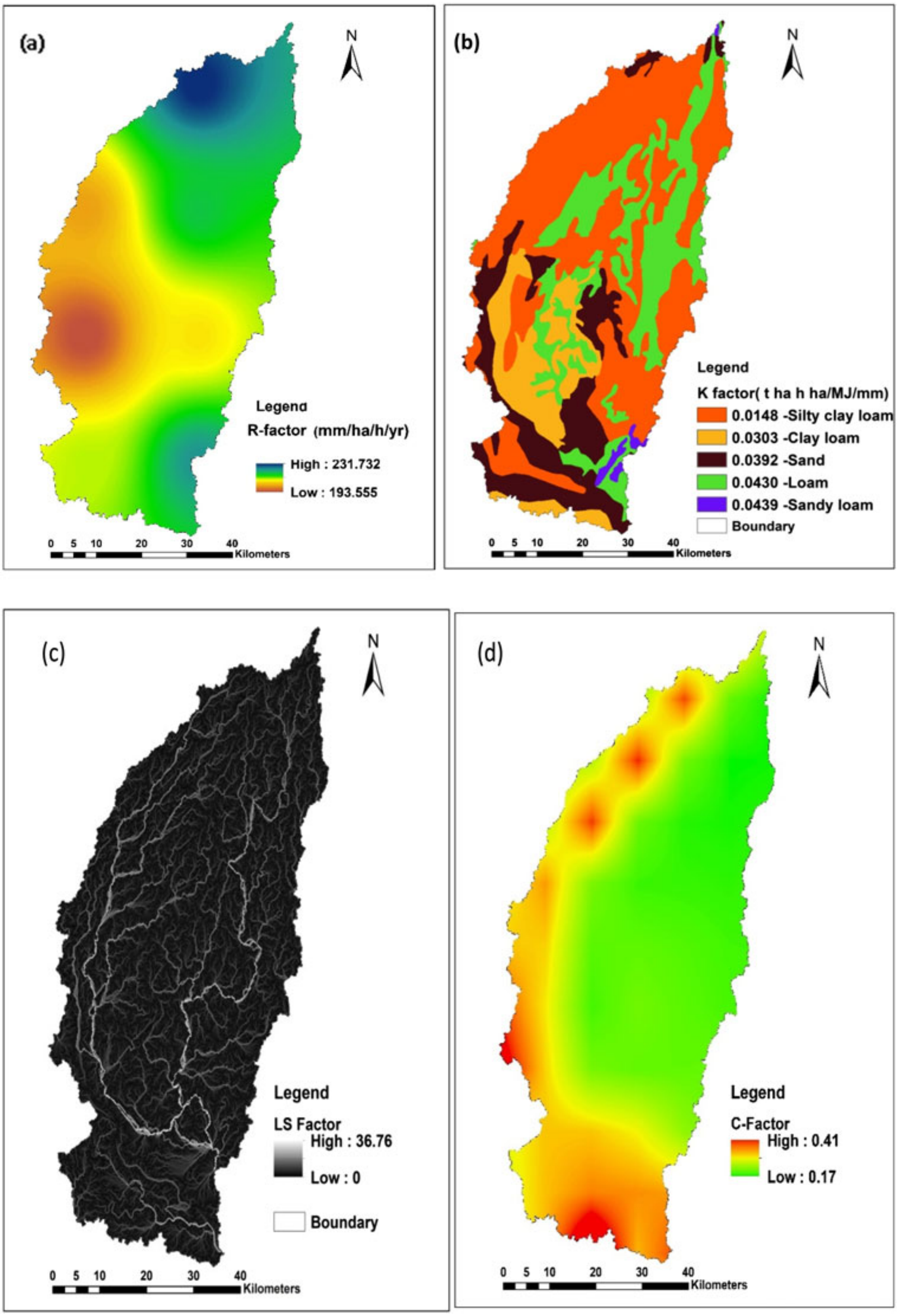

Figure 4. (a) R-factor (b) K-factor (c) LS-factor (d) C- factor (e) P-factor (f) Soil erosion.

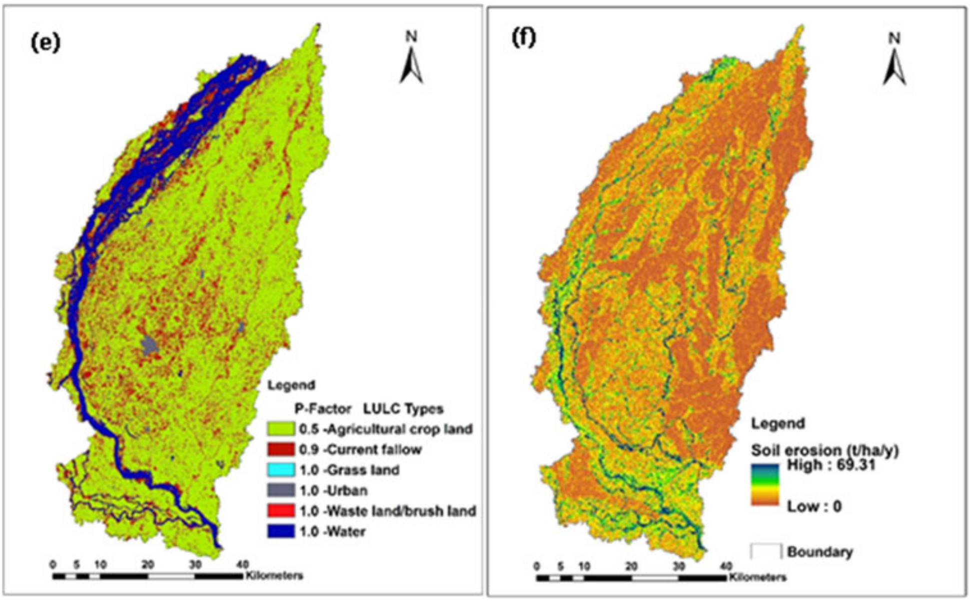

Figure 4. Continued.

sub-watershed 13 is having the last rank (9.7) and details are shown in Table. 4 and Figure 3(b).

4.2. Revised universal soil loss equation (RUSLE)

As per the result, R factor varies from 193.55 to 231.73 mm ha^{-1} $h^{-1}yr^{-1}$ and the generated R factor map is shown in Figure 4(a). It can also be observed from the Figure 4(a) that the maximum value of R is found in the Northern-Western parts. Clay loam, sand, silty clay loam, loam and sand loam are the dominant soil types found in the basin. The values K- factor lies between 0 and 1, where 0 represents less susceptibility to erosion and 1 indicates the higher chances of erosion. In KRB the estimated K- factor values varies from 0.0148 to 0.0439 t ha h $ha^{-1}MJ^{-1}mm^{-1}$and the texture of the soil varies from silty clay loam to sandy loam (Figure 4(b)). As shown in the Figure 4(c) the LS factor values in KRB are found up to 36.7 and the maximum values are found in the regions where the river forms deep valleys. The C-factor ranges from 0.17 to 0.41 and the values are shown through Figure 4(d). Figure 4(e) shows the land use-land cover types and their corresponding P-factor values. The values of the P-factor for various land cover types are taken from the literature, and the values of 0.5 assigned for agricultural/crop land, 0.9 for current fallow land and 1 for the water bodies, waste lands and grass lands (Naqvi et al. 2013). A P value of 0.5 is taken for KRB, as agricultural crops are dominant in the region. In contrast, P value of 1 is assigned to the streamlines and the water bodies.

Lastly, all the R, K, LS, C and P thematic layers of RUSLE are overlaid and multiplied for soil erosion assessment. The quantity of the annual soil loss from the RUSLE model showed a value of 69.315 t $ha^{-1}yr^{-1}$. It can be also observed from the Figure 4(f) that the actual soil loss is typically high along the steep slope and from the poor vegetative areas. Further, the prevailing high erosion prone sites are situated in central and southeast portion of the KRB. In overall, the majority of sub-watershed comes under low to moderate erosion category.

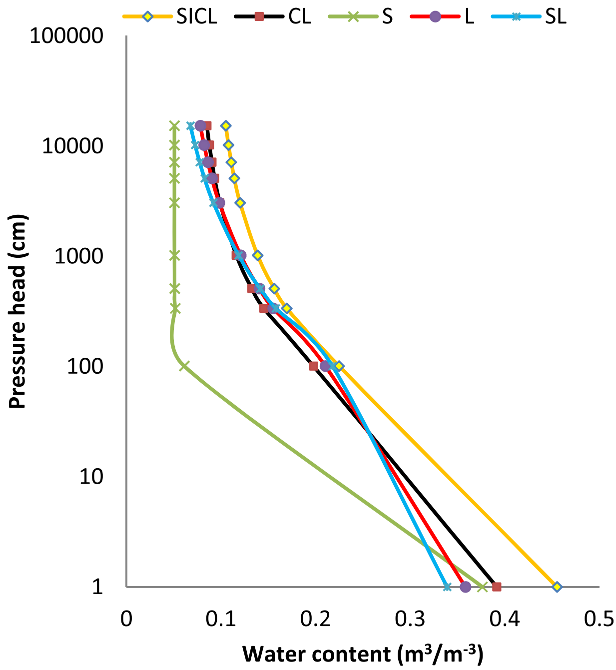

Figure 5. A schematic diagram of Water retention curve for different soil types of the Kosi River Basin.

4.3. Soil hydraulic parameters

The soil hydraulic properties are estimated using ROSETTA, based on the water retention curves (WRCs), which can be defined as the amount of water retained in a soil under a definite metric potential (Maurya et al. 2016). From the literature, −33 kpa is taken as a benchmark for the estimation of field capacity (Wösten et al. 2001). As per the result found silty clay loam shows the highest field capacity (0.169 m^3/m^3), followed by sandy loam (0.157 m^3/m^3), loam (0.155 m^3/m^3), sand (0.05 m^3/m^3) and clay loam (0.145 m^3/m^3). The soils with high field capacity retain and accumulate most of the rainfall on the surface and thus create high runoff leads to higher erosion. Figure 5 shows the water retention curve of the various soil types of the KRB.

4.4. Multicriteria evaluation (MCE) and prioritization of watershed

Three factors namely, compound factor, soil erosion from RUSLE and field capacity are integrated to prioritize the areas prone to soil erosion and subsequent conservation measures. Then, the AHP based MCE is used to assign weighting to each of the factors corresponding to their effect on soil erosion (Gupta and Srivastava 2010). Afterwards, to make sure that the weighting is consistent, the consistency ratio is calculated which is found to be 0.055, which is less than (<0.1) and hence indicates good consistency in the weighting assignment. Further, the rating factor varies from 1 to 9 in which 9 reflects higher influence on soil erosion and 1 for least or minimum influence on soil erosion (Maurya et al. 2016). As shown in Table 5, the highest normalised weighting is assigned to RUSLE factor (64.3), followed by compound factor (28.3) and field capacity (7.4). Finally an integrated map is prepared from the above three factors by using the weighted overlay tool of Arc GIS 10.1 spatial analyst extension and the resulted map categorised

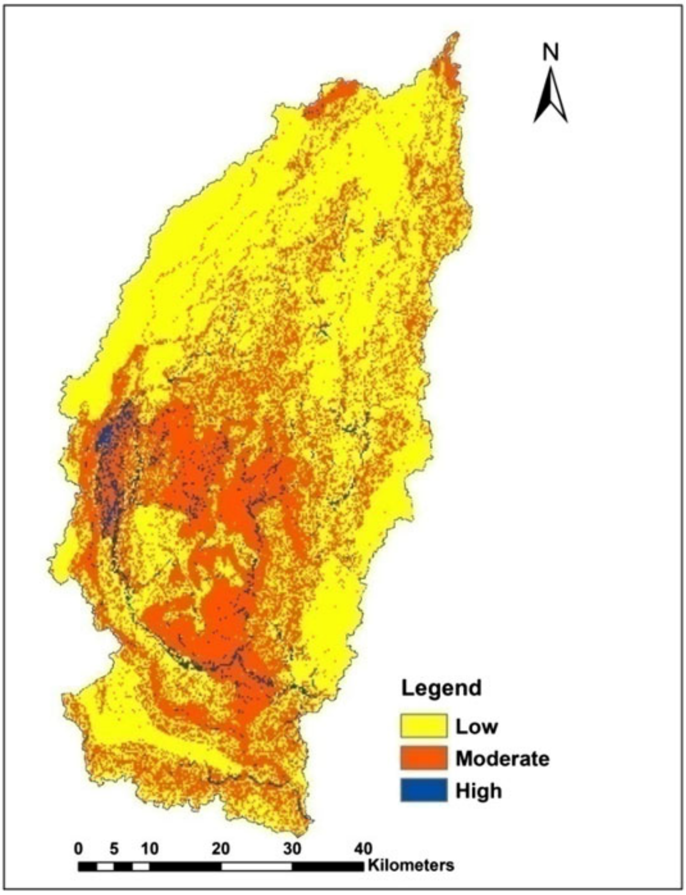

Figure 6. Prioritized map for implementation of conservation practices.

Table 5. Pair comparison matrix of features.

	RUSLE	Compound factor	Field capacity	Normalized weight
RUSLE	1	3	7	64.3
Compound factor	1/3	1	5	28.3
Field capacity	1/7	1/5	1	7.4
CR	0.055			

Table 6. Area distribution of soil erosion severity classes in KRB.

Classes	Area (km^2)	Area (%)
Low	2360.59	59.28
Moderate	1516.30	38.08
High	104.64	2.62

into three zones namely: Low, Moderate and High erosion (Figure 6). The result presented in Table 6 shown that out of 3981.53 km^2 about 2360.59 km^2 (59.2%) falls under low category, whereas 1516.1 km^2 in moderate and the rest of 104.2 km^2 (2%) in the high erosion categories. As per the result found the sub-watershed number 5, 8 and 7 are falling under the high priority regions and hence need utmost conservation measures to check the soil and water loss in these watersheds. Whereas the remaining sub-watersheds fall under moderate to low priority categories. Although the moderate and high category areas represent relatively small proportion compared to the total area, these are still important to check the loss of fertile soil and control floods in KRB.

5. Conclusions

The mappings of soil erosion prone area for conservation of soil and water management studies are in demand and implemented in the recent years. The current study is carried out in the KRB to assess the annual average soil loss and its spatial pattern over the basin for the detection of high soil erosion prone sites by integrating the RUSLE output, compound factor, and field capacity through the AHP-MCE technique. This study also reveals the application of GIS and remote sensing in soil erosion modelling and prioritization erosion prone regions. As per the result it is observed that the estimated annual average soil erosion of KRB is up to 169.34 t ha^{-1} y^{-1}. Finally, from the result, it is concluded that sub-watershed 5, 8 and 7 required utmost attention for the conservation practices because of high erosivity characteristics. The study indicates that the methodology is useful and cost effective for the regions where financial resources and labour are limited. Therefore, prioritization of sub-watershed according to their vulnerability will assist in determining conservation measures so that maximum benefit can be obtained from the limited resources. This type of approach provides a new approach for an effective management and planning for water resources, siltation and flood control of any basin. The outcome from the study can be utilised in implementation of effectual conservation measures to reduce the high runoff and soil erosion and can be used by hydrologist, disaster monitoring, management and mitigation agencies and policy makers.

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