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Research Article

MORPHOMETRIC STUDY OF BAINK RIVER, SUB-WATERSHEDS OF SONAR RIVER (A SUB-BASIN OF KEN RIVER BASIN) USING RS & GIS

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A B S T R A C T

The quantitative analysis of the watershed is important for the quantification of the channel network and to understand its geo-hydrological behavior. Assessment of drainage network and their relative parameters have been quantitatively carried out for the baink watershed of Madhya Pradesh, India, to understand the prevailing geological variation, topographic information and structural setup of the watershed and their interrelationship. RS & GIS has been used for the delineation and calculation of the morphometric parameters of the watershed. The Bank watershed is sprawled over an area of about 433.75 km with dendritic, parallel and trellis drainage pattern. It is sub-divided into seven sub-watersheds. The study area is designated as sixth-order basin and lower and middle order streams mostly dominate the basin. The main watershed had a drainage density value 1.46 km/km^2 while rest of 7 sub watershed had drainage density value range from 1.35 to 1.59 km/km^2 fells in its low category with high precipitation. The results from the morphometric assessment of the watershed are important in water resources evaluation and its management and for the selection of recharge structure in the area for future water management.

INTRODUCTION

Morphometry is the measurement and mathematical analysis of the configuration of the earth surface, shape and dimension of its landforms. Morphometric analysis is an important technique to evaluate and understand the behaviour of hydrological system; it provides quantitative specification of basin geometry to understand initial slope or inconsistencies in rock hardness, structural controls, recent diastrophism, geological and geomorphic history of drainage basin (Strahler 1964; Esper Angillieri 2008).

The fast emerging Geospatial technology (GT) viz. remote sensing, GIS, and GPS have been used as an effective tool to overcome most of the problems of land and water resources planning and management on the account of usage of conventional methods of data process (Tripathi *et al* 13; Soni *et al*. 2013; Banerjee *et al*. 2015).

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Objective of the Study

Objective of the study (a) to attain quantitative description of the basin geometry to understand its slope, structural controls, geological and geomorphic history of drainage basin by using the morphometric analysis (b) to understand the influence of drainage morphometry on landforms and their characteristics.

Study Area

Baink River is an important sub-tributary of the river Sonar. Total basin area of Baink River is 433.75 km². Area bounded by 24^0 0' to 24^0 15'N and 79^0 13' to 79^0 21' E longitudes having altitude of 305 to 555 m above mean sea level (msl), fall under two districts of Madhya Pradesh i.e., Chhatarpur and Damoh. In Damoh district it covers 276.45 km2 and in Chhatarpur covers 157.32 km2 (Fig. 1).

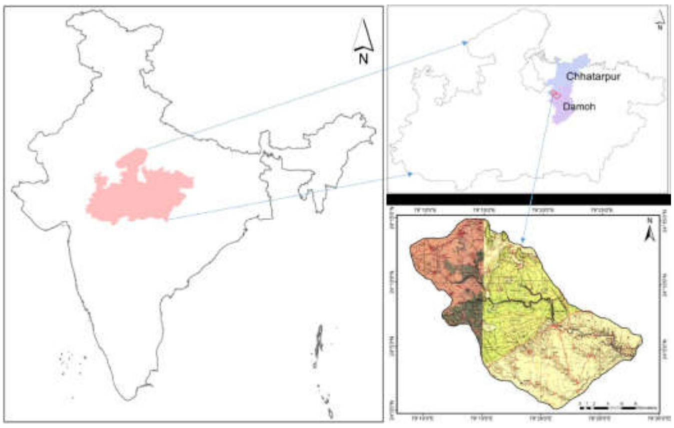

Fig 1 Location Map of Study Area

Geology and Soil

Predominant geological formation is limestone, sandstone and shales. Soil of the district is of medium black (Chromesterts), shallow black (Utochrepts) and skeletal soil (Lithic Enti soils) type.

Predominant geological formation is recent alluvium, Deccan Traps, Vindhyans and Bijawar and granite. Major soil type of the district is alluvial, red & yellow, mixed red & black and medium black soils.

MATERIAL AND METHOD

In this present study, Survey of India (SOI) toposheet number 53P/4 and 54P/4 was used for the preparation of base map on the scale of 1: 50,000. Remote Sensing and GIS software were used for georeferencing of the topomap and generation of thematic layer. Land use land cover classification was conducted in Landsat-7 TM satellite image through vector based visual image interpretation using ArcGIS 9.3 software.

The study area were delineated from rectified/referenced geographically mosaic topomap with the help of ArcGIS9.2 software. The delineated watershed boundary was further subdivided into sub-watersheds. Morphometric analysis was carried out all the seven sub-watersheds. The parameters computed using GIS technique including area, perimeter, stream order, stream length, stream number and elevation, which were obtained from the digitized coverage of the drainage network map. However, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circulatory ratio, elongation ratio and compactness ratio were calculated by standard formulae as given in the subsequent text in ''Morphometric analysis''. Drainage network was digitized from topomap and extracted from DEM using ArcGIS 9.3 software inside watershed boundary. Digitized stream network was updated with stream network from DEM and with satellite data (Figure-2). These data were used to calculate linear aspect, areal aspect and relief aspect using ArcGIS 9.3 software.

RESULTS AND DISCUSSION

This analysis is carried out for quantitative evaluation of drainage basin and for planning and management of water resources. Three major aspects: Linear, Areal and Relief have been described for analysis. Linear aspect morphometry is characterized by basin length, stream order, stream number, and stream length and bifurcation ratio. Areal aspect represents the characteristics of catchment area and describes how catchment area controls and regulates the hydrological behavior. Relief aspect defines terrain setup of the catchment and terrain characteristics. The morphometric parameters of the Baink watershed and its 7 sub-watersheds (SWS-1, SWS-II, SWS-III, SWS-IV, SWS-V, SWS-VI and SWS-VII) (figure -3) have been examined and detailed was discussedin subsequent paragraphs.

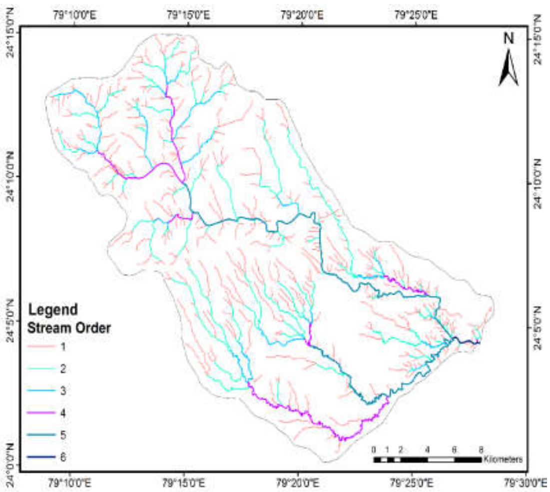

Fig 2 Order of Drainage Netwok

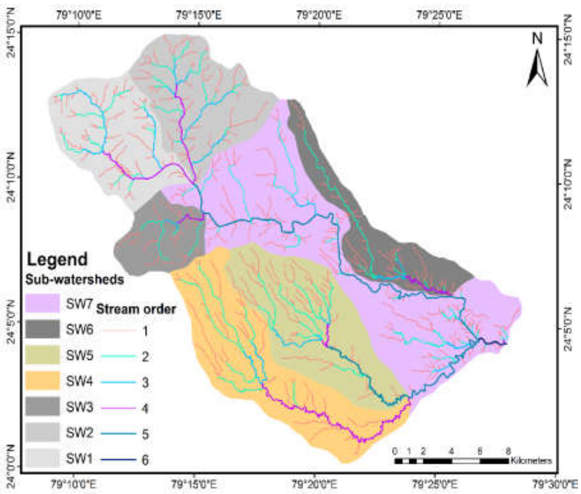

Fig 3 Sub-watersheds with stream order

SLOPE

Slope analysis is an important parameter in geomorphic studies. A detailed understanding of slope distribution as the map helps in planning for various aspects like, settlement, agriculture, planning of engineering structure, etc. It helps to understand and identify the area prone to erosion and sediment runoff. The slope map for the study area was extracted from SRTM data using spatial analysis tool in ArcGIS 9.3. A lower slope value indicates relatively flat terrain, and a higher slope value indicates steeper terrain. The degree of slope vary between 0º to 17.77º, 0º to 28.89º, 0º to 20.75º, 0º to 16.80º, 0º to 19.15º, 0º to 22.07º, and 0º to 51.50º, in subwatershed SWS-1, SWS-II, SWS-III, SWS-IV, SWS-V, SWS-VI and SWS-VII respectively (Figure 4).

ASPECT

The aspect of a terrain is the direction to which it faces. Aspect influences vegetation type, and precipitation patterns. The aspect map of Baink watershed is shown in Figure 5.

Maximum slope is south facing which collects a large amount of sun light for a long time period during a day and indicate dry land. Another maximum slope is east facing and north facing in the study area, which has a higher moisture content and lower evaporation rate and hence has high vegetation index.

between logarithm of number of streams against stream order shows a straight line with a deviation which indicates that the number of streams decreases as stream order increases and describes homogeneous subsurface material subjected to weathering and latter basin is characterized by lithologic and topographic variation (Nag and Lahiri 2011).

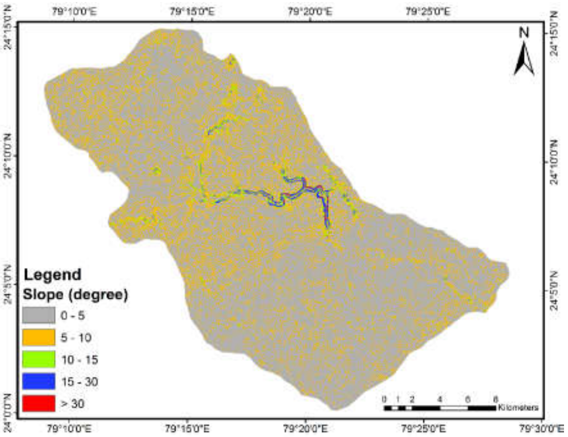

Fig 4 Slope Map of the area

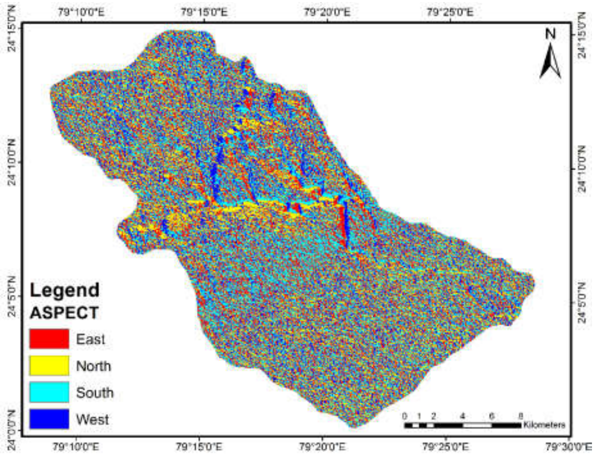

Fig 5 Aspect of the study area

Linear Aspects

Perimeter

Overall perimeter of Baink Watershed (Main Watershed, MW) is 97.80 km while the data of all other sub-watersheds (SW) is expressed in Table 2. Among the sub-watersheds SW 7 has the largest value i.e. 77.01 km covering larger basin area of 127.43 km2 while SW3 covering smallest perimeter of 19.58 km and attain an area of 51.86 km^2.

Basin Length (LB)

The basin length of MW is 49.57 km and rest of 7 SW is discussed in Table 3. All the sub-watersheds are longer ones except SW3 (8.09 km). It shows positive correlation (r = 0.83) with basin area tends to head-ward erosion. Basin length is defined as straight line distance from a basin mouth to the outlet point (Horton 1932).

Stream Order (NU)

Stream ordering is an important aspect for drainage basin analysis. It is defined as a measure of the position of a stream in the hierarchy of streams (Horton 1945; Strahler 1957). Strahler (1964) proposed a method of ranking of streams. The smallest fingertip tributaries are designated as order 1. Where the two first order channels join, a channel segment of 2nd order is formed and so forth. The highest order stream carries discharge and sediment loads. It reveals about size of stream, runoff, drainage area and its extent is directly proportional to the size of watershed. Ordering of 7 SW is tabulated in Table 1. It has been found that the study area is a 6th order drainage basin having 515 total streams, sprawl over 433.75 km2 (Fig. 2).

Stream Number (NT)

The number of streams of each order in a given watershed is known as stream number. Law of stream order (Horton 1945) describes that the number of streams of each order forms an inverse geometric sequence against stream order. Relationship

The graph (Fig. 2) validates the Horton's law of stream number as the coefficient of correlation is -0.79.

Table 1 Linear aspects of the MW and sub-watersheds

Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	MW
Perimeter	30.58	31.95	19.58	50.00	37.38	41.39	77.01	97.80
Basin Length	10.13	10.97	8.09	31.55	18.62	24.68	33.94	49.57
Number of streams								
N1	60	51	20	32	37	43	140	383
N2	15	16	7	7	11	8	34	98
N3	3	5	2	2	4	2	5	23
N4	1	1	1	1	2	1		7
N5					1	2		3
N6							1	1
NT	79	73	30	42	55	54	182	515
Total stream length								
LT1	44.62	42.73	19.15	47.85	51.19	29.57	96.05	331.16
LT2	15.94	17.20	8.82	26.44	23.14	17.91	31.02	140.47
LT3	13.52	12.79	1.55	7.26	9.71	5.20	7.44	57.46
LT4	8.14	7.22	2.68	20.68	2.82	5.65		47.20
LT5					11.06	41.99		53.05
LT6							2.19	2.19
Total	82.21	79.94	32.21	102.24	97.92	58.33	178.67	631.52
Mean stream length								
Lm1	0.74	0.84	0.96	1.50	1.38	0.69	0.69	0.86
Lm2	1.06	1.08	1.26	3.78	2.10	2.24	0.91	1.43
Lm3	4.51	2.56	0.78	3.63	2.43	2.60	1.49	2.50
Lm4	8.14	7.22	2.68	20.68	1.41	5.65		6.74
Lm5					11.06		20.99	17.68
Lm6							2.19	2.19
Bifurcation ratio								
Rb 1-2	4.00	3.19	2.86	4.57	3.36	5.38	4.12	3.91
Rb 2-3	5.00	3.20	3.50	3.50	2.75	4.00	6.80	4.26
Rb 3-4	3.00	5.00	2.00	2.00	2.00	2.00	2.50	3.29
Rb 4-5					2.00	2.00		2.33
Rb 5-6								3.00
Mean Rb	4.00	3.80	2.79	3.36	2.70	3.79	4.47	3.82
Stream length ratio								
Rl 2-1	1.43	1.28	1.32	2.53	1.52	3.26	1.33	1.66
Rl 3-2	4.24	2.38	0.62	0.96	1.15	1.16	1.63	1.74
Rl 4-3	1.81	2.82	3.46	5.69	0.58	2.17	14.12	2.70
Rl 5-4					7.84			2.62
Rl 6-5							0.10	0.12
Mean	2.49	2.16	1.80	3.06	2.77	2.20	4.30	1.77
Rho coefficient								
Rho	0.62	0.57	0.64	0.91	1.03	0.58	0.96	0.46

Stream Length (LT)

The mean and total stream length of each order is measured using GIS technique and tabulated in Table 1. It shows development of the stream segments and surface runoff characteristics. Streams having relatively smaller lengths indicate that the area is with high slopes. Longer stream lengths are indicative of flatter gradient. According to Strahler (1964), mean stream length describes the characteristic size of components of stream network. The mean stream length of a given order is less than the next higher order while total stream length is maximum in first order and decreases as the stream order increases.

Bifurcation Ratio (RB)

Bifurcation ratio is the ratio of the number of streams of any given order to the number of streams in the next higher order (Schumm 1956). It is a measure of degree of distribution of stream network (Mesa 2006) and influences the landscape morphometry and control over the ‘‘peakedness’’ of the runoff (Chorley 1969). The Rb value ranges from 3.0 to 5.0 for networks formed on homogeneous rocks when the influences of geologic structures on the stream network is negligible (Strahler 1964; Verstappen 1995; Nag 1998; Vittala *et al*. 2004) and values higher than 10 where structural controls play dominant role with elongate basins (Mekel 1970; Chow *et al*. 1988).

Stream Length Ratio (RL)

Stream length ratio is the ratio of the mean length of the one order to the next lower order of the stream networks. The stream length ratio gives an idea about the relative permeability of the rock formation. Horton’s law (1945) of stream length states that mean stream length segments of each of the successive orders of a basin tends to approximate a direct geomorphic series with stream length towards higher order of streams. The mean Rl of MW is 1.77 and varies for 7 SW from 1.80 to 4.30 (Table 1).

Areal Aspects

AREA

The MW has a catchment area of 433.73 km2. SW3 is the smallest of all (23.80 km2) whereas SW7 is the largest one among the 7 sub-watersheds (Table 2).

Drainage Density (DD)

Drainage density is the ratio of total stream length of all the orders per unit basin area (Horton 1945). Dd is a numerical measure of landscape dissection and runoff potential (Chorley 1969). It shows infiltration capacity of the land and vegetation cover of the catchment. Dd influences the output of water and sediment from the catchment area (Ozdemir and Bird 2009) and erosion susceptibility (Anon 1988; Gregory and Walling 1973). Dd of the drainage basin depends on climatic condition and vegetation (Moglen *et al*. 1998), landscape properties like soil and rock and relief (Oguchi 1997). The drainage density indicates the groundwater potential of an area, due to its relation with surface runoff and permeability. Low drainage density generally results in the areas of permeable subsoil material, dense vegetation and low relief (Nag 1998). While high drainage density is the resultant of impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture. The MW had a Dd value 1.46 km/km^2 while rest of 7 SW had a Dd value range from 1.35 to 1.59 km/km^2 (Table 2) (fig.6) fells in its low category which indicates gentle to less steep slope terrain, medium dense vegetation, and permeable with high precipitation.

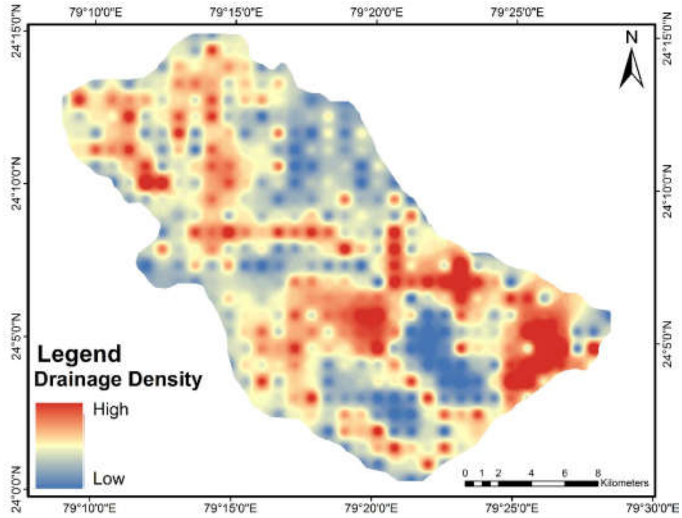

Fig 6 Drainage Density

Table 2 Areal aspects of the MW and sub-watersheds

Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	MW
Area	51.86	54.37	23.80	73.49	66.02	36.78	127.43	433.75
Drainage density	1.59	1.47	1.35	1.39	1.48	1.59	1.40	1.46
Stream frequency	1.52	1.34	1.26	0.57	0.83	1.47	1.43	1.19
Drainage texture	2.41	1.97	1.71	0.80	1.24	2.33	2.00	1.73
Length overland flow	0.32	0.34	0.37	0.36	0.34	0.32	0.36	0.34
Constant of Channel Maintenance	0.63	0.68	0.74	0.72	0.67	0.63	0.71	0.69
Form factor	0.51	0.45	0.36	0.07	0.19	0.06	0.11	0.18
Circularity ratio	0.70	0.67	0.78	0.37	0.59	0.27	0.27	0.57
Elongation ratio	0.80	0.76	0.68	0.31	0.49	0.28	0.38	0.47
Shape index	1.98	2.21	2.75	13.54	5.25	16.56	9.04	5.67

Stream Frequency (SF)

Stream frequency of a basin is defined as the number of streams per unit area (Horton 1945). A higher stream frequency points to a larger surface runoff, steeper ground surface, impermeable subsurface, sparse vegetation and high relief conditions. Low stream frequency indicates high permeable geology and low relief. The Sf of MW is 1.19 numbers per km^2 while Fs of 7 SW vary from 0.57 to 1.52 indicating poor runoff. Sf values of all the sub-watersheds have close correlation with Dd indicating the increase in stream population with respect to increase in drainage density.

Drainage Texture (DT)

Drainage texture is the product of Dd and Sf and is a measure of relative channel spacing in a fluvial-dissected terrain, which is influenced by climate, rainfall, vegetation, lithology, soil type, infiltration capacity and stage of development (Smith 1950). Vegetation cover, its density and types also plays an important role in determining the drainage texture. The soft or weak rocks unprotected by vegetation produce a fine texture, whereas massive and resistant rocks cause coarse texture. Sparse vegetation of arid climate causes finer textures than those developed on similar rocks in a humid climate. The texture of a rock is commonly dependent upon vegetation type and climate. Drainage lines are numerous over impermeable areas than permeable areas. Horton (1945) recognized infiltration capacity as the single important factor which influences drainage texture and considered drainage texture which includes drainage density and stream frequency. Dt is categorized into five different classes based on Dd values viz; very course (< 2), course (2-4), moderate (4-6), fine (6-8) and very fine (> 8). The MW and all the 7 SW shows very course to course texture (Table 2).

Length of Overland Flow (LG)

Length of overland flow is described as half of reciprocal of drainage density. It is the length of water over the ground before it gets concentrated into main stream which effect hydrologic and physiographic development of drainage basin (Horton 1945). According to Suresh (2000), when rainfall intensity exceeds soil infiltration capacity, the excess water flows over the land surface as overland flow. This factor depends on the rock type, permeability, climatic regime, vegetation cover and relief as well as duration of erosion (Schumm 1956). The MW has Lg value of 0.34 while all the sub-watersheds value range 0.32 to 0.37, as shown in Table 2, indicates the influence of less structural disturbance, high permeability, gentle to steep slopes and less surface runoff. The MW and sub-watersheds show a developed stream network and less mature geomorphic stage.

Form Factor (FF)

Form factor is a dimensionless ratio of the area (A) of a drainage basin to the square of its maximum length (Lb) (Horton 1932). Basin shape may be indexed by simple dimensionless ratios of the basic measurements area, perimeter and length (Singh 1998). Form factor is an indicator for flood formation and move, degree of erosion and transport capacities of sediment load in a watershed. The Ff of MW is 0.18 and that of 7 sub-watersheds (Table 2) varies from 0.06 to 0.51. The value of Ff varies from 0 (highly elongated shape) to unity i.e.; 1 (perfect circular shape). Main watershed and sub-watersheds shows a lower value of Ff which implies more elongated basin with flatter peak of low flow for longer duration, lower erosion and sediment transport capacities and favors a diminution of floods because streams flow into the main stream at greater time intervals and space which leads to ground water percolation.

Relief Aspect

Basin Relief (R)

According to Rao *et al*. (2011), calculation of basin relief to show spatial variation is predominant. Basin relief is the maximum vertical distance between the lowest and the highest point of a basin. Basin relief is responsible for the stream gradient and influences flood pattern and sediment volume that can be transported (Hadley and Schumm 1961). It is an important factor in understanding denudation characteristics of the basin (Sreedevi *et al*. 2009). To define relief DEM is shown in Figure 7. The R value of MW is 250 m while rest of 7 sub-watersheds is described in Table 3.

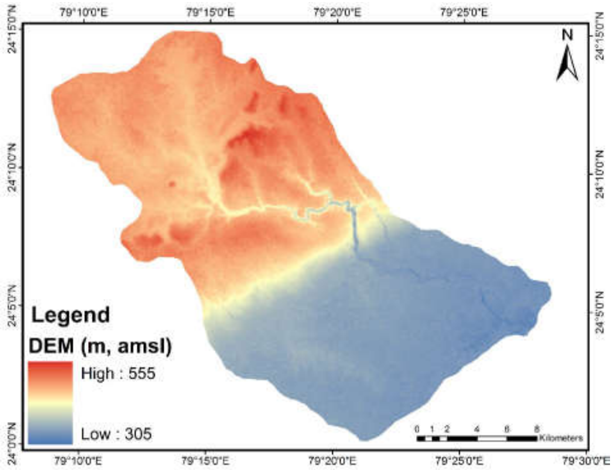

Fig 7 DEM

Table 3 Relief aspects of the MW and sub-watersheds

Parameters	SW1	SW2	SW3	SW4	SW5	SW6	SW7	MW
Basin Relief	66	122	102	186	187	205	243	250
Relief Ratio	6.52	11.12	12.61	5.90	10.04	8.31	7.16	5.04
Ruggedness Number	0.10	0.18	0.14	0.26	0.28	0.33	0.34	0.36
Dissection Index	0.13	0.22	0.19	0.36	0.36	0.39	0.44	0.45
Elevation at source	487	487	489	482	501	514	506	487
Elevation at mouth	443	443	435	340	342	331	328	328
Gradient Ratio	4.35	4.01	6.67	4.50	8.54	7.41	5.25	3.21
Melton Ruggedness	0.01	0.02	0.02	0.02	0.02	0.03	0.02	0.01

Relief Ratio (RR)

Relief ratio is a dimensionless ratio of basin relief and basin length and effective measure of gradient aspects of the watershed (Schumm 1956). It shows overall steepness of a drainage basin and is an indicator of the intensity of erosion processes operating on slopes of the basin. The Rr value of MW is 5.04 while values of 7 SW are given in Table 3. Values are relatively low suggesting gentle to less steep slope.

Ruggedness Number (RN)

To combine the qualities of slope steepness and length, a dimensionless ruggedness number is defined as the product of basin relief and drainage density (Strahler 1958). It is a measure of surface unevenness (Selvan *et al*. 2011). The Rn value of MW is 0.36 and rest of 7 sub-watersheds is provided in Table 3. The Rn value is relatively low which suggests less prone soiling erosion and having intrinsic structural complexity in association with relief and drainage density (Paretha and Paretha 2011).

Dissection Index (DI)

Dissection index is determined for understanding morphometry, physiographic attribute and magnitude of dissection of terrain (Schumm 1956; Singh 2000; Singh and Dubey 1994). Dissection index is the ratio between actual dissection made by the rivers and potential up to base levels (Pal *et al*. 2012). Di value of MW is 0.45 while 7 sub watersheds show values 0.13 - 0.44. Lower value of Di implies old stage (Deen 1982) of basin and less degree of dissection capacities.

Land USE/LAND Cover Classification

In visual image interpretation, the overall accuracy was found as 89.32%. In land use/land cover classification scheme 6 classes were identified (fig. 8) (Table 4) in satellite image. Maximum area of the watershed was covered by agricultural land which is low land plain area. Some patches of agricultural land were found in high elevated land and inside forest. Another maximum area was covered by forest which is high land elevated area. The forest type was found as open and scattered. A few of 3.29 percent area was covered by open scrub.

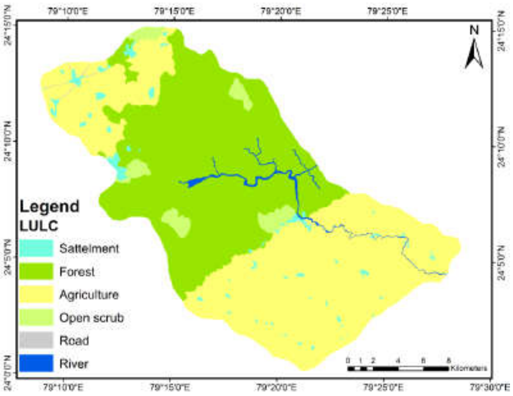

Fig 8 LULC

Table 4 Land use/Land cover classification

S.No.	Land use/Land cover classes	Area (km2)	In %
1.	Settlement	8.11	1.87
2.	Forest	194.17	44.76
3.	Agriculture	212.32	48.95
4.	Open scrub	14.26	3.29
5.	Road	0.30	0.07
6.	River	4.60	1.06

CONCLUSION

River basin is an important geomorphological unit which reflects topographic and hydrological unity. River basin characterization of Baink watershed and its sub-watershed revealed the importance of morphometric analysis in terrain depiction and basin evolution. GIS technique provided high accuracy in mapping and measurement of morphometric analysis. The analysis presents developed drainage network and less mature geomorphic stage in the watershed. Drainage network of the watershed indicates the homogeneity in texture and lack of structural control and helps understand various terrain parameters such as nature of the bedrock, infiltration capacity, runoff, etc. The Dd value indicates low moderate slope terrain with sparse to dense vegetation, higher infiltration rate, low surface runoff and less dissection. The watershed and its sub-watersheds are elongated in shape having less prone to flood, lower erosion and sediment transport capacities. Thus, morphometric parameters provide relevant information about terrain characteristics and hydrological behavior of the watershed. It is concluded that the integration of morphometric analysis with watershed assessment methods would be beneficial in watershed management plan.

The results observed in the present work can be used for site suitability analysis of soil and water conservation structures in the area and subsequently, these parameters were integrated with other hydrological information viz., land use/cover, land forms, geology, water level and soil in the GIS domain to arrive at a decision regarding a suitable site for soil and water conservation structures (nala bund, check dam, and percolation tank, recharge shaft, etc.) in the area for groundwater development and management. The study recommended that the watershed needs a hydrogeological and geophysical investigation in future for proper water management and selection of artificial groundwater recharge structures within the study area.

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