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Geological Controls of Dyke Networks on Drainage Morphometry: Evidence from the Bhad River Basin, North Maharashtra

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Abstract

Drainage morphometry provides vital insights into the interaction between geological structures and fluvial processes. The present study investigates the influence of mafic dyke intrusions on the drainage morphometric characteristics of the Bhad River basin, located within the Nandurbar–Dhule dyke swarm region of North Maharashtra, India. The basin covers an area of 164.32 km² and is structurally dissected by 27 prominent dykes, which exert a strong control on drainage orientation, basin geometry, and stream network development. Remote sensing data, topographic maps, and GIS-based techniques were employed to extract and analyze linear, areal, and relief morphometric parameters. The structural analysis reveals that the dykes display a dominant E-W orientation, with strike angles ranging between 10° and 110° and a mean strike of N80°, indicating strong regional structural control. Dyke lengths and thicknesses exhibit inverse and weak linear relationships, respectively, suggesting heterogeneous emplacement conditions. Morphometric evaluation shows that the Bhad River is a sixth-order basin with a total stream length of 450.19 km and a bifurcation ratio of 3.39, reflecting moderate structural disturbance. Drainage density (2.74 km/km²), stream frequency (3.15), and drainage texture (7.08) indicate a moderately dissected terrain with efficient surface runoff.

Relief parameters such as basin relief (271 m), ruggedness number (0.74), and dissection index (0.68) suggest moderate relief and ongoing erosional activity influenced by dyke-controlled topography. The hypsometric integral value of 0.49 places the basin in a late youthful to early mature stage of geomorphic evolution. Overall, the study proves that dyke intrusions meaningfully influence drainage alignment, basin morphology, and hydrological response. These findings highlight the importance of structural controls in morphometric studies and provide valuable inputs for watershed management, geomorphic interpretation, and regional planning in dyke-dominated terrains.

Keywords: *Bhad River Basin, Drainage Morphometry, Drainage Network Analysis, Dyke Intrusions, Geomorphic Evolution, GIS and Remote Sensing, Structural Control*

Introduction

Drainage basin morphometry is a quantitative approach used to realise the association between geological structure, geomorphology, and hydrological processes functioning within a river basin. Since the pioneering works of Horton and Strahler, morphometric analysis has been widely applied to understand basin evolution, runoff characteristics, erosion intensity, and tectonic impact (Horton, 1945; Strahler, 1952). In hard-rock terrains, especially those affected by intrusive structures such as dykes, drainage networks often display strong structural control in terms of orientation, spacing, and channel development (Zernitz, 1932; Howard, 1967). The Deccan Volcanic Province of India is characterized by extensive mafic dyke swarms that significantly influence surface and subsurface hydrological behaviour (Deshmukh and Sehgal, 1988; Ray et al., 2007).

The Bhad River basin, located within the Nandurbar–Dhule dyke swarm of North Maharashtra, provides an ideal setting to study the interaction between dyke intrusions and drainage morphometry. The presence of closely spaced, predominantly E-W trending dykes has modified stream alignment, basin shape, and relief characteristics. Recent studies emphasize the use of remote sensing and GIS techniques for accurate extraction and analysis of morphometric parameters, enabling better understanding of structural controls on drainage evolution (Nag and Chakraborty, 2003; Rekha et al., 2011).

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Therefore, the present study aims to analyze the influence of dyke intrusions on the drainage morphometric characteristics of the Bhad River basin and to assess their implications for geomorphic evolution and watershed management.

Study Area

The Bhad River basin is located in the Nandurbar–Dhule dyke swarm region of North Maharashtra, India (Fig. 1.1) and forms part of the lower Tapi river system. The basin extends from 21° 17'39" to 21° 25'24"N and 74° 19'19" to 74° 32'33"E, covers an area of 164.32 km² and extends for about 31.28 km from its source to its confluence with the Tapi River near Arate village.

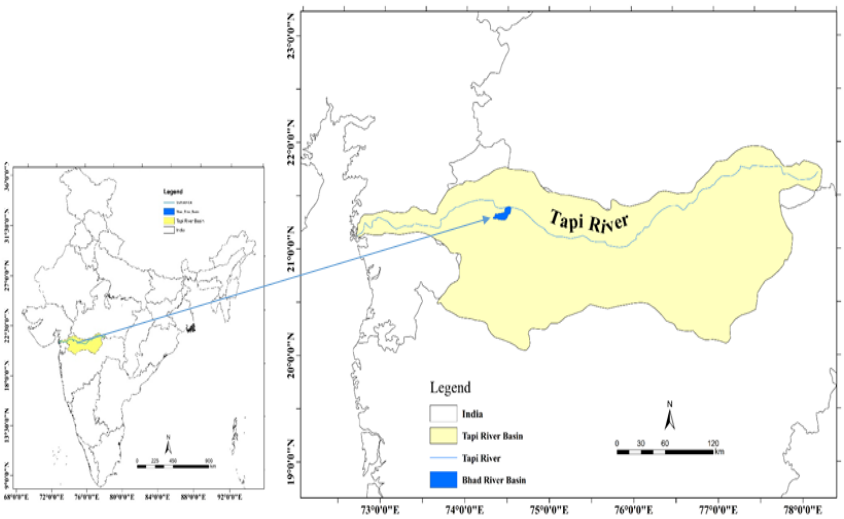

Figure 1.1 *Location map of the Bhad River Basin*

Geologically, the basin is underlain by Deccan Trap basalt, intruded by 27 mafic dykes that are unevenly distributed across the catchment. These dykes display a strong E-W orientation with a mean strike of N80°, indicating pronounced structural control on surface processes. Geomorpholgically, the basin is characterized by moderate relief, dissected plateaus, dyke-controlled ridges, and narrow valleys. Climatically, the basin experiences a monsoonal rainfall regime, resulting in seasonal flow conditions and moderate runoff response. These physical characteristics make the Bhad River basin an ideal area for investigative the influence of dyke intrusions on drainage morphometry and geomorphic evolution.

Objectives: The objectives of the research paper is:

- To analyze the structural characteristics and spatial distribution of dyke intrusions in the Bhad River basin and their influence on drainage network orientation.
- To evaluate the impact of dyke-controlled structural features on the linear, areal, and relief morphometric parameters of the Bhad River basin using GIS-based techniques.

Methodology

The present study adopts an integrated approach using remote sensing, GIS, and quantitative morphometric techniques to evaluate the impact of dyke intrusions on the drainage characteristics of the Bhad River basin. Survey of India topographic maps 46K/7 and 46K/11 (1:50,000 scale) and Cartosat DEM were used to delineate the basin boundary, drainage network, and dyke features. Dyke orientation, length, thickness, and spatial distribution were mapped and analyzed using GIS 10.7.1 software. Rose diagrams were prepared in GeoRose Software, histograms, and scatter plots were prepared to examine dyke strike patterns and their relationship with drainage alignment. Linear, areal, and relief morphometric parameters were computed following standard methods proposed by Horton and Strahler. Statistical techniques, including regression analysis and correlation coefficients, were applied to assess relationships between dyke attributes and morphometric variables. Digital elevation models were used to derive elevation, slope, and relief parameters. The results were interpreted to understand structural control on drainage development, geomorphic evolution, and hydrological behaviour of the basin.

Analysis and Interpretation

The structural features of the Bhad river basin dykes:

The area of the Nandurbar-Dhule dyke swarm contains the Bhad river basin. It has a 164.32 km² catchment area and containing 27 dykes. Dykes are distributed unevenly across the basin. The dykes strike angles in the basin is from 10° to 110° (Fig.1.2). A general trend of dyke swarms in the basin is indicated by the mean strike of dykes, which is 80° N. Only one of the 27 dykes has the N-S trend, while the other 26 have an E-W strike angle. The basin's dykes have a significant parallel tendency.

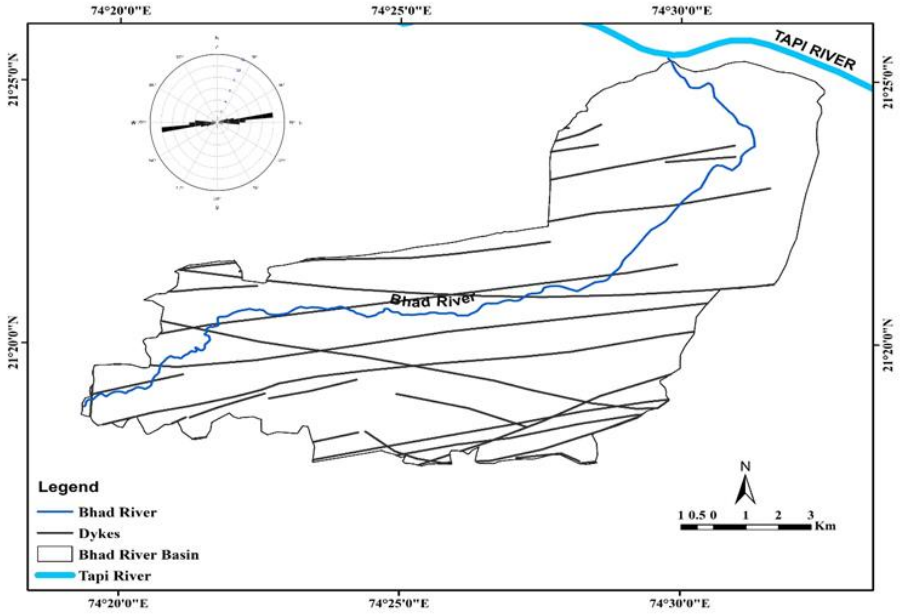

Figure 1.2: Spatial distribution of dykes in the Bhad river basin. The upper left corner shows the rose diagram of dyke's strikes.

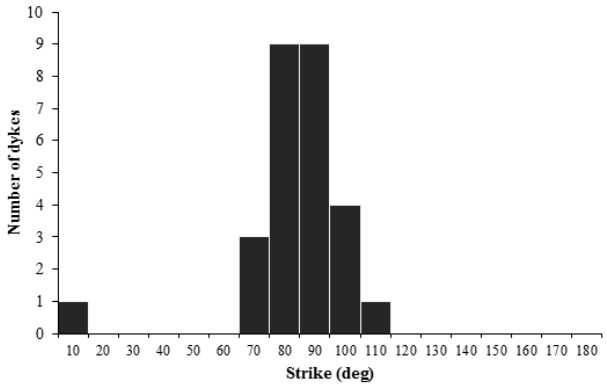

Figure 1.3.: Histogram showing strikes of dykes in the Bhad river basin

The Histogram of strike angles and their frequency of 27 dykes strike within the Bhad river basin. Most dyke strike angles are concentrated 70° to 110° from the north (Fig.1.3) . That is an indication of dykes' orientation in the E-W direction. A single dyke is N-S oriented in the basin.

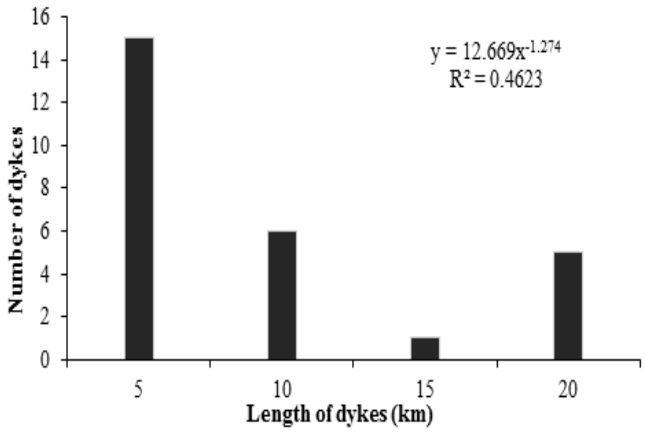

Figure 1.4: Bargraph showing the length and number of dykes in the Bhad river basin

The inverse relationship in the length of dykes to their number is shown in the figure 1.4. This bargraph shows 15 dykes laid within 5km in length and 5 dykes laid within 20km in length. The relationship between the length and number of dykes in the basin is computed through Power Law equation $y = 12.669x^{-1.274}$ (Fig.1.4). The correlation coefficient computed value is $R^2 = 0.4623$. The lengths and numbers of dykes are inversely correlated, as indicated by the negative exponent -1.274. This basin's dyke length and number show a substantial negative correlation, as indicated by $R^2 = 0.4623$.

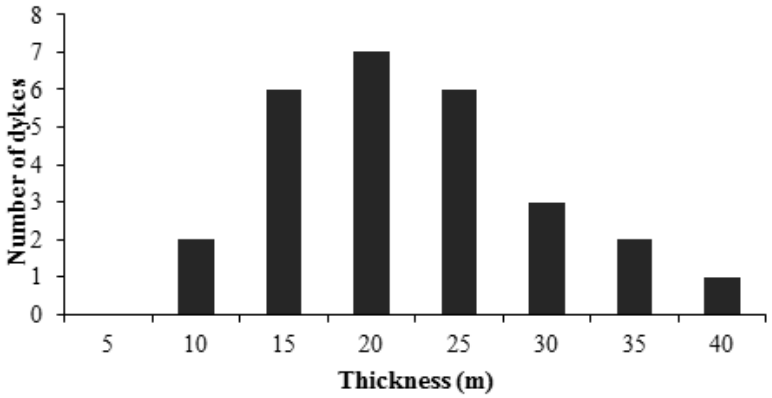

Figure 1.5: Bargraph showing thickness and number of dykes in the Bhad river basin

The thickness of dykes in the Bhad river basin ranges from 10 m to 40m, out of 27 dykes.2 dykes placed under 10m thickness, 6 dykes 15m,7 dykes 20m, 6 dykes 25m, 3 dykes 30m, 2 dykes 35m, and one dyke in 40m thickness class respectively.

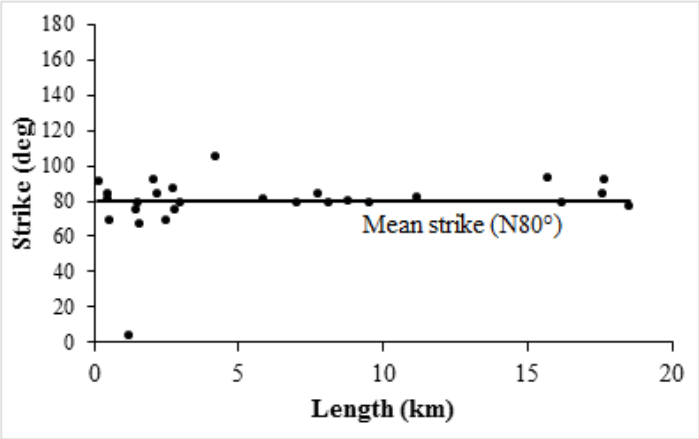

Figure 1.6.: Scatter plot showing length vs. strike of dykes in the Bhad river basin

The length and strike of the Bhad river basin's dykes are shown in a scatter diagram (Fig 1.6). That depicts the up to 20km longer dykes are aligned to the E-W direction. One shorter dyke is oriented N-S so it is away from the mean strike angle. Most of dykes strike angle orientation is uniformly. Longer dyke in Bhad river basin (over 17 km) has tended to cluster along the mean strike (N80°).

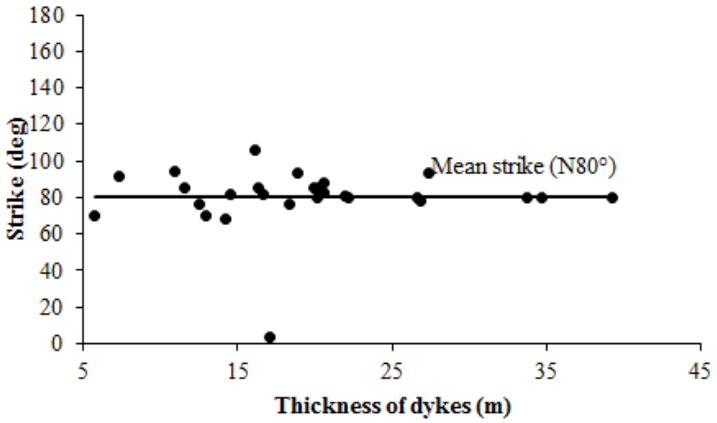

Figure 1.7: Scatter plot showing thickness vs. strike of dykes in the Bhad river basin

The thickness and strike angles of Bhad river basin's dykes' are depicted in a scatter diagram. Thickness ranges from around 5 m to 39.27 m, with the majority of data concentrated between 10 m and 27 m (Fig 1.7). The average thickness of dyke is 19.55m. The mean strike angle of Bhad river basin dykes is marked at N80°, indicating that most dykes are aligned nearly East-West.

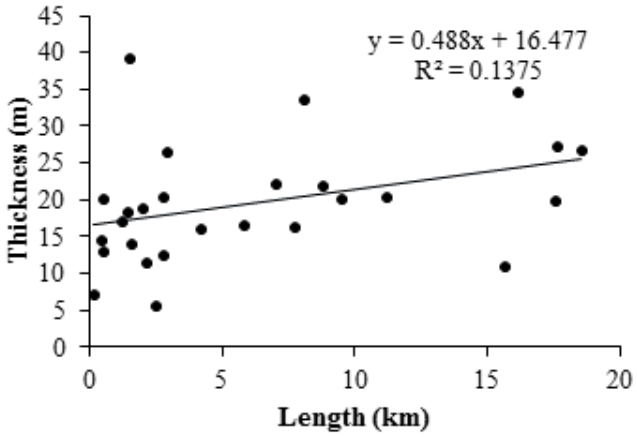

Figure 1.8: Relationship of length and thickness of dykes in the Bhad river basin

The relationship between the length and thickness of the Bhad river basin's dykes is computed and plotted on the scatter diagram. The linear regression model depicts the relation of length and thickness of Bhad river basin dykes. The equation $y = 0.488x + 16.477$ is a linear regression model that describes the relationship between dyke length and thickness (Fig. 1.8). Each-unit increase in the length of dykes (x), thickness of dykes (y) increases by nearly 0.488 units. When the length of dyke, x=0, the predicted value of thickness (y) is 16.477. The R^2 value is the coefficient of determination of the dyke length and thickness in the Bhad river basin's R^2 is 0.1375. The coefficient of determination indicates that changes in the length of dykes (x) account for around 13.75% of the variability in thickness of dykes (y). The low R^2 value (0.1375) indicates a weak linear relationship between dyke length (x) and thickness (y).

The Bhad River basin has an average aspect ratio of 323:1. The highest aspect ratio in the basin is 1428:1, while the minimum is 17:1. The standard deviation for the 27 dykes' aspect ratio is 314. The entire area of the Bhad river basin is 164.32 km², with 27 dykes. The basin's 27 dykes extend a total of 169.77 kilometers. The density of dykes in the basin is 1.03 km/km².

Catchment morphometrics of the Bhad River basin

The Bhad basin covers a 164.32 sq. km area of the Nandurbar-Dhule dyke swarm. It runs 31.28 km long distance from the origin at 360 m and joins the Tapi River at Arate village at an elevation near 128 m asl . The Loki Nala is a single right bank sub-tributary. The river is a sixth-order stream network. There are 27 dykes and 518 streams spread out geographically over the drainage basin area. The river's streams have a total length of 450.19 km, with an average length of 4.13 km (Table 1.1). The Bhad River has a bifurcation ratio of 3.39, indicating a drainage basin that is considerably impacted by geological formations. The basin has a modest drainage network structure, influenced by topographic differences, according to its Rho value of 0.53.The river basin's stream frequency is 3.15. The DI value of 1.16 for the tiver shows moderate drainage intensity. A strong drainage network throughout the basin is indicated by the drainage texture of 7.08.

This implies that the basin has a large number of streams in relation to its perimeter, which is frequently coupled with moderate to high rainfall and steep topography. The Bhad River's texture ratio of 8.64 indicates a moderate drainage system with balanced runoff characteristics and a moderate possibility for erosion. The length of overland flow in this basin is 180 meters, indicating that water flows over the surface for a short distance before entering a stream or channel. The 0.18 kilometer overland flow in the Bhad river basin suggests an extensive drainage network and quick surface runoff. The constant of channel maintenance is 0.36. This basin has a form factor of 0.34. An elongation ratio of 0.66 indicates that the basin is fairly extended and compacted. The basin's circularity ratio of 0.39 illustrates its irregular shape, which is typical of basins formed by topographic features such as mountains and dyke ridges.

Table1.1 Morphometric parameters of the Bhad river basin in the Nandurbar-Dhule dyke swarm area

Aspect	Parameters	Bhad	Aspect	Parameters	Bhad	Aspect	Parameters	Bhad
Linear	River Stream Length (Km)	31.28	Areal	Stream Frequency (Fs)	3.15	Relief	Basin Relief (Bh)	271
	Basin Length (Km)	22.02		Area (A)	164.32		Relative Relief (Rr)	1.65
	Valley Length (Km)	28.27		Drainage Density (Dd)	2.74		Relief Ratio (Rh)	0.0123
	Perimeter	73.14		Drainage Texture (Dt)	7.08		Maximum Elevation (H)	399
	Stream Order (U)	6		Texture Ratio	8.64		Dissection Index (D.I)	0.68
	Stream Number (Nu)	518		Drainage Intensity (Di)	1.16		Minimum Elevation (H)	128
	Stream Length (Lu)	450.19		Infiltration Number (If)	8.63		Ruggedness Number (Rn)	0.74
	Stream Length Ratio (RL)(MEAN)	4.13		Length Of Overland Flow (Lo)	0.18		Hypsometric Integral (HI)	0.49
	Mean Bifurcation Ratio (Rbm)	3.39		Constant Of Channel Maintenance (Ccm)	0.36			
	Si=Cl/Vl	1.21		Form Factor	0.34			
	Dyke Impact Si Index	2.16		Circulatory Ratio (Rc)	0.39			
	Rho Coefficient	0.53		Elongation Ratio (Re)	0.66			

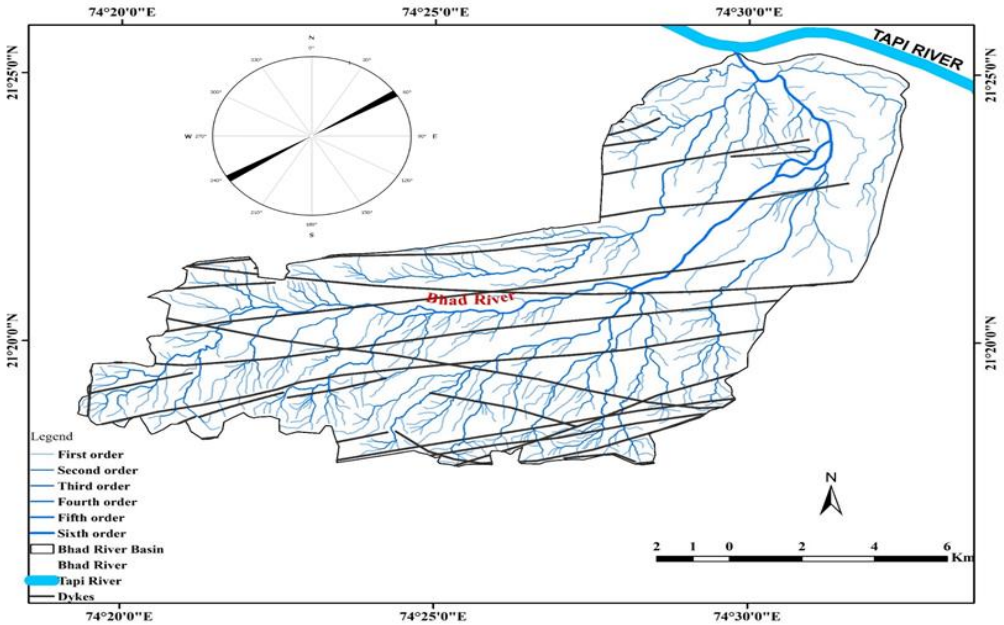

Figure 1.9 Stream networks-dykes map of the Bhad river basin with rose diagram of river strike.

A Relative Relief (Rr) value of 1.65 indicates that the Bhad River basin has moderate to high elevation differences relative to its area, implying considerable roughness. A relative relief (Rr) value of 1.65 indicates a high degree of difference in elevation within catchment area. The basin reaches a maximum elevation of 393 meters and a minimum of 112 meters, giving it a relief of 281 meters. The Rr value of this basin is 0.0123. It implies that the basin is not particularly rocky and has soft slopes. It probably has slower runoff and less potential for erosion, The Bhad River basin has a Dissection Index (DI) of 0.68, indicating a fairly fragmented dyke ridges landscape with evident erosion and fragmentation. This basin has low to moderate roughness, as indicated by its ruggedness number of 0.74. Although there is significant variation in height and drainage density. It implies that the drainage network in the basin is comparatively mild and that the relief is moderate. The basin has a hypsometric integral (HI) of 0.49, indicating a late young to early mature stage of geomorphic evolution. The value spans between very rough (youthful) and

gently eroded (mature) basins.

Table 1.2 Stream number and stream length of the Bhad River basin

Basin	Stream Number (Nμ∑)							Stream Length (Lμ)						
	1st	2nd	3rd	4th	5th	6th	∑Nμ	1st	2nd	3rd	4th	5th	6th	∑Lμ
Bhad	385	95	27	8	2	1	518	247.4	97	43.2	42.9	7.1	12.6	450.2

Table 1.3 Mean stream length and bifurcation ratio of the Bhad River basin

Mean Stream Length (Km)							Bifurcation Ratio (Rbm)					
$_1^{st}$	$_2^{nd}$	$_3^{rd}$	$_4^{th}$	$_5^{th}$	$_6^{th}$	∑Nμ	$_1^{st}/_2^{nd}$	$_2^{nd}/_3^{rd}$	$_3^{rd}/_4^{th}$	$_4^{th}/_5^{th}$	$_5^{th}/_6^{th}$	Rbm
0.64	1.02	1.60	5.36	3.55	12.60	4.13	4.05	3.52	3.38	4.00	2.00	3.39

Table 1.4 Stream length ratio of the Bhad River basin

Basin	STREAM LENGTH RATIO					
	2nd/1st	3rd/2nd	4th/3rd	5th/4th	6th/5th	7th/6th
Bhad	0.39	0.45	0.99	0.17	1.77	0

Summary and Conclusion

The study demonstrates that the drainage morphometry of the Bhad River basin is strongly influenced by mafic dyke intrusions associated with the Nandurbar–Dhule dyke swarm of North Maharashtra. Structural analysis reveals a dominant east–west orientation of dykes, which has directed stream alignment, basin geometry, and superimposed drainage development. The computed linear, areal, and relief morphometric parameters indicate a moderately dissected basin with efficient surface runoff and noticeable structural disturbance. Values of bifurcation ratio, drainage density, and stream frequency reflect the combined influence of lithology, topography, and dyke-controlled structural features. Relief parameters and hypsometric analysis suggest that the basin is in a late youthful to early mature stage of geomorphic evolution. Overall, the study confirms that dyke intrusions play a critical role in modifying drainage characteristics and landscape evolution. The findings are valuable for understanding geomorphic processes, assessing hydrological behaviour, and supporting effective watershed management and regional planning in hard-rock, dyke-dominated terrains.

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Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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