Evaluation of Morphometric Parameter for Prioritization of *Kantori Nala* Mili Watershed

Abstract

Watershed morphological and hydrological properties can be derived from the drainage morphometric parameter.Morphometricanalysis with the help of remote sensing and GIS techniques is consideredto be the most useful approach for prioritization of watersheds. The main aim of the study is to evaluate the morphometric parameters of *Kantori nala*mili watershed located at Mahasamund district of Chhattisgarh state, India. This study outlines the significance of digital elevation model for assessment of drainage pattern and extraction of relative parameters. Mili watershed was automatically delineated and divided into eleven micro watersheds MWS 1 to MWS 11 on the basis of topography from the Depression less Digital Elevation Model (DEM) with 10 m resolution prepared by Inverse Distance Weighted (IDW) interpolation technique. Stream order in study area mili watershed ranges from one to two. Each parameter has beenassigned their ranks according to their value.Thereafter, an average value of the rank score for each of the micro watershed is calculated.The micro watershed with the lowest compound factor (Cp) was given the highest prioritized rank out of the group of micro watersheds, and vice versa.The result from the priority ranking of morphometric analysis shows that MWS 7 is having high priority while MWS 8 is having low priority. Micro watersheds MWS 9 and MWS 11 falls under same priority i.e. 6 and also micro watersheds MWS 2 and MWS 4 falls under same priority i.e. 7. To control soil erosion, various land rehabilitation programmes and bioengineering methods should be adopted on the micro watershed of high priority categories, followed by medium and low priority categories.

Key words: Compound factor (C_p), Digital Elevation Model (DEM), Morphometric analysis, watershed prioritization.

INTRODUCTION

One of the crucial components that sustain life on earth is water.Since water, land, and other natural resources are limited and pose a severe threat to the environment, especially in developing countries like India, it is essential to sustainable development to conserve and manage these resources sustainably. Further, climatic conditions–rainfall and temperatureand their altered patterns are impacting the watercycle and natural recharge processes (Mall *et al.*, 2007;Kumar *et al.*, 2014). The watershed is considered to be the most appropriate spatial arrangement and functional unit for managing complex environmental problems. It is an ideal hydrological unit for management of natural resources that also supports land and water resource management for mitigation of the impact of natural disasters and activities of living beings for achieving sustainable development.Watershed management is considered as an essential approach for the overall development of the nation's water resources, especially in the dry and semi-arid regions. Watershed management is the process of developing and implementing a plan of action that involves altering the watershed's natural system in order to achieve specific goals. It further implies appropriate use of land and water resources of a watershed for optimum production with minimum hazard to natural resources (Patel *et al*., 2011).

The prioritization of sub-watersheds is of paramount importance in developingcatchment area treatment plan and implementing watershed management activities. Itcan help in taking necessary precautionary Soil and Water Conservation (SWC)measures a priori to ensure effectivedevelopment (Jaiswal *et al.*, 2015).Thus,watershed characterization and managementrequire detail information for topography, drainage network, water divide, channel length, geomorphologic and geological setup of the area for watershed managementand its prioritization (Javed *et al.*, 2009). Watershed Prioritization involves identification and ranking of environmentally degraded micro watersheds for treating them for the conservation of soil and degraded land on priority basis (Shelar *et al.*, 2022, Verma *et al*., 2022, Moharir *et al*., 2021). Sub-watersheds can be prioritized on the basis of a number of factors such as drainage basin morphometry, Universal Soil Loss Equation (USLE), Sediment Yield Index (SYI), Land use / cover (LULC) analysis etc.

Morphometricanalysis with the help of remote sensing and GIS techniques is consideredto be the most useful approach for prioritization of watersheds (Reddy *et al*., 2004, Singh and Singh, 1997, Nautiyal, 1994). It is the mathematical measurement of the configuration of the basin geometry of the earth's landforms and its analysis which provide knowledge about the characteristics of the watershed and the hydrological process occurring in the watershed (Reddy *et al.*, 2002, Agrawal, 1998, Clarke, 1966). It provides a quantitative description of the drainage basin that is very helpful in studies like hydrologic modeling, prioritizing watersheds, conserving and managing natural resources and rehabilitation. A systematic analysis is essential for the configuration of a catchment, and its streamcourses involve relief aspects, linear aspects, and aerial or shape aspects of the catchment. Since they have a direct or indirect relationship to peak flow, runoff, and soil erosion risks therefore, these have been used to prioritise most susceptible sub-watersheds (Nookaratnam*et al*., 2005, Javed*et al*., 2009, Singh and Gupta, 2014, Sharma *et al.*,2018, Rais and Javed, 2014). With advent of highresolution Digital Elevation Model (DEM), the extraction of drainage parameters from DEM gets more popularityin last three decades due to rapid, precise, updatedand cost effective way of performing watershed analysis(Maathuisand Wang, 2006; Moore*et al.*,1991).The objectives of the current study were to evaluate morphometric parameters derived from DEM generated from Global Positioning System (GPS) survey of*Kantorinala*mili watershed for priortisation of micro watershed for management purpose..

STUDY AREA

The study area is the part of Mahasamund district of Chhattisgarh state. The selected mili watershed falls within the middle Mahanadi basin and known as *Kantori nala* watershed. It belongs to *Kodar* river catchment of *Kodar* dam. It receives mean annual rainfall of about 1433 mm. The topography of the catchment almost flat and agriculture is predominant. The *Kantori nala* joins to *Kodar*river at *Achhridih* village in Mahasamund block of the district. Since references are not available regarding the name of the selected milli watershed therefore, on the basis of main channel i.e. *Kantori nala*, it is called as *Kantorinala* watershed. *Kantori nala* watershed lies between the 21°6'7.2"N to 21º12'39.6" N latitudes and 82º2'38.4" E to 82º6'14.4" E longitudes. The total catchment area of the Kantorinala watershed is reported to be 45.10 km^2. It comprises of *Kharora, Belsonda, Bemcha, Paraswani, Kampa, Khatidih, Birkoni, Achhridih*, part of *Muski, Tumadabri* villages and Mahasamund town. The map of the study area is shown in Fig. 1. The size of Kantorinala watershed is less than 100 km^2, therefore it is called as *Kantori nala*miliwatershed.

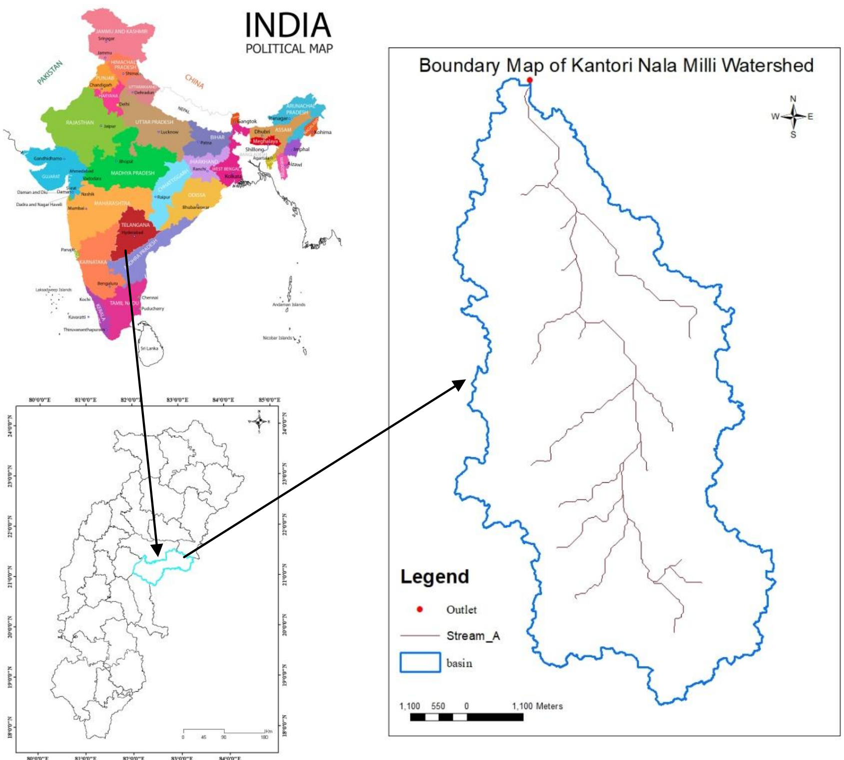

Fig. 1: Location map of *Kantori nala* milli watershed

MATERIAL AND METHODS

Generation of Depression Less Digital Elevation Model (DEM)

A GPS survey was done in the study area in gridded pattern and the values for XYZ dimensions for latitude, longitude and altitude, respectively were are recorded in the field. These recorded gridded data were tabulated in excel and imported to the ArcGIS software. The grids wereinterpolated using the Inverse Distance Weighted (IDW) technique available in ArcGIS. The output after running the programme was the Digital Elevation Model (DEM) with 10 m resolution (Fig. 2). DEM contains depressions that hinder flow routing which are considered as DEM errors. Therefore, these depressions in DEM were filled to route the flow and resultant DEM called as depression less DEM of the study area. This DEM was used for delineation of drainage network,mili watershed and micro watershedsautomatically based on topography.

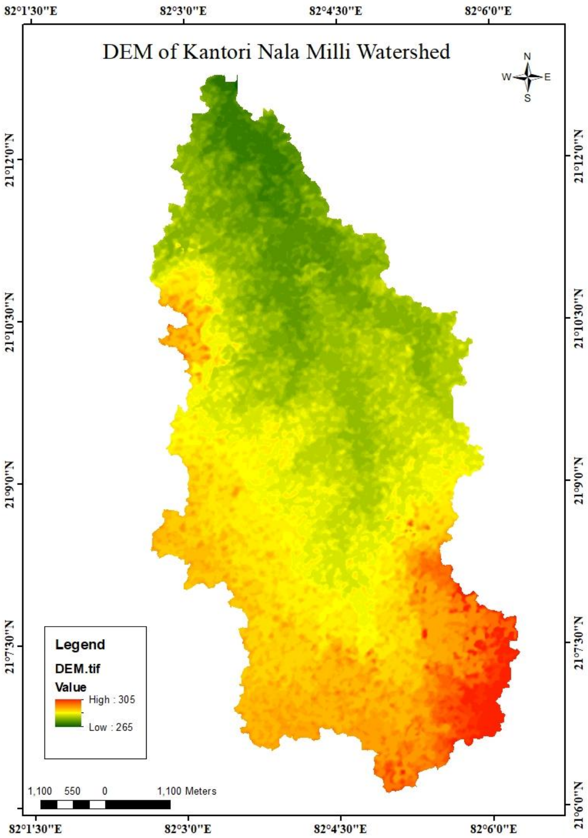

Fig. 2: depression less Digital Elevation Model of study area

Micro Watershed Prioritization

Evaluation of morphometric parameters of thewatershed including linear, and shape parameters as well as relief aspects has been carried out by morphometric analysisfor prioritization of micro watersheds of *Kantori nala* mli watershed. The equation / formulas used for analyzing/determining the different morphometric parameters are describe below:

Stream order: Stream order may also be defined as the number of order like first, second, third, and fourth order channels, etc. First order channels are the non-branching fingertip channel segments. Second order channel are those channel which receives water from only the first ordered channels. Third order channels are those which receive flow from two second ordered channels (Strahler, 1964) and so on. In other words, higher order will be formed when two channels of same order meet. Order of stream always increases while moving towards downward in watershed geo-morphology.

Streams number (N_u): Number of streams describes the total count of stream segments of different orders and is inversely proportional to the stream order. Stream number is denoted by N_u(Horton, 1945).

Total stream length (L_u): Total stream length is measured as the total length of all ordered perennial streams within the watershed and is denoted by L_u(Horton, 1945). In general, the total stream length is measured on 1: 100000 topographical maps.

Mean stream length($L_{\bar{u}}$): Mean stream length is the ratio of total stream length of particular order to the total number of same order stream and is denoted by $L_{\bar{u}}$ (Horton, 1945).

Stream Length Ratio (RL): It is the ratio of the cumulative mean length of the stream of a given order $L_{\bar{u}1}$ to the cumulative mean length of the streams of the next lower order $L_{\bar{u}1-1}$ (Horton, 1945).

$$RL = \frac{L_{\bar{u}1}}{L_{\bar{u}1-1}} \qquad \text{.......} \quad (1)$$

Watershed perimeter (P_r): Watershed perimeter is the total length of outer boundary of the watershed (Khan *et al.,* 2021). It is calculated by the instrument called as planimeter.

Maximum length of the watershed(L_b): It is the distance between the remotest point of the watershed to the outlet (Nookaratnam*et al.,* 2005).

Bifurcation ratio (R_b): The bifurcation ratio is the ratio of the number of streams in lower order (N_u) to the next order (N_{u+1}) (Schumm, 1956). It is generally seen that the bifurcation ratio is lower in alluvial region as compare to the hilly region.

Form factor (R_f): Form factor is defined as the ratio of basin area (A) to the square of maximum length of the basin (L_b). The smaller is the value of form factor, more elongated will be the watershed. The watershed with high form factor has high peak flows of shorter duration (Horton, 1932).

$$R_f = \frac{A}{L_b^2} \qquad \ldots\ldots\ (2)$$

Elongation ratio (R_e): It is calculated as the ratio of equal diameter of the circle which has same area as that of the watershed to the maximum length of the basin (Schumm, 1956).

$$R_e = \frac{2}{L_b}\sqrt{\frac{A}{\pi}} \qquad \ldots\ldots\ (3)$$

Circulatory ratio(R_c): The circulatory ratio is influenced by the length and frequency of stream (Miller, 1953). The circularity ratio is a similar measure as that of elongation ratio, and is defined as the ratio of area of the basin to the area of the circle having equivalent circumference as the basin perimeter.

$$R_c = \frac{12.57A}{P_r^2} \qquad \ldots\ldots\ (4)$$

Drainage density (D_d): Drainage density is the linear parameter of the morphometric analysis and is sensitive indicator for erosion calculation by the stream and effect of topographic characteristics to the outlet. It is defined as the ratio of the total length of the streams in all orders to the area of watershed (Schumm, 1956). It provides the link between the forms attributes of the basin and the processes operating along stream course (Gregory and Walling, 1973). The unit of the drainage density is km/km2, which indicates the proximity of channel spacing.

$$D_d = \frac{L_u}{A} \qquad \ldots\ldots\ (5)$$

Drainage frequency (F_s): Drainage frequency calculated as the number of streams per unit area of the watershed (Schumm, 1956). It mainly depends upon the lithology of the catchment and indicates the texture of the drainage network.

$$F_s = \frac{N_u}{A} \qquad \ldots\ldots\ (6)$$

Texture ratio (T): It is the ratio of the total number of first order stream segments (N1) to the perimeter of the watershed (Schumm, 1956).

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$$T = \frac{N_1}{P_r} \qquad \ldots\ldots\ (7)$$

Compactness coefficient (C_c): Compactness coefficient is the shape parameter of a watershed and is the ratio of perimeter of watershed (P) to circumference of equivalent circular area of the watershed $L_{\bar{u}1-1}$(Horton, 1945).

$$C_c = \frac{P}{\sqrt{4\pi A}} \qquad \ldots\ldots\ (8)$$

Maximum watershed relief (H): Maximum watershed relief is the maximum elevation difference between highest and lowest point of the watershed.

Morphometric analysis

The DEM is opened in ArcGIS 10.5 software for morphometric analysis as raster format image. The Arc-Map 10.5 software has Spatial Analyst Tools with a sub-module for hydrology. This hydrology module is utilized for getting different layers of information such as fill, flow accumulation, flow direction, flow length, stream link, drainage network, stream order, and boundaries of mili watershed and micro watershed according to drainage network. Morphometric analysis sub-divided into three parameters i.e., linear, relief and aerial parameters. However, stream order, stream length, stream length ratio and bifurcation ratio are taken as linear parameters, basin relief and relief ratio considered as relief parameter, and drainage density, stream frequency, form factor, circulatory ratio, elongation ratio, length of overland flow are considered under as aerial parameters, which has responsible for characterization of the watershed.

The soil loss in the watershed is either proportional or inversely proportional to these factors. For example, soil loss is proportional to bifurcation ratio, drainage density, stream frequency, texture ratio, relief ratio, and length of overland flow. It is inversely proportional to circulatory ratio, form factor, elongation ratio, and compactness coefficient. Micro watersheds are given score for each of the parameters accordingly. The micro watersheds which are more vulnerable to soil loss will have higher value of the directly proportional parameter and the rank will be lower (say 1) and the vice-versa. Thereafter, an average value of the rank score for each of the micro watershed is calculated. On the basis of this, the micro watershed with lower rank is identified as the most vulnerable to soil loss. Therefore, the micro watershed with lower rank score should be given top priority for soil conservation measures. Steps of the morphometric analysis are shown graphically in the form of flow chart in Fig 3.

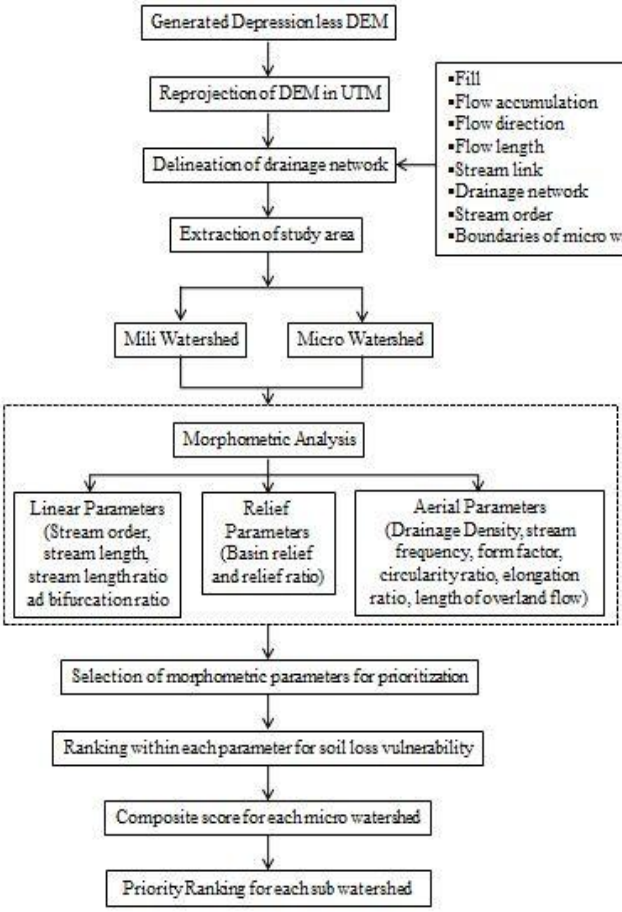

Fig. 3: Flowchart of methodology used in morphometric analysis

RESULT AND DISCUSSION

The quantitative morphometric measurements give information on the catchment's hydrological features. The influence of climate on geomorphic processes among distinct landforms is revealed by the morphometry of a drainage basin. The watershed was divided into elevenmicro watersheds. Morphometric analysis was utilizedfor prioritization of the *Kantori Nala*mili watershed by evaluating the basin's linear aspect, aerial aspect and relief aspect of each micro watershed.The watershed was divided into elevenmicro watersheds and the information about basic morphometric parameters such as area (A), perimeter (P), length

(L), and number of streams (N) was obtained from micro watershed delineated layer, and basin length (L_b) was calculated from stream length, while the bifurcation ratio (R_b) was calculated from the number of streams. Other morphometric parameters were calculated using the standard equations as earlier and the results are presented in Table 1.

Basic Parameters of Mili Watershed

Area of watershed (A): It is one of the important parameters which can directly reflect the overall volume of water. The total geographical area of *Kantori nala*mili watershed is 45.1 km^2 and he largest and smallest micro watershed areas are 7.07 km^2 (MWS 7) and 2.17 km^2 (MWS 9), respectively.

The perimeter of a watershed (P): The watershed perimeter is the outside limit that encloses the watershed's area (Khan*et al.*, 2021) and is designated by P. Out of the eleven micro watersheds, the largest and smallest micro watershed perimeters are 26.40 km (MWS 7) and 11.00 km (MWS 10), respectively.

Watershed length (L_b): The watershed length, sometimes referred to as hydrologic length, is conceptually the distance travelled by the surface drainage. The watershed length is measured along the principal flow path from the watershed outlet to the basin boundary.

Stream order (U): According to Strahler, 1964, the order of stream is termed as the calculation of the position of a stream in the hierarchy of streams. First stream order refers to the smallest finger type and any unbranched tributaries. Two first stream orders are combined to generate a second stream order. Following that, the second stream order combines the third, and so on. The *Kantori nala*mili watershed consists of eleven micro watersheds, in that 2th order for MWS 1, MWS 3, MWS 5, MWS 7, MWS 9, MWS 10 and 1st order for remaining micro watershed. Watershed is dominated by overland flow.

Stream number (N_u): The number of streams in a specific catchment is equal to the number of streams in each order (Horton, 1945) and is denoted by the symbol N_u. MWS 7 have highest (7) and MWS 2, MWS 4, MWS 6, MWS 8, MWS 9 MWS 11 have lowest (1), stream numbers.

Table 1: Micro watershed wise morphometric parameters of *Kantori nala*mili watershed

Micro watershed Name	Bifurcation ration	Drainage density	Stream frequency	Circulatory ratio	Form factor	Elongation ratio	Texture ratio	Compactness coefficient	Relief ratio	Length of overland flow
MWS-1	0.50	0.76	0.53	0.207	0.458	0.764	0.161	2.20	5.54	0.66
MWS-2	-	0.74	0.18	0.152	0.459	0.765	0.046	2.57	3.50	0.68
MWS-3	0.67	1.00	1.43	0.206	0.490	0.790	0.342	2.20	7.24	0.50
MWS-4	-	0.57	0.33	0.245	0.499	0.797	0.080	2.02	5.38	0.88
MWS-5	0.67	0.80	0.93	0.188	0.462	0.767	0.264	2.31	5.55	0.62
MWS-6	-	0.79	0.28	0.213	0.488	0.788	0.069	2.17	3.68	0.63
MWS-7	0.75	1.01	0.99	0.127	0.445	0.753	0.265	2.80	4.42	0.49
MWS-8	-	0.84	0.37	0.147	0.508	0.804	0.066	2.61	4.35	0.60
MWS-9	-	0.69	0.46	0.209	0.523	0.816	0.088	2.19	8.47	0.72
MWS-10	1.50	0.64	1.07	0.292	0.505	0.802	0.273	1.85	7.29	0.78
MWS-11	-	0.49	0.29	0.247	0.491	0.791	0.075	2.01	5.58	1.03

Linear Aspects

Bifurcation ratio (R_b): Bifurcation ratio describes the branching pattern of adrainage network and is defined as ratio between the total numbers of stream segments of a given order tothat of the next higher order in a basin (Schumm, 1956).The range of bifurcation ratio is between 0.5 to 1.5which,indicates that there is minimum structure disturbancein this mili watershed.

Stream frequency (F_s): Stream frequency is defined as the number of stream segments of all orders per unit catchment area, according to Schumm, 1956. In the current study, the higher stream frequency is at MWS 3 and the lower stream frequency is at MWS 2.

Drainage density (D_d): It is an expression to indicate the closeness of spacing of channels. A fine drainage texture results from high drainage density, whereas a coarse drainage texture results from low drainage density. In this study, drainage density is higher at MWS 7 and lower at MWS 11.

Length of the overland flow (L_o): Horton (1945) defined length of overland flow as the amount of time that water remains above the earth before it concentrates into distinct stream channels. It is one of the mostimportant independent variables, affecting both thehydrological and physiographical developments of thedrainage basin (Horton, 1945). The length of the overland flow's maximum value corresponds to greater surface runoff, and its lowest value corresponds to shorter surface runoff. The length of the overland flow is higher at MWS 11 and lower at MWS 7.

Texture ratio (T): The relative spacing of drainage lines is indicated by the texture ratio or drainage texture. Drainage texture is influenced by the temperature, rainfall, rock types, relief, and development stage.In this study, MWS 3 has a greater texture ratio than MWS 2.

Areal Aspect

Circularity ratio (R_c): The circularity ratio is influenced by geologicalstructures, climate, relief, land cover and streamlength and slope of the basin. Its ratio indicates the shape of the catchment. In the given area circulatory ratio variesfrom 0 to 1. In the current study, MWS 10 has a higher circulatory ratio and MWS 7 has a lower circulatory ratio.

Elongation ratio (R_e): An active denudational process with high infiltration capacity and low runoff is indicated by a basin's higher elongation ratio, and higher elevation and higher headward erosion along tectonic lineaments are indicated by a basin's lower elongation ratio (Reddy*et al.*, 2004; Yadav *et al*., 2014).The values of the elongationratio generally vary from 0.6 to 1.0 over a largevariety of climatic and geologic types (Rudraiah,*et al*., 2008).MWS 9 has a higher elongation ratio and MWS 7 has a lower elongation ratio in the study area watershed.

Form factor (F_f): The form factor describes the flow rate of a basin for a specific area.The form factor valueranges zero to one. The basin will have a more elongated shape with the lower form factor value.MWS 9 has a greater form factor in this study, while MWS 7 has a lower form factor.

Compactness coefficient (C_c): It derives the relationship between the actual hydrologic basins and the exact circular basin with the same area as the hydrologic basin.MWS 10 has a lower compactness coefficient in this study than MWS 7, which has a greater compactness coefficient

Relief Aspects

Watershed relief: Watershed relief is described as the elevation variation between the maximum value and outlet value on the perimeter of the catchment and is denoted by B_h (Strahler, 1952). It is one of the morphometric variables that aids in understanding the basin's denudational characteristics. It also regulates the stream gradient and has an impact on surface runoff and sediment.In the study area watershed, MWS 10 has the maximum relief (20 m), and MWS6 and 10 has the minimum relief (10 m).

Relief ratio (R_r): It is actually influenced by rocks and slope of thebasin. If the values of relief ratio are high it indicateshilly region and low ratio indicates pediplain and valleyregion (Kumar *et al*., 2011). In this study, MWS 9 has the larger relief ratio and MWS 2 has the lower relief ratio value.

Prioritization of Micro Watershed

According to Nookaratnam*et al.*(2005), linear parameters and erodibility are directly correlated; the greater the value, the more erodible the parameter. The highest value of the linear parameters was assigned as rank 1, the second highest value as rank 2, and so on, with the lowest value being rated last in rank for sub watershed priority. However, the shape parameters have an inverse relationship with the linear parameters, meaning that the more erodibility there is, the lower their value. (Patel *et al.*, 2012; Patel and Dholakia, 2010). The lowest value of the shape parameters was therefore ranked as rank 1, the next lowest value as rank 2, and so on, with the highest value being ranked last in rank as given in Table 2. Then, the compound factor was calculated by adding up all the ranks of the linear parameters and the shape parameters, and dividing by the total number of parameters. The micro watershed with the lowest compound factor (Cp) was given the highest prioritized rank out of the group of micro watersheds, and vice versa (Patel *et al.*, 2012). The result from the priority ranking of morphometric analysis shows that MWS 7 is having high priority ranking while MWS 8 is having low priority ranking (Fig. 4). MWS 9 and MWS 11 falls under same priority ranking 6 and also MWS 2 and MWS 4 falls under same priority ranking 7.

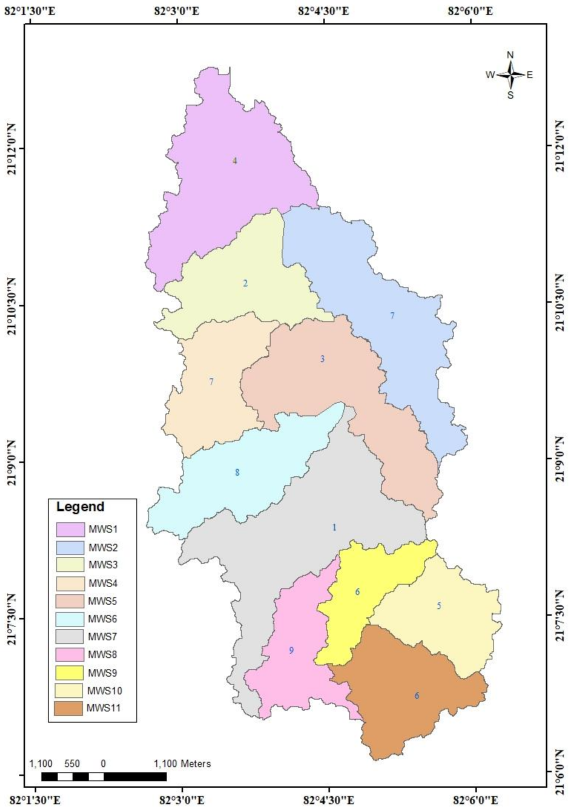

Fig. 4: Prioritized ranking of micro watersheds by morphometric analysis

Table 2: Prioritized rank of micro watersheds using the morphometric parameter

Micro watershed Name	Bifurcation ration	Drainage density	Stream frequency	Circulatory ratio	Form factor	Elongation ratio	Texture ratio	Compactness coefficient	Relief ratio	Length of overland flow	Composite score	Final priority
MWS-1	5	6	5	6	2	2	5	6	6	6	4.9	4
MWS-2	1	7	11	3	3	3	11	8	11	5	6.3	7
MWS-3	4	2	1	5	6	6	1	6	3	10	4.4	2
MWS-4	1	10	8	9	8	8	7	3	7	2	6.3	7
MWS-5	4	4	4	4	4	4	4	7	5	8	4.8	3
MWS-6	1	5	10	8	5	5	10	4	10	7	6.5	8
MWS-7	3	1	3	1	1	1	3	10	8	11	4.2	1
MWS-8	1	3	7	2	10	10	9	9	9	9	6.9	9
MWS-9	1	8	6	7	11	11	6	5	1	4	6.0	6
MWS-10	2	9	2	11	9	9	2	1	2	3	5.0	5
MWS-11	1	11	9	10	7	7	8	2	4	1	6.0	6

CONCLUSIONS

The drainage morphometric parameter of the watershed provides insight into its morphological and hydrological characteristics. The morphometric factors also assisted in understanding a variety of terrain characteristics, including the type of bedrock, infiltration rate, surface runoff, etc. Different watersheds exhibit distinct hydrological behaviours, depending on their morphometric and topological features. Therefore, identifying a crucial watershed is an essential step in a watershed management programme.Watershed prioritization helps in the identification and ranking of different degraded watersheds or micro watersheds into different risk categories which can be used to prioritize the conservation treatments and budgets effectively. The most vulnerable micro watershed to erosion was found to be MWS 7, whereas MWS 8 had the lowest risk. To control soil erosion, various land rehabilitation programmes and bioengineering methods should be adopted on the micro watershed of high priority categories, followed by medium and low priority categories.

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