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ORIGINAL ARTICLE

Hydro-morphometric characterization and prioritization of sub-watersheds for land and water resource management using fuzzy analytical hierarchical process (FAHP): a case study of upper Rihand watershed of Chhattisgarh State, India

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Abstract

Rihand reservoir is continuously experiencing siltation due to erosion in upper basin; thus study of morphometric-based prioritization of sub-watershed has become prerequisite for implementation of measures for conservation of soil and water resource. In present study an attempted has been made to analyze characterization and prioritization of sub-watersheds in upper basin of Rihand watershed based on hydro-morphometric parameters, in an environment of Geographical Information System (GIS), with the help of Multicriteria Decision Making through Fuzzy Analytical Hierarchy Process (FAHP) techniques in order to identify critical sub-watersheds for conservation and management of soil and water resource. The morphometric characterization has been done through measurement of linear, areal and relief aspect of over seven sub-watersheds using SOI topographical sheet and SRTM data with the help of Q GIS 3.10 and White box software. In the purpose prioritization of sub-watersheds FAHP method has been implemented through assigning fuzzy membership function to each of 15 morphometric parameters by deriving their relationships with erosional hazard and criterion weight has been obtained using Saaty's (Fundamentals of decision making and priority theory with analytical hierarchical process, RWS Publications University of Pittsburgh, Pittusburgh, 1980) proposed method. Based on prioritization approach the entire sub-watershed has divided into 3 vulnerable zones, i.e., high, medium and low. This study reveals that about 29% area of the watershed is falls under high vulnerable zone as they obtained high priority value and required immediate measures. In addition, ideal locations for measure structure to prevent soil erosion and maximize infiltration has been proposed which will be useful to the decision maker for land and water resource conservation, management, and sustainable agricultural development.

Keywords Fuzzy analytical hierarchy process (FAHP) · Erosional hazard · Geographical information system (GIS) · Hydro-morphometric parameter · Multicriteria decision making (MCDM) · Rihand watershed

Abbreviations

AHP	Analytical hierarchy process
DEM	Digital elevation model
GIS	Geographical information system
FAHP	Fuzzy analytical hierarchy process
LU/LC	Land use/land cover
MCDM	Multicriteria decision making
SOI	Survey of India
MSL	Mean sea level
TFN	Triangular fuzzy number
SRTM	Shuttle Radar Topography Mission
SW	Sub-watershed
CI	Consistency index
C_c	Compactness constant
R_c	Circularity ratio
D_d	Drainage density
I_f	Infiltration no
L_{sm}	Mean stream length
R_{bm}	Mean bifurcation ratio

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F_s	Stream frequency
R_t	Drainage texture ratio
R_e	Elongation ratio
O_l	Length of overland flow
R_r	Relative relief
R_h	Relief ratio
R_n	Ruggedness no.
HI	Hypsometric integral
S_g	Stream gradient
R_f	Form factor

Introduction

Land and water are two vital resources for all living organism on the earth surface; human beings also required these to ensure food security, economic development and social progress. Amount of fresh water and fertile soil on the earth is limited and rapid rate of population growth increasing pressure on these non-renewal natural resources all over the world. As a result soil and water resources are deteriorating due to human activities such as deforestation, land-use changes, agricultural activity, industrialization, road construction, and river bed mining, etc. This environmental issue in turn gives birth of several hydro-morphological hazards, e.g., soil erosion, flood, drought, reduction in land capability, etc., within watershed boundary. Therefore, a sustainable management plan for conservation soil and water resources is required to fulfill demand of increasing population for food and other needs. Watershed deterioration has become a common environmental issue all over the world including India. A watershed is a natural hydrological unit that generates surface runoff from the rainfall which flows through channel, streams, river, lakes or oceans (Prabhakar et al. 2019; Chopra et al. 2005). Natural resources of a watershed may be deteriorated due to increase in surface runoff which leads soil erosion and which in turns decrease productivity of the land and groundwater level. Thus, water resources management decisions depend on the timings of runoff characteristics of a watershed (Dinpashoh et al. 2019). The timing of runoff generally depends on surface hydrology, morphometric configuration, lithological characteristics and climatic condition of a basin. Morphometric configuration of a watershed is not only predominantly control the timing of surface runoff but also it is the reflection of lithological, geological, hydrological and climatic condition; therefore, morphometry analysis can play a vital role in finding out the characteristics of watershed (Prabhakar et al. 2019; Tripathi et al. 2003). Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms (Rahaman et al. 2015; Obi Reddy et al. 2002; Agarwal 1998). Horton (1932) was the pioneer followed by Miller (1953); Schumm (1956); Strahler (1957, 1964), Hadley (1961); Leopold (1964), and Morisawa (1985) have laid the foundation of quantitative analysis of basin morphometry. Many researchers (Maurya et al. 2016; Pandey et al. 2012; Srivastava and Sharma 2012; Kiran and Srivastava 2012; Thakur et al. 2012; Ratnam et al. 2005) have been suggested that morphometric analysis of sub-watershed can be applied for Selection of suitable location of check dams, trenches, grooves, farm ponds, spillways, etc., constructed for soil and water conservation, and (Sangma and Guru 2020; Mohd and Sajjad 2014; Biswas et al. 1999) can be applied as a single factor without considering the soil characteristics for prioritization of sub-watershed. Morphometric parameters are divided into three aspects, i.e., linear aspects, areal aspects, and relief aspects, to analyze the shape and dimension of the earth surface (Sangma and Guru 2020; Putty 2007; Nag and Chakraborty 2003a, b; Bats and Jackson 1987; Clarke 1966).Use of Remote Sensing GIS techniques in morphometric analysis of watershed has been widely used across the world by many researchers (Fang 2020; Gautam 2020; Islam and Deb Barman 2020; Sinha et al. 2019; Adhami 2019; Jafarzadegan and Merwade 2017; Roy and Sahu 2016a, b; Das et al. 2016; Sharma and Tiwari 2014; Koshak and Dawod 2011; Manu and Anirudhan 2008; Kouli et al. 2007; Vijith and Satheesh 2006; Grohmann 2004; Svetlitchnyi et al. 2003; Lapena and Martz 1996) and suggested that as a proficient tools for morphometric characterization of sub-watersheds (Farhan and Anaba 2016; Rahaman et al. 2015; Aher et al. 2013; Kanth and Hassan 2012; Sreedevi et al. 2009; Grohmann 2004; Singh 1994).

Prioritization of watershed is a crucial part of watershed management as in contains some sensitive information regarding surface hydrology and able to answer some crucial questions such as where to construct check dam, reservoir, embankment, etc., to minimize soil erosion, flooding, bank erosion and maximize infiltration. Traditional approach in watershed prioritization from basin morphometry is based on calculating compound parameter value, as averages of individual parameter values (Gopinath 2016). But recently a large number of studies have been undertaken for prioritizing sub-catchments with consideration of different factors by multicriteria decision-making models (MCDM) (Chitsaz and Malekian 2016; Rahaman et al. 2015; Ahmadisharaf et al. 2015; Kim et al. 2013; Chung et al. 2011). Some researcher have used (Gopinath 2016; Chowdary et al. 2013) Analytic network process (ANP) while a large number of researcher (Jain and Ramsankaran 2019; Balasubramani et al. 2019; Meshram et al. 2019; Rahmati et al. 2016; Jaiswal et al. 2014) suggested analytical hierarchical process (AHP). Many researchers (Chang 1996; Boender et al. 1989; Van Laarhoven and Pedrycz 1983) have preferred fuzzy AHP over AHP as it provides more adequate portrayal of basic leadership and used (Hembram and Saha 2020; Meshram 2019; Jaiswal et al. 2015) analytical hierarchical process (FAHP)as a reliable tools for prioritization of sub-watershed.

Rihand river is mainly a rain feed river and an important tributary of river Son, originated from Matiranga hills, in the region south west of the Mainpat plateau, which is about 1,100 meters above mean sea level. Due to steep slope and undulated topography along with human interference, the upper part of the watershed is continuously subjected to erosion and as a result eroded materials were deposited in Rihand Reservoir. In present study an approach has been made to compute prioritization index for sub-watersheds of Rihand watershed based on morphometry parameters with application of analytical hierarchical process (APH) to identifying and ranking suitable micro-watersheds for soil and water conservation and proper utilization in a sustainable way. The study combined with geology and geomorphology studies, helps to construct a primary hydrological diagnosis (Kumar et al. 2017; Hungr 2000).

Materials and methods

Study area

Rihand River is an important right bank tributary of river Son originated from Matiranga hills in the region south west of the Mainpat plateau flows toward north through Chhattisgarh, Madhya Pradesh Uttar Pradesh and joins to River Son near Sonbhadra district of Uttar Pradesh. The main tributaries of Rihand river are the Mahan, the Morana (Morni), the Geur, the Gagar, the Gobri, the Piparkachar, the Ramdia and the Galphulla. The study area comprise in upper part of Rihand river which is lies between geographic 22° 30′ N to 24° 00′ N latitudes and 82° 15′ E to 83° 45′ E longitudes (Fig. 1) and a total area of about 10, 210 km^2. The maximum and minimum elevation encountered in the watershed about 277 m and 1200 m above mean sea level (MSL). Southern parts of the basin covered by dense forest while agricultural activity is dominate in the northern part. This river is mainly rain feed river and the maximum rainfall is received during the month of July to October. Geologically, the Rihand River watershed is part of Vindhyan Supergroup, composed

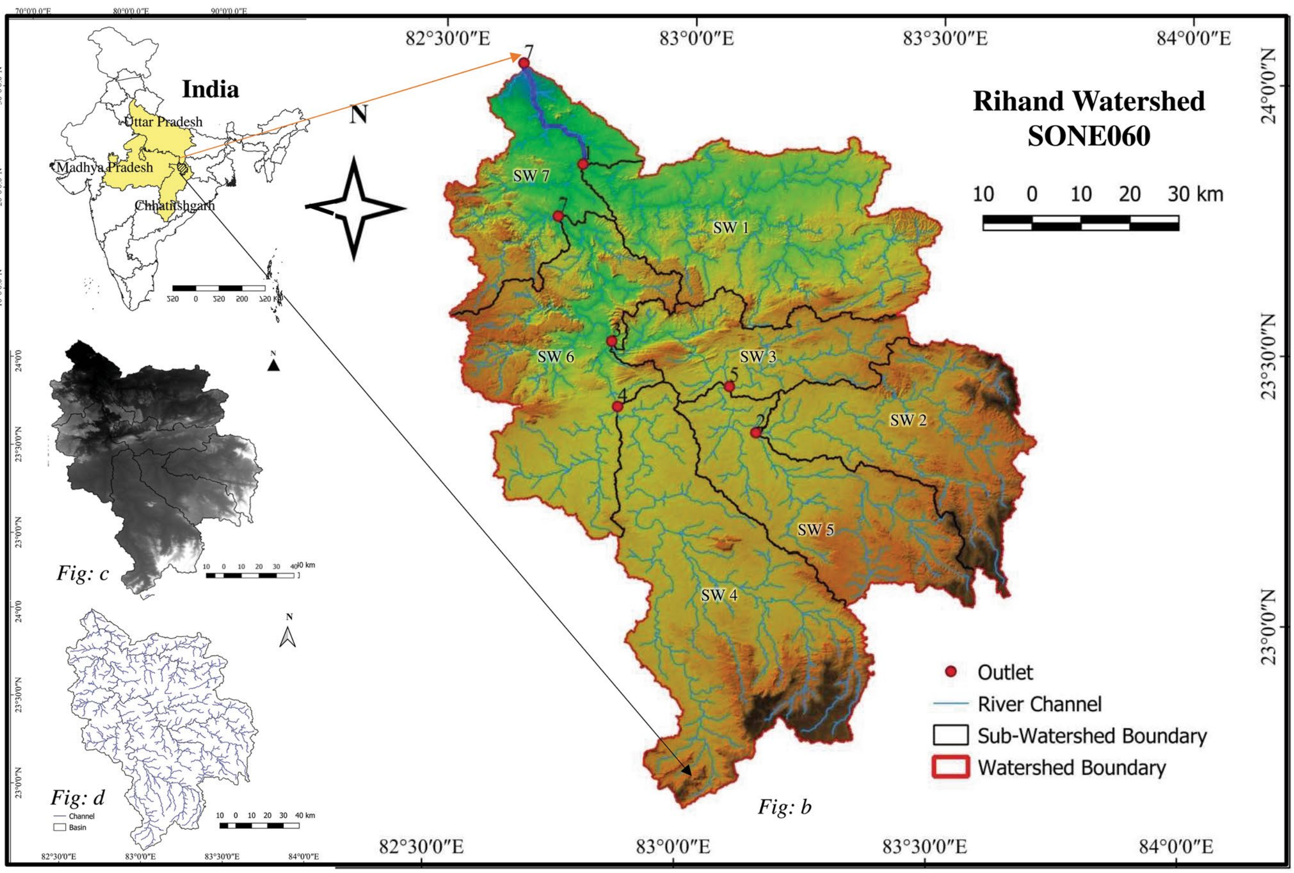

Fig. 1 **a**, **b** Location of Rihand watersheds **c** DEM; **d** channel

of low dipping formations of sandstone, shale and carbonate, with a few conglomerate and volcanic beds, separated by a major regional and several local unconformities (Kumar et al. 2017; Bhattacharyya 1996). The entire area occupied by 3 group of rock, i.e., (1) Mahakoshal Group made of phyllite with quartzite, andalusite mica schist, limestone, acid intrusive, metabasic rocks, cherty quartzite, slate, marble and tuff, (2) Dudhi group overlie the Mahakoshal Group and consist of medium- to fine-grained diorite, gray granodiorite, epidotized pink tourmaline gneiss, leucocratic granite, and enclaves of metamorphites, amphibolites, granite gneiss, migmatite and metasedimentaries and (3) Damuda Group consist of coarse ferruginous sandstone intercalated with coal seams and green shale (Kumar et al. 2017). Rihand dam also known as Govind Ballabh Pant Sagar has been constructed over this river in the year of 1962 at Pipri in Sonbhadra District in Uttar Pradesh, the north most point of the study area.

Data and software

For the delineation of watershed boundary Survey of India (SOI) topographical map no64I/9, 63 L/16, 64 M1, 63P/4, 64 I/13 and 63 L/12 has been used. For better accuracy and avoid data gap or any distortion Digital Elevation has been used along with SOI topographical sheet. A number of researchers suggested that Shuttle Radar Topography Mission Digital Elevation (SRTM-DEM) is much better than ASTER DEM as its vertical and horizontal accuracy is greater and able to provide more accurate data to morphometric analyses (Prakash et al. 2019; Patel et al. 2016; Kaushik and Ghosh 2015; Forkuor and Maathuis 2012; Farr et al. 2007). Therefore, Shuttle Radar Topography Mission (SRTM) Digital Elevation data with a spatial resolution of 90 m (downloaded from the https://www.srtm.csi.cgiar.org) has been used in this study. Missing data in SRTM-DEM are filled by interpolation techniques and sink fill algorithm applied as preprocessing of DEM for minimizing errors (Prakash et al. 2019). Drainage map and basin map were prepared from SOI topographical sheet. Extraction of channel network and delineation of sub-watersheds has been done by processing SRTM data of the study area in White Tool box. After delineating 7 sub-watersheds the morphometric parameter (length of the individual stream, basin area and perimeter of the basin) was extracted in the Q GIS-3.12 platform and used for the morphometric analysis (linear, areal and relief aspects).

Morphometric parameters

In the study of the watershed prioritization is important to understand hydrological behaviors along with the morphology and relief of the watershed; thus selection of the appropriate parameters largely influences the result of the study. In these regards 15 morphometric parameters (Table 1) including the linear, areal and relief aspects which are closely associated with soil and water resource degradation has been considered for prioritization of Rihand sub-watersheds.

Application of fuzzy analytical hierarchical process (FAHP)

Various methods such as quantitative, fuzzy logic, statistic methods, ANP and AHP have been used widely by several researches to prioritize sub-watersheds. In present study Fuzzy Analytical Hierarchical Process (FAHP) has been used to prioritize sub-watersheds based on morphometric analysis. AHP is one of the most popular multicriteria decision-making tools which relies on a hierarchical structure to explain the decision problem and does a pair-wise comparison between criteria to arrive at the weights used in the prioritization ranking (Gopinath et al. 2016; Triantaphyllou and Mann 1995). In spite of popularity of AHP, this method is often criticized for its inability to adequately handle the inherent uncertainty and imprecision associated with the mapping of the decision maker's perception to exact numbers (Rahaman, et al. 2015). In fuzzy AHP a crisp number (1, 2, 3) is replaced by fuzzy number {(1,1,1), (2,3,4), (3,4,5)….} to remove uncertainty and vagueness in expert's decision making. Therefore, AHP has been used through fuzzy operations for prioritization of sub-watersheds in Rihand basin.

A brief of fuzzy set and triangular fuzzy number (TFN)

Fuzzy set theory was introduced by (Zadeh 1965), deals with uncertainty and source of vagueness and has been utilized for incorporating imprecise data into the decision framework (Brahma 2018). A fuzzy number is a fuzzy set in which the membership function satisfy condition of normality and of convexity and a triangular fuzzy number (TFN) is a set of 3 crisp numeric value can be expressed as $\mu = [l, m, u]$ where $[l < m < u]$ and in case of $[l = m = u]$ it can't be consider as a fuzzy number. In this study the relative important of each pair of criterion has been expressed through TFN using numerical value ranges between 0 and 9 as suggested by Saaty (1980) and stated in (Mishra et al. 2018; Jaiswal et al. 2014).

Construction of fuzzy pair-wise comparison matrix

The first task of the fuzzy AHP method is to decide on the relative importance of each pair of factors in the same hierarchy (Chang 1996). The triangular fuzzy number used for pair-wise comparison matrix, the fuzzy evolution matrix

Table 1 Morphometric parameters

Morphometric parameters		Computation	References
Linear Aspect	Stream order	Hierarchical rank	Strahler (1964)
	Stream length ($L\mu$)	Length of the stream	Horton (1945)
	Mean stream length (L_{sm})	$L_{\mathrm{sm}}=L\mu/N\mu$ ($N\mu$ = total no. of stream segments of a given order)	Strahler ((1964)
	Stream length ratio (R_{l})	$\mathrm{RL}={L_u}/{L_u-1}$ (L_u = total stream length of a given order; and L_u-1 = total stream length of its next lower order)	Horton (1945)
	Bifurcation ratio (R_{b})	$R_{\mathrm{b}}={N\mu}/{N\mu+1}$ ($N\mu$ = total no. of stream segments of a given order; and $N\mu+1$ = no. of segments of the next higher order)	Schumm (1956)
	Mean bifurcation ratio (R_{bm})	R_{bm} = average of bifurcation ratios of all orders	Strahler (1957)
Areal Aspect	Drainage density (D)	$D=L_u/A$ (L_u = total stream length of all orders; and A = area of the basin)	Horton (1932)
	Stream frequency (F_{s})	$F_{\mathrm{s}}=N_u/A$ (N_u = total no. of streams of all orders; and A = area of the basin)	Horton (1932)
	Drainage texture ratio (R_{t})	$R_t=\mathrm{Nu/P}$ (N_u = total no. of streams of all orders; and P = perimeter of the basin)	Horton (1945)
	Infiltration no. (I_{f})	$I_{\mathrm{f}}=R_{\mathrm{t}}\times F_{\mathrm{s}}$ (R_{t} = drainage texture ratio; and F_{s} = drainage frequency)	Faniran (1968)
	Length of overland flow (L_g)	$L_g=1/D\times 2$ (D = drainage density)	Horton (1945)
	Circulatory ratio (R_{c})	$R_{\mathrm{c}}=4\,\pi\times A/P2$ ($\pi=3.14$; A = area of the basin; and $P2$ = square of the perimeter)	Miller (1953)
	Form factor (R_{f})	$R_{\mathrm{f}}=A/L_{\mathrm{b}}^2$ (A = area of the basin; and L_{b}^2 = square of basin length)	Horton (1932)
	Elongation ratio (R_{e})	$R_{\mathrm{e}}=\sqrt[2]{\left(\frac{A}{\pi}\right)}\Big/L_{\mathrm{b}}$ (A = area of the basin $\pi=3.14$; and L_{b} = basin length)	Schumm (1956)
Relief aspect	Relative relief (R_{r})	Maximum elevation minus minimum elevation of the basin	Strahler (1952)
	Relief ratio R_h	$R_h=H/L_{\mathrm{b}}$ (H = total relief (relative relief) of the basin in kilometers; and L_{b} = basin length)	Schumm (1956)
	Ruggedness no. (R_{n})	$R_{\mathrm{n}}=D\times T_{\mathrm{r}}/1000$ (D = drainage density; and T_{r} = total relief)	Strahler (1964)
	Hypsometric integral	$\mathrm{HI}=\frac{\text{mean elevation}-\text{minimum elevation}}{\text{maximum elevation}-\text{minimum elevation}}$	Strahler (1952, 1964)
	Stream gradient (S_{g})	$S_{\mathrm{g}}=\frac{E_1-E_2}{L}=\frac{\Delta H}{\Delta L}$ E_1-E_2 = difference in the elevation between two points on the stream (ΔH) SL = Stream length (ΔL)	Hack (1957)

($\tilde{A}=\tilde{a}_{ij}$)of n criteria is constructed using Eq. 1 has given as follows

$$\tilde{A}=\begin{bmatrix} 1 & \tilde{a}_{12} & \cdots & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \cdots & \tilde{a}_{2n} \\ \cdots & \cdots & \ddots & \cdots \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \cdots & 1 \end{bmatrix} \tag{1}$$

where $\tilde{a}_{ij}$ is a fuzzy triangular number, $\tilde{a}_{ij}=(l_{ij},m_{ij},u_{ij})$, and $\tilde{a}_{ij}^{-1}=\frac{1}{\tilde{a}_{ij}}$. For each TFN, $\tilde{a}_{ij}$ or $M=1$, m, its membership function $\mu_{\tilde{a}}(x)$ or $\mu_{\tilde{m}}(x)$ is a continuous mapping of real number $-\propto\leq x\leq\propto$ to the close interval [0, 1] and can be define by equation below

$$\mu_{\tilde{a}}(x)=\begin{cases} \frac{(x-1)}{(m-1)'} & l\leq x\leq m \\ \frac{(u-x)}{(u-m)'} & m\leq x\leq u\ . \\ 0, & \text{otherwise} \end{cases}$$

The operations on TFNs can be additional, multiplication and inverse. Suppose M1 and M2 are two TFNs where $M_1=(l_1,m_1,u_1)$, and $M_2=(l_2,m_2,u_2)$, then, Additional $M_1 \oplus M_2 = \left(l_1 + l_2, m_1 + m_2, u_1 + u_2\right)$

Multiplication $M_1 \otimes M_2 = \left(l_1 \times l_2, m_1 \times m_2, u_1 \times u_2\right)$

Inverse $M_1^{-1} = \left(l_1, m_1, u_1\right)^{-1} = \frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}.$

After computing pair-wise comparison matrix from all decision makers, these matrices can were aggregated by using the fuzzy geometric mean method (Buckley 1985) using following formula.

$$l_i = \left[\prod_{j=1}^{n} lij\right]^{1/n} \ \& \ l = \left[\sum_{i=1}^{n} l_i\right] \tag{2}$$

$$m_i \left[\prod_{j=1}^{n} m_{ij}\right]^{1/n} \ \& \ m = \left[\sum_{i=1}^{n} m_i\right] \tag{3}$$

$$u_i \left[\prod_{j=1}^{n} u_{ij}\right]^{1/n} \ \& \ u = \left[\sum_{i=1}^{n} u_i\right] \tag{4}$$

The fuzzy membership function describing the weights of different parameters is defined by the following equation.

$$\bar{x}_i = \left[\frac{l_i}{u}, \frac{m_i}{m}, \frac{u_i}{l}\right] \tag{5}$$

The center of area (COA) method is employed to de-fuzzify the membership function, which gives crisp weights for all the parameters using following formula.

$$x_i = \frac{l_i + m_i + u_i}{3} \tag{6}$$

In fuzzy AHP, pair-wise matrix is computed by decision maker itself based on his/her personal knowledge and ability hence consistency checking is to eliminate any subjectivity in decision-making process. Thus, consistency has been measured using consistency Ratio (CR) using following formula

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{7}$$

where CI is the consistency index which depends on size of the matrix and can be estimated using the following equation

$$\mathrm{CI} = \frac{\lambda_{\max} - N}{N - 1} \tag{8}$$

where $\lambda_{\max}$ is the principal eigenvalue (Han and Tsay 1998; Malczewski 1999) that can be computed approximately by calculating the product of the pair-wise comparison matrix and the weight vectors, de-fuzzifying this matrix and adding all elements of the resulting vector of the resulting vector (Mishra et al. 2018). RI is the random consistency index a unitless predefined value which depends on number of criterion (n) that used to generate a matrix as given in Table 1. If the value of CR is less than 0.1 then the decision is considered as consistent.

The values of morphometric parameters may vary in the diverse ranges and therefore, there is a need to bring down those on same scale. Normalization approach to restrict the variation in the range from 0 to 1 is applied using Eq. (9) as follows;

$$W_{ij} = \frac{\frac{P_{ij}}{P_i\max}}{\sum_{i=1}^{n} p} \text{ or } \frac{\frac{P_i\min}{P_{ij}}}{\sum_{i=1}^{n} p} \tag{9}$$

where W_{ij} is the normalized value of ith morphometric parameter (P) of jth watershed; $P_{i\,\min_i}$ and $P_i\max$ are the original upper and lower bound for ith morphometric parameter (P). P_{ij} is the original value of ith morphometric parameter (P) of jth watershed. Here first equation is applicable for beneficial parameters; which are positively correlated with degradation and second one is for inversely correlated parameters. After this, final priority (F_j) of a watershed in the present FAHP-based MCDS is computed by summing the product of normalized value of all alternative and its corresponding criterion weights obtained from FAHP analysis, as follows:

$$F_j = \sum_{i=1}^{n} x_i \times w_{ij}. \tag{10}$$

Based on the final priorities of all sub-watersheds in Rihand watershed, they are categorized in different priority classes for conservation measures. Entire methodology of sub-watershed prioritization is shown in Fig. 2.

Results

Morphometric characterizations

Stream order

The first step in the drainage basin analysis is the order designation (Fig. 5a) following a system (Strahler 1964), i.e., assigning the value of first order to every finger-tip stream and promote their order to next order (e.g., first order to second order, second order to third order, third order to fourth and so on) if two channels of the same order meet and order remains unchanged in case of two channel of different orders meet. As per Horton's low of stream numbers, number of

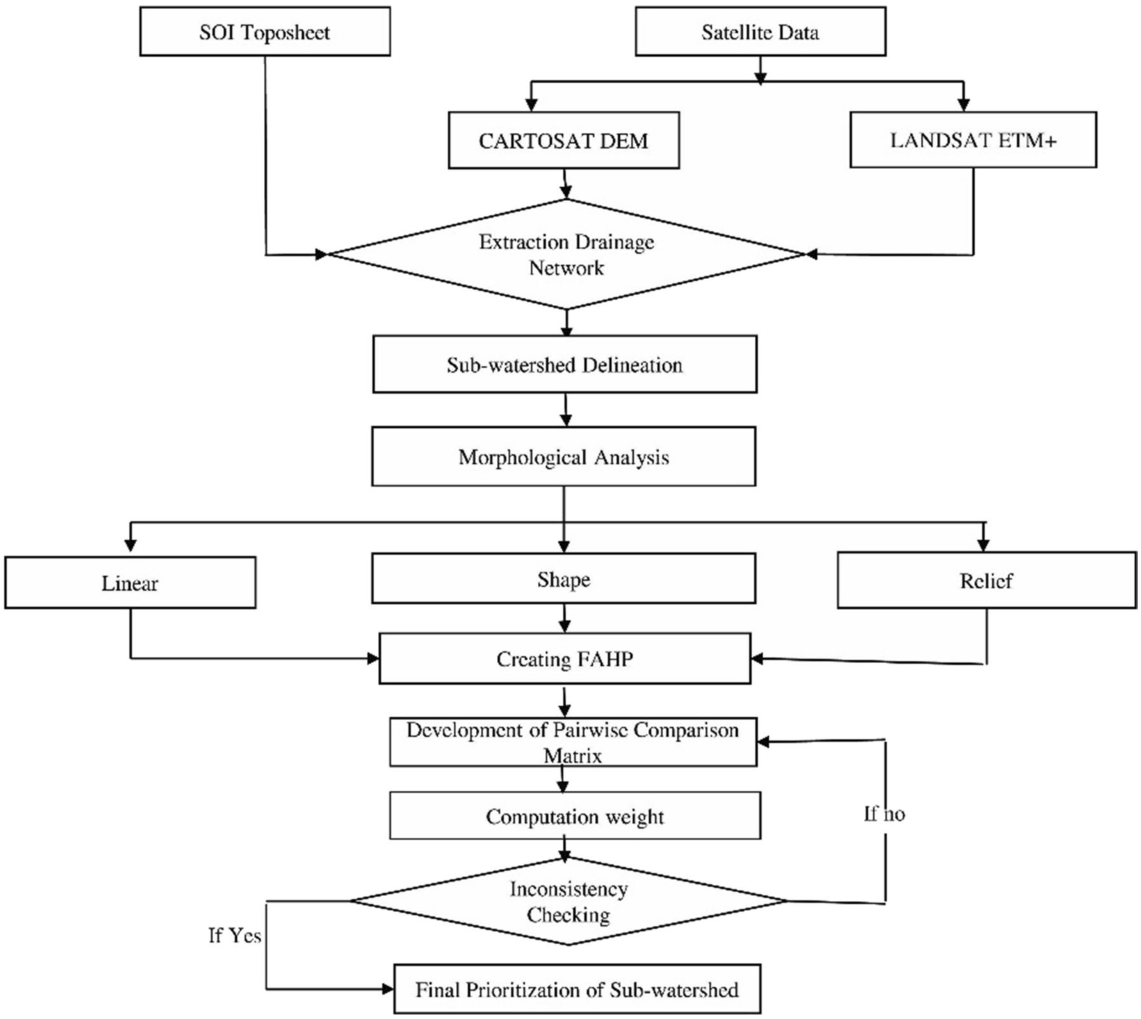

Fig. 2 Flowchart of methodology for sub-watersheds prioritization

stream segment decrease with increasing order as shown in Fig. 3. Table 2 indicates that there are seven sub-watersheds, out of these one sub-watershed (SW-7) is seventh ordered and 2 sub-watersheds (SW-2 and SW-4) are fifth ordered and rests of the sub-watersheds are sixth ordered.

Bifurcation ratio (R_b)

Horton introduced the term 'bifurcation ratio (R_b)' to express the ratio of the number of any stream of any given order to the number in the next lower order (Leopold 1964). According to Horton (1945, p. 290) the value of bifurcation ratio may range between 2 and 4 while Strahler (1964) suggested that In natural drainage system has a value of bifurcation ratio 3.0–5.0 in which geologic structures do not distort the drainage pattern. The value of bifurcation ration generally indicates tectonic and hydrological properties of a basin. Higher the value of bifurcation ratio means more chances of occurrence flood hazard, soil erosion and increase in overland flow on the other hand lower the value of bifurcation ratio means well developed drainage system, minimum surface flow, and no soil erosion and flood would be take place. In present study, the value of the mean R_b lies between 2.634 and 4.915 which are shown in Table 2.

Stream length ($L\mu$)

The law of stream lengths expresses the average length of streams of a given order in terms of stream order, average length of streams of the 1st order, and the stream length ratio (Horton 1945). As per Horton's second law, the total length of the stream decreased with increasing in stream order that's means 1st order stream occupy maximum length (Fig. 4). Sub-watershed wise stream length and total stream length for each order are expressed in (Table 3).

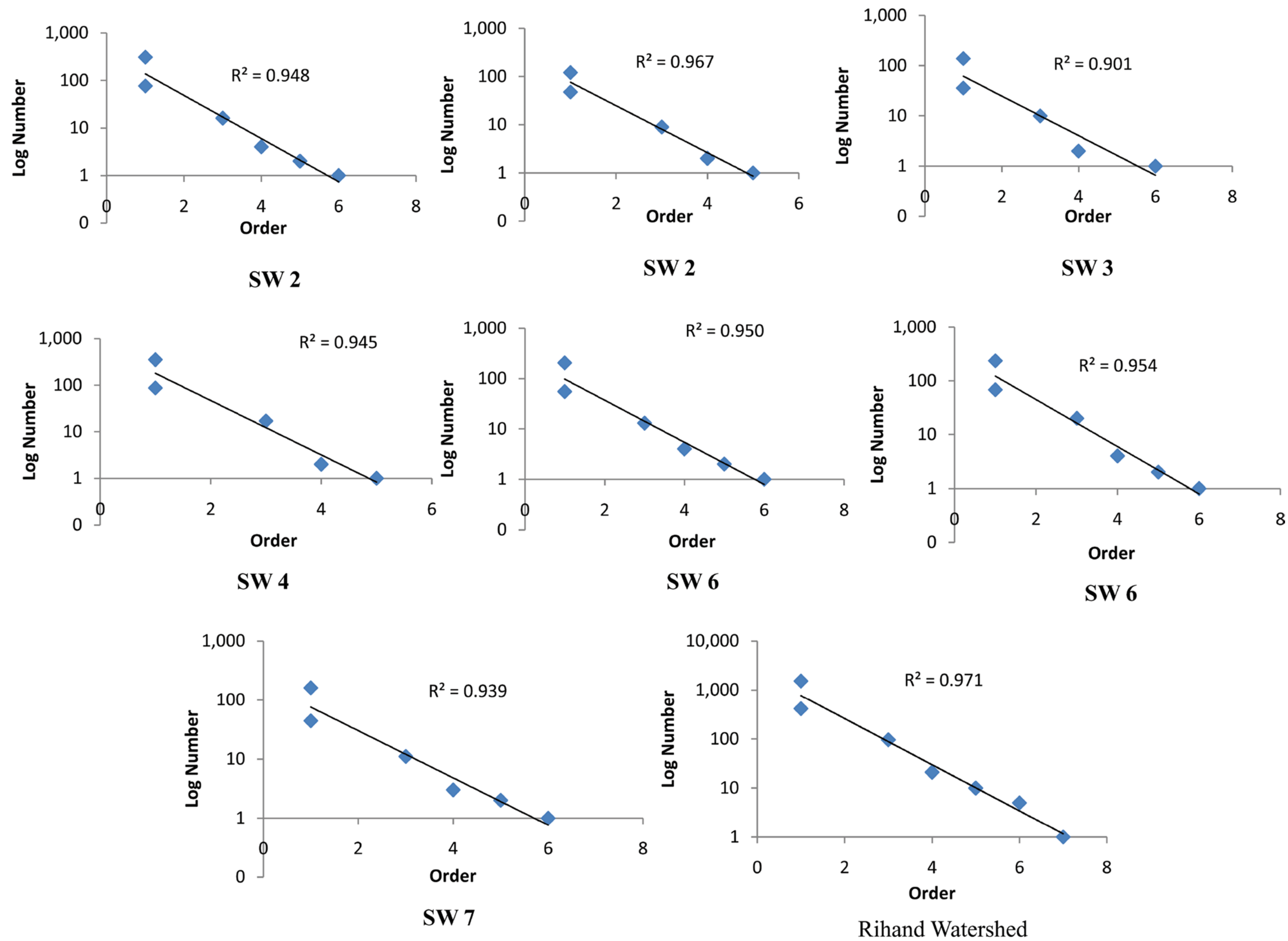

Fig. 3 Horton's law of stream number (*x* axis—stream order (*u*); *y* axis—log total number of stream)

Table 2 Sub-watershed wise stream Numbers and bifurcation ratio (R_b)

Sub-watershed	Order wise number of stream							Total	Order wise R_b						Mean R_b
	I	II	III	IV	V	VI	VII		I	II	III	IV	V	VI	
SW1	307	76	16	4	2	1	0	406	4.039	4.75	4.00	2.00	2	–	3.357
SW2	122	48	9	2	1	0	0	182	2.541	5.333	4.50	2.00	–	–	3.593
SW3	139	36	10	2	0	1	0	188	3.861	3.60	5.00	–	–	–	3.115
SW4	352	87	17	2	1	0	0	459	4.045	5.117	8.50	2.00	–	–	4.915
SW5	204	55	13	4	2	1	0	279	3.709	4.230	3.25	2.00	2	–	3.037
SW6	235	68	20	4	2	1	0	330	3.455	3.40	5.00	2.00	2	–	3.171
SW7	160	44	11	3	2	1	1	222	3.636	4.00	3.667	1.50	2	1	2.634
Total	1519	414	96	21	10	5	1	2066	3.67	4.31	4.57	2.1	2	5	3.608

Mean stream length (L_{sm})

According to Strahler (1964), the stream length is a characteristic property related to drainage network components of drainage basins. Generally, the longest mean length of the stream associate with the highest stream order (Fig. 4).

Stream order-wise means length of the stream for each watershed has been calculated by dividing the total stream length of a order by total number of stream segment under that particular order (Table 3). Sw-4 recorded highest mean stream length which indicates greater erosion and less infiltration.

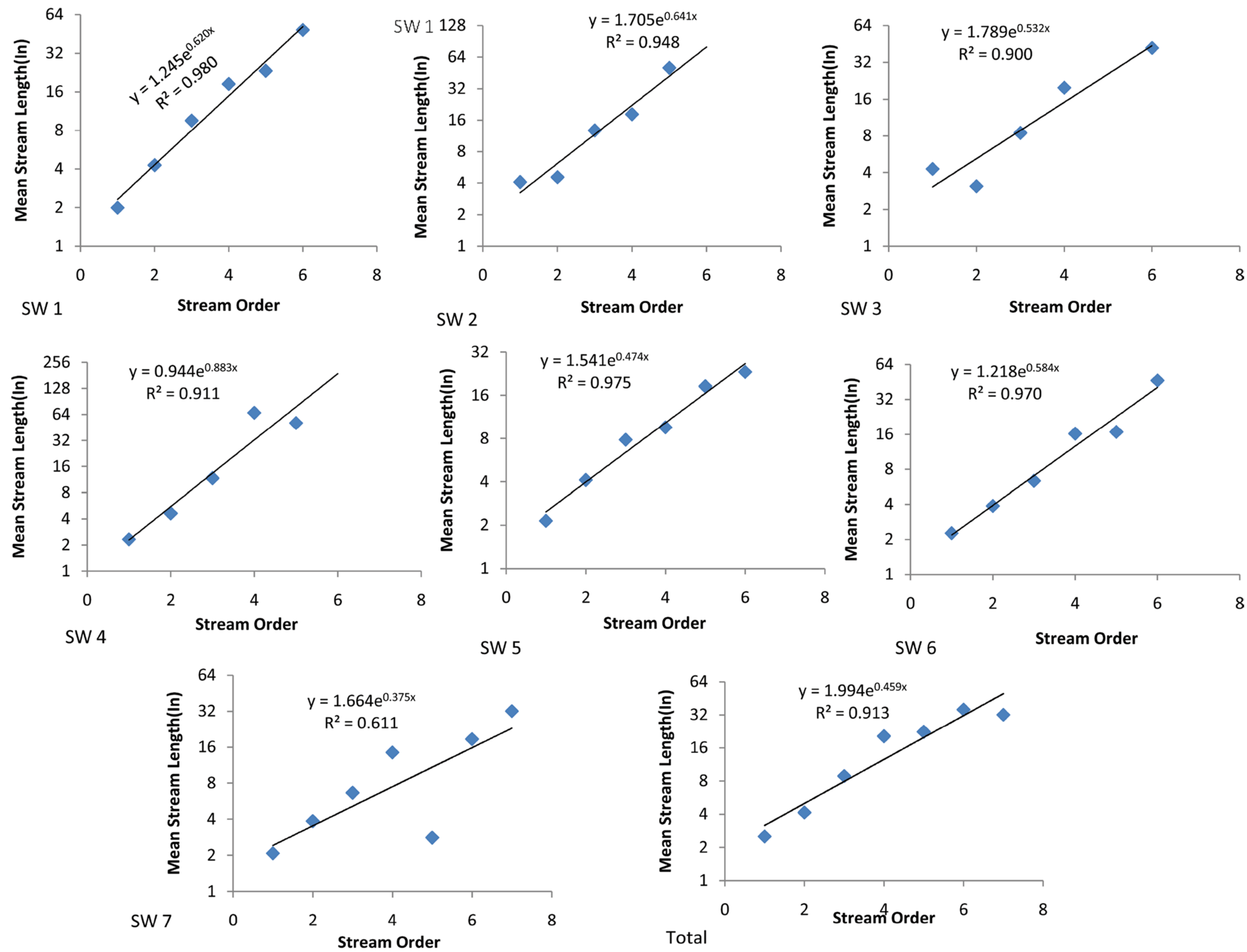

Fig. 4 Horton's law of stream length (*x* axis—stream order (*u*); *y* axis—log mean stream length

Table 3 Total stream length ($L\mu$) and mean stream length (L_{sm})

Sub-watershed	Stream order wise total length of stream ($L\mu$)							Total	Stream order wise mean length of stream (L_{sm})							Mean
	I	II	III	IV	V	VI	VII		I	II	III	IV	V	VI	VII	
SW1	611.93	324.63	152.77	73.79	46.7	48.54		1258.38	1.99	4.27	9.54	18.44	23.35	48.54		17.69
SW2	498.54	218.19	114.46	36.38	50.39			917.97	4.08	4.54	12.71	18.19	50.39			17.98
SW3	592.55	110.98	84.33	39.64		41.9		869.38	4.26	3.08	8.43	19.82	0	41.9		15.5
SW4	819	402.89	199.12	133.56	50.85			1605.43	2.32	4.63	11.71	66.78	50.85			27.26
SW5	438.39	226.52	101.98	38.29	37.01	23.26		865.45	2.14	4.11	7.84	9.57	18.5	23.26		10.9
SW6	531.62	263.09	126.82	64.69	33.48	46.56		1066.28	2.26	3.86	6.34	16.17	16.74	46.56		15.32
SW7	332.43	169.62	73.11	43.27	5.61	18.64	32.08	674.79	2.07	3.85	6.64	14.42	2.8	18.64	32.08	11.5

Length of overland flow (L_O)

Length of overland flow denoted by 'L_O' is used to describe the length of flow of water over the ground before it becomes concentrated in definite stream channels (Horton, 1945). It is important morphometric variables, can independently control rate of infiltration and soil loss. In Rihand watershed, the length of overland flow ranges from 0.48 to 0.76 (Table 4)

Table 4 Value of morphometric analysis

Sub-watersheds parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7
L_{sm}	17.69	17.99	12.91	27.26	10.9	15.32	11.5
D_d	0.68	0.69	1.03	0.67	0.7	0.66	0.71
D_f	0.219	0.136	0.224	0.191	0.23	0.206	0.234
R_t	1.12	0.55	0.77	1.09	1.04	1	0.92
R_{bm}	3.357	3.593	3.115	4.915	3.037	3.171	2.634
C_c	2.4	2.58	2.41	2.45	2.18	2.34	2.21
R^f	0.33	0.41	0.24	0.33	0.24	0.37	0.36
R_e	0.64	0.72	0.55	0.65	0.54	0.69	0.68
R_c	0.18	0.15	0.17	0.16	0.21	0.28	0.2
O_l	0.73	0.73	0.48	0.76	0.71	0.75	0.7
I_f	0.25	0.07	0.12	0.24	0.18	0.19	0.14
S_g	1.87	8.46	2.11	5.52	3.08	5.89	4.41
HI	0.214	0.4823	0.304	0.241	0.22	0.347	0.471
R_n	0.302	0.54	0.44	0.4	0.37	0.47	0.35
R_r	443.5	774.9	426	633	510.8	706.05	585
R_h	0.0059	0.0136	0.0071	0.0074	0.0071	0.0102	0.0094

Infiltration number (I_f)

Infiltration Number is an important morphometric parameter which helps to predict permeability of surface of the watershed and generally depends on relief, slope, lithology and vegetation cover. Greater values of 'I_f' indicates impermeable surface and resistance to soil loss and contrary the lower values point toward erosive nature of the watersheds (Hembram et al. 2020). In the present study, sub-watershed wise infiltration numbers are computed. SWS-2 has recorded lowest value of I_f (0.07) which indicates higher risk for erosion, and SWS-4 has the highest value with maximum infiltration and minimum erosion (Table 4).

Drainage density (D_d)

Drainage density (D_d) is an important areal morphometric parameter and can be defined as total length of the stream per unit drainage area and reflects the degree of drainage development within a basin (Horton 1945). Horton (1932) suggested that if the length of the stream measured from a map then map scale should be sufficiently large enough (U. S. Geological Survey topographic maps) to show the entire permanent stream. Generally, its values depend upon the function of climate, lithology and structure characteristics of the drainage basins and higher values of drainage density reflect higher dissected drainage watershed and rapid response with respect to rainfall events and for lower values vice versa (Prabhakar et al. 2019). It is also important that the drainage density is the reciprocal of the constant channel maintenance; that means basin with lower drainage density has higher constant channel maintenance and vice versa (Morisawa 1985). The D_d of sub-watersheds ranges from 0.66 to 1.03 km/km^2 which is shown in Table 4 and Fig. 5b.

Stream frequency (F_S)

Stream frequency or Drainage frequency (F_S) is the total number of stream of all orders per unit area of the watershed (Horton 1932). Stream frequency of a drainage basin generally depends upon lithology, relief, and climatic conditions of the watersheds and has a close correlation with drainage density. Higher the value of Stream frequency indicates high degree of surface runoff and high probability of soil erosion and occurrence of flood. The stream frequency value of Rihand River Basin is less than other river basins present in Central India (Rai et al. 2017, Kumar et al. 2017; Singh et al. 2013). In this study, value of stream frequency ranges from 0.14 to 0.23 as shown in Table 4. SW-5 and SW-7 has recorded maximum drainage frequency as produced maximum surface runoff.

Texture ratio (R_t)

Cotton (1935) and others have used the term "texture" to express composition of a drainage net as related both to drainage density and stream frequency (Horton, 1945). It can be define as the length of the stream segments of the all orders per unit perimeter of the basin. Smith (1950) has developed texture ratio to describe the degree of closeness or proximity of one stream segment to another (Leopold et al. 1964). Texture ratio of a drainage basin depends on its lithology, relief, amount of slope and climatic conditions and its value reflect degree rate of infiltration and soil erosion.

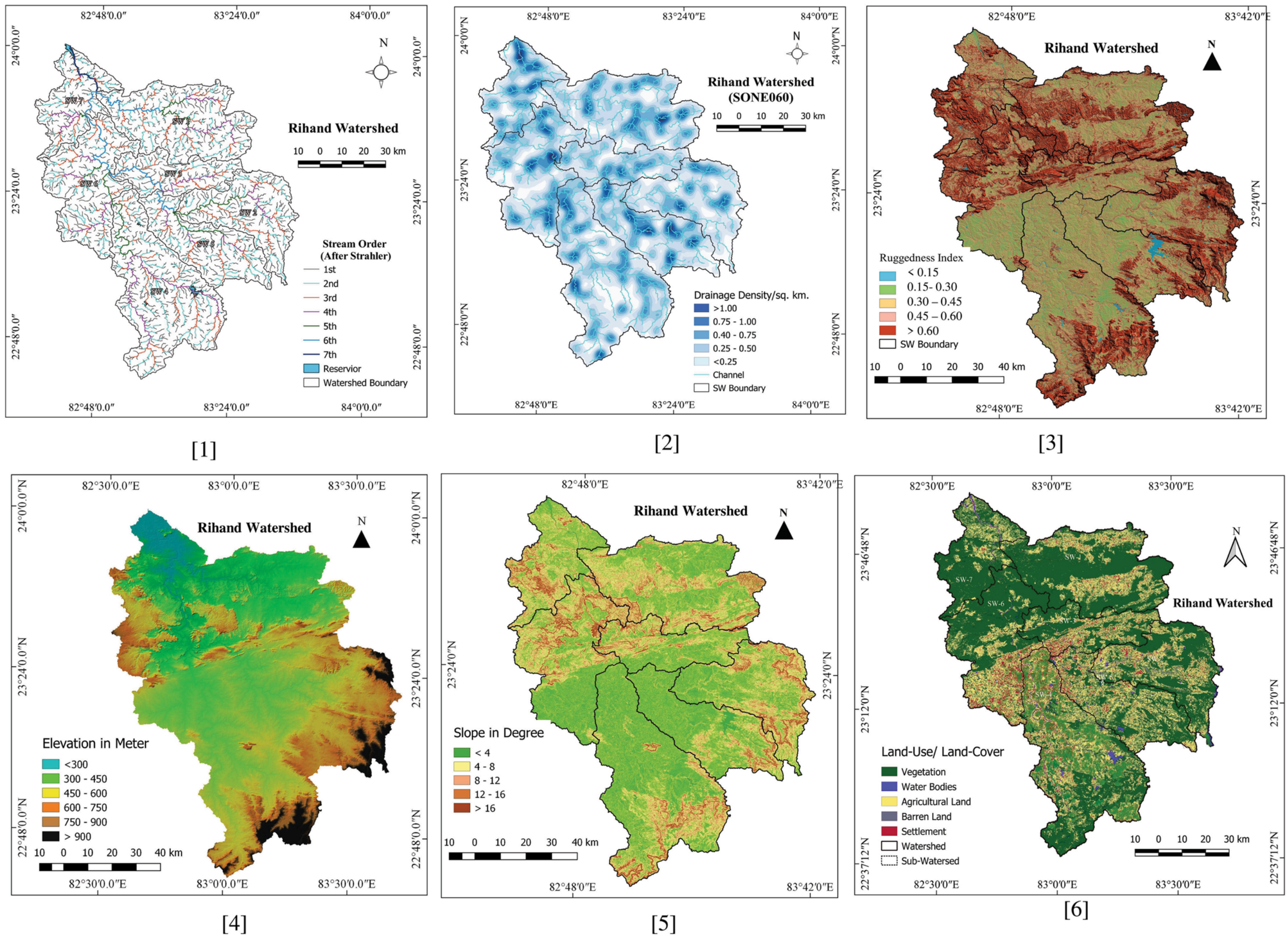

Fig. 5 **a** Stream ordering; **b** Drainage density; **c** Ruggedness ratio; **d** Relief; **e** Slope; **f** Land-use/land-cover map

Texture is classified into four categories < 4 per km coarse, 4–10 per km intermediate, 10–15 per km fine and > 15 per km ultra fine (Choudhari et al. 2018). Texture ratio for all 7 sub-watersheds varies from 0.55 to 1.12 (Table 4) which indicates that the entire watershed falls under coarse category.

Circulatory ratio (R_c)

Circulatory ratio is the most useful shape measure in correlation with stream flow (Morisawa 1959) can be define as the ratio of the basin area to the area of a circle proportionate with the same perimeter as the basin (Miller 1953). The values of circulatory ratio range between 0 and 1, while 1 indicated a perfect round shape and low the value express high degree of irregularity and early stage of life cycle. The circulatory ratio for Rihand sub-watershed falls between 0.15 and 0.21 (Table 4) which indicates high relief with less circular basin characterized by youth stage of development. Lowest R_c in SW-2 exposing higher rate in erosion and least infiltration and seeking greater attention for conservation.

Elongation ratio (R_e)

Elongation ratio is the ratio between the diameter of a circle with the same area of a basin and the maximum length of that basin (Schumm 1956). The value 1 indicates a complete circular shape with very low relief of the drainage basin and produces a high peak discharge while low value of R_e elongated shape with high relief and steep slope. Thus, R_e is very useful for flood forecasting. Elongation ratio of a river basin depends on structure, lithology, climate, relief, slope and pattern of LU/LC. The values of the elongation ratio generally vary from 0.6 to 1.0 over a large variety of climatic and geologic types (Choudhari et al. 2018; Rudraiah et al. 2008). Elongation ratio varies from 0.54 to 0.72 (Table 4) which expressed that lower to average peak flow of longer duration, with high relief, steep slope and elongated basin.

Form factor (R_f)

Form factor is simply ratio between area and square of the length of a watershed. Horton (1932) stated that the length to be used is not necessarily the maximum length but is to be measured from a point on the watershed-line opposite the head of the main stream. In this study Form factor has been calculated by measuring length of each basin from the mouth to the opposite side (Morisawa 1959). In this study the form factor of all the 7 sub-watersheds ranges from 0.24 to 0.41 (Table 4). SW-3 and SW-5 has recorded lowest value of R_f which indicates flatter peak flow for longer duration of discharge and SW-2 has recorded highest R_f (0.41) followed by SW-6 and SW-7 characterized by relatively high peak discharge.

Compactness constant (C_c)

Gravelius introduced Compactness Index as the ratio of the perimeter of the drainage basin to the perimeter of a circle with equal area (Horton 1932). Lowe value of Compactness index indicates an ideal circular shape. Two watersheds with same areal extension but different Compactness index approaches difference in hydrologic characteristics. In this study C_c of 7 sub-watersheds is shown in Table 4 which indicates diversity among the sub-watershed in surface hydrology.

Form factor (R_f)

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Relative relief (R_r)

Total relief has a direct impact on hydrological behavior of the watershed and may be defined as the difference between maximum elevation and minimum elevation within the boundary of watershed (Hadley and Schumm 1961). Total relief for each of 7 sub-watersheds has been computed by capturing value of maximum and minimum elevation from DEM. The value of R_h ranges from 583 to 774.90 (Table 4).

Relief ratio (R_h)

Schumm (1956) defined as the ratio between the total relief of a basin (elevation difference of lowest and highest points of a basin) and the longest dimension of the basin parallel to the principal drainage line. The maximum R_h values of is 0.0133 (Table 4), has recorded in SW-7 which signifying the presence of higher relief underlain by resistant rocks and lowest value of R_r 0.0078 (Table 4) has recorded in SW-4 which indicates relatively low relief and more denudation.

Ruggedness number (R_n)

Ruggedness Number has devised by R J Chorley can be expressed by multiplication amplitude of relief with drainage density (Sen 1993). It indicates the undulation of relief and implies to compute the flood potentiality of watersheds (Hembram and Saha 2020). The value of ruggedness number is proportionately associated with risk of erosion and inversely related with rate of infiltration. Therefore, SW-2 is more exposed to erosion with an index value of 0.60 (Table 4) comparing to rest. SWS-1, 4 and 5 has the least 'R_n' value (<0.45) with less erosion threat and rest of the sub-watersheds falls under moderate class (Fig. 5c)

Stream gradient (S_g)

The stream gradient (S_g) is simply different in elevation between source and mouth point of a river which is related to the power of a stream to transport material of a given size and to the characteristics of the bedrocks that resist flow (Hack 1957). Thus, it is a geometric property that can quantitatively describe rate of erosion, runoff and nature peak discharge. The high value of stream gradient of has recorded in SW-2, SW-4 and SW-7 (>250) (Table 4) which indicates high relief and steep slope, and high runoff, while SW-1 and SW-3 has the low value (<150) which indicates gentle slope and more efficient in discharge of runoff. A compound long profile for the entire watershed has been prepared (Fig. 6) for the better understanding of the stream gradient.

Hypsometric integral (HI)

The hypsometric integral (HI) is related to the uplift rate and recently uplifts anticlines in the tectonically active region (Sangma and Guru 2020; Hurtrez et al. 1999). The hypsometric integral (HI) value for entire Rihand watershed lies between 0.22 and 0.34, (Table 4). SW-2 and SW-7 has recorded highest value (>0.45) indicates high risk of erosion on the other hand lowest value of Hypsometric integral in SW- 1 and SW-5 (<0.22) expresses old and low risk of erosion. Sub-watershed wise relative hypsometric curve has been plotted (Fig. 7) which showing diversity in erodibility.

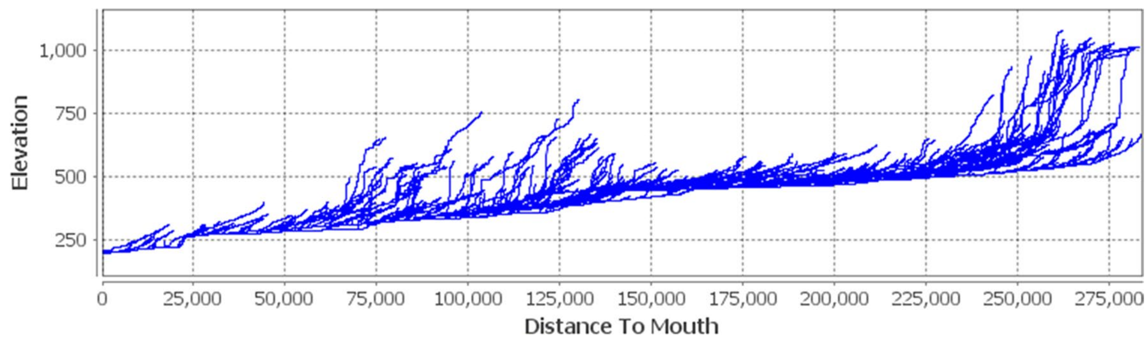

Fig. 6 Long profile (elevation and distance in meter)

Land use/land cover

Increasing population at a rapid rate has often leads alteration of land-use/land-cover pattern of an area through deforestation, settlement, agriculture, infrastructural development, etc. If the present need is fulfilled in unplanned manner, it will deteriorate the watershed. The rate of soil erosion is directly proportional to the runoff and the rate of flow is directly proportional to the settlement, fallow land, wasteland and water and inversely proportional to shrubland, agricultural land, and forestland. Thus, in order to conserve water and soil resources in a sustainable way, a systematic management of land use is required. In present study Land-use/Land-cover map (Fig. 5e) of the entire watershed has been prepared using LANDSAT ETM + image. It was found that 43.80% of the entire watershed area is covered with forest while agricultural land and settlement occupied 29.19% and 14.60% of the total area, respectively. Water body covered 8.94% of the total land and rest of the area of the watershed is under Barren land (Table 5).

Prioritization of sub-watersheds

All sub-watersheds are considered as a hydrological unit as they are unique in terms of morphometric characteristics and hydrological response. Thus, it is important to identify crucial sub-watersheds under a watershed for planning and management. In this view selection of appropriate parameters and assigned them most suitable weightage is the most challenging part of watershed

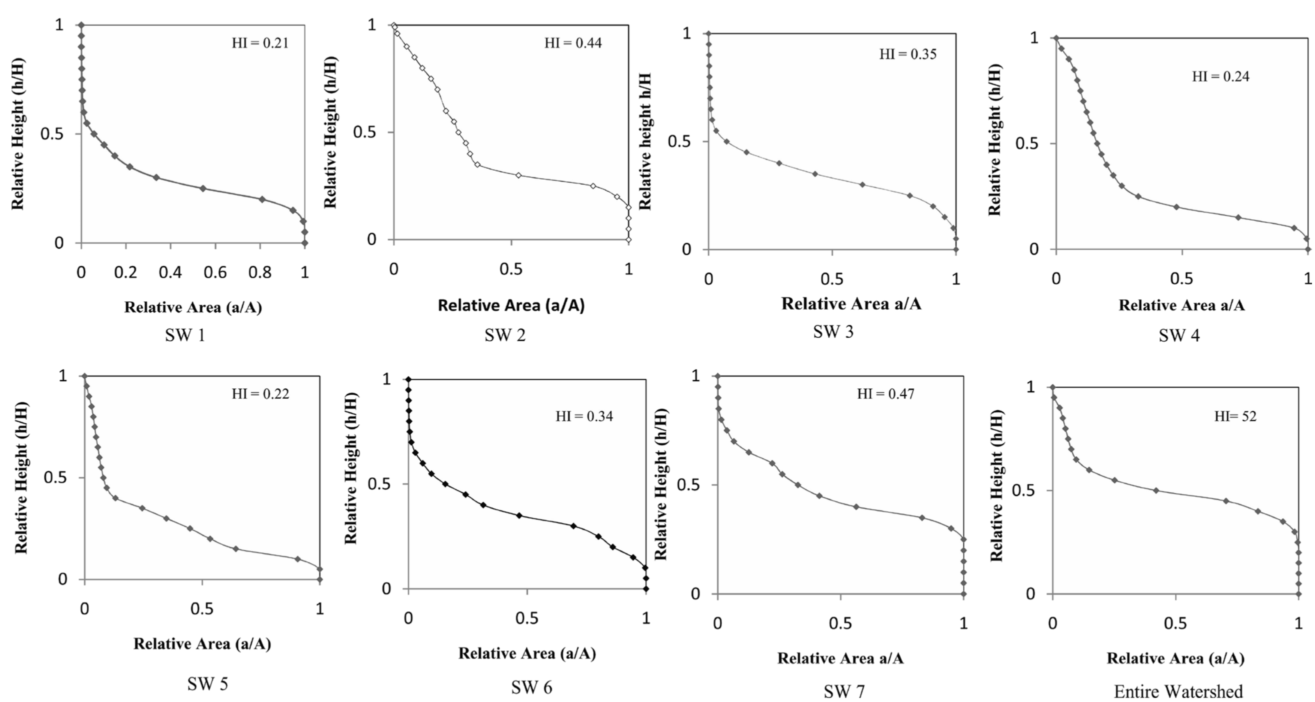

Fig. 7 Hypsometric curve (relative)

Table 5 Pair-wise comparison matrix for fuzzy AHP

Parameters	L_{sm}	D_d	D_f	R_t	R_{bm}	C_c	R_f	R_e
L_{sm}	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)
D_d	(1, 2, 3)	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)
D_f	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)
R_t	(2, 3, 4)	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)
R_{bm}	(3, 4, 5)	(2, 3, 4)	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)
C_c	(3, 4, 5)	(3, 4, 5)	(3, 4, 5)	(2, 3, 4)	(2, 3, 4)	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)
R_f	(4, 5, 6)	(3, 4, 5)	(3, 4, 5)	(3, 4, 5)	(2, 3, 4)	(1, 2, 3,)	(1, 1, 1)	(1/3, 1/2, 1)
R_e	(4, 5, 6)	(3, 4, 5)	(3, 4, 5)	(3, 4, 5)	(3, 4, 5)	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)
R_c	(5, 6, 7)	(4, 5, 6)	(4, 5, 6)	(3, 4, 5)	(3, 4, 5)	(2, 3, 4)	(2, 3, 4)	(1, 2, 3)
O_l	(5, 6, 7)	(5, 6, 7)	(4, 5, 6)	(4, 5, 6)	(3, 4, 5)	(2, 3, 4)	(2, 3, 4)	(2, 3, 4)
I_f	(6, 7, 8)	(5, 6, 7)	(5, 6, 7)	(5, 6, 7)	(4, 5, 6)	(3, 4, 5)	(3, 4, 5)	(3, 4, 5)
S_g	(6, 7, 8)	(6, 7, 8)	(5, 6, 7)	(5, 6, 7)	(4, 5, 6)	(3, 4, 5)	(3, 4, 5)	(3, 4, 5)
HI	(6, 7, 8)	(6, 7, 8)	(5, 6, 7)	(5, 6, 7)	(5, 6, 7)	(4, 5, 6)	(4, 5, 6)	(3, 4, 5)
R_n	(7, 8, 9)	(6, 7, 8)	(6, 7, 8)	(6, 7, 8)	(5, 6, 7)	(4, 5, 6)	(4, 5, 6)	(4, 5, 6)
R_h	(7, 8, 9)	(6, 7, 8)	(6, 7, 8)	(5, 6, 7)	(5, 6, 7)	(5, 6, 7)	(5, 6, 7))	(4, 5, 6)

Parameters	R_c	O_l	I_f	S_g	HI	R_n	R_h	X_i
L_{sm}	(1/7, 1/6, 1/5)	(1/7, 1/6, 1/5)	(1/8,1/7,1/6)	(1/8, 1/7, 1/6)	(1/8, 1/7, 1/6)	(1/9, 1/8, 1/7)	(1/9, 1/8, 1/7)	0.011
D_d	(1/6, 1/5, 1/4)	(1/7, 1/6, 1/5)	(1/7,1/6,1/5)	(1/8, 1/7, 1/6)	(1/8, 1/7, 1/6)	(1/8, 1/7, 1/6)	(1/8, 1/7, 1/6)	0.013
D_f	(1/6, 1/5, 1/4,)	(1/6, 1/5, 1/4)	(1/7,1/6,1/5)	(1/7, 1/6, 1/5)	(1/8, 1/7, 1/6)	(1/8, 1/7, 1/6)	(1/8, 1/7, 1/6)	0.015
R_t	(1/5, 1/4, 1/3)	(1/6,1/5,1/4)	(1/7, 1/6, 1/5)	(1/7, 1/6, 1/5)	(1/7, 1/6, 1/5)	(1/8, 1/7, 1/6)	(1/7, 1/6, 1/5)	0.017
R_{bm}	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1/7, 1/6, 1/5)	(1/7, 1/6, 1/5)	(1/7, 1/6, 1/5)	0.021
C_c	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1/7, 1/6, 1/5)	0.169
R_f	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	(1/7, 1/6, 1/5)	0.033
R_e	(1, 2, 3)	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/6, 1/5, 1/4)	(1/6, 1/5, 1/4)	0.038
R_c	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	(1/6, 1/5, 1/4)	0.045
O_l	(1, 2, 3)	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/5, 1/4, 1/3)	(1/5, 1/4, 1/3)	0.06
I_f	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)	(1/3, 1/2, 1)	(1/3, 1/2, 1)	(1/5, 1/4, 1/3)	(1/4, 1/3, 1/2)	0.075
S_g	(2, 3, 4)	(1, 2, 3)	(1, 2, 3)	(1, 1, 1)	(1/3, 1/2, 1)	(1/4, 1/3, 1/2)	(1/4, 1/3, 1/2)	0.093
HI	(3, 4, 5)	(2, 3, 4)	(1, 2, 3)	(1, 2, 3)	(1, 1, 1	(1/3,1/2,1)	(1/3, 1/2, 1)	0.11
R_n	(3, 4, 5)	(3, 4, 5)	(2, 3, 4)	(2, 3, 4)	(1, 2, 3)	(1, 1, 1	(1/3, 1/2, 1)	0.135
R_h	(4, 5, 6)	(3, 4, 5)	(2, 3, 4))	(2, 3, 4)	(1, 2, 3,)	(1, 2, 3,)	(1, 1, 1)	0.163

prioritization. Considering previous contributions (Sangma and Guru, 2020; Mishra et al. 2018; Ahmed et al. 2017; Rahaman, et al. 2015; Aher et al. 2014; Thomas et al. 2012; Magesh et al. 2011; Suresh et al. 2004; Khan et al. 2001) linear aspect such as bifurcation ratio (R_b), Mean Stream length and Length of overland (O_l); Areal aspect such as drainage density (D_d), stream frequency (F_s), drainage texture (D_t), Shape factor (F_s), circularity ratio (R_c), and elongation ratio; and relief factors such as relief ratio (R_r), ruggedness number (R_n) Stream Gradient (SL) and Hypsometric Integral (HI) have been selected to prioritize sub-watersheds as these are directly termed with surface runoff, soil erosion and other hazardous phenomena. Uncertainty in morphometric parameters was overcome by assigning triangular fuzzy numbers (TFN) to morphometric parameters on the basis of their influence on resource degradation (Ahmed et al. 2017). To assign weights to the selected parameters, triangular fuzzy number has been used at 9 point scale, i.e., equally important (1, 1, 1), (1, 2, 3), (2, 3, 4), (3, 4, 5), (4, 5, 6) (5, 6, 7), (6, 7, 8), (7, 8, 9), extremely important for pair-wise comparison. Morphometric parameters those are inversely correlated with erosion hazard such as Shape factor (F_s), circularity ratio (R_c), and elongation ratio membership value assigned inversely correspondent to index value, i.e., lower the value of shape parameters was higher the membership value was assigned. Rests of the parameters are directly correlated with erodibility thus highest TFN were assigned to the most important criteria as shown in Table 6.

After compute criterion weights for each parameter through FAHP alternative weight has been assigned to each sub-watershed through normalizing the values of morphometric parameters (Table 6). In case of those parameters which are directly correlated with erodibility, normalized value has obtained by dividing the actual value by highest value among the 7 sub-watershed for the same parameter on the other hand parameters which are inversely correlated with erodibility normalized value has obtained by dividing the lowest value of a parameter among 7 sub-watershed by actual value of each sub-watershed.

The final values of priority assessment (F_j) have been obtained for different sub-watersheds by multiply criterion weight with normalized morphometric parameters weights (Table 7). The prioritization values obtained from morphometric parameters through using fuzzy AHP ranges between 0.100 and 0.200 (Fig. 9b) which categorized into 3 category, i.e., highly prioritized (> 0.15), Moderately prioritized (0.125–0.15) and Low prioritization category (Fig. 9a).

Discussion

The analyzed results of sub-watersheds' prioritization using FAHP (Table 7 and Fig. 9) depicted that out of 7 sub-watersheds, 2 sub-watersheds (SW-2 and SW-6) covering a total area of 3450.20 km^2 could be categorized as high priority in which soil conservation measures and catchment area treatment plan would be urgently necessary. These watersheds have high altitude, moderate slopes with high drainage density (D_d) and length of the overland flow (L_o) which supports to more surface erosion. Least value of Circularity ratio (R_c) and higher value of form factor (R_f) in these sub-watersheds indicates relatively high peak discharge which increase the erodibility of soil. Other 3 sub-watersheds (SW-3, SW-4 and SW-7) occupied an area of 4192.53 km^2. Could be put under moderately prioritized categories which are located near reservoir also need measures for soil conservations. Moderate erosion can be observed in these watersheds as higher value of Texture Ratio (R_t), Drainage frequency (F_d) and Bifurcation ratio (R_{bm}). Rest of the Sub-watershed (SW-1 and SW-5) are categorized as a low prioritization which can be bringing under the part of conservation plan at later stage. These watersheds are characterized by low drainage density, plain surface and low erosion activities with comparatively good agriculture. Well irrigation in rainy season is observed for commercial crops near to streams. Therefore, these watersheds are suggested with comparatively low priorities for planning and development. Present study revealed the utility of hydro-morphometric-based prioritization study before adopting any comprehensive plan for watershed at micro-level. In the purpose of investigation at micro scale

Table 6 Normalized value of morphometric parameters (W_{ij})

Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7
L_{sm}	0.155	0.158	0.1137	0.24	0.095	0.135	0.101
D_d	0.132	0.134	0.201	0.13	0.136	0.128	0.138
D_f	0.152	0.094	0.156	0.133	0.159	0.143	0.162
R_t	0.172	0.085	0.119	0.167	0.16	0.154	0.141
R_{bm}	0.14	0.151	0.13	0.206	0.127	0.133	0.11
C_c	0.144	0.156	0.145	0.147	0.131	0.141	0.133
R_f	0.135	0.109	0.186	0.135	0.186	0.121	0.124
R_e	0.141	0.125	0.164	0.138	0.167	0.13	0.132
R_c	0.147	0.177	0.156	0.165	0.126	0.094	0.132
O_l	0.15	0.15	0.098	0.156	0.146	0.154	0.144
I_f	0.082	0.293	0.17	0.085	0.113	0.107	0.146
S_g	0.059	0.27	0.067	0.176	0.098	0.187	0.14
HI	0.093	0.212	0.133	0.105	0.096	0.152	0.206
R_n	0.105	0.188	0.153	0.139	0.128	0.163	0.121
R_h	0.097	0.224	0.116	0.121	0.116	0.168	0.158

Table 7 Prioritization values and rank

Sub-watersheds	SW1	SW2	SW3	SW4	SW5	SW6	SW7
Prioritization score $F_j = \sum (X_i * W_{ij})$	0.100	0.200	0.133	0.135	0.123	0.151	0.136
Priority rank	7	1	5	4	6	2	3
Vulnerable zone	Low	High	Medium	Medium	Low	High	Medium

it is impotent to study sub-watershed because each of these have some strengths and some challenges and to address those challenges and utilize their strength it is essential to study morphometric configuration of the sub-watershed at micro scale.

Though land-use/land-cover data have not used in prioritization of the sub-watersheds but the results obtained from Land-use/Land-cover analysis can be directly correlate with land and water resource deterioration. LU/LC information derived from the satellite imaginaries and their integration with GIS can be useful for estimation of runoff, infiltration, evaporation, soil erosion and sediment yield (Prabhakar et al. 2019). It was found that Sub-watershed 6 and sub-watershed-2 occupied highest percentage of settlement area, barren land and agricultural land which leads more soil erosion and minimize infiltration. On the other hand, sub-watershed 1 and 5 have highest percentage of forest cover area which leads infiltration, thus low priority has been assign to these sub-watersheds. Therefore, morphometric and Land-Use/Land-Cover analysis are quite useful soil and water resource conservation, management and planning of a watersheds.

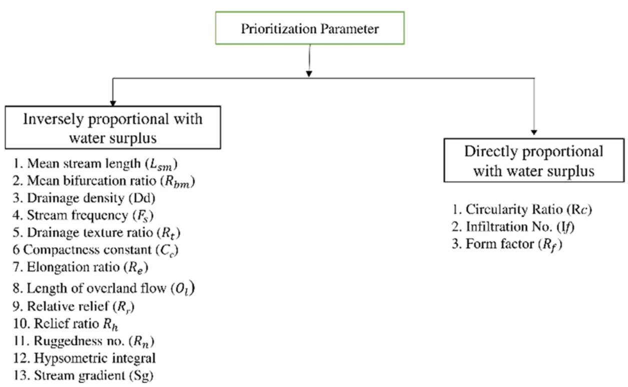

Fig. 8 Morphometric parameter used for sub-watershed prioritization and their relation with water surplus

Suitability measures

Morphometric analysis based on Remote sensing GIS techniques would serve as a powerful tool in watershed prioritization and management considering multiple criterions and their complex interrelationship. The purpose of applying multicriteria decision-making techniques is to exercise a proper approach to identify areas of high- priority for watershed management. Water and soil resources management decisions depend on timing of runoff characteristics and runoff characteristics of a watershed depends on surface hydrology, surface relief, slope lithology, basin geometry and other morphometric parameters. Figure 8 showing relationship between morphometric parameters and water surplus where Circularity Ratio (R_c), Infiltration No. (I_f) and Form factor (R_f) are directly proportionate with water surplus, as they increase rate of infiltration. Rest of the 13 parameters used in sub-watershed prioritization are inversely correlated with water surpluses as they promote surface runoff. Therefore, morphometric parameters are useful tool for sustainable management plan for soil and water resources. Based on result of morphometric-based prioritization analysis and by overlaying drainage ruggedness, Relief (Fig. 5d) slope map (Fig. 5e) and land-use/Land-cover map a suitable location for conservation measure structure consist of 12 Check dam, 40 Percolation tank and 65 Nala bund has been proposed to minimize soil erosion and promote groundwater recharge. As prioritization study has revealed that SW-2 and SW-6 are the most critical sub-watersheds in terms of erodibility thus a large number (total 46) of conservation measure structures sites was suggested out of these out of which 22

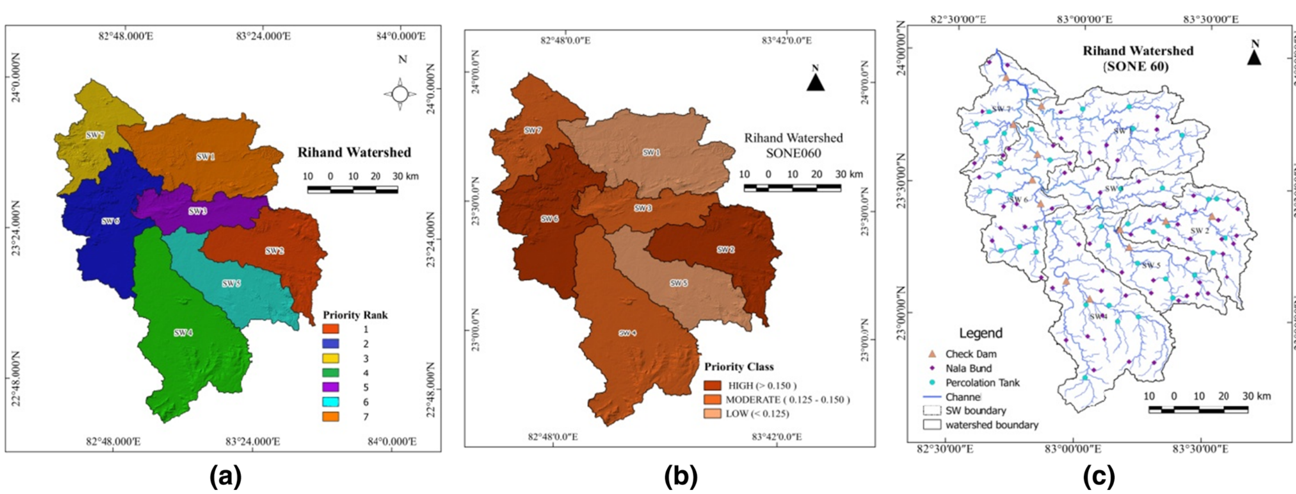

Fig. 9 **a**, **b** Prioritization map of the watersheds; **c** Location for conservation measure structure

sites for nala bund, 18 sites for percolation tank and 6 sites for the check dam (Fig. 9c). This study will not only help to planner and decision maker to take watershed development plan for land and water resource management in an effective way but also promote sustainable development through increase in agricultural production.

Conclusion

Morphometric analysis of watersheds is useful to reveal relationship among different aspects of the drainage basin including geology surface hydrology and climatic condition which are closely associated with erodibility, groundwater recharge, flood susceptibility and other hazardous phenomena. Therefore, priority analysis of sub-watersheds based on morphometric parameters is essential in soil and water resource conservation, construction of an integrated framework for watershed development, and to increase awareness of natural hazards. In present study a GIS-based prioritization of sub-watersheds has carried out based on morphometric parameters using Multicriteria Decision making (MCDM) to evaluate usefulness of morphometric parameters in the identification of soil erosion and groundwater potential zonation. Morphological characterization has been carried out through the measurement of linear, areal, and relief aspects to figure out hydrological behavior of the watershed with concern about soil and water resource depletion. In present study it has found that SW2 and SW6 are falls in the high priority category which indicating greater risk of erosion and most deficit zone of groundwater and may be taken for immediate conservation measurement by planning authority. SW 3, SW 4 and SW 7 are characterized by moderate soil erosion and groundwater recharge. SW 1 and SW 5 are ideal for groundwater storage as falls in the low priority zone. On the basis of priority analysis, a framework for the construction of small storage dam (check dams) in the area to recharge the groundwater and further to improve the water table and minimize soil erosion has been proposed which may be taken for conservation measurement by decision maker for planning and development.

Scope and limitation

This study revealed the applicability of morphometric analysis in prioritization of sub-watersheds to conserve soil and water resources. The result obtained from this study would be quite useful for hydrologic engineers for planning and management. Land-use/land-cover data in sub-watersheds is also helpful for management of soil and water resource. This study also revealed the benefits of remote sensing data and GIS techniques in morphometric analysis and land-use/land-cover analysis based on which further study may be carried out for sustainable management of soil and water resource.

Major limitation of this study area—unavailability of secondary data regarding water discharge, soil, land-use, etc. SRTM-DEM used in this study have 90-m spatial resolution so vertical accuracy is not enough for a plain land area. Thus, lack of high-resolution DEM is another limitation of this study.

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