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MORPHOMETRIC ANALYSIS AND PRIORITIZATION OF SUB-WATERSHEDS IN NAHRA WATERSHED OF BALAGHAT DISTRICT, MADHYA PRADESH: A REMOTE SENSING AND GIS PERSPECTIVE

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ABSTRACT

In this study, morphometric analysis and prioritization of the eleven sub-watersheds of Nahra watershed, located in the Central-Eastern part of the Balaghat district of Madhya Pradesh, India, was carried out using Remote Sensing (RS) and Geographical Information System (GIS). The morphometric parameters considered for analysis are stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio, elongation ratio, and compactness coefficient. The Nahra watershed has a dendritic drainage pattern. The highest bifurcation ratio among all the sub-watersheds is 6.667 which indicates a strong structural control on the drainage. The maximum value of circularity ratio and elongation ratio are 0.696 and 0.684, respectively for the SW8. The form factor values are in the range of 0.181 to 0.368, which indicates that the Nahra watershed has a moderately high peak flow of shorter duration. The compound parameter values were calculated and a prioritization rating of eleven mini-watersheds in Nahra watershed was carried out. The mini-watershed with the lowest compound parameter value is given the highest priority. The SW8 has a minimum compound parameter value of 4.222 is likely to be subjected to the maximum soil erosion; hence, it should be provided with immediate soil conservation measures.

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1 Introduction

Soil erosion is putting severe threats to human existence. Food and water are the two core pillars of the sustenance of human life on earth. Conversely, population explosion, the congregation of people, availability of limited arable land, and economic imbalance is putting a great burden on food security and water availability (Patil et al., 2016). Providing ample quantity of food, water for drinking and sanitation purposes and energy for a growing world is always a major challenge to science (Sharma et al., 2010; Sharma & Seth, 2010; Bisen et al., 2019).

A watershed can be defined as a part of landform biophysically defined by the flow of water in it, drained by a current or spatial pattern of currents pointing towards a common exit point or a gathering area lying at a lower elevation (Sharma et al., 2008; Sharma et al., 2012). In the last few decades, watershed management has attained due global recognition for the management of natural resources with significant importance on both environmental sustainability and improvising socio-economic condition of the residing rural population of the watershed (Patle et al., 2017; Patle, 2018; Patle & Awasthi, 2019a; Patle & Awasthi, 2019b).

Morphometric analysis refers to the quantitative assessment of characteristics of the earth's surface and any landform unit (Sharma et al., 2013). It is the most preferable method of prioritizing sub-watersheds by measurement of linear, aerial, relief, and gradient of channel network (Nag & Chakraborty, 2003). Understanding the hydrogeomorphological behavior of watershed is essential in managing natural resources at such scale triggering an in-depth study of discrete watersheds for the progression of an amenable management plan which needs massive data (Tignath et al., 2014). Major numbers of watersheds in India are deprived of the appropriate gauging facility (Gajbhiye et al., 2015). Investigation of morphometric parameters of a watershed represents its attributes that can be valuable in integrating hydrological behavior (Meshram & Sharma, 2018). Geomorphological and Hydro-geological investigations like morphometric analysis, hypsometric analysis, identification of groundwater potential zones, groundwater management, and environmental assessment can be effectively executed in watersheds as an implementation of the suitable action plan is comparatively easier as that on a provincial level (Rao, 2019; Rao et al., 2019; Awasthi & Patle 2019).

Over recent years, numerous studies have been performed for prioritization of sub-watershed on the foundation of morphometric parameters (*i.e.* linear, areal and shape factors) using perspectives of remote sensing and GIS such as Meshram & Sharma (2015), Sharma et al. (2015), Balasubramanian et al. (2017); Gaikwad & Bhagat (2018) and Malik et al. (2019). Further, Meshram & Sharma (2015) employed remote sensing and GIS for the successful accomplishment of morphometric analysis by incorporating Principal Component Analysis (PCA) and consequently prioritizing sub-watersheds of Shakkar river catchment, India. Poongodi & Venkateswaran (2018) achieved the prioritization of micro-watersheds employing morphometric analysis in Vasishta Sub Basin of the Vellar river of Tamil Nadu in India. Similarly, Arulbalaji & Padmalal (2020) performed a morphometric analysis to prioritize sub-watersheds of the Cauvery river basin situated in South India using a simple compound parameter approach.

In this study, an effort has been made to assess the morphological parameters of individual sub-watersheds of Nahra watershed using RS and GIS techniques. Furthermore, consequent prioritization of sub-watersheds based on final priority rank was executed to suggest appropriate action strategy for soil and water conservation measures to be established in different sub-watersheds of Nahra watershed. Manual methods of executing morphometric analysis are prone to human error and cumbersome that can create bias in the study thus making the use of GIS in such investigations can help to minimize such errors.

2 Materials and Methods

2.1 Study Area

Nahra watershed lies between 21°54'00.84" & 21°55'41.49" N latitudes and 80°23'13.74" to 80°25'52.61" E longitudes in the central-eastern part of the Balaghat district of Madhya Pradesh state of India. The Nahra nala watershed lies in Wainganga basin whose climate differs from Himalayan sub-tropical to sub-temperate. Total area of the watershed is 35 km^2. Watershed receives an annual rainfall of 1295 mm due to southwest monsoon from the midst of June to the midst of September. The temperature variation is watershed ranges from 43° C during summer in May to 8° C in winters in December. Figure 1 shows the location map of Nahra watershed.

2.2 Geo-referencing and delineation of watersheds

The delineation of Nahra watershed was executed by utilizing toposheet No. 64C/5 of Survey of India (SOI) on a scale of 1:50,000. The geo-referencing of toposheet was performed so as obtain the watershed boundary of Nahra watershed by digitizing in ArcMap™ environment. The position of the outlet was set at the confluence point of Nahra river with the Malwara nala. The watershed was further sub-divided into 11 sub-watersheds. The categorization of these sub-watersheds for delineation was accomplished based on increasing stream order commencing from third-order stream to trunk order stream. The nomenclature of sub-watersheds was given as SW1, SW2, SW3, SW4, SW5, SW6, SW7, SW8, SW9, SW10, and SW11 whose pictorial representation is depicted in Figure 2.

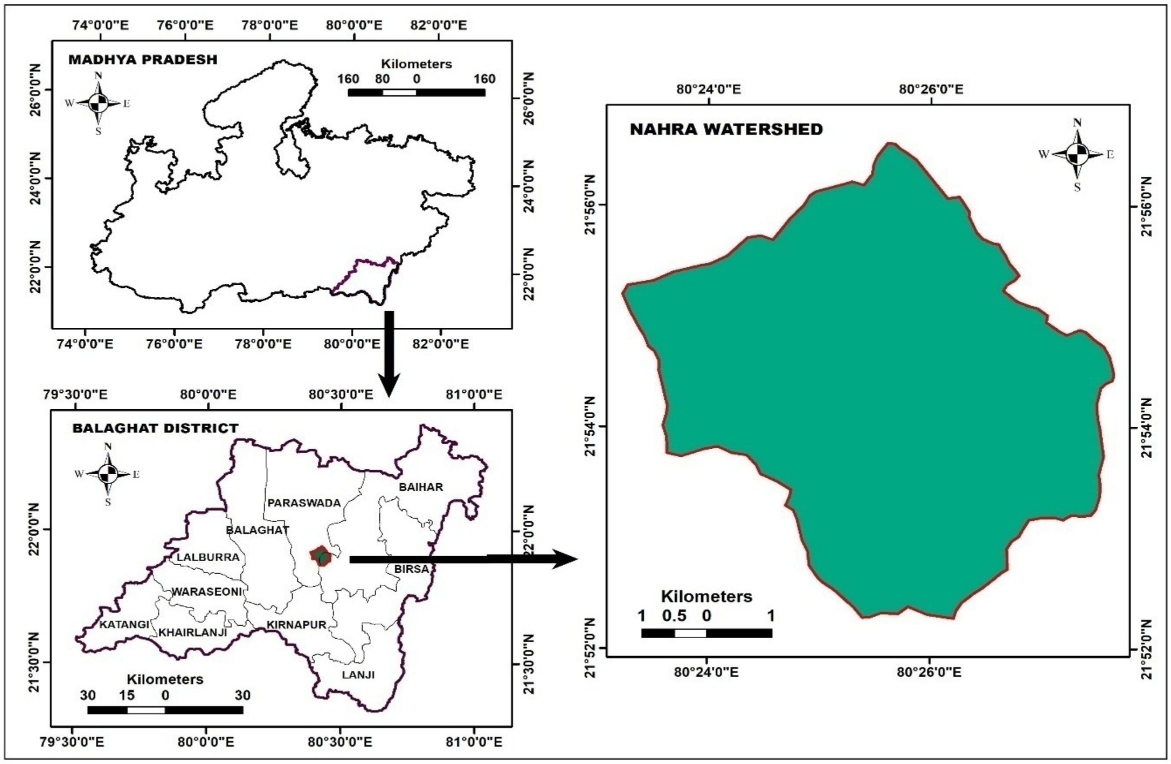

Figure 1 Location map of the Nahra Watershed

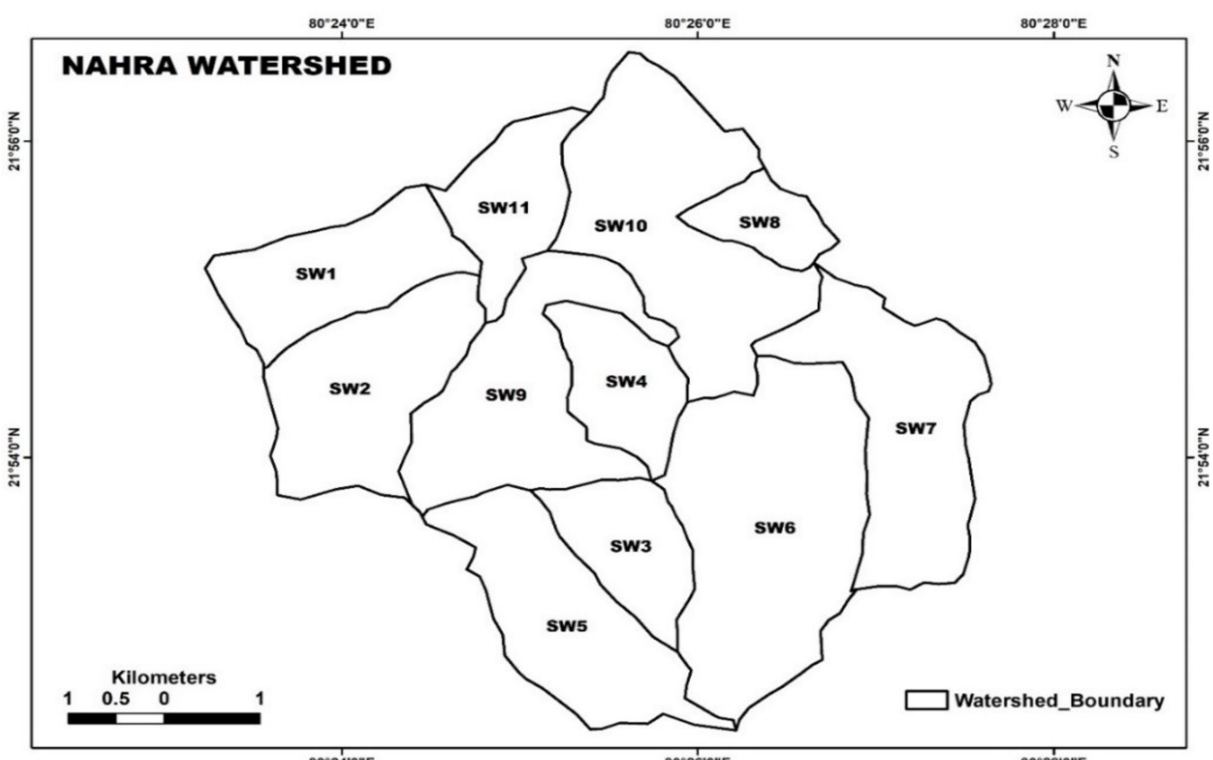

Figure 2. Sub-watersheds of Nahra watershed

2.3 Geomorphologic parameters of watershed

Geomorphologic characterization is an efficient representation of the geometry and stream channel arrangement in the watershed. Geometry and stream channel system of the watershed requires the estimation of (i) linear phase; (ii) areal phase; and (iii) relief phase of the channel system and contributing ground slopes. The initial two phases (i) and (ii) are planimetric and the third phase looks at the verticalim balances in the drainage basin. The geo-morphological parameters of stream network in a watershed are required tounderst and the hydrologic manner of the watershed so that planning and management of its assets could be done effectively. The factors computed in the present study using ArcMap™ environment include area (*A*), perimeter (*P*), stream order (*u*), stream length (L_u), and stream number (N_u), which were acquired from the digitized coverage of the drainage network. However, linear/areal factors of the sub-watersheds such as bifurcation ratio (R_b), drainage density (D_d), stream frequency (F_s), texture ratio (R_t), the mean length of overland flow (L_{om}), and the shape parameters such as form factor (F_f), circularity ratio (R_c), compactness coefficient (C_c) and elongation ratio (R_e) were calculated by the standard formula as shown in Table 1.

2.4 Sub-watershed prioritization

Prioritization of sub-watersheds was based on morphometric parameters which were assessed according to the linear, aerial, and shape factors. The linear and areal factors are in direct relation to the phenomena of soil erosion taking place in sub-watersheds (Biswas et al., 1999; Sharma et al., 2010; Malik et al., 2019) which allocates the highest value of each parameter as highest priority rank starting from the one which increases gradually for decreasing values of the factors. On the contrary, shape factors possess an inverse relationship concerning soil erosion, hence the parameters with the lowest value are assigned highest priority rank that decreases gradually with increasing value of the parameter (Nooka et al., 2005). Final priority ranking was obtained on the basis of the compound parameter, obtained by taking an average of allocated rankings to different factors of morphometric analysis. The final priority ranking was in direct relationship to the numeric values of a compound parameter such that lowest value of compound parameter was designated highest rank that increases with increasing values of compound parameters.

3 Results

The stream order analysis of the Nahra watershed was attained using the spatial analyst tool in ArcMap™ environment. The drainage network map of Nahra watershed is depicted in Figure 3 showing a dendritic pattern. Investigation of morphometric parameters of each sub-watershed of Nahra watershed was achieved whose numeric values are presented in Table 2 and 3. Furthermore, the succeeding allotment of ranks to morphological parameters is tabulated in Table 4.

Basin length (L_b) for all sub-watersheds of Nahra nala was calculated through the measure tool available in ArcMap™ environment. Assessment of basin length indicated that SW6 possessed the highest value of L_b (*i.e.*4.400 km) and was minimal for SW8 (*i.e.*1.600 km) amidst all the sub-watersheds.

Table 1 Various morphological parameters and formula used for computation

Geomorphologic parameters	Formula	References
Stream order (*u*)	Hierarchical rank	Strahler (1964)
Mean stream length (L_{sm})	$L_{sm} = L_u/N_u$ where L_u = total length of streams of order *u*, N_u = total number of stream segments of order *u*	Strahler (1964)
Basin length (L_b)	$L_b = 1.312\ A^{0.568}$	Nooka et al. (2005)
Bifurcation ratio (R_b)	$R_b = N_u/N_{u+1}$	Schumn (1956)
Drainage density (D_d)	$D_d = L_u/A$	Horton (1945)
Mean length of overland flow (L_{om})	$L_{om} = 1/\ 2 \times D_d$	
Stream frequency (F_s)	$F_s = N_u/A$	Horton (1945)
Texture ratio (R_t)	$R_t = N_u/P$ where *P* = watershed perimeter (km)	Horton (1945)
Form factor (F_f)	$F_f = A/L_b^2$ where, L_b = length of basin (km)	Horton (1945)
Elongation ratio (R_e)	$R_e = 1.128\ A^{0.5}/L_b$	Schumn (1956)
Circularity ratio (R_c)	$R_c = 12.57\ A/P^2$	Miller (1953)
Compactness coefficient (C_c)	$C = 0.2821\ P/A^{0.5}$	Horton (1945)

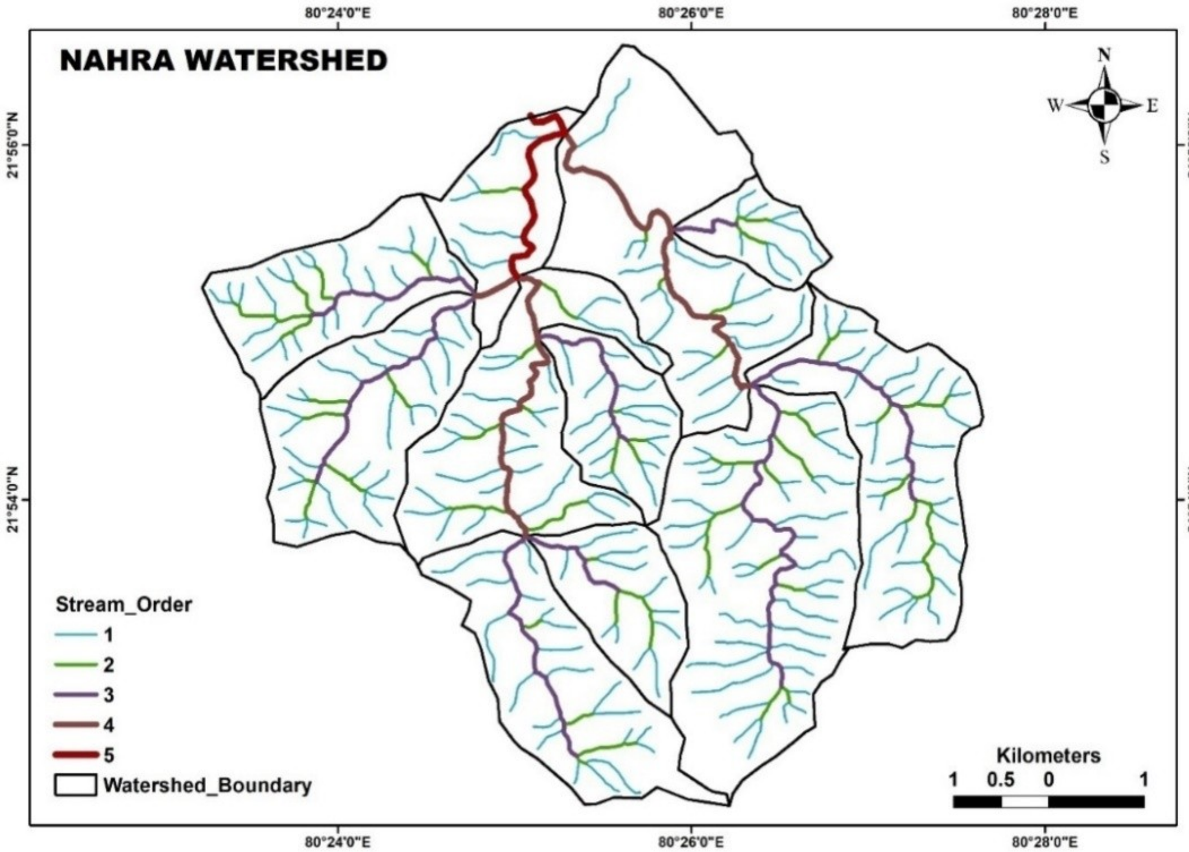

Figure 3 Drainage network map of Nahra watershed

Table 2 Sub-watershed wise morphometric parameters of Nahra watershed

Sub-watershed (SW) Name	Number of Stream Order					Total Number of Streams	Total Length of Stream (km)	Drainage Area (km^2)	Basin Length (km)	Perimeter of Basin (km)
	1st	2nd	3rd	4th	5th					
SW1	22	5	1	0	0	28	11.026	2.600	2.750	7.442
SW2	26	6	1	0	0	33	14.077	3.450	3.230	8.383
SW3	11	3	1	0	0	15	6.616	1.720	2.500	5.756
SW4	15	4	1	0	0	20	8.258	1.670	2.400	5.670
SW5	20	4	1	0	0	25	12.185	3.460	3.680	9.533
SW6	32	6	1	0	0	39	16.614	6.190	4.400	11.360
SW7	7	2	1	0	0	10	4.397	4.000	4.200	11.119
SW8	23	6	0	1	0	30	15.909	0.940	1.600	4.120
SW9	39	9	1	0	0	49	24.107	3.870	4.630	12.031
SW10	15	4	0	1	0	20	12.899	5.080	4.260	12.480
SW11	5	1	0	1	1	8	5.987	1.810	2.440	6.749

Table 3 Linear/areal and shape parameters of various sub-watersheds of Nahra watershed

Sub-watershed (SW) Name	Linear/ areal parameters					Shape parameters			
	R_b	D_d	F_s	R_t	L_{om}	F_f	R_c	C_c	R_e
SW1	4.700	4.241	10.769	3.763	0.118	0.344	0.590	1.302	0.661
SW2	5.167	4.080	9.565	3.937	0.123	0.331	0.617	1.273	0.649
SW3	3.333	3.847	8.721	2.606	0.130	0.275	0.653	1.238	0.592
SW4	3.875	4.945	11.976	3.528	0.101	0.290	0.653	1.238	0.607
SW5	4.500	3.522	7.225	2.622	0.142	0.255	0.479	1.446	0.570
SW6	5.667	2.684	6.300	3.433	0.186	0.320	0.603	1.288	0.638
SW7	2.750	1.099	2.500	0.899	0.455	0.227	0.407	1.568	0.537
SW8	1.917	16.924	31.915	7.281	0.030	0.367	0.696	1.199	0.684
SW9	6.667	6.229	12.661	4.073	0.080	0.181	0.336	1.725	0.479
SW10	1.875	2.539	3.937	1.603	0.197	0.280	0.410	1.562	0.597
SW11	2.000	3.308	4.420	1.185	0.151	0.304	0.500	1.415	0.622

Table 4 Ranking of sub-watersheds on the basis of linear/areal and shape parameters

Sub-watershed (SW) Name	Linear/ areal parameters					Shape parameters				Compound rank	Priority ranking	Priority category
	R_b	D_d	F_s	R_t	L_{om}	F_f	R_c	C_c	R_e			
SW1	4	4	4	4	8	2	6	6	2	4.444	2	Very High
SW2	3	5	5	3	7	3	4	8	3	4.556	3	High
SW3	7	6	6	8	6	8	3	9	8	6.778	7	Low
SW4	6	3	3	5	9	6	2	10	6	5.556	5	Medium
SW5	5	7	7	7	5	9	8	4	9	6.778	7	Low
SW6	2	9	8	6	3	4	5	7	4	5.333	4	High
SW7	8	11	11	11	1	10	10	2	10	8.222	11	Very Low
SW8	10	1	1	1	11	1	1	11	1	4.222	1	Very High
SW9	1	2	2	2	10	11	11	1	11	5.667	6	Low
SW10	11	10	10	9	2	7	9	3	7	7.556	10	Very Low
SW11	9	8	9	10	4	5	7	5	5	6.889	9	Very Low

The tectonic and watershed characteristics of a watershed are revealed by R_b. The value of R_b as calculated for each sub-watershed showed a variation from 1.875 to 5.667. High values of R_b express mature topography of terrain features producing high runoff potential and least infiltration. Such behavior is expected in terrain features predominant in steep sloping rock strata with narrow valleys circumferential by ridges. Regions with lower R_b are areas with less structural control. Such fluctuations in R_b for all sub-watersheds are identified to be diversified in plentiful phases of geomorphic evolution and topographic variations.

Areal factors of morphometric parameters taken into consideration for the study were D_d, F_s, R_t, and L_{om}. D_d and F_s possessed a good positive correlation coefficient (i.e. 0.985) thus conveying a linear relationship between the two factors such a manner that an increase in the value of one variable shows a gradual increase in other variables. However, in the case of R_t and L_{om} it was -0.703 which indicated an inverse relationship between the two. Sub-watersheds that generate higher values of F_s produce more runoff due to numerous streams in the area. SW8 generated highest F_s (i.e. 31.915) followed by SW9 (i.e. 12.661) and was least for SW7 (i.e.

2.500). Data investigation of numerous variations in geologic and climatic circumstances indicates that small vales of D_d is positively expected in areas predominant with subsoil topography of high permeability. Such areas do not possess high elevation differences, condensed with dense vegetal cover. Contradictorily, sub-watersheds with higher D_d is expected where subsoil geology comprises of impermeable particles as weak subsoil topography with sparse vegetation and huge differences in terms of relief aspects. For Nahra nala, SW7 generated lower values of D_d indicating maximum infiltration rate due to permeable subsoil material creating a barrier in runoff generation and consequent stream generation in case of heavy rainfalls. On the other hand, SW8 assimilated higher values of D_d reflecting minimum infiltration rate thus by creating a scenario of high runoff in the region. High values of D_d in sub-watersheds create situations of a dense network of stream channels that aids in prompt disposal of runoff resulting from extreme flood situations.

The length of overland flow (L_{om}) for SW8 was least and for SW5 was highest. R_t computed for sub-watersheds directed a variation from 0.899 km^{-1} for SW7 to 0.721 km^{-1} for SW8. The most important morphometric parameters primarily responsible for defining the shape of watershed *i.e.* F_f, R_c, C_c, and *R*e were calculated for each sub-watershed of Nahra nala. The values of the aforementioned shape factors of morphometric analysis are displayed in Table 3. F_f ranged from 0.181 to 0.367. Watersheds with higher values of F_f from 0.7854 are perfectly circular and if this value falls below 0.7854 then they are elongated in shape. Numeral value of F_f tending towards unity generate peak flows of shorter duration and those moving away from unity generate lower peak hydrographs with flatten peak having a short duration. For Nahra watershed, F_f varied from 0.181 to 0.367 depicting shapes of all inherent sub-watersheds as elongated on which if a high intensity and long duration rainfall occurs, then the subsequent hydrograph generated would be subdued in terms of its peak and the total duration for successful commencement of a flood hydrograph will also be high. Fluctuations in values of R_c are due to numerous factors such as stream length, stream frequencies, geological materials, land use/land cover, relief aspects and slope of the basin. R_c for different sub-watersheds of Nahra nala differed from 0.336 to 0.696 suggesting that the drainage system is structurally confined. R_e started from 0.479 to 0.661 expressing elongated watershed shape and high relief producing steep slope.

The final priority rankings for sub-watershed prioritization was carried out by initially allocating rankings to different morphometric parameters in such a manner that all those factors which are in linear relation with soil erosion susceptibility were given high ranks and those parameters showing inverse relationship were assigned lower ranks for high parameter values. Thus based on the value of the compound parameter as obtained by the ranking of individual priority rankings for morphometric parameters, prioritization of sub-watersheds in Nahra nala was executed. The obtained results showed that all suitable soil and water conservation measures should be adopted heading from SW8 to SW1 and so on based on their respective priority rankings.

4 Discussion and Conclusions

The present study makes use of remote sensing and GIS techniques for morphometric analysis and consequent prioritization of sub-watersheds in Nahra watershed of Wainganga River basin in Balaghat district of Madhya Pradesh state of India. The morphometric attributes of various sub-watersheds reveal their relative qualities for hydrologic response of the Nahra watershed. Linear and areal parameters are in direct relation with phenomena of soil erosion whereas it is completely inverse in case of shape factors (Biswas et al., 1999; Nooka et al., 2005; Thakkar & Dhiman, 2007; Sharma et al., 2010; Malik et al., 2019). The consequences of morphometric investigation indicated that sub-watersheds SW8 and SW1 were highly prone to soil erosion and should be taken up first for the execution of appropriate soil and water conservation and management measures for soil erosion control and safeguard the land from further erosion in the study region.

Conflict of interest

Authors would hereby like to declare that there is no conflict of interests that could possibly arise.

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