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# Morphotectonics Study of Dhamani River Basin in Kolhapur District, Maharashtra, India

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## ABSTRACT

*The Geomorphic Indices of Active Tectonics (GIAT) or morphotectonic parameters are applied for assessment of influence of tectonic setting in the Dhamani River and its thirty three watersheds. Dhamani River is a tributary of river Kumbhi (it covers 38.3% area of Kumbhi River) and Kumbhi is the main tributary of river Bhogavati (Panchaganga). The trend of Dhamani River is SW-NE and occupies an area of about 196.4 sq km. This river originates from Western ghat on its eastern slope. Geologically, it flows over three formations viz. 'aa' type of Deccan Volcanic Basalt (DVB), plateau Lateritic and Quaternary formation. To reveal the tectonic activity in the basin, different morphotectonic parameters are studied, such as: Drainage analysis, Bifurcation ratio (Rb), Basin Elongation ratio (Re), Drainage Basin Asymmetry Factor (AF), Hypsometric Integral (HI), Stream Length Gradient Index (SL), Standard Sinuosity Index (SI), lineament analysis and anomalous behaviour of streams. Finally, correlate the nature and depositional condition of the Quaternary deposits observed during the fieldwork with the morphotectonic indices and found that the Dhamani river is flowing through a NE-SW trending lineament (23.24 km) which reflects some tectonic activity in the upper and middle reaches in Tertiary-Quaternary age.*

**KEYWORDS**: *Dhamani, DVB, GIAT, GIS, Morphometric analysis and Quaternary Geology.*

## INTRODUCTION

In the present study, Geomorphic Indices of Active Tectonics (GIAT) or morphotectonic parameters correlate with Quaternary sediments in the Dhamani River. The study highlights (i) to evaluate tectonic history of the basin using surface analysis techniques, (ii) to understand the relationship between Quaternary sediment depositional condition and the tectonic setting of the area, (iii) Tectonic evidences in the Dhamani river correlated with the other DVB tectonic evidences, (iv) to evaluate tectonic setting in Western Ghat. The basin is selected for the present study because it is originated from eastern sloping surface of Western Ghat and occurs nearer to the Koyna-Warna river basin area (Fig. 1), where continuous reservoir induced earthquakes has been reported, since 1960s (Talwani 1997) in Western Ghat Scarp (WGS). Till today the seismic activity is being experienced here.

Keller and Pinter (1996) opined that 'tectonic geomorphology is the study of landforms produced due to tectonic activity'. The results of analysis of several morphometric indices or GIAT can be combined in order to highlight tectonic activity and to provide an assessment of a relative degree of tectonic activity in an area. GIAT parameters are basic reconnaissance tools to identify area experiencing rapid tectonic deformation based on the calculation of geomorphic indices using topographic maps and remote sensing data (Keller and Pinter 1996).

Last three decades different researchers have published research on uplift along the western continental margin of India (Widdowson and Cox 1996; Widdowson and Mitchell 1999; Gunnell 2001; Valdiya 2001; Gokarn et al 2003; Mishra et al 2004; Veeraswamy and Raval 2005; Tiwari et al 2006; Catherine et al 2007; Sheth 2007; Campanile et al 2008; Mukhopadhyay et al 2008). The GIAT parameters are also successfully analysed in central Maharashtra by Babar et al 2000 and 2011; Kaplay et al 2016; Gurav et al 2019; Gurav and Babar 2019.

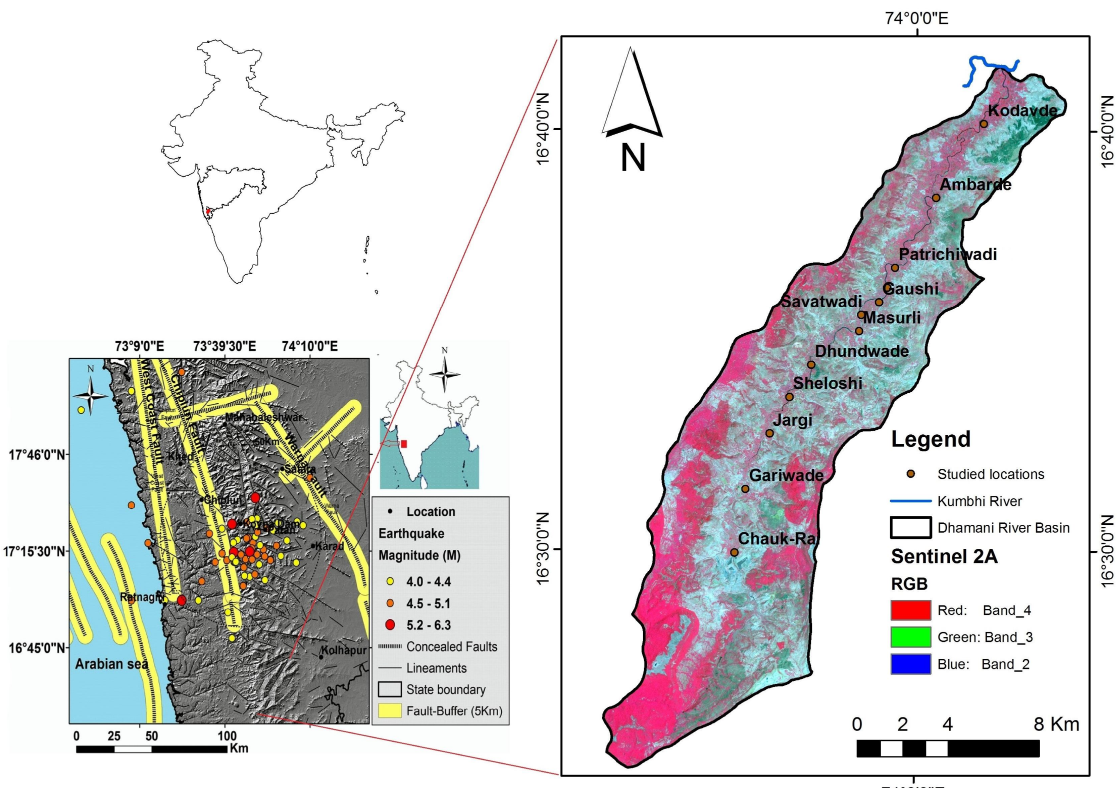


**Figure 1: Location map of Dhamani river basin, Kolhapur district, Maharashtra.**
(Source: Dev and Nagarajan, 2017)

Leroy et al. (2008) inferred that volcanic margins, such as the Western India Margin (WIM) are characterized by 2-3 times higher uplift since breakup and drifting than the non-volcanic margins. Furthermore, the adjustment in response to denudational isostacy and the resulting activation of faults and fractures has been suggested as the major contributory cause of sporadic seismic activity in the Deccan Volcanic Basalt (DVB) over the past few decades (Mahadevan and Subbarao 1999; Winddowson and Mitchell 1999). Kale and Shejwalhkar (2008) used GIAT parameters for 30 rivers on the both sides of the Western Ghat. He evaluate broadly the relationship between tectonics and basin morphology along with other field geomorphic evidences from DVB provide a very modest support to the widespread view that the WIM has undergone protracted uplift and tectonic deformation from Tertiary to recent times. It is now believed that Western Ghat escarpment of India was initiated as a continental edge at the time of the separation of the Seychellen micro continent following the eruption of the Deccan Trap lavas in Late Cretaceous (Widdowson 1997; Subrahmanaya 1998; Gunnell and Fleitout 2000; Kale and Shejwalhkar 2008).

Similarly, in DVB drainages are structurally controlled and neotectonics influence on the geomorphic set up and drainage configuration of the Terna basin. The lineaments and faults controlled drainage pattern, entrenched meanders, incised cliffs of Quaternary sediments and bedrock and a rejuvenated topography points to a dominant control of neotectonic activity on the landscape evolution of the area in DVB (Babar et al 2000, 2011 and 2012). All these evidences point towards uplift in the Tertiary-Quaternary time in DVB. Hence to find out tectonic setting, GIAT parameters are correlated with the Quaternary sediment of the Dhamani river basin.

## STUDY AREA

The Dhamani River is originated near Manbet village of Gaganbawada tehsil in Kolhapur district, Maharashtra, India. It takes abrupt turn in SW-NE direction and confluence with Kumbhi river near Akurde village (Fig. 1). The study area is occupied by an area of 196.4 sq km in the latitude 16°24'47"N to 16°41'18"N and longitude 73°52'54"E to 74°03'06"E. That falls in Survey of India (SOI) toposheet no. 47H/14, 47 H/15 and 47 L/2 on the scale 1:50000. The climate is tropical, received rainfall from SW monsoon between June to September. The normal annual rainfall in the area is 5000 mm. The highest temperature occurs in May is 38°C and lowest is 15°C in January.

## GEOLOGY OF THE STUDY AREA

Geologically, three types of formations cover whole study area viz., DVB, plateau Laterite and Quaternary formation along the river channel (Table 1). The basalt flow is mainly 'aa' type in nature. Geological fieldwork carried by Geological Survey of India (GSI) in Sangrul hill and adjoining area (Athavale and Natu 2005) has been given in Table 1. This hill is major watersheds divide in between Dhamani and Kumbhi River. The lava flows in the area are separated by red bole beds also called Tachylitic beds. Lithostratigraphically, present study area comes under Mahabaleshwar formation of Upper Deccan Traps in India (Godbole et al 1996).

The hill top above 920 m height in the area is covered by plateau Laterite rock (Pleistocene age) formation. Lateritic caps on basaltic flows occurs in the upland region, known as high level laterite whereas the laterite in the western region of Konkan costal belt are known as low level Laterite (Widdowson and Cox 1996). The Quaternary deposits are observed in middle and upper reaches in Dhamani River (Fig. 3a and 5a). It consists of reddish coloured cobbles, pebbles, sand, silt and clay formations deposited over the basaltic rock. The large part of the study area is covered by reddish silty soil which is important for agricultural purpose (Fig. 10).

**Table 1: Lithostratigraphic succession of Sangarul hill area in Dhamani River**

| Age | Geological formation | Elevation | Thickness |
|---|---|---|---|
| Quaternary to Recent | Clay mixed with silt, sand and cobble, pebble, gravels | 541 to 551 | 5.0 to 7.0 m |
| Pleistocene | Laterite/Bauxite | > 920 m | |
| 63-69 Ma | Deccan Volcanic Basalt | | |
| Proterozoic | Kaladgi Formation | | |

(Source: GSI report Athavale and Natu, 2005; fieldwork)

## METHODOLOGY

In this study, Survey of India (SOI) topographic maps (on the scale 1:50000), Shatter Radar Topographic Mission (SRTM) Digital Elevation Model (DEM), Sentinel 2A satellite imagery (10 m resolution) downloading from United States Geological Survey (USGS) official site (https://earthexplorer.usgs.gov/) and Google Earth imagery. The topographic maps are geo-referenced by using ArcGIS 10.1 software and same is used for digitization and data compilation. The location map (Fig. 1), Drainage map (Fig. 3a), Basin Asymmetry map (Fig. 3b) and 33 watersheds are prepared using the same. Three semi-log graphs are plotted for verification of the relationship of the streams in the Dhamani river, (i) stream order against number of streams (Fig. 4a), (ii) stream order against length of the streams (Fig. 4b) and stream order against mean stream length (Fig. 4c). The Hypsometric Integral (HI) analysis of Dhamani River as well as its thirty three watersheds is carried out based on percentage HI integral method. For this, SRTM DEM is processed by using ArcGIS 10.1 software for minimising the error and then 20 m contour extraction process is applied. After contours are extracted finally all contours are converted into polygon for calculating the area within two consecutive contour intervals. The Geological map (Fig. 5a) preparation is carried out based on Groundwater Survey and Development Agency Maharashtra (GSDA) data and detail geological fieldwork in the area. Lineament map and its rose diagram (Fig. 5b) are prepared based on structural lineaments, which are interpreted considering the straight course and acute right angle turn of the streams. The stream orientation is noted for rose diagram preparation. Finally, comparative analysis of watersheds represented by maps as Bifurcation ratio (Rb) (Fig. 6a), Basin elongation ratio (Re) (Fig. 6b), Basin Asymmetry Factor (AF) (Fig. 7a), percentage Hypsometric Integral (HI) (Fig. 7b) and river sinuosity index (SI) (Fig. 8a) of the Dhamani River and its 33 watersheds are plotted. The stream length gradient index is calculated by using river longitudinal profile. The Anomalous behaviour of streams (Fig. 9a and b) is identified based on the Google Earth image (2018). The morphotectonic data is used to correlate the sediments deformation evidences to study the tectonic setting of the basin (Fig. 10). All the morphotectonic parameters which are used for present research are given in Table 2 and simplified methodology is presented in flow chart (Fig. 2).

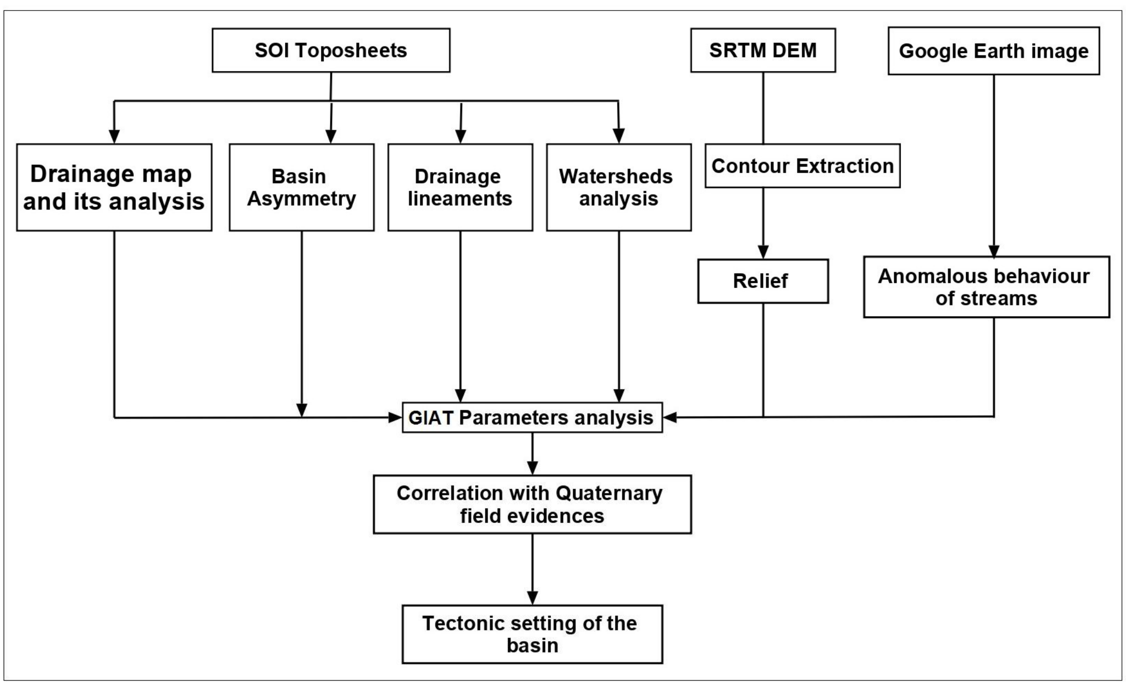


**Figure 2: Flow chart of overall methodology adapted for present research.**

## RESULTS

### Drainage Patterns

In the Dhamani river basin, three types of drainage pattern are observed, such as, dendritic to sub-dendritic and trellis as shown in Fig. 3a. The streams are directly linked with land surface, topographic controls of the underlying rocks, geologic and geomorphic features, original slope and original structure of the basin (Thornbury 1969). The dendritic to sub-dendritic drainage pattern is very common in DVB. It is the indicator of regional slope, homogeneous lithology and high relief (Babar and Kaplay 1998). But in present study area, trellis drainage pattern developed along the Dhamani river channel. It is the indicator of strong sub-surface control in the area. The trellis drainage pattern developed as a system of sub-parallel streams aligned along the joints in the basalt rock formation (Willis 1895).

**Table 2: Morphotectonic indices computed for Dhamani River and its watersheds.**

| Parameters | Formula | Reference | Values, Inferences |
|---|---|---|---|
| Bifurcation Ratio (Rb) | Rb=Nu / Nu+1Where, Nu is the total number of streams of all orders | Horton (1945); Strahler (1957) | <2 for flat, 2- 4 for mountainous area, >5structural controlled |
| Basin Elongation Ratio (Re) | Re=$(2\sqrt{A}:\sqrt{\pi})/LB$ Where, A= Basin Area, L= Basin Length | Bull and McFadden (1977) | Re<0.50, Tectonically Active, Re=0.50-0.75, Slightly Active, Re.>0.75, Inactive setting. |
| Hypsometric Integral (HI) | The Percentage HI method. | Strahler (1952) | HI<30% younger Stage, 30-60% mature stage, >60% old stage. |
| Basin Asymmetry Factor (AF) | AF=100(Ar / At) Where, Ar is right hand side area of drainage looking downstream and At is total area of drainage basin. | Keller and Pinter (1996) | AF=50.0 Stable setting Environment, 50.0 <AF>50.0 Suggest tilt basin |
| Stream Length Gradient Index (SL) | $SL_{Segment} / SL_{total}$ | Hack (1973) | Value >2.00-High tectonic activity, Values <2.00 Low tectonic activity. |
| Standard Sinuosity Index (SI) | SI (Standard Sinuosity Index) = CI / VI | Mueller (1968) Morisawa (1985) | Straight SI< 1.05<br>Sinuous SI > 1.05<br>Meandering SI> 1.50<br>Braided SI> 1.30<br>Anastomosing SI> 2.00 |

### Morphometric analysis

The Dhamani River is 5th order stream (Strahler, 1964) having total number of streams are 961, length of all the streams is 687.55 km. The Bifurcation ratio (Horton 1945) ranges from 3.82 to 9.00 with an average is 5.53 (Table 3). The first to second order streams show minimum structural control but the Rb value of third to fourth order abnormally high i. e. 9.00. The drainage density of the basin is 3.50 km/km$^2$ (Horton 1932), stream frequency is 4.89 streams/ km$^2$ (Horton, 1945) indicates that the impermeable sub-surface rocks and high runoff from the basin. The drainage texture ratio is 11.43 km$^{-1}$ (Horton 1945) which is above 8 indicates very fine drainage texture (Smith 1950). The highest elevation in the area is 1011 m and lowest is 547 m. Therefore, relief of the area is 464 m.

**Table 3: Linear morphometric aspect of the Dhamani River basin**

| (u) | (Nu) | (Rb) | (Lu) | MSL | (Rl) |
|---|---|---|---|---|---|
| 01 | 738 | | 446.0 | 0.60 | |
| | | 4.29 | | | 0.78 |
| 02 | 172 | | 133.8 | 0.77 | |
| | | 3.82 | | | 0.58 |
| 03 | 45 | | 59.51 | 1.32 | |
| | | 9.00 | | | 0.52 |
| 04 | 05 | | 12.66 | 2.53 | |
| | | 5.00 | | | 0.07 |
| 05 | 01 | | 35.60 | 35.60 | |
| **Total** | **961** | **--** | **687.6** | **40.82** | **--** |
| **Mean** | **--** | **5.53** | **--** | **--** | **0.49** |

Where, Stream order (u), Number of streams (Nu), Bifurcation ratio (Rb), Total length of streams in km (Lu), Mean stream lengths (MSL) in km and Stream Length ratio (Rl).

**Semi-log plot of Dhamani River**

The plot of semi logs of stream order against number of streams, length of the stream and mean stream length shows a straight line relationship with small deviation. Any deviation will be indicative of lithological control on drainage development. The semi log graph of stream order against number of streams (Fig. 4a) represents those streams of 1st to 5th ordered streams lies in the straight line indicating there are no structural disturbances but a slight deviation is visible for 3rd order streams. The semi-log graph (Fig. 4b) of stream order against the length of the streams shows that streams of 1st to 3th are lies in straight line, but streams of 4th and 5th order show some anomaly. In semi-log graph (Fig. 4c) stream order against mean stream length observed all the streams are not lies in straight line. Based on the semi-logs graphs (Fig. 4 a, b, and c), pointed that the area between streams of 3rd to 5th order are slightly structurally controlled.

**Geomorphic indices of Active Tectonics (GIAT)**

The analysis of the bifurcation ratio, basin elongation ratio, basin asymmetry factor, hypsometric integral, stream length gradient index, sinuosity index, lineament analysis and anomalous behaviour of streams carried out under GIAT separately.

**Bifurcation Ratio (Rb)**

The Bifurcation ratio (Rb) of the basin is 'the ratio of no of streams of lower order (u) to the number of streams of next higher order (u+1)' (Strahler 1964). For present investigation it is calculated by using the formula, Rb = Nu / Nu+1, where, Nu is the total number of streams of one order (Horton 1945; Strahler 1957).

The average bifurcation ratio of Dhamani River basin is 5.53 (Table 3), which is indication of strong geological control in the development of drainages within the basin. The Rb value is less than 5.00 is found in watershed no 01, 02, 03, 04, 05, 06, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, 31, 32 and 33 while more than 5.00 is in watershed no 07, 28 and 30 shown in Table 4 and Fig. 6a. Such high Rb value may be due to the basin is elongated in shape and there may be a structural control (Strahler 1964; Zavoianu 1985; Chunchekar 2012).

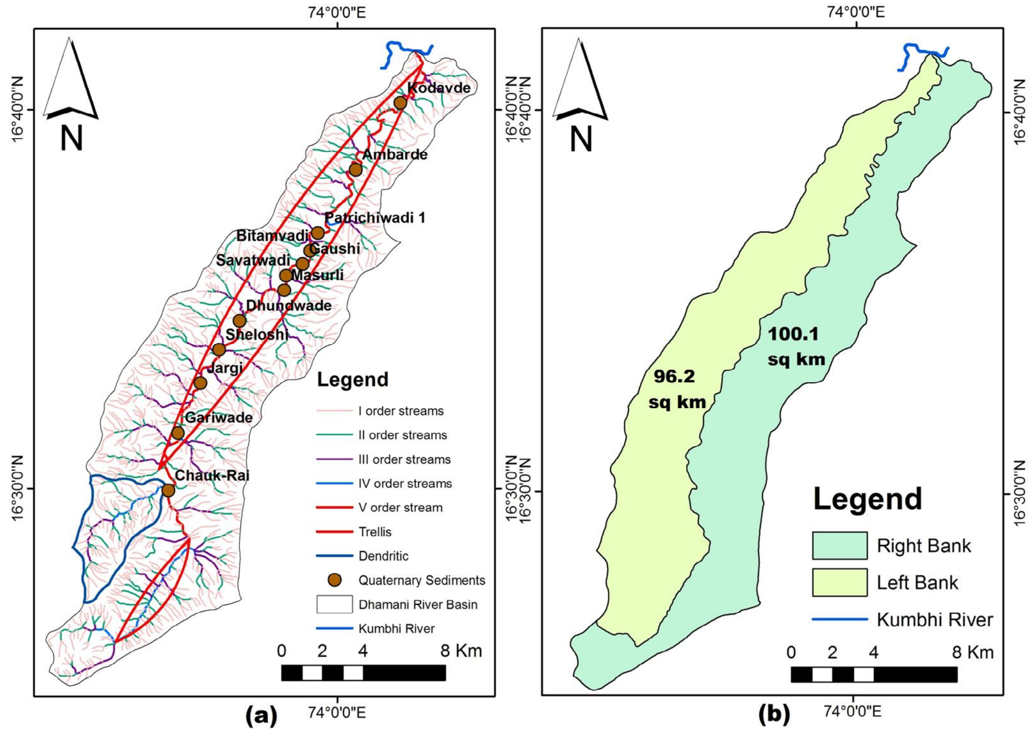


Figure 3: (a) Drainage map and (b) Basin Asymmetry map of Dhamani River basin.

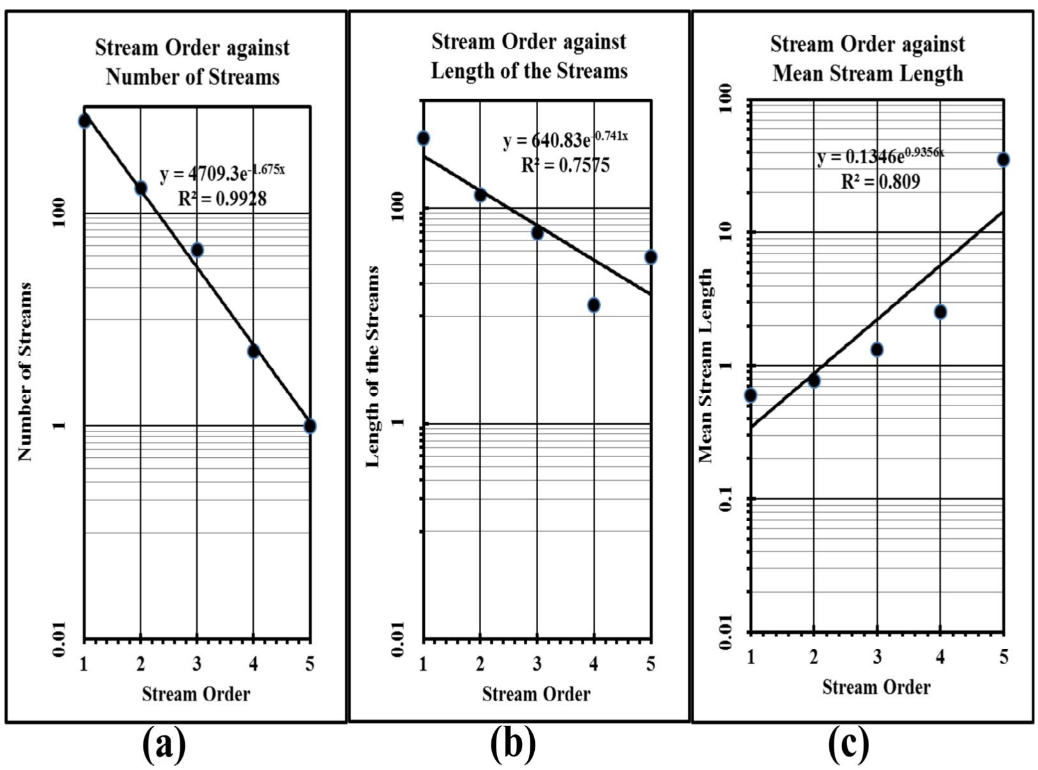


Figure 4: Semi log graphs of Dhamani River basin. (a) Stream order against Number of streams, (b) Stream order against Length of streams, (c) Stream order against Mean stream Length.

**Basin Elongation ratio (Re)**

The basin elongation ration (Re) is defined as "the ratio between diameter of a circle of the same area as the drainage basin and the maximum length of the basin" (Schumm, 1956). It also provides indirect information about the degree of maturity of the basin landscape. It is calculated using the formula proposed by Bull and McFadden (1977) (Table 2). Value close to 1.0 is typical of regions of very low relief, whereas that of 0.6-0.8 are associated with high relief and steep ground slope. The ratio is classified into three categories, as circular (>0.9), oval (0.9-0.8) and elongated (<0.7) (Bull and McFadden, 1977). Dhamani River Re value is 0.26 indicates that basin is highly elongated in shape. The Re values of watershed ranges from 0.34 to 0.93. It indicates watersheds are highly elongated to nearly circular in shape as suggested by Schumm (1956); Farooq et al (2015); Kaplay et al (2016). The value of Re for watershed number 02 is < 0.50 indicates tectonically active, the value of Re for watersheds numbers 01, 03, 04, 06, 07, 08, 09, 10, 13, 14, 15, 16, 17, 18, 21, 22, 24, 26, 27, 29 and 32 in between 0.50-0.75 (Table 4). Watershed no 05, 11, 12, 19, 20, 23, 25, 28, 30, 31 and 33 are >0.75 shown in Table 4 and Fig. 6b is inactive setting. Singh (2008a) and Singh and Jain (2009) observed that the basins or sub-basins are poorly elongated (high elongation ratio), where the smaller watersheds are highly elongated (low elongation ratio).

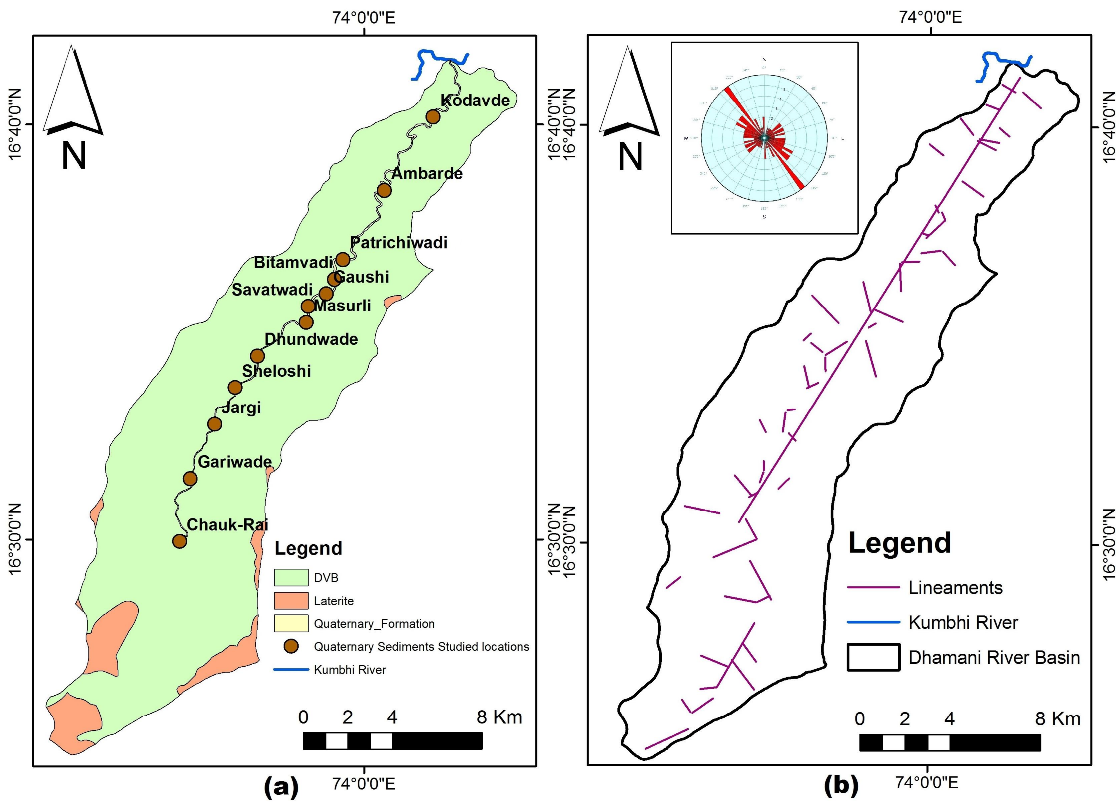


**Figure 5: (a) Geological map, (b) Lineaments with rose diagram of Dhamani River basin.**

**Basin Asymmetry (AF)**

The influence of tectonics on the drainage pattern is also reflected by the drainage basin asymmetry (Molin et al 2014; Kaplay et al 2016). The AF is the areal morphometric variable that deciphers the presence or absence of regional tilt in the basin (Keller and Pinter 1996). It is also calculated using the formula proposed by Keller and Pinter (1996) (Table 2). If AF value of the basin is less than or more than 50% is the indication of basin is tectonically tilted but value is nearly close to 50% is indication of drainage basin is in stable condition (Keller and Pinter 1996).

In the Dhamani river basin, AF value is very close to the 50.00% i. e. 49.00% (Fig. 3b) is indication of basin is not tectonically tilted. Using basin asymmetry, we divided basin in to two parts, western bank is 96.22 sq km and eastern bank 100.14 sq km. The individual morphometric analysis of western and eastern banks of the basin asymmetry also calculated. The morphometric analysis of western bank indicate that, the Dd is 3.45 km/km$^2$ (Horton 1932), Fs is 5.22 streams/ km$^2$ (Horton, 1945) and Rt is 5.93 km$^{-1}$ (Smith 1950). The morphometric analysis of eastern bank is calculated as Dd is 3.27 km/km$^2$ (Horton 1932), Fs is 4.66 streams/ km$^2$ (Horton 1945) and Rt is 5.05 km$^{-1}$ (Smith 1950). The value of the basin asymmetry factor is calculated for 33 watersheds (Table 4). Out of that the watershed numbers 01, 02, 03, 05, 08, 09, 10, 12, 13, 14, 15, 17, 18, 19, 20, 22, 23, 24, 25, 26, 27, 28, 32 and 33 shows slight tectonic tilting whereas watershed no 04, 06, 07, 11, 16, 21, 29, 30 and 31 (Fig. 7a) shows stable conditions.

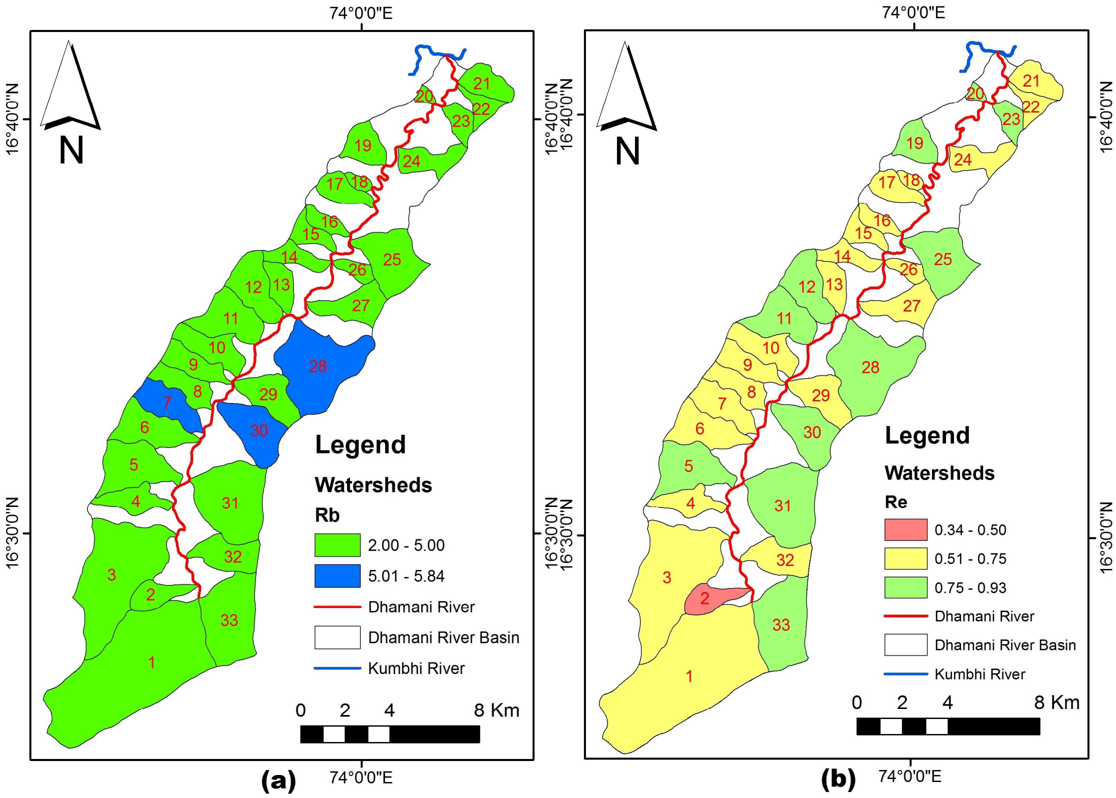


**Figure 6: Watersheds classification maps. (a) Bifurcation ratio, and (b) Basin elongation ratio.**

### Percentage Hypsometric Analysis (HI)

The percentage Hypsometric integral (HI) analysis is recently commonly used for studying the erosional condition of the basin (Gajabhiye et al 2014; Gurav and Babar 2018) and also to understand the tectonic activity in the basins by Singh 2008b; Kaplay et al 2016; Gurav et al 2019; Gurav and Babar 2019.

In order to study the tectonic setting in Dhamani river basin, percentage hypsometric integral method is used; two ratios are computed from contours which are extracted by using SRTM DEM in 20 m interval. The HI is an indication of the “cycle of erosion” (Strahler 1957; Cox 1994; Obi Reddy et al 2002). The cycle of erosion is the total time required for reduction of land area to the base level. This entire period or the “cycle of erosion” can be divided into the three stages, namely old stage/ stable (HI<30%) in which the watershed is fully stabilized; mature stage/ slightly tectonic (HI 30 to 60%); and youth stage/ tectonically active (HI >60%), in which the watershed is highly susceptible to erosion (Strahler 1952).

The percentage Hypsometric Integral value is 40.5% (Table 4) indicates basin is at present mature stage of river development. The HI analysis of 33 watersheds is also carried out based on Strahler (1952) classification. The watershed numbers 02, 03, 04, 05, 06, 07, 08, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 27, 28, 29, 30, 31, and 32 (i.e. 84.9% of all watersheds) shows mature stage / slightly active, while watersheds numbers 01, 09, 25, 26, and 33 i.e. 15.1% of all watersheds (Fig. 7b) shows younger stage / active tectonic. Large area of the basin is more affected by erosion while small area of watershed is less affected by erosion as observed by Gurav and Babar (2018).

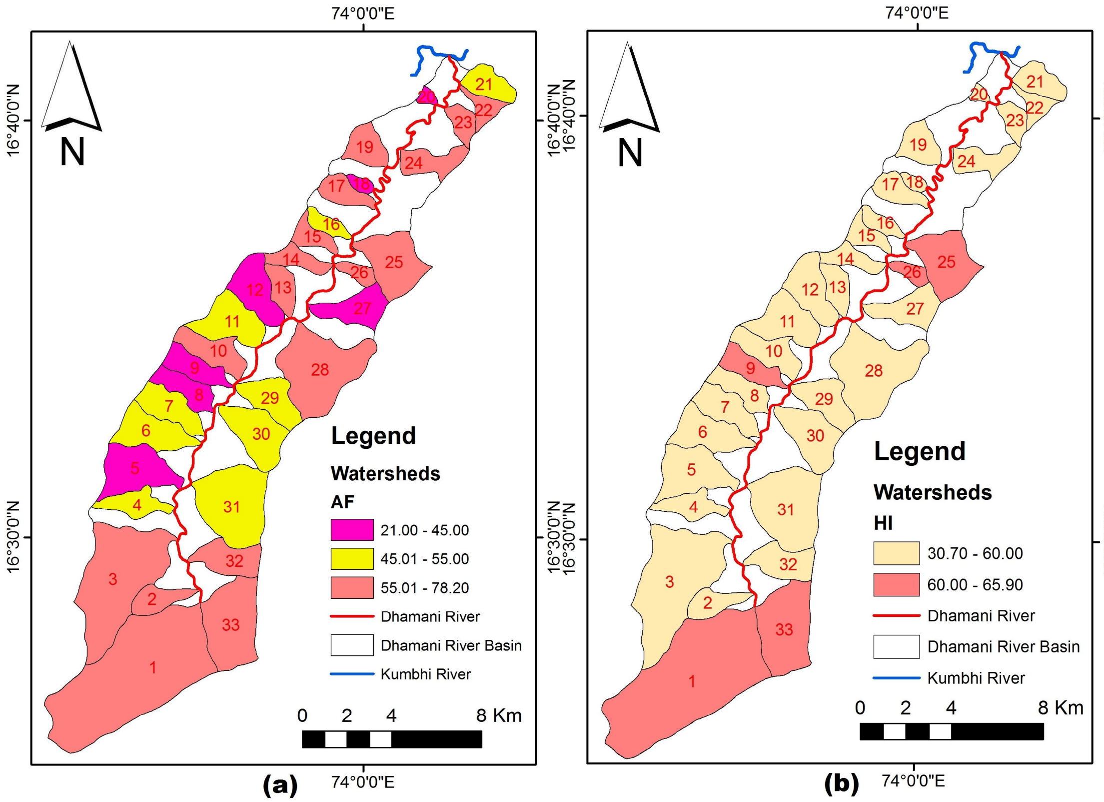


**Figure 7: Watershed classification maps. (a) Basin Asymmetry, (b) Hypsometric Integral**

**Stream Length Gradient Index (SL)**

This ratio is first proposed by Hack (1973) facilitates the identification of factors that controls the drainage network such as occurrence of resistant rock, tectonic activity, change in the local base level, tributary confluence, human interference etc. It is calculated using the formula, $SL = (H_1 - H_2) / (\ln L_2 - \ln L_1)$ where, H1 and H2 are the elevations of each end of a given reach L1 and $L_2$ are the distances from each end of the reach to the source (Hack 1973). In this study, SL ratio has been analyzed from Dhamani and its watersheds in order to determine the influence of lithology and tectonic setting. For this SL ratios are classified based on Seebar and Gornitz (1983) proposed classification $SL_{channel}$ to $SL_{total.}$ The SL index less than 2 is the indication of no anomalies, while the ratio between 02 and 10 is shows second order anomalies, if the index is 10 or more it is first order anomaly. The average stream length-gradient index value of Dhamani River is 2.50. The SL index obtained for watersheds is between 2.78 and 5.32 (Table 4). In this study we observed second order anomaly that exist all over the basin. All the watersheds and Dhamani river SL ratio varies from 02 to 10 shows second order anomaly (Table 4).

**Standard Sinuosity Index (SI)**

The standard sinuosity index of river is the ‘ratio of channel length to valley length’ (Leopold and Wolman 1957; Leopold et al 1964, Morisawa 1985). It deals with the pattern of channel of the drainage basin. If the SI value is greater than 1.5 that shows a characteristic of meandering of river channel

(Singh 1998). The sinuosity of a meandering stream is the result of topography and hydraulic factors, which can be expressed by a ratio called the index of sinuosity (Miller 1953). Such type of observation are made by Sapkale et al (2016) in Dhamni River in the lower part (14 km) of the river show meandering due to inundating water in the agricultural field during heavy rain and floods. In this study the classification of Sinuosity Index of watersheds followed by Bull and McFadden (1977) is carried out. All the watersheds are found to be tectonic active except watershed number 12, which is found to be slightly tectonically active (Table 4 and Fig. 8a).

**Table 4 Morphometric attributes for GIAT of Dhamani River watersheds.**

| W | A | u | Rb | Re | AF | SL index | HI | (SI) (CL/VL) | Overall inference |
|---|---|---|---|---|---|---|---|---|---|
| **Watersheds in the western part of the Dhamani River** | | | | | | | | | |
| 01 | 25.3 | 04 | 4.95 | 0.64 | 60.6 | 5.32 | 61.8 | 1.35 | Active |
| 02 | 2.28 | 03 | 2.75 | 0.34 | 75.9 | 4.12 | 55.5 | 1.16 | Active |
| 03 | 14.3 | 04 | 4.70 | 0.64 | 56.0 | 5.04 | 53.8 | 1.28 | Active |
| 04 | 2.59 | 03 | 3.84 | 0.52 | 46.0 | 3.85 | 42.9 | 1.08 | Slightly Active |
| 05 | 5.54 | 03 | 4.88 | 0.77 | 38.5 | 4.83 | 38.4 | 1.31 | Slightly Active |
| 06 | 4.41 | 03 | 4.50 | 0.67 | 45.0 | 4.10 | 52.4 | 1.11 | Slightly Active |
| 07 | 3.57 | 03 | 5.25 | 0.63 | 52.4 | 3.96 | 47.0 | 1.10 | Slightly Active |
| 08 | 2.67 | 03 | 3.50 | 0.60 | 43.1 | 4.03 | 50.8 | 1.14 | Slightly Active |
| 09 | 2.70 | 03 | 3.50 | 0.58 | 43.3 | 3.97 | 61.6 | 1.12 | Slightly Active |
| 10 | 3.39 | 03 | 3.50 | 0.60 | 61.7 | 4.25 | 42.9 | 1.18 | Active |
| 11 | 4.66 | 03 | 4.25 | 0.91 | 48.1 | 4.31 | 36.7 | 1.22 | Inactive |
| 12 | 4.22 | 03 | 4.50 | 0.77 | 40.5 | 5.72 | 45.1 | 1.57 | Slightly Active |
| 13 | 2.04 | 03 | 3.00 | 0.61 | 66.7 | 4.02 | 43.3 | 1.15 | Slightly Active |
| 14 | 1.94 | 03 | 2.50 | 0.52 | 66.5 | 3.82 | 43.8 | 1.13 | Slightly Active |
| 15 | 1.66 | 03 | 3.25 | 0.67 | 59.0 | 4.07 | 42.2 | 1.18 | Slightly Active |
| 16 | 1.31 | 03 | 2.50 | 0.56 | 48.9 | 3.65 | 34.8 | 1.08 | Slightly Active |
| 17 | 2.19 | 03 | 3.00 | 0.54 | 69.9 | 3.81 | 47.7 | 1.11 | Slightly Active |
| 18 | 0.63 | 03 | 2.00 | 0.65 | 39.7 | 3.43 | 30.7 | 1.08 | Slightly Active |
| 19 | 2.55 | 03 | 3.17 | 0.84 | 58.4 | 3.61 | 43.5 | 1.07 | Inactive |
| 20 | 0.47 | 03 | 2.00 | 0.86 | 29.8 | 3.01 | 39.7 | 1.02 | Inactive |
| **Mean** | | | **3.58** | **0.65** | **51.3** | **4.11** | **45.7** | **1.17** | - |
| **Watersheds in the eastern part of the Dhamani River** | | | | | | | | | |
| 21 | 2.48 | 03 | 3.00 | 0.71 | 46.4 | 4.18 | 45.7 | 1.20 | Inactive |
| 22 | 1.47 | 03 | 2.00 | 0.67 | 78.2 | 4.12 | 53.2 | 1.20 | Slightly Active |
| 23 | 1.52 | 03 | 2.00 | 0.80 | 69.1 | 3.56 | 52.5 | 1.08 | Slightly Active |
| 24 | 2.69 | 03 | 3.25 | 0.73 | 56.5 | 3.85 | 52.3 | 1.12 | Slightly Active |
| 25 | 5.71 | 04 | 2.92 | 0.75 | 62.4 | 4.53 | 60.1 | 1.26 | Active |
| 26 | 1.10 | 03 | 2.50 | 0.60 | 55.5 | 2.78 | 61.2 | 1.06 | Active |
| 27 | 3.60 | 03 | 3.33 | 0.65 | 21.0 | 4.01 | 55.6 | 1.13 | Slightly Active |
| 28 | 10.0 | 03 | 5.84 | 0.83 | 56.9 | 3.39 | 36.9 | 1.18 | Inactive |
| 29 | 3.62 | 03 | 4.17 | 0.67 | 48.1 | 4.08 | 40.3 | 1.15 | Slightly Active |
| 30 | 4.87 | 03 | 5.17 | 0.78 | 53.0 | 3.83 | 48.0 | 1.07 | Inactive |
| 31 | 8.91 | 04 | 3.36 | 0.93 | 45.2 | 3.92 | 48.0 | 1.09 | Inactive |
| 32 | 3.47 | 03 | 3.33 | 0.68 | 70.0 | 3.71 | 51.1 | 1.06 | Slightly Active |
| 33 | 7.93 | 04 | 3.23 | 0.91 | 64.7 | 4.26 | 65.9 | 1.19 | Active |
| **Mean** | | | **3.39** | **0.75** | **55.9** | **3.86** | **51.6** | **1.14** | **-** |

Where, W (Watersheds), A (Area in sq km), u (highest stream order), Rb (Bifurcation ratio), Re (Basin Elongation Ratio), AF (Basin Asymmetry Factor), SL(Stream Length Gradient Index), HI (Percentage Hypsometric Analysis), RLP (River Longitudinal Profile), SI (Standard Sinuosity Index), CL (Channel Length) and VL (Valley Length).

**Lineament Analysis**

Lineaments are the linear features of land, straight or nearly straight course of streams, vegetation and the dark tone on the satellite imagery. It is the expression of joint or fractures etc., developing generally due to tectonic stress and strain. Lineaments provide important clue on surface features and are responsible for infiltration of surface runoff into sub-surface and also for movement and storage of groundwater (Subba Rao et al 2001). They play an important role in identifying suitable sites for artificial recharge of groundwater because they reflect rock structures through which water can percolate and travel up to several meters (Krishnamurty et al 2000). In the study area, the lineaments are marked based on linear stream channels based on Survey of India topographic maps on 1:50000 scale. Finally, ploted the rose diagram of all the lineaments in the Dhamani River and found that, a maximum lineament shows NW-SE directions (Fig. 5b).

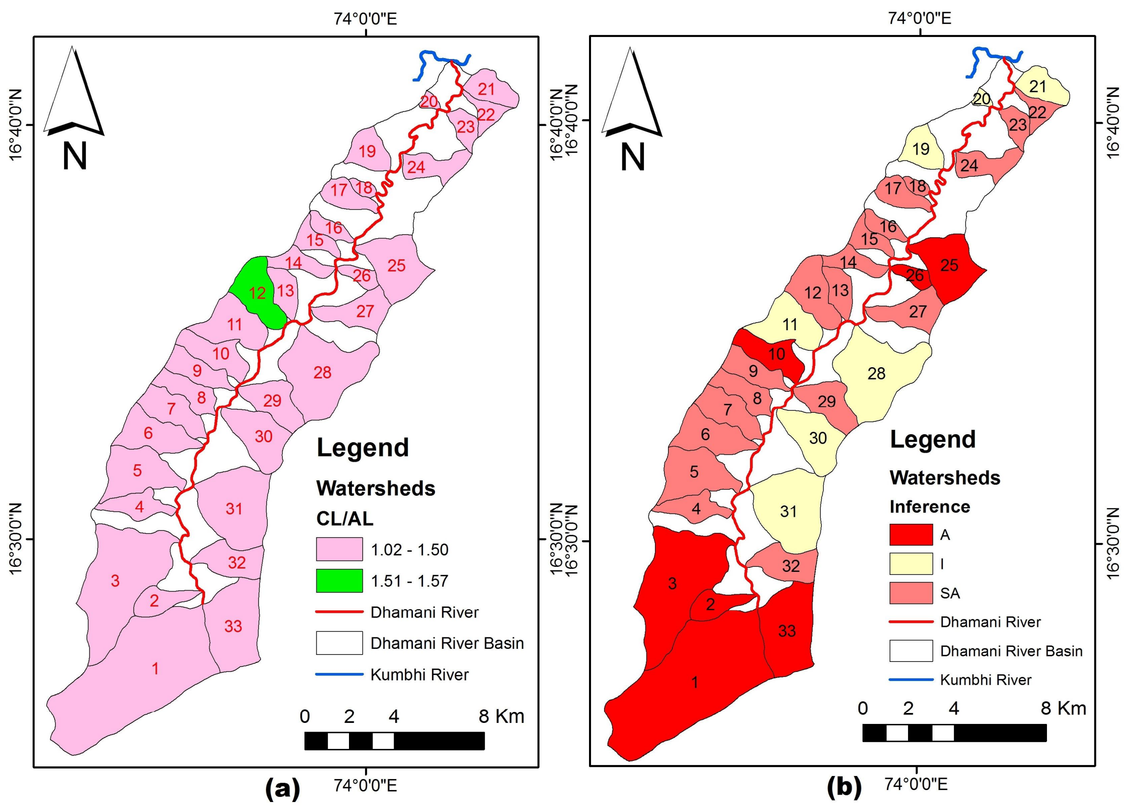


**Figure 8: Watershed classification maps. (a) Sinuosity Index and, (b) Morphotectonic evidences overall inference map.**

**Anomalous Behaviour of Streams**

In the present study, two locations are observed where streams are structurally controlled. The response of streams to tectonic deformation is demonstrated by channel deflection (Whitney and Hengesh 2015). The lineament in and around Nanded city are mapped based on their characteristics features like sharp turn in the stream, particularly at ninety degree and straight course (Kaplay et al 2016). Sharp bends in the streams, 90° turn of the streams and in general anomalous behaviour of streams indicate that the drainage pattern of the region is controlled by subsurface discontinuities or structures (Babar et al 2000). In this study, we observed behaviour of the streams with the Dhamani river main channel such as sharp knee-bend turn, off sequent stream at two locations. In Fig 9a (16°37'06.43" N, 73°59'41.79" E based on Google Earth imagery) shows that the tributary stream runs parallel to some distance before confluence with Dhamani River. It is nearly 0.8 km run parallel to main Channel. In Fig. 9b (16°30'02.73"N, 73°55'26.44"E) shows sharp right angle turn of the tributary streams before joining the Dhamani River. Such types of evidences give information about the structural controls in the drainage basins.

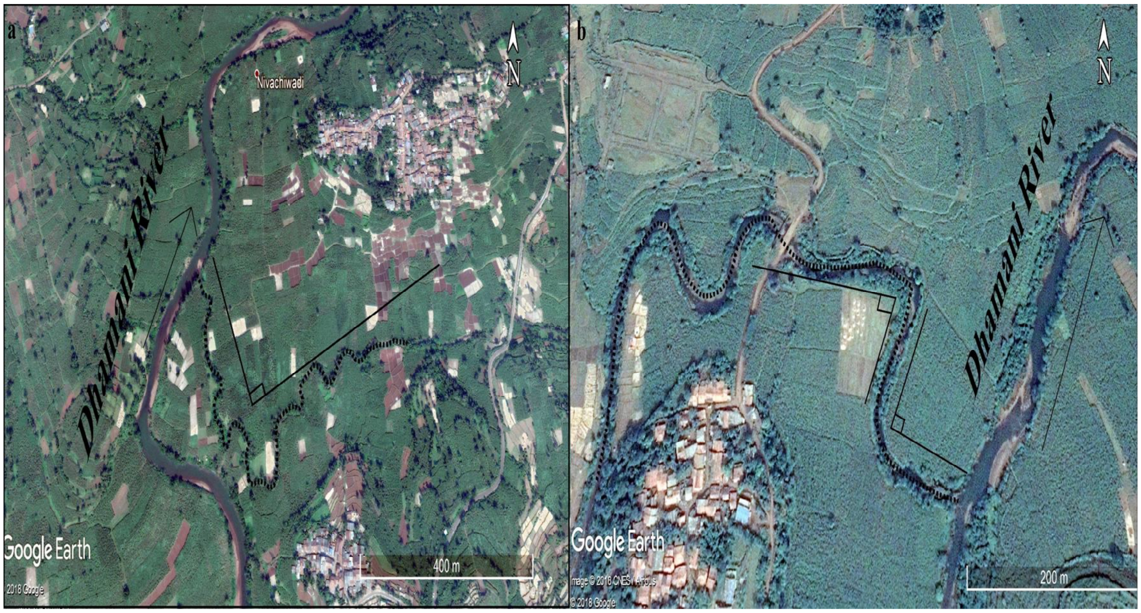


**Figure 9: (a) and (b) is the drainage anomalous behaviour of streams in Dhamani River basin. (Source of the images: Google Earth 2017).**

## DISCUSSION

In the present study, based on the stream ordering method proposed by Strahler (1964), found that the Dhamani River is fifth order stream. The Dd, Fs and Rt values of the basin indicate the area is hilly, steep gradient with impermeable sub-surface geology. The average bifurcation ratio (Rb) of this river is more than 5 and the stream order 3rd to 5th show some structural control based on bifurcation value (i.e. between 3rd and 4th order is 9.00 and between 4th and 5th order is 5.00). Such abnormally high Rb ratio may be due to elongated shape of the basin and the structural control (Strahler, 1964; Zavoianu, 1985; Chunchekar and Babar 2012). In Dhamani River three types of drainages are seen (Fig. 3a) such as dendritic, sub-dendritic and trellis. Out of that trellis drainage pattern gives primary evidences of structural controls of most stream course, except the truck streams, where the tributary valleys are usually subsequent strike valleys (Thornbury 1969).

The basin elongation ratio (Re) is 0.26, indicating that the basin is elongated. The basin elongation ratio <0.50 indicates the basin to be tectonically active, values ranging 0.50-0.75 reflect slightly / moderately active basins, and those >0.75 reflect inactive basins (Cuong and Zuchiwicz 2001). Based on this river basin shows some tectonic activity, whereas majority of watersheds does not shows tectonic activity within the basin.

The basin asymmetry factor (AF) very close to 50.00 is the indication of basin is not tectonically tiled in geological past (Hare and Garner, 1985). Based on basin asymmetry Dhamani basin is divided in two parts west and east. The individual morphometry of watersheds is calculated for Dd, Fs, and Rt parameters and found that the western part of the basin is highly elevated, steep sloping surface as compared to eastern part of the basin. It is observed that 07 watersheds (i.e. 21.2%) were found to have AF value <45.0%, 09 watersheds (27.3%) values range from 45.0 % to 55.0% we considered these values as the near normal, 16 watersheds (48.5%) were found to have AF value >55.0%. This indicates that about 70.1% watersheds in the area are tectonically tilted.

The percentage Hypsometric analysis of the basin revels that the basin is in mature stage of river development. The 15.1% of the watersheds in the basin shows younger stage of erosional development and tectonically active whereas 84.9% watersheds (Fig. 7b and Table 4) shows mature stage of erosional development and slightly tectonic active. The erosional condition of any watershed not only depends upon climate and sub-surface geology of the area but also on the tectonic setting, shape and size of the watershed or sub-basin or basin (Gurav and Babar, 2018).

The lineaments are plotted based on straight course of the stream. Based on this rose diagram is also plotted and found that the maximum lineaments are trending in NW-SE direction (Fig. 5b). The main Dhamani River is flowing along a lineament which is 23.24 km in length and its trend is NE-SW. It is similar with the trend of the Dhamani basin (SW-NE). The anomalous behaviour of the streams (Fig. 9a and b) also shows some tectonic influence in the basin. Stream length gradient index (SL) and sinuosity index point towards the origin of the basin is due to tectonic activity. Sapkale et al (2016) carried out sinuosity study in Dhamni river in Kolhapur district of Maharashtra and found that the lower part (14 km) of the river show meandering due to inundating water in the agricultural field during heavy rain and floods.

Geologically, entire Dhamani River is covered by DVB formation. If seismic activity occurs in the past it reflects some evidences in the rock formation. Such characters are very difficult to study in the basaltic rock because of its composition and arrangements of the grains. During the fieldwork in the Dhamani river, observed some Quaternary sediments, deposited on both the banks of the river (Fig. 10). Based on its depositional condition, compaction and structures are noted and correlated this data with the morphotectonic analysis of the river. The tilting and dislocation in the terraces is observed at five sites along Dhamani River, which are near Bhitamwadi, Gaushi, Sheloshi, Jargi and Gariwade villages where sediments reflect that they are affected due to tectonics after their formation. The sediments show 20° dip and consists of thick layers of mixture of gravel, pebble, silt, sand bed. Thick fluvial deposits in the upper and middle reaches of the river basins testing to either differential block subsidence along the channels or uplift of the flanks so as to accommodate the sediment fills (Peshwa and Kale 1997).

At Bhitamwadi (Latitude 16°36'16.33''N, Longitude 73°59'17.11''E) the pebble gravel bed exposed in left bank of the river. It is nearly 4.5 m thick and it is slightly tilted. Its tilting is identifying based on nature of the sediments and animals behaviour. Some animals (like crabs) have made burrow holes in the soft part of the sediments. Such types of burrows are observed in straight linear form and tilting of sediments is nearly 10° to 12° towards NE (Fig. 10e). Next site is observed near Gaushi village (Latitude 16°35'55.608'' N, Longitude 73°59'4.83'' E). Here sediments upper sediments consists pebble gravels are slightly tilted. The dip is 15° to 20° due NE (Fig. 10a) and thickness of the whole succession is about 4.0 m.

The Quaternary sediments exposed at Sheloshi village (Latitude 16°33'39.729''N, Longitude 73°56'52.976''E) on left bank of Dhamani River. The top of the pebble and cobbles bed shows dip is 20° to 30° towards NE direction (Fig. 10b). On the top of the cobble, pebble bed (5.4 m thick) is tilted towards NE direction. In location Jargi (Latitude 16°32'46.906''N, Longitude 73°56'22.986"E) the tilting of the pebble gravel bed (total thickness of the succession is 6.5 m) is exposed on left bank of the river but the nature of tilting is different. Here the sediments are tilted in to 15° towards SW direction (Fig. 10d). In this location upper sediments show some tilting in nature but lower part is nearly stable in condition. At Gariwade (Latitude 16°31'27.628''N to Longitude 73°55'48.112''E) the Quaternary sediments are exposed on both the banks of Dhamani River. But the cobble gravel bed (total thickness of the succession is 6.0 m) observed in the left bank is tilted 18° towards NW direction (Fig. 10c). This bed was deposited over compact basalt formation.

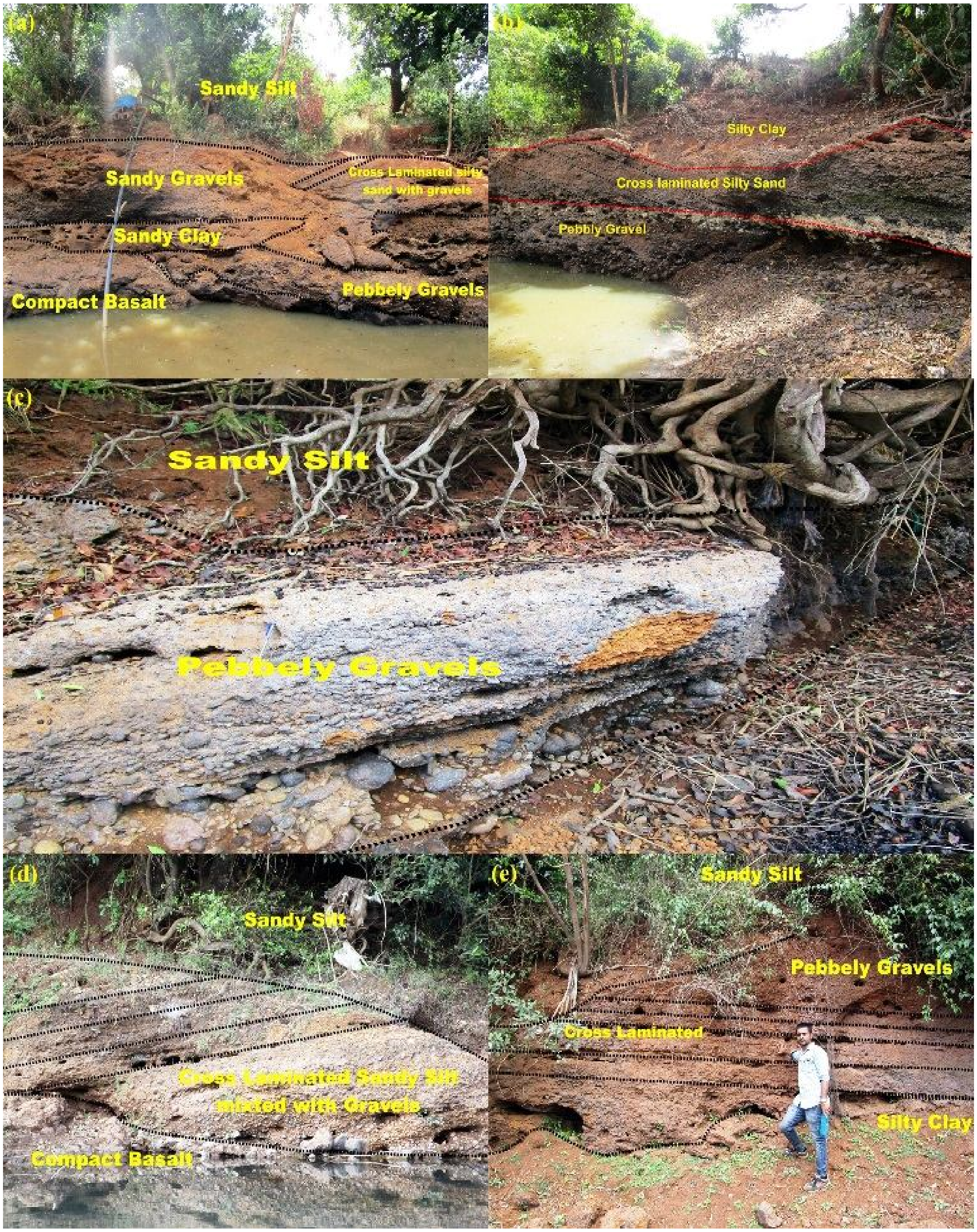


**Figure 10: Quaternary deposits show tilting nature. (a) near Gaushi, (b) near Sheloshi village, (c) near Gariwade, (d) near Jargi and (e) near Bhitamwadi.**

## CONCLUSION

The Dhamani River is found to be the 5th order stream. In the basin there is no evidence of neotectonic activity. Morphotectonic evidences in the form of drainage analysis, semi log graphs, bifurcation ratio, trellis drainage pattern, basin elongation ratio, basin asymmetry factors, hypsometric integral analysis, stream gradient length ratio, sinuosity index, anomalous behaviour of the streams and lineament analysis points towards some structural control in the basin. Based on Quaternary sediment depositional condition and lineaments observed along the river channel, it is apparent that the basin is uplifted in geological past. The Dhamani River is flowing through a strong lineament which reflects some tectonic activity in Tertiary and Quaternary time. So the detailed study of tectonic activity of the area is required in order to understand the tectonic behaviour of DVB.

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## REFERENCES

1. Athavale, H., and Natu, S. R., (2005). Report on transvers mapping in toposheet 47L/1, 2 and 3 in Sangali and Kolhapur District, Maharashtra 050/MAP/CR/MH/2004/2009.
2. Babar, Md., Chunchekar R.V., Yadava, M.G., and Ghute, B.B., (2012). Quaternary geology and geomorphology of Terna river basin in western cwntral India. *E&G Quaternary Science journal;* v 61(2), pp. 159-168.
3. Babar, Md., and Kaplay, R.D. (1998). Geomorphometric analysis of Purna river basin in Parbhani district Maharashtra, India. *Indian J. Geomorphology*, Vol.3 (1), pp. 29-39.
4. Babar, Md., Ghute, B.B., and Chunchekar, R.V., (2011). Geomorphic indicators of Neotectonics from the Deccan Basalt Province: a study from the upper Godavari River Basin, Maharashtra, India. *International Journal of Earth Science and Engineering*, 4 297-308.
5. Babar, Md., Kaplay, R.D., and Panaskar, D. B., (2000). Structural controls on drainage pattern in the Terna river Catchment, Central west India. *Indian Journal of Geomorphology*, 5, 126-133.
6. Bull, W.B., and McFadden, L.D., (1977). Tectonic Geomorphology north and south of Garlock Fault, Californiya, in arid regions. *Proc. Eighth Annual Geomorphological Symp., State University, New York, Binghamton*, pp. 115-138.
7. Campanile, D., Nambiar, C.G., Bishop, P., Widdowson, M., and Brown. R., (2008). Sedimentation record in the Konkan-Kerala Basin:Implications for the evolution of Western Indian passive margin; *Basin Research*, 20, 3-22.
8. Catherine, J. K., Gahalaut. K. and Gahalaut. V.K., (2007). Role of flexure in earthquake triggering along the western Ghat escarpment India; *J. Asian Earth Sci.* 31 104-111.
9. Chunchekar, R.V. (2012). Quaternary Geology and Geomorphology of Terna river basin, Eastern Maharashtra. Ph.D. thesis Swami Ramanand Teerth Marathwada University, Nanded, Maharashtra, India.
10. Cox, R.T. (1994). Analysis of drainage basin asymmetry as a rapid technique to identify areas of possible Quaternary tilt-block tectonics: an example from the Mississippi embayment. *Geological Society of America Bulletin*, vol. 106, pp. 571-581.
11. Cuong, N. Q., and Zuchiewicz, W. A. (2001). Morphotectonic properties of the Lo River Fault near Tam Dao in North Vietnam. *Jour. Natural Hazards and Earth System Sci*., v.1, pp. 15-22.
12. Dev, S. M. S. P.; Nagarajan, R. (2017). Seismic hazard assessment of Koyna region, Peninsular India: using geospatial approach. Geoenvironmental Disasters, 4(1), 27. doi:10.1186/s40677-017-0092-y
13. Farooq, S., Naxish Khan, M. and Sharma, I. (2015). Assessment of active tectonics in eastern Hummaon Himalaya on the basis of morphometric parameters of Goriganga River Basin. *International Journal of Advancement in Earth and Environmental Science*, 3, 14-21.

14. Gajabhiye, S., Mishra, S.K. and Pandey, A. (2014). Hypsometric analysis of Shakkar river Catchment through Geographical Information System. *Jour. Geol. Soc. of India*, v. 84, pp. 192-196.
15. Godbole, S.M., Rana, R.S., and Natu S.R. (1996). Lava stratigraphy of Deccan Basalt of Western Maharashtra. *Gondwana Geol. Mag. Spl*. Vol. 2 125-134.
16. Gokarn S G, Gupta G, Rao C K and Selvaraj J (2003). Some interesting observations on the tectonics in the Deccan Volcanic Province observed from magnetotelluric studies; *Journal of Virtual Explorer*, 12, 55-65.
17. Gunnell, Y., (2001). Dynamics and kinematics of rifting and uplift at the western continental margin of India: Insights from geophysical and numerical model; *Geol. Soc. India Memoir* 47 475-496.
18. Gunnell, Y., and Fleitout, L., (2000). Morphotectonic evolution of the Western Ghats India; *In: Geomorphology and Global Tectonics (ed.) Summerfield M (Chichester: John Wiley & Sons)* 321-338.
19. Gurav Chandrakant and Babar Md. (2019). Morphotectonic Analysis of Tiru River Sub-basin of Lendi River, Maharashtra, India based on GIS. *Dnyanopasak Research Journal*, vol. 1, Issue 1, March 2019, pp. 21-31.
20. Gurav, Chandrakant and Babar, Md. (2018). Hypsometric Analysis of Gharni River Sub-Basin of Manjra River, Maharashtra, India- Using Geographical Information System (GIS) Techniques. *Journal of Applied Geochemistry*, vol. 20, No. 4 (2018), pp. 447-454.
21. Gurav, Chandrakant., Babar Md., and Asode, Ajaykumar., (2019). Morphometric Analysis of Yelganga- Shivbhadra- Kohilla River Basins in Aurangabad District Maharashtra India-Using GIS Techniques. *International Journal of Research and Analytical Reviews* (IJRAR), E-ISSN 2348-1269, P- ISSN 2349-5138, vol. 6, Issue 1, pp.250-257 http://www.ijrar.org/IJRAR19J1855.
22. Hack, J., (1973). Drainage adjustment in the Appalachians; In: Fluvial Geomorphology (ed.) *Morisawa M (London: George Allen and Unwin)* 51–69.
23. Hare, P.W. and Gardner, T.W. (1985). Geomorphic indicators of vertical neotectonism along converging plate margins, Nicoya Peninsula, Costa Rica, In: Tectonic Geomorphology: *Proceedings of the 15th Annual Binghamton Geomorphology Symposium, (Eds) Morisawa, M. and Hack, J. T., Allen and Unwin, Boston*, pp. 90-104.
24. Horton, R.E. (1932). Drainage basin Charcteristics, Trans. *Amr. Geophy. Union*, 13, 1932, 350-361.
25. Horton, R.E., (1945).Erosional development of streams and their drainage basins: Hydrophysical approach to quantitative morphology. *Geological Society of America Bulletin*. vol. 56, 275-370.
26. Kale, V.S., and Shejwalkar, R.N., (2008). Uplift along the western margin of the Deccan Trap basalt Province: is there any geomorphic evidence? *Journal of Earth System Science*, 117, pp. 959-971.
27. Kaplay, R.D., Babar, Md., Mukherjee, Soumyajit., and T. Vijaykumar., (2016). Morphotectonic Expressions of geological Strucures in the eastern part of South East Deccan Volcanic Province (around Nanded, Maharashtra, India). *Tectonics of the Deccan Large Igneous Province. Geological Society, London, Special Publication*, 445, pp. 317-335.
28. Keller, E.A. and Pinter, N., (1996) Active Tectonics: Earthquake, uplift and landscapes. *Prentice Hall, New Jersey*.
29. Krishnamurty, J., Arul Mani, V., Jayaraman., and M. Manivel., (2000). Groundwater resources development in hard terrain-An approach using remote sensing and GIS techniques, *International journal of Applied geology*, 2(3/4), 204-215.
30. Leopold, L.B., and Wolman, M.G., (1957). River Channel Patterns, Braided, Meandering and Straight. *U.S. Geol. Surv*. Paper. 282-B.
31. Leopold, L.B., Wolman, M.G., Miller, J.P., (1964). Fluvial Processes in Geomorphology. Freeman, San Francisco.
32. Leroy, M., Gueydan, F., and Dauteuil, O., (2008). Uplift and strength evolution of passive margins inferred from 2-D conductive modelling; *Geophys. J. Int*. 172 464–476.
33. Mahadevan, T.M., and Subbarao, K.V. (1999) Seismicity of the Deccan Volcanic Province- An evaluation of some endogenous factors. *Memoir Geological Society of India*; v. 43, pp. 453-484.

34. Miller, V.C. (1953). A Quantitative geomorphic study of drainage basin characteristics in Clinch Mt. Area Verginea and Tennessec. Tech. Rep. No.3, Dept. Geog. Columbia Univ., New York, Contract N6 ONR 271-030, pp. 1-30.
35. Mishra, D.C., Laxman, G., and Arora, k., (2004). Large wavelength gravity anomalies over the Indian continent: Indicators of lithospheric flexure and uplift and subsidence of Indian Peninsular Shield related to isostasy; *Curr. Sci.* 86 861-867.
36. Molin, P., Pazzaglia, F.J. and Dramis, F. (2014). Geomorphic expressions of active tectonics in a rapidly deforming forearc, Sila Massif, Calabria, Southern Italy. *American Journal of Science,* 304, 559-589.
37. Morisawa, M. (1985). River - Forms and Process. Longman, London.
38. Mueller, J. R. (1968). An Introduction to the Hydraulic and Topographic Sinuosity Indexes. *Annals of the Association of American Geographers*, vol.58, No.2, 371-385.
39. Mukhopadhyay, R., Rajesh, M., De S Chakraborty B., and Jauhari, P., (2008). Structural highs on the western continental slope of India: Implication for regional tectonics; Geomorphology, 96, 48-61.
40. Obi Reddy, G.P., A.K. Maji and K.S. Gajbhiye GIS India (2002). (11), Vol. 31 pp. 25-35
41. Peshwa, V.V. and Kale, V.S. (1997). Neotectonics of the Deccan trap Province: focus on Kurudwadi lineament. *Journal of Geophysics*, 18, 77-86.
42. Sapkale, J.B., Kadam, Y.U., Jadhav, I.A., and Kamble, S.S., (2016).River in planform and variation in sinuosity index: A study of Dhamni river, Kolhapur (Maharashtra), India. *International Journal of Science and Engineering Research*, vol. 7, Issue 2, pp.863-867.
43. Schumm S.A., (1956). Evolution of drainage system and slope in Badlands at perth Amoboy, New Jersey, *Geological Society of America, Bulletin*, 67, 1956, 597-646.
44. Seeber, L., and Gornitz, V., (1983). River profile along the Himalayan arc as indicator of active tectonics. *Tectonophysics*, v.92, p.335-367.
45. Sheth, H. C., (2007). Plume-related regional pre-volcanic uplift in the Deccan Traps: Absence of evidence, evidence of absence. In; Plates, Plumes and Planetary processes (eds) foulger G R and Jurdy D M, Geol. *Soc. Am Spec. Pap*. 430 785-813.
46. Singh, Savindra., (1998). Geomorphology, (edited by Savindra Singh), Prayag Pustak Bhavan, Allahabad, pp. 334-412.
47. Singh, Tejpal., (2008a). Tectonic implications of geomorphic characterization of watersheds using spatial correlation: Mohand Ridge, NW Himalaya, India. Zeitschriftfür Geomorphologie, 54, pp. 489-501.
48. Singh, Tejpal., (2008b). Hypsometric analysis of Watersheds developed on actively deforming Mohand anticlinal ridge, NW Himalaya. *Geocarto International*, v. 23 (6), pp. 417-427.
49. Singh, T. and Jain, V. (2009). Tectonic contraints on watershed development on frontal ridges: Mohand Ridge, NW Himalaya, India. *Geomorphology*, 106, 231-241.
50. Smith, K.G. (1950). “Standard for grading texture of erosional topography”. Ame. J. Soc., 5 (298), 655-668.
51. Strahler, A.N. (1964). Quantitative Geomorphology of Drainage Basin and Channel Network, *Handbook of Applied Hydrology*.
52. Strahler, A.N. (1957). Quantitative analysis of watershed geomorphology. Trans. Am. *Geophys. Union*. 38, 1957, 913-920.
53. Strahler, A.N. (1952). Hypsometric (area-altitude) analysis of erosional topography. *Geol. Soc. Am. Bull*. 63 (11), pp. 1117-1142.
54. Subba Rao, N., Chakradhar, G.K.J., and Srinivas, V., (2001). Identification of Groundwater Potential Zones Using Remote Sensing Techniques In and Around Guntur Town, Andhra Pradesh, India. *Journal of the Indian Society of Remote Sensing*, vol. 29(1), pp. 69-78.
55. Subrahmanya, K.R., (1998). Tectono-magmatic evolution of the West Coast of India; *Gondwana Res*. 1, 319-327.
56. Talwani, Pradeep. (1997) Seismotectonics of Koyna-Warna Area, India. Pure appl. Geophys. 150 (1997) 511-550.
57. Thornbury, William, D., (1969). Principles of Geomorphology by ohn Wiley & Sons Inc; 2nd edition B01A65JWHA.
58. Tiwari, P. K., Surve, G., and Mohan, G., (2006). Crustal constraints on the uplift mechanism of the Western Ghats of India; *Geophys. J int*. 167 1309-1316.

59. Valdiya, K.S., (2001). Tectonic resurgence of the Mysore plateau and surrounding regions in cratonic Southern India; *Curr. Sci*. 81 1068-1089.
60. Veeraswamy, K., and Raval, U., (2005). Remobilization of the palaeoconvergent corridors hidden under the Deccan Trap cover and some major stable continental Region Earthquake; *Curr. Sci*. 89 522-530.
61. Whitney, B.B. and Hengesh, J.V. (2015). Geomorphological evidences of neotectonic deformation in the Carnarvon Basin, West Australia. *Geomorphology*, 228, 579-596.
62. Widdowson, M., (1997). Tertiary palaeosurfaces of the SW Deccan western India: Implication for passive margin uplift; Palaeosurface; Recognition reconstruction and palaeoenvironmental interpretation (ed.) Widdowson M. London; *Geol. Soc, Spec. Publ*. 120 221-248.
63. Widdowson, M., and Cox, K.G. (1996). Uplift and erosional history of the Deccan trap India: Evidences from laterite and drainage patterns of the Western Ghats and Konkan coast; Eartn planet. *Sci. Latt*. 137, 57-69.
64. Widdowson, M., and Mitchell, C., (1999). Large scale stratigraphical, structural, geomorphological constraints for earthquakes in the southern Deccan Traps India: The case for denudationally driven seismicity; In: Deccan Volcanic province (ed.) Subbarao K V, Bangalore: *Geol. Soc. India Mamoir* 43 245-274.
65. Willis. (1895). The Northern Appalachians. Nat. Geog. Soc. Mon. 1: i69~202. Development of the Geologic Atlas of the United States. *Bull. Am. Geog. Soc*, 27:337-351.
66. Zavoianu, I., (1985). Morphometry of drainage basins. Developments in water science, Zo, Elsevier, Amsterdam (Ed Ion Zavoianu), pp. 63-195.