



Assessment of Soil Erosion Susceptibility Based on Morphometric and Landcover Analysis: A Case Study of Netravati River Basin, India

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Abstract

In this study, we assess the soil erosion susceptibility at the sub-basins scale using remote sensing data with the integration of the Geographical Information System (GIS) for the Netravati river basin in Western Ghats, India. The Cartosat digital elevation model was used for the calculation of morphometric parameters, and Landsat satellite images were used for land cover classification. The whole river basin was divided into five sub-basins for identifying the spatial variation of morphometric parameters and different land use categories. A weighted sum approach (WSA) was used for the ranking of each morphometric parameter and land use types. Then each sub-basin was assigned as very low, low, medium, high, and very high priority ranking. The final prioritization map based on the combined (morphometric and land cover) analysis showed erosion susceptibility is very high for sub-basin 4, high for sub-basin 2, medium for sub-basin 5, low for sub-basin 1, and very low for sub-basin 3. Further, the soil erosion susceptibility analysis has been done separately for morphometric and land cover at the sub-basins scale. The results of this study will be useful for the water resource manager and policymaker while considering the soil erosion-prone areas in the region, and the methodology can be adapted for other river basins.

Keywords Morphometric analysis · Land cover · Soil erosion · Remote sensing · GIS · River basin

Introduction

Soil erosion is a natural phenomenon and causes major environmental and agricultural degradation which directly affects the economy and social advancement of the considered region. However, human activities have greatly influenced the rate of soil erosion by overgrazing, deforestation, and other land conversions when compared to natural causes (Pradhan, 2010). Approximately, 75 billion metric tons of soil unfetters through water and wind, mostly from agricultural areas (Myers, 1993). In recent years, it has greatly increased (Morgan (2009) due to deforestation, agriculture expansion, and urbanization. In India, according to the Ministry for Environment and Forest (2001), approximately 53% of the total geographical

area was suffered from serious soil erosion and land degradation resulting in the loss of topsoil in the 132 mha area. The soil erosion from the agricultural sector imposes an immense threat to the economy of a region (Sartori et al. 2019). The impact is even large in regions of complex and undulated mountainous topography like the Himalayas (Altaf et al., 2014) and Western Ghats of India where floods, landslides, and debris flow are common phenomena of natural hazards (Sinha et al., 2020a). It is a fact that the soil formation rate is much lesser than the soil erosion in many areas (Kadam et al., 2019). For understanding the factors which influence soil erosion such as topography, intensity of rainfall, land cover types, soil moisture and other physicochemical characteristics that play a vital role in the soil erosion from landscape need to be studied (Kavian et al., 2013; Romshoo et al., 2012). However, assessing these parameters over large areas is a difficult task and time-consuming process (Kadam et al., 2019); therefore, study at the sub-basins scale is the best option for river basin management. Hence, it is necessary to assign a relative priority to a different region within a river basin to carry out essential management practices and to understand

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the requirement of their conservation. Morphometric analysis is a quantitative measurement of different morphological parameters of landforms, and these quantitative values play a vital role to understand geohydrological characteristics of drainage pattern and form relation to the feature and terrain of the basin. According to Pandey et al., (2018), quantitative morphometric analysis of the river basin is the most suitable approach for proper river basin planning and management. It helps to understand the relationship between different features of the drainage network in the river basin (Kumar et al., 2012).

But only morphometry cannot be enough criteria to understand the priority status of any river basin. Coupling morphometric parameters with other parameters such as hypsometry and land cover can give a more reliable and accurate prediction of soil erosion susceptibility.

Various studies of geomorphometric analysis for soil erosion susceptibility at the sub-basin level have been carried out for assessment of different hydrological problems around the world (Altaf et al., 2014; Arabameri et al., 2018; Bhattacharya et al., 2019; Javed et al., 2009; Kadam et al., 2019; Samal et al., 2015; Sarkar et al., 2020; Sinha et al., 2020b; Sutradhar, 2020; Yadav et al., 2014). Morphometric analysis can be performed by conventional techniques like using toposheet and ground survey; however, some researchers (Krumbein & Shreve, 1970; Lubowe, 1964; Mark, 1983) found that it is rather possible but ground-based drainage assessments may neglect many channels network which can contribute to soil erosion and water transport in the river basin. In this perspective, the digital elevation model (DEM) is the most suitable and efficient idea for estimating channel network and sub-basin boundaries (Ozdemir & Bird, 2009). The morphometric and land cover analysis is important tools for sub-basins prioritization because it can apply for an assessment of various parameters based on different norms to identify the best alternatives. In the Netravati river basin of Western Ghats, India, land use change such as deforestation, agriculture expansion, population growth, and hilly landscape has led to serious soil erosion and related problems for the last few decades (Sinha & Eldho, 2018).

By keeping this into consideration, the objectives of the present study are to assess the soil erosion susceptibility based on morphometric parameters and land cover types of different sub-basins of the Netravati river basin. Additionally, the relationship among morphometric parameters and land cover types was assessed using the cross-correlation matrix. The combined (morphometric and land cover) compound factor (CF) was calculated using the weighted sum approach technique (WSA) at the sub-basin scale for ranking the final priority of soil erosion susceptibility in the basin.

Study Area

The Netravati river basin is a west-flowing river that flows into the Arabian Sea and located in Karnataka state of the Western Ghats region of India (Fig. 1). The river is in the south of India between $12^{\circ}30'N$ and $13^{\circ}10'N$ latitudes and $74^{\circ}50'E$ – $75^{\circ}50'E$ longitudes. The basin area is approximately 3410 km^2 , the average annual precipitation is 3076 mm, and the average annual air temperature ranges from 20° to 26° C. The maximum elevation of the river basin is 1884 m from the mean sea level (Fig. 1). Geologically, the area is exclusive of the Precambrian formations. The soil types of the river basin consist of sandy clay loam types of soil which are mainly found in the upper river basin (approximately 84%), while clay loam soil type is found in the lower basin (approximately 16%). Clay loam soils occur mainly on gently undulating topography as a long strip along the coast in the high rainfall region of the basin. Figure 1b shows the different levels of stream order present in sub-basins. Figure 1c and 1d represents the stream orders and sum of stream length in sub-basins. The upper regions of the river are categorized by high elevation and covered with mostly forests, while downstream is an undulated plane area where agriculture and urban lands are predominant.

Materials and Methods

Data Collection

Cartosat digital elevation model (DEM) at $30 \times 30\text{ m}$ grid size (<http://www.nrsc.gov.in/>) is used for the generation of drainage network in the river basin. For the land cover, Landsat satellite data (<http://earthexplorer.usgs.gov/>) at 30-m resolution is used to generate land cover information and to validate the drainage network derived from the Cartosat DEM. For the calibration and accuracy assessment of the drainage network and different land cover types, an extensive field survey was done during the post-monsoon season in the river basin.

Methodology

The complete methodology of this study is divided into four steps: The first step includes database development and assessments of morphometric parameters; the second step involves the establishment of intercorrelation among morphometric parameters and land cover types; the third step includes selected morphometric parameters (linear, relief, and shape) for assessment of morphometric-based soil erosion susceptibility, and the fourth step includes

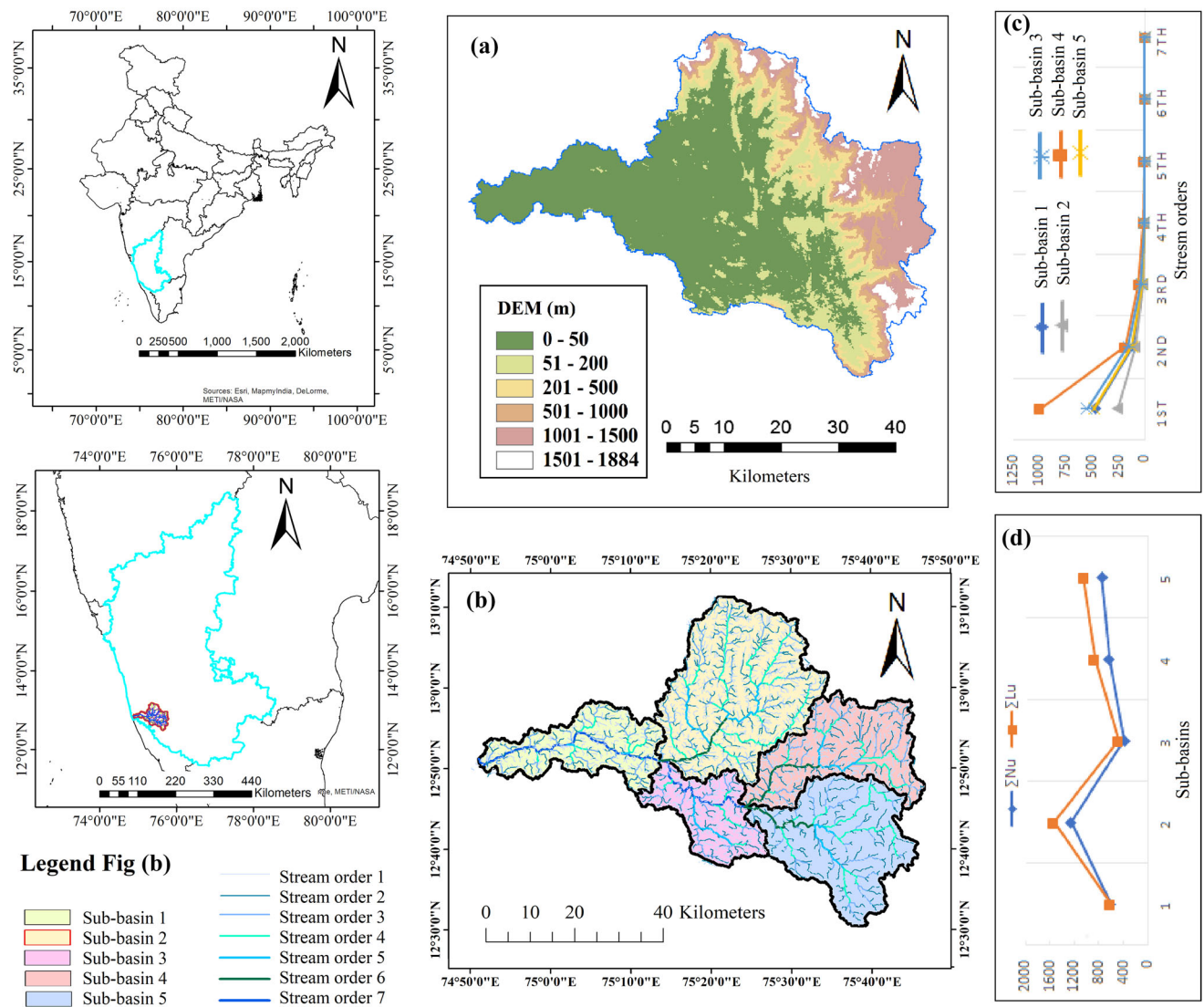


Fig. 1 Location of the river basin, **a** DEM, **b** sub-basins and drainage network, **c** stream order in sub-basins, and **d** sum of stream length and stream segment in sub-basins in Netravati river basin

calculation of land cover for analysis of land cover-based soil erosion analysis and finally with combined (morphometric and land cover)-based soil erosion susceptibility at the sub-basin scale. The flowchart of complete methodology at the sub-basin scale for prioritization of soil erosion susceptibility is given in Supplementary File (in Fig. 1).

DEM sinks were identified and filled before the calculation of proper drainage network, flow direction, and flow accumulation in the basin. The Netravati river basin was divided into five sub-basins based on its different tributaries and location (see Fig. 1b). The sub-basins elevation distribution of the basin is presented in Supplementary File (Fig. 2). For stream ordering, Strahler’s technique has been applied, which was initially given by Horton and later improved by Strahler (1952). The formulae used for the analysis of morphometric parameters in different aspects of

the river basin such as linear, relief, and shape are presented in Table 1. The linear aspects of the basin give the information related to one-dimensional parameters such as stream number, stream order, and bifurcation ratio. Shape parameters define the shape of the river basin and two-dimensional parameters like circulatory ratio, elongation ratio, form factor, etc., while the relief aspect of the basin is three-dimensional parameters such as relief ratio, slope ratio.

For the calculation of the correlation matrix, sixteen morphometric parameters and five land cover types were taken into consideration for all five sub-basins. The matrix consists of $n \times n$ format (where n is parameter number which is used in the calculation of correlation) with one as a diagonal element. During river sub-basins prioritization, only statistically significant ($p < 0.05$) values were

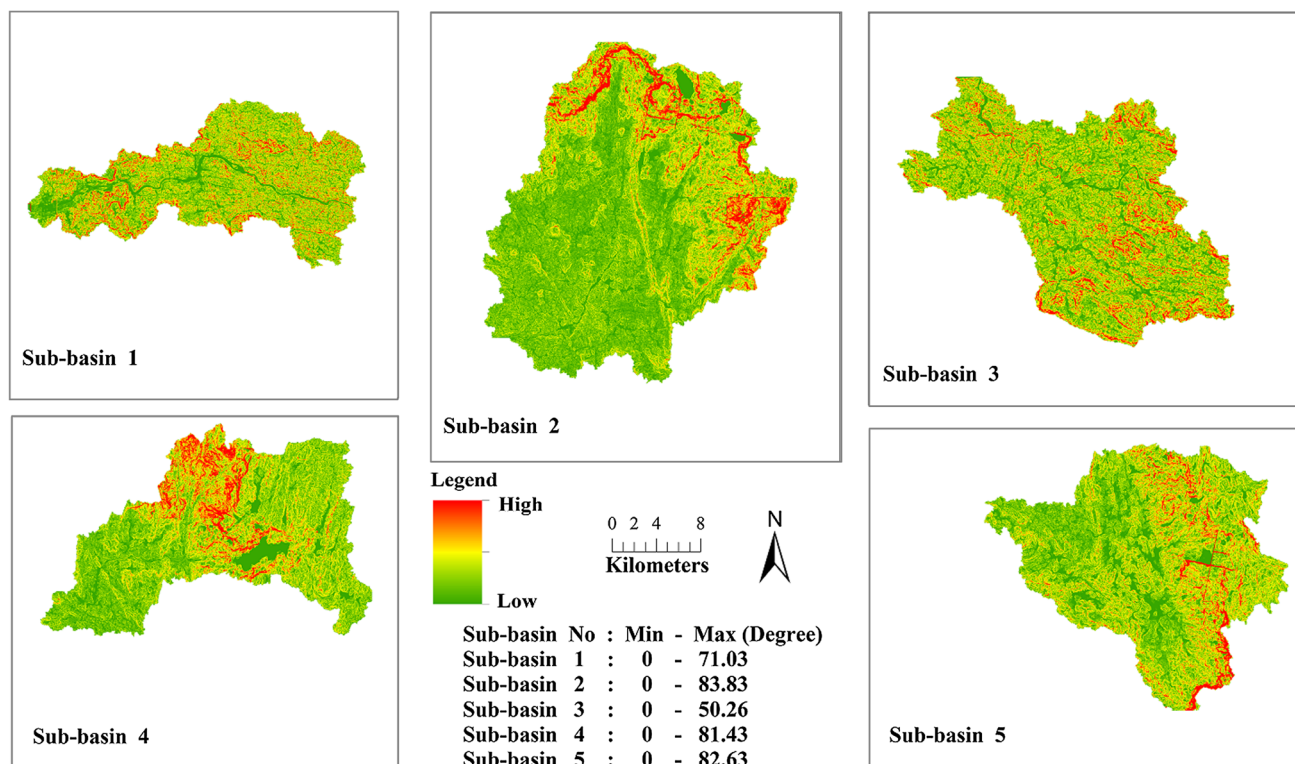


Fig. 2 Sub-watersheds slope distribution of Netravati river basin

considered and discussed because it shows the strength of the relation between two variables. Landsat satellite images are used for land cover at 30-m resolution. There are six types of land cover presented in the river basin such as forest, grassland, agriculture, wasteland, water bodies, and urban areas. The classified land covers are validated by ground truth (100 points of different land cover types) and Google Map. Kappa coefficient was estimated, and accuracy is found to be 94% for the final classified map.

Initial Priority Ranking of Sub-Basins

The initial ranking of sub-basins was assigned based on morphological characteristics and LULC categories in the river basin. In morphometric parameters, we were used linear (bifurcation ratio, perimeter, etc.), areal (stream frequency, drainage density, etc.), and shape parameters (circulatory ratio, elongation ratio, etc.). The linear and aerial parameters influence to increase soil erosion (Gajbhiye et al., 2014) means, higher the values of these parameters, the more soil erosion, and vice versa. In contrast, shape parameters decreasing the soil erodibility potential, which means higher the values, lower the soil erodibility, and vice versa. Hence sub-basins with higher values of linear and areal parameters are given rank 1, and next higher values are given rank 2 and so on (Ratnam

et al., 2005). On the other hand, the shape parameters have an opposite relationship with soil erosion and thus lower values of shape parameters were given rank 1 (Ratnam et al., 2005).

Weighted Sum Approach

The weighted sum approach (WSA) is used for calculating the final priority of soil erosion at the sub-basins scale. In this approach, the relative significance of each parameter is established by estimating the cross-correlation among all variables and assessing the weightage of individual parameters concerning its importance in soil erodibility potential. The prioritization of all five sub-basins of the Netravati river basin was established by calculating compound values obtained by the WSA approach. The sub-basins having minimum values of compound factor assigned rank 1 (highest priority). The details of mathematical expression can be found from the equation given below (Aher et al., 2014):

$$CF = IPR_{MP} \times W_{MP} \quad (1)$$

where CF = compound factor and represented by IPR_{MP} = initial priority rank, and W_{MP} = weight of parameter based on the morphometric parameter and LULC types.

Table 1 Various parameters for morphometric analysis, the formulae used for evaluation and references

S. No	Morphometric parameters	Formulae	References
1	Stream Length (L_u)	Length of the stream	Horton (1945)
2	Basin Length (L_b)	$1.312 * A^{0.568}$ where A = Area	Schumm (1956)
3	Basin Perimeter (P)	GIS Software Analysis	Schumm (1956)
4	Bifurcation Ratio (R_b)	$R_b = N_u / N_{u+1} + 1$ where R_b = Bifurcation ratio; N_u = Total no. of stream segments of order 'u'; N_{u+1} = Number of segments of the next higher order	Schumm (1956)
5	Drainage Density (D)	$D = L_u / A$ where D = Drainage density; L_u = Total stream length of all orders; A = Area of the basin (km^2)	Horton (1932)
6	Stream Frequency (F_s)	$F_s = N_u / A$ where F_s = Stream frequency; N_u = Total no. of streams of all orders; A = Area of the basin (km^2)	Horton (1932)
7	Drainage Texture (R_t)	$R_t = N_u / P$ where R_t = Drainage texture; N_u = Total no. of streams of all orders; P = Perimeter (km)	Horton (1945)
8	Length of overland flow (L_g)	$L_g = 1 / D^{*2}$, where L_g = Length of overland flow; D = Drainage density	Horton (1945)
9	Basin relief (H)	H = Maximum relief – Minimum relief	Schumm (1956)
10	Relief ratio (R_h)	$R_h = H / L_b$ where H = Basin relief L_b = Basin length	Schumm (1956)
11	Elongation Ratio (R_e)	$R_e = 2 / L_b \sqrt{A / \pi}$ where R_e = Elongation ratio A = Area of the basin (km^2); π = 'Pi' L_b = Basin length	Schumm (1956)
12	Circularity Ratio (R_c)	$R_c = 4 * \pi * A / P^2$ where R_c = Circularity ratio; π = 'Pi' A = Area of the basin (km^2); P = Perimeter (km)	Miller (1953)
13	Form Factor (R_f)	$R_f = A / L_b^2$ where R_f = Form factor; A = Area of the basin (km^2); L_b^2 = Square of basin length	Horton (1932)
14	Shape index (S_i)	L_b^2 / A where L_b = Basin length; A = Area of basin	Horton (1945)
15	Compactness coefficient (C_c)	$C_c = P_c / P_u$ where P_c = Perimeter of watershed; P_u = circumference of circle having watershed area	Suresh et al., (2004)
16	Constant of Channel Maintenance (C)	$C = 1 / D$	Schumm (1956)

Table 2 Different morphometric parameters analysis and its rank at sub-basin level of NRB

SB	P	L_u	R_b	D	L_g	F	Rt	H	C	L_b	R_h	R_c	R_e	R_f	S_i	C_c
1	166.69	606.13	2.65	1.26	0.63	1.27	1.61	149	0.79	43.23	3.45	0.22	0.57	0.26	3.89	2.15
Rank	4	4	5	5	5	1	1	5	4	3	5	1	1	1	5	5
2	201.61	1530.65	3.55	1.38	0.69	1.13	1.56	1169	0.73	45.29	25.81	0.34	0.83	0.54	1.85	1.71
Rank	1	1	2	1	1	2	2	1	1	2	1	5	5	5	1	1
3	135.68	481.8	2.73	1.29	0.65	1.01	1.31	268	0.77	33.12	8.09	0.25	0.66	0.34	2.94	1.98
Rank	5	5	4	4	4	3	4	4	3	5	4	3	3	3	3	3
4	184.64	869.3	3.16	1.36	0.68	1.00	1.36	954	0.73	45.79	20.83	0.24	0.62	0.30	3.28	2.06
Rank	2	3	3	2	2	4	3	3	1	1	3	2	2	2	4	4
5	180.84	1051.61	3.62	1.36	0.68	0.96	1.30	1052	0.74	41.1	25.6	0.30	0.77	0.46	2.18	1.83
Rank	3	2	1	3	3	5	5	2	2	4	2	4	4	4	2	2

SB = Sub-basin, P = Perimeters (Km), L_u = Stream length (km), R_b = Bifurcation ratio, D = Drainage Density, L_g = Length of overland flow (km), F = Stream Frequency, Rt = Drainage Texture, H = Basin relief (km), C = Const. of ch. Maintenance, L_b = Basin length (km), R_h = Relief ratio, R_c = Circulatory ratio, R_e = Elongation ratio, R_f = Form factor, S_i = Shape index and C_c = Compactness coefficient

Results

Morphometric Analysis of Netravati River Basin

Morphometric parameters give a complete description of different hydrological processes such as land surface process, geomorphology, hydrology. (Ifabiyi & Eniolorunda, 2012). Strahler's method of stream order is used for the hierarchical ranking of channel networks. In the Netravati river basin, total stream segments were identified as 3630 number, in which 75.78% (2751) is first order, 18.26% (663) is second order, 4.54% (165) is third order, 0.99% (36) is fourth order, 0.27% (10) is fifth order, 0.08% (3) is sixth order, and 0.05% (2) is seventh order (Supplementary File in Table 1). In general, the linear and relief aspect of the morphometric parameters directly increases the soil erosion intensity of the river basin. However, shape parameters of the basin have opposite relation with soil erosion intensity (Ratnam et al., 2005). Based on these parameters (linear, relief, and shape), we assigned rank 1 to 5 of sub-basins for soil erosion susceptibility. The following parameters are used for the assessment of soil erosion susceptibility based on the morphometric parameters.

Stream Length (L_u)

Stream length is the linear properties of the drainage network, which deals with the measurement of the channel length of a given order. L_u of a given order is computed by the combined length of all streams of an order, u to the total number of stream segments in that order. In the Netravati river basin, there is a totally 4539.48 km length of drainage networks, out of which 2308.06 km (49.84%) is first order,

1169.28 km (25.25%), 548.21 km (11.83%), 337 km (7.29%), 103.35 km (2.23%), 72.82 km (1.57%), and 91.01 km (1.96%) are second, third, fourth, fifth, sixth, and seventh order, respectively (Table 2).

Length of the Basin (L_b)

According to Schumm (1956), the length of the basin (L_b) is calculated as the longest dimension running parallel to the main drainage line. L_b of the river basin determines the shape of the basin. The highest length of basin indicates an elongated basin. In the Netravati river basin, the maximum basin length in sub-basin is 4 (45.79 km) and the lowest is sub-basin 3 (33.12 km), while sub-basins 1, 2, and 5 have (43.23 km), (45.29 km), and 41.10 km, respectively (Table 2).

Basin Perimeter (P)

The outer boundary of the watershed that enclosed its area is called the basin perimeter. It is used to estimate the size and shape of the river basin. In this study, the basin perimeter has calculated by using ArcGIS 10.4 software. The sub-basins 2 and 3 have the largest (201.61 km) and smallest (135.68 km) basin perimeter, respectively, while sub-basins 1, 4, and 5 has 166.69 km, 184.64 km, and 180.84 km, respectively.

Bifurcation Ratio (R_b)

The bifurcation ratio is related to permeability and structural complication of the river basin. High R_b of the basin has less permeability and chance to flash flood during the storm events, whereas results in maximum soil erosion

(Howard, 1990). The mean R_b for the Netravati river basin is 3.14, while it varies between 2.65 and 3.61 (Table 2) in various sub-basins. Greater R_b value quantitatively verified that sub-basins are the mountainous origin. Therefore, the higher the R_b , the more susceptibility to soil erosion, and their rank 1 was assigned to sub-basin 5 (3.62) and the lowest rank was assigned to sub-basin 1 (2.65). The sub-basin 2 (3.55), sub-basin 4 (3.16), and sub-basin 3 (2.73) are assigned as rank 2, 3, and 4, respectively (Table 2).

Drainage Density (D)

The less drainage density in the basin indicates good vegetation cover, low relief, and a good permeable surface (Luo, 1900). Drainage density for the Netravati river basin is 1.34, though it varies from 1.26 to 1.37 in different sub-basins (Table 2). Comparatively more drainage density is observed in sub-basins 2, 4, and 5 which are directly linked to more relief, and average vegetation cover. Less drainage density is found in sub-basins 1 and 3, which are linked with low relief and less vegetation cover in the basin.

Stream Frequency (Fs)

The stream frequency is the ratio of stream numbers per unit area of the basin (Melton, 1958) and directly linked with the drainage density and runoff process and high value of stream frequency produces more runoff which leads to more soil erosion in the basin. In the Netravati river basin, maximum stream frequency was found in sub-basin 1 ($1.27/\text{km}^2$), which indicated that it has more surface runoff and thus the highest erosion susceptibility, and hence the assigned rank 1. Minimum stream frequency was found in sub-basin 5 ($0.96/\text{km}^2$) and was assigned as the lowest rank among the sub-basins. The other sub-basins which followed in decreasing order of stream frequency were sub-basin 2 ($1.13/\text{km}^2$) to sub-basin 4 ($0.99/\text{km}^2$) assigned ranks 2, 3, and 4, respectively (Table 2).

Drainage Texture (R_t)

The R_t of the river basin is calculated as the ratio of the complete number of streams network from entire orders to the perimeter of the sub-basin (Horton, 1945). The drainage texture of the river basin is calculated by the ratio of the total number of channels including all orders to the basin perimeter (Horton, 1945). According to Horton (1945), the drainage texture of the river basin is highly governed by the infiltration rate, which means that the drainage lines were numerous over the impermeable area than permeable that leads to more surface runoff and hence more soil erosion in the basin. In the Netravati river basin, the highest R_t in sub-basin 1 (1.61) representing maximum

soil erosion and assigned rank 1. The minimum R_t in sub-basin 5 (1.30) was given rank 5, which is the least erosion susceptibility. Sub-basins 2 (1.56), sub-basin 4 (1.35), and sub-basin 3 (1.31) were given ranks as 2, 3, and 4, respectively (Table 2).

Length of Overland Flow (L_g)

L_g is an independent variable and affects both the physiographic and hydrologic development of the drainage basin (Horton, 1932). L_g will be more for gentle slope and less for steeper slopes. The low values of L_g in the Netravati river basin were observed in sub-basins 2, 3, and 4 that are associated with a steep slope and high relief (Table 3). On the other hand, sub-basins 1 and 5 have higher L_g values with a relatively gentle slope and low relief. Therefore, rank 1 was assigned to sub-basin 1 (0.40) and rank 5 was assigned to sub-basin 2 (0.36). The sub-basin 3 (0.39), sub-basin 5 (0.38), and sub-basin (0.37) were assigned as rank 2, 3, and 4, respectively (Table 2).

Basin Relief (H)

The difference between the maximum and minimum points of the sub-basins is called total relief (Schumms, 1956). In the Netravati river basin, minimum basin relief was found in sub-basin 1 (149) that represented its minimum slope and therefore 207 low erosion susceptibility (Fig. 2). Henceforth, it was given rank 5. The maximum slope found in sub-basin 2 (1668), hence given rank 1 because of maximum slope and more soil erosion susceptibility. Sub-basins 3 (268), sub-basin 4 (954), and sub-basin 5 (1430) were assigned ranks 2, 3, and 4, respectively (Table 2).

Relief Ratio (R_h)

The R_h is the ratio of basin length to basin relief. The high value of R_h indicates the hilly region, and low values indicate the valley and pediplain. R_h measures the overall steepness of the basin and vital indicator of soil erosion intensity process influencing due to the slope of the basin. In this study, the highest R_h is for sub-basin 2 and the lowest for sub-basin 1 which is 25.81 and 3.45, respectively, while sub-basins 3, 4, and 5 have 8.09, 20.83, and 25.6, respectively (Table 2).

Elongation Ratio (R_e)

The R_e of the basin generally differs from 0.6 to 1.0 and represents the geology of the basin. Higher R_e is associated with less low relief and vice versa (Dar et al., 2013). In the Netravati river basin, the highest R_e is observed in sub-basin 2 (0.83) and given rank 5 because of minimum

Table 3 Correlation matrix of morphometric properties for the NRB

P	Lu	Rb	D	Lg	H	F	C	Re	Lb	Rc	Rf	T	Rh	Si	Cc
P	1	0.88	0.76	-0.75	0.82	0.064	-0.75	0.55	0.89	0.56	0.57	0.35	0.76	-0.47	-0.51
Lu	0.88	1	0.87	0.83	0.87	-0.057	-0.8	0.85	0.6	0.87	0.87	0.25	0.84	-0.79	-0.84
Rb	0.76	0.87	1	0.9	0.95	-0.45	-0.9	0.86	0.43	0.82	0.85	-0.18	0.97	-0.85	-0.83
D	0.76	0.83	0.9	1	0.98	-0.54	-0.99	0.74	0.48	0.71	0.73	-0.24	0.97	-0.76	-0.72
Lg	-0.75	0.83	-0.9	-0.99	1	0.55	0.72	-0.74	-0.48	-0.71	-0.72	0.24	-0.96	0.75	0.72
H	0.82	0.87	0.95	0.98	1	-0.48	-0.98	0.76	0.55	0.73	0.76	-0.18	0.99	-0.77	-0.74
F	0.064	-0.057	-0.45	-0.54	-0.48	1	0.55	-0.3	0.29	-0.22	-0.26	0.94	-0.55	0.44	0.3
C	-0.75	-0.8	-0.9	-0.99	-0.98	0.55	1	-0.74	-0.47	-0.71	-0.73	0.26	-0.97	0.76	0.72
Re	0.55	0.85	0.86	0.74	0.76	-0.3	-0.74	1	0.12	0.99	0.99	-0.05	0.8	-0.98	-0.99
Lb	0.89	0.6	0.43	0.48	0.55	0.29	-0.47	0.12	1	0.15	0.15	0.5	0.45	-0.037	-0.09
Rc	0.56	0.87	0.82	0.71	0.73	-0.22	-0.71	0.99	0.15	1	0.99	0.02	0.76	-0.97	-0.99
Rf	0.57	0.87	0.85	0.73	0.76	-0.26	-0.73	0.99	0.15	0.99	1	-0.01	0.79	-0.98	-0.99
T	0.35	0.25	-0.18	-0.24	-0.18	0.94	0.26	-0.05	0.5	0.02	-0.01	1	-0.26	0.2	0.06
Rh	0.76	0.84	0.97	0.97	0.99	-0.55	-0.97	0.8	0.45	0.76	0.79	-0.26	1	-0.81	-0.77
Si	-0.47	-0.79	-0.85	-0.76	-0.77	0.44	0.76	-0.98	-0.037	-0.97	-0.98	0.2	-0.81	1	0.98
Cc	-0.51	-0.84	-0.83	-0.72	-0.74	0.3	0.72	-0.99	-0.09	-0.99	-0.99	0.06	-0.77	0.98	1
SoC	5.484	7.073	4.3	3.86	4.28	1.277	-4.03	3.86	4.533	4	4.01	2.9	4.01	-3.287	-3.69
GT	36.16	36.16	36.16	36.16	36.16	36.16	36.16	36.16	36.16	36.16	36.16	36.16	36.16	36.16	36.16
W	0.1517	0.1956	0.1189	0.1067	0.1184	0.0353	-0.1114	0.1067	0.1254	0.1106	0.1109	0.0802	0.1109	-0.0909	-0.1020

Correlations marked bold are significant at $p < 0.05$; SoC = Sum of correlations, GT = Grand total, W = Weight

erosion susceptibility. On the other hand, sub-basin 1 (0.57) was given rank 1, which indicates maximum erosion susceptibility of the basin. The rivers sub-basin 4 (0.62), sub-basin 3 (0.65), and sub-basin 5 (0.76) were given ranks 2, 3, and 4, respectively (Table 2).

Circularity Ratio (R_c)

The greater the R_c value, the more circular of the basin and high to gentle relief surface, and lower R_c value indicates an elongated basin and impermeable surface. In the Netravati river basin, it is observed that sub-basin 1 (0.21) has the lowest R_c and given rank 1 because of more impermeable and more susceptibility to soil erosion. The sub-basin 2 (0.34) has the maximum R_c , and given rank 5 as it indicates it has low relief and less impermeable rate and low erosion susceptibility. The sub-basin 4 (0.23), sub-basin 3 (0.25), and sub-basin 5 (0.29) were given ranks 2, 3, and 4, respectively (Table 2).

Form Factor (R_f)

The R_f of the basin was calculated from the ratio of basin area to the square of L_b where L_b is measured parallel to the mainstream, as stated by Horton (1932) and define basin shape. The smaller value of R_f forms a more elongated and shape larger value form a more circular shape of the basin. The elongated basin has more flatter peak flow over time and easier to manage in comparison with the circular basin. The sub-basin 1 of the Netravati river basin has lower R_f (0.25), and sub-basin 2 (0.54) has higher values, given rank 1 and 5, respectively. Sub-basin 4 (0.30), sub-basin 3 (0.33), and sub-basin 5 (0.45) were given rank 2, 3, and 4, respectively (Table 2).

Shape Index (S_i)

The rate of water and sediment yield along the length and relief of the drainage basin is largely affected by its shape. In the context of soil erosion, the shape index largely behaves like a basin form factor. Therefore, the ranking of shape index is adopted like the ranking of the form factor of the basin. In the Netravati river basin, sub-basin 2 has the lowest basin shape index (1.84) and given rank 1 because of maximum erosion susceptibility. The highest basin shape index (3.89) was found in sub-basin 2 that was given rank 5 representing least soil erosion susceptibility. Sub-basins 5 (2.17), sub-basin 3 (2.94), and sub-basin 4 (3.28) were assigned ranks 2, 3, and 4, respectively (Table 2).

Compactness Coefficient (C_c)

The C_c of a basin was calculated as the ratio of basin perimeter to the circular perimeter of the same area of river basin (Horton, 1945) and directly related to the erosion risk assessment factor of the basin. The higher value of C_c indicates more vulnerable to soil erosion, and lower values indicate less vulnerable to soil erosion. In the Netravati river basin, the minimum C_c was found in sub-basin 2 (1.70) which represented the least infiltration capacity and given rank 1. Similarly, the maximum C_c was found in sub-basin 1 (2.14) representing it has utmost infiltration capacity and given rank 5. Sub-basins 5 (1.83), sub-basin 3 (1.98), and sub-basin 4 (2.06) were assigned ranks from 2, 3, and 4, respectively (Table 2).

Constant of Channel Maintenance (C)

The constant of channel maintenance is a reciprocal of drainage density (Schumm, 1956), and indirectly, it can be exposed as required minimum area of the development and channel maintenance. To maintain a single stream unit, the plain land area is required to have a comparatively bigger surface basin area than a hilly terrain. Low C value minimizes the overland flow length that leads water flows rapidly to the channel discharge under thin vegetation cover. Mountain environment generally has low CCM values due to lower infiltration of bare soil and high overland flow. In the Netravati river basin, the lowest values of C found in sub-basin 2 and sub-basin 4 are 0.73, while sub-basin 1 has the highest values (0.79). In addition, sub-basin 3 and sub-basin 5 have 0.77 and 0.74, respectively (Table 2).

Correlation of Morphometric Parameters of Netravati River Basin

The hydrological processes of the river basin are influenced by geomorphometry through their reliance on multiple other factors like geology, soil, climate, land cover (Schmidt et al., 2000). However, the interrelationship among morphometric parameters varies from one basin to another basin and is influenced by topography and climatic condition. To identify the morphometric variables for the sub-basin prioritization, it is important to understand the relationship among variables of morphometric parameters for the river basin. According to Saaty (1980), the decision criteria for different morphometric parameters should be independent and non-redundant. The independent decision criteria of morphometric parameters were identified by correlation matrix, Table 3, and implemented in an analytical hierarchical process. Hence, after identifying the correlation and given ranks of each morphometric

parameter by the WSA method in the Netravati river basin, compound factor (CF) was calculated for the final assessment of soil erosion susceptibility. The sub-basins having maximum CF will be less susceptible to soil erosion and vice versa. Based on CF values, the sub-basins of Netravati river basin were ranked into five urgency groups: (1) very high priority (sub-basin 2), (2) high priority (sub-basin 1), (3) medium priority (sub-basin 4), (4) low priority (sub-basin 5), and (5) very low priority (sub-basin 3). Table 4 shows the priority of sub-basins based on the morphometric parameters.

Prioritization of Sub-Basin Based on WSA for Morphometric Parameters

From the WSA method, the grand total which is calculated from sum of correlation of parameters is 36.16. The weightage of each parameter is calculated from the ratio of the sum of correlation of individual parameter to grand total of correlation, as given in Aher et al (2014). Thus, the formula derived for the basin is as follows:

$$\begin{aligned}
 &\text{Compound Factor} \\
 &= (0.1517 \times \text{IPR of } P) \\
 &+ (0.1957 \times \text{IPR of } Lu) + (0.1189 \times \text{IPR of } Rb) \\
 &+ (0.1067 \times \text{IPR of } D) - (0.0669 \times \text{IPR of } Lg) \\
 &+ (0.1184 \times \text{IPR of } H) + (0.0353 \times \text{IPR of } F) \\
 &- (0.1114 \times \text{IPR of } C) + (0.1067 \times \text{IPR of } Re) \\
 &+ (0.1254 \times \text{IPR of } Lb) + (0.1106 \times \text{IPR of } Rc) \\
 &+ (0.1109 \times \text{IPR of } Rf) + (0.0802 \times \text{IPR of } T) \\
 &+ (0.1109 \times \text{IPR of } Rh) - (0.0909 \times \text{IPR of } Si) \\
 &- (0.1020 \times \text{IPR of } Cc)
 \end{aligned}
 \tag{2}$$

where P = Perimeters (Km), Lu = Stream length (km), Rb = Bifurcation ratio, D = Drainage Density, Lg = Length of overland flow (km), H = Basin relief (km), F = Stream Frequency, C = Const. of ch. Maintenance, Re = Elongation ratio, Lb = Basin length (km), Rc = Circulatory ratio, Rf = Form factor, T = Drainage Texture, Rh = Relief ratio, Si = Shape index and Cc = Compactness coefficient.

Establishing the Level of Soil Erosion Susceptibility Using Land Cover Parameters

The spatial coverage of land cover greatly affects the drainage pattern and susceptibility of soil erosion of the sub-basins (Rosenqvist & Birkett, 2002). The impervious land cover either by settlement or natural process directly contributes to the surface runoff due to the impediment of the infiltration process (Dams et al., 2013). Additionally, it contributes an important role in the decisive drainage pattern in the river basin (Fohrer et al., 2001). According to Badar et al., (2013), an excessive amount of plant cover and root biomass in the basin reduces the rate of erosion. On the other hand, canopy coverage of plants reduces soil erosion by interception of rainfall (Romshoo et al., 2012). The classes generated were forest, agriculture, wasteland, grassland, and urban in the Netravati river basin (Fig. 3). The comparative area and percentage land cover of the sub-basins are presented in Table 5.

Agriculture Areas

The agriculture areas having steep slope topography get comparatively less time for water to percolate to the groundwater in comparison with flat slope because from

Table 4 LULC percentage, ranks, slope, and topographic parameters at sub-basin scale of Netravati river basin

		FS	WL	AG	GL	Urban	SL1	SL2	SL3	SL4	SL5	BL(Km)	BR (m)
SB1	%	4.19	0.07	54.13	21.05	13.59	49.11	34.96	15.56	0.35	0.02	43.23	149
	Rank	1	3	5	5	1	1	1	5	5	4	3	5
SB2	%	37.31	0.50	42.05	11.72	6.31	35.05	29.59	25.34	7.87	2.19	45.29	1169
	Rank	3	1	2	3	3	3	3	3	2	1	4	1
SB3	%	20.15	0.00	51.26	20.68	4.76	48.86	34.79	15.77	0.56	0.01	33.12	268
	Rank	2	5	4	4	4	2	2	4	4	5	1	4
SB4	%	42.82	0.12	44.20	2.47	8.52	27.13	28.28	31.13	11.66	1.79	45.79	954
	Rank	4	2	3	2	2	5	5	2	1	2	5	3
SB5	%	60.95	0.06	32.22	2.41	3.02	29.67	29.24	32.86	6.93	1.29	41.1	1052
	Rank	5	4	1	1	5	4	4	1	3	3	2	2

SB = Sub-basin, FS = Forest, WL = Wasteland, AG = Agriculture, GL = Grassland, SL1 = Slope 0°-5°, SL2 = Slope 5°-10°, SL3 = Slope 10°-20°, SL4 = Slope 20°-35°, SL5 = Slope > 35° BL = Basin Length, BR = Basin Relief

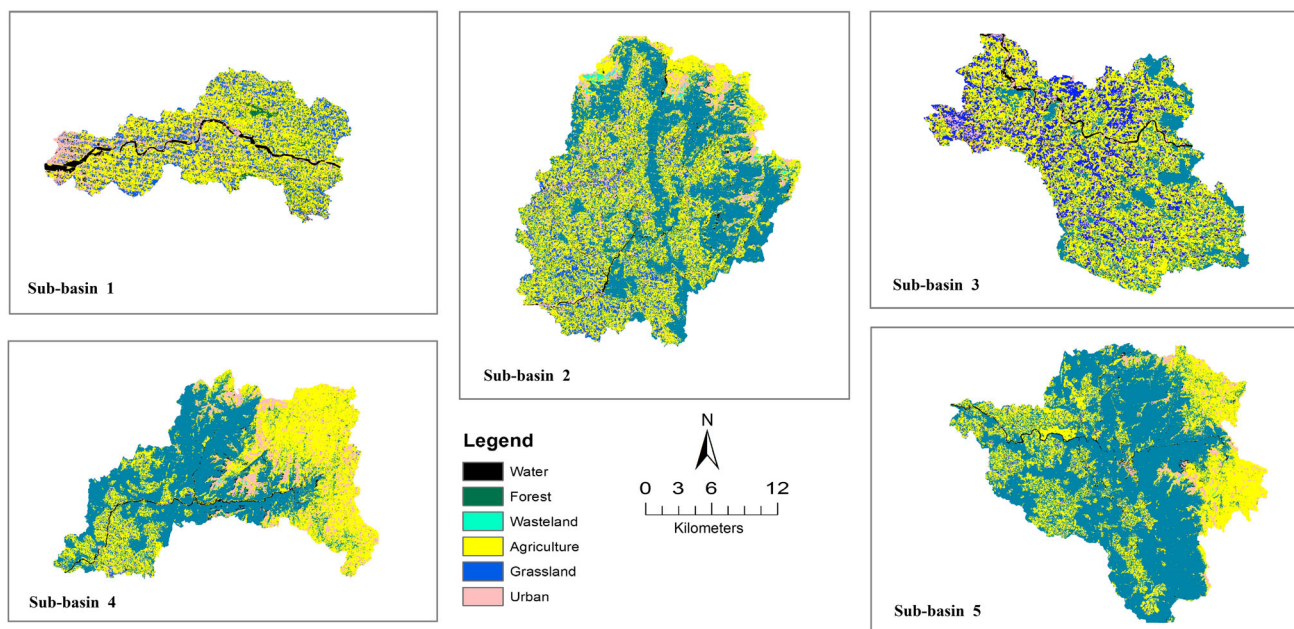


Fig. 3 Land use/land cover classification map of sub-basin for Netravati River

Table 5 Correlation matrix of LULC types and topographic parameters for the NRB

	FS	WL	AG	GL	UB	SL1	SL2	SL3	SL4	SL5	BL	BR
FS	1	0.17	-0.97	-0.92	-0.73	-0.89	-0.87	0.94	0.76	0.71	0.23	0.86
WL	0.17	1	-0.22	-0.13	-0.04	-0.29	-0.44	0.21	0.42	0.74	0.57	0.61
AG	-0.97	-0.22	1	0.85	0.70	0.81	0.80	-0.89	-0.64	-0.66	-0.25	-0.85
GL	-0.92	-0.13	0.85	1	0.43	0.98	0.94	-0.99	-0.90	-0.76	-0.50	-0.84
UB	-0.73	-0.04	0.70	0.43	1	0.40	0.40	-0.45	-0.26	-0.31	0.42	-0.52
SL1	-0.89	-0.29	0.81	0.98	0.40	1	0.99	-0.98	-0.96	-0.86	-0.59	-0.90
SL2	-0.87	-0.44	0.80	0.94	0.40	0.99	1	-0.96	-0.97	-0.93	-0.62	-0.95
SL3	0.94	0.21	-0.89	-0.99	-0.45	-0.98	-0.96	1	0.89	0.79	0.51	0.88
SL4	0.76	0.42	-0.64	-0.90	-0.26	-0.96	-0.97	0.89	1	0.91	0.66	0.88
SL5	0.71	0.74	-0.66	-0.76	-0.31	-0.86	-0.93	0.79	0.91	1	0.69	0.96
BL	0.23	0.57	-0.25	-0.50	0.42	-0.59	-0.62	0.51	0.66	0.69	1	0.55
BR	0.86	0.61	0.85	-0.84	-0.52	-0.90	-0.95	0.88	0.88	0.96	0.55	1
SoC	0.29	2.6	-0.32	-0.84	1.04	-1.29	-1.61	0.95	1.79	2.28	2.67	1.68
GT	9.24	9.24	9.24	9.24	9.24	9.24	9.24	9.24	9.24	9.24	9.24	9.24
W	0.0314	0.2814	-0.0346	-0.0909	0.1126	-0.1396	-0.1742	0.1028	0.1937	0.2468	0.2890	0.1818

Correlations marked bold are significant at $p < 0.05$

FS = Forest, WL = Wasteland, AG = Agriculture, GL = Grassland, UB = Urban, SL1 = Slope 0°–5°, SL2 = Slope 5°–10°, SL3 = Slope 10°–20°, SL4 = Slope 20°–35°, SL5 = Slope > 35° BL = Basin Length, BR = Basin Relief, SoC = Sum of correlations, GT = Grand total, W = Weight

steep slope surface runoff is more and there is a possibility to erode topsoil from the agricultural landscape. In the Netravati river basin, the agricultural area is the dominant land cover and occupied approximately 43% of the total land areas. The maximum agriculture areas were found in sub-basin 1 (54.12%), and it was thus assigned rank 1

representing most soil erosion susceptibility. Minimum agriculture areas are present in sub-basin 5 (32.22%) and thus ranked 5 and indicated less susceptible to soil erosion. Sub-basin 3 (51.26%), sub-basin 4 (44.20%), and sub-basin 2 (42.05%) were ranked 2, 3, and 4, respectively (Fig. 3 and Table 5).

Forest Areas

Forest (dense and moderately dense) areas in the Netravati river basin are the second dominant land categories which covered 36.82% of its total area. Because of the strong root system present in the forest areas, it can have good water infiltration capacity and thus less surface runoff, which leads to minimizing soil erosion. Therefore, those sub-basins have a maximum percentage of forest cover given rank 5 and have less percentage of forest given rank 1. In the Netravati river basin, the maximum forest areas are present in the sub-basin 5 (60.94%) and minimum forest areas present in the sub-basin 1 (4.19%); hence, it is given rank 5 and 1, respectively. Sub-basin 3 (20.15%), sub-basin 2 (37.30%), and sub-basin 4 (42.81%) were assigned ranks 2, 3, and 4, respectively (Fig. 3 and Table 5).

Wasteland

Wasteland areas are a degraded and unutilized land area which is prone to water and wind erosion. Hence, sub-basins having minimum wasteland areas considered as least erosion and maximum wasteland areas considered as the most susceptibility to soil erosion. In the Netravati river basin, total wasteland areas covered by 0.23% of the total study area. The maximum wasteland areas were observed in the sub-basin 2 (0.49%) and given rank 1, and minimum wasteland areas were observed in sub-basin 3 and given rank 5, representing the maximum and minimum soil erosion susceptibility, respectively, in the basin. The sub-basin 4 (0.11%), sub-basin 1 (0.07%), and sub-basin 5 (0.05%) were assigned ranks 2, 3, and 4, respectively (Fig. 3 and Table 5).

Grassland

As with forests, grassland also acts to decrease erosion susceptibility in the basin. Therefore, the ranking method of grassland is the same as in adopted in forest areas. In the Netravati river basin, the grassland area is 10.13% of the total study area. The maximum grassland is found in sub-basin 1 (21.05%), and minimum grassland was observed in sub-basin 5 and that was assigned rank 5 and 1, respectively, which indicated less and more soil erosion susceptibility in the basin, which was given rank 5. Sub-basin 3 (20.68%), sub-basin 2 (11.72%), and sub-basin 4 (2.46%) were assigned ranks 2, 3, and 4, respectively (Fig. 3 and Table 5).

Urban Area

We assumed that the sub-basins having maximum urban areas will contribute to maximum soil erosion

susceptibility because urban areas have less root systems to hold soil. In the Netravati river basin, the urban area is 7.06% of the total study area with the low and medium dense urban areas. The highest urbanization was found in sub-basin 1 (13.59%) and lowest in sub-basin 5 (3.02%) representing maximum and minimum soil erosion susceptibility, respectively, due to increased soil, wind, and water interactions. Hence, sub-basin 1 was given rank 1, and sub-basin 5 was given rank 5 in the basin. Further, sub-basin 4 (8.52%), sub-basin 2 (6.30%), and sub-basin 3 (4.76%) were assigned rank 2, 3, and 4, respectively (Fig. 3 and Table 5). However, soil erosion from LULC change also depends upon the other topographic factors like slope, slope length, and basin relief at the sub-basins scale. In this study, we have considered five different slope classes such as 0° – 5° , 5° – 10° , 10° – 20° , 20° – 35° , and $> 35^{\circ}$ to better define the soil erosion susceptibility (Table 4). Furthermore, we also consider the slope length and basin relief while considering LULC-based sub-basin prioritization of soil erosion. Greater the slope and basin relief, are more susceptible to soil erosion. Hence, the sub-basin having the highest slope and basin relief considers rank 1, and the lowest value considers rank 5 (Table 4).

As seen in the case of morphometry, no single class can explain the erosion susceptibility of a sub-basin. Therefore, after assigning ranks to each LULC class, a compound value (C_p) was calculated by WSA method of ranks of individual LULC categories and topographic parameters for each sub-basin. The sub-basin with the lowest C_p value is most susceptible to soil erosion and needs the highest priority for soil conservation measures.

Correlation of LULC Types and Topographic Parameters of the Netravati River Basin

The correlation matrix is developed among different LULC types and topographic factors (Table 5) and tested at a significant level of 5%. It is found that forest shows negative significance from agriculture, grassland, and urban areas, while agriculture showed positive significance from grassland and urban but negative correlation to the wasteland in the NRB. Similarly, high slope and basin relief show a negative correlation with urban, agriculture, and grassland but a positive correlation with forest and wasteland (Table 5). After assessing the correlation (LULC and topographic parameters), compound factor followed by the ranks of each sub-basin was calculated by the WSA method. Based on CF values of LULC types and topographic parameters, the sub-basin 2 is assigned as rank 1, sub-basin 4 is assigned as rank 2, sub-basin 5 is assigned as rank 3, sub-basin 3 is assigned as rank 4, and sub-basin 1 is assigned as rank 5 (Table 6).

Table 6 Combined morphometry and LULC-based prioritization for erosion susceptibility of NRB

SB	MCF	MPR	LTCF	LTPR	CC _p	FPR	Urgency
1	2.76	3	4.29	5	0.2319	4	Low
2	2.56	2	1.71	1	0.1404	2	High
3	4.44	5	4.23	4	0.2850	5	Very Low
4	2.31	1	1.94	2	0.1398	1	Very High
5	3.34	4	2.83	3	0.2029	3	Medium

SB = Sub-basins, MCF = Morphometric-based compound factor, MPR = Morphometric-based priority rank, LTCF = LULC and topographic-based compound factor, LTPR = LULC and topographic-based Priority rank, CC_p = Combined Compound value, FPR = Final Priority Rank

Prioritization of Sub-Basin Based on WSA for LULC and Topographic Factors

Like the compound factor calculated in Sect. 4.3 for morphometric parameters, we have also developed a formula for the calculation of compound factor for land cover types and topographic parameters. In this case, the sum of correlation of parameters is 9.24, and the weightage of each LULC type and topographic parameters is estimated by a ratio from sum of correlation of concerned parameters to grand total of correlation. The formula is represented as follows:

$$\begin{aligned}
 \text{Compound Factor} = & (0.0314 \times \text{IPR of FS}) \\
 & + (0.2814 \times \text{IPR of WL}) \\
 & - (0.0346 \times \text{IPR of AG}) \\
 & - (0.0909 \times \text{IPR of GL}) \\
 & + (0.1126 \times \text{IPR of UB}) \\
 & - (0.1396 \times \text{IPR of SL1}) \\
 & - (0.1742 \times \text{IPR of SL2}) \\
 & + (0.1028 \times \text{IPR of SL3}) \\
 & + (0.1937 \times \text{IPR of SL4}) \\
 & + (0.1818 \times \text{IPR of BR})
 \end{aligned} \tag{3}$$

where FS = Forest, WL = Wasteland, AG = Agriculture, GL = Grassland, UB = Urban, SL1 = Slope 0°–5°, SL2 = Slope 5°–10°, SL3 = Slope 10°–20°, SL4 = Slope 20°–35°, SL5 = Slope > 35° BL = Basin Length, BR = Basin Relief.

Finally, CF values for both morphometric parameters and land cover types are calculated for all parameters, and rank is assigned such a way that the lowest value of CF was given rank one and second lowest value assigned rank 2 and so on for all five sub-basins of Netravati river basin (Table 6).

Establishing the Level of Erosion Susceptibility, Based on the Combined Influence of LULC and Morphometry

In the present study, morphometric and LULC-based soil erosion susceptibility was assessed to find a single answer for the contribution of soil erosion at the sub-basins scale. To get a final sub-basin prioritization, we have calculated combined compound value (CC_p) by WSA of morphometric, LULC, and topographic compound factor components of sub-basins. In the Netravati river basin, the very high priority is assigned to sub-basin 4, high priority to sub-basin 2, medium priority to sub-basin 5, low priority to sub-basin 1, and very low priority sub-basin 3. Figure 4 and Table 6 shows the final priority of sub-basins based on the morphometric LULC analysis.

Discussion

To assess the soil erosion susceptibility, the use of remotely sensed data and application of GIS for assessment of morphometric parameters with the addition of land cover and their effects on landforms, soils, and eroded land characteristics are more appropriate than the conventional approaches. According to Samal et al. (2015), gridded-based DEM provides accurate terrain information to prepare the slope map and other morphometric parameters for assessment of soil erosion susceptibility. On the other hand, land use plays an important role in soil erosion in the basin. Therefore, it is important to consider the role of different land cover categories in the sub-basins level. In morphometric parameters, we consider the linear, shape, and circulatory factors of the basin since linear factors increase the erosion, while the shape and circulatory factor decrease

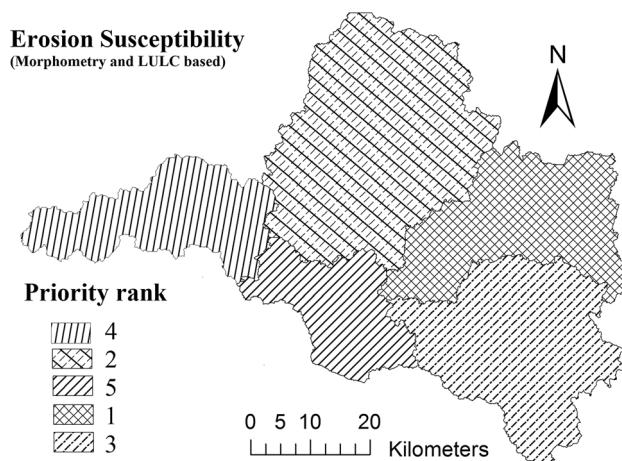


Fig. 4 Sub-basin prioritization ranking map of Netravati river basin based on the combined impact of morphometry and land use/Land cover

the soil erosion susceptibility and affect the hydrological processes in the basin. Netravati river basin is an elongated basin with moderate relief and steep slope due to its mountainous nature. Samal et al. (2015) found that the Western Ghats river basin generally has high elevation, more drainage density, and basin slope that can minimize the constant of channel maintenance and length of overland flow in the basin. The correlation matrix of the morphometric parameters, LULC types, and topographic parameters shows different inter-relationship and statically significant variables which also helps to understand the way of response to the river basin to various topographic attributes. Additionally, the correlation matrix helps to identify an optimum number of parameters for the prioritization of sub-basins. On the other hand, the higher percentage of agricultural areas in the sub-basin is assumed to influence the erosion rate (Zhang et al., 2015), while forest may decrease the rate of erosion in the basin because of the high infiltration rate.

Conclusions

In this study, we have selected the Netravati river basin in the Western Ghats, India, which is facing human pressure in terms of deforestation, agricultural expansion, and increasing of unorganized urban growth for prioritizing the sub-basins for soil erosion susceptibility based on the morphometric and LULC. The river is well-drained in nature to the Arabian sea and stream order varying from 1 to 7. The WSA approach provided a better indication for assessing the soil erosion susceptibility based on the morphometric parameters, land cover, and topographic factors.

Based on the only morphometric analysis, sub-basin 4 is identified as a very high soil erosion susceptibility zone, sub-basin 2 (high), sub-basin 1 (medium), sub-basin 5 (low), and sub-basin 3 (very low). In the case of land cover and topographic parameters-based soil erosion prioritization analysis indicates sub-basin 2 falls into very high categories, sub-basin 4 (high), sub-basin 5 (medium), sub-basin 3 (low), and sub-basin 1 (very low). The combined morphometric and land cover analysis, results showed that sub-basin 3 falls in very low priority categories to soil erosion, however, very high priority to sub-basin 4, high priority to sub-basin 2, medium priority to sub-basin 5, low priority to sub-basin 1. Hence, based on these results, appropriate control measures for further prevention of soil erosion can be required at the sub-basin level. The conservation strategies recommended include afforestation, tree plantation in urban areas, stop excessive overgrazing, contour farming, develop water conservation system at the local level, etc., for these sub-basins. The given methodology in this study will be useful for soil erosion susceptibility studies of other river basins.

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Appendix

See Figs. 5 and 6.

Fig. 5 Flowchart of methodology for both morphometry and land cover-based watershed prioritization

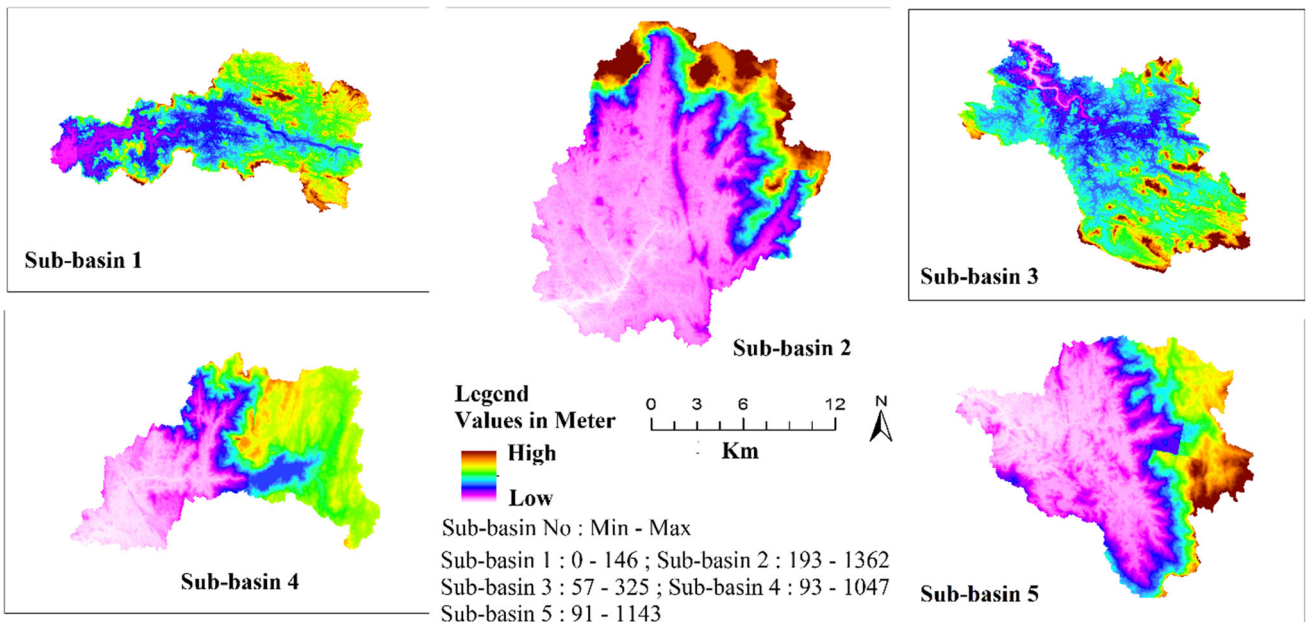
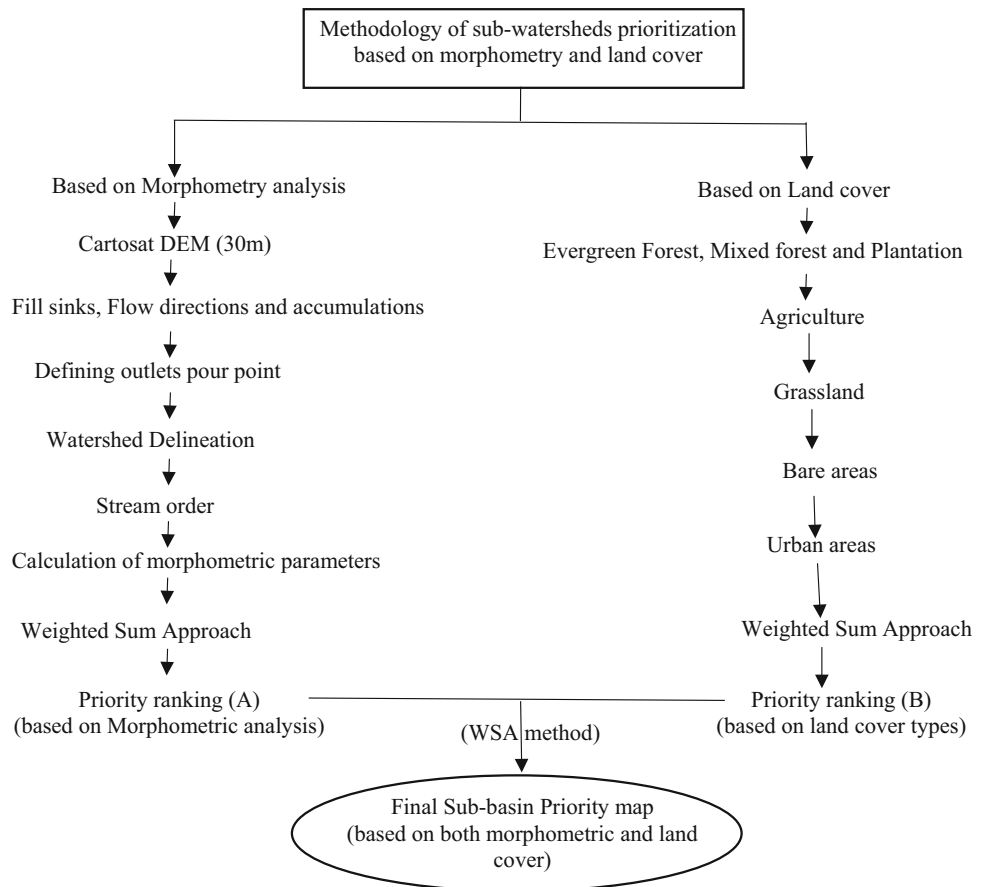


Fig. 6 Sub-basin elevation distribution of Netravati river basin

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