Morphometric Indication of Dykes Network Control on Drainage Development in the Amaravati River Basin, Northern Maharashtra

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Abstract

Drainage basin development in hard rock and basaltic terrains is strongly directed by subsurface structural elements, particularly dyke intrusions, yet the quantitative assessment of their influence on drainage organization and geomorphic development remains inadequate in many parts of the Deccan Volcanic Province. The Amaravati River Basin, situated within the Nandurbar–Dhule dyke swarm region of North Maharashtra, represents a structurally complex landscape where drainage patterns appear to be significantly controlled by dyke-induced lineaments. The dominant problem addressed in this study is to evaluate how dyke networks impact drainage morphology, basin geometry, and geomorphic maturity through systematic morphometric analysis. The Amaravati River Basin covers an area of 760.47 km² and contains 64 mapped dykes with a cumulative length of 569.07 km, resulting in a dyke density of 0.75 km/km². The basin exhibits a sixth-order drainage network comprising 2448 stream segments with a total stream length of 2131 km. The methodology integrates remote sensing, GIS-based spatial analysis, and quantitative morphometric techniques. Drainage networks were delineated from topographic maps and digital elevation models and classified using the Strahler stream ordering system. Dyke attributes—including strike, length, thickness, density, and aspect ratio—were analyzed using rose diagrams, histograms, scatter plots, and regression models to understand structural trends and emplacement characteristics..

The results indicate a distinct structural control of dyke systems on drainage morphology. Dyke orientation analysis reveals a dominant East–West to ENE–WSW trend, with a mean strike of N82°, reflecting a consistent regional stress regime during dyke emplacement. Morphometric indices reveal a moderately to highly dissected basin, with a bifurcation ratio of 4.57, drainage density of 2.8 km/km², and drainage intensity of 1.15, indicating structurally guided drainage development. Basin shape parameters—form factor (0.40), elongation ratio (0.71), and circularity ratio (0.36)—suggest an elongated basin configuration influenced by dyke-controlled topography. Relief parameters, including a ruggedness number of 1.49, dissection index of 0.81, and hypsometric integral of 0.47, indicate a late youthful to early mature stage of geomorphic evolution. The study concludes that dyke networks show a leading role in directing stream orientation, basin geometry, and geomorphic development in the Amaravati River Basin, emphasizing the necessity of integrating structural analysis with morphometric evaluation for understanding drainage evolution in dyke swarm terrains.

Keywords: *Amaravati River Basin, Deccan Volcanic Province, Drainage Morphometry, Dyke networks, GIS-based analysis, River basin analysis, Structural control*

Introduction

Drainage basin morphology is the outcome of complex interactions among lithology, tectonic structures, climate, and geomorphic processes. In hard rock and volcanic terrains, subsurface structural elements such as faults, joints, fractures, and dyke intrusions exert a dominant control on drainage orientation, basin geometry, and landscape evolution (Zernitz, 1932; Howard, 1967; Nag and Chakraborty, 2003). Mafic dyke swarms, in particular, represent major tectonic-magmatic features that influence surface processes by acting either as zones of structural weakness or as resistant barriers to erosion, thereby guiding stream alignment and basin development (Delaney et al., 1986; Powar, 1981; Sheth et al., 2009). The Deccan Volcanic Province (DVP) located in western India contains some of the largest flood basalt formations globally and is marked by numerous extensive dyke swarms that developed under varying regional stress conditions (Deshmukh and Sehgal, 1988; Ray et al., 2007).

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Among these, the Nandurbar–Dhule dyke swarm stands out as a significant structural feature within the DVP, noted for its dense network of dyke intrusions predominantly oriented from East to West (Bondre et al., 2006; Babar et al., 2017). Previous studies have emphasized the role of tectonics and structural fabrics in influencing drainage evolution across the Deccan region (Kale and Gupta, 2001; Kale et al., 2014). However, basin-scale quantitative assessments linking dyke attributes to drainage morphometry remain limited.

Morphometric analysis has long been recognized as an effective quantitative tool for understanding drainage basin characteristics, tectonic influence, and stages of geomorphic evolution (Horton, 1945; Strahler, 1964; Davis, 1899). Parameters such as bifurcation ratio, drainage density, stream frequency, basin shape indices, relief measures, and hypsometric integrals provide critical insights into drainage network development and landscape maturity (Chorowicz et al., 1992; Font et al., 2010; Whipple et al., 2013). When integrated with structural analysis of dyke orientation, length, thickness, and density, morphometric evaluation becomes a robust framework for deciphering tectonic-geomorphic controls on river basins (Ericson et al., 2005; Hodgkinson et al., 2006). The present study aims to analyze the structural characteristics of dyke networks and assess their impact on drainage morphology and basin evolution in the Amaravati River Basin using GIS-based morphometric techniques.

Study Area

The study area lies on the Deccan Traps Region, which is a part of volcanic province located on the Deccan Plateau. The area of this research is Amaravati river basin. It is a part of the Narmada-Tapi giant dyke swarm. The basin is located within 21°09’52’’ to 21°24’ 36’’N latitude and 74°12’51’’to 74° 43’06’’E (Fig.1.1) longitude and covers 760.47 km^2 area. Geomorpholgically, the study area forms a part of the Tapi River Basin. The area is drained by Amaravati, as a left bank tributary of the Tapi River. This river is a rainfed river and dominantly rocky and usually dry during the dry season. The region being examined is characterized by a monsoon climate, where the majority of yearly precipitation occurs within the four monsoon months from June to September (Kale and Hire, 2004). Nandurbar receives an average annual rainfall of approximately 1000 mm, while Dhule records an annual total of around 540 mm.

Methodology

The study employs an integrated remote sensing, GIS 10.7.1, and quantitative morphometric approach to evaluate dyke control on drainage development in the Amaravati River Basin. Drainage networks were delineated from Survey of India topographic maps (46K/3, 46K/4, 46K/7, 46K/8, 46K/11, 46K/12, 1:50000) and Cartosat DEM and classified using the Strahler stream ordering system. Dyke mapping was carried out using satellite imagery interpretation, existing District Resource Maps of Nandurbar and Dhule (1:250000) and field-verified secondary data. Dyke attributes including strike, length, thickness, density, and aspect ratio were statistically analyzed using rose diagrams (GeoRose), histograms, scatter plots, and regression models. Linear, areal, and relief morphometric parameters—including bifurcation ratio, drainage density, stream frequency, drainage intensity, form factor, elongation ratio, circularity ratio, relative relief, ruggedness number, dissection index, and hypsometric integral—were calculated employing established geomorphological equations. Spatial relationships between dyke orientation and drainage alignment were examined within a GIS environment to assess tectonic-structural influence on basin morphology and geomorphic evolution under regional tectonic stress conditions.

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.

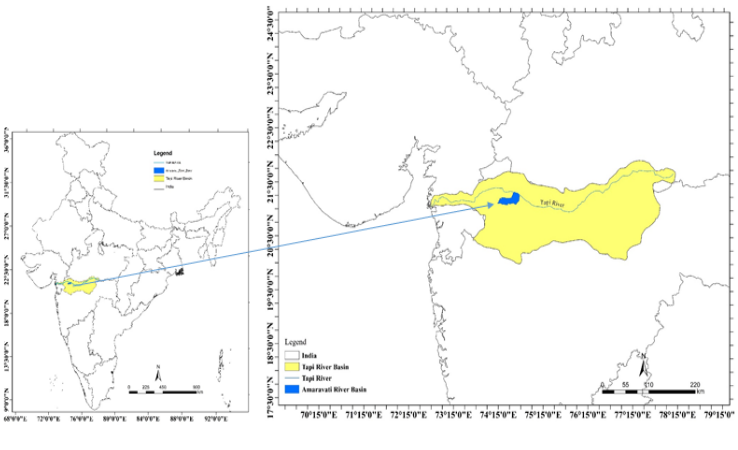

Figure 1.1 Location map of the Amaravati River basin

Analysis and Result

The structural features of the Amaravati river basin dykes

The Amaravati river basin has an entire catchment area of 760.47 km^2, accounting for including 64 dykes (Fig.1.2). Dykes are dispersed unevenly throughout the basin and ranges at angles between 0 and 180°. The average dyke strike is 82 °N, which indicates a generally aligned pattern of dyke swarms in the basin. Two dykes have ENE-WSW trends, 4 have N-S trends, and 59 have E-W strikes. This variation in dyke patterns reveals orientations of crustal extension during dyke formation.

The strike angles of dykes in this basin range from 10° to 180°. The basin's 46 dykes strike angles are concentrated from 80° to 100°. The basin's part of dyke swarms indicates the mean strike angle of dykes, which is 82° north. The lower and higher degree of strike show N-S directional strike angles of dykes.

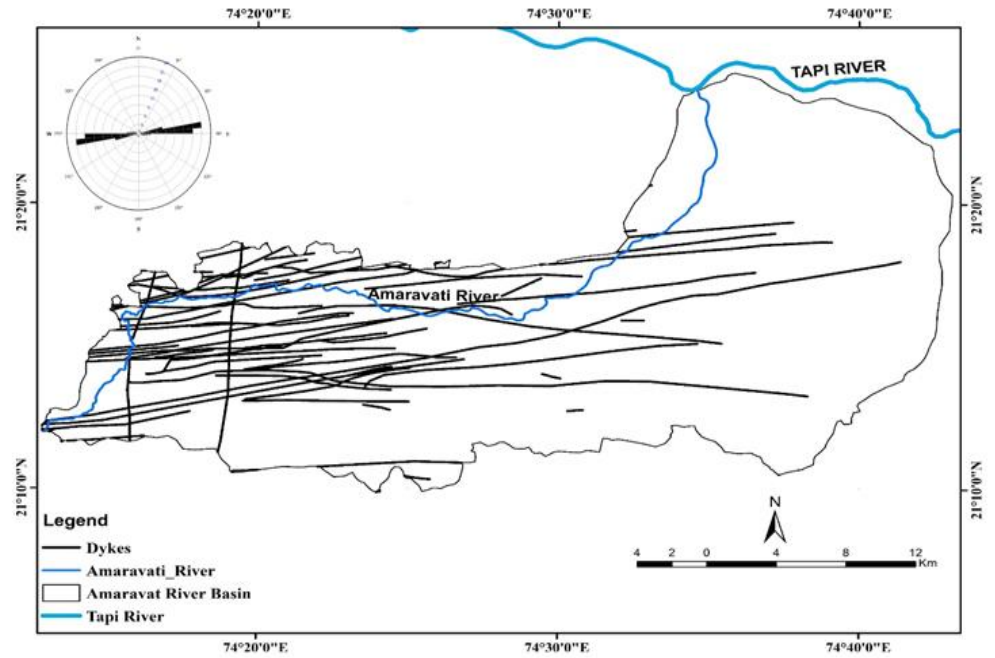

Figure 1.2.: Spatial distribution of dykes in the Amaravati river basin with the rose diagram of dyke's strikes.

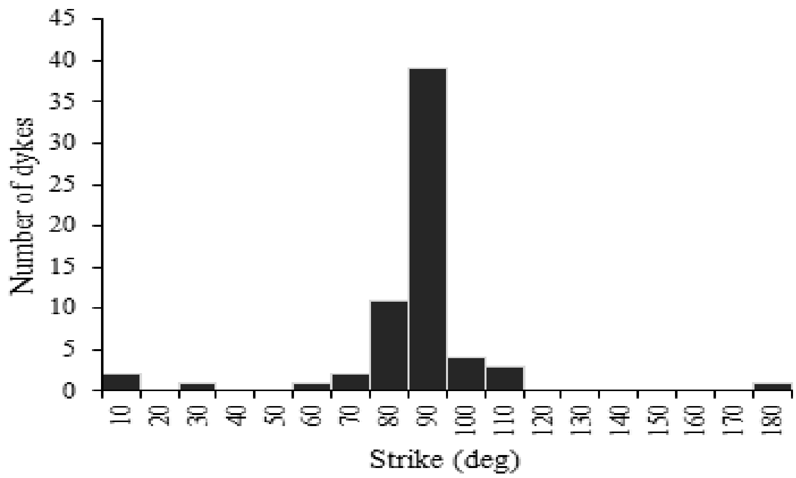

Figure 1.3: Histogram showing Strikes of dykes in the Amaravati river basin

The above Histogram indicates 64 dykes strike angles within the Amaravati river basin. Absence of dyke strike angles from 120° to 170° from north. That is an indication of no dykes aligned in the ESE- WNW direction (Fig. 1.3).

The inverse relationship in the length of dykes to their number is shown in the figure 1.4. This bargraph exhibits that shorter dykes have the largest frequency and longer dykes have a lower frequency. As dykes length increases, the number of dykes decreases.

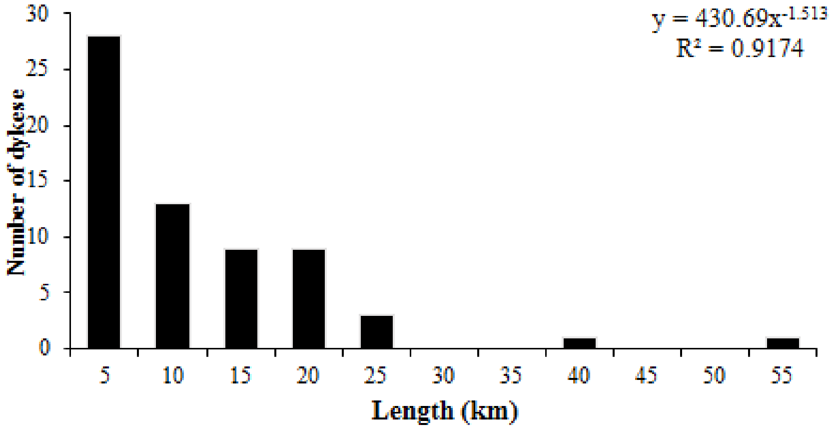

Figure 1.4: Bargraph showing the length and number of dykes in Amaravati river basin

The power law formula is used to calculate the relationship between the basin's dyke number and length. The power law equation shows y = 430.69x-1.513. The correlation coefficient computed value is R2 = 0.9174. The lengths and numbers of dykes are inversely correlated, as indicated by the negative exponent-1.513. In the Amaravati river basin, there is a significant inverse association between the number and length of dykes (R2 = 0.9174). This basin's dyke length and number exhibit a significant negative correlation, as indicated by R2 = 0.9174.

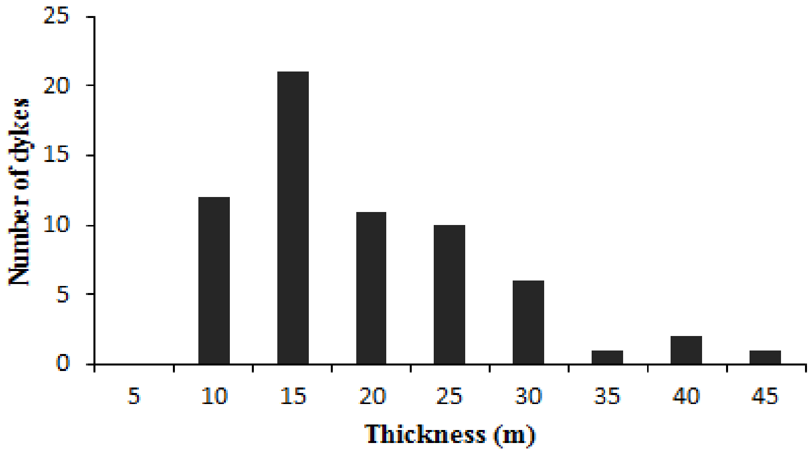

Figure 1.5: Bargraph showing thickness and number of Amaravati river basin dykes

The thickness of dykes in the Amaravati river basin ranges from 10 m to 45m, out of 64 dykes.12 dykes are 10m thick, 21 dykes are 15m,11 dykes are 20m, 10 dykes are 25m, 6 dykes are 30m, 2 dykes are 40m and one dyke is included in the 45m thicker class (Fig. 1.5).

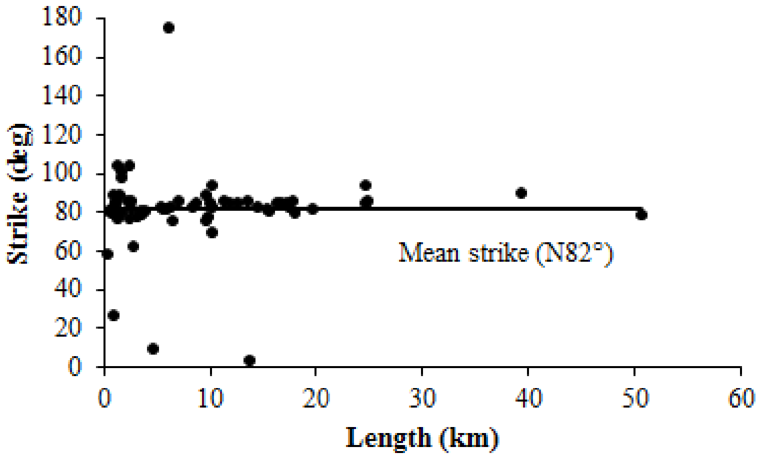

Figure 1.6: Scatter plot showing length vs. strike of Amaravati river basin dykes

The length and strike of the Amaravati river basin's dykes are shown in a scatter diagram (Fig. 1.6). That depicts the 20km long dykes are aligned in E-W direction. Few shorter dykes are located away from the mean strike angle. That shows dykes strike angles orientation diversity. Longer dyke in the Amaravati river basin (over 50 km) is rare and tends to cluster along the mean strike (N82°), implying that longer dyke is more consistently aligned with the regional stress direction.

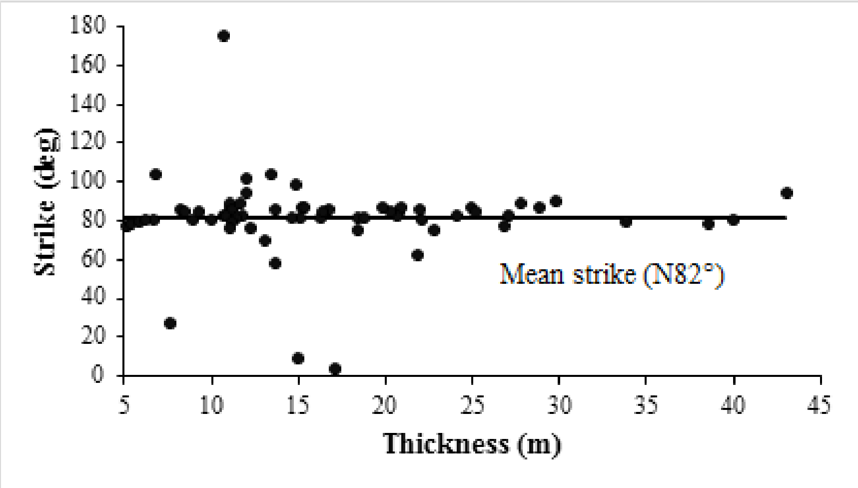

Figure 1.7: Scatter plot showing thickness vs. strike of Amaravati river basin dykes

The river basin's dykes' thickness (x-axis) and strike angle (y-axis, in degrees) are depicted in this scatter diagram (Fig. 1.7). Thickness ranges from around 5 m to 42.95 m, with the majority of data concentrated between 10 m and 30 m. The average thickness of dyke is 16.33 m. The mean strike angle of dykes is marked at N82°, indicating that most dykes are aligned nearly E-W. Few dykes are scattered at lower thickness values of 5m showing a wide range of strike angles, primarily between N28° and N105°.

The relationship among the length and thickness of the Amaravati river basin's dykes is computed and plotted on the scatter diagram (Fig.1.8). The 'X' axis shows the length of dykes and the 'Y' axis shows the thickness of dykes. The linear regression model depicts the relation of length and thickness of dykes.

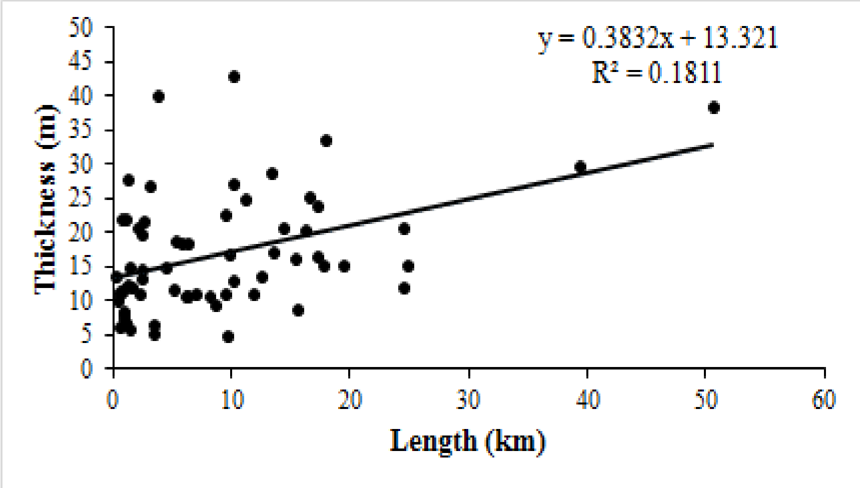

Figure 1.8: Relationship of length and thickness of Amaravati river basin dykes

The equation $y= 0.3832x+ 13.321$ is a linear regression model that describes the relationship between dyke length and thickness. Each-unit increase in length of dykes (x), thickness of dykes (y) increases by nearly 0.3832 units. This relation shows 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 13.321. 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 of two variables. The R^2 score indicates how effectively the linear model accounts for the variability in the data. The coefficient of determination of the dyke length and thickness in the Amaravati river basin's R^2 is 0.1811. The coefficient of determination indicates that changes in the length of dykes (x) account for around 18.11% of the variability in thickness of dykes (y). The low R^2 value (0.1708) indicates a weak linear relationship between dyke length (x) and thickness (y).

The Amaravati river basin has an average aspect ratio of 546:1. The major aspect ratio in the basin is 2046:1, while the minimum is 19:1. The standard deviation for the 64 dykes' aspect ratio is 500. The whole area of the Amaravati river basin is 760.47 km^2, with 64 dykes. The basin's 64 dykes extend a total of 569.07 kilometers. The density of dykes in the basin is 0.75 km/km^2.

Catchment morphometrics of the Amaravati River basin

The Amaravati is a left bank tributary of the Tapi River (Fig 1.9). The total area of basin is 760.47 km^2. It flows 59.75 km long distance from the origin at 620m on the eastern slope of the Western Ghat near Chhadvel Korde village. At Shendvade village, which is nearby 128 msl, it merges with the Tapi River. The Nandan, Nai, Gusardi, Bhogavati, Kanori and Madari are right bank sub- tributaries of the Amaravati River. The River has evolved a 6^{th} order stream network. The drainage basin region has 64 dykes and 2448 streams spread out spatially. The river's streams are 2131 km long overall, with a mean length of 8.95 km. Rho coefficient for this river is 0.4, and its bifurcation ratio is 4.57. The basin has a generally balanced capacity to store and release water. The stream frequency is 3.22. The DI value 1.15 shows moderate drainage intensity. This suggests that, relative to its size, the basin has a higher concentration of streams. A drainage texture of 14.99 suggests a highly dissected and possibly rugged terrain, with numerous small streams and rapid runoff. The texture ratio 9.02 suggests the moderate drainage system, with balanced runoff characteristics and a modest risk of erosion.

This basin has a length of overland flow value of 180 meters, indicating that water flows over the surface for a short distance before entering a stream or channel. 0.18 kilometer overland flow in the Amaravati river basin suggests an extensive drainage network and quick surface runoff. The basin's Constant of Channel Maintenance is 0.36. This basin is fairly elongated, as shown by its form factor (Ff) of 0.4. The basin is somewhat elongated, as indicated by its elongation ratio (Er) of 0.71, which causes a slow hydrological response and moderate flow during rainfall events. The value of the circularity ratio (Rc) for the basin is 0.36, shows long. A Relative Relief of 0.70 indicates that the basin has moderate to high elevation differences relative to its area, implying considerable roughness. The basin reaches a maximum elevation of 660 meters and a minimum of 128 meters. The basin relief of 532 meters, indicates a dissected and rough drainage basin with substantial elevation changes (Table 1.1).

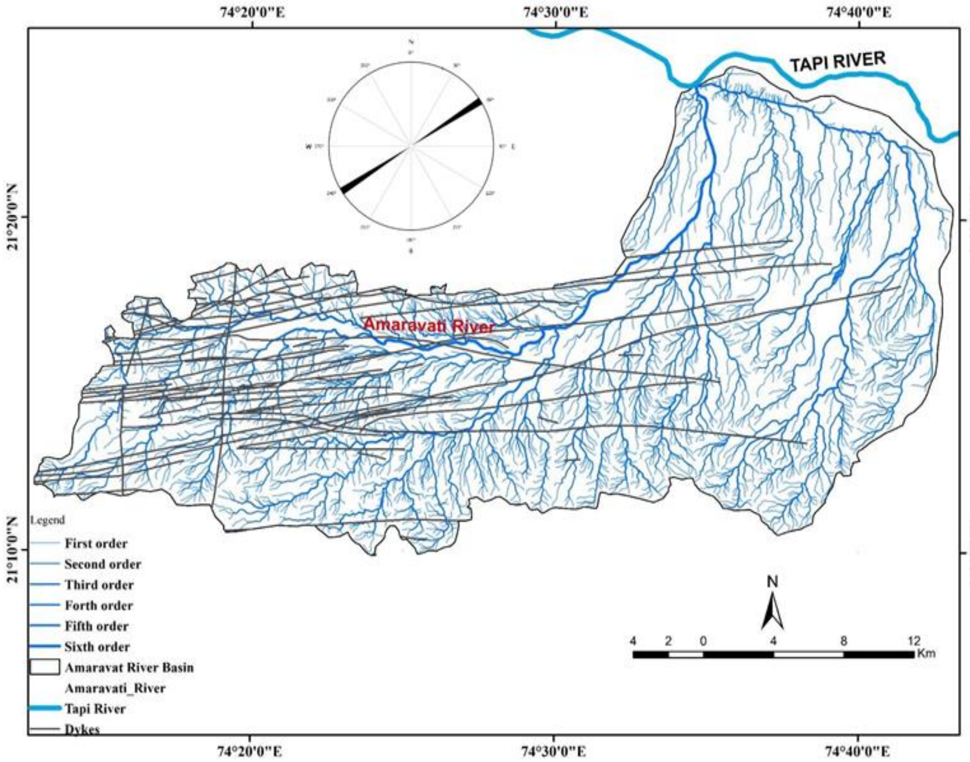

Figure 1.9 Stream networks and dykes map of the Amaravati river basin with rose diagram of river strike.

Table 1.1 Linear aspects of the Amaravati river basins in the Nandurbar-Dhule dyke swarm area

Aspect	Parameters	Amaravati	Aspect	Parameters	Amaravati	Aspect	Parameters	Amaravati
	River Stream Length (Km)	59.75		Stream Frequency (Fs)	3.22		Basin Relief (Bh)	532
	Basin Length (Km)	43.64		Area (A)	760.47		Relative Relief (Rr)	0.7
	Valley Length (Km)	52.41		Drainage Density (Dd)	2.8		Relief Ratio (Rh)	0.0122
	Perimeter	163.3		Drainage Texture (Dt)	14.99		Maximum Elevation (H)	660
	Stream Order (U)	6		Texture Ratio	9.02		Dissection Index (D.I)	0.81
	Stream Number (Nu)	2448		Drainage Intensity (Di)	1.15		Minimum Elevation (H)	128
Linear	Stream Length (Lu)	2131	Areal	Infiltration Number (If)	9.02	Relief	Ruggedness Number (Rn)	1.49
	Stream Length Ratio (RL)(MEAN)	8.95		Length Of Overland Flow (Lo)	0.18		Hypsometric Integral (HI)	0.47
	Mean Bifurcation Ratio (Rbm)	4.57		Constant Of Channel Maintenance (Ccm)	0.36			
	Si=Cl/Vl	1.14		Form Factor	0.4			
	Dyke Impact Si Index	2.28		Circulatory Ratio (Rc)	0.36			
	Rho Coefficient	0.4		Elongation Ratio (Re)	0.71			

Table 1.2 Stream number and stream length

Basin	Stream Number (Nµ∑)							Stream Length (Lµ)						
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**∑Nµ**	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**	**∑Lµ**
Amaravati	1872	436	106	27	6	1	2448	1180.4	437	238.9	167.4	76.5	30.9	2131

Table 1.3 Mean stream length and bifurcation ratio

Basin	Mean Stream Length (Km)							Bifurcation Ratio (Rbm)					
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**∑Nµ**	**1st/2nd**	**2nd/3rd**	**3rd/4th**	**4th/5th**	**5th/6th**	**Rbm**
Amaravati	0.63	1	2.25	6.2	12.74	30.88	8.95	4.29	4.11	3.93	4.5	6	4.57

Table 1.4 Stream length ratio of the drainage basins

Basin	STREAM LENGTH RATIO					
	2nd/1st	3rd/2nd	4th/3rd	5th/4th	6th/5th	7th/6th
Amaravati	0.37	0.55	0.7	0.46	0.4	0

The basin has a gentle gradient, according to the Relief Ratio value of 0.0122. This signifies that the basin does not have significant elevation fluctuations relative to its length. The 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. A Ruggedness Number (Rn) of 1.49 indicates a fairly rugged basin. The number shows that the basin has moderate to high terrain irregularity. The basin has a hypsometric integral (HI) of 0.47, indicating a late young to early mature stage of geomorphic evolution. The value spans between very rough (youthful) and gently eroded (mature) basins.

Summary and Conclusion

The present study evaluates the structural control of dyke networks on drainage morphology in the Amaravati River Basin, located within the Nandurbar–Dhule dyke swarm region of North Maharashtra. The basin covers 760.47 km² and contains 64 dykes with a total length of 569.07 km, indicating high structural density and tectonic influence. The drainage network is of sixth order, comprising 2448 stream segments and a total stream length of 2131 km, reflecting a well-developed fluvial system.

Dyke orientation analysis reveals a strong East–West to ENE–WSW alignment, with a mean strike of N82°, suggesting emplacement under a consistent regional stress regime. The inverse power-law relationship between dyke length and frequency ($R^2 = 0.92$) indicates pronounced structural segmentation, whereas the weak correlation between dyke length and thickness ($R^2 = 0.18$) implies that dyke thickness is largely independent of dyke length. These results reflect complex dyke emplacement dynamics within the Deccan Volcanic Province.

Morphometric parameters demonstrate significant structural influence on drainage development. A high bifurcation ratio (4.57) and moderate Rho coefficient (0.40) indicate structurally guided drainage branching with balanced hydrological response. Drainage density (2.8 km/km²) and stream frequency (3.22) suggest a dense drainage network with efficient runoff. Basin shape indices—form factor (0.40), elongation ratio (0.71), and circularity ratio (0.36)—confirm an elongated basin geometry constrained by dyke-controlled topography. Relief characteristics, including a basin relief of 532 m, ruggedness number of 1.49, and dissection index of 0.81, indicate a rugged and highly dissected terrain. The hypsometric integral value (0.47) suggests that the basin is in a late youthful to early mature stage of geomorphic evolution.

Overall, the study confirms that dyke networks play a central role in controlling drainage alignment, basin geometry, and landscape evolution in the Amaravati River Basin. The incorporation of dyke structural analysis with morphometric evaluation provides a strong framework for understanding tectonic-geomorphic processes in volcanic terrains and offers valuable insights for future geomorphological and watershed-based studies.

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Conflicts of interest

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

References

1. Babar, M. D., Kaplay, R. D., Mukherjee, S., & Kulkarni, P. S. (2017). Evidence of dyke deformation in the central Deccan Volcanic Province, Aurangabad, Maharashtra, India. Geological Society, London, Special Publications, 445(1), 337–353. https://doi.org/10.1144/SP445.13
2. Bhatt, S. C., Suresh, M., & Gupta, M. K. (2014). The structural influence on the drainage pattern of the upper-middle

Pahuj River basin and the role of remote sensing in watershed management within the Bundelkhand craton of central India. Journal of Multidisciplinary Scientific Research, 2(4), 9–14.

3. Bondre, N. R., Hart, W. K., & Sheth, H. C. (2006). An analysis of the geology and geochemistry associated with the Sangamner mafic dyke swarm in the western Deccan Volcanic Province of India: Insights into regional stratigraphy. The Journal of Geology, 114(2), 155–170. https://doi.org/10.1086/499570
4. Chorowicz, J., Ichoku, C., Riazanoff, S., Kim, Y.-J., & Cervelle, B. (1992). A unified algorithm for extracting automated drainage networks. Water Resources Research, 28(5), 1293–1302. https://doi.org/10.1029/92WR00097
5. Davis, W. M. (1899). The concept of the geographical cycle explored in detail.The Geographical Journal, 14, 481–504.
6. Delaney, P.T., Pollard,D.D., Ziony,J.I.& McKee,E.H.(1986). Investigating field relationships between dikes and joints to understand emplacement processes and perform paleostress analysis.Journal of Geophysical Research: Solid Earth,91(B5),4920-4938.http://doi.org/10...
7. Deshmukh,S.S.& Sehgal,M.N.(1988). Overview of mafic dyke swarms present in Madhya Pradesh and Maharashtra's Deccan Volcanic Province.Memoirs of the Geological Society of India,10:323-340.
8. Ericson,K.Migon,P.& Olvmo,M.(2005). Analysis of fractures and drainage systems in granite mountainous regions: A case study from Sierra Nevada USA.Geomorphology64(1-2):97–116.doi:10...
9. Font,M.Amorese,D.& Lagarde,J.L.(2010) .Utilization of DEM and GIS for stream gradient index analysis to assess tectonic influences: Study from Normandy intraplate region,NW France.Geomorphology119(3-4):172–180.doi:10...
10. Hodgkinson,J.H.McLoughlin,S.& Cox,M.(2006) .Exploring how geological fabric and scale affect drainage pattern analysis in a metamorphic terrain catchment located in southeast Queensland Australia.Geomorphology81(3–4):394–407.doi:10...
11. Howard,A.D.(1967) .A summary on drainage analysis as it relates to geological interpretation.The American Association of Petroleum Geologists Bulletin51:2246–2259.
12. Kale,V.S.& Gupta,A.(2001) .An introductory text on geomorphology.Orion Longman.
13. Kale,V.S.Sengupta,S.Achyuthan,H.& Jaiswal,M.K.(2014) .Investigating tectonic influences on Kaveri River's drainage within Peninsular India's cratonic regions.Geomorphology227:153–165.doi:10...
14. Nag,S.K.& Chakraborty,S.(2003) .Examining how rock types and structural formations influence drainage network development in hard rock areas.Journal of Indian Society Remote Sensing31(1):25–35.doi:10...
15. Powar,K.B.(1981) .Analysis Of lineament fabric alongside dyke patterns found in western Deccan Volcanic Province.In Deccan volcanism & related basalt provinces globally(pp77--89).
16. Ray,R.Sheth,H.C& Mallik,J.(2007) .Investigating structure& emplacements regarding Nandurbar-Dhule mafic dykes located amidst Deccan Traps;India.Bulletin Of Volcanology69 :537 –551.doi
17. Schick,A.P.(1965) .Analyzing how lineative factors impact stream courses over uniform bedrock conditions.International Association Scientific Hydrology Bulletin ,10(2):5 –11
18. Sheth,H.C.Ray.J.S.Ray,R.Vanderkluysen,L.Mahoney,J.J.Kumar,A.Shukla,A.D.Das,P.Adhikari,S.Jana,B.(2009).Exploration into geology&geochemistry involving Pachmarhi dykes&sills situated within Satpura Gondwana Basin;central India.Contributions To Mineralogy&Petrology158 (3):357 –380.doi
19. Strahler,A.N.(1964) Quantitative geomorphologic examination concerning both channels&drainage basins.In V.T.Chow(ed.), Handbook Of Applied Hydrology(pp4 -39--76).McGraw-Hill
20. Whipple,K.X.DiBiase,R.A& Crosby,B.T..Bedrock rivers discussed;in J.F.Shroder(ed.),Treatise On Geomorphology(vol9 pp550—573);Elsevier doi:
21. Zernitz,E.R..Drainage patterns analyzed along significance lines.The Journal Of Geology40 :498 –521