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Original Article

Quantifying the Role of Dyke Networks in Controlling Drainage Patterns Using Morphometric Parameters of Buray River basin in the North Maharashtra

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Abstract

This study investigates the structural characteristics of dykes and their geomorphic influence on the drainage morphometry of the Buray River basin, located in the Nandurbar–Dhule dyke swarm of North Maharashtra. The basin covers 1101.39 km² and contains 29 dykes that vary significantly in length, width, and orientation. Dyke trends range from N–S, ENE–WSW, to predominantly E–W, reflecting complex crustal extension patterns associated with regional tectonic forces. Statistical analyses, including power law relationships, regression modelling, and aspect ratio assessment, reveal strong inverse correlations between dyke length and frequency, and a negligible linear relationship between dyke length and thickness. The mean dyke strike of N95° indicates a dominant tectonic stress direction during dyke emplacement. Morphometric evaluation of the drainage basin indicates a seventh-order stream network, moderate drainage density, elongated basin form, high dissection index, and a rugged topographic character. Integration of dyke attributes with drainage parameters demonstrates how dyke intrusions influence stream orientation, drainage texture, channel network development, and surface runoff behaviour. This study contributes to understanding structural–geomorphic interactions in basaltic terrains and highlights the role of dyke swarms in shaping drainage evolution and basin morphology.

Keywords*: Buray River Basin; Drainage Morphometry, Dyke Density, Strike Orientation, Aspect Ratio, Power Law Relationship, Linear Regression, Structural Control, Basaltic Terrain*

Introduction

Drainage morphometry provides a quantitative basis for analyzing the geometric characteristics of river basins and is widely used to interpret hydrological behaviour, basin evolution, and fluvial responses to underlying geology (Horton, 1945; Strahler, 1964). Parameters such as stream order, bifurcation ratio, drainage density, drainage texture, and relief ratio help in understanding the structural and lithological controls operating within a terrain (Schumm, 1956; Faniran, 1968). In regions underlain by volcanic and tectonic structures, morphometric properties often reflect the influence of intrusive bodies, fractures, and major lineaments (Sreedevi et al., 2005; Mesa, 2006).

Among intrusive features, dolerite dykes are prominent linear bodies that significantly influence topography and drainage development. Their strike orientation, density, and geometric attributes often guide stream alignment, divert channel courses, modify slope morphology, and control erosional processes (Delaney & Pollard, 1981; Gudmundsson, 1987). Dyke swarms also provide valuable information regarding crustal extension, magma emplacement, and regional tectonic stress fields (Ernst & Baragar, 1992). In basaltic provinces, such as the Deccan Volcanic Province of India, dykes form an integral part of the structural framework and exert strong geomorphic control (Bondre et al., 2004).

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The Deccan Volcanic Province (DVP) displays one of the world's largest dyke systems, where N–S, ENE–WSW and E–W trending dykes reflect multiple phases of tectonomagmatic activity (Hooper, 1990; Subbarao & Hooper, 1988). Such dykes influence fluvial networks by acting as both barriers and linear guides for stream development, thereby modifying drainage patterns and morphometric characteristics (Pascoe, 1964; Kale & Shejwalkar, 2007). The Buray River basin, located within the Nandurbar–Dhule dyke swarm of North Maharashtra, is a representative landscape where numerous basaltic dykes intersect an actively evolving drainage system. The basin exhibits a seventh-order drainage hierarchy, high drainage texture, substantial relief, and an elongated basin form, suggesting the combined impact of erosional processes and structural control.

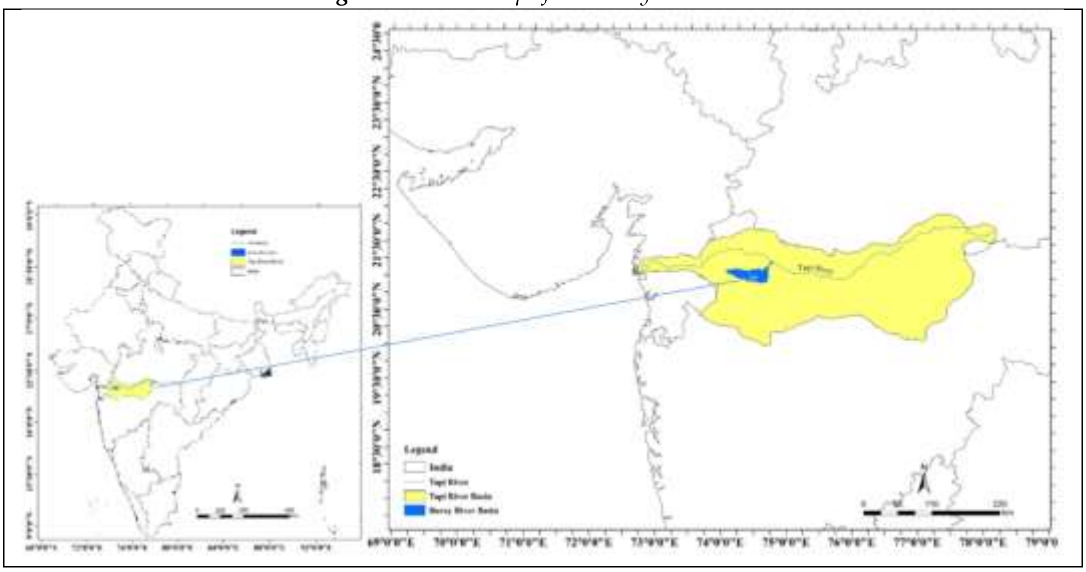
Despite the geomorphic significance of the Buray basin, a comprehensive integration of dyke attribute analysis with drainage morphometry has not been previously undertaken. Existing studies on the Deccan basalts acknowledge dyke influence on channel patterns, but basin-scale quantitative assessments remain limited (Das & Mukherjee, 2020; Sridhar et al., 2018). Examining dyke orientation, aspect ratio, thickness, and spatial distribution alongside morphometric parameters provides valuable insight into how intrusive structures regulate fluvial evolution, sediment pathways, and basin dynamics.

Therefore, the present study employs GIS-based morphometric techniques, structural mapping, statistical modelling, and dyke–drainage integration to analyse the geomorphic configuration of the Buray River basin. The objective is to evaluate how geometry, density, and orientation influence drainage evolution dyke and landscape development in a basaltic terrain. The findings contribute to broader understanding of structural–geomorphic interactions within the Deccan Volcanic Province and enrich regional interpretations of basin morphodynamics.

Study Area

The study area lies on the Deccan Traps Region, which is a subset of volcanic province located on the Deccan Plateau. The Buray river basin, forming a part of the Narmada-Tapi giant swarm, is the focus of this research paper. The area extends from 20°59′20′′ to 21°18′ 29′′N latitude and 74°03′ 45′′ to 74° 47′51′′E (Fig.1.1). longitude. Geomorpholgically, the study area forms a part of the Tapi River Basin. The area is drained by a left bank tributary Buray of the Tapi River. This river is a rainfed river and dominantly rocky and usually dry during the dry season. The area under research study is dominated by monsoon type of climate with most of the annual rainfall falling during the four monsoon months – June to September (Kale and Hire, 2004). The average annual rainfall at Nandurbar is ~1000 mm and at Dhule the annual total is ~540 mm.

Fig. 1.1 *Location map of the Buray River basin*



Methodology:

SOI Topographic maps 46K/4, K/8,K/11,K/12,K/15 and 46L/5 (1:50000), Cartosat DEM data, and Google Earth imagery were used to delineate the Buray River basin and identify drainage networks. Geological information on dykes, including their strike, thickness, and length, was interpreted using District Resources Maps of Nandurbar-Dhule (1:250000) geological maps, satellite imagery, and field-verified data. All spatial datasets were georeferenced in ArcGIS 10.7.1, Global Mapper 20 and GeoRose for further processing. Basin Delineation and Stream Ordering of the Buray River basin boundary was digitized from topographical sheets and extracted from Cartosat DEM data using GIS watershed tools. The drainage network was generated and classified using the Strahler stream ordering system. Stream numbers, lengths, and cumulative lengths were derived for each order.

Morphometric Parameter Calculation is assessed through morphometric analysis. This was performed under linear, areal, and relief aspects: Linear parameters: stream number (Nu), stream length (Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb).Areal parameters: drainage density (Dd), stream frequency (Fs), drainage texture (Dt), infiltration number (If), constant of channel maintenance (Ccm), form factor (Ff), elongation ratio (Re), circulatory ratio (Rc).Relief parameters: basin relief (Bh), relative relief (Rr), relief ratio (Rh), ruggedness number (Rn), dissection index (DI), hypsometric integral (HI).Standard morphometric formulae were applied following Horton (1945), Strahler (1964), Schumm (1956), Faniran (1968) and other recognized methodologies.Dyke Mapping and Attribute Analysis: Dykes were digitized manually in GIS using georeferenced District Resources maps of Nandurbar and Dhule. Dyke attributes—length, thickness, orientation (strike), and spatial distribution—were quantified. Rose diagrams for strike analysis were generated to identify dominant structural trends in the GeoRose software. Dyke density was calculated using the total dyke length per unit basin area. Statistical and Graphical Analysis: A power law model was used to explore the relationship between dyke length and frequency. A linear regression model examined the relationship between dyke length and thickness. Scatter plots were created to understand the interaction between: dyke length vs. strike, dyke strike vs. thickness, stream order vs. stream length/number, Aspect ratio and standard deviation of dyke geometry were computed to assess dyke morphometry.

Integration of Dyke and Drainage Data: Dyke and drainage layers were overlaid to examine structural control on stream orientation. The Dyke Impact Index was used to measure the degree of dyke influence on drainage alignment. Spatial comparison maps were prepared to identify segments of streams affected by dyke intrusions.

Analysis and Result

Results were interpreted in the context of regional tectonics, geomorphic evolution, and fluvial processes. Dyke-controlled deviations in stream direction, drainage texture, and basin form were evaluated. The findings were compared with similar basaltic terrain studies to draw broader geological implications.

The structural features of the Buray river basin dykes

The Buray River Basin is the second southernmost basin in the Nandurbar-Dhule research area. The river basin has a catchment area of 1101.39 km². There are 29 dykes in this region. Dykes are dispersed unevenly throughout the basin. The upper left corner of the map, rose diagram shows dykes alignment in the Buray river basin (Fig.1.2). The angles at which dykes strike in the Buray River basin range from 0 to 180 ° (Fig. 1.3). The basin's overall tendency of dyke swarms is indicated by the mean strike of dykes, which is 95 ° north.

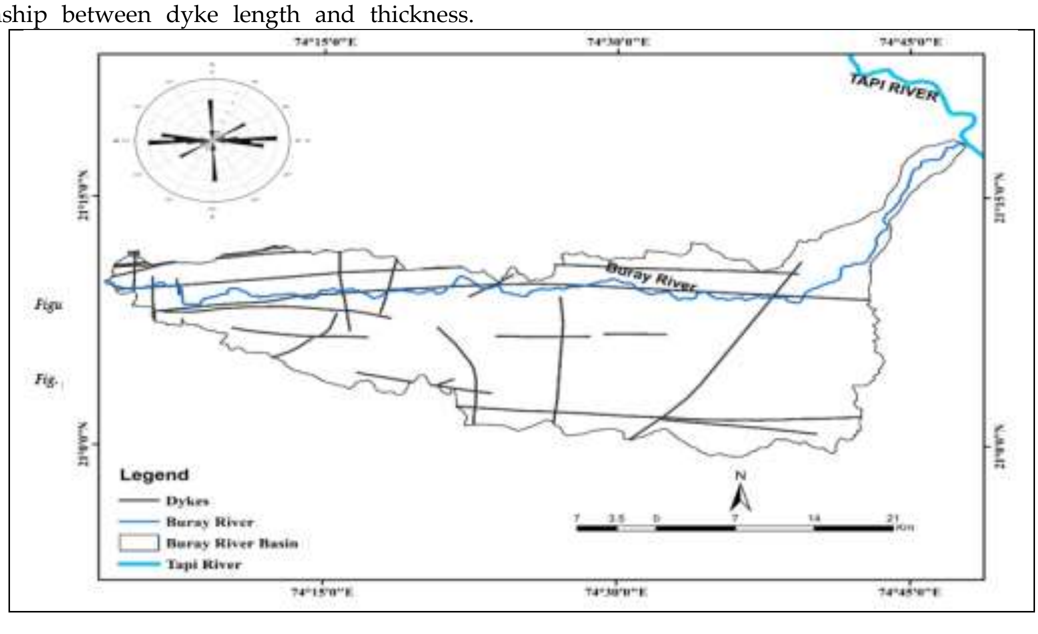


Fig. 1.2 Spatial distribution of dykes in the Buray river basin with the rose diagram of dyke's strikes.

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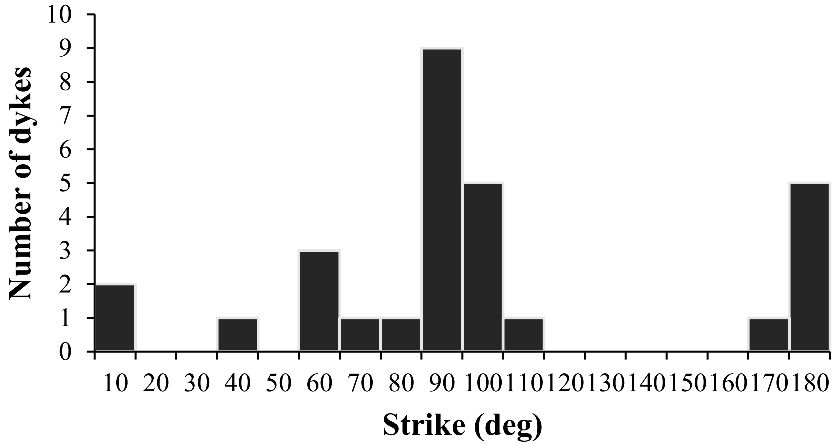

Fig. 1.3 Histogram showing strikes of dykes in the Buray river basin

Of the 29 dykes, 4 have ENE-WSW trends, 8 have N-S trends, and 17 have E-W strikes. The directions of crustal expansion during dyke development are shown by this variety in dyke trends.

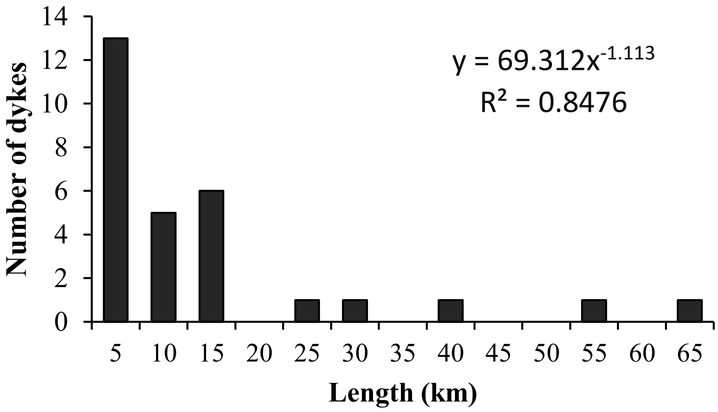

Fig. 1.4 Bargraph showing the length and number of dykes in the Buray river basin.

The Power Law equation depicts the relationship between length and number of dykes.. The power law equation is $y = 69.312x^{-1.113}$, and $R^2 = 0.8476$ is used to determine the relationship between the length and number of dykes (Fig.1.4). The lengths and numbers of dykes are inversely correlated, as indicated by the negative exponent -1.113. In the Buray River basin, there is a substantial inverse association between the number and length of dykes ($R^2 = 0.8476$). The Buray River Basin's dyke length and number exhibit a significant negative correlation, as indicated by $R^2 = 0.8476$. The E-W longer dykes have 63.74km, 50.80km, and 335.91km length extent in the basin. North-South oriented dykes have 14.08km, 8.80km and 6.17km length.

The Buray River basin dykes range in thickness/width from 5 meters to 55.30 meters. There are a total of 29 dykes scattered throughout the basin. A bar graph showing thickness vs dyke count is shown in Figure 1.5.

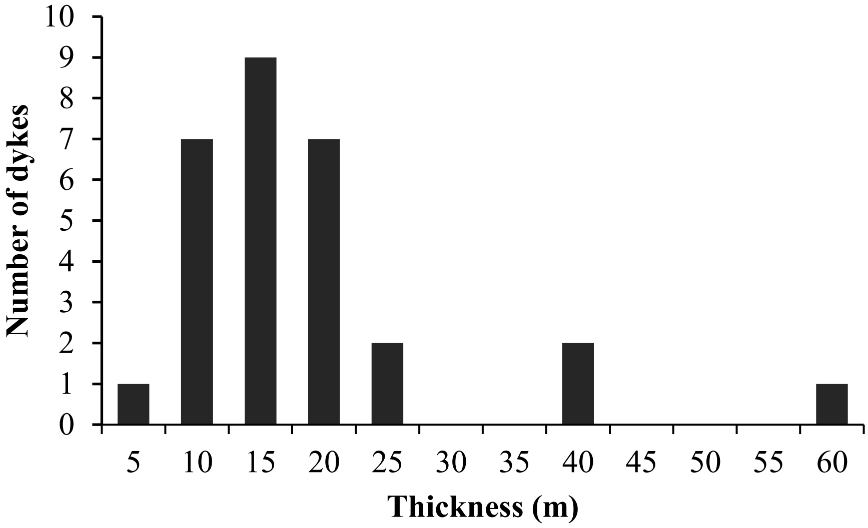

Fig. 1.5 Bargraph showing thickness and number of dykes in the Buray river basin

Nine dykes out of 29 fall into the 15 m thickness class, while seven falls into the 10 m and 20 m thickness classes. There are two dykes that are near 25 m thicker, two that are around 40 m wider, and one that is 59 m thick.

The length and strike of the Buray River basin dykes plot in a scatter diagram. That describes the dykes' length (x-axis) and dykes strike angle (y-axis). Most shorter-length dykes (less than 15 km) have strike angles that range from 10° to 110°, showing orientation diversity (Fig. 1.6). Longer dykes in the Buray River basin (over 50 km) are rare and tend to cluster along the mean strike (N95°), implying that longer dykes are more consistently aligned with the regional stress direction. North-South oriented dykes are shorter in length compared to E-W aligned dykes in the Buray River basin.

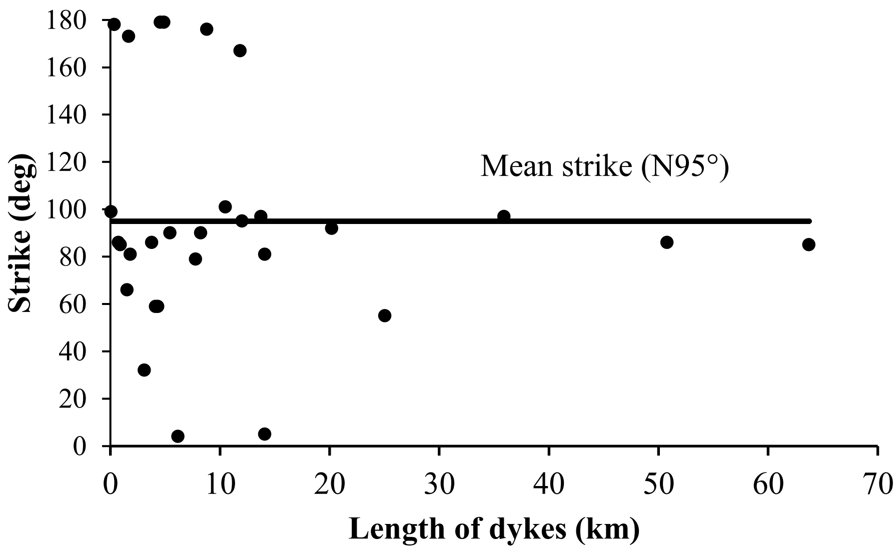

Fig 1.6 Scatter plot showing length vs. strike of dykes in the Buray river basin

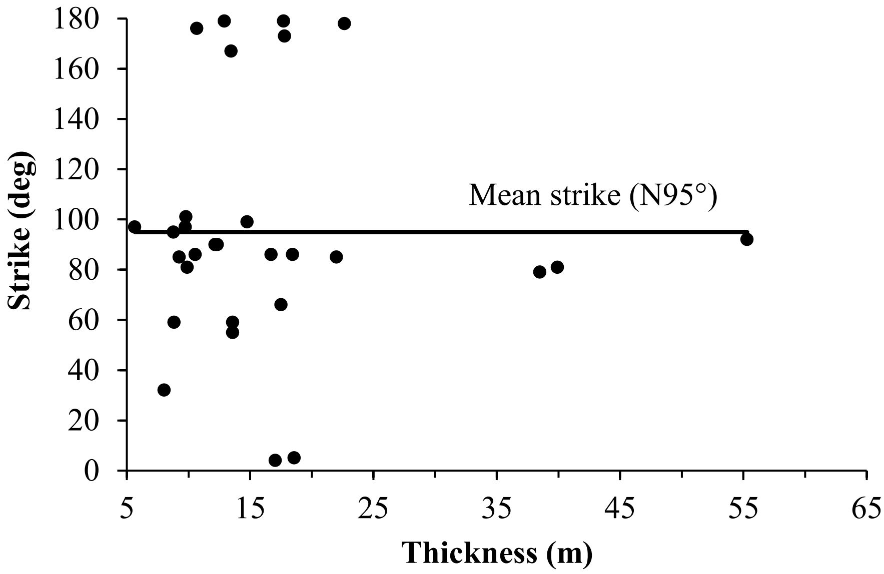

Fig.1.7 Scatter plot showing strike vs. thickness of dykes in the Buray river basin

The collecting of strike angles around mean strike N95° shows a dominant tectonic stress direction during dyke emplacement, likely related to the regional stress regime in the Buray River basin. The mean strike angle of dykes is N95°. The basin's thicker dykes are oriented E-W. Within a basin, dykes with higher and lower-degree strikes are narrower. The maximum thickness of dykes is 55.30m and the lowest thickness is 5m. The mean thickness of dyke is 16.77 m. (Fig. 1.7)

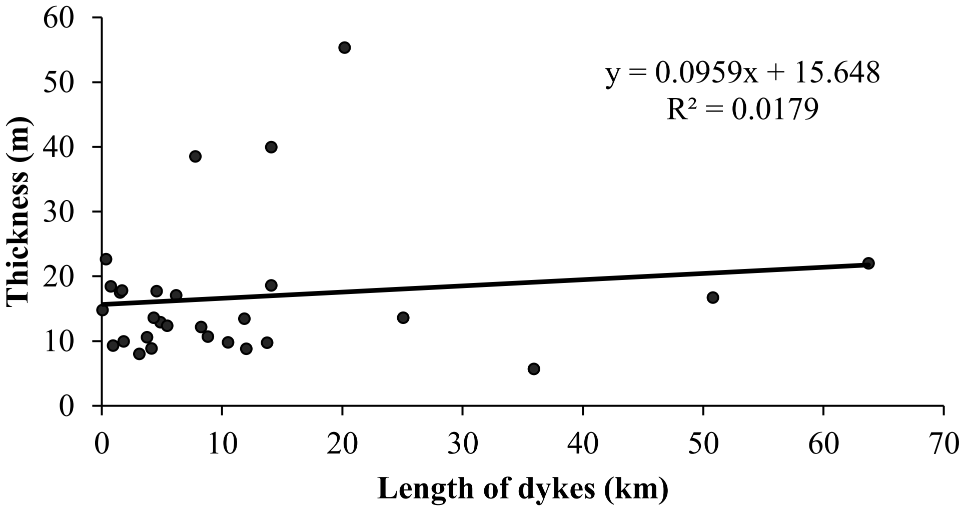

Fig. 1.8 Relationship of length and thickness of dykes in the Buray river basin

The relationship of Buray river basin dykes length and thickness is computed using a linear regression model. The equation $y= 0.0959x+$ 15.648 $R^2 = 0.0179$ is a linear regression model that describes the relationship between dyke length and thickness in the Buray river basin (Fig.1.8).

Each-unit increase in length of dykes (x), thickness of dykes (y) increases by nearly 0.0959 units. This relation displays the rate of change in dyke thickness (y) to the length of dykes (x). When the length of dyke, x=0, the predicted value of thickness (y) is 15.648. This is the baseline value of thickness (y) when there is no contribution from length of dykes (x). The R^2 value is the coefficient of determination of the dyke length and thickness two variables... The coefficient of determination of the dyke length and thickness in the Buray River basin R^2 is 0.0179. The coefficient of determination specifies that changes in the length of dykes (x) account for around 1.79% of the variability in thickness of dykes (y). The low R^2 value (0. 0179) indicates a very weak linear relationship between dyke length (x) and thickness (y). The mean aspect ratio of a dyke in the Buray River basin is 880:1. The basin's minimum aspect ratio is 4:1, while its maximum is 6345:1. The standard deviation of aspect ratio for the 29 dykes is 1284.The basin's 29 dykes have a combined length of 340.43 kilometers The basin's dyke density is 0.31 km/km^2.

Catchment morphometrics of the Buray River basin

The Buray River has occupied 1101.39 km^2 area of the Nandurbar-Dhule dyke swarm. It flows 99.02 km long distance from the origin at 700 m on the eastern slope of the Western Ghat (Fig.1.9) . This river confluence with the Tapi River is located in Sulvade village at a level 139 meters asl. The Pan, Sevri, Londa, Shama, Kasai, and Patli are right bank sub-tributaries of the Buray River. On the left bank of Buray, there are no major sub- tributaries. Its stream network is of the seventh order. In the drainage basin region, there are 3888 streams spread out geographically, together with 29 dykes and linear ridges. The river's streams have an average length of 9.15 km, with a combined total length of 3193.42 km (Table 1.1). In the Buray River, the average bifurcation ratio is 3.91. A mean bifurcation ratio of 3.91 indicates a rather stable structure. (Table 1.3)

The Buray River has a Rho coefficient value of 0.50. The basin's average stream frequency is 3.25, meaning that there are 3.25 streams per km^2. This implies a drainage system with a low density. This basin's drainage intensity is 1.22, indicating moderate drainage development. A DI of 1.22 specifies moderate runoff potential. The drainage texture value for the Buray River is 16.62, which measures the roughness or coarseness of a basin's drainage network. It signifies that the basin has an extremely high drainage texture. The Buray River’s texture ratio (Dt) is 10.24. It indicates a fine drainage texture. The basin likely has high stream density and frequent stream channels, reflecting high surface runoff and steep slopes.

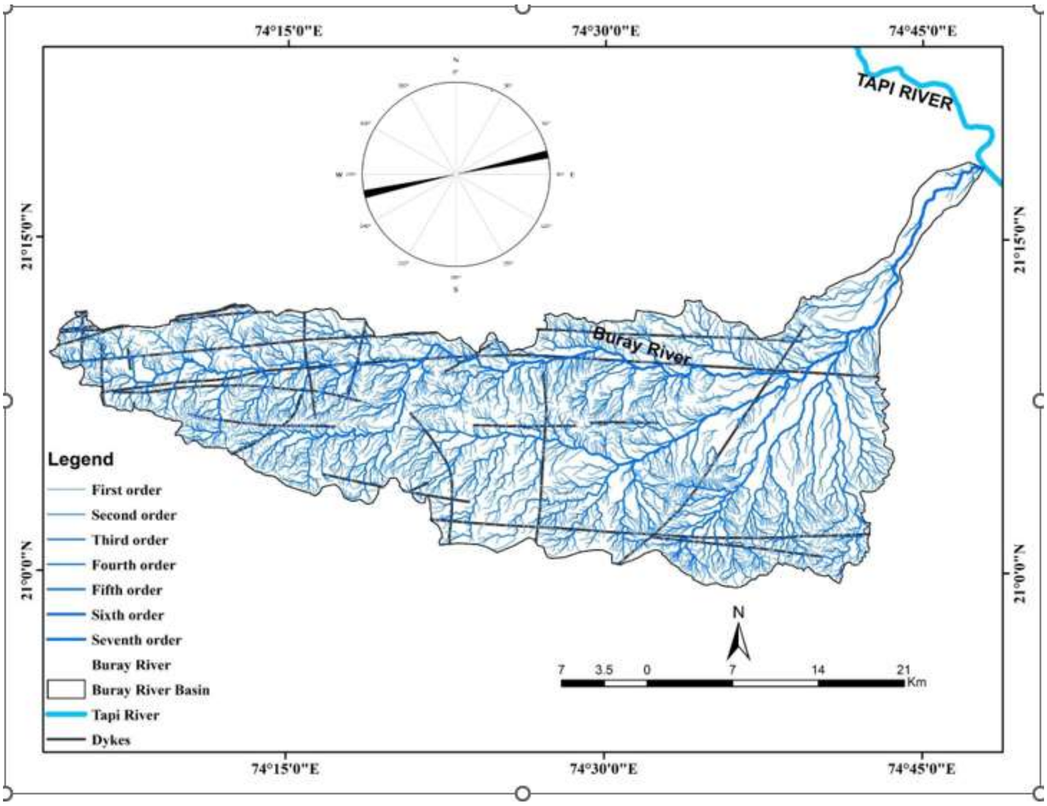

Fig.1.9 Stream networks-dykes map of the Buray river basin with rose diagram of river strike.

The length of overland flow (Lg) in the Buray River basin is 170 meters, indicating that water flows over the surface for a short distance before entering a stream or channel. A 0.17-kilometer overland flow in the Buray river basin suggests an extensive drainage network and quick surface runoff. The basin's Channel Maintenance Constant is 0.34. The basin’s form factor of 0.18 implies an elongated basin, which has a substantially longer length relative to its breadth.

The Buray River basin has a low elongation ratio of 0.48, suggesting its elongated shape rather than round. Low elongation ratios are frequently associated with basins in steep or tectonically active areas. The Buray River has a relative relief (Rr) value of 0.58, indicating fairly dissected terrain, similar to basins in hilly and upland parts of the Deccan Plateau. The Buray River basin has a relief

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of 642 meters, with the highest elevation being 781 meters and the lowest being 139 meters. The Buray River has a basin relief of 642 meters, indicating a dissected and rough drainage basin with substantial elevation changes. The basin's rugged terrain, including dykes and hills, may lead to rapid runoff and erosion. The relief ratio of 0.0083 for the basin is regarded as being comparatively low. This implies that the basin slopes gently overall. This basin has low-gradient streams, where water flows more slowly, and there is less energy for erosion and sediment transport.

The Buray River basin has a Dissection Index (DI) of 0.81, indicating a highly fragmented and rugged environment with extensive vertical erosion. The basin has advanced in its geomorphic cycle, demonstrating traits characteristic of mature or late mature stages, such as steep slopes and a well-developed drainage network. The Buray River basin has a Ruggedness Number of 1.68, which indicates relatively rugged terrain. This indicates that the basin has significant relief and a relatively dense drainage network. The Buray River basin has a hypsometric integral (HI) of 0.48, indicating a late young to early mature stage of geomorphic evolution. The value spans between very rough (youthful) and gently eroded (mature) basins.

Table 1.1 Buray River Basin Morphometry

Aspect	Parameters	Buray	Aspect	Parameters	Buray	Aspect	Parameters	Buray
Linear	River Stream Length (Km)	99.02	Areal	Stream Frequency (Fs)	3.53	Relief	Basin Relief (Bh)	642
	Basin Length (Km)	77.8		Area (A)	1101.39		Relative Relief (Rr)	0.58
	Valley Length (Km)	82.88		Drainage Density (Dd)	2.9		Relief Ratio (Rh)	0.0083
	Perimeter	233.98		Drainage Texture (Dt)	16.62		Maximum Elevation (H)	781
	Stream Order (U)	7		Texture Ratio	10.24		Dissection Index (D.I)	0.81
	Stream Number (Nu)	3888		Drainage Intensity (Di)	1.22		Minimum Elevation (H)	139
	Stream Length (Lu)	3193.42		Infiltration Number (If)	10.24		Ruggedness Number (Rn)	1.68
	Stream Length Ratio (RL)(MEAN)	9.15		Length Of Overland Flow (Lo)	0.17		Hypsometric Integral (HI)	0.48
	Mean Bifurcation Ratio (Rbm)	3.91		Constant Of Channel Maintenance (Ccm)	0.34			
	Si=Cl/Vl	1.19		Form Factor	0.18			
	Dyke Impact Si Index	2.79		Circulatory Ratio (Rc)	0.25			
	Rho Coefficient	0.5		Elongation Ratio (Re)	0.48			

Table 1.2 Stream number and stream length of Buray River basin

Basin	Stream Number (Nμ∑)								Stream Length (Lμ)							
	1st	2nd	3rd	4th	5th	6th	7th	∑Nμ	1st	2nd	3rd	4th	5th	6th	7th	∑Lμ
Buray	2941	703	185	47	8	3	1	**3888**	1865.5	646.7	348.6	162	87.1	55.9	27.6	**3193.4**

Table 1.3 Mean stream length and bifurcation ratio of Buray River basin

Basin	Mean Stream Length (Km)								Bifurcation Ratio (Rbm)						
	1st	2nd	3rd	4th	5th	6th	7th	∑Nμ	1st/2nd	2nd/3rd	3rd/4th	4th/5th	5th/6th	6th/7th	Rbm
Buray	0.63	0.92	1.88	3.45	10.89	18.63	27.61	**9.15**	4.18	3.8	3.94	5.88	2.67	3	**3.91**

Table 1.4 Stream length ratio of Buray River basin

Basin	STREAM LENGTH RATIO					
	$2^{nd}/1^{st}$	$3^{rd}/2^{nd}$	$4^{th}/3^{rd}$	$5^{th}/4^{th}$	$6^{th}/5^{th}$	$7^{th}/6^{th}$
Buray	0.35	0.54	0.46	0.54	0.64	0.5

Summary and Conclusion

The Buray River basin exhibits a complex interplay between structural features and geomorphology, primarily driven by the presence of 29 basaltic dykes. These dykes show significant variation in orientation and geometry, with a dominant E–W trend aligned around a mean strike of N95°, indicating a prevailing regional stress regime during emplacement. Power law relationships confirm that shorter dykes are more frequent, while longer dykes show consistent alignment with tectonic directions. The weak relationship between length and thickness suggests independent controls on dyke propagation and magma viscosity.

Morphometric analysis of the Buray basin reveals a seventh-order drainage network, moderate drainage density, high drainage texture, elongated basin form, and a rugged topographic surface. The dissection index and hypsometric integral indicate a youthful to mature geomorphic stage. Dyke intrusions have significantly influenced drainage orientation, stream frequency, overland flow, and channel development. Overall, the study demonstrates that dyke swarms act as structural barriers and conduits influencing drainage evolution, sediment pathways, and landscape development in the Deccan basalt region.

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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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