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Morphometric Analysis of Dhasan River Basin, Madhya Pradesh, India, Using Remote Sensing and Arc GIS Techniques

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Abstract

The morphometric study of a basin is essential for a better understanding of the geological nature and groundwater conditions of that area. This study emphasizes on the identification of the types of drainage pattern determined by Arc GIS technology and computation of various parameters of morphometric analysis. The scarcity of water for irrigation and domestic purposes is the major issue in the Dhasan river area. The drainage network has been prepared from the SRTM DEM (30 m) using hydrology tools of Arc GIS 10.2.2. The GIS techniques have been used to evaluate various morphometric aspects which include linear, aerial and relief parameters. The field of research shows a dendritic drainage pattern because the entire area is a hard rock formation. The basin drainage density is 1.13, suggesting a very coarse grain texture that demonstrates homogeneous rock type and low surface runoff. This study incorporates the probability of the suitability of hydrogeological conditions that can be taken care of to use groundwater for domestic, industrial and irrigation purposes.

Keywords: Arc GIS, Remote sensing, Morphometric analysis, Dhasan basin, SRTM DEM

Introduction

Morphometry is a quantitative assessment of the geometry of a river basin and interpretation of the landforms in terms of their shape and size. There are 3 significant aspects of morphometry, viz. (i) linear (ii) aerial and (iii) relief aspects. Parameters like the hierarchical order of streams, number of streams and length of stream channel and their interrelationship that are related to the morphometric laws belong to the linear aspects. Aerial features encompass the study of perimeter, shape and basin area. Other factors like the relief of the basin, ruggedness number and relief ratio are dealt within the relief aspects. Remote sensing is a very useful tool for generating a panoramic view of a wide area of a basin.

In the past few decades, several studies have been done for morphometric analysis incorporating Arc GIS techniques. There is a serious problem regarding the occurrence of groundwater because of its over-usage. Many areas have been dried up and there is not adequate water for drinking and irrigation purposes. Therefore, to resolve this problem, we have to think for the betterment of groundwater by undertaking a morphometric analysis of the basin [1-3]. Sharma *et al.* [4] suggested that the Arc GIS application gives the latest information about the drainage map and management of natural resources. Remote sensing and GIS techniques are also being used very successfully for flood hazard assessments [24-26].

Hasan *et al.* suggested that a bifurcation ratio of less than 5 shows that the area has not been distorted structurally and that the high drainage density indicates low permeability in the soil. Prakash *et al.* [6] suggested that the low flow peaks are suggestive of longer duration of flood flow in a basin having an elongated shape.

Dhasan river drains through the hard rocks of the archean age, popularly known as Bundelkhand Craton. Besides, the rocks belonging to Bijawar group and Vindhyan supergroup are also exposed in the area that is overlain by Deccan Basalt [6]. The terrain along the entire course of this river contains granitoid, Banded Iron

Formations, sandstones and basaltic rocks. Their very low porosity and permeability do not allow adequate groundwater recharge. Therefore, the whole Dhasan basin gets inadequately recharged. Groundwater available for drinking and irrigation purposes is either surface runoff accumulated in small ponds from shallow wells distributed mostly in small sections of alluvium or from heavily fractured/jointed rocks. The present study involves a strategic survey for groundwater recharge and management in the investigated area.

Study area

Dhasan basin is intermediate in size. This river drains into the Betwa river which, in turn, pours into the Yamuna river in the poorly rain-fed parts of central India. The study area lies on the SOI Toposheet No. 54 P/6 on the scale of 1:50,000. Dhasan river basin lies to the S-E part of the Malwa plateau, which extends from 79°00′20″ to 79°30′00″ East Longitude and 24°07′30″ to 25°00′00″ North Latitude (**Figure 1**). The Dhasan river is having an area of 3,060.68 km^2 and a perimeter of 403 km. Most of the basin area shows more or less undulating topography extending from S-W to N-E direction. The scarcity of potable water and that for irrigation of farmlands is the main cause of concern for the inhabitants of the Dhasan river basin.

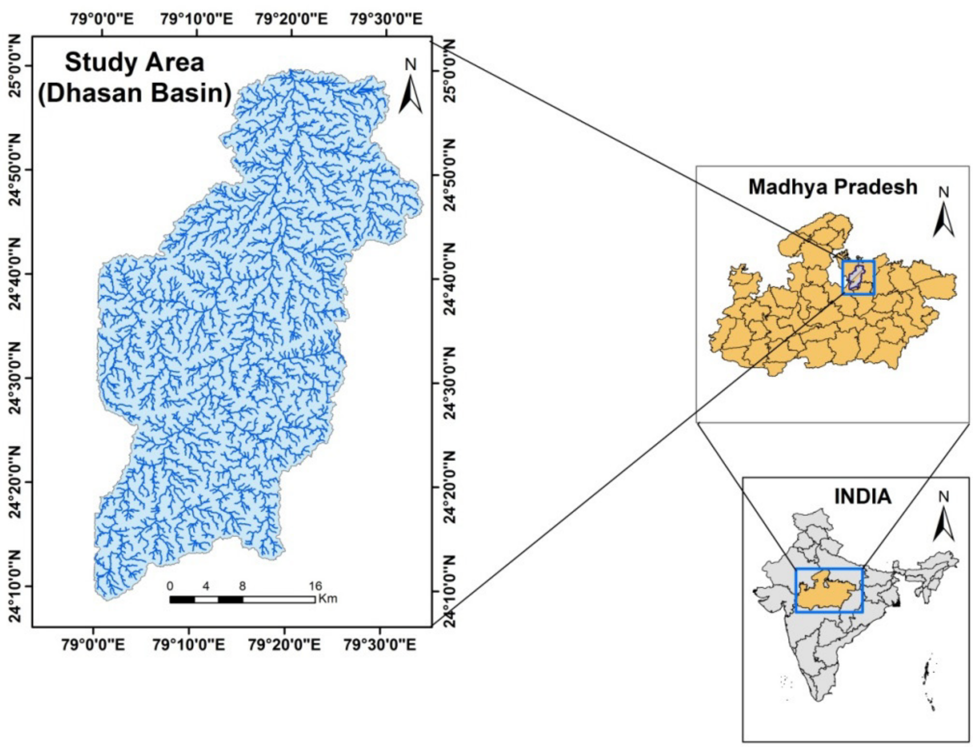


Figure 1 Location map of the study area.

Geological setup

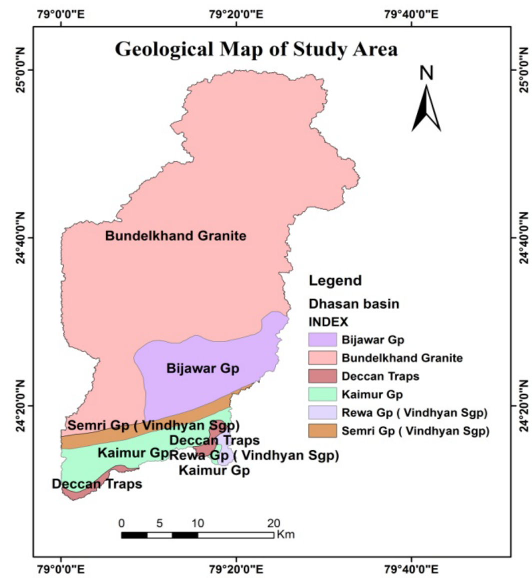
The entire area, in question, is a terrain made primarily up of hard rocks. The rock formations reported are Bundelkhand granite (granite, gneiss, granodiorite and pegmatite), Bijawar series (white quartzite, red shale and limestone), Vindhyans, Deccan traps, Intertrappean beds, alluvium and laterites (**Table 1**). Bundelkhand granite is the oldest rock which is overlain by the Bijawars series of rocks which, in turn, are unconformably overlain by various flows of basaltic lava (**Figure 2**). The complete stratigraphic succession, in the study area, is given in (**Table 1**) (after Rajrajan, 1978).

Geomorphological features

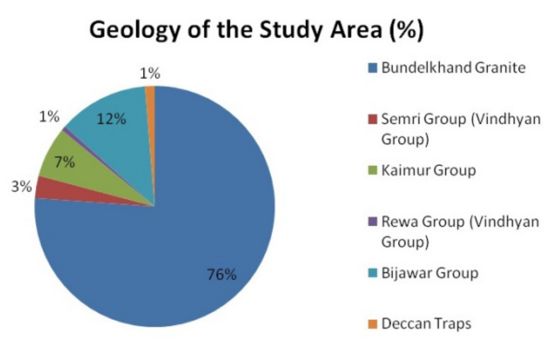
Geomorphic landforms play a pivotal role in setting artificial recharge structures. Based on the analysis the area has been categorized into the following geomorphological features such as (i) Highly dissected denudational hills (ii) Lowly dissected structural hills (iii) Lowly dissected structural plateau (iv) Moderately dissected denudational hills (v) Moderately dissected structural hills (vi) Moderately dissected structural plateau and (vii) Pediment pediplain complex (**Figure 3**). The main portion of the basin area is dominated by a pediment pediplain complex with an area of about 2,285.25 km^2 The moderately dissected structural hills with associated valleys and lowly dissected structural hills with accompanying valleys are spread in an area of about 292.44 and 91.7 km^2, respectively.

Land use/land cover (LULC)

The land use/land cover map of the area, in question, has been delineated using remote sensing. The majority of the region investigated area is dominated by vegetation and barren land. The LULC map of the study area includes deciduous broadleaf forest, cropland, built-up area, mixed forest, shrubland, fallow land and water bodies. LULC data is very important for the preparation of an artificial recharging structure (**Figure 4**).

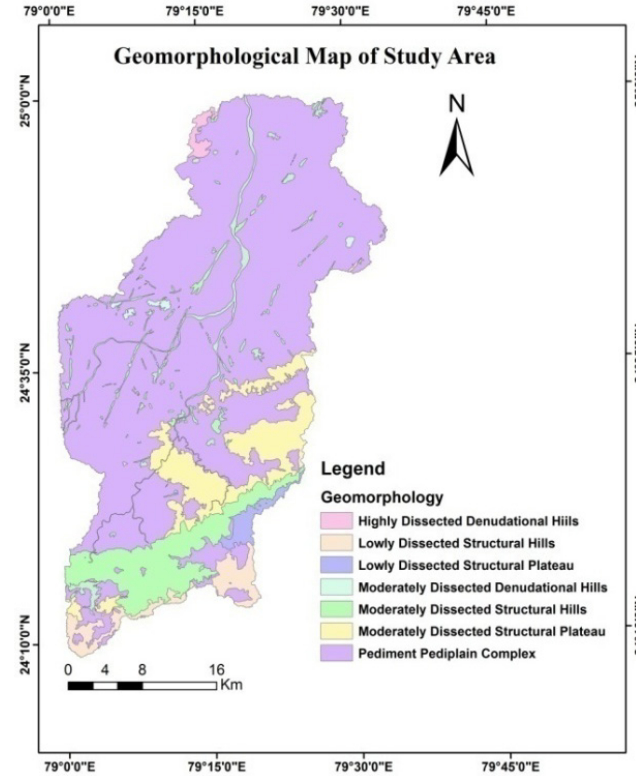


(a)



(b)

Figure 2 Geological map **(a)** Spatial distribution of geology of the investigated area **(b)** Pie diagram showing the geology of the study area.



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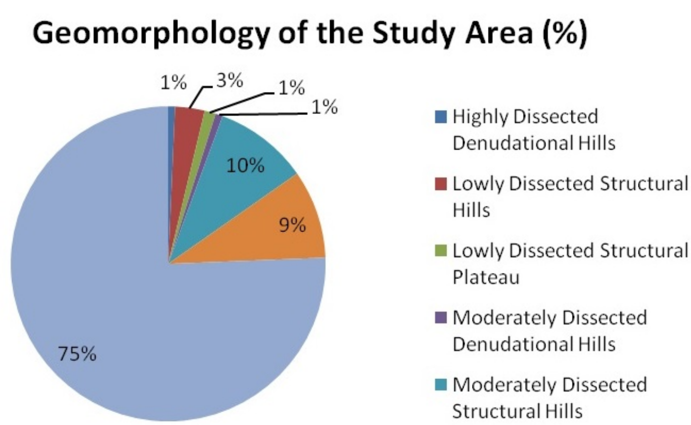
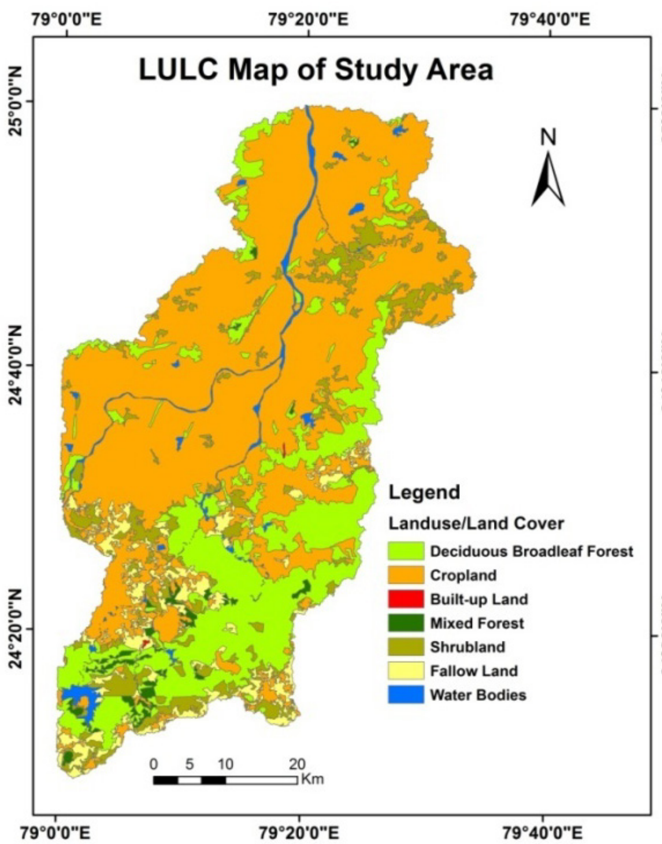


(b)

Figure 3 Geomorphological map (a) Spatial distribution of geomorphology of the investigated area (b) Pie diagram showing geomorphology of the area.



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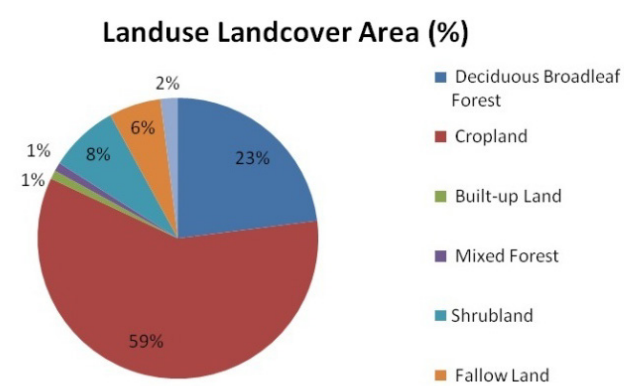

(b)

Figure 4 Land use/Land cover map **(a)** Spatial distribution of land use/land cover **(b)** Pie diagram showing land use/land cover of the investigated area.

Slope

The slope has a significant impact on surface and groundwater flow which controls the water infiltration or percolation rate, surface runoff and erosion rate. Therefore, it plays a critical role in setting up recharging structures. Slope of the investigated area may be categorized into following 5 types (i) Very gentle slope (< 3) (ii) Gentle slope (3 - 5) (iii) Moderate slope (5 - 10) (iv) Strong slope (10 - 15) and (v) Very strong slope (> 15) (**Figure 5**).

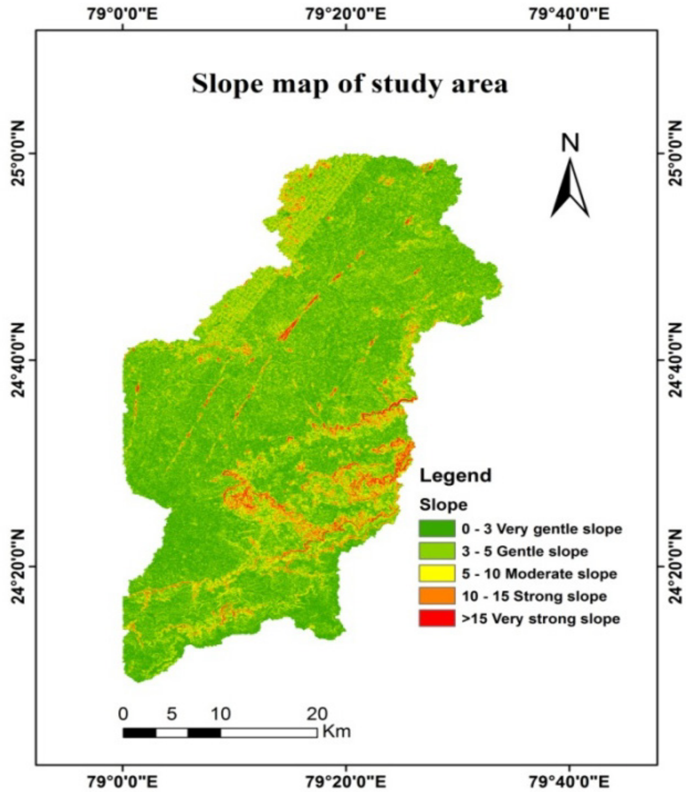

Figure 5 Slope map.

Materials and methods

The main purpose of the study is to establish a reliable technique that can be obtained to produce a GIS data model that can be used for the morphometric analysis. For this, SRTM DEM (30 m) has been used to prepare a map and to measure relief characteristics of the Dhasan basin. Various morphometric parameters like the stream length, basin frequency, stream order number, periphery and area have been demarcated by the Digital Elevation Model (**Figure 6**). Using Arc GIS 10.2.2 hydrology tools, various morphometric parameters have been computed. Various morphometric dimensions of the Dhasan basin have been determined for the future development and mapping of the watershed using GIS techniques. The systematic methodology undertaken is as under (**Figure 7**).

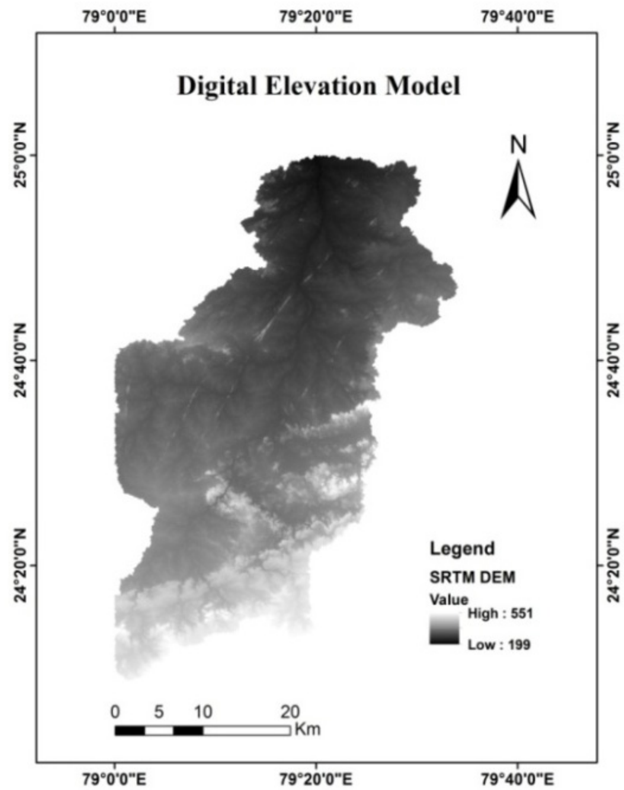

Figure 6 Digital elevation model.

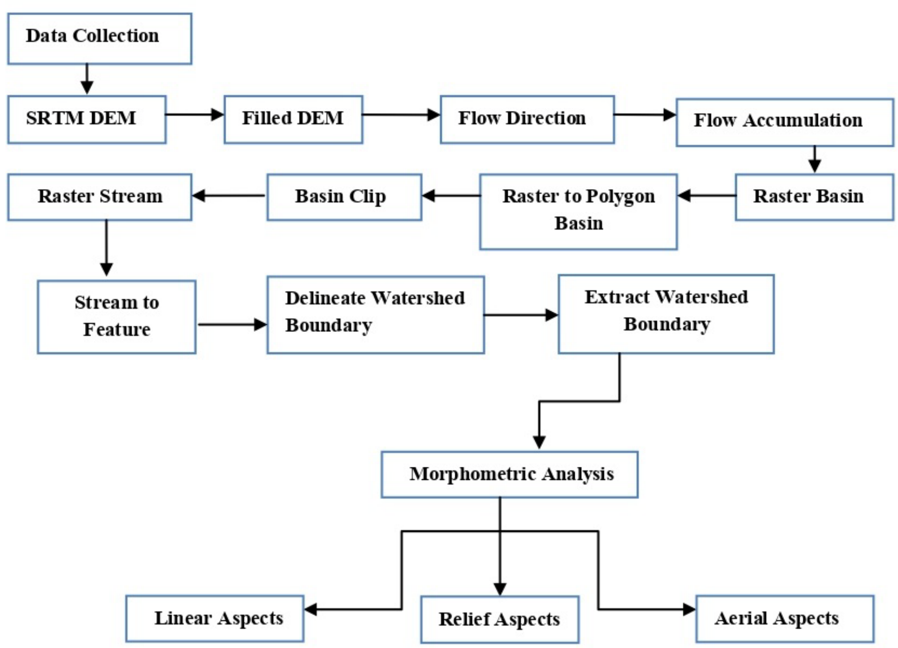

Figure 7 Flowchart of the methodology.

Table 1 Stratigraphic succession of the Dhasan river basin area (after Rajrajan, 1978).

Recent Lower Eocene and Upper Cretaceous		**Alluvium and Laterite Deccan Traps and Intertrappean Beds**
	~ ~ ~ ~ ~ **Unconformity**~ ~ ~ ~ ~ ~	
Pre Cambrian to Upper Cambrian	Rewa Series	Upper Rewa Sandstone Lower Rewa Sandstone
(Upper Vindhyan)	Kaimur Series	Kaimur Sandstone Kaimur Conglomerate
	~ ~ ~ ~ ~ **Unconformity**~ ~ ~ ~ ~ ~ ~	
Lower Vindhyan	Semri Series	Porcellanite Shales Semri Sandstones Dulchipore Conglomerate
	~ ~ ~ ~ ~ **Unconformity**~ ~ ~ ~ ~ ~ ~	
Precambrian	Bijawar Series	White Quartzite and Red Shales
	~ ~ ~ ~ **Non-conformity**~ ~ ~ ~ ~ ~ ~	
Archean		Quartz veins and Basic dykes Bundelkhand Granite

Results and discussion

Aspects of morphometric analysis

The key parameters investigated for the morphometric analysis of the Dhasan river basin are elevation, size, gradient, pattern and texture of the landforms. Various approaches can be utilized to evaluate the basin. The area of the basin has been analyzed using Arc GIS technology. Various aspects of morphometric analysis measured in this study include relief, linear and aerial characteristics. The outcome of the various parameters has been explained below.

Linear aspects

The linear features help one deduce the pattern of the drainage network which, in turn, is indicative of surficial characteristics of the various segments of the stream [7]. The linear features studied are (i) stream length (Lu), (ii) bifurcation ratio (Rb), (iii) stream order (U), (iv) stream length ratio (RL) and (v) stream number (Nu).

Stream order (U)

The first aspect of linear features is the identification of stream order. Order of streams is assigned according to hierarchic ordering [8]. The stream order of the Dhasan river basin has been computed following Strahler [9]. According to this scheme, a second order channel section is created at the intersection of two first-order channels. Likewise, the intersection of two second-order channels creates a third-order channel section and so forth [10]. The stream order is considered to be a dimensionless number that is useful in the geometric correlation on a varying linear scale for a given drainage system. The channel, by which all water discharges, is 6^{th} order and it is considered to be the highest order stream (**Figure 8**). It is evident from (**Figure 9**) that no. of streams decreases sharply with an increase in stream order. A very large number of 1^{st} order streams converge to create a 2^{nd} order stream and this goes on progressively and lastly, only 7 streams merge to form a single 6^{th} order stream.

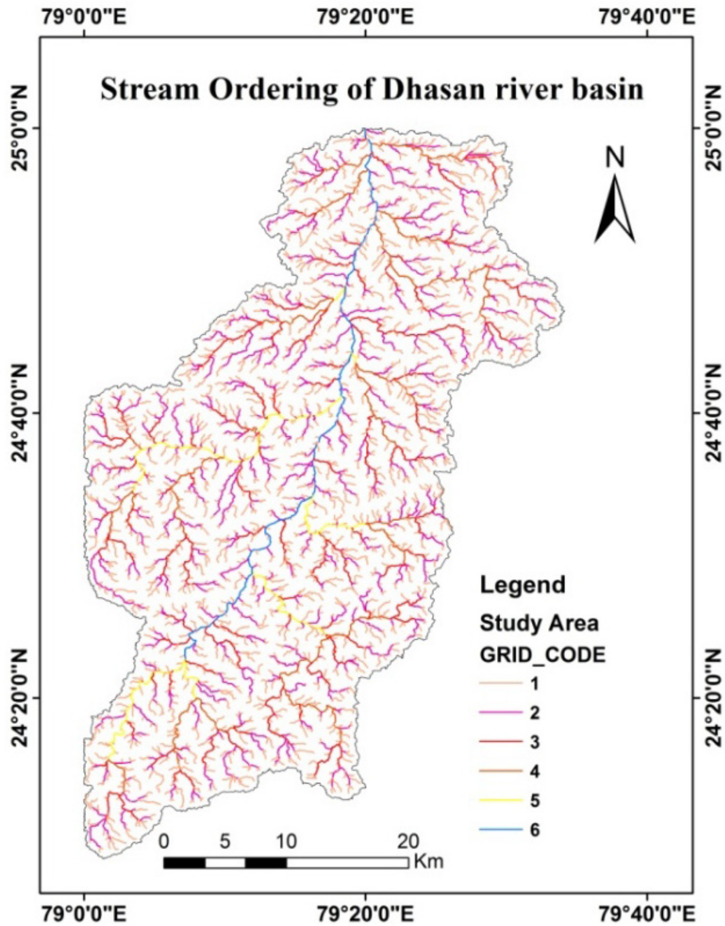

Figure 8 Stream Ordering of study area.

Stream number (Nu)

The total number of streams represented in each stream order is referred to as stream number. The Arc GIS has been used to measured stream number. The streams number decreases with increasing stream order. Thus, the entire study area is of 6th order (**Table 2**).

Stream length (Lu)

The stream length (Lu) is the cumulative length of the actual stream segment of each order. It has been computed using the Arc GIS technique. The total stream length of the first order is 1,741.15 km, that of second order 863.43 km, for the 3rd order stream it is 444.77 km, those of 4th, 5th and 6th order are 232.41, 103.00 and 89.74 km, respectively. As in (**Figure 10**), it has been seen that stream length decreases with an increase in stream order. There is a progressive decline in stream length with increasing stream order. And mean stream length increases with increasing stream order (**Figure 11**). Initially, there is a very marginal increase in mean stream length is seen but there is an abrupt increase in mean stream length from 5th to 6th stream order.

Stream length ratio (RL)

The ratio of the average length of the 1st order to the average length of the 2nd order is referred to as the stream length ratio. The entire basin is having RL that ranges between 1.45 to 6.10. An increasing pattern from lowest to the highest order, throughout the stream length ratio, suggests that a mature geomorphic stage appears to have been attained in the investigated area.

Bifurcation ratio (Rb)

The ratio of 1st order stream number to the next higher order is the bifurcation ratio [11]. Chow reported that the Rb values lie around 3 to 5 for those basins where structural formations do not indicate the effect on the drainage pattern. A basin is said to be structurally controlled if the value of the bifurcation ratio is more than 5. It has also been seen that, even where the lithology is influential, the bifurcation ratio shows a very limited variation for that particular region. Rb is a dimensionless property. The average Rb of the area, in question, is 4.71 which suggests the pattern of the drainage system is not a structurally controlled one.

Aerial aspects

The aerial aspects include the parameters such as (i) drainage texture, (ii) drainage density, (iii) elongation ratio, (iv) stream frequency, (v) form factor and (vi) circulatory ratio. These aspects have been analyzed. The result of each parameter has been discussed as under.

Drainage density (Dd)

The ratio of the total length of all segments of channels to the area of a basin is designated as the drainage density. Its unit of expressed is km/km^2. It shows the proximity of the spacing of various channels. It is a quantitative indicator of the average length of spacing of channels [12]. A poor drainage density is found in regions where (i) rocks exposed onto the earth's surface are highly resistant ones (ii) subsoil material is porous which leads to the growth of widespread vegetation and (iii) topographic relief is poor. On the basis of the values of drainage density, a basin may be categorized into following 5 types (i) very fine (> 8) (ii) fine (8 to 6) (iii) moderate (6 to 4) (iv) coarse (4 to 2) and (v) very coarse (< 2) [13]. The Dd of the investigated area is 1.13 which suggests a very coarse texture.

Stream frequency (Fs)

The total number of streams, of all orders, per unit area is referred to as stream frequency [14]. It is indicative of the lithological characteristics of the area [15]. The Fs of the investigated area is 0.84 km^{-2}.

Drainage texture (Dt)

The cumulative number of stream channels, of all orders, at the periphery of a basin, is designated as drainage texture [16]. The texture of the drainage depends on the geomorphology, infiltration capability of a geographic region, the relief features of the landscape and natural factors such as weather, precipitation, regolith, flora, fauna and type of soil. Smith [17] classified drainage texture into following 5 distinct categories (i) very fine (> 8) (ii) fine (8 to 6) (iii) moderate (6 to 4) (iv) coarse (4 to 2) and (v) very coarse (< 2). The value of Dt of the investigated area is 6.39 which shows a fine drainage texture.

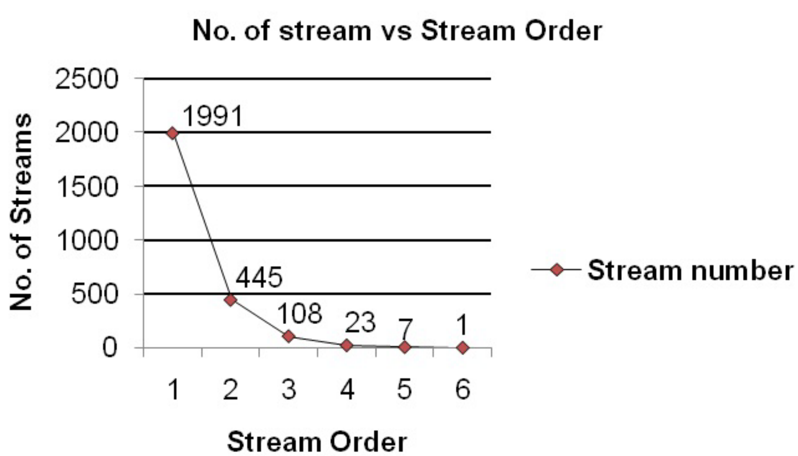

Figure 9 Plot between stream order vs no. of streams of the investigated area.

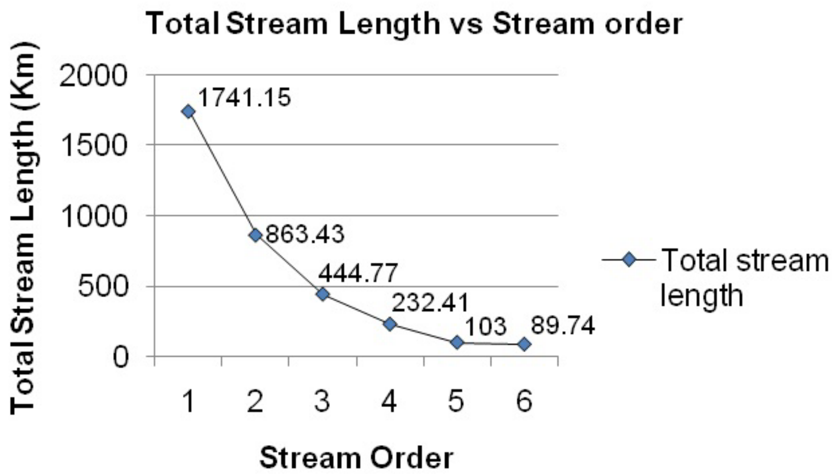

Figure 10 Plot between stream order vs total stream length of the study area.

Table 2 Linear parameters of the study area.

S. No	Stream order	First	Second	Third	Fourth	Fifth	Sixth
1	No. of the streams (Nu)	1,991	445	108	23	7	1
2	Total length of the streams (Lu) (km)	1,741.15	863.43	444.77	232.41	103.00	89.74
3	Mean stream length (Msl) (km)	0.87	1.94	4.11	10.10	14.71	89.74
4	Bifurcation ratio (Rb)	4.47	4.12	4.69	3.28	7	-
5	Mean bifurcation ratio (Rbm)			4.71			
6	Stream length ratio (Lur)	-	2.22	2.11	2.45	1.45	6.10

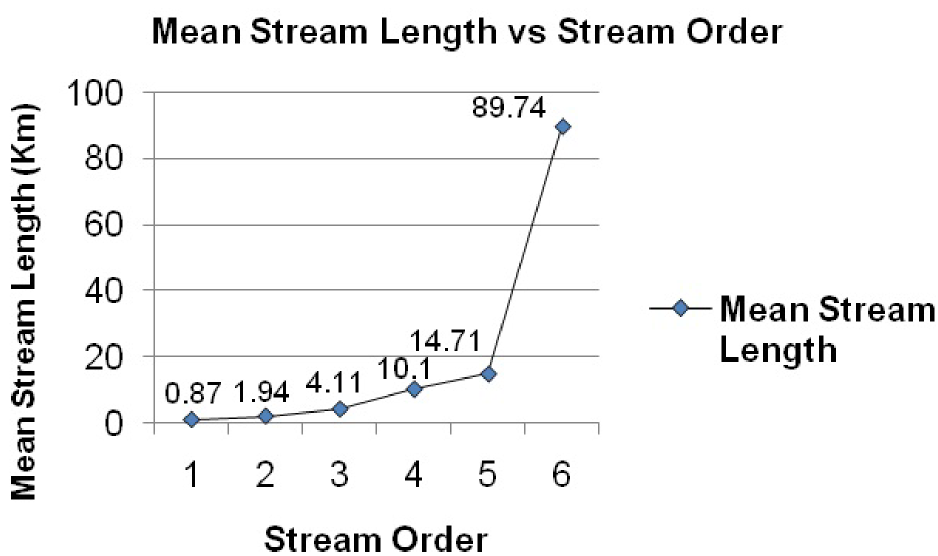

Figure 11 Plot between stream order vs mean stream length of the study area.

Form factor (Rf)

The ratio of the basin area to the square of the basin length is called the form factor [18]. The Rf value ranges between 0 and 1, where 0 indicates a highly elongated shape of a basin and 1 suggests a perfectly circular shape of a basin. The smaller the form factor value the higher is the elongation of a basin. Besides, the greater/higher value of form factor is suggestive of a short period of high peak flow whilst the lower value of form factor points to a relatively long period of low peak flow. The Rf value of the area, in question, is 0.30 which suggests an elongated shape of the basin.

Elongation ratio (Re)

The ratio of the diameter of a circle of the same area as the basin to the basin length is referred to as the elongation ratio [19]. It is a dimensionless property. There are 2 categories of basins based on values of elongation ratio (i) an elongated basin; if Re value is low (ii) a circular basin; if Re value is high [16]. The elongation ratio ranges between 0, indicating a line (elongated shape) and 1 indicating a circle or circular shape of a basin [20]. Re values close to 1 indicate areas of very low relief, while those values close to 0 are suggestive of high relief i.e. a rugged terrain [9]. On the basis of the values of Re, Strahler [9] suggested following 5 categories of basins i.e. (i) More elongated (< 0.5), (ii) Elongated (0.5 - 0.7), (iii) Less elongated (0.7 - 0.8), (iv) Oval (0.8 - 0.9) and (v) Circular (0.9 - 1.0). The Re for the investigated area is 0.62 which indicates an elongated shape of the basin.

Circulatory ratio (Rc)

The ratio of the area of a basin to the area of a circle having the same circumference as the diameter of the basin is designated as a circulatory ratio [21]. It is similar to the elongation ratio of Schumm [19]. The Rc values range from 0 to 1, where 0 indicates a line and 1 indicates a circle. The circulatory ratio depends upon factors like volume and length of the streams, land use cover, geological formation, weather, topographic relief and gradient of the basin. The circulatory ratio is suggestive of the maturity of the life cycle of a drainage basin. Thus a low, medium and high circularity ratio indicate early, mature and old stages, respectively [20]. The Rc of the area, in question, is 0.23 which indicates that the shape of the basin is elongated.

Relief aspects

Relief aspects include the study of landscape, elevation and depression of the ground surface. The various parameters that define and describe relief aspects are (i) basin relief, (ii) relief ratio and (iii) ruggedness numbers. These parameters have been described as under.

Basin relief (H)

The difference between the highest points and the lowest points of elevation/altitude of an area is designated as basin relief. It helps one understand the relief characteristics of an area, in question. The lowest elevation point, in the investigated area, is 199 m and the highest point is 551 m. Basin relief of the study area is 352 m.

Relief ratio (Rh)

The ratio of the difference in relief/topography between origin/source and convergence of a river to the overall length of that river/stream is relief ratio [22]. The Rh of the investigated area is 0.003 which indicates an area of low relief. Low relief is primarily due to the presence of resilient rocks with minimum inclination.

Ruggedness number (Rn)

A product of basin relief and the drainage density is defined as a ruggedness number. The computation of ruggedness number requires the length and steepness of the slope [23]. The Rn of the area, in question, is 0.39 . The low value of Rn indicates that vulnerability of the region to soil erosion is less and which, in turn, indicates inherent structural characteristics that define relief and drainage density.

Table 3 Outcome of morphometric analysis

S. no.	Measurements	Symbol	Unit	Value
1	Total area	A	km^2	3,060.68
2	Perimeter of the basin	P	Km	403
3	Highest order			6^{th}
4	Basin relief	H	M	352
5	Stream frequency	Fs	km^{-2}	0.84
6	Texture ratio	T	dimensionless	6.39
7	Basin length	Lb	Km	99.76
8	Elongation ratio	Re	dimensionless	0.62
9	Drainage density	Dd	km/km^2	1.13
10	Mean bifurcation ratio	Rb	dimensionless	4.71
11	Constant channel maintenance	C	Km	0.88
12	Shape factor	Sf	dimensionless	3.25
13	Relief ratio	Rh	dimensionless	0.003
14	Length of overland flow	Lg	Km	0.44
15	Ruggedness number	Rn	dimensionless	0.39
16	Form factor	Rf	dimensionless	0.30
17	Circulatory ratio	Rc	dimensionless	0.23

Conclusions

The study area is predominantly composed of granite and the basin is drained by streams that range in order from 1^{st} to 6^{th}. The type of drainage pattern, prevalent in the area, is dendritic. Sporadic occurrence of other types of patterns of drainage such as subparallel to parallel, circular, radial, pinnate, etc. have also been found. In the Upper Dhasan Basin, 3 distinct high drainage density zones are found along the western margin of the basin. It is due to the greater density of fractures in the host rock i.e. Bundelkhand granite. The other 2 high density zones are aligned with the South-Western margin. The various landforms identified include dissected plateau, alluvial plains, inter-mountain valleys, flood plains; residual, structural and denudational hills; long narrow linear ridges and scattered mesa and butte. The low drainage density (1.13) is attributed to the presence of resistant rocks such as granite, gneiss and schist. The number of first order streams is 1991, which shows that the overall volume is contained in the 1^{st} order stream. The average bifurcation ratio varies from 3.0 to 5.0, which suggests that the geology of the area is not structurally disturbed. The average bifurcation ratio of the basin is 4.71. The drainage density is 1.13, suggesting a very coarse texture and dry characteristics of the region. The circulatory ratio is 0.23, which delineates an elongated shape of the basin and low surface runoff. Thus, it may be concluded that the area is favourable for recharging provided there is sufficient rainfall. If it happens, we may expect the occurrence of a good quantity of groundwater that can be utilized for domestic, irrigation and other purposes.

Future scope

The morphometric study of Dhasan river basin offers a detailed summary and research of the landscape. Morphometric analysis is an essential method for hydrogeological research. The findings of this study will pave the way for water and land conservation in the investigated area. The interpretation and findings of the present study can further be extended to drainage basins with similar landforms. Quantitative evaluation of the region helps identify the drainage network, location of the region, slope, topographic relief and other characteristics. These parameters statistically correlate and describe the characteristics of a river system and the hydrogeology of the basin. This research shall play a vital role in studying the geo-hydrological nature of the drainage area, its geology, geomorphology and structural characteristics.

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