



Prioritization of sub-watersheds for soil erosion based on morphometric attributes using fuzzy AHP and compound factor in Jainti River basin, Jharkhand, Eastern India

Tusar Kanti Hembram¹ · Sunil Saha¹ 

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Abstract

Land degradation in the fringe extents of Chotanagpur plateau causes extensive harms to the land and agricultural productivity thereby human sustainability which magnets special provisions. So, this study intends to trace the erodibility nature in sub-basin scale to allocate the sub-watersheds that are very sensitive to soil erosion. Fourteen morphometric attributes which highly related to erosion processes is considered to prioritise the watersheds through the application of fuzzy inference-based analytical hierarchical process and compound factor (CF). A digital elevation model of 30 m spatial resolution along with Survey of India topographical maps and Google earth imagery are considered for extraction of basic, areal, landscape and shape morphometric attributes. Morphometric indices are converted into the unitless 8-bit data format (0–255), and priority weights are assigned to the specified range of control points in fuzzy AHP while consecutive ranks are assigned to indices based on their association with erosion process to get the CF values for each of watershed. The results of prioritisation through both approaches show a quite alike output that is both identifies sub-watershed 6 and 13 as very high erosion prone and CF classifies sub-watershed 4 and 8 as high erosion prone while fuzzy AHP recognises sub-watershed 4, 8, 5, 11, 14 under high-risk category. Therefore, both the results display good efficiency of morphometric indices in the assessment of erodibility priority in sub-basin scale.

Keywords Morphometry and soil erosion · Fuzzy AHP · Compound factor · Sub-watershed prioritization

✉ Sunil Saha
sunilgeo.88@gmail.com

Tusar Kanti Hembram
tusarpurulia1991@gmail.com

¹ Department of Geography, University of Gour Banga, Malda, West Bengal, India

1 Introduction

Soil is one of the lives sustaining natural resources for the humans as well as for biosphere widely (Kouli et al. 2009; Keesstra et al. 2016). Soil erosion in the different part of India causes for land degradation and 3.975 million ha land are under deterioration by gullying which is considered as the most visible form of soil erosion process (Ghosh and Guchhait 2016). Though soil erosion and deposition, both are the part of soil forming mechanism, it considered as the hazard when it effects on rivers sedimentation, agricultural loss, deforestation and land fragmentation. By the process of soil erosion, disintegrated soil particles, associated rocks and minerals, masses are separated, transported and placed in other areas (Masselink et al. 2017). Water as an erosional agent plays a vital role in degrading land quality as well as productivity (Rodrigo-Comino et al. 2016, 2017) and eliminates the uppermost layer of fertile soil, leads to threat for plant growth, sedimentation of dams, river valleys and delta development (Biswas et al. 2015) and is crucial for biosphere (Mol and Keesstra 2012; Sharma et al. 2017). Therefore to evaluates the consequences of soil erosion on environment and world economy and to framework management tactics, handling of quantitative measures of soil erosion and delineation of potential erosion risk areas at micro-, meso- and macroscale is required (Nasre et al. 2013; Alexakis et al. 2013; Shit et al. 2015). A drainage basin is the source of erosional materials that are transported through the various erosional agents such as water and air and these are mirrored in various landscape forms which offers a base for morphometric characterisation (Patel et al. 2012, 2013; Chopra et al. 2005).

Watersheds of different rivers are dynamic and progressively very significant unit of the physical environment (Patel and Srivastava 2013). Morphometric evaluation of these drainage basins can be designated as numerical characterisation and scientific exploration of basin surface attributes, stream properties and measurement of diverse forms of allied landscapes (Clarke 1996; Kottagoda and Abeysingha 2017). It discovers numerical specification regarding the geometry of basin to comprehend slope of initial surface or irregularities in hardness of rocks, structural impact, prevailing diastrophism and illustrates geological and geomorphological evolutionary phases of the basin surface (Strahler 1964; Esper Angillieri 2008). Morphometric characterisation of various river basins through advanced technological implication was done by a number of researchers. Application of remotely sensed data viz. satellite imagery, digital elevation model (DEMs) along with GIS platform is an effective tool in this context in recent days (Rai et al. 2017; Magesh et al. 2013). Therefore, morphometric variables can be recognised as the significant influencing factors in order to figure out topographical nature, soil and erosional behaviour of river basins. Most of these investigations were carried out considering the whole basin as the unit of investigation. Prioritization of small-scale sub-watersheds in this regard could be used for further improvement in the study (Biswas et al. 1999). Prioritisation may be done in respect of morphometric diversity (Khan et al. 2001; Abdul Rahaman et al. 2015; Aher et al. 2014); groundwater potentiality (Deepika et al. 2013; Jasmin and Mallikarjuna 2012); soil erosional risk (Ameri et al. 2018), etc.

In recent times, a number of research works have shown prioritization of sub-watersheds is an effective way for watershed management programmes, soil as well as land conservation, plant growth supervision and water management (Rudraiah et al. 2008; Malik et al. 2011; Okumura and Araujo 2014; Kadam et al. 2017). In light of present scenario of the high quantity of soil loss and sediment production, certain sub-watersheds reflects probable regions for special conservation implementation, and the necessity to be prioritised

instantly for further soil and water safeguarding plans to uphold sustained prospect in the agricultural sector (Farhan and Anaba 2016). Predisposing parameters for assessing erosion risk represented by linear, areal and shape attributes must be computed for conserving soil and land. All these attributes have some direct and indirect influence on the erodibility event (Ratnam et al. 2005; Patel et al. 2012, 2013). Drainage arrangement, geometry, texture, density primarily follows the topographical, geological and climatical control (Mesa 2006), that's why it could be said that these are reflective of watershed characteristics. According to Pike (2000), drainage pattern implies the consequence of varying these attributes from one place to another. So, the prioritization model can be considered as much supportive in order to understand the fluvial system, the morphological composition of each sub-watersheds for configuring well-organised soil management frame and deploying water harvesting measures to control soil erosion (Patel et al. 2013). Investigations in recent decades employed various approaches regarding sub-watershed prioritization viz. combined approach of SYI (Sediment Yield Index) and SPR (Sediment production Rate) with morphometric evaluation (Sureh et al. 2004; Meraj et al. 2017); linear, areal and shape parameter-based approach (Ameri et al. 2018; Farhan and Anaba 2016); Snyder synthetic hydrograph model (Singh and Singh 2014) and coupling of USLE (Bera 2017) or RUSLE model (Wijesundara et al. 2018) with morphometric inspection, etc. in this regard are important. Some studies have focused on MCA and MCDM (Multi-criteria decision making) models for achieving goals as it considers a number of criteria rather than single one towards accurate decision making (Meraj et al. 2015; Georgiou et al. 2015; Mulliner et al. 2016). AHP (Analytical Hierarchy Process), ANP (Analytic Network Process) and VIKOR (Ameri et al. 2017) are widely used MCDM models in the decision making procedure (Saha 2017). Combined approach fuzzy logic with MCDM techniques has come out as an effective tool for sub-watershed prioritization in the present decades (Aher et al. 2014; Abdul Rahaman et al. 2015; Kharat et al. 2016). Estimation of diverse vulnerability causes parameters in the process of decision making is linked with the foundation of system knowledge information that includes several parameters and alternatives, resulting in a high complexity (Abdul Rahaman et al. 2015). Therefore, in the present swot of research, an effort was made for erodibility prioritization of sub-watersheds of Jainti River basin by employing a novel assemble of fuzzy logic and analytical hierarchy process (FAHP). The application of MCDM models considering morphometric indices in locating sub-watersheds that are highly sensitive to soil erosion would be decisive for developing appropriate strategies to launch soil erosion control measures (Mekonnen et al. 2017).

2 Geo-hydrological appearances of the study area

Jainti River is a sixth-order tributary of Ajay River draining through the lateritic eastern part of the Chotanagpur plateau in the Deoghar and Giridih district of Jharkhand. The length of main water channel is about 49.14 km with a catchment area of 542.69 km² extends from 24°5'56"N to 24°17'52"N latitudes and from 86°23'19"E to 86°47'49"E longitudes (Fig. 1). This river basin comprises of five of fifth-order, 17 of fourth-order, 90 of third-order, 440 of second-order, 1884 of first-order streams according to Strahler's stream ordering and includes two main sub-watersheds, i.e. Dilia and Baghdaru River. The climate of the catchment area varies from sub-tropical to sub-humid experiencing dry hot summer (March to May) and heavy rains in monsoon (June to September) followed by cool dry winters (October to February). Mean annual rainfall is 1239 mm. Mean minimum

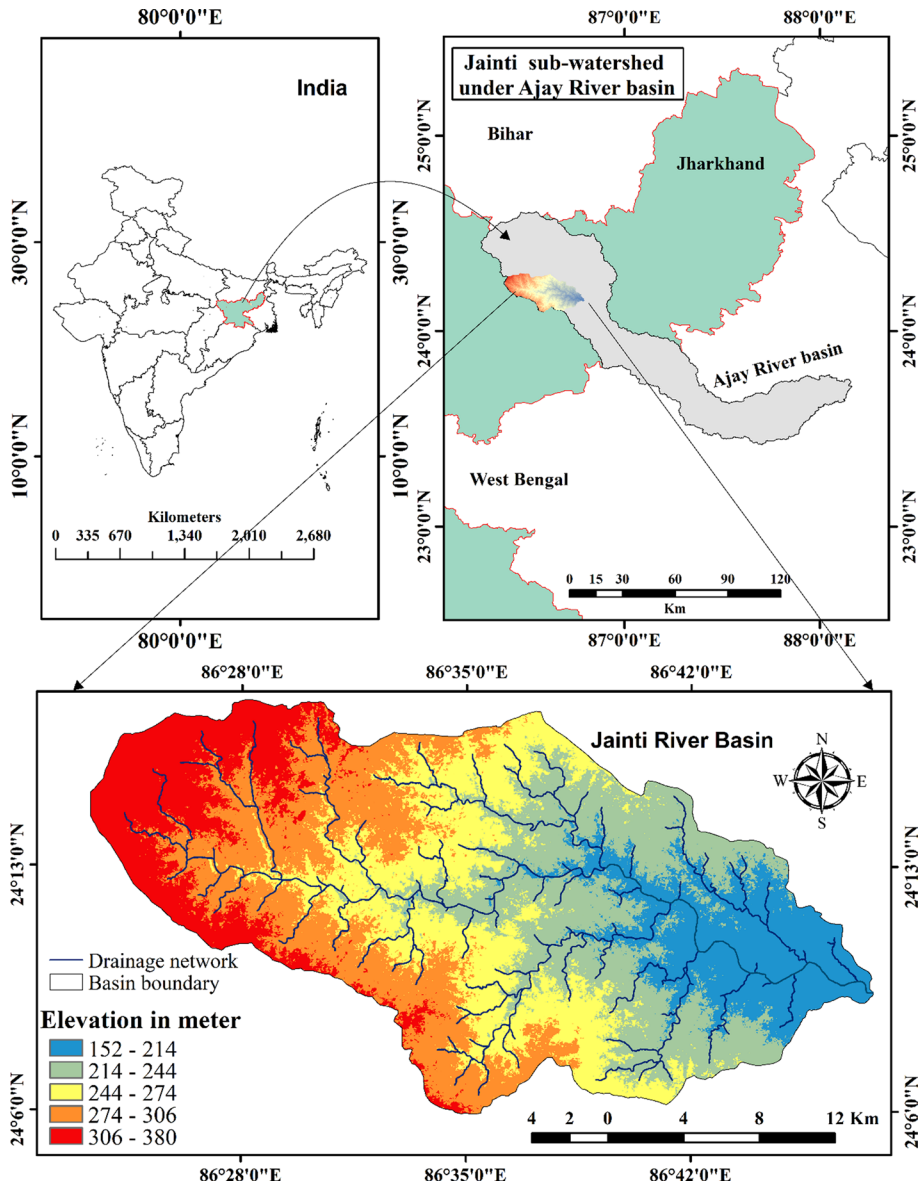


Fig. 1 Location of Jainti River basin with elevation categories

temperature in winter is 8 °C, while mean maximum temperature in summer is 43 °C. Geomorphologically, the area is a denudational plateau with irregularly distributed denudational dissected hills and valleys. This area belongs to the part of the Chotanagpur plateau with an average elevation of 270 m above mean sea level (MSL) and the direction of slope, in general, is from north-west to south-east. The watershed consists of moderate to steep slope tracts, isolated flat-topped small hills and rugged land surfaces. Overall, the slopes are gradual which lead to the development of terraced paddy fields. This basin area

consists of granitic gneissic rock of Pleistocene age overlaid by weathered lateritic regolith according to Geological Survey of India report in 1985. The whole study area covered with primary lateritic and denudated laterite. Texturally loamy-skeletal fine loamy and soils are major types of soil in this part. In the context of land cover, the amount of vegetation is very low as revealed by the land use/land cover classification (about 4.16% of the total area), quantitatively the amount of barren land (14.78%) and fallow lateritic tract (26.16%) is high. This reveals that these areas are open and exposed to erosion by surface runoff and overland flow which can be triggered up with the geo-environmental settings. This erosive nature of catchment area justified and made a point of interest for this study.

3 Materials and methodologies

3.1 Data sources

3.1.1 Watershed and sub-watershed delineation, drainage and relief extraction

The watershed boundary has been demarcated using the Survey of India (SOI) topographical maps-No. 72L/7, 72L/8, 72L/11, 72L/12, 72L/15 and 72L/16 on a scale of 1:50,000 (Table 1). At very first, the topographical maps were scanned, georeferenced and rectified using ArcGIS software version 10.3.1. Then, the georeferenced sheets were masked, mosaicked and resampled into Universal Transverse Mercator projection WGS 1984, Zone 45 North. The boundary of Jainti River basin delineated following conventional method (using contour lines) (Youssef et al. 2011). For précising the measurement, geocoded topographical maps were compared and correlated with a digital elevation model from the Shuttle Radar Topography Mission (SRTM) in Erdas Imagine Software. To delineate the boundaries of sub-watersheds, the ArcSWAT extension of ArcGIS 10.3.1 software has been used. ArcSWAT is an automated watershed delineation tool which draws the catchment boundaries considering flow direction and accumulation of each pixel of DEM, upslope contributing area and outlets. A total of 16 sub-watershed (Fig. 2) has categorised for Jainti River basin. Streams segments and relief aspects have been extracted correlating DEM (Youssef et al. 2011) and topographical maps using GIS software. Land use/land cover map has been prepared using Landsat 8 (OLI) satellite imagery from USGS earth explorer.

3.2 Application of fuzzy AHP model (FAHP)

3.2.1 Fuzzy inference system

In GIS analysis, in the decision making processes such as allocation of land and suitability analysis the concept of fuzzy is expressed as fuzzy set membership. Regarding prioritisation of sub-watersheds several techniques, i.e. statistical models, AHP and MCDM were used in various works of literature. Fuzzy logic, in this regards, has high applicability (Pradhan and Pirasteh 2010; Keshavarzi and Heidari 2010). Fuzzy logic stands up with a set of fuzzy functions that investigate each of involved attributes in the operation. It can offer a higher precision in models output by assigning various membership grades to the specified pixels (Dubois et al. 2007) and the goal is achieved through maximisation of membership degrees (Ahmed et al. 2017). Analytical hierarchical process (AHP) model

Table 1 Different data types

Data/software	Sources/URL	Type and time period	Purpose
Digital Elevation Model (DEM)	http://gdem.ersdac.jspacesystems.or.jp/	Shuttle Radar Topography Mission (SRTM) DEM; Acquisition date February, 2011, resolution 1-ARC	Sub-watershed delineation, Relief attributes
Watershed boundary and drainage properties	Survey of India (SOD), Toposheet no. 72L/7, 72L/8, 72L/11, 72L/12, 72L/15 and 72L/16	Scale 1:50,000; published in 1979-1984	Boundary demarcation of Jainti River basin; Drainage extraction
Satellite imagery (Landsat 8 OLI)	https://earthexplorer.usgs.gov/	24th March 2016, spatial resolution 30 m. Path/row- 140/043	Land use/land cover mapping
GIS software	Web platform	ArcGIS 10.3.1; ERDAS IMAGINE 2014; Excel 2013; IDRISI Selva 17.0	

Sources and purposes of use in the present study

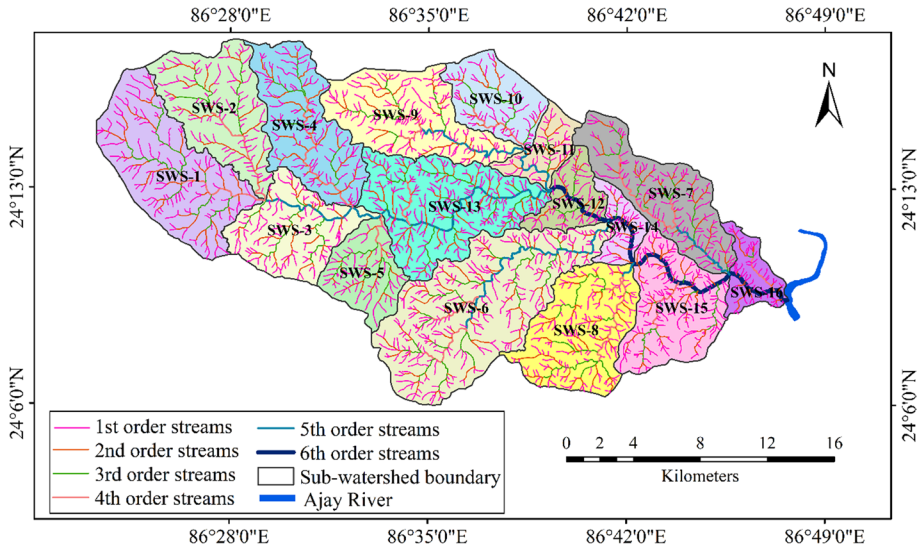


Fig. 2 Sub-watersheds and stream segments under different order classes in Jainti River basin

operated through fuzzy operations to analyse the morphometric attributes to determine the priority among sub-watersheds in respect of soil erosion risk.

3.2.2 Fuzzy model setting

Fuzzy model setting necessitates two phases (I) Determination of fuzzy membership function considering the character of the data layer (morphometric attributes in this study) and in which way behave (relationship with goal or soil erosion in definite) as per the varying nature of the data values (II) Assignment of control points for classifying which portions of the data series contributes mostly to the decision goal (Fig. 3).

(I) Membership functions and control point assignment Membership function for every predisposing morphometric attributes is allotted depending on their nature of values throughout the catchment to create the fuzzy layers of the input variables and control points (Table 2) to categorised the value ranges that is a significant slice of the specific data layer in order to influence most on the expected decision result. Thus control points for each morphometric indices are determined to convert the input variables into 8-bit data or 0–255 range for formatting it into unidirectional and dimensionless (Bharath et al. 2014) which is a very acceptable way of overlaying the various data layers with different unit values. Monotonically decreasing membership function (Eq. 1) is consigned to the fuzzified attributes which specify the declining importance with the growing distance from an objective, whereas monotonically increasing membership function is consigned to those fuzzified layers whose priority intensifies as the distance grows from the object. Particulars of Membership function and corresponding control points are enlisted in Table

$$\mu = \frac{1}{\left\{ 1 + \left(\frac{x-c_2}{c_2-c_1} \right)^2 \right\}} \tag{1}$$

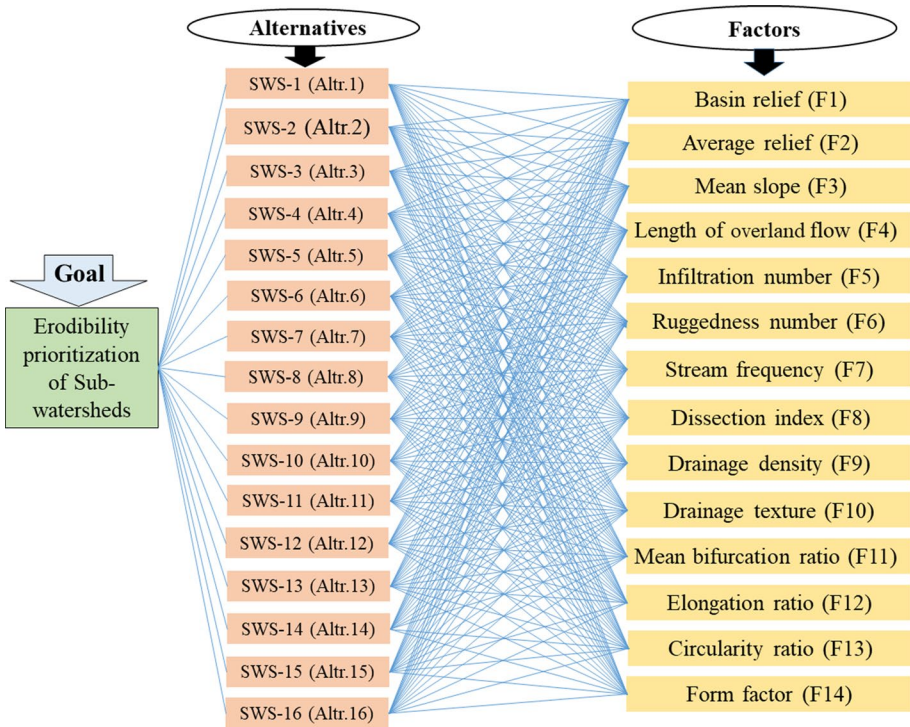


Fig. 3 Framework of fuzzy operation among the goal, alternatives and factors of the present analysis

Table 2 Assignment of control points and determination of fuzzy membership function and shape for conversion of data layers and pairwise comparison in AHP

Morphometric factors	Relation with the goal	Control points		Fuzzy membership function	Fuzzy membership shape	
		C_1	C_2			
Landscape parameter	B_r	+	85	134	Monotonically increasing	Sigmoidal
	R_n	+	0.20	0.37	Monotonically increasing	Sigmoidal
	D_i	+	0.30	0.41	Monotonically increasing	Sigmoidal
	A_r	+	275	318.5	Monotonically increasing	Sigmoidal
	M_{slp}	+	2.50	2.90	Monotonically increasing	Sigmoidal
Areal parameter	R_{bm}	+	4.50	6.95	Monotonically increasing	Sigmoidal
	D_d	+	2.40	3.13	Monotonically increasing	Sigmoidal
	F_s	+	110	357	Monotonically increasing	Sigmoidal
	R_t	+	5.0	8.31	Monotonically increasing	Sigmoidal
	L_{of}	+	1.25	1.56	Monotonically increasing	Sigmoidal
	I_f	-	500	140	Monotonically decreasing	Sigmoidal
Shape parameter	R_e	-	0.65	.53	Monotonically decreasing	Sigmoidal
	R_c	-	0.55	0.40	Monotonically decreasing	Sigmoidal
	R_f	-	0.33	0.22	Monotonically decreasing	Sigmoidal

where μ signifies the standardised score of an attribute, x represents primary score, c_1 base control value and c_2 is end control value. This c_1 and c_2 used for optimisation of the decision space.

$$\mu_d(x_n) = \exp \left((x_n - v_n)^2 / 2s_n^2 \right) \tag{2}$$

This (Eq. 2) generates fuzzy sets laws for instance, if A is a fuzzy set, derivative result from all the inputs of S rules, fuzzy set $\mu_{e_j}(S)$ where s goes to 'S' with different choices of agent X and can be expressed as following (Eq. 3):

$$\mu_E(X) = \bigoplus_1^S \mu_{E(S)} \tag{3}$$

(II) AHP weight computation and weighted linear combination overlay model AHP is the statistical illustration of the fuzzy behavioural system and recognises which factor is more influential and which factor is less influential. To contract the influential capability of the morphometric attributes, all these are used as input elements to compute relative weights of each attribute through pairwise comparison matrix. At very first, this method involves breakdown of the decision goal into a hierarchy of factor, i.e. consideration of the conditioning variables. Further, the preference values are dispensed to each morphometric criteria as per AHP importance scale to define relative importance of them in association with the soil erosion susceptibility (Saaty 1977; Saaty and Vargas 2001). The degree of association of each attribute is considered based on literature (Ouma and Tateishi 2014; Ameri et al. 2018), nature of the study area and expert choice-based model operated through row geometric mean approximation (Richardson and Amankwatia 2018). Computed weights for every individual attribute is calibrated and validated following the laws of consistency ratio (CR) that is the value of <0.1 which constitute the trustworthiness and applicability for further progression. Pairwise comparison matrix and their relative weights are shown in the table below which designates that which attributes are the determining factor for erosion hazard assessment among the sub-watersheds of Jainti River basin. The pairwise comparison matrix formulated based on Eq. 4.

$$A = \begin{matrix} & a_{11} & a_{12} & a_{13} & a_{1n} \\ a_{21} & & a_{22} & a_{23} & a_{2n} \\ \dots & \dots & a_{ij} & \dots & \dots \\ a_{n1} & a_{n2} & a_{n3} & & a_{nn} \end{matrix} \tag{4}$$

where

$$a_{ij} = \frac{W_i}{W_j} = \frac{\text{weight for attribute } i}{\text{weight for attribute } j}$$

The consistency ratio is computed following the equation:

$$CR = CI/RI \tag{5}$$

where CI = Consistency Index and RI = Random Index. CI reflects the judgement consistency in the analysis (Saaty 1980; Ouma and Tateishi 2014).

Further, the computed weights for each attribute along with the fuzzy converted layers of the factors are integrated to get the erosion priority values employing weighted

linear combination overlay approach (Eq. 6) as all the attributes are unitless and unidirectional in nature.

$$LC = \frac{1}{n} * \sum_{i=1}^n D_i * W_i \quad (6)$$

where LC signifies the linear sum of weights, n denotes the number of attributes used, D is the decisive parameter and weight of the attributes is W .

3.3 Compound factor (CF) model

The compound factor method follows the codes of the knowledge-driven framework (Todorovski and Džeroski 2006) and changes over the subjective understanding of a phenomenon by logical learning into a quantitative estimation. This method involves in assigning a sequential rank to each of the parameters based on their degree of determination to the aim. The mean value of the assigned ranks for a watershed represents its relative priority compared to others (Altaf et al. 2014). This method can be expressed as (Eq. 7):

$$CF = 1/n \sum_{i=1}^{Pn} R \quad (7)$$

where CF is the compound factor value, 'R' is the rank of the parameters and 'Pn' is the count of parameters.

Aiming to prioritize erodibility nature of sub-watersheds a total of 14 areal, linear and shape morphometric indices were assigned ranks for 16 SWS of Jainti River basin. The maximum compound value of areal and linear indices was ranked 1 for its high erosion risk, second largest value ranked as 2 and rest were done as the same while in case of shape indices the procedure was vice-versa that is lowest CF value considered as rank 1 and so on. Comparing to areal and linear indices, shape attributes has an inverse connection with them, i.e. least values denotes the higher erodibility (Balasubramanian et al. 2017; Patel et al. 2012).

4 Results and discussion

4.1 Evaluation of morphometric parameters and their influence on soil erosion

Geomorphometric investigation was carried out to chalk out the connections among various earth system processes and elements that are geomorphology, geohydrology and aspects of geology (Ifabiyi and Eniolorunda 2012). Assessment of probable soil erosion vulnerability necessitates several parameters concerning drainage and relief aspects. Morphometric properties have a great role in runoff and infiltration capacity. The Jainti River basin spreads over an area of 542.69 km² with a perimeter of 114.70 km and textured with a number of 2395 streams. The count of first-order stream is about 1836 and accounts 76.66% of all streams pointing the erosional risk of this catchment. Fourteen morphometric indices of basic, linear, landscape, areal and shape attributes (Tables 3 and 4) was included for 16 sub-watersheds to prioritize them on the basis of erodibility risk (Fig. 5).

Table 3 Morphometric attributes and formula/method used for computation for the sub-watersheds of Jainti River basin

Morphometric attributes	Equation/method used	References
Watershed area (W_a)	Area of the catchment in km ² derived through GIS operation	Horton (1945)
Watershed perimeter (W_p)	Length of catchment boundary in km (GIS analysis)	Horton (1945)
Basin length (L_b)	Length of the longest dimension of the watershed	Schumm (1956)
Stream order (μ)	Hierarchical order of streams (GIS analysis)	Strahler (1964)
No. of streams (N_μ)	Sum of streams for all order (GIS analysis)	Strahler (1957)
Length of stream (L_u)	Linear measurement of each stream in km (GIS analysis)	Horton (1945)
Mean length of streams (L_{sm})	$L_{sm} = L_u / N_\mu$ where L_u = total length of all streams and N_μ = no. of streams in an order	Strahler (1964)
Frequency of stream (F_s)	$F_s = N_\mu / W_a$	Horton (1945)
Drainage density (D_d)	$D_d = L_u / W_a$	Horton (1945)
Bifurcation ratio (R_b)	$R_b = N_\mu / N_{\mu+1} + 1$ where $N_{\mu+1} + 1$ = total stream in next order	Schumm (1956)
Mean bifurcation ratio (R_{bm})	Average value of bifurcation ratio in all order for a watershed	Strahler (1964)
Drainage texture ratio (R_t)	$R_t = N_\mu / W_p$	Horton (1945)
Infiltration number (I_f)	$I_f = F_s \times D_d$	Faniran (1968)
Length of overland flow (L_{of})	$L_{of} = 1 / D_d \times 2$	Horton (1945)
Ruggedness number (R_n)	$R_n = D_d \times (B_r / 1000)$	Moore et al. (1991)
Watershed relief (B_r)	$B_r = H_{max} - H_{min}$	Strahler (1952)
Dissection index (D_i)	$D_i = B_r / H_{max}$	Singh and Dubey (1994)
Maximum relief (H_{max})	Highest elevation within a specific unit of area	Smith (1935)
Minimum relief (H_{min})	Lowest elevation within a specific unit of area	Smith (1935)
Average relief (A_r)	$A_r = \frac{H_{max} - H_{min}}{2}$	Smith (1935)
Mean slope (M_{slp})	Analysed through GIS software	–
Form factor (R_f)	$R_f = W_a / L_b^2$ where L_b^2 = square of basin length	Horton (1945)
Elongation ratio (R_e)	$R_e = 2 / L_b \times (W_a / 0.5)$	Schumm (1956)
Circularity ratio (R_c)	$R_c = 4 \times \pi \times W_a / W_p^2$	Miller (1953)

4.1.1 Basic morphometric variables

The basic parameters are basin area, basin parameter, length of the basin and maximum and minimum relief of the basin which are very much important in analysing areal, linear and landscape indices for a river basin (Balasubramanian et al. 2017). The Jainti River is a sixth-order tributary of river Ajay with 542.69 km² area and 114.70 km perimeter. The number of streams under each order classes represented in Fig. 4. The catchment is further sub-divided into 16 sub-watersheds using the ArcSWAT extension. Table 5 denotes that SWS-6 has the biggest catchment and boundary while SWS-14 is the smallest one.

Table 4 Calculation of linear morphometric indices of sub-watersheds in Jainti River basin

SWS	Stream numbers (N_p)						Bifurcation ratio (R_b)						Stream length in km (L_{ij})											
	N_1	N_2	N_3	N_4	N_5	N_6	Total	N_1/N_2	N_2/N_3	N_3/N_4	N_4/N_5	Sum	Mean	N_1	N_2	N_3	N_4	N_5	N_6	Total				
1	114	27	6	17	0	0	164	4.22	4.50	0.35	0.00	9.08	3.03	62.31	26.80	18.74	6.57	0.00	0.00	0.00	114.42			
2	92	17	3	1	0	0	113	5.41	5.67	3.00	0.00	14.08	4.69	48.02	18.62	9.91	7.97	0.00	0.00	0.00	84.52			
3	99	28	5	0	1	0	133	3.54	5.60	0.00	0.00	9.14	4.57	46.10	17.81	11.82	0.00	8.55	0.00	0.00	84.28			
4	122	33	5	1	0	0	161	3.70	6.60	5.00	0.00	15.30	5.10	54.90	23.40	9.73	9.78	0.00	0.00	0.00	97.81			
5	63	14	3	1	0	0	81	4.50	4.67	3.00	0.00	12.17	4.06	31.80	9.48	8.86	3.21	0.00	0.00	0.00	53.35			
6	270	67	16	3	1	0	357	4.03	4.19	5.33	3.00	16.55	4.14	122.17	40.23	27.27	8.40	15.19	0.00	0.00	213.26			
7	143	32	8	2	1	0	186	4.47	4.00	4.00	2.00	14.47	3.62	56.25	18.41	10.11	9.27	5.08	0.00	0.00	99.12			
8	151	39	8	2	1	0	201	3.87	4.88	4.00	2.00	14.75	3.69	61.11	25.90	17.79	8.27	1.20	0.00	0.00	114.27			
9	132	32	5	2	1	0	172	4.13	6.40	2.50	2.00	15.03	3.76	61.25	21.53	10.98	3.79	8.16	0.00	0.00	105.71			
10	64	15	4	1	0	0	84	4.27	3.75	4.00	0.00	12.02	4.01	28.32	9.61	8.37	4.85	0.00	0.00	0.00	51.15			
11	42	8	1	0	1	0	52	5.25	8.00	0.00	0.00	13.25	6.63	17.82	7.23	2.32	0.00	4.67	0.00	0.00	32.04			
12	62	11	5	0	0	1	79	5.64	2.20	0.00	0.00	7.84	3.92	25.34	7.24	4.46	0.00	0.00	4.47	0.00	41.51			
13	242	64	12	2	2	0	322	3.78	5.33	6.00	1.00	16.11	4.03	90.97	36.27	17.68	3.34	13.81	0.00	0.00	162.07			
14	39	10	1	0	0	1	51	3.90	10.00	0.00	0.00	13.90	6.95	15.74	6.45	0.97	0.00	0.00	3.84	0.00	27.00			
15	150	36	6	1	0	1	194	4.17	6.00	6.00	0.00	16.17	5.39	63.63	24.69	8.35	3.93	0.00	7.49	0.00	108.09			
16	51	13	2	1	0	1	68	3.92	6.50	2.00	0.00	12.42	4.14	18.90	6.84	0.71	2.74	0.00	4.40	0.00	33.59			
Total	1836	446	90	34	8	4	2418	-	-	-	-	-	-	804.6	300.5	168.07	72.12	56.7	20.2	0.00	1422.2			
SWS	Mean length of streams (L_{sm})						Mean stream length ratio (L_{rm})																	
	N_1	N_2	N_3	N_4	N_5	N_6	N_2/N_1	N_3/N_2	N_4/N_3	N_5/N_4	N_6/N_5	Total												
1	0.55	0.99	3.12	0.39	0.00	0.00	1.82	3.15	0.12	0.00	0.00	5.09												
2	0.52	1.10	3.30	7.97	0.00	0.00	2.10	3.02	2.41	0.00	0.00	7.53												
3	0.47	0.64	2.36	0.00	8.55	0.00	1.37	3.72	0.00	0.00	0.00	5.08												
4	0.45	0.71	1.95	9.78	0.00	0.00	1.58	2.74	5.03	0.00	0.00	9.35												

Table 4 (continued)

SWS	Mean length of streams (L_{sb})						Mean stream length ratio (L_{rm})					
	N_1	N_2	N_3	N_4	N_5	N_6	N_2/N_1	N_3/N_2	N_4/N_3	N_5/N_4	N_6/N_5	Total
5	0.50	0.68	2.95	3.21	0.00	0.00	1.34	4.36	1.09	0.00	0.00	6.79
6	0.45	0.60	1.70	2.80	15.19	0.00	1.33	2.84	1.64	5.43	0.00	11.23
7	0.39	0.58	1.26	4.64	5.08	0.00	1.46	2.20	3.67	1.10	0.00	8.42
8	0.40	0.66	2.22	4.14	1.20	0.00	1.64	3.35	1.86	0.29	0.00	7.14
9	0.46	0.67	2.20	1.90	8.16	0.00	1.45	3.26	0.86	4.31	0.00	9.88
10	0.44	0.64	2.09	4.85	0.00	0.00	1.45	3.27	2.32	0.00	0.00	7.03
11	0.42	0.90	2.32	0.00	4.67	0.00	2.13	2.57	0.00	0.00	0.00	4.70
12	0.41	0.66	0.89	0.00	0.00	4.47	1.61	1.36	0.00	0.00	0.00	2.97
13	0.38	0.57	1.47	1.67	6.91	0.00	1.51	2.60	1.13	4.13	0.00	9.38
14	0.40	0.65	0.97	0.00	0.00	3.84	1.60	1.50	0.00	0.00	0.00	3.10
15	0.42	0.69	1.39	3.93	0.00	7.49	1.62	2.03	2.82	0.00	0.00	6.47
16	0.37	0.53	0.36	2.74	0.00	4.40	1.42	0.67	7.72	0.00	0.00	9.81

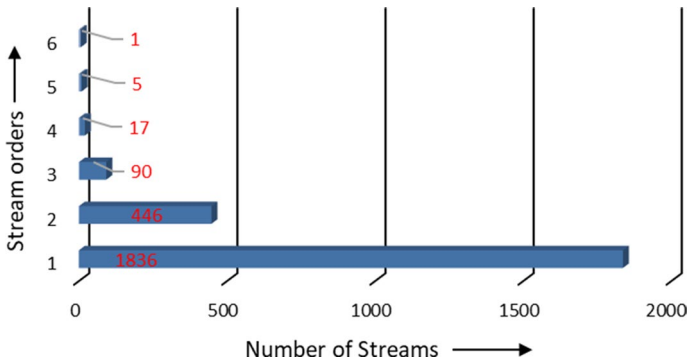


Fig. 4 Number of streams under different orders of Jainti River basin

Table 5 Sub-watershed wise basic and landscape attributes for Jainti River basin

Sub-watershed	Area of the basin (km ²)	Basin parameter (km)	Length of the basin (km)	Minimum relief (m)	Maximum relief (m)
SWS-1	53.08	38.54	12.51	257	380
SWS-2	39.65	33.93	10.35	258	361
SWS-3	32.74	28.71	9.51	229	328
SWS-4	39.39	34.89	11.45	241	354
SWS-5	20.92	20.79	7.11	233	319
SWS-6	78.66	47.54	16.30	189	323
SWS-7	37.18	32.51	12.86	170	248
SWS-8	41.21	30.19	9.44	174	286
SWS-9	41.53	35.28	12.44	211	316
SWS-10	22.95	20.49	7.11	211	287
SWS-11	11.89	18.49	5.95	193	291
SWS-12	14.00	19.57	5.53	185	241
SWS-13	51.76	38.71	11.83	193	295
SWS-14	9.34	17.09	4.75	177	231
SWS-15	36.89	27.88	8.96	165	251
SWS-16	11.51	18.86	6.01	162	213

Highest elevated areas found in SWS-1 to SWS-6 and low land areas spread over SWS-11 to SWS-16 watersheds. The length of the basin (L_b) is the ratio between main watercourse and longest length of the catchment. ' L_b ' is the key to determine shape indices. The ' L_b ' within 16 watersheds ranges from 4.75 km to 16.30 km.

4.1.2 Landscape attributes

Relief of basin (B_r) The basin relief may define as the maximum difference in altitude between highest and lowest point within a unit of area. ' B_r ' has the direct connection with the hydrological behaviour of a watershed (Schumm 1956; Sreedevi et al. 2009). It is one

SWS	Landscape parameter					Areal Parameter					Shape parameter			
	Rn	Br	Di	Ar	Mslp	Rbm	Dd	Fs	Rt	Lof	If	Re	Rc	Rf
1	0.23	105	0.28	318.5	2.45	3.03	2.16	164	4.26	1.08	353.52	0.66	0.45	0.34
2	0.22	103	0.29	309.3	2.42	4.69	2.13	113	3.33	1.07	240.85	0.69	0.43	0.37
3	0.25	99	0.3	278.5	2.60	4.57	2.57	133	4.63	1.29	342.4	0.68	0.5	0.36
4	0.28	113	0.32	297.5	2.49	5.1	2.48	161	4.61	1.24	399.81	0.62	0.41	0.3
5	0.22	86	0.27	276	2.91	4.06	2.55	81	3.9	1.27	206.54	0.73	0.61	0.41
6	0.36	134	0.41	256	2.77	4.14	2.71	357	7.51	1.36	967.89	0.61	0.44	0.3
7	0.21	78	0.31	209	2.44	3.62	2.67	186	5.72	1.33	495.82	0.54	0.44	0.22
8	0.31	112	0.39	230	2.71	3.69	2.77	201	6.66	1.39	557.38	0.77	0.57	0.46
9	0.27	105	0.33	263.5	2.48	3.76	2.55	172	4.88	1.27	437.76	0.58	0.42	0.27
10	0.17	76	0.26	249	2.59	4.01	2.23	84	4.1	1.11	187.25	0.76	0.69	0.45
11	0.16	58	0.2	242	2.77	6.63	2.7	52	2.81	1.35	140.16	0.65	0.44	0.34
12	0.17	56	0.23	213	2.63	3.92	2.97	79	4.04	1.48	234.3	0.76	0.46	0.46
13	0.32	102	0.35	244	2.83	4.03	3.13	322	8.32	1.57	1008.26	0.69	0.43	0.37
14	0.16	54	0.23	204	2.69	6.95	2.89	51	2.98	1.45	147.49	0.73	0.4	0.41
15	0.25	86	0.34	208	2.53	5.39	2.93	194	6.96	1.46	568.36	0.77	0.6	0.46
16	0.15	51	0.24	187.5	2.19	4.14	2.92	68	3.61	1.46	198.5	0.64	0.41	0.32

Fig. 5 Data bars showing the distribution of values of selected parameters for sub-watersheds for erodibility prioritisation

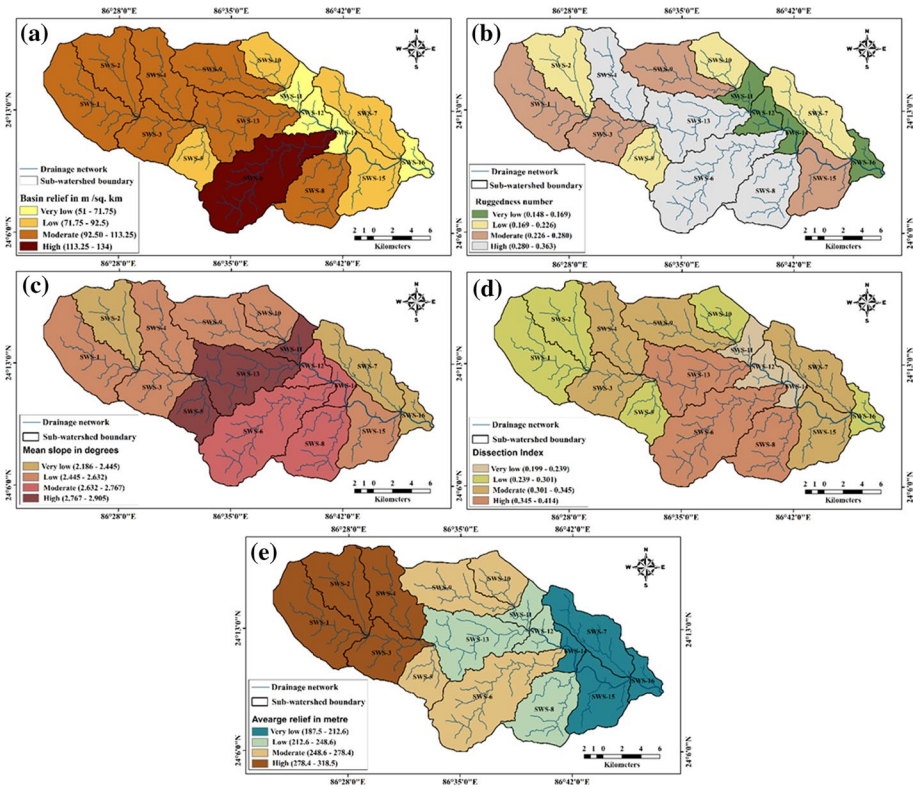


Fig. 6 Landscape morphometric attributes of sub-watersheds in Jainti River basin: a basin relief, b ruggedness number, c mean slope, d dissection index, e average relief

of the indicators slope and erosional events (denudation and weathering, water erosion) that are prevailing within catchment. The 'B_r' in the sub-watersheds contrasts from 51 m in SWS-16 to 134 m in SWS-6 (Fig. 5). Comparatively highland areas are found in the upper catchment and SWS-1, 2, 4, 8, 9 denotes a notably 'B_r' (Fig. 6a).

Mean slope (M_{slp}) The mean slope is computed from DEM for each of sub-watershed. Mean value of slope measured by considering each pixel value and the total number of pixel within a watershed. Runoff volume, length of runoff and runoff rapidity which directly causes soil surface erosion, depends on the amount of slope (Mesa 2006). In the present scenario all of the watersheds are identical (Fig. 5) relating to ' M_{slp} ', which indicates large relief diversity in each watershed and are sensitive to erosion (Fig. 6c).

Ruggedness number (R_n) ' R_n ' indicates the undulation of relief and implies to compute the flood potentiality of watersheds (Ameri et al. 2017). Erodibility nature of a watershed increase with increasing value of ' R_n ' and vice-versa. Therefore, SWS-4, 6, 8, 13 are more disposed to erosion with an index value of >0.28 comparing to rest. SWS-10, 11, 12, 14 and 16 has the least ' R_n ' value (<0.17) with less erosion threat and others can be categorised into moderate class (Fig. 6b).

Dissection Index (D_i) ' D_i ' value of a watershed assume the magnitude of vertical cutting by streams and surface runoff and elucidate the gradations of landform evolution of physiographic units (Rai et al. 2017). The value of ' D_i ' ranges from 0 to 1 of which closest to 0 denotes non-appearance of vertical cutting while values inclined to 1 explains the presence of vertical erosion. Among the sub-watersheds of Jainti River basin, ' D_i ' values varies from 0.20 in SWS-11 to 0.41 in SWS-6 indicates less dissection (Fig. 6d).

Average relief (A_r) Average relief of the watersheds varies between 187.5 m to 318.5 m pointing a rapid gradient in overall relief from source to the outlets. Higher relief accelerates surface runoff and thus subjected to soil erosion event (Phillips 1990). Though most of the watersheds have higher average relief (>250 m), SWS-1 and SWS-2 denote the highest ' A_r ' are very sensitive to erosional phenomena (Fig. 6e).

4.1.3 Areal morphometric variables

Drainage density (D_d) Drainage density lay emphasis on spacing among the streams and is the ratio of total length of drainage in all orders to a specific unit of area. It is determined by materials of underlying surface, type and amount of vegetation cover and relief properties. High ' D_d ' areas specify higher runoff, less infiltration capacity and contrary (Prasad et al. 2008; Thomas et al. 2012). In the sub-watersheds of Jainti River basin, the ' D_d ' value varies between 2.13 in SWS-2 to 3.13 in SWS-13 (Fig. 7a). Therefore, each SWS has very high drainage density (>1.5) and exposure to erode (Fig. 5) (Deju 1971).

Mean bifurcation ratio (R_{bm}) Bifurcation ratio is the proportion of the total number of streams in a particular order to the total number streams of the next larger order (Table 4) (Horton 1945). Low ' R_{bm} ' values point towards less geologic controls and direct the less distortion in drainage development. High values of ' R_b ' indicates the dominance of overland flow and flash flood risk during heavy rainstorm event (Kanth and Hassan 2012). SWS-11, 14 and 15 has the highest sensitivity of erosion considering ' R_{bm} ' individually (Fig. 5). The ' R_{bm} ' values throughout the sub-watersheds differ between 3.03 in SWS-1 and 6.95 in SWS-14 (Fig. 7b). High values of bifurcation ratio between first- and second-order drainages are the indication of enhanced soil erosion in a watershed (Ameri et al. 2017), and Table 4 shows the high values as well.

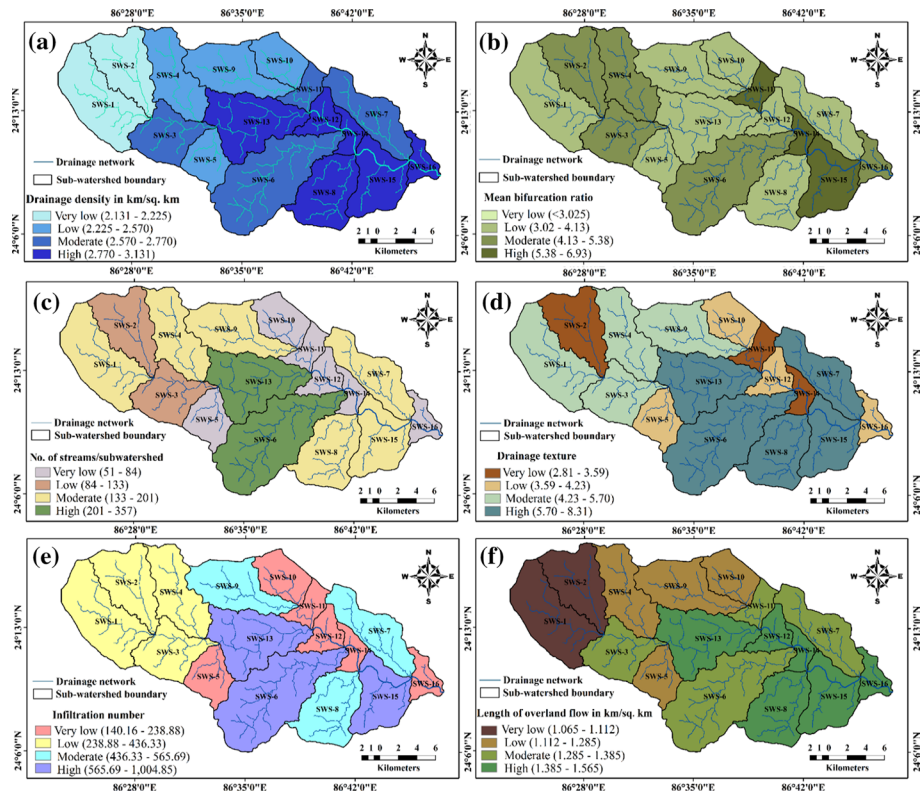


Fig. 7 Areal morphometric attributes of sub-watersheds in Jaiti River basin: **a** drainage density, **b** mean bifurcation ratio, **c** stream number, **d** drainage texture ratio, **e** infiltration number, **f** length of overland flow

Drainage texture ratio (R_t) In order to trace out the erosional behaviour of basin surface, ' R_t ' is a considerable factor in the geomorphic study of the watershed which is governed by a number of geo-environmental parameters, i.e. soil type, rainfall and temperature, soil infiltration rate, and stages of soil formation (Ameri et al. 2017). The ' R_t ' in the present scenario ranges from 2.81 for SWS-11 to 8.32 for SWS-13 (Fig. 7d). Smith (1950) enlisted ' R_t ' as supersoft (more than 15), soft (10–15), moderate (4–10) and rough (<4) and the present categorisation denotes that SWS-6, SWS-7, SWS-8, SWS-13 and SWS-15 falls within the moderate category with moderate sensitivity to erosion individually. Contrary, SWS-2, SWS-11, and SWS-14 has the least sensitivity to erosional event and specifies the presence of hard rock materials against penetration.

Length of overland flow (L_{of}) The measure of non-channel water flow over the earth surface from a location of drainage divide to the place before it turns into a channel flow is termed as the length of overland flow (Horton 1945). It independently influences the topsoil detachment and transportation and is more effective on gently sloped areas rather than steep slope areas. SWS-8, 12, 13, 15 and 16 have the ' L_{of} ' of > 3.185 km/km² area indicating high risk for erosion in an individual stretch (Fig. 7f). The ' L_{of} ' values have an extent from 1.065 to 1.565 km per sq. km area in the sub-watersheds of Jaiti River basin.

Infiltration number (I_f) As one of the morphometric indices of the watershed, infiltration number implies to understand the permeability of the surface soil and inversely associate with the erosion event. Greater values of ' I_f ' reveals impermeable surface and resistance to soil loss and contrary the lower values point towards erosive nature of the watersheds. In the present study, sub-watershed wise infiltration numbers are computed. SWS-11 has the lowest ' I_f ' value with higher risk for erosion, and SWS-13 has the highest value with resistance to erosion (Fig. 7e).

4.1.4 Shape morphometric variables

Elongation ratio (R_e) Elongation ratio of a river basin reveals its evolutionary phases and existing structural processes viz. elongated figure denotes earlier phase of development with the presence of neotectonic event (Lykoudi and Angelaki 2004) while less elongated rather circularity trend recommends high efficiency in resistance to runoff. ' R_e ' values in the sub-watersheds of Jainti River basin differs between 0.535 and 0.767 (Fig. 8a). Generally, values near to the 1, the region are characterised with lower altitude, whereas regions closer to the value of 0.6 are marked with steep slope tracts with higher elevation. Therefore, considering ' R_e ' as an individual index, SWS-7 is more prone to erosion and SWS-8, SWS-15 are more resistance to erode (Fig. 5).

Circularity ratio (R_c) ' R_c ' is associated with drainage discharge and is governed by the length and number of streams, topography, geology and land cover types of the catchment (Miller 1953). Greater ' R_c ' values epitomise the circular form of the basins with permeability and roughness of the soil surface while lower value indicates the elongated shape with the presence of impenetrable surface layer and low roughness. The ' R_c ' values range from 0.40 to 0.68 in the sub-watersheds (Fig. 8b). SWS-4 and SWS-14 have the lowest ' R_c ' values with greater erosion risk (Fig. 5).

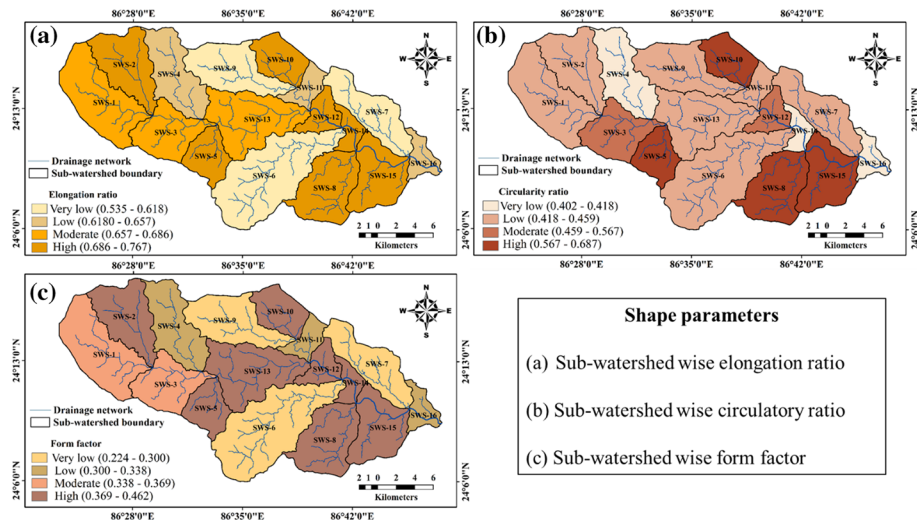


Fig. 8 Shape morphometric attributes of sub-watersheds in Jainti River basin: **a** elongation ratio, **b** circularity ratio, **c** form factor

Form factor (R_f) ' R_f ' is the ratio of watershed area to the square of the longest dimension of the watershed that is length of the watershed (Schumm 1956). The values of > 0.7854 for ' R_f ' denotes circular shape of the watershed (Rai et al. 2014) while decreasing values indicates elongated nature of watersheds. Form factor values among the sub-watersheds in this basin area differ between 0.224 and 0.462 means all of 16 sub-watersheds are closest to the elongated shape rather than circularity (Fig. 8c). This attribute has an inverse association with soil erosion process that is SWS-7 with ' R_f ' value of 0.22 has the highest sensitivity to erode while SWS-8 and SWS-12 with a value of 0.46 fall under lowest risk (Fig. 5).

4.2 Erodibility prioritization by fuzzy AHP

The final result of erosion risk assessment is derived from fuzzy operation through computation of comparison matrices to get weights for each parameter as per AHP model (Table 6) (Saaty and Vargas 2001) and assigning weighting values to the converted fuzzified layers of morphometric attributes. The result shows unitless range values from 40 to 167. Sub-watersheds with the highest value that is 167 ranked as first in terms of sensitivity to soil erosion and rest are ranked consecutively in decreasing order with decreasing result value. The rank suggests the SWS-6 is very highly under erosion risk and requires special conservation measures (Fig. 9a). The next high erosive sub-watersheds are SWS-13, 11, 8, 4 also magnets the attention of management planners. Further, sub-watersheds are clustered to find out watersheds that are similar in erodibility nature. To categorised them on the basis of derived result values Jenks (1989) natural breaks classification method employed and the classes are very low risk (40–46), low (46–66), moderate risk (66–80), high (80–129) and very high risk (129–167) (Fig. 9b). Table 7 describes the watersheds fall under different risk category of soil erosion.

Table 6 Pairwise comparison matrix for the calculation of eigenvector of weights of each morphometric attributes based on their degree of importance with soil erosion process

	B_r	M_{slp}	I_f	L_{of}	D_d	R_{bm}	R_n	D_i	F_s	A_r	R_t	R_e	R_c	R_f	Eigenvector of weight
B_r	1														0.1447
M_{slp}	1	1													0.1394
I_f	0.5	1	1												0.1195
L_{of}	0.5	0.5	1	1											0.1081
D_d	0.5	0.5	0.5	1	1										0.1103
R_{bm}	0.5	0.5	0.5	0.5	0.5	1									0.0727
R_n	0.33	0.33	0.5	0.5	0.33	1	1								0.0591
D_i	0.33	0.33	0.5	0.33	0.33	0.5	1	1							0.0476
F_s	0.33	0.33	0.33	0.33	0.33	0.5	0.5	1	1						0.0441
A_r	0.33	0.33	0.33	0.33	0.33	0.5	0.5	1	1	1					0.0490
R_t	0.25	0.25	0.25	0.33	0.25	0.33	1	0.5	0.5	0.5	1				0.0322
R_e	0.25	0.25	0.25	0.25	0.25	0.33	0.33	0.5	0.5	0.33	1	1			0.0265
R_c	0.25	0.25	0.25	0.25	0.25	0.33	0.33	0.5	0.5	0.33	0.5	1	1		0.0254
R_f	0.20	0.20	0.20	0.20	0.20	0.20	0.33	0.33	0.33	0.25	0.5	0.5	0.5	1	0.0184
Consistency ratio = 0.020															

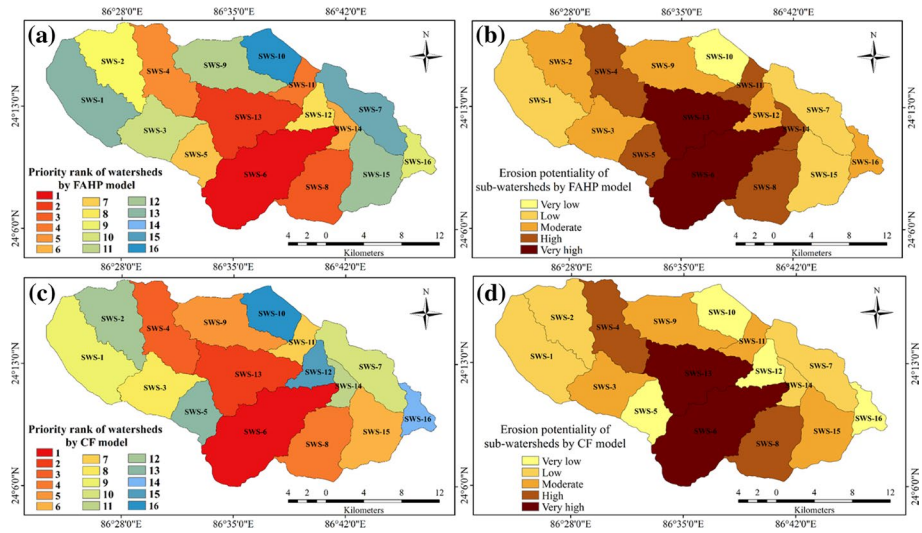


Fig. 9 The outcome of the present investigation: **a** Priority rank of sub-watersheds by FAHP model, **b** categorisation of sub-watersheds into different priority classes derived through FAHP, **c** Priority rank of sub-watersheds by CF model, **d** categorisation of sub-watersheds into different priority classes derived through CF model

Table 7 Categorisation of sub-watersheds based on erosion priority classes produced by FAHP and CF model

Result of FAHP model	Erosion priority classes	Result of CF model
SWS-10	Very low risk	SWS-10, 5,12, 16
SWS-1, 7, 15,	Low risk	SWS-1, 2, 7, 14
SWS-2, 3, 9, 12, 16	Moderate risk	SWS-3, 9, 11, 15
SWS-4, 5, 8, 11, 14	High risk	SWS-4,8
SWS-6, 13	Very high risk	SWS- 6, 13

4.3 Erodibility prioritization by CF model

Compound factor model is a very précised method to evaluate the earth surface properties particularly for the basin scale in various works of literature and comprehensively used for sustainable water resource management and scientific planning of sub-watersheds in data scarce areas (Altaf et al. 2014). In the present swot of analysis, considering a total of 14 significant areal, landscape and shape morphometric indices in respect of soil erosion are analysed to get the CF values against each sub-watershed. The CF values are derived by summing up the indices rank values and then by averaging them (Eq. 6). The values of indices that can mostly direct the soil erosion are assigned with rank 1 and so on (Fig. 9c). Thus, lowest compound factor value is marked as rank 1 (Table 8) and is extremely sensitive to soil erosion (Patel et al. 2012; Balasubramanian et al. 2017). As a final point, all of the watersheds are categorised into five priority class, i.e. very low, low, moderate, high, and very high (Fig. 9d) in terms of soil erosion risk using natural breaks classification method (Jenks 1989; Nooka Ratnam et al. 2005). In the study area, nine types of major land use /land cover have been identified (Table 9 and Fig. 10). Slope stability and instability are

Table 8 Assignment of priority rank for individual morphometric parameters and computation of compound factor values

SWS	R_n	B_r	D_i	A_r	M_{slp}	R_{bm}	D_d	F_s	R_t	L_{of}	I_f	R_c	R_c	R_f	SUM	CF	RANK
1	8	4	10	1	13	16	15	7	7	15	9	7	10	1	123	8.79	9
2	9	6	9	2	15	5	16	10	10	16	7	10	5	13	133	9.50	12
3	6	8	8	4	8	6	10	9	9	10	8	8	12	16	122	8.71	8
4	4	2	6	3	11	4	13	8	8	13	10	4	3	4	93	6.64	3
5	10	9	11	5	1	9	11	12	12	11	5	12	15	14	137	9.79	13
6	1	1	1	7	4	8	7	1	1	7	15	3	8	8	72	5.14	1
7	11	11	7	13	14	15	9	5	5	9	12	1	9	7	128	9.14	10
8	3	3	2	11	5	14	6	3	3	6	13	16	13	5	103	7.36	4
9	5	5	5	6	12	13	12	6	6	12	11	2	4	10	109	7.79	5
10	12	12	12	8	9	11	14	11	11	14	3	13	16	9	155	11.07	16
11	14	13	16	10	3	2	8	15	15	8	1	6	7	3	121	8.64	7
12	13	14	15	12	7	12	2	13	13	2	6	14	11	11	145	10.36	15
13	2	7	3	9	2	10	1	2	2	1	16	9	6	2	72	5.14	2
14	15	15	14	15	6	1	5	16	16	5	2	11	1	6	128	9.14	11
15	7	10	4	14	10	3	3	4	4	3	14	15	14	15	120	8.57	6
16	16	16	13	16	16	7	4	14	14	4	4	5	2	12	143	10.21	14

sometimes determined by various types of land use and land cover. Areas protected with dense vegetation cover, agricultural fields usually stay more stable to erosion event. Fallow and barren lands are more risk-prone areas for faster soil erosion and slope instability, as these are highly exposed lands to rain drop hit and surface runoff (Cevik and Topal 2003). Distribution of fallow and barren lands (14.33 and 13.89% area of the total basin) throughout the each sub-watersheds is remarkably high (Table 9). Amount of vegetation cover (16.38% of the total basin area) which (both scattered and dense) reflects the resistance of basin surface is very little. However, large number of human settlement and mass agricultural practices (10.34% and 41.10% of the total area of the Jainti basin, respectively) signifies the needs for agriculture as well as livelihood sustainability (Fig. 10). These also imply the significance of basin surface characteristics in identifying high priority sub-watersheds for conserving agricultural consumptions and societal benefits among the basin dwellers.

4.4 Comparison and validation of the results

The present study finds the erosion sensitivity magnitude among the sub-watersheds and ranking and categorisation of them. To validate the final outcome of the present investigation, two approaches are employed. The first one is the cross-validation of the results of fuzzy AHP and CF model. The comparison shows a quiet similarity viz. both models identifies the SWS-6 and SWS-13 as very high erosion prone. In case of high-risk class FAHP and CF, both models identify SWS-4, 8 though FAHP also categorised SWS-8, 11 and 14 in this class and rest risk classes are categorised in Table 8. The second method for validating the result is field pilot survey in some selected sub-watersheds and Google earth observation. The filed situations of some locations are represented in Fig. 11. The pilot survey carried out with GPS receiver and revealed high erosion nature of SWS-4, 5, 6 and 13.

Table 9 Amount (in %) of land use/land cover types to the total area of each sub-watershed

Land use/land cover	Sub-watersheds															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Waterbodies	5.00	3.71	4.64	4.30	1.82	3.18	2.10	2.02	2.00	2.12	3.08	4.89	4.88	6.20	7.88	7.88
Sand deposit	0.03	0.00	0.18	0.00	0.04	0.04	0.07	0.01	0.04	0.01	0.68	1.10	0.83	3.00	0.63	0.63
Cropped agricultural land	17.88	23.28	17.77	20.82	16.58	22.51	30.28	21.26	19.04	20.41	29.24	24.84	22.11	25.24	38.78	38.78
Scattered vegetation	19.56	16.83	18.38	18.52	15.66	15.99	9.62	13.17	16.57	17.45	14.33	15.05	17.10	7.21	8.76	8.76
Barren land	22.28	15.42	22.02	23.17	16.15	12.59	6.42	13.67	14.38	12.15	5.78	9.62	10.57	5.75	5.49	5.49
Seasonal agricultural field	8.37	8.51	5.40	7.81	8.94	19.76	36.61	28.48	15.37	20.04	30.04	27.22	18.59	35.94	29.86	29.86
Settlement and built-up	7.08	9.61	8.20	8.57	11.61	12.54	10.88	10.77	9.90	18.57	10.48	11.25	9.92	11.29	7.08	7.08
Fallow unproductive land	18.79	22.29	21.96	14.72	27.93	13.13	4.00	10.58	22.25	9.22	6.34	5.95	15.58	5.36	1.20	1.20
Dense forest	1.02	0.35	1.45	2.08	1.27	0.25	0.02	0.03	0.44	0.05	0.02	0.08	0.42	0.01	0.34	0.34

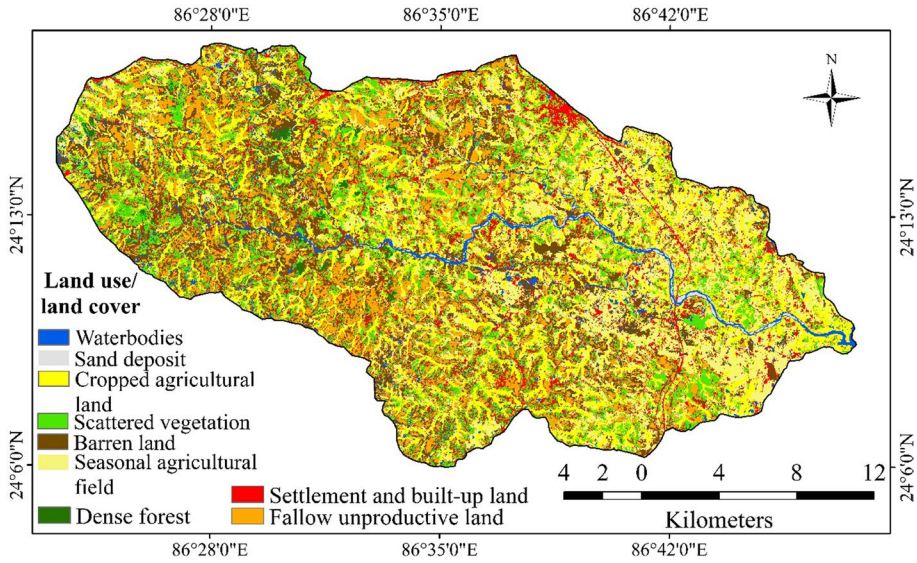


Fig. 10 Categorized land use/land cover types of the Jainti River basin

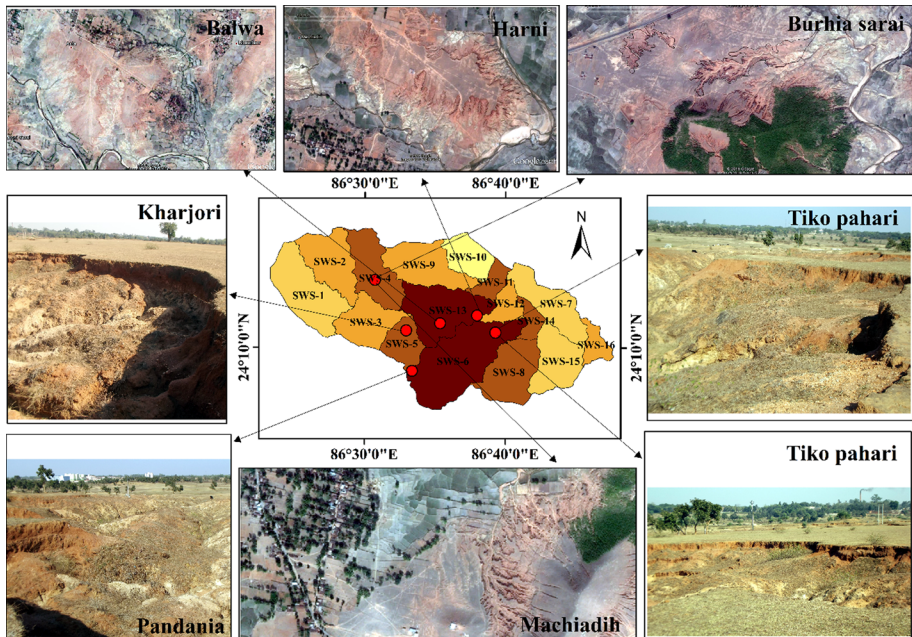


Fig. 11 Affected areas of some selected sub-watersheds by different forms of soil erosion states the erodibility nature of these magnates planners attention for conservation practices

5 Conclusion

This study illustrates the effectiveness of fuzzy AHP and compound factor-based prioritization methods with the assist of GIS techniques. Integration of fuzzy set rules with analytical hierarchical process is employed to precise the results. The result confirms quite similarity with the outcome by Compound Factor, a widely and successfully used prioritization technique. Both approaches identify SWS-6 and SWS-13 as most sensitive to erosional hazard risk and magnets specific measures. Therefore, fuzzy AHP can be used as a proficient and feasible technique in watershed prioritization tactics for framing and constructing the effective sustainable supervision.

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