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Fluvial Morphometric Analysis of Dwarka River Basin, Eastern India

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Research Paper

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ABSTRACT

The mathematical evaluation of the earth's surface and landforms is known as morphometry. It offers a comprehensive overview of a region's topography and hydrological features, which is crucial for resource management. The present study encompasses an analysis of a drainage basin's linear, areal, and relief aspects, providing valuable insights into its geo-hydrological characteristics and other relevant variables. Drainage morphometry is crucial to understanding the physical properties of soil, the processes involved in the production of landforms, and the features of erosion. The development of quantitative physiographic methods to depict the growth and behaviour of surface drainage networks has received a great deal of attention over the years.

The present study discusses the geomorphological characteristics and significance of River Dwarka Basin (DRB). The river basin encompasses plateau, floodplain, and plateau fringe areas, and exhibits variations in slope, rainfall, and geological formations. The population density is higher in the central and eastern parts, with agriculture being the primary occupation. A comprehensive fluvial morphometric analysis of the Dwarka river basin is essential for understanding its geo-hydrological nature and developing effective management strategies.

I. Introduction

Morphometry is the dimension and mathematical appraisal of earth's surface, form and the measurement of the landforms (J. I. Clarke, 1966). According to A. N. Strahler (1969), "Measurement of the shape or the geometry of any natural form- be it plant, animal or relief features- is termed morphometry." Fluvial morphometry is a tool to have a synoptic view of the hydrological and topographic characteristics of a region. It is the first step in undertaking studies on resource management in general and water resource management in particular. In the present studies these morphometric tools have been used to have a synoptic view of the water resource base of the basin. It includes the linear, areal and relief aspect of a drainage basin. The morphometric analysis of the drainage basin and channel network plays a noteworthy position in comprehension of the geo-hydrological nature of drainage basin and describes the existing climate, geological setting, geomorphology and structural antecedents of the catchment area. It is often known that comprehending the physical qualities of soil, the processes behind landform formation, and the characteristics of erosion greatly depend on the influence of drainage morphometry (Rai et al, 2017). A major weight in geomorphology over few decades has been on the development of quantitative physiographic methods to illustrate the evolution and behaviour of surface drainage networks (Horton, 1945; Abrahams, 1984). River Dwarka is one of the rivers in eastern India with moderate importance as compared to the surrounding major rivers like River Mayurakshi, River Ajay etc. But the river basin is very much interesting in geographical point of view. First of all, from physiographic perspective this area covers plateau (western part) and flood plain (eastern part). Some area comes under plateau fringe (central part). Climatologically, the rainfall decreases towards the east of the basin. On the other hand, the western part of the basin is under steep, the central part is under moderate and the lower part is under low slope. As per geological history, the area is made of different geological formation. Among those, Chhotonagpur Gneissic complex, Rajmahal formation, Barakar formation, Talchair formation, Rampurhat formation and Sijua formation are very poor to moderately permeable (Bhattacharyya, 1976; Ray Barman and Bishui, 1994; Mukherjee et.al, 2019). From demographic point of view, the population density is more in central and eastern part than the western part. Most of the working forces are engaged in agricultural activity. So, the basin as a whole is an interesting unit for water resource management studies- specially, the transitional zone which is neither a water deficit nor a water surplus zone. The plateau fringe region is equivalent to ecotone in ecological studies. Ecotones are very productive and rich in biological species. But by some parallel studies, the author has identified that the fringe region or transitional zone in the present study, is not that much prosperous in water resource. For a holistic view, the whole area has been taken into consideration. The fluvial morphometric analysis of Dwarka river basin will produce more clarity in understanding the geo-hydrological nature of the basin under a specific geographical environment which is the basic need to undertake management strategies in the particular basin.

II. Description of the study area

For the present study Dwarka River Basin (DRB) has been selected. Dwarka river is a right bank tributary of Mayurakshi river. Total length of the river is approximately 2914.82 km. Latitudinal extension of the basin is 23º57′43.905″ North to 24º29′27.685″ North and longitudinal extension is 87º17′39.515″East to 88º10′36.061″ East, covering an area of 3402.91 sq. Km. The administrative status of the basin area is shown in the following table.

Name of States	Name of Districts	Name of C. D. Blocks
Jharkhand	Pakur	Maheshpur, Pakuria, Amrapara
	Godda	Sundarpahari
	Dumka	Gopikandar, Kathikund, Ramgarh, Dumka, Shikaripara, Ranishwar
West Bengal	Birbhum	Murarai II, Nalhati I, Nalhati II, Rampurhat I, Rampurhat II, Mayureshwar I, Md. Bazar
	Murshidabad	Raghunathganj I, Sagardighi, Nabagram, Khargram, Kandi

Overall the river is semi perennial in nature. Agriculture dominates most parts of this basin. Some forest and wastelands are found in upper catchment and few wetlands are there in the lower catchment of the basin. Geologically, the study area is covered by chhotonagpur gneissic complex of proterozoic eon, Rajmahal trap of Createaceous period, Dubrajpur formation of Createaceous (Jurassic epoch) period, barakar formatin of Permian period, Rampurhat formation of Quaternary period (Pleistocene- Holocene epoch), Talchair formation of carboniferous period, Lalgarh formation of Quaternary period (Pleistocene epoch), Bhagirathi-Ganga formation of Quaternary period (Holocene epoch), Sijua formation of Quaternary period (Pleistocene-holocene epoch) and recent day deposits of Meghalaya age. The major rock types found in this area are granite gneisses, sandstone, siltstone, shale with coal, hornblende schist, amphibolites etc. The older and younger alluvium is consisted of sand, silt, clay, calcareous concretions and laterite (Bhattacharyya, 1976; Ray Barman and Bishui, 1994; Mukherjee et.al, 2019).

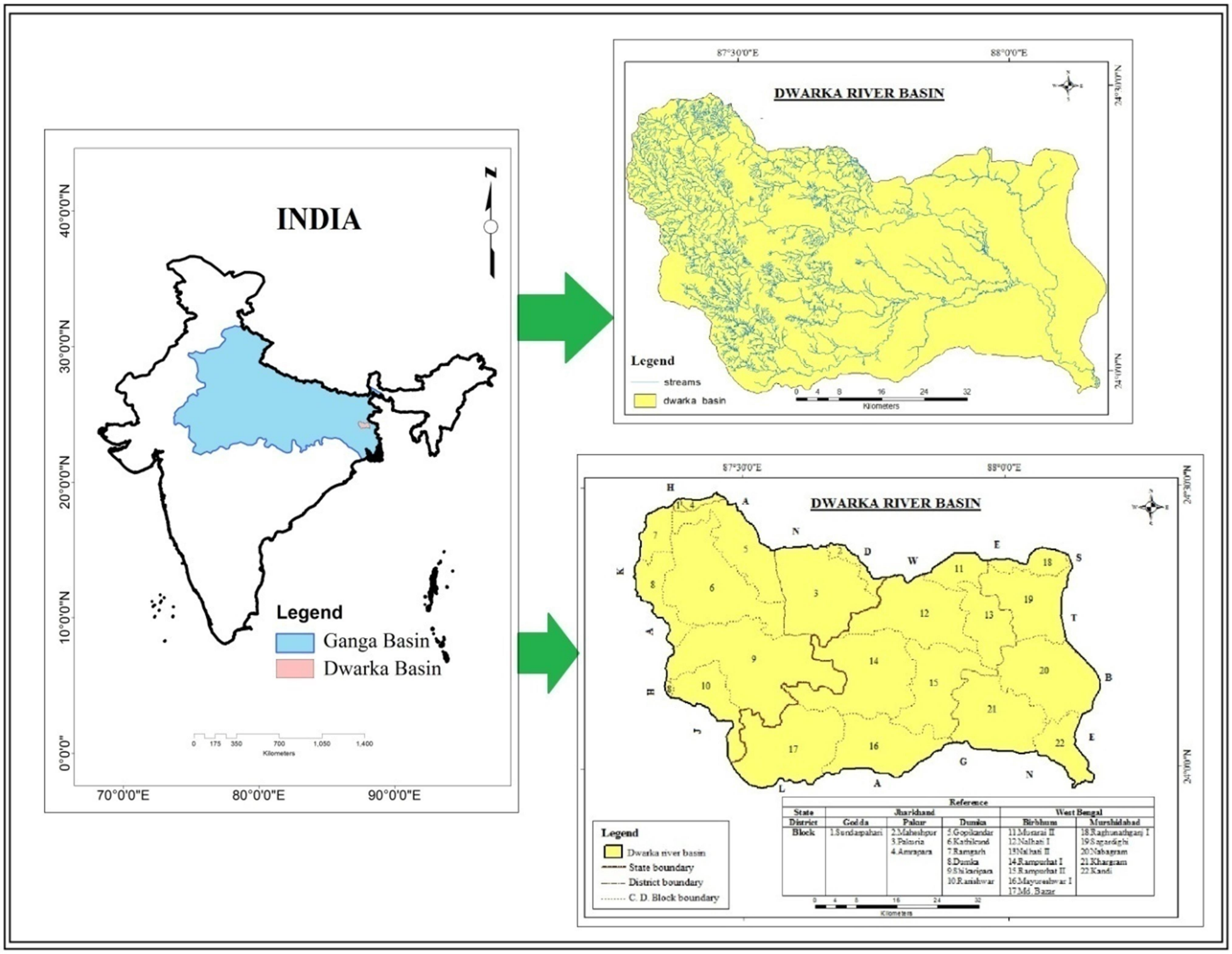


Figure 1: Location of the study area

III. Materials and Methods

The whole study area and Morphometric analysis are based on secondary information and the information are being recorded from toposheets (72 P/7, 72 P/8, 72 P/11, 72 P/12, 72 P/15, 72 P/16, 73 M/9, 73 M/13, 78 D/3, 78 D/4, 79 A/1) published by Survey of India (scale 1:50,000), ASTER Digital Elevation Model (DEM) having 30m spatial resolution, Google Earth. Different morphometric layers have been generated in Arc GIS 10.5 environment. Geological data has been collected from official website of Geological Survey of India. Other related information has been collected from various websites, journals and literatures (sources are given along with the information). Microsoft Excel 2007 software has been used for mathematical calculation. Details methodology is enclosed in the following section.

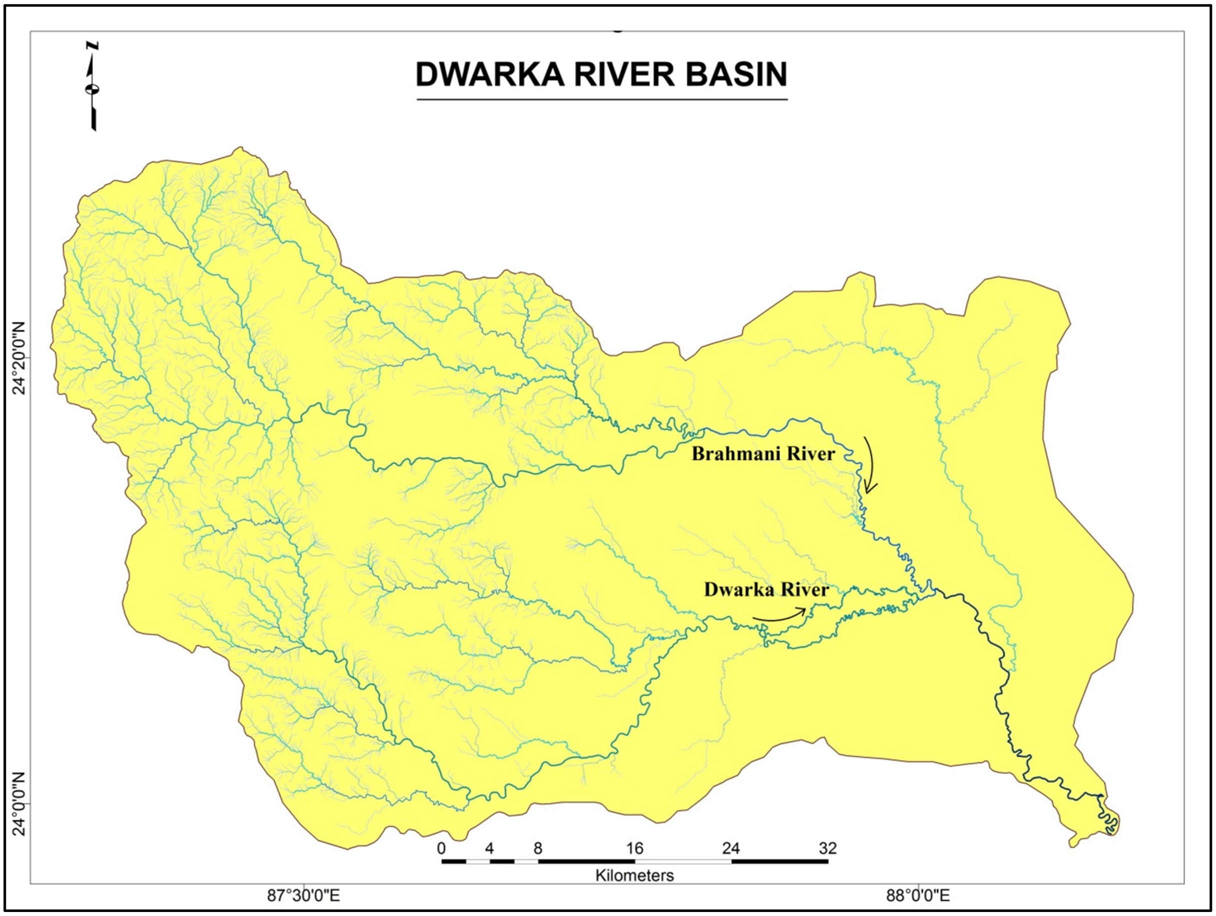


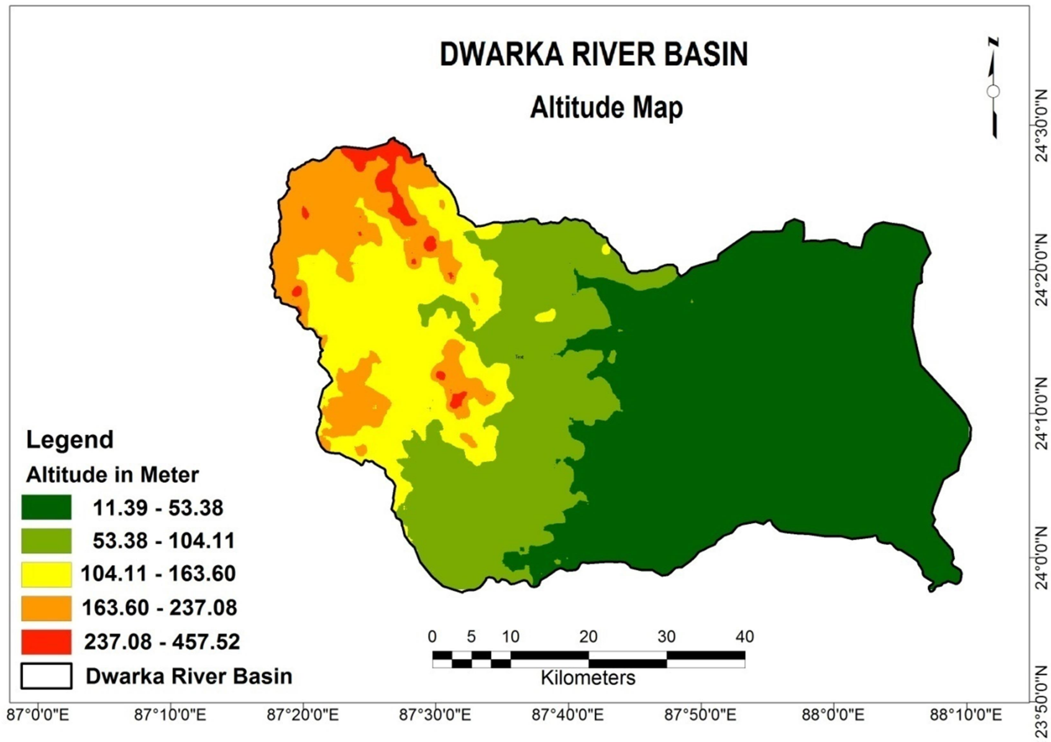
Fig 2: Dwarka River Network

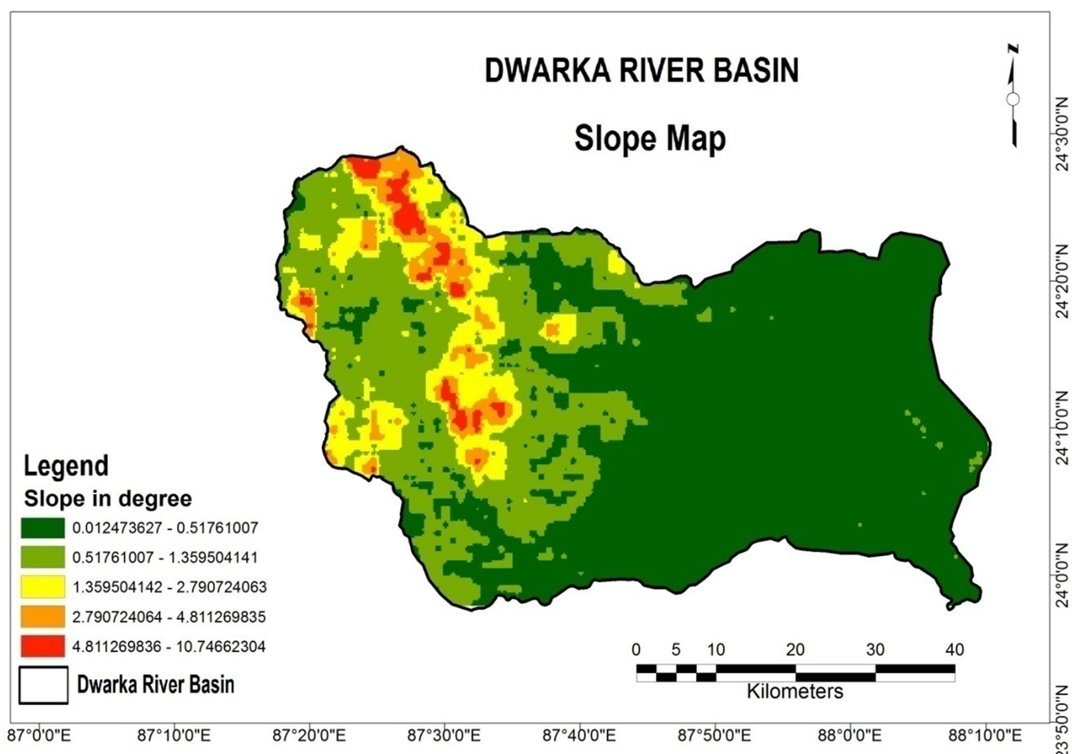
IV. Result and Discussion

The term 'Morphometry' literally means measurement of forms introducing quantitative description for landform. The most dominant geomorphic systems of earth's surface are rivers and fluvial processes which lead to morphometric changes in drainage basin or the watershed (Kulkarni, 2013). Morphometric analysis of drainage network developed in the study area can help in understanding the geomorphic processes and hydrological characteristic of the watersheds under study. The linear, relief and areal aspects of the watershed have been analysed to understand the nature of the basin.

Linear aspects-

Linear aspects of DRB are related to the channel pattern of the drainage network. It includes the discussion and analysis of Stream Order (S_u), Stream Length (L_u), Bifurcation Ratio (R_b), Weighted Mean Bifurcation Ratio (WmR_b) etc.


DWARKA RIVER BASIN
Altitude Map
Legend
Altitude in Meter
11.39 - 53.38
53.38 - 104.11
104.11 - 163.60
163.60 - 237.08
237.08 - 457.52
Dwarka River Basin
0 5 10 20 30 40
Kilometers
87°0'0"E
87°10'0"E
87°20'0"E
87°30'0"E
87°40'0"E
87°50'0"E
88°0'0"E
88°10'0"E
24°30'0"N
24°20'0"N
24°10'0"N
24°0'0"N
23°50'0"N


DWARKA RIVER BASIN
Slope Map
Legend
Slope in degree
0.012473627 - 0.51761007
0.51761007 - 1.359504141
1.359504142 - 2.790724063
2.790724064 - 4.811269835
4.811269836 - 10.74662304
Dwarka River Basin
0 5 10 20 30 40
Kilometers
87°0'0"E
87°10'0"E
87°20'0"E
87°30'0"E
87°40'0"E
87°50'0"E
88°0'0"E
88°10'0"E
24°30'0"N
24°20'0"N
24°10'0"N
24°0'0"N
23°50'0"N

Stream Order (S_u): According to Leopold, Wolman and Miler (1969), "Stream Order is defined as a measure of the position of a stream in the hierarchy of the tributaries." A river basin consists of a huge number streams and those must have their own characteristics. From the study of stream orders, hierarchical organisation of stream segments is envisaged. Gravellius was the pioneer of stream ordering. Scholars like Horton (1932, 45), Strahler (1952, 53, 57), Scheidegger (1965), Shreve (1966, 67), Woldenberg (1967) presented different schemes of stream ordering. In this present study has been done based on Stream ordering scheme postulated by A.N. Strahler (Table 1). According to A.N. Strahler, the finger-tip streams are known as first order streams. Any two first order streams give rise to a second order stream at their junction. At the junction of any two second order streams a third order stream is produced and likewise next higher orders. It is a fact that a mature topography is characterised by less number of streams in a given basin whereas presence of large number of streams shows that the topography is yet to achieve maturity (Kelson, 2011). The total number of streams in Dwarka basin is 2652 (see table 1) among them 2014 (75.94%), 478 (18.04%), 119 (4.49 %), 27 (%), 7 (0.26%), 4 (0.15%), 2 (0.08%), and 1 (0.038%) streams are in 1st, 2nd, 3rd, 4th, 5th, 6th, 7th and 8th order respectively. In this basin lower order streams are more in number and also these kinds of streams are more in upper reach of the stream. It implies the upper basin comes under upland topography and younger topography adjacent to such lower order streams. The higher number of streams in 1st, 2nd and 3rd order indicates high propensity to soil erosion and also huge water flux in lower reach of the stream. Sudden decrease in the number of 2nd and 3rd order streams indicates morphological changes and structural control in the basin.

Table 1

<table>
<tr><th>Stream Orders</th><th>Number of streams</th><th>Bifurcation Ratio</th><th>Mean Bifuctation Ratio</th><th>Weighted Mean Bifuctation Ratio</th></tr>
<tr><td>First</td><td>2014</td><td></td><td rowspan="5">3.177821</td><td rowspan="5">4.168341</td></tr>
<tr><td>Second</td><td>478</td><td>4.213389</td></tr>
<tr><td>Third</td><td>119</td><td>4.016807</td></tr>
<tr><td>Fourth</td><td>27</td><td>4.407407</td></tr>
<tr><td>Fifth</td><td>7</td><td>3.857143</td></tr>
</table>

Sixth	4	1.75		
Seventh	2	2		
Eighth	1	2		
Total	2652	3.17782085714		

Stream Number (N_u): The number of streams present in different stream order is known as stream number. Generally, total number of streams gradually decreases with the increasing stream order(Triatominae, 2012). Horton (1945) states **"**that the number of stream segments of successively lower orders in a given basintend to form a geometric series beginning with the single segment of the highest order and increasing according to constant bifurcation ratio." In other words the numbers of stream segments of each order form an inverse geometric sequence with order number (Pareta and Pareta, 2011), Table 1. High values of first-order streams indicate risk of sudden flash floods after heavy precipitation in the downstream parts.

Basin length (L_b): Basin length is defined as straight line distance from a basin mouth to the outlet point (Horton, 1932). The basin length of Dwarka River Basin is 83.637657 km.

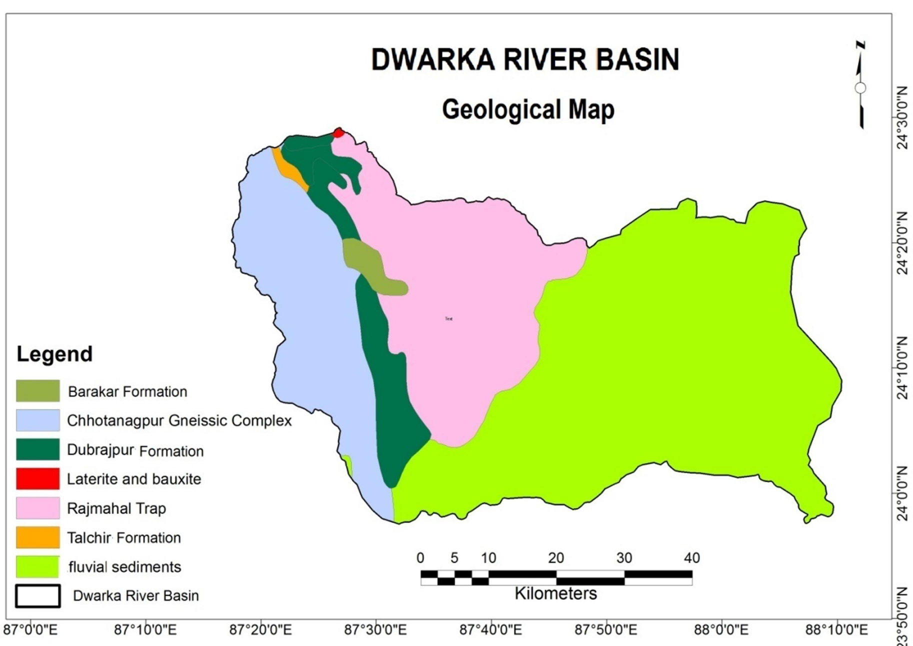
Stream Length (L_u): As per the Horton's Law of Stream length (1945) "the cumulative mean length of stream segments of successive higher orders increase in geometric progression starting with the mean length of the first order segments with constant length ratio." It indicates the successive stage of stream segment development (Castillo et al, 1988). If the bedrock is permeable, a small number of comparatively longer streams are formed in a well drained basin area. Alternatively, if the bed rock is less permeable, a large number of comparatively shorter streams are formed in the basin (Kulkarni, 2013). The stream length of each stream order is measured from starting point to the ending point of the stream (table 2). The stream length has decreased with increasing order, except the sixth order streams. It indicates the lithological irregularities in some parts of the basin. But on an average, the consistency in the stream length indicates stage of mature to old in the cycle of erosion.

Table 2

Stream Order	First	Second	Third	Fourth	Fifth	Sixth	Seventh	Eighth
Total Length(km)	1342.97	620.04	385.41	152.96	130.95	196.87	42.97	42.65
Mean Stream	0.67	1.30	3.24	5.67	18.71	49.22	21.49	42.65

Length(Km)								
Stream Length Ratio		0.46	0.62	0.40	0.86	1.50	0.22	0.99
Order Length Ratio		2.17	1.61	2.52	1.17	0.67	4.58	1.01
Rho Coefficient		0.11	0.15	0.09	0.22	0.86	0.11	0.50

Mean Stream Length ($L_u m$): The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964, Vijith & Satheesh, 2006). The mean stream length ($L_u m$) has been calculated by dividing the total stream length of each order by the number of streams in each order. The mean stream length of stream increases with increasing stream order (Tribhuvan & Sonar, 2016). The mean length of channel segments of a given order is more than that of the next lower order and less than the next higher order. It means that the watershed evolution follows erosion laws acting on geologic material with homogeneous weathering erosion characteristics (Nag & Chakraborty, 2003). In the present basin, (table 2) the mean stream length increases with increasing stream order, except for 7^{th} and 8^{th} order. It indicates that 7^{th} and 8^{th} order streams are yet to complete the stream lengthening process. Consistent gradual higher value indicates the gradually low erosion potentiality and mature to old landform development stage.



Stream Length Ratio (R_l): The proportion of mean lengths of any stream order to the mean stream length of its successive lower order is known as Stream Length Ratio. It tends to be constant throughout the successive orders of a basin (Pareta & Pareta, 2011). A change of stream length ratio from one order to another order indicates their late youth stage of geomorphic development (Singh & Singh, 1997). In the present study (table 2), irregularities in the trend of stream length ratio indicates the irregular hydrological behaviour and presence of differential lithology. The values are not much higher, which are the indicators of mature to old landforms.

Order Length Ratio (R_o): The proportion of mean lengths of any stream order to the mean stream length of its successive higher order is known as Stream Length Ratio. This parameter expresses sequential development of the higher to lower orders of stream lengths resulting from the interaction of climatic factors and underlying geology, with episodes of slow or fast development of streams. In the present study (table 2), there is no definite trend of progressive increase or decrease in order length ratio of the streams.

Bifurcation Ratio (R_b): The bifurcation ratio is the ratio of the number of the stream segments of given order (N_u) to the number of streams in the next higher order (N_{u+1}). It is a dimensionless property. If the value is in between 3 and 5, it indicates that the structural control is not much dominant factor for drainage pattern. Generally ranges from 2 to 5. (Chow, 1964, Joji et al, 2013). Horton (1945) has considered the bifurcation ratio as index of relief and dissertation. According to Strahler (1957) bifurcation shows a small range of variation for different regions or for different environment except where the powerful geological control dominates. It is observed that the bifurcation ratio is not same from one order to its next order these irregularities are dependent upon the geological and lithological development of the drainage basin (Strahler, 1964). The lower values of bifurcation ratio are characteristics of the watersheds, which have suffered less structural disturbances (Strahler, 1964) and the drainage pattern has not been distorted because of the structural disturbances (Pareta & Pareta, 2011). Lower the bifurcation ratio, higher the risk of flooding as water tends to accumulate rather than spreading out. The human intervention plays important role to reduce bifurcation ratio which in turn augment the risk of flooding within the basin (Eze and Efiong, 2010; Nag, 1998). According to Horton (1945), the bifurcation ratio varies from a minimum of 2 in flat or rolling drainage basins to 3 or 4 in mountainous or highly dissected drainage basins. In the present study, (Table 1) the R_b value is higher in the upper and middle reach than the lower reach. So the lower reach is more prone to flood than the rest of the part. If the R_b values using streams of successive orders are separately taken into consideration, the values are consistent which indicates the overall mature stage of cycle of erosion in the present basin. Bifurcation ratio is 3.18 for the whole basin. This is due to the fact that the basin covers dissected plateau, plateau fringe region and flat region as well.

Table 3

Morphometric Parameters		Formula	Values	Unit	References
Linear Aspects	Stream Order	See table 1	See table 1	-	Strahler (1964)
	Stream Number	See table 1	See table 1	-	Strahler (1964)
	Stream Length	See table 2	See table 2	km	Horton (1945)
	Mean Stream Length (L_um)	L_u / N_u	See table 2	km	Strahler (1964)
	Stream Length Ratio (R_l)	L_u / L_{u-1}	See table 2	Dimensionless	Horton (1945)
	Bifurcation Ratio (R_b)	N_u / N_{u+1}	See table 1	Dimensionless	Horton (1945), Schumn (1956)
	Mean Bifurcation Ratio (mR_b)	See table 1	See table 1	Dimensionless	Strahler (1964)
	Weighted Mean Bifurcation Ratio (WmR_b)	See table 1	See table 1	Dimensionless	Strahler (1953)
	Rho Coefficient (ρ)	R_l / R_b	See table 2	Dimensionless	Horton (1945)
Aspec	Drainage Density (Dd)	L_u / A	0.856566	Km/sq. Km	Horton (1932, 45)

	Circularity Ratio (R_c)	$4\pi A/P^2$	0.513165	Dimensionless	Miller (1953)
	Elongation Ratio (R_e)	$2\sqrt{A}/\pi.L_b$	0.737007	Dimensionless	Schumn (1952)
	Form Factor (Ff)	A/L_b^2	0.48646	Dimensionless	Horton (1932)
	Shape Factor (Sf)	1/Ff	2.055669	Dimensionless	Horton (1932)
	Stream Frequency (F_s)	N_s/A	0.779333	Per km^2	Horton (1932, 45)
	Constant Channel Maintenance (C)	1/Dd	1.167452	Km^2/ Km	Schumn (1956)
	Drainage Texture (D_t)	N/ P	9.187	Per km	Horton (1945)
	Texture Ratio (R_t)	N_1/P	6.976825	Per km	Schumn (1956)
	Compactness Co efficient (Cc)	$0.282P/\sqrt{A}$	1. 45	Dimensionless	Gravelius (1914)
	Length Area Relation (R_{la})	$1.5\times A^{0.6}$	197.28511	Sq. Km	Hack (1957)
	Drainage Intensity(D_i)	F_s/Dd	0.909834	Per km	Faniran (1968)
	Infiltration Number (I_n)	$F_s\times Dd$	0.66755	dimensionless	Faniran (1968)
	Length of Overland Flow (L_g)	1/2Dd	0.583726	Km	Horton (1945)
	Geometric	A/L_b^2	0.48646	Dimensionless	Strahler

	Similarity Constant (C_{gs})				(1957)
	Leminscate's Ratio (K)	$L_b^2/4A$	0.513	Dimensionless	Chorley (1957)
Relief Aspects	Basin Relief (B_h)	H - h	446.13	Km	Schumn (1956)
	Relief Ratio (R_h)	B_h / L_b	5.954256	Dimensionless	Schumn (1956)
	Dissection Index (DI)	Relative Relief/ Absolute Relief	0.976471	Dimensionless	Singh and Dubey (1994)
	Gradient Ratio (R_g)	Relative Relief/ L_b	5.954256	Dimensionless	Sreedevi (2004)
	Ruggedness Number (R_n)	Dd*B_h	426.5699	Dimensionless	Strahler (1958)
	Melton's Ruggedness Number (MR_n)	B_h / $\sqrt{A}$	8.536977	Dimensionless	Melton (1965)

Mean Bifurcation Ratio (mR_b): Mean bifurcation ratio register very small variations from region to region irrespective of structural control (Singh et al, 1984). In the present study, (Table 1) the mR_b value is 3.177821

Weighted Mean Bifurcation Ratio (WmR_b): To achieve a better representative bifurcation number Strahler (1953) used weighted mean bifurcation ratio obtained by multiplying the bifurcation ratio for each successive pair of orders by the total numbers of streams involved in the ratio and taking the mean of the sum of these values. In the present study, (Table 1) the mR_b value is 4.168341 which means that the basin is not too much flood prone.

Rho Coefficient (ρ): Rho coefficient is defined as ratio of stream length ratio and bifurcation ratio (Horton 1945). It indicates storage capacity of drainage network. Rho coefficient value of Dwarka River Basin is 0.57 (Table 1) indicating higher hydrologic storage during floods.

Areal aspects-

Basin area is one of the important morphometric attributes as it is related to the spatial distribution of a number of significant attributes. The areal aspects of the drainage basin include basin perimeter, basin shape, drainage density, stream frequency etc.

Drainage Densiy (Dd): Drainage density is the ratio of total stream length of all the orders per unit basin area (Horton 1945). Langbein (1947) suggested that the drainage density value varies between 0.55 and 2.09 km/sq.km in humid regions (Soni, 2016). The lower value of drainage density is observed in the regions underlain by highly resistant permeable material with vegetative cover and low relief. High drainage density value is observed in the regions of weak and impermeable subsurface material and sparse vegetation and mountainous relief. Generally, Low drainage density is found in the areas of permeable soil, dense vegetation and low relief (Nag 1998). While high drainage density is found in the areas of impermeable soil, lower and thin vegetative coverage and in mountainous region. Low drainage density results in coarse drainage texture while high drainage density results in fine drainage texture (Soni, 2016).

Stream Frequency (F_s): Stream frequency of a basin is defined as the number of streams per unit area (Horton 1945). A higher stream frequency indicates larger surface runoff, steeper ground slope, impermeable soil, spare vegetative coverage and high relief conditions while low stream frequency indicates just the opposite. Stream frequency of Dwarka River Basin is 0.779333 numbers per km^2 (Table 3) indicating good runoff.

Drainage Texture (D_t): Drainage texture is the product of drainage density and stream frequency. According to Horton (1945) it is total number of stream segments of all orders per perimeter of that area. It is an indicator of relative channel spacing in a fluvial-dissected terrain. It is influenced by climate, vegetation, lithology, soil type, infiltration capacity and stage of development (Smith 1950; Dornkamp and King, 1971; Pareta & Pareta, 2011). Smith (1950) has classified drainage texture into five different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). In the present study, the drainage texture of Dwarka River Basin is 0.66755 (Table 3). It indicates very coarse drainage texture.

Texture Ratio (R_t): The texture ratio is defined as the ratio between the number of first order streams and perimeter of the basin and it depends on the underlying lithology, infiltration capacity and relief aspects of the terrain. In the present study, the texture ratio of Dwarka River Basin is 6.976825 and categorized as moderate in nature, Table 3.

Drainage Intensity (D_i): Drainage intensity is defined as the ratio of the stream frequency to the drainage density (Faniran, 1968). This low value of drainage intensity implies that drainage density and stream frequency have little effect (if any) on the extent to which the surface has been lowered by agents of denudation (Pareta & Pareta, 2011). The present study shows a low drainage intensity of 0.909834 for the watershed, Table 3. With these low values of drainage density, stream frequency and drainage intensity, surface runoff is not quickly removed from the watershed, making it highly susceptible to flooding, gully erosion and landslides.

Constant of Channel Maintenance (C): Constant of channel maintenance is defined as the area of the basin surface needed to sustain a unit length of stream channel (Schumm, 1956). It is reciprocal of the value of drainage density. Hence, the basins having higher values of constant of channel maintenance will have lower value of drainage density. It is a function of the ground permeability. Higher value indicates higher permeability of the surface material.

The constant of channel maintenance value for Dwarka River basin is 1.167452 (Table 3) meaning 1.167452 km^2 of surface area is required to maintain each kilometre of channel length.

Compactness Constant (Cc): According to Gravelius (1914), compactness constant of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed. Compactness constant is a direct indicator of the shape of a river basin. Compactness constant is unity for a perfect circle and increases as the elongation of basin increases. The compactness constant for Dwarka River basin is 1.395486145 (Table 3) indicating its elongated shape.

Circularity Ratio (R_c): Circularity ratio is the ratio of the basin area to the area of the circle of basin perimeter (Miller, 1953). It is the measure of the degree of circularity of the given basin. High value of circularity ratio indicates circular basin and old stage topography. Circularity and elongation ratios may be of practical use in predicting certain hydrological characteristics of a drainage basin.The circularity ratio of the Dwarka River Basin is 0.513165 (Table 3), indicating moderately circular basin with mature stage topography.

Elongation Ratio (R_e): It is defined as the ratio between the diameter of a circle of the same area as the drainage basin to the maximum length of the basin (L_b) (Schumm, 1956). The elongation ratio ranges in between 0 to 1. The elongation ratio is 1 for a circular basin and 0 for a perfectly straight basin. Elongated basins with high bifurcation ratio produce a low but extended peak flow while circular basins with low bifurcation ratio produce a sharp peak flow. The elongation ratio for the entire Dwarka river basin is 0.787007 (Table 3) indicating that the basin is moderately elongated.

Form Factor (Ff): Form factor is defined as a dimensionless ratio of the area (A) of a drainage basin to the square of its maximum length (L_b) (Horton 1932, 1945). The value of form factor varies from 0 to 1. The former represents highly elongated shape of river basin and the latter represents a perfect circular basin. It is an indicator for flood formation and move, degree of erosion and transport capacities of sediment load in a watershed (Soni, 2016). The smaller the value of the form factor, the more elongated will be the basin. Basins with high form factors receive larger peak flows of shorter duration, whereas basins with low form factors receive flatter peak flows of longer duration and result in lower erosion and sediment transport capacities and help reduction of floods because streams flow into the main stream at greater time intervals and space which leads to ground water percolation (Waikar & Nilawar, 2014, Soni, 2016). The Ff value for study area is 0.48646 (table 3), indicating elongated basin with lower peak flows of longer duration than the average.

Shape Factor (Sf): Shape factor is the reciprocal of form factor. The Shape factor for Dwarka River Basin is 2.055669 (Table 3).

Length of Overland Flow (L_g): The Length of Overland Flow (L_g) is the length of water over the ground surface before it gets concentrated into definite stream channel (Horton, 1945). The length of overland flow is almost equal to the half of the reciprocal of drainage density. It is negatively related to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large degree (Waikar & Nilawar, 2014). Smaller the value of length of overland flow, quicker is the surface runoff and lesser erosion and vice-versa. In this study, the length of overland flow of the Dwarka River Basin is 0.582736 Km, (Table 3), which shows moderate surface runoff of the study area, indicating moderate slope and moderate infiltration of the study area.

Infiltration Number (I_n): The infiltration number of a watershed is defined as the product of drainage density and stream frequency and given an idea about the infiltration characteristics of the watershed. The higher the infiltration number, the lower will be the infiltration and the higher ran-off (Soni, 2016). For Dwarka river basin infiltration number is 0.66755 (Table 3).

Length Area Relation (R_{la}): Hack (1957) found that for a large number of basins, the stream length and basin area are related by a simple power function (see table 3). For the present study, the value of R_{la} is 184.1782

Geometric Similarity Constant (C_{gs}): Geometric similarity constant is defined as the ratio of area of watershed to the square of the maximum length of stream (Vincy et al, 2012). For the present study it is 0.48646 (Table 3).

Leminscate's Ratio (K): Chorely (1957), express the lemniscate's ratio as a function of basin length and area of the basin. The lemniscates's ratio for the present river basin is 0.513917 (Table 3), which shows that the watershed occupies the maximum area in its regions of inception with large number of streams of lower order.

Relief aspects-

The relief aspects of drainage basins are related to the study of three dimensional features of the basin involving area, volume and altitude of vertical dimensions of landform wherein different morphometric methods are used to analyse terrain characteristics.

Basin Relief (B_h): 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. It controls the stream gradient and therefore influences flood patterns and the amount of sediment that can be transported (Hadley and Schumm 1961). The high basin relief indicates the gravity of water flow, low infiltration and high runoff conditions.

Relief Ratio (R_h): The relief ratio (R_h) is ratio of basin relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line. It is a dimensionless ratio that effectively measures 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 (Schumn, 1956; Javed et al. 2009). Generally it increases with decreasing drainage area and size of watersheds of a given drainage basin (Waikar & Nilawar, 2014). The value of R_h in Dwarka river basin is 5.954256 indicating low to moderate relief and moderate slope.

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). DI value of Dwarka river basin is 0.976471 (table 3).

Ruggedness Number (R_n): 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). Low R_n value suggests that the basin is less prone to soil erosion and have intrinsic structural complexity in association with relief and drainage density (Pareta & Pareta, 2011). An extreme high value of ruggedness number occurs when both variables are large and slope is steep (Strahler, 1956). The value of ruggedness number in present basin is 426.5699 (table 3).

Melton's Ruggedness Number (MR_n): According to Melton (1965), Melton Ruggedness number is a slope index that provides specialized representation of relief ruggedness within the watershed. It is 8.536977 for Dwarka river basin (table 3).

Gradient Ratio (R_g): Gradient ratio suggests channel slope from which runoff volume could be evaluated (Sreedevi et al. 2009). Low Rg values show moderate relief terrain and main stream flow through plateau (Soni, 2016). Rg values for Dwarka river basin is 5.954256 (Table 3). Dwarka River mostly flows through plateau region and the relatively low R_g value indicates the same.

V. Conclusion

It is evident from the above discussion that the lower reach of the basin is water surplus and flood prone zone whereas the upper reach is water deficit zone. The plateau fringe region shows the combination of both the aforementioned zones. Minor water harvesting structures can be installed to the areas of moderate to high run-off to improve ground water recharge.

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