Soil erosion risk assessment in a humid sub-tropical trans boundary river basin

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Abstract

Soil erosion is a challenging natural environmental hazard which is not possible to stop yet, can be reduced by conservation practices. Here, for these issues, we have applied Revised Universal Soil Loss Equation (RUSLE) and Soil and Water Assessment Tool (SWAT) model to assess soil erosion in Ghaghara river basin. We have estimated morphometric parameter to understand susceptibility of sub-basin for soil loss. The result of soil erosion estimated by RUSLE is 287.13 t 〚h_a〛 ^(-1) yr^(-1) and by SWAT is 338.65 t 〚h_a〛 ^(-1) yr^(-1) in study area. Water retention curve of soil using hydrous model and hypsometry of basin using QGIS were estimated to know water holding capacity of soil and geomorphic age of basin respectively. The results of water retention curve showed that Clay_Loam (Bd29-3c-3661) Loam (I-Bh-U-c-3717) and Clay_Loam (Rd30-2b-3851) were showing highest water holding capacity as (0.317 m^3/m^3), (0.311 m^3/m^3) and (0.271 m^3/m^3) in the study area respectively. The final prioritized map generated by integration of SWAT, RULSE, water holding capacity and morphometric results showed that upper and middle portion of basin need higher conservation measures to control soil erosion compared to lower portion of basin. The hypsometry of basin indicates the sub-basins age from young to mature stage due to subsequent soil erosion in upper and middle portion in basin.

Abstract

Soil erosion is a challenging natural environmental hazard which is not possible to stop yet can be reduced by conservation practices. Here, for these issues, we have applied Revised Universal Soil Loss Equation (RUSLE) and Soil and Water Assessment Tool (SWAT) model to assess soil erosion in Ghaghara river basin. We have estimated morphometric parameter to understand susceptibility of sub-basin to soil loss. The result of soil erosion estimated by RUSLE is $287.13 t{h_a}^{-1}\mathrm{yr}^{-1}$ and by SWAT is 338.65 $\mathrm{t}{h_a}^{-1}\mathrm{yr}^{-1}$ in the study area. Water retention curve of soil using hydrous model and basin hypsometry using QGIS are analyzed to know water holding capacity of soil and geomorphic age of the basin respectively. The results of water retention curve show that Clay_Loam (Bd29-3c-3661), Loam (I-Bh-U-c-3717) and Clay Loam (Rd30-2b-3851) are showing highest water holding capacity as $(0.317 m^3/m^3)$, (0.311 m^3/m^3) and (0.271 m^3/m^3) in the study area respectively. The final prioritized map generated by integration of SWAT, RULSE, water holding capacity and morphometric results show that upper and middle portion of basin need higher conservation measures to control soil erosion compared to lower portion of basin. The hypsometry of basin indicates the sub-basins age from young to mature and old stage due to soil erosion in basin.

Keywords: Morphometry, RUSLE; SWAT; Hydrous; Hypsometry, Soil erosion

Introduction

Natural and anthropogenic process detach top surface of the soil and enhance soil erosion (Parveen et al. 2012). The natural resources and agricultural production are severely affected by rapid action of soil erosion.

The topography, rainfall dry periods, inept land use (Kumar et al. 2018) and natural calamities are various factors that determine speed and process of erosion in a basin (Gitas et al. 2009). Kosmas et al. (1997) elaborated that basic properties of soil-layer (upper soil thickness, silt and organic matter percentage) are also responsible for severe erosion. Li et al. (2016) explained that climate change directly alter trend and pattern of rainfall and consequently due to intense rainfall, rate of runoff increases and accelerate soil erosion.

Rivers originating in Himalayan and Tibetan plateau supply almost 25% sediment load (Raymo and Ruddiman 1992). The lower part of Himalayan sub-basin are now facing these problems (Jain et al. 2001). The Shivalik formation (lower Himalaya) which is source of Ganges river system, has weak geological combinations and thus, susceptible to degrade. Therefore it is vital to understand soil erosion which will help to control the erosion and ecological restoration. Currently, application of remote sensing (RS) and geographic information system (GIS) is most appealing tool for hydrological complex problems (Murmu et al. 2019; Rawat et al. 2019; Choudhari et al. 2018; Yadav et al 2018; Kumar et al. 2018; Thakur et al. 2016; Szabo et al. 2015; Yadav et al. 2014). RS and GIS techniques have been implemented in various available erosion models which predict soil loss (Brady et al. 2008). The USLE (Wischmeier and Smith 1978), CREAMS (Knisel et al. 1980), AGNPS (Young et al.1989), RUSLE (Renard et al. 1991), and MUSLE (Williams et al. 1975) are empirical models while MMF (Morgan et al. 1984), EUROSEM (Morgan et al. 1992), GUEST (Ciesiolka et al. 1995); LISEM (De et al. 1998); WEPP (Laen et al. 1991) and SWAT (Arnold et al. 2012) are the various physical process based model.

Among these models, empirical model RUSLE and hydrological model SWAT are more robust for analysis of water induced soil erosion (Mosbahi et al.2012; Bieger et al.2015; Briake et al.2019). SWAT is an internationally accepted hydrological model which has been applied almost over the 100 countries for sediment yield, surface runoff, water quality, climate change and agricultural issues (Spruill et al. 2000; Borah and Bera 2004; Zhang et al. 2010; Boini et al. 2015; Kumar et al. 2017; Kumar et al. 2018). Shaikh et al. (2018) apply RUSLE and SWAT for soil erosion in Aurangabad region of Maharashtra, India. Jain et al. 2001 estimated soil erosion in Himalayan sub-basin using empirical model USLE. Also RUSLE has been successfully applied to worldwide in different regions for the assessment of soil erosion (Koirala et al. 2019; Chaliseet al.2018; Tiwari et.al.2015; Jien et al.2015; Ganasriet al.2014; Rosewell 1996). The RUSLE and GIS interface has several advantages and has shown good results to model soil loss (Perovic et al. 2013; Adediji et al. 2010).

Although various researches have been done excellent research to predict soil erosion (Panagos et al. 2019; Koirala et al. 2019; Panagos et al. 2015a, b; Uddin et al. 2015; Waikar et al. 2014; Das 2014; Borrelli et al. 2013) yet some attention was left toward those region which have complex topography like river system of Himalayan region.

The overall goal of the study was to assess the spatial distribution of soil erosion in a humid subtropical river. The objectives to fulfill the goal were (1) to address soil loss using erosion models RUSLE and SWAT; (2) to point out relevance of water retention of soil types in erosion processes; (3) to get the prioritized erosion zones in Ghaghara river basin for conservation practices; (4) to determine efficiency of hypsometric analysis for recognition of basin age due subsequent soil erosion in basin.

2. Materials and methods

2.1. Study area

The Ghaghara River is a trans-boundary river also known as Karnali in Nepal (Figure 1). The perennial Ghaghara River originates near to Lake Mansarovar (30.60° N, 81.48° E) with catchment area 127950 km^2 and meets with its tributaries Sarda at Brahmaghat in India form where it is known as Ghaghara River. The Ghaghara River Km^2 joins to Ganga at Dorigang situated at the downstream of Chhapra town, Bihar. The other important tributaries of the Ghaghara River are Sarju, Rapti and Little Gandak. There are two streams, Seti River and Bheri River which drains Ghaghara River in Nepal. The river basin is heterogeneous form source to mouth and having longest distance river in Nepal (~507 km). The dominant land use type is crop land followed by mixed forest and grassland. The quaternary age sediment are dominant in the basin as Pleistocene age older alluvium (yellow to brown color) and Holocene age newer alluvium (gray to black color). The soil types are mostly clay-loam, loam and glacier type. The geomorphology of Ghaghara River contains structural origin highly, moderately and low dissected hills and valleys. In alluvial plains Ghaghara shows meandering pattern with several oxbow lakes. The Ghaghara is a humid sub-tropical river basin having 1041 mm (annual) average rainfall. The distribution of temperature is 47*C (max.) in summer to 2*C (min) in winter. The higher elevation zone is occupied by northeast and northwest while lower elevation zone occupy their position in lower alluvium zone (Southeast).

Figure 1 : Location map of Ghaghara river basin showing maximum and minimum elevation with major streams

Ghaghara is a unique river with respect to fluctuation of

discharge (Very high discharge during monsoon and very low discharge during dry sea-

son), high sediment load, and channel instability. It has higher discharge than the Ganga

before its confluence near Maharajganj, Chhapra district of Bihar

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2.2. Methodology

The estimation of erosion in Ghaghara basin was calculated using a Digital Elevation Model (DEM), soil map and land use/land cover (LULC) map. These datasets have been used as inputs in SWAT and RUSLE models for estimation of soil loss. The DEM was also used in the morphometric analysis of basin and while soil was used in calculation of water holding capacity of soil. Meteorological datasets were used as weather information for SWAT (https://swat.tamu.edu/). Besides these, to know the erosional stage of the basin, the Calhypso tool in QGIS was used to assess the geomorphic stages of basin. The process of work can be seen in the methodology chart in Figure 2.

Figure 2 : Adopted methodology for assessment of soil loss in Ghaghara river basin

2.2.1. Topographic data

We used the DEM for the elevation data having 3 arcs second (approx.90m form SRTM) resolution. The pre-procedures before using DEM like fill, flow direction, flow accumulation and then stream definition were performed using the D-8 algorithm by Archydro tool. The variation in the topography ranges from 7707 m (max) to 36 m (min) in the basin (Figure 1). DEM was used to delineate the basin using semi-distributed model SWAT for the analysis of spatial variation of input and to create the slope map for the study.

2.2.2. Soil types and Meteorological data-sets

Soil map for the study region has been prepared using the Food and Agriculture Organization (FAO) soil data-sets having 90 m resolution. The classes extracted from soil data in the study are CLAY_LOAM (Bd29-3c-3661), LOAM (Bd34-2bc-3663), LOAM (Bd35-1-2b-3664), LOAM (Be74-2a-3675), LOAM (Be84-2a-3685), LOAM (Bk39-2a-3694), LOAM (Bk40-2a-3695), LOAM (I-Bh-U-c-3717), LOAM (I-X-2c-3731-LO), LOAM

(Jc50-2a-3743), LOAM (Je75-2a-3759), CLAY_LOAM (Rd30-2b-3851), GLACIER-6998. Among these soil classes LOAM (Be84-2a-3685) is dominant soil type with 41275.25 Km^2 (32.12 %) followed by CLAY_LOAM (I-Bh-U-c-3717) and LOAM (Bd34-2bc-3663). The lowest coverage area soil is LOAM (Be74-2a-3675) having 27.56 Km^2 Km^2 of total area (Table 1). These soil information has been used in the RUSLE and SWAT as input.

The Meteorological data-sets as precipitation, temperature (max/min), relative humidity, solar radiation and wind speed were used as input data-sets in SWAT model to estimate the sediment yield. The rainfall was used in empirical model RULSE for calculating the rainfall-runoff erosivity factor (R).

2.2.3. Land use/land cover (LULC)

The LULC map from Modis (https://archive.usgs.gov/archive/) of 0.5Km resolution was for the basin to see the HRU (Hydrological Response Unit) level information. We have distinguished 15 LULC types: water, evergreen needle and broad leaf forest, deciduous needle and broad leaf forest, mixed forest, shrubland, savanna, grassland, wetlands-mixed, agricultural land, built-up, cropland/woodland mosaic, snow or ice and barren or sparsely vegetated. The cropland is the highest covering land use followed by mixed forest and grassland while the lowest covering land use is the deciduous needle leaf forest (Table 3 & Figure 3).

Figure 3 : Land use land cover map showing land use distribution in the study area

2.2.4. Estimation of morphometric parameters

The entire region was delineated into 30 sub-basins for detailed and sub-basin level morphometric analysis. The basic, linear and shape morphometric parameters (Table 2) were estimated using the stream order generated during the delineation of basin using DEM. The method used for the ordering of the streams was the developed by the Strahler (1964). The number of streams (N) of different order, stream length (Lu), area (A), perimeter (P), basin length ($L_b L_b$) are the basic parameters (Table 4). The Strahler (1964) suggested the smallest and un-branched streams are the 1^{st} order stream and when two 1^{st}order streams confluence, generates2^{nd} order stream and when two 2^{nd}order streams join they form 3^{rd}order and so on. Following the rule suggests by the Strahler (1964) when two different order streams join together then the higher order will be counted.

The total length of an individual stream in each order is the stream length (L_u) of that order (Horton 1945). The drainage area (A) is the total area where the fluvial generated stream or systems of streams are drained in the corresponding space (Table 4) and this area provides more detailed information about the basin. The linear morphometric parameters and other basin parameters such as the total runoff and sediment load can easily understand and estimated using the drainage area (A) help (Pradhan et al. 2018). The water divide is the ridgeline which separates two drainage basins and the horizontal projection of water divide is the perimeter (P) (Zavoianu 1985). The basin length (Lb) is the longest dimension of that basin along the main channel from the sub-basin outlet (river mouth) to sub-basin boundary point which is farthest point on the basin divide. Further this morphometric parameter help to calculate the other linear parameters like form factor, shape factor and elongation ratio. Here method used to calculate the basin length was developed by Ratnam et al. (2005).

Stream length ratio(R_L), bifurcation ratio(R_b), drainage density(D_d), stream frequency(S_f) and length of overland flow (L_oLo) are the linear parameters (Table 5). These linear parameters were calculated using the basic parameters information. The R_L is dimensionless ratio which is simply ratio of stream length and this method was proposed by Horton (1945). The (R_b) is the ratio of stream number and formula used her to calculate the(R_b) is given by Schumm (1956). Horton (1945) described the (D_d) as ratio of stream and area of a sub-basin and(S_f) as ratio stream number and area a sub-basin. Horton (1945) explained the length of overland flow (L_o) as one half of the drainage density of the sub-basin.

Furthermore, the shape parameters are form factor (F_f), elongation ratio ($R_e R_e$), circulatory ratio ($R_c C_r$), shape factor ($B_s B_s$), compactness constant ($C_c C_c$) has been tabulated in the Table 5. The definition of the (F_f) was proposed by the Horton (1945), which is the ratio of area (A) to square of the basin length (${L_b}^2$).

The (R_eR_e) was estimated using the formula given by Schumm (1956) and is ratio of diameter of a circle having the same area as of the basin and the basin length (Table 2).

The (R_cC_r) given by Strahler (1964) is the ratio of basin area (A) to the square of basin perimeter for which the area is calculated (Table 2). The (B_sB_s) was estimated following the Horton (1932) rule and it is the ratio of square of basin length (${L_b}^2$) to area (A) of that basin. The (C_cC_c) is the proposed by Horton (1945) and also expressed by Gravelius (1914) as ratio of basin perimeter (P) divided by the circumference of a circle which has same basin area (A).

The linear and shape parameters were used to estimate the compound factor and then prioritization of sub-basin.

2.2.5. Compound factor and prioritization of sub-basin

The linear and shape parameters of morphometry play important role to prioritize the basin and to compute the compound factor. The linear parameters (Table 5) are directly concerns to erosion activity and this means that the higher values of linear factor in a sub-basin explain the high degree of erosion for that area. While the shape parameters have opposite concern to the linear parameters and therefore the sub-basin having lower value of shape factor indicates the higher erosion in that area. Therefore for our study area rank 1 is given to the sub-basin which has higher value of the linear parameters and lower value of the shape parameters and rank 30 is given to the sub-basin which has lowest linear and highest shape factor and so on (Table 6). The compound factor has been estimated by the addition of the all rank of shape and linear parameters and after this we have divide the total sum by total no of parameters (Table 6). Using results of compound factor, prioritization of sub-basin is done by giving first rank to the sub-basin which has lower value of compound factor and similarly last rank is assigned to the sub-basin which has higher value of compound factor (Maurya et.al. 2016).

2.2.6. RUSLE model

RUSLE is an advanced form of the USLE developed by Wischmeier and Smith (1978). This model was used around the various places to estimate the erosion of the upper surface soil due to rainfall and other factor such as soil and slope (Maurya et al. 2017).

The equation of the RUSLE is given as follows:

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

Where A: annual sediment yield (t $ha^{-1}y^{-1}$); R: rainfall erosivity factor ($MJmmha^{-1}h^{-1}y^{-1}$); K: soil erodibility factor ($thahha^{-1}MJ^{-1}mm^{-1}$); LS: slope length and steepness factor; C: cover management factor (C); P: conservation practice factor$A = R \times K \times LS \times C \times P$

LS, C and P are the dimensions less factor.

The R factor was estimate using the monthly rainfall and the formula for this was given by McGarigal (2002). The K-factor was calculated using the soil properties and sand, silt, clay and organic carbon using the Sharpley and Williams (1990) formula. The slope length (L) and steepness factors (S) together constitute the topographic factor was calculated using the SAGA GIS and formula given by the Desmet and Govers (1996). The value of C- factor was assigned by choosing representative values of C from tables 5, 10, and 11 in Wischmeier and Smith (1978). Here the value of P was selected using the land use /land cover map and from the published sources (Jain et. al. 2000; Liu et.al.2015; Renard et al. 1997.). Finally, the all RUSLE factors are multiplied in order to determine soil loss in Ghaghara river basin.

2.2.7. SOIL WATER ASSESSMENT TOOL (SWAT)

SWAT is a physical process based hydrological model which is semi-distributed and depicts the LULC and climate change impact on hydrological cycle. The more detailed information about the SWAT model can be find out form the SWAT database (https://swat.tamu.edu/). The basic equation used in SWAT model is as follows

$\mathrm{Sw}_t = \mathrm{Sw}_0 + \sum_{i=1}^{t} \left(R_{\mathrm{day}} - Q_{\mathrm{surf}} - E_a - W_{\mathrm{seep}} - Q_{\mathrm{qw}}\right)$(Eq. 6)

Sw_t : *final soil water* ; Sw_0 : *Initial soil water*; $\mathrm{R_{day}}$: precipitation; $\mathrm{Q_{surf}}$: surface runoff; $\mathrm{E_a}$: evapotranspiration, $\mathrm{Q_{gw}}$: return flow; $\mathrm{W_{seep}}$: water entering the vadose zone from the soil profile; Units are mm at each parameter.

The SWAT model used here for calculation of soil erosion at sub-basin scale to see the distribution of sediment yield for the whole basin.

2.2.8 ROSETTA Model

The ROSETTA from hydrous model was used to calculate soil hydraulic properties for the Ghaghara river basin. The water retention curve was prepared using ROSETTA and this curve describes about the water holding capacity of soil under differential pressure head (Maurya et al. 2016). The hydraulic parameters of the soils are essential to study water resources and but usually, these data are not available in the appropriate scale (Schaap et al. 2001). ROSETTA is a commonly used software to achieve the hydraulic parameters of the soil from the sand, silt and clay proportional values (Pradhran et al. 2018). The ROSETTA model applies the hierarchical Pedotransfer Functions (PTFs) and a neural network algorithm with bootstrapping (Schaap et al. 2001). The hierarchy in Pedotransfer Functions (PTFs) allows ROSETTA model to predict Van Genuchten (1980) water retention curves. The formula for the water retention curve is as follows

$\theta_h = \theta_r(\mathit{residual\ water\ content}\ ) + \frac{[\theta_{\varsigma}\ - \theta_r\ ]}{(1+(\alpha\eta)^n)^m}$(Eq.5)

Where $\theta\,(h)$ is the water content $(\frac{\mathrm{cm}^3}{\mathrm{cm}^3})$ at soil water pressure head h (cm) and α is the scaling parameter, n is the curve shape factor and$m = 1 - 1/n$;θ_{s} : *saturated water content*θ_r : *residual water content*

There are 33 kPa and 1500 kPa pressure head (H) are defined in the ROSSTEA model for the preparation of the water retention curve using the sand, silt and clay value of soil. The 33 kPa indicate the upper limit of water availability by plants known as field capacity and whereas the 1500 kPa indicates the lower limit of water availability by plants known as wilting point respectively (Adhikary et al. 2008). We have estimated the field capacity of soil at 33 kPa for the all soil types occurring in the study catchment.

2.2.9. Multi-Criteria Evaluation (MCE) and Weighting Assignment

Multi-criteria evaluation (MCE) is a 5 step pair-wise comparison relation process as (i) pair wise ranking, (ii) decision matrix, (iii) Eigen value/vector, (iv) consistency ratio and (v) priority of criteria. Gupta and Srivastava (2010) explain the MCE which is AHP based to assign the weighting of each factor keeping the view that which parameters is most influencing to soil erosion and which parameters has least importance to cause the soil erosion in the basin. In the MCE which support the multi-criteria decision making and developed by Saaty (1980), ranking ranges 1 to 9 where 1 indicate less important parameter and 9 refers to most responsible factor for soil erosion (Saaty et al. 1980; Srivastava et al. 2012). The ratio scales were generated using paired comparisons of criteria in AHP with some inconsistencies in judgments. Then, priorities (weightings) of criteria and a consistency ratios are calculated (Goepel et. al. 2018). The priorities (weightings) of the criteria is derived using the principal eigenvector (e) of the matrix M, as follows

$M_e = \lambda_{\max} \times e\ldots\ldots\ldots\ldots\ldots$(Eq.7)

According to Saaty (1980) the value of consistency ratio = $(CR) \leq 0.1$. The CR can be estimated using the following formula given below.

$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}}\ldots\ldots\ldots\ldots$ (Eq.8)

$\mathrm{CI} = \frac{(\lambda\max - n)}{(n-1)}\ldots\ldots\ldots$ (Eq.9)

Where λmax = largest eigen value and e= principle eigen vector

$$CI = \text{(Consistency index)}\,,\quad RI = \text{(Random Inconsistency)}$$

Where, n is the number of variables.

2.3.0 Final prioritized Map

Further results from the SWAT, field capacity (water holding capacity), compound factor and RUSLE were used to generate an integrated map to see the distribution of erosion pattern in the basin. The integrated map was prepared using the above four factors and weighing overlay method on the GIS platform. Final erosion map was classified into five zones to the erosion variability in the region as very low, low, moderate, high and very high zone in respect of erosion.

2.3.1. Hypsometry of sub-basins

The hypsometry simply relates to the measurement of land elevation which aims to develop a dimensionless ratio of cross section area of basin to its elevation (Dowling et al. 1998). Strahler (1952) stated that the hypsometric analysis could be useful to identify the erosion status at different level. The hypsometric integral (HI) and hypsometric curve (HC) are the two special outcome of the hypsometry which serves as indicator of sub-basin condition (Ritter et al. 2002). The HI and HC have calculated using the DEM with QGIS (QGIS Development Team, 2019) using the Calhypso extension for the hypsometry at basin and sub-basin level. The basic method behind the calculation of hypsometric integral (HI) is given by Pike and Wilson (1971) which is simply an elevation-relief ratio. The following relationship is as given below:-

$HI = (\text{Elev}_{\text{mean}} - \text{Elev}_{\text{min}})/(\text{ Elev}_{\text{max}} - \text{Elev}_{\text{min}})$.................... (Eq.9)

WhereElev$_{\text{mean}}$: weighted mean elevation of the sub-basin; Elev$_{\text{max}}$: Maximum elevation within the sub-basin; Elev$_{\text{min}}$: Minimum elevation within the sub-basin.

4. Results

4.1. Morphometric analysis and prioritization of sub-basin

The results of morphometric analysis showed total fifth order of streams (1$^{\text{st}}$ order to 5$^{\text{th}}$ order) for quantitatively evaluation of basin and also to interpret the morphodynamic characteristics (Table 4 and Table 5). The highest number of streams (465) was occupied by the 1$^{\text{st}}$ order stream while the lowest number (46) by the 5$^{\text{th}}$ order stream (Table 4). Among the sub-basin, maximum 64 streams were lied in the sub-basin 18 while minimum 7 streams were lied in the sub-basin 30. The results showed that 1$^{\text{st}}$ order streams were of smaller length stream but their total length were greater than other higher order streams for each sub-basin (Table 4). The sub-basin 18 was occupied by the higher stream length (1186.93 Km) while 30 sub-basin occupied by the lower stream length (117.56 Km). The sub-basin 18 had highest drainage area (9240.95 km^2) while the sub-basin 30 had the lowest (958.71 km^2) drainage area (Table 4). The highest (1240 Km) and lowest (349.76Km) value of perimeter was found in sub-basin 18 and sub-basin 30 respectively (Table 4). Similarly the basin length (L_b)was highest (234.67Km) for the sub-basin 18 and lowest (64.79 Km) for sub basin 30.

The R_L value for the basin was ranged from 5.513 (max.) to 0.524 (min.) for the sub-basin 25 and 1 respectively (Table 5) whereas the value of R_b ranged from 4.392 (max) to 1.205 (min) for the sub-basin 13 and 28, respectively. The overall R_b for the basin was 1.821 (Table 5). The other linear parameters as Dd was varied over 0.182 (max) to 0.072 (min) for sub-basin 25 and 6, respectively while the Sf showed maximum value (0.012) for the sub-basin 28 and minimum value (0.005) for sub-basin 23 and 24. The value of L$_{\text{o}}$was max (0.091) for sub-basin 25 and min (0.036) for sub-basin 6.

The results of shape morphometric parameters showed that form factor(F_f) was varied from 0.228 (maximum) to 0.168 (minimum) for sub-basin 30 and 18 while elongation ratio (R_e) was 0.539 (max.) to 0.462

(min.) for the sub-basin 30 and 18 (Table 5). The circulatory ratio (R_c) was ranged from 0.288 (maximum) to 0.058 (minimum) for sub-basin 17 and 28 while the shape factor was from 5.959 (maximum) to 4.379 (minimum) for the sub-basin 18 and 30. The Compactness factor (C_c) for study area varied from 4.158 (maximum) to 1.864 (minimum) for the sub-basin 28 and 17.

The prioritization for Ghaghara river basin was done and sub-basin 19 was assigned as first rank following sub-basin 13 and 9 and while the last rank was assigned to sub-basin 26 (Table 6).

RUSLE and Semi-distributed (SWAT) model

The rainfall-erosivity factor (R) estimated for Ghaghara River was ranged from 298.8 (northeast and north-west part of basin) to the 11171.8 MJmmha^{-1}h^{-1}y^{-1}(middle and lower part of basin) (Figure 4).

Figure 4: Rainfall-runoff erosivity (R) factor map in the study area

The range of the soil erodibility factor (K) lies between zero to one, where K-factor near to 0 express the less susceptibility to erosion and k-factor near to 1 represent the higher susceptibility. The value of K-factor (Figure 5) estimated for the basin ranges 0.014 to 0.022 ($th_a hh_a{}^{-1}$MJ^{-1}mm^{-1}). The upper portion of basin was occupied by lower k-factor while middle and central portion was occupied by the higher erodivility factor in the basin.

Figure 5: Soil erodibility factor (K) map in the study area

The value of LS-factor for basin varied over 0.03 to 128 in the Ghaghara river basin. The higher value of LS –factor was augmented by the upper portion of basin and while lowest value of LS –factor lied in middle and downstream portion of the basin (Figure 6).

Figure 6: Topographic factor (LS) map showing high and low value of LS-factor in the study area

The cover management factor (C-factor) in Ghaghara river basin ranged from 0 to 0.2. The higher value of C-factor was found in the central and lower region of the basin while upper part of basin was occupied by the lower value of C-factor in basin (Figure 7).

Figure 7: Cover-management factor (C) in the study area

The P-factor value in Ghaghara river basin ranged from 0 to 1 (figure 8). The lower central portion the basin was occupied by the moderate p-factor value. The upper portion was mostly showed the higher value of p-factor nearly 1 or close to 1 but some portion of upper part of the basin was also occupied by the lower or 0 p-factor value in the basin.

Figure 8: Support practice factor (P) in the study area

The soil erosion estimated by multiplication of five RUSLE factors shown minimum and maximum value of soil loss as 0.11 to 287.13$th_a{}^{-1}$yr^{-1} respectively (Figure 9). The result of RUSLE showed that the northern portion of basin depicted the higher soil loss including some south-east portion of basin where the rainfall erosivity (Figure 4) was maximum. The central and lower portion of the basin was showing the lower soil loss including some upper north-west parts of the basin.

Figure 9: Soil erosion estimated in the study area using RUSLE model

The sediment yield estimated by using SWAT showed the variation in soil erosion over entire basin. The Higher value (338.65.8$th_a{}^{-1}$yr^{-1}) of soil loss was shown by the upper portion of the basin whereas the central and lower portion showed the lower soil erosion (from 0.16$th_a{}^{-1}$yr^{-1}) in the basin (Figure 10).

Figure 10: Soil erosion estimated in the study area using SWAT model

Soil hydraulic parameters

Table 8 showed water holding capacity of soil types in Ghaghara river basin. The soil CLAY_LOAM (Bd29-3c-3661) is showing the highest value of field capacity (0.317 m^3/m^3) while the LOAM (I-Bh-U-c-3717) and

CLAY_LOAM (Rd30-2b-3851) has the 2nd rank (0.311 m^3/m^3) and 3rd rank (0.271 m^3/m^3) respectively. The other soil types (Table 8) showed moderate to lower capacity while lowest rank was accounted by GLACIER-6998 (0.059 m^3/m^3) (Figure 11).

Figure 11: A schematic diagram of water retention curve for different soil types in Ghaghara river basin

Multi criteria evaluation (MCE) and final prioritized map

Here for the Ghaghara river basin in order to use the MCE based methodology, four factors (SWAT model result of sediment yield, compound factor from morphometric analysis, erosion of soil from RUSLE and filed capacity (ROSETTA) from soil) have been constituted. MCE is applied to these factors to schedule soil erosion prone zone in the entire basin and so that subsequent conservation measures can be applied. Following the procedure of AHP based MCE, the estimated consistency ratio is the 0.05 which is less than 0.1 which according to Saaty (1980) is considered good and acceptable. The above four factors was explained by their decision matrix and priority criteria (weighting) using the MCE (Table7). The highest weighting was given to SWAT model (47.1%) followed by RUSLE (34.6%) whereas the compound factor (12.6%) and field capacity (6.1%) have 3rd and 4th rank, respectively.

The result of final prioritized map (Figure12) showed that erosion activity in middle part of the basin ranges from low to very low (SB-18, SB-23, and SB-24). The middle northern and lower parts are showing moderate (SB-13, SB-22, SB-30) erosion while SB-1, SB-2, SB-3, SB-4, SB-6, SB-11 are showing high to very high erosion activity.

Figure 12: Finally prioritized map showing areas need for conservation practices in Ghaghara river basin

Hypsometric Analysis

Hypsometric parameters (HC and HI) of Ghaghara River were acquired at sub-basin level for the detailed analysis of mass movement (erosion) happening in the basin (Figure 13 and Figure 14). The HI values here were bifurcated into 3 zones to easily identify the erosion prone zone and these zones are as 0 to 0.3, 0.3 to 0.6 and above the 0.6 (Figure 13).

Figure 13: A schematic diagram showing Hypsometric Integral (HI) at sub-basin level in the study area

The HI value of the sub-basin 0.3 means that the 30% of original rock mass still exist in that sub-basin. The HI value of the Ghaghara ranges from 0.032 (min) for the sub-basin 22 to 0.664 (max) for the sub-basin 28. The rest of the sub-basins (almost 50%) are showing almost value between 0.3 to 0.6 while others are below the 0.3 and few are above the 0.6 level.

Figure 14: Sub-basin wise hypsometric curve in Ghaghara river basin

Discussion

The relation of master streams with their joining tributaries is the drainage system which shows effect of topography on streams (Strahler 1957). Ghaghara River occupies more undulating structure from Himalayan chains (upper confluences) to Indo-Gangetic plain (downstream) which results occurrence of different drainage patterns. The upper parts have trellis pattern which is rectangular type (northern and north-east portion) while lower parts consume dendritic and sub-dendritic types. Strahler (1964) has explained method for ordering streams based on hierarchic ranking. For Ghaghara river total fifth orders of stream were analyzed where on increasing the order, the stream length is decreasing (Table 4). This inverse relation between stream order and stream length is an indicative of variation in lithology, moderately steeper slopping pattern and high altitude flowing streams (Singh et al. 2013). Sethupathi et al. (2011) describes roll of stream length in recognizing hydrologic properties (permeability) of rock. Small streams that are large in number follow the less permeable path while the longer streams of smaller counts follow more permeable zone. Waikar et al. (2014) explains roll of stream length for revealing surface run-off as small length streams are characterized in slopping area and therefore finer texture while the lager length streams are indicative of plainer zone. This is also happening in Ghaghara river basin where larger length streams are maximally dominated in plain area (lower and middle portion of basin). The relative capacity of rock to pass the fluid, discharge and erosion condition in a basin can also be estimated by taking ratio of stream length as suggested by Horton (1945) and which is stream length ratio (R_L). In Ghaghara basin sub-basin 25 has highestR_L value which is supported by permeable zone (almost sandy area) and gentler gradient than the sub-basin 1 which has the lowest $R_L$value and depict opposite condition of sub-basin 25 (Table 5 & Figure 15(a)).

Figure 15: (a) sub-basin wise stream length ratio in Ghaghara river basin

The above variation in the topographic condition due to R_L in basin is also supported by Vittala et al. 2004. There are basically two types of bifurcation ratio (R_b), one is low value and another is high value R_b. The low value R_b indicate those drainages which are not affected by the geologic constrains while high valueR_b is largely influenced by geologic constrains. Gajbhiye et al. (2014) stated that higher values of R_b is supported steeply sloping surface with narrow confined valley therefore higher chances of more runoff and less recharge in that area. In Ghaghara basin, sub-basin 13 and 17 have higher value of R_b (Table 5; Figure 15(b)) and these sub-basins are confines to the north-eastern part of basin proving steeply sloping surface with narrow confined valley.

Figure 15: (b) sub-basin wise bifurcation ratio in Ghaghara river basin

Nag and Chakraborty (2003) stated that low R_b has characteristics of less structural disturbances in that area and lower value $R_b$are confined to lower part of Ghaghara basin where drainages are not structurally distorted yet they are flowing in plain of maturity (Table 5). The lower part of the basin is permeable and having soft strata therefore good chance to percolate/infiltrate the surface water to ground water. The D_d the most vital linear parameters depict the quantitative measure of average length of stream in a particular sub-basin or for whole area. The lithological properties in term of porosity and permeability of earth material can also be recognize usingD_d therefore good in decision making for artificial recharge site. The low D_d area is generally occupied by highly registrant track and dense vegetation (Nag 1998) and these areas in Ghaghara are captured by hilly tracks and middle part having characteristics of dense vegetation whereas high value D_d (Figure15(c)) areas are found in basin where subsurface materials are weak and dominantly occupied by sparse vegetation cover.

Figure 15: (c) sub-basin wise drainage density in Ghaghara river basin

The vegetation pattern and hydrologic properties of soil (permeability) have a big roll to decide surface-runoff and therefore directly decide density of drainages in that area (Dash et al. 2019). Ali and Khan (2013) also supported above that low D_d has course drainage while high D_d has fine drainage texture. Moglen et al. (1998) stated that L_o is inversely related to D_d and important linear parameter governs the hydrologic and physiographic characteristics of a drainage basin. Rama (2014) pointed out that lower L_o indicated quicker runoff process and vice-versa. Here for the Ghaghara river basinL_o (Figure15 (d)) vary from 0.036 to 0.091 with mean value of 0.055 whereas upper tracks have lower value while lower parts have higher value.

Figure 15: (d) sub-basin wise length of over land flow in Ghaghara river basin

The sub-basins in Ghaghara basins that have lower L_o lie in hilly mountains region where faster runoff carry water from upstream to low lying area. And therefore sub-basin that has higher value of $L_o$get a chance to accommodate the more water for flooding during intense rainfall period and this is the main characteristics of lower part of Ghaghara river basin which causes flooding and erosion in basin. While on the dry period situation become to opposite in sense.

The sub-basins 4, 5, 11, 15 and 28 have higher S_f value (Table 5; Figure 15(e)) while other sub-basins have low to medium range.

Figure 15: (e) sub-basin stream frequency in Ghaghara river basin

The high S_f is the characteristics of impermeable subsurface litholog and high relief while other hydrological properties like infiltration capacity and percolation also help to decide the $S_f$of the region. The sub-basins that are occupied by highest value ofS_f and impermeable lithologs in the basin generally produce faster runoff. This faster runoff originates the floods in downstream of the basin and during the rainfall period the downstream parts of the Ghaghara river basin especially the Bahraich, Faizabad, Basti, Ambedkar nagar, Azamgarh are inundated with the muddy water. One of the serious impacts of the flooding in Ghaghara River is the siltation which is a complex environmental problem than to land sliding in the upper part of the basin. Therefore it is a subject of keen interest to mitigate the hazard of flooding in cities/villages which are situated in plainer area where Ghaghara river comes to mature stage and the chances of flooding and lateral meandering becomes more dangerous than to down-cutting the basin.

The form factor (F_f) is one of the important shape parameter of morphometry which defines whether basin is circular or acathetic (elongated). There is a threshold value 0.78 for deciding the basin to be elongated (if F_f<0.78) or circular shape (if F_f>0.78) (Kumar et al. 2019) and sinceF_f for Ghaghara is always less than 0.78 therefore basin is elongated in shape (Table 5, (Figure16 (a)).

Figure 16: **(a)** sub-basin wise form factor in Ghaghara river basin

The lower part of basin especially sub-basin 25, 26, 28 and 30 have higher value than upper part of the basin therefore these higherF_f valued sub-basin will be derived by high intensity (peak flow) within short time whereas more elongated sub-basins will show lower peak (low flow) of longer time. The factor which influence peak flow and low flow is the basin length, as higher basin length reduces the peak discharge and vice-versa (Rao 2016). And therefore this elongated sub-basin can be easily managed than circular sub-basin. The elongation ration (R_e) characterized by shape of the basin varies from 0.6 to 1.0 in the variability of climatic and geologic setup. The value ofR_e varies from 0 (in highly elongated shape) to unity 1.0 (in circular shape). The value close to 1.0 depicts the area of low relief whereas R_e close to 0.6–0.8 is usually associated with high relief (Strahler 1964). The infiltration capacity of the basin can be checked by the elongation ratio as high R_e (Figure16 (b)) indicate high infiltration capacity and in Ghaghara basin, the higher value are close to sub-basin 28 and 30 where the subsurface material (alluvium) is more permeable therefore higher infiltration capacity.

Figure 16: **(b)** sub-basin wise elongation ration in Ghaghara river basin

Reddy et al 2004 stated about R_e that lower value areas are found in the zones which have higher susceptibility to erosion and sediment load and these areas are dominated in the low stream and upper stream of the Ghaghara. The appraisal of flood prone area can easily be done using the shape morphometric parameter circulatory ratio (R_c) as the flood concerning parameters like stream length and its frequency, geological structures, climate etc have great control on R_c. The higher R_c cause chance of flooding during peak rainfall condition at outlet point of their sub-basins as these outlet becomes inlets for lower R_c sub-basin in downstream part of river basin. Same is true for Ghaghara basin as the downstream sub-basins have lowerR_c (Figure16 (c)) and receives more water from upper part of sub-basin having the higher value R_c value.

Figure 16: **(c)** sub-basin wise circulatory ratio in Ghaghara river basin

Bali et al. (2012) reported the range of R_c from zero to one and John Wilson (2012) explains morphological stage using this range as lower value of R_c suggests young/mature stage of river while higher value indicates the old stage. For Ghaghara basin, the circulatory ratio always closer to lower circulatory ratio which suggests that basin is in young to mature stage. The mean $R_c$value is 0.134 which is always less than unity and shows that the shape of the basin is not in circular pattern and R_c & R_e both have confirmed that Ghaghara has elongated shape of basin.

The shape factor (B_s) which is inversely related to the form factor (F_f) defines shape irregularity of sub-basin. The upper and middle sub-basin have higher shape factor while downstream sub-basin have lower value (Table 5, (Figure16 (d)).

Figure 16: (d) sub-basin wise shape factor in Ghaghara river basin

Shape factor help to quantify the head (highest) discharge at the pour point of the basin. As tributary pattern of a circular-shaped basin is more compactly organized than to an elongated-shaped basin having the same area and tributaries flow joins to mainstream at roughly the same time therefore peak discharge will arrive faster at the outlet of circular basin. Thus outlet gains the higher flood within shorter duration. Choubey et al. (1997) described that the shape morphometric parameters have an inverse relation to the soil erosion therefore the compactness factor (C_c) should show the opposite trend to soil erosion and it can conclude that the lower the value of $C_c$depicts the higher erosion in that area and vice-versa. The results ofC_c show that the sub-basins having the lower value of $C_c$follow the high to moderate erosion in that area (Table 5 & Figure16 (e)) and these sub-basins are in the upper portion.

Figure 16: (e) sub-basin wise compactness factor in Ghaghara river basin

The results of hypsometric analysis (Figure 13) also validate the results of C_c as the upper stream sub-basins are in young to mature stage of the river and hence more erosion might be in process. While the middle and downstream sub-basins occupy the higher value ofC_c (Table 5) in comparison to upper portion of basin and therefore lower erosion comparison to upstream. Since it has an inverse relationship to elongation ratio and therefore the downstream sub-basins are more elongated. Gravelius (1914) status that if the C_c value is unity then basin will be perfectly circle and for the Ghaghara river basin the value of C_c is greater than unity therefore the elongated river basin.

The compound factor and then the prioritization of sub-sub-basin help to know the sub-basin susceptibility to loss of soil in the Ghaghara. It is very typical to manage whole basin at once step therefore the prioritization helps to implement the conservation practices accordingly the sub-basin condition of soil erosion. Gajbhiye et al. (2014) also status about the prioritization of sub-basin as the ranking of sub-basins needed for the conservation practices. The low prioritize sub-basin demands the higher conservation practices (Pradhan et at. 2018) and vice versa (Table 6). The results of compound factor showed that for Ghaghara River basin, sub-basin 19 is more prioritized followed by sub-basin 13 and 9 (Table 6).

The hydraulic properties of soil help to understand the erosion condition of that area and therefore the field capacity of soil was estimated at different pressure head for Ghaghara basin (Table 8). The water retention curve (Figure 11) depicts that soil clay-loam (Bd29-3c-3661) has more field capacity which means that this soil will retain and accumulate most rainfall than other soil types and therefore will causes severe erosion during high peak flow. Similar condition will be followed by the loam (I-Bh-U-c-3717) and clay-loam (Rd30-2b-3851) has the 2nd rank and 3rd rank respectively.

The soil loss has been estimated using RUSLE and SWAT model for soil and water conservation measures needed in the Ghaghara River basin. The soil erosion by RUSLE showed that upper, middle and some lower portions of basin have high contribution in soil erosion (Figure 9). The soil erosion by SWAT (Figure 10) also depicts similar result as by RUSLE model. In can be concluded from the both figures that higher erosion zone are those areas which occupy their position mostly in hilly terrain and where headword and deep erosion process is mostly activated due to their natural topography. Mahapatra (2010) also supported the above argument that hilly terrain areas are characterized by headword and vertical erosion due the high energy in streams. Since we have used results of four parameters namely RUSLE, compound factor, SWAT and water holding capacity (filed capacity) to understand erosion pattern in entire basin as erosion process is very complex and constitutes the roll of various factors. Therefore we have followed MCE based AHP procedure in order to tag weighting of each factor (Table 7). The meaning of weighing here indicated the efficiency of parameters to depict soil erosion. The SWAT model has the highest weighting followed by RUSLE and compound factor. The lowest weighing was assigned by filed capacity. Although the SWAT model sediment yield equation is same as RUSLE equation but performance by SWAT model was more accurate than RUSLE. The reason behind this, is input data in SWAT which is more compared to RUSLE and SWAT work on distributed approach of physical equation while RUSLE is imperial only. The final prioritized map (Figure 12) prepared by overlay analysis and has been classified in to five zone to understand soil erosion in entire basin. The final prioritized map of soil erosion shows that 10.67 % of the basin (upper part of basin) falls under very high erosion categories and 22.50 % falls under high categories in upper and some middle portion of basin (Table 9). Areas under low erosion are having their percentage as 33.07 % in middle and lower parts of the basin where basin is almost in monadnok stage. The percentage of the moderate erosion is 33.40 %

in lower, middle and some upper part of basin (Table 9).

The hypsometric analyses help to know the disequilibria and landscape evolution in Ghaghara and there are 3 types of hypsometric curve accordingly the geomorphic age of the river basin. Strahler (1952) described convex upward shape curve for young stage while S shape curve for mature stage having the upper portion concavity while lower portion convexity. For the old stage (peneplain/monadnok) of basin, the concave upward shape was suggested by the Strahler (1952).

Here in the Ghaghara river basin most of the hypsometric curves of sub-basins are of all 3 types (Figure14). Although not all the sub-basins are the S-shaped, some are convex upward (sub-basin 28 & 30) and some others are the concave upward following the equilibrium condition (Figure 14). The hypsometric integral (HI) values are also help to grasp the geomorphic condition of the basin therefore plotted for 30 sub-basins (figure13). The HI values validate the same results as the hypsometric curves as the maximum sub-basins of Ghaghara River occupy their position in mature stage of erosion cycle and moving toward the monadnock (old stage). Ritter al. (2002) stated that these mature stages sub-basins would face the moderate erosion but might be intense in the high runoff period or in case of entrenched meandering. Therefore the HC and HI are useful parameters to understand the sub-basin health. Ghaghara river basin occupies its position in the Himalayan region particular in the lesser and Siwalik range and these areas attaining the mature stage from the young.

Conclusion

The estimation and recognition of soil erosion will be for helpful to control soil loss in Ghaghara river basin. Therefore current study has used RUSLE and SWAT modeling approach to estimate soil loss in the basin. The other parameters as morphometric analysis and water holding capacity of soil have also been calculated. Further AHP based MCE methodology has been adopted using four factors (sediment yield from SWAT, soil loss from RUSLE, compound factor from morphometric analysis, and water holding capacity of soil) to schedule soil erosion prone zone for subsequent conservation measures. The estimated annual soil loss from SWAT is 338.65 $\mathrm{t}h_a{}^{-1}\mathrm{yr}^{-1}$ while from RUSLE is 287.13 $th_a{}^{-1}\mathrm{yr}^{-1}$. The final prioritized map of soil erosion shows that the upper part of the basin are mostly facing high soil erosion in comparison to lower portion and middle portion in basin. The hypsometric analysis outcomes depict the geomorphic age basin as old and mature stage form young. The outcomes of study can be useful to reduce soil erosion due to high surface runoff and suggest to hydrologist for disaster monitoring and management.

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Table 1: The soil types, their areal distribution and soil texture in the study area

Soil types	Area (Km2)	Area (%)	Texture
Bd29-3c-3661	10384.07	8.08	CLAY_LOAM
Bd34-2bc-3663	22516.69	17.52	LOAM
Bd35-1-2b-3664	3970.02	3.09	LOAM
Be74-2a-3675	27.56	0.02	LOAM
Be84-2a-3685	41275.75	32.12	LOAM
Bk39-2a-3694	5207.00	4.05	LOAM
Bk40-2a-3695	43.93	0.03	LOAM
I-Bh-U-c-3717	23190.87	18.05	LOAM
I-X-2c-3731	214.09	0.17	LOAM
Jc50-2a-3743	315.81	0.25	LOAM
Je75-2a-3759	9361.77	7.29	LOAM
Rd30-2b-3851	7276.55	5.66	CLAY_LOAM
GLACIER-6998	4716.10	3.67	UWB

Table 2: Morphometric parameters for assessment of soil erosion in study area

Parameters	Formula
Stream order (U)	Hierarchical rank
Stream length (Lu)	Length of the stream
Stream length ratio (RL)	$RL=L_u/(L_u\text{-}1)$ Where L_u-1 = Total stream length of its next lower order
Bifurcation ratio (R_b)	$R_b=N_{u}/N_u+1$ Where N_u =Number of stream, N_u+1=Number of stream of its next order
Drainage density (D_d)	$D_d=L_u/A$, where A = Area of study region
Stream frequency (F_s)	$Fs=N_u/A$
Elongation ratio (R_e)	$Re=D/L_b= 1.128HA/L$ Where D = Diameter of a circle having the same area as of the bas
Circulatory ratio (R_c)	$R_c = 4\pi A/P^2$, Where P = Perimeter of basin
Form factor (F_f)	$F_f=A/{L_b}^2$ Where L_b = Basin length
Shape Factor(B_s)	$B_s={L_b}^2/A$
Length of over land flow (L_o)	$L_o=0.5\times Dd$
Basin Length (L_b)	$L_b=1.312\times A\hat{}0.568$
Compactness Factor(C_c)	$C_c= (0.2821\times P)/A\hat{}0.5$ Where P= perimeter

Table 3: Land use classes, areal percentage and their SWAT code in study area

Land use Classes	Area (Km^2)	Area (%)	SWAT Code
Water	74.12	0.058	WATR
Evergreen Needle leaf Forest	62.22	0.048	FOEN
Evergreen Broadleaf Forest	15.2	0.012	FOEB
Deciduous Needle leaf Forest	4.68	0.004	FODN
Deciduous Broadleaf Forest	7.02	0.005	FODB
Mixed Forests	34083.55	26.52	FRST
Closed hrublands/Open Shrublands	667.05	0.52	SHRB
Woody Savannas/Savannas	7115.59	5.54	SAVA
Grasslands	22373.49	17.41	GRASS
Permanent Wetland	128.14	0.10	WETL
Croplands	49269.48	38.34	AGRL
Urban and Built-Up	381.71	0.29	URBN
Cropland/Natural Vegetation Mosaic	6167.68	4.80	CRWO

Land use Classes	Area (Km^2)	Area (%)	SWAT Code
Snow and Ice	3568.13	2.78	ICES
Barren or Sparsely Vegetated	4581.58	3.57	BSVG

Table 4 Basic parameters of morphometry used in the Ghaghara river basin

Watershed Sr. No	I Or.Nu	II Or.Nu	III Or.Nu	IV Or.Nu	V Or.Nu	Total Str. Nu	I Or.Lu	II Or.Lu	III Or.Lu	IV Or.Lu	V Or.Lu	Total Lu.(Km)	Area (Km
1	17	9	6			32	190.844	135.32	45.062			371.226	4305
2	9	5	6			20	118.974	68.167	82.028			269.169	2674
3	20	11	7	3		41	242.68	124.59	112.9	40.75		520.92	6103
4	19	9	11	4		43	131.12	131.21	139.41	43.16		444.9	4798
5	17	10	6			33	174.71	101.24	77.76			353.71	3814
6	14	10	3			27	125.41	97.49	32.75			255.65	3546
7	12	6	1	7		26	191.06	82.84	19.63	76.71		370.24	3829
8	14	3	5	7		29	232.42	41.12	76.65	71.02		421.21	4963
9	18	8	2	9		37	236.43	145.43	64.59	248.78		695.23	5333
10	25	8	16			49	282.51	123.17	174.11			579.79	6992
11	31	20	10			61	196.48	214.71	113.74			524.93	6927
12	10	4	3	8		25	105.71	62.68	37.36	144.84		350.59	2927
13	21	7	1	15	2	46	239.32	66.39	15.7	228.88	67.73	618.02	5509
14	10	5	3	3		21	184.57	53.11	40.58	39.11		317.37	3384
15	17	8	8		2	35	188.35	79.57	76.91		25.75	370.58	3107
16	23	9	13			45	363.91	192.52	310.64			867.07	7381
17	14	10	2			26	125.55	145.75	49.66			320.96	3411
18	30	12	2	3	17	64	546.61	192.59	99.33	110.13	238.27	1186.93	9240
19	25	5	20			50	263.32	64.87	370.92			699.11	5832
20	22	12	7	2		43	264.52	147.13	144.53	44.62		600.8	4614
21	18	11	4	5		38	268.96	190.64	43.28	92.58		595.46	4223
22	13	9	3			25	98.31	149.22	42.85			290.38	2792
23	6	2	5	1		14	86.14	79.65	194.55	16.61		376.95	2799
24	11	6	1		5	23	291.54	135.13	7.88		112.58	547.13	4248
25	7	4	1	5		17	193.74	67.28	7.91	120.59		389.52	2146
26	6	5				11	168.59	90.08				258.67	2430
27	9	3		6	8	26	203.91	92.22		166.02	185.81	647.96	4700
28	9	4		3	7	23	116.56	33.29		31.18	104.17	285.2	1943
29	15	5	9		2	31	166.89	79.52	101.87		37.41	385.69	3559
30	3	1			3	7	68.92	17.19			31.45	117.56	958.7
Total	465	221	155	81	46	968	6068.06	3204.12	2482.6	1474.98	803.17	14032.91	1285

Table 5 Morphometric parameters in Ghaghara river basin

	Linear parameter	Linear parameter	Linear parameter	Linear parameter	Linear paramete
Sub-basin	$\mathbf{R_b}$	$\mathbf{R_L}$	$\mathbf{D_d}$	$\mathbf{L_o}$	$\mathbf{S_f}$
1	1.691	0.524	0.086	0.043	0.007
2	1.312	0.894	0.101	0.050	0.007

	Linear parameter	Linear parameter	Linear parameter	Linear parameter	Linear paramete
3	1.901	0.594	0.085	0.043	0.007
4	1.891	0.795	0.093	0.046	0.009
5	1.684	0.674	0.093	0.046	0.009
6	2.372	0.563	0.072	0.036	0.008
7	2.713	1.522	0.097	0.048	0.007
8	1.991	0.984	0.085	0.042	0.006
9	2.164	1.625	0.130	0.065	0.007
10	1.833	0.923	0.083	0.041	0.007
11	1.772	0.812	0.076	0.038	0.009
12	1.401	1.72	0.120	0.060	0.009
13	4.392	3.822	0.112	0.056	0.008
14	1.551	0.661	0.094	0.047	0.006
15	2.122	0.573	0.119	0.060	0.011
16	1.622	1.062	0.117	0.059	0.006
17	3.203	0.751	0.094	0.047	0.008
18	2.331	1.034	0.128	0.064	0.007
19	2.621	2.984	0.120	0.060	0.009
20	2.354	0.611	0.130	0.065	0.009
21	1.730	1.021	0.141	0.070	0.009
22	2.224	0.903	0.104	0.052	0.009
23	2.803	1.171	0.135	0.067	0.005
24	2.671	4.934	0.129	0.064	0.005
25	1.981	5.513	0.182	0.091	0.008
26	1.205	0.532	0.106	0.053	0.005
27	1.424	1.122	0.138	0.069	0.006
28	1.205	1.621	0.147	0.073	0.012
29	2.681	0.711	0.108	0.054	0.009
30	1.672	1.035	0.123	0.061	0.007
Total	1.821	0.610	0.109	0.055	0.008

Table 6 Calculation of compound factor and prioritized ranking of the sub-basins

Linear parameter ranking	Linear parameter ranking	Linear parameter ranking	Linear parameter ranki
sub-basins No.	$\mathbf{R_b}$	$\mathbf{R_L}$	$\mathbf{D_d}$
1	21	30	25
2	28	18	19
3	16	26	26
4	17	20	23
5	22	23	24
6	8	28	30
7	4	8	20
8	14	15	27
9	12	6	6
10	18	16	28
11	19	19	29
12	27	5	11
13	1	3	15
14	25	24	21
15	13	27	13

Linear parameter ranking	Linear parameter ranking	Linear parameter ranking	Linear parameter ranki
16	24	11	14
17	2	21	22
18	10	13	9
19	7	4	12
20	9	25	7
21	20	14	3
22	11	17	18
23	3	9	5
24	6	2	8
25	15	1	1
26	29	29	17
27	26	10	4
28	30	7	2
29	5	22	16
30	23	12	10

Table7 Pair comparison matrix by MCE -AHP method for weighting four factors

Parameters	RUSLE	Compound Factor	SWAT	Field Capacity	Priority (Normalized weight)	R
RUSLE	1	4	0.5	6	34.6%	2
Compound Factor	0.25	1	0.25	3	12.6%	3
SWAT	2	4	1	5	47.1%	1
Field Capacity	0.17	0.33	0.2	1	6.1%	4

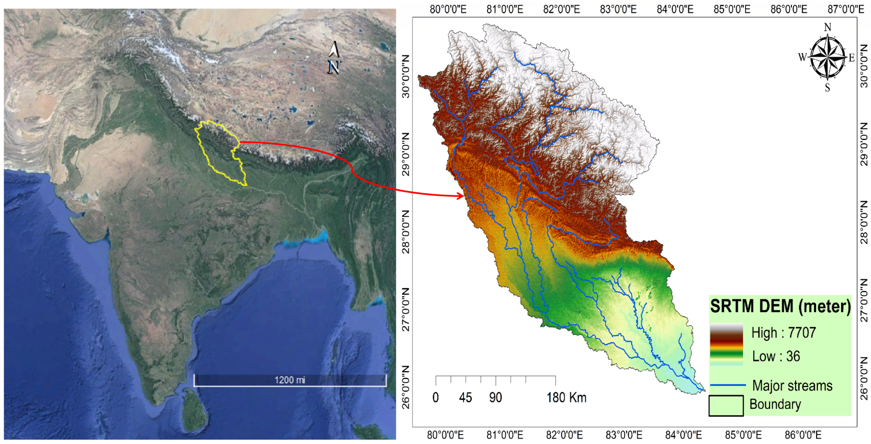
Table 8 Water holding capacity of soil types in Ghaghara river basin

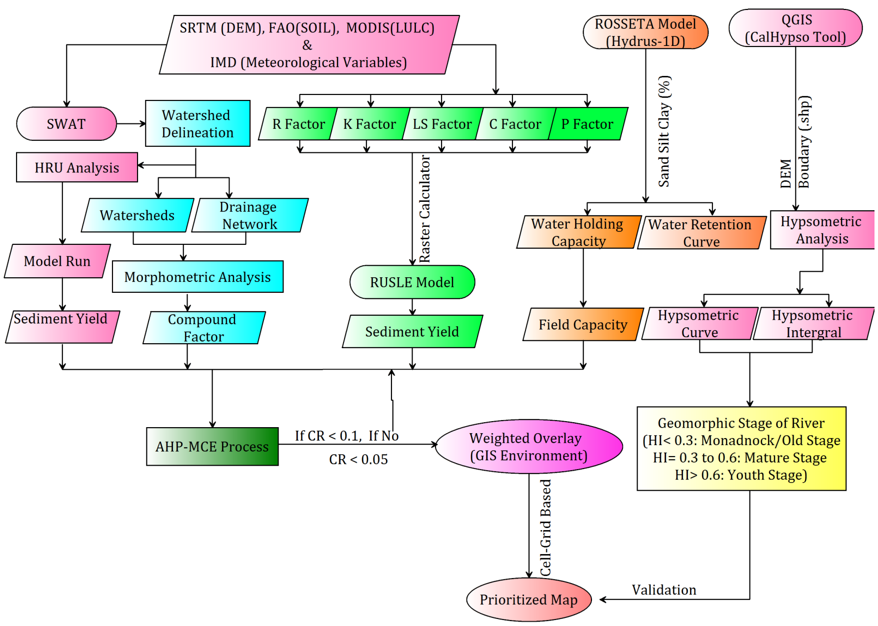
Sr. No.	Soil Types	Water holding capacity (m^3/m^3)
1	CLAY_LOAM (Bd29-3c-3661)	0.317
2	LOAM (Be74-2a-3675)	0.270
3	LOAM (Be84-2a-3685)	0.255
4	LOAM (Bk39-2a-3694)	0.239
5	LOAM (Bk40-2a-3695)	0.270
6	LOAM (I-Bh-U-c-3717)	0.311
7	LOAM (Jc50-2a-3743)	0.236
8	LOAM (Je75-2a-3759)	0.270
9	CLAY_LOAM (Rd30-2b-3851)	0.271
10	GLACIER-6998	0.059

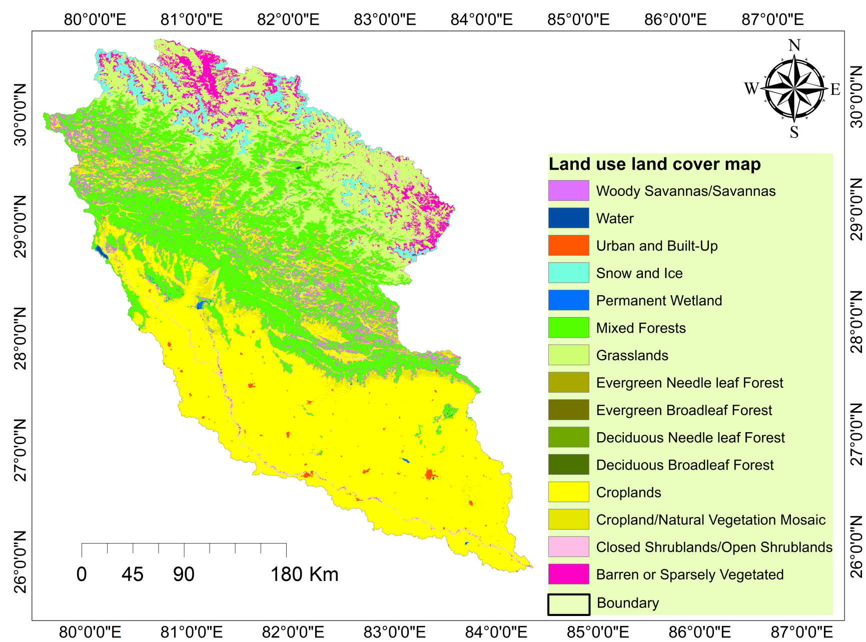
Table 9 Percentage wise Soil erosion zone in Ghaghara river basin

Categories	Area(Km2)	Area (%)
V low	465.2	0.37
Low	41885.7	33.07
Moderate	42298.3	33.40
High	28500.9	22.50

Categories	Area(Km2)	Area (%)
V high	13510.2	10.67
Total	126660.2	100



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Land use land cover map
Woody Savannas/Savannas
Water
Urban and Built-Up
Snow and Ice
Permanent Wetland
Mixed Forests
Grasslands
Evergreen Needle leaf Forest
Evergreen Broadleaf Forest
Deciduous Needle leaf Forest
Deciduous Broadleaf Forest
Croplands
Cropland/Natural Vegetation Mosaic
Closed Shrublands/Open Shrublands
Barren or Sparsely Vegetated
Boundary
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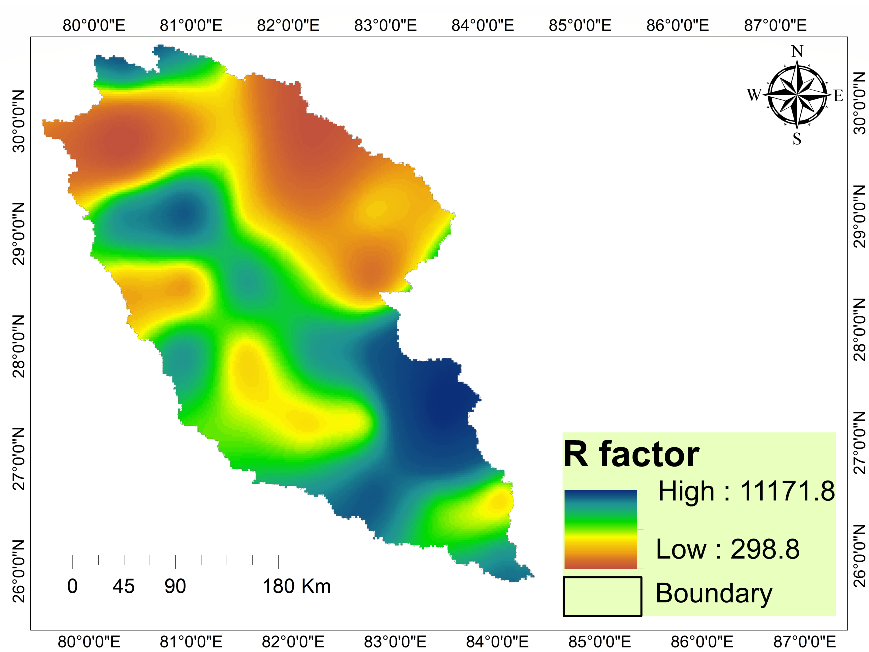
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R factor
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Low : 298.8
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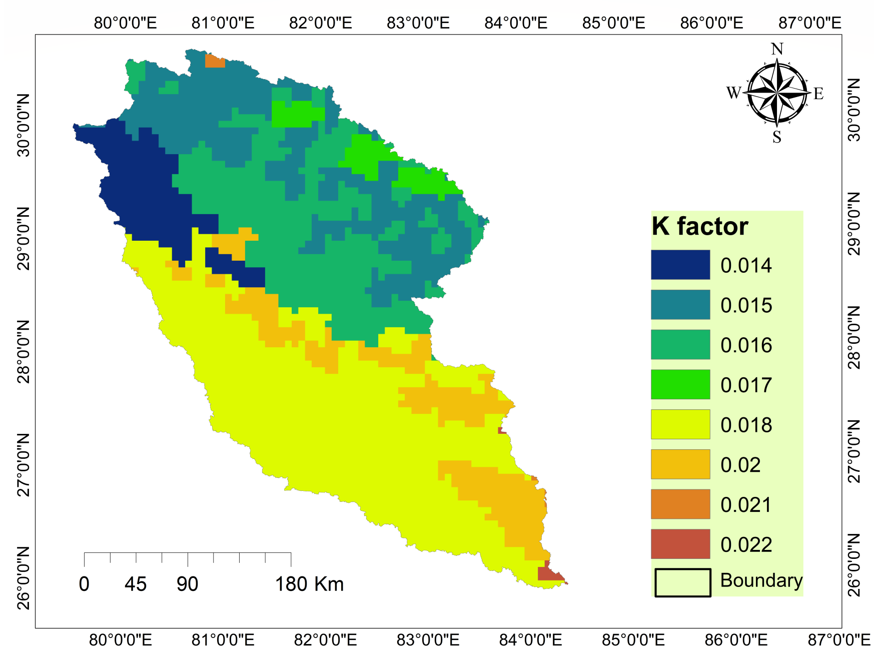
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Boundary
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81°0'0"E
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83°0'0"E
84°0'0"E
85°0'0"E
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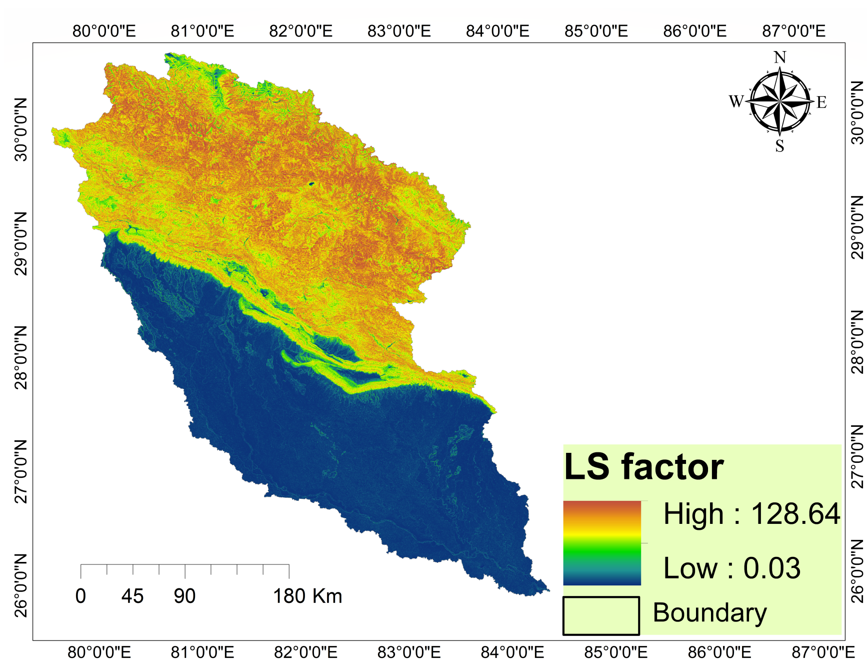
LS factor
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Low : 0.03
Boundary
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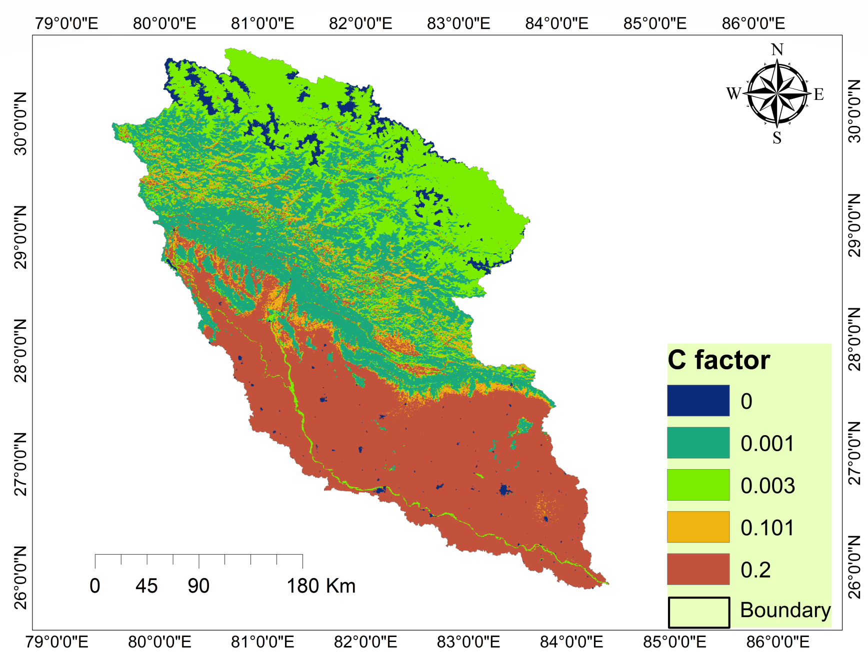
30°0'0"N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0.003
0.101
0.2
Boundary
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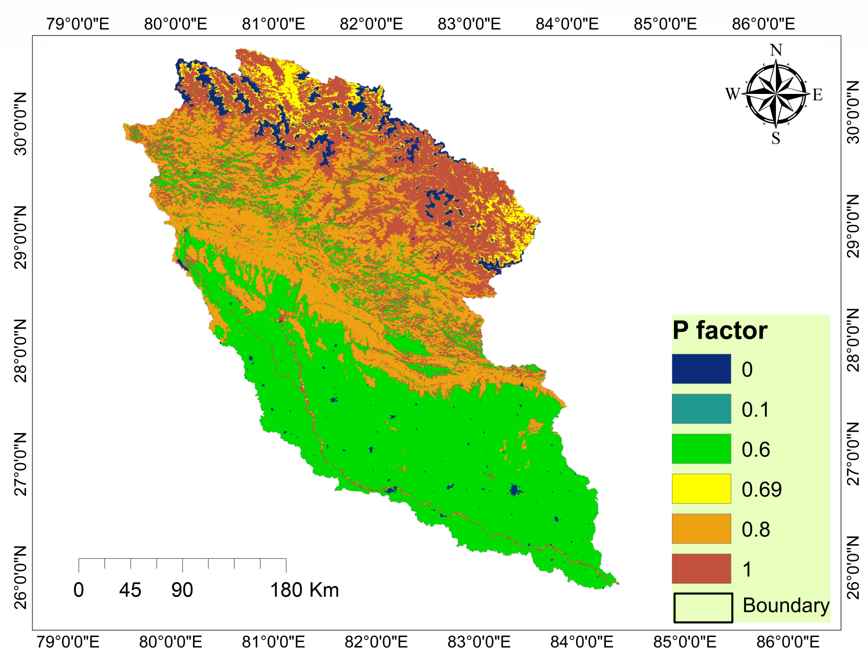
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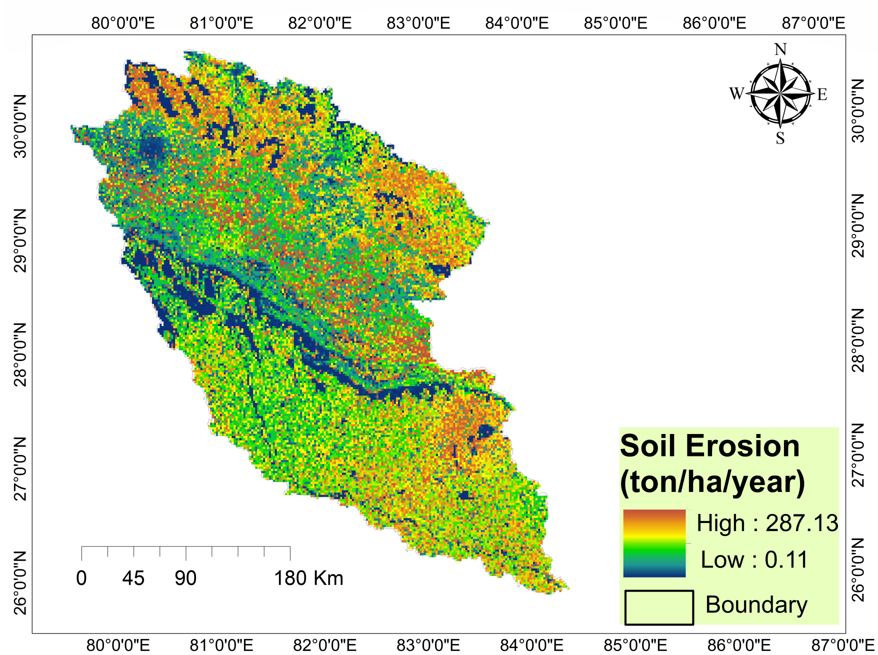
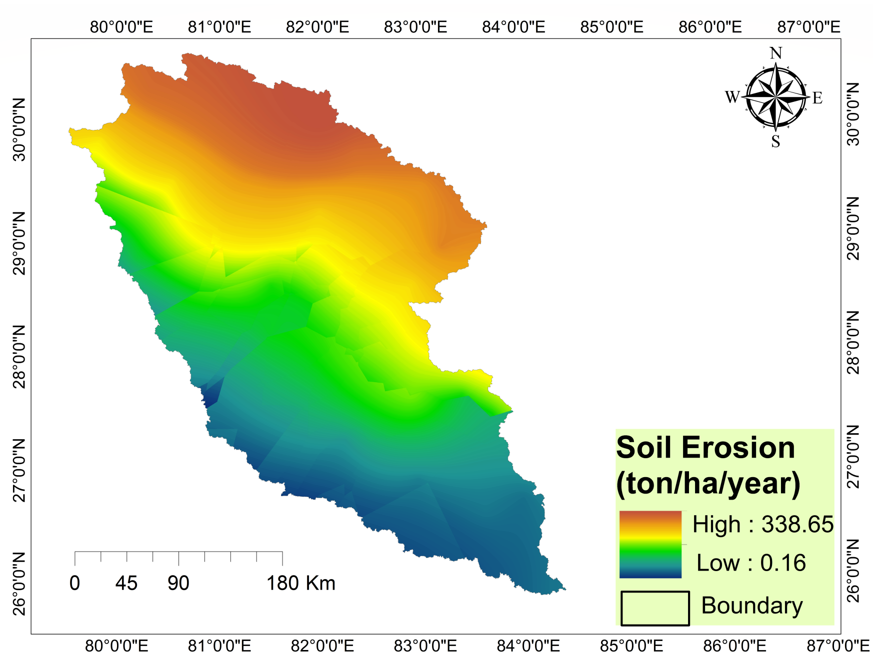
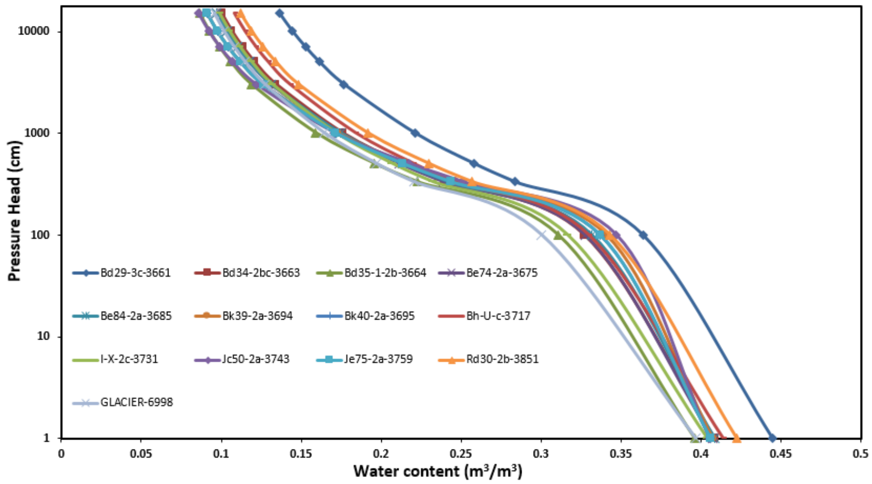
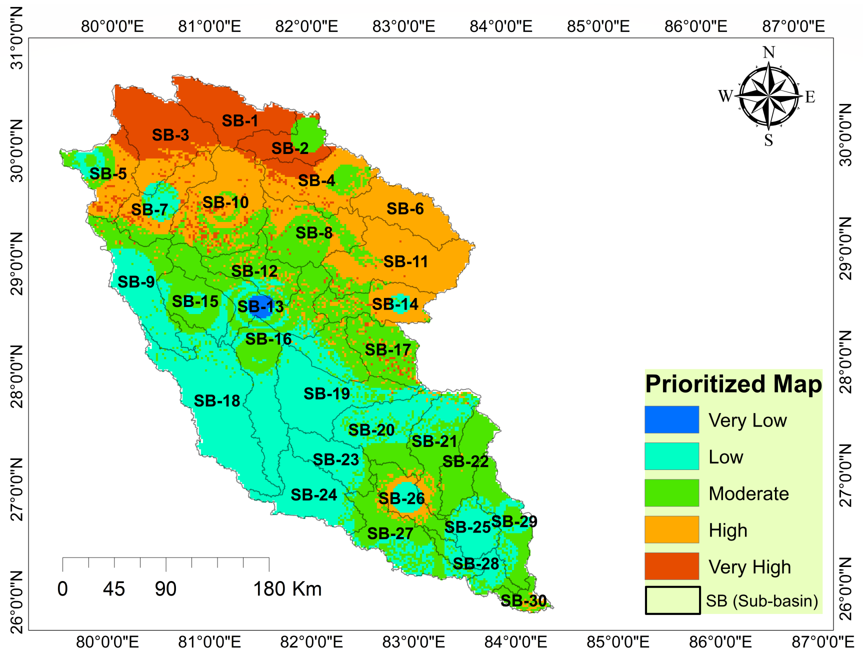
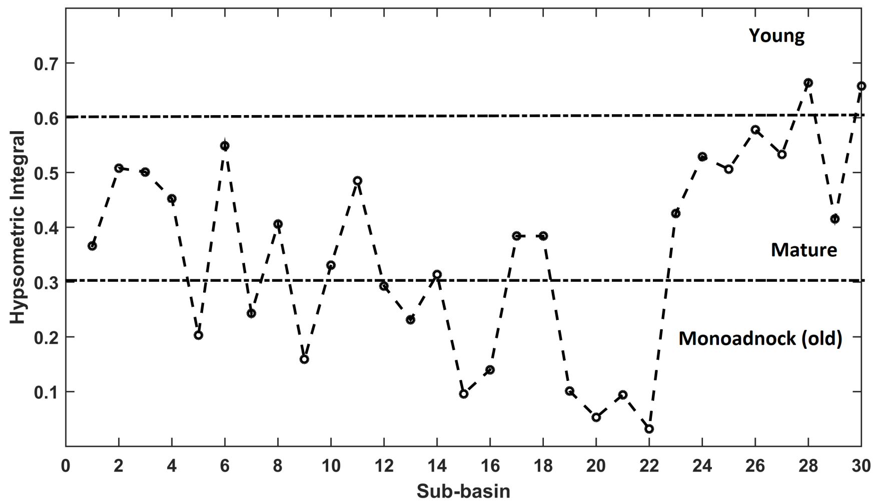
28°0'0"N
27°0'0"N
26°0'0"N
N
W
E
S
P factor
0
0.1
0.6
0.69
0.8
1
Boundary
0 45 90 180 Km

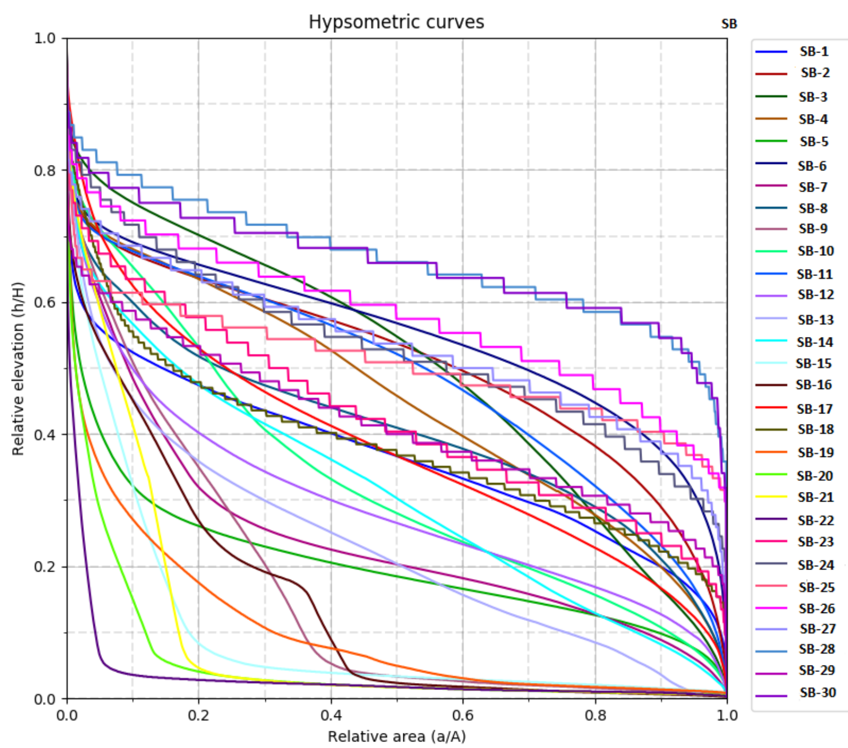

80°0'0"E
81°0'0"E
82°0'0"E
83°0'0"E
84°0'0"E
85°0'0"E
86°0'0"E
87°0'0"E
30°0'0"N
29°0'0"N
28°0'0"N
27°0'0"N
26°0'0"N
N
W
E
S
Soil Erosion
(ton/ha/year)
High : 287.13
Low : 0.11
Boundary
0 45 90 180 Km

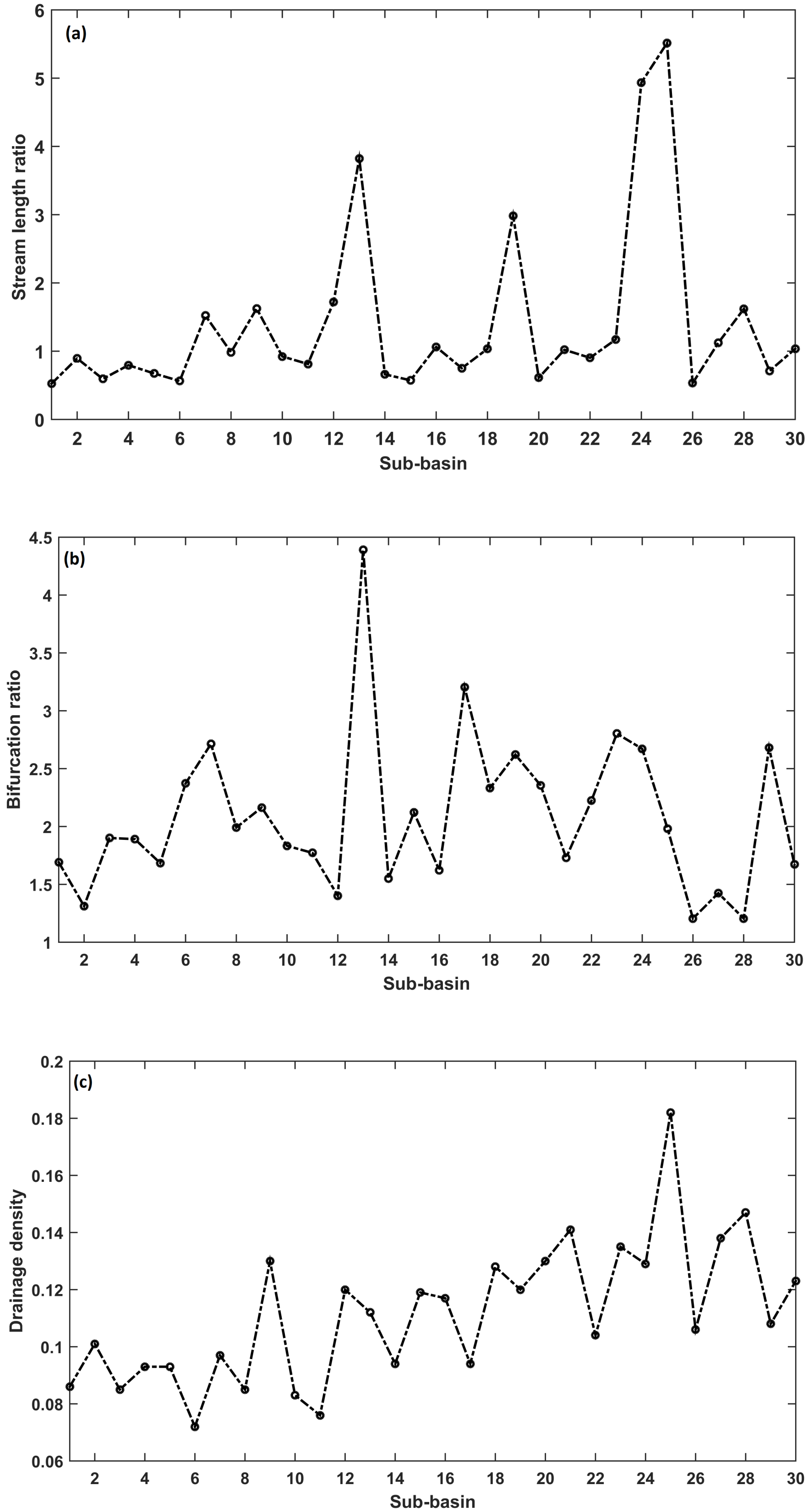

80°0'0"E
81°0'0"E
82°0'0"E
83°0'0"E
84°0'0"E
85°0'0"E
86°0'0"E
87°0'0"E
30°0'0"N
29°0'0"N
28°0'0"N
27°0'0"N
26°0'0"N
N
W
E
S
Soil Erosion
(ton/ha/year)
High : 338.65
Low : 0.16
Boundary
0 45 90 180 Km

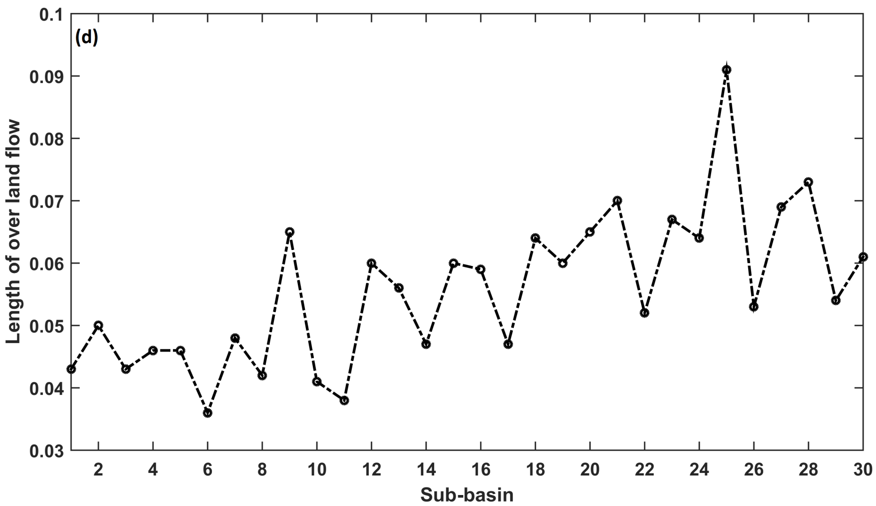

Pressure Head (cm)
Water content (m³/m³)
10000
1000
100
10
1
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Bd29-3c-3661
Bd34-2bc-3663
Bd35-1-2b-3664
Be74-2a-3675
Be84-2a-3685
Bk39-2a-3694
Bk40-2a-3695
Bh-U-c-3717
I-X-2c-3731
Jc50-2a-3743
Je75-2a-3759
Rd30-2b-3851
GLACIER-6998

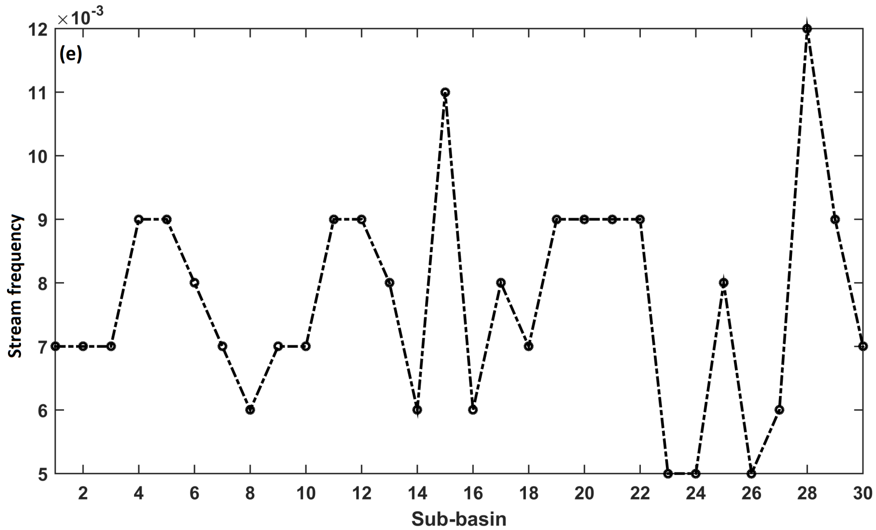

80°0'0"E
81°0'0"E
82°0'0"E
83°0'0"E
84°0'0"E
85°0'0"E
86°0'0"E
87°0'0"E
31°0'0"N
30°0'0"N
29°0'0"N
28°0'0"N
27°0'0"N
26°0'0"N
N
W
E
S
SB-1
SB-2
SB-3
SB-4
SB-5
SB-6
SB-7
SB-8
SB-9
SB-10
SB-11
SB-12
SB-13
SB-14
SB-15
SB-16
SB-17
SB-18
SB-19
SB-20
SB-21
SB-22
SB-23
SB-24
SB-25
SB-26
SB-27
SB-28
SB-29
SB-30
Prioritized Map
Very Low
Low
Moderate
High
Very High
SB (Sub-basin)
0
45
90
180 Km

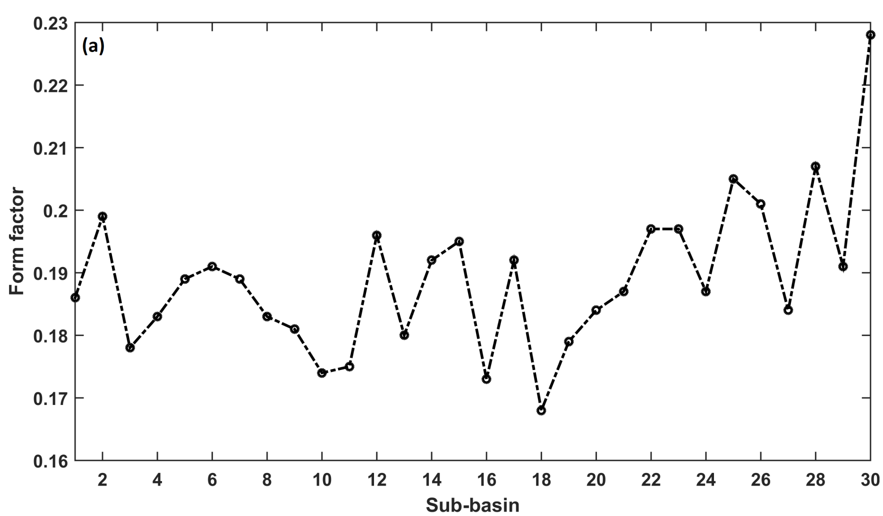

Young
Mature
Monoadnock (old)
Hypsometric Integral
Sub-basin

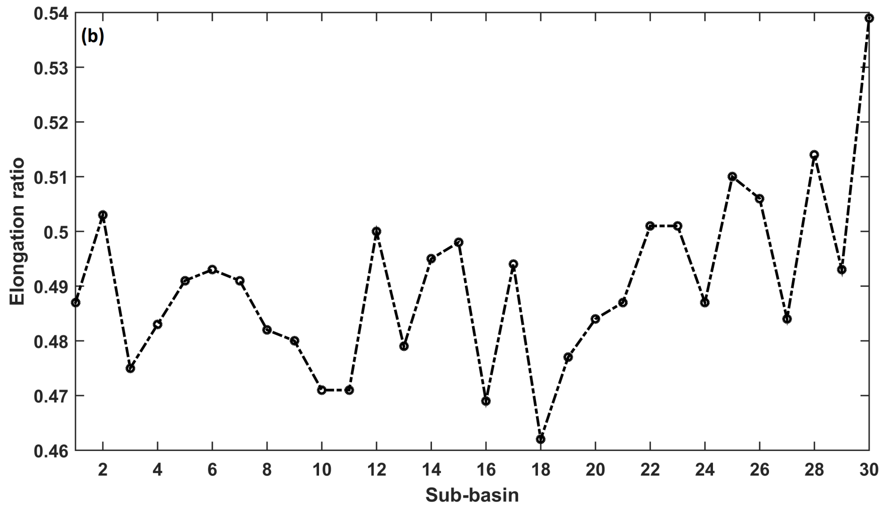

Hypsometric curves
SB
Relative elevation (h/H)
Relative area (a/A)
SB-1
SB-2
SB-3
SB-4
SB-5
SB-6
SB-7
SB-8
SB-9
SB-10
SB-11
SB-12
SB-13
SB-14
SB-15
SB-16
SB-17
SB-18
SB-19
SB-20
SB-21
SB-22
SB-23
SB-24
SB-25
SB-26
SB-27
SB-28
SB-29
SB-30

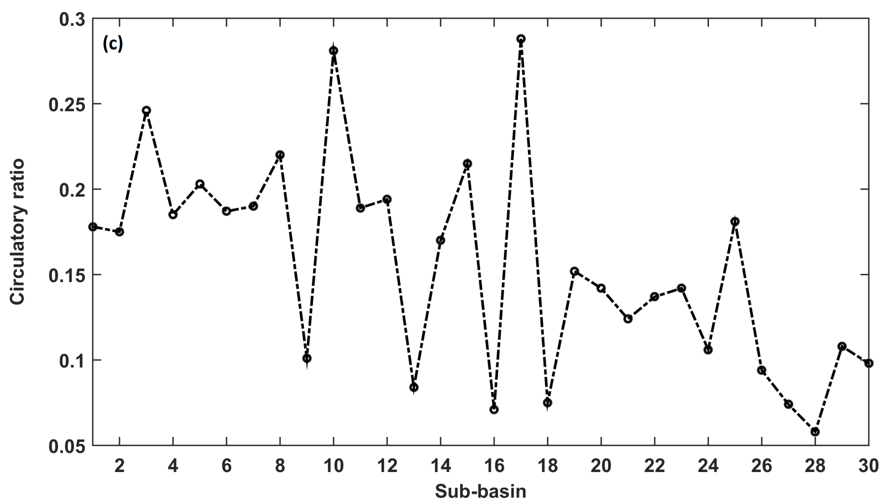

(a)
Stream length ratio
Sub-basin
(b)
Bifurcation ratio
Sub-basin
(c)
Drainage density
Sub-basin

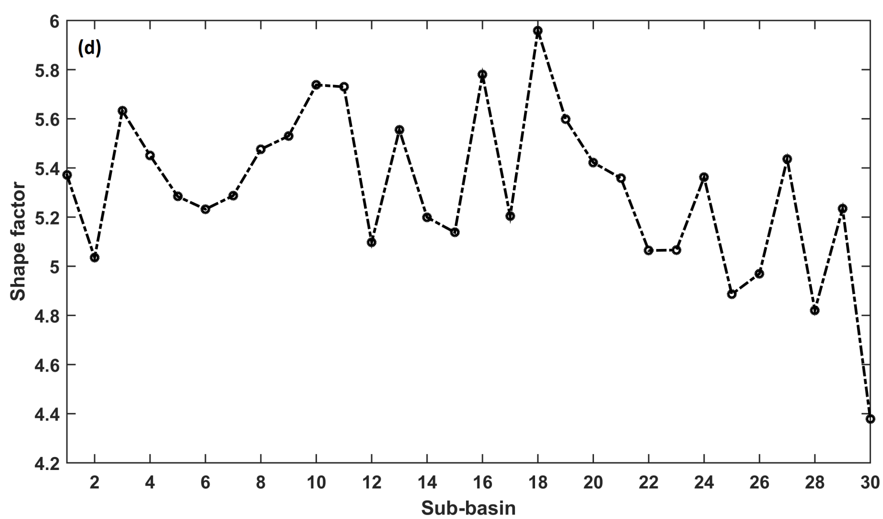

(d)
Length of over land flow
Sub-basin
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30

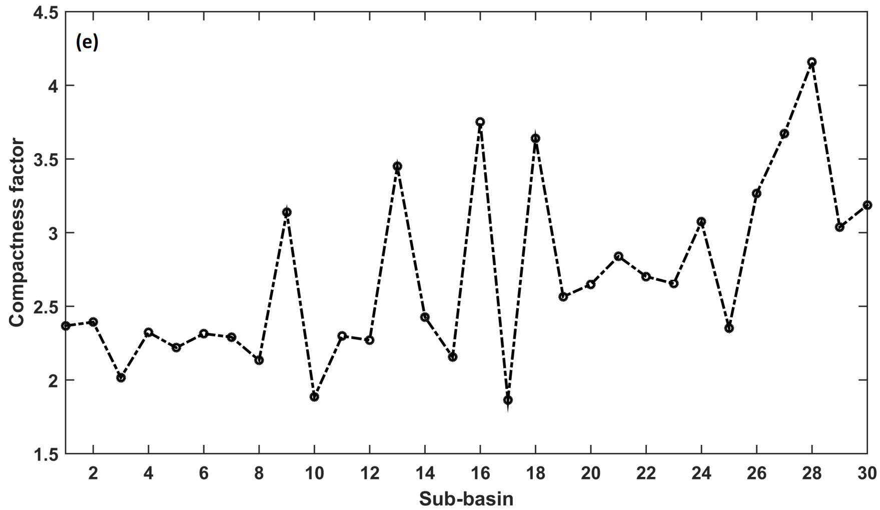

$\times 10^{-3}$
(e)
Stream frequency
Sub-basin
12
11
10
9
8
7
6
5
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30


(a)
Form factor
Sub-basin
0.23
0.22
0.21
0.2
0.19
0.18
0.17
0.16
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30


(b)
Elongation ratio
0.54
0.53
0.52
0.51
0.5
0.49
0.48
0.47
0.46
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Sub-basin


(c)
Circulatory ratio
0.3
0.25
0.2
0.15
0.1
0.05
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Sub-basin


(d)
Shape factor
6
5.8
5.6
5.4
5.2
5
4.8
4.6
4.4
4.2
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Sub-basin


(e)
Compactness factor
Sub-basin
4.5
4
3.5
3
2.5
2
1.5
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30