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Assessing the Influence of Dykes on the Drainage Network of the Shivan River in North Maharashtra

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Abstract

The prominent linear dyke ridges outcropped in the Narmada-Tapi dykes' swarm represent an intrusion in the Deccan Traps. Understanding the relationship among the underlying geological structures, the strike of the dykes, and the channel patterns is essential. Dykes act as obstructions to stream flow, causing diversions, and their geometry and patterns significantly impact the rivers and streams that drain and cross the dyke swarm zone. For this study, Google Earth images, LISS III images, and Cartosat DEM were used to delineate the Shivan basin and extract dyke features. The Shivan River basin is a sixth-order drainage system that reflects superimposed drainage systems within the Tapi dyke swarm zone. About 65% (169 km^2) of its area is controlled by dyke orientation. The dyke ridges align predominantly in an East-West (E-W) direction, a pattern mainly followed by lower-order streams, which have developed an insequent, transverse drainage network within the dyke swarm zone. In the lower parts of the Shivan basin, where the number of dykes decreases, the drainage network follows the general slope and is oriented in a North-South direction. The Shivan River and its tributaries have partially adjusted to the dyke orientation, resulting in a transverse drainage pattern in areas characterized by parallel dyke ridges.

Keywords

Deccan Traps, Narmada-Tapi Dyke Swarm, Google Earth, LISS III, Cartosat DEM

1. Introduction

The relationship between lithology and structure on one hand and the drainage network pattern on the other has long been established [1]-[3]. Several studies in the past have shown that the drainage network pattern and river channel morphology reflect the integration of multiple processes and forces [4]. The litho-structural control on drainage network pattern is strongly evident in an area of complex structure and diverse lithology. Alignment of drainage lines, sharp bends in river courses, obtuse junction angles and breaks in the river profiles are some of the geomorphic features that could be detected visually on maps and images and could be related to joints, fractures, faults, dykes and lithological boundaries. However, in areas of uniform or homogenous lithology, the control of structure is less evident. Therefore, the assessment of the control of lithology and structure in such areas is often subjective and challenging [2]. Dykes are discordant igneous bodies of more or less tabular shape and exhibit a cross-cutting relationship with the country rocks. They occur commonly in the form of group called as swarm. When molten magma flows upward through near-vertical cracks (faults or joints) toward the surface and cools, dykes are formed. Dykes are sheet-like igneous intrusions that cut across any layers in the rock they intrude.

The objective of this paper is to explore the drainage-dyke relationship and to establish the nature and extent of the control of the dykes on the drainage network properties and orientation of streams.

The large mafic dyke swarm around Nandurbar is mapped within basin area of 262 km^2. The total length of Sivan River is 59.33 km. There are total of 37 dykes exposed ranging from <1 km to 14 km in length. The intruded dykes are of highly weathered basalt flow of compound pahoehoe. Total length of dykes is 201.58 km. with density of 0.76 km per sq. km. Sinuosity index of Shivan River is 1.21, which indicates sinuous river characteristics. The orientation of lower and middle order tributary streams is controlled by the dyke properties formed by genetic streams evolution in the basin. The response of the drainage network to dyke control is inversely related to the stream order network. The dykes have a greater control on lower order stream than the higher order stream attributes. Diversion of streams, bends, insequent, subsequent and resequent streams are developed in the river basin. The dyke ridges play an important role as water divides in the drainage basin, which directs shape and size of drainage basin to some extent.

The present study is significant in understanding the geological setting and the structural deformation caused by lineaments, which would help to understand the influence of lineaments on the alignment of the drainage network. This is also important for improving the understanding of the level of structural control on landscape evolution in general and stream alignment in particular. Such studies also disclose the level of changes that have occurred in the drainage network due to structural deformation caused by dykes [3].

2. Study Area

The area under investigation covers Shivan River basin which forms part of east-west trending Tapi gaint swarm. The area extends from 21˚10'49.3''N to

21˚30'51.3''N latitudes and 74˚05'23.0''E to 74˚16'15.3''E longitudes (**Figure 1**). It originates on the northern slope of the Sahyadri mountain range at an elevation of 706 M above mean sea level and joins to the Tapi River at 100 M above mean sea level. The Shivan River flows from south-west to north-west for 59.33 KM. It is a left bank tributary of the Tapi River. The basin relief is 606 m. It is crossing through prominent linear dyke ridges. The south eastern boundary of the basin is marked by Western Ghats with steep escarpment towards west.

The southern region of the basin is occupied by plateau extent. North face of the plateau is characterized by valleys of northward flowing streams. Plateaus as well as valleys are intruded by east-west running dyke ridges. The slope of the Shivan basin ranges from >70˚ to ~5˚ from source to the confluence with the Tapi River. The basin relief is generally steep to gentle from south to north.

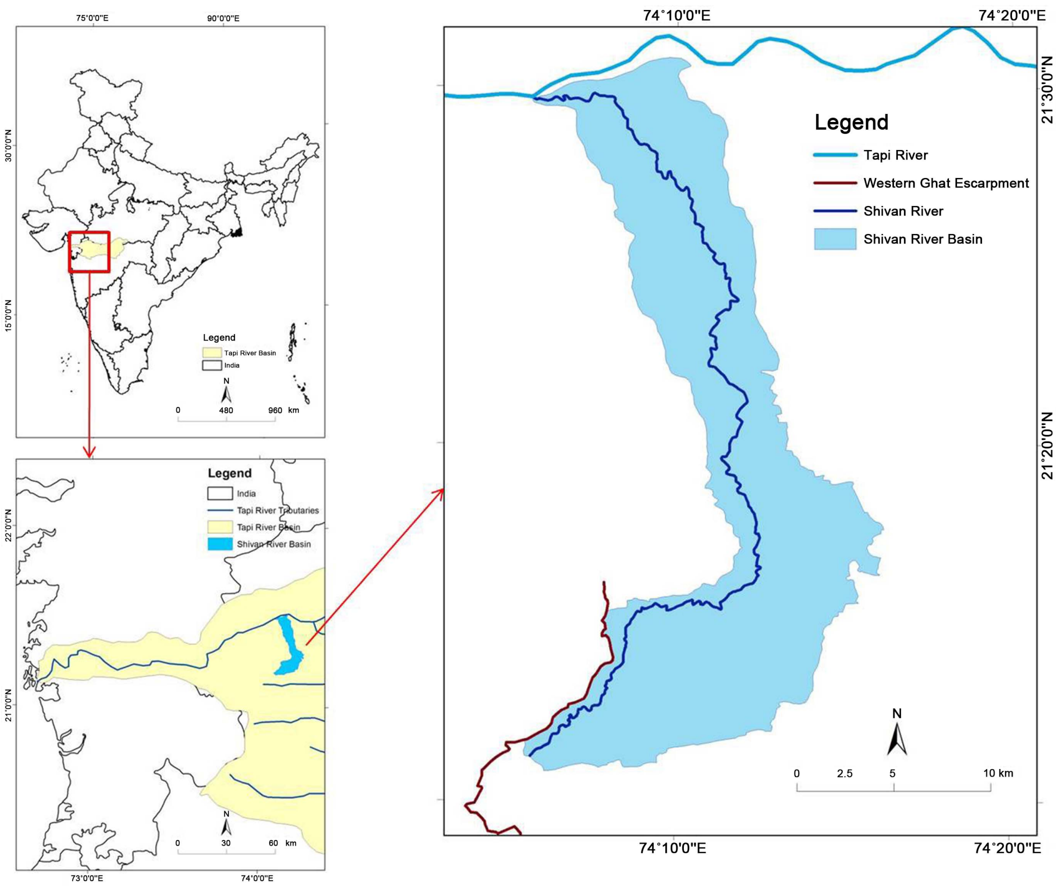

Figure 1. Location map of the study area.

Climate of the entire basin is controlled by SW monsoon. The basin experiences average annual rainfall from >700 mm in the source region to ~590 mm in the basin [5].

3. Data and Methods

This study is based on two different datasets. The first set includes the information about the attributes of the dykes and the second dataset consists of the data regarding drainage basin and network parameters.

3.1. Dyke Attributes

The dykes in the study area are mapped and digitized from Google Earth and IRS LISS-III images in ArcGIS. The Carto DEM (30 m resolution) was used to identify and map the dykes in the study area. A Survey of India map of Nandurbar Quadrangle 46 K (1:250,000) of Gujarat, Madhya Pradesh and Maharashtra was used to verify dyke orientation. District resource maps and geological maps of the Nandurbar and Dhule Districts, prepared by Geological Survey of India are used to identify and validate dykes. Elongated contours and form lines are helpful to trace dyke ridges and that verified on the hill shaded DEM.

The digitized maps are used to estimate various attributes of the dykes, such as length, orientation and density. Rose diagrams are prepared in the Rockworks 16 software to draw the trends of the dykes and streams orientations to compare them to understand drainage orientation.

3.2. Catchment Morphometrics

The drainage basin morphometric data is obtained from Survey of India (SOI) topographical maps 46-K/2, K/3, K/4 and K/7 (Scale is 1:50,000), and 30-m Cartosat Digital Elevation Model (DEM). The drainage network is manually digitized and the basin is demarcated in ArcGIS using SOI toposheets. Quantitative analysis of the drainage pattern obtained from SOI toposheets. The derived morphometric parameters included – drainage basin area, stream order, basin relief, slopes, sinuosity index, etc.

The scanned maps of SOI toposheets and quadrangle maps are used and georeferenced by using ArcGIS 9.3 software. The present study is based on the analysis of 30-m Cartosat-DEM data. Linear ridges of several kilometers of length are clearly extracted from the Cartosat-DEM. In many cases the dykes do not form continuous ridges, but can be identified by strongly aligned spot heights over long distances on the topographic maps.

Field work is carried out to investigate some of the plotted dyke to understand their morphological attributes. Some of dykes are very clearly visible on the surface but some of the dykes are less than 5 m height. The Shivan River channel reaches are visited near Biladi, Nandurbar, Khamgaon and Ashte settlements. Dykes' length and width and density are measured and their orientation is also identified.

3.3. Dykes and Superimposed Drainage Development

The drainage of the Shivan River system is not uniformly distributed over the study area. A modified dendritic drainage pattern is identified on the lithological, structural variations limited at the dyke ridges zones. The uncommon nature of the local geological structure and slope has determined the extent of superimposed

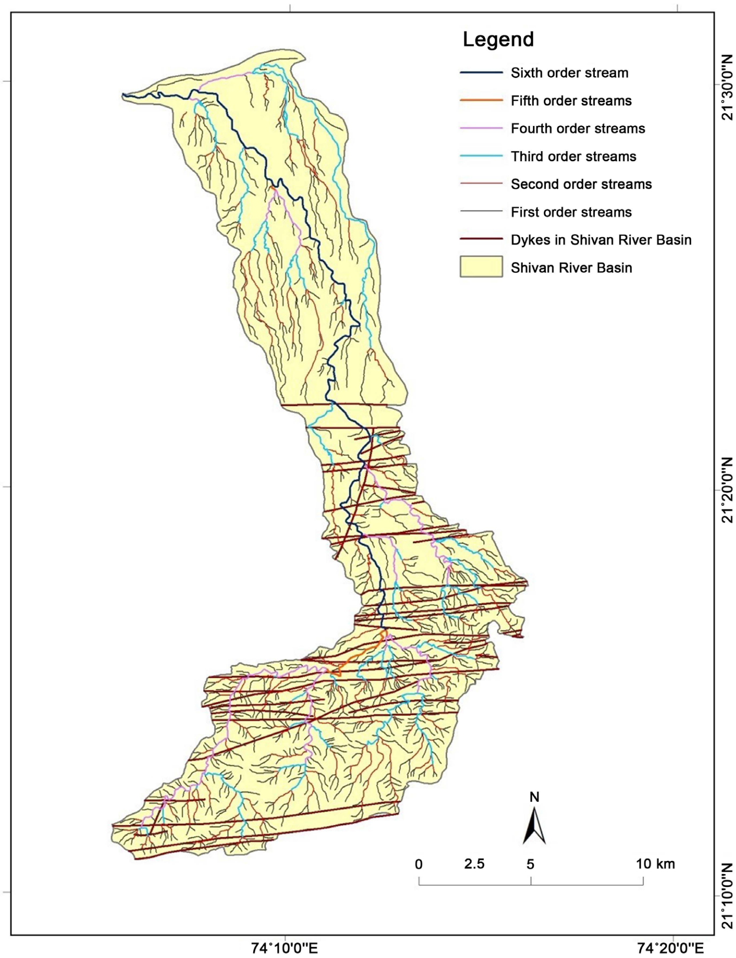

Figure 2. Drainage and Dyke orientation in the Shivan River basin.

drainage characteristics. Transverse or lateral consequent streams originate on the slope of dykes and joined the main stream. Many streams of Shivan flow transversely across dyke structures and slope. Channel curves, bends, diversions, junction angles, breaks in path are anomalies noted in the basin.

The present dyke-drainage network expression is superimposed drainage system in relations to the well outcropped dyke structure. In the 65% area of the Shivan drainage basin (169 km^2), represents superimposed drainage in dyke structure zone (**Figure 2**).

Shivan river basin reflects superimposed drainage systems in the Tapi dyke swarm subset region. Dyke ridges are aligned in the East-West (E-W) direction which are mainly followed by lower order streams which has developed insequent, transverse drainage network in the dyke swarm zone. Since the number of dykes is less in lower parts of Shivan basin drainage network follow the general slope and oriented in North-South direction. Shivan River and its tributary streams have adjusted with dyke orientation to some extent and developed transverse drainage pattern in the area of parallel ridges of dyke. The Shivan basin shape is typically narrower than surrounding drainage basins.

4. Results and Discussion

Analysis of drainage network morphology, or drainage pattern, can provide information about regional slope, underlying structures, and bedrock characteristics [1] [4]-[8]. Shivan river basin shows an indication of superimposed drainage characteristics in the Tapi dyke swarms subset region. E-W oriented dykes is considered here as a main component for the relationship within dykes and drainage pattern and stream orientation. Slope along dyke ridges shows important features to determine stream alignment in genetic form.

Attributes of the dykes, such as length, orientation and density are considered in the context on drainage pattern analysis (**Table 1**). Dykes' width is measured during field visits. Width of dykes do not imprint on streams network like as a positive, elevated parallel dyke ridges. Rose diagrams are helpful to compare the dykes and streams orientations relations which prepared in the Rockworks 16 software. Rose diagrams are created from endpoint data in Rockworks software.

Table 1. Influence of dykes on the drainage networks in Shivan River basin.

Total number of streams	Number of dyke control streams	Total length of streams (km)	Total length of dyke control streams (km)	Percentage based on number	Percentage based on stream length control under dykes orientated zone
722	539	429.11	272.44	74.65	63.49
165	116	156.63	91.68	70.30	58.53
42	28	90.32	43.84	66.67	48.54
10	6	48.43	37.84	60.00	78.14
3	2	4.6	4.08	66.67	88.61
1	1	39.18	14.32	100.00	36.55
943	**692**	**768.27**	**464.20**	**73.38**	**60.44**

Positive outcrops of dykes are more impact on alignment of streams and channel orientation. That strongly guide to drainage networks. The lower part of the Shivan Rver basin clearly represents no appearance of dyke ridges where streams are parallel to slope. This outcome focuses on dyke structures control on drainage networks.

The Rockwork 16 software is used to prepare rose diagrams of dykes orientation and stream directions for each stream order. Rockwork software helps to draw rose diagram by using a line endpoint data and generates a directional diagram that depicts the orientations of the linear features. The dykes' strikes are mainly orient in E-W direction.

Figure 3 shows conspicuous strike of dykes and streams order wise rose diagrams. The mean value of dykes' orientation is 83˚N. In each stream order the stream flow direction and the dyke strikes show coinciding directions over certain distances. It is observed that dyke orientation has greatly impacted on first order streams. The streams in each order have east-west orientation which shows an impact of dykes. The streams flow in other direction are insequent streams and

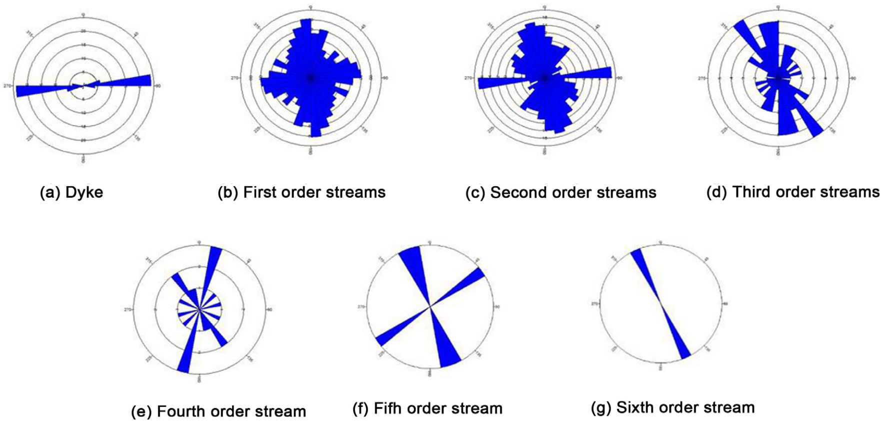

Figure 3. Rose diagrams of dykes and streams orientation.

are the indicator of dyke impact within the basin. The dyke orientation impact is greatly observed on initially developed streams along dyke ridges on either slope. Hence, it can be interpreted that, lower the stream order, higher is the impact of dykes on stream orientation. While higher the stream order, lower is the control of dyke on stream orientations.

5. Conclusion

The investigation of orientation of dykes and stream directions in the Shivan drainage basin throws light on the relationships between them. The alignment of stream flow is oriented to some extent to the respect of geological structure of dykes. Shivan river course has adjusted to some extent to dyke orientation and developed transverse drainage pattern in the alternating parallel ridges of dyke. Linear ridges of dykes have modified main dendritic drainage pattern. The results of the present study revealed that dykes guided the flow of streams with low stream power. This was observed mainly for the streams of the lower order, including the streams of the first and second order, which together accounted for approximately 83% of the total length of the whole drainage network in the study area. The streams of the middle and higher orders were relatively less influenced by dykes. The change in the course of higher-order streams is mainly attributed to the control caused by the dykes and the subsurface lithology. In the present study, the influence of dykes on lower-order streams was observed to have manifested mainly in the form of stream routing or alignment according to the orientation of the dykes. The findings of the present study are important as they revealed the geological setting and its structural deformation caused by dykes, which would, in turn, assist in further exploration of the drainage network and also in water resource management.

Conflicts of Interest

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

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