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Morpho-tectonic appraisal of Peninsular India by comprehensive morphometric investigations

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Abstract

It has long been under the notion that Peninsular India was tectonically inactive, until the devastating earthquake struck Killari and Koyna, raising number of debates regarding the stability of the region. The Western Ghat escarpment has been under scrutiny for over a century due to its youthful and magnificent geomorphic signatures. In spite of the long-held belief of the tectonic passiveness of the plateau, widespread geomorphic signatures that occur all along the margins of the Ghat challenge this presumption. There are many planation surfaces at varying altitudes over the peninsula that undoubtedly indicates periodic eperiogenic uplifts, leading to polycyclic landscape evolution. The youthful appearance of the region immediately east of the Western Ghat escarpment is indicative of rejuvenation along the Ghat margin. Recent investigations in the wake of the Killari earthquake reveal tectonic activities not only along the margins of the Ghat but also in the least tectonically active central part of the plateau. Based on the common active tectonic indices, a few site-specific studies on the region's morpho-tectonics have been published, although their effectiveness is doubtful and their findings are contradictory. Given the heterogeneity in the scale of the tectonic setup within the landform, the competing arguments are inevitably the result of subjectivity that affected the efficacy. When comparing the tectonic activity for small scale watersheds to that at the regional scale, a significantly different scenario emerges. The purpose of the current paper is to provide a comprehensive regional-scale morphometric assessment of Peninsular India. In order to clarify the relationship between the established or proposed tectonic frame and its morphometric manifestation, the results of the morphometric analysis were examined in greater detail in a GIS environment. According to the findings, there is a statistically significant relationship between the tectonic settings and the morphometric signatures of the Peninsular India.

Keywords: *Peninsular India, morphometry and morpho-tectonics, GIS, polycyclic landscape, Western Ghats.*

Introduction

A Peninsular India encompassing Deccan volcanic province has long been under scrutiny and debate over its stability or instability status, which has never been resolved so far. The origin and youthful nature of the most striking geomorphological feature- the Western Ghat escarpment– running the entire length of the west coastline, has been the focus of research and discussion for more than ten decades. The origin of the Western Ghats and or geomorphic evidence of tectonics along the Deccan Basalt Province are constantly under

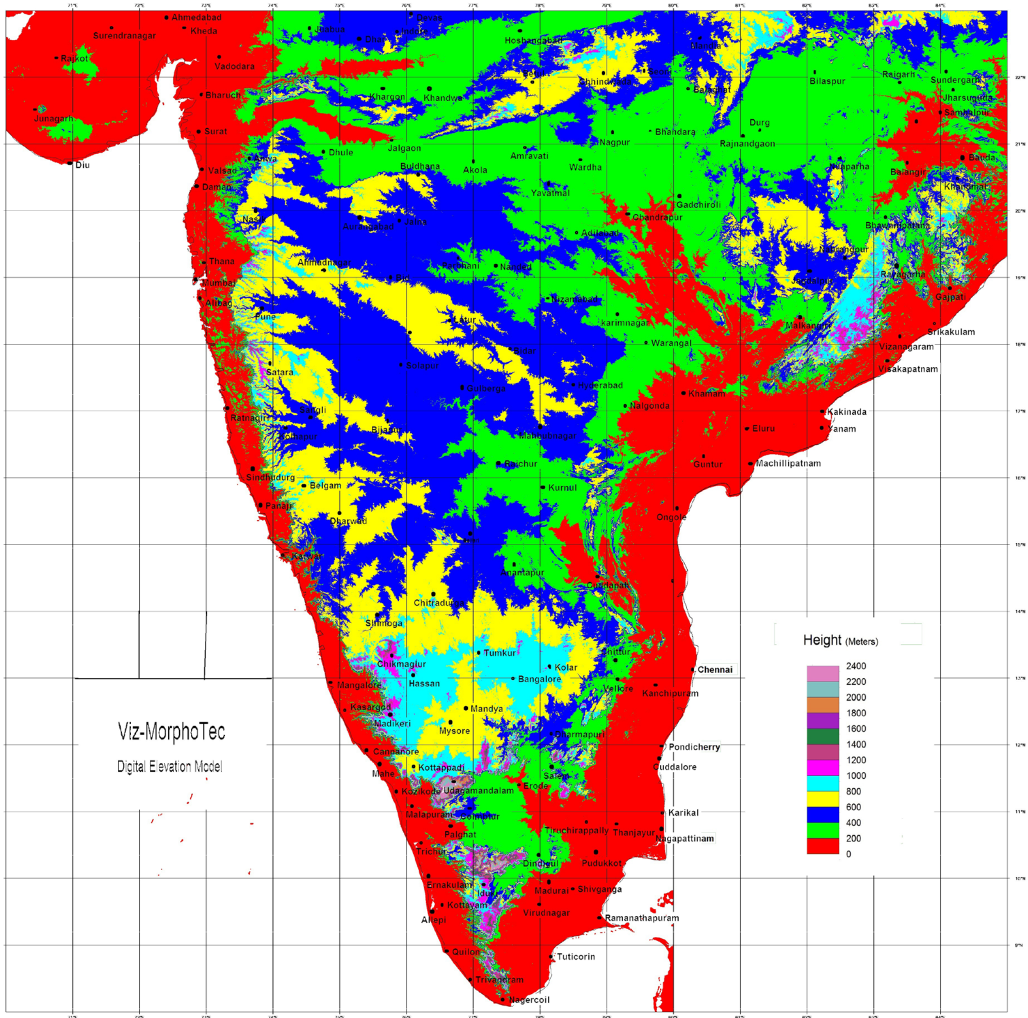

Fig. 1. Digital Elevation Model (DEM) of the study area at the resolution of 15″.

review (Powar & Patil 1982; Kale 2000; Kale & Shejwalkar 2008; Markose & Jayappa 2011; Herlekar & Sukhtankar 2011; Jayappa *et al* 2012; Elzien *et al* 2013; Joshi & Nagare 2013; etc). Powar & Patil (1980) identified the primary lineaments over the Deccan Volcanic Province, which were roughly oriented in the NE-SW, NW-SE and N-S directions. These lineaments reflect shear fractures driven by the North-South compression as a result of the northward migration of the Indian subcontinent during the Miocene Period. Isostatic readjustment brought on by the Indian Subplate's collision with the Eurasian Plate caused vertical cymatogenic oscillations (Powar & Patil, 1980). During Neogene and Quaternary, the Indian Peninsula, which had previously been tectonically quiescent, began to experience significant tectonic activity. It was hypothesized that the eastward inclination of the Indian Peninsula and the formation of the Great Escarpment of the Western Ghats coincided at some point during the mid-Miocene (Radhakrishna 1967; Krishnan 1982). Radhakrishna (1993) narrated the events in Quaternary which have fashioned the Indian peninsular landscape. He put forward that 'it is now becoming increasingly clear that the stable Peninsular Shield has had its share of Earth movements, although somewhat different from those which have affected the Extra-Peninsular Region'. Qureshi (1981) based on the Geologic analysis of Bauger anomalies over Peninsular India proposed epiorogenic subsidence of crustal blocks with respect to surrounding horst like structures. He tentatively concluded that large blocks have moved up and down epirogenically during the geologic past in a rhythmic way as if the earth breaths. These subtle epeirogenic movements postulated by many researchers are bound to have a morphological expression. The present study is undertaken to investigate morphological expression of the tectonics in the regional scale.

Study area

The area of 15°X15° bound by 70ºE to 85ºE latitude and 8ºN to 23ºN of the Peninsular India is taken for investigation. Fig1 demonstrates the input re-sampled Digital Elevation Model (DEM) of the study area at the resolution of 15″. The area covers parts of the Indian states of Gujarat, Madhya Pradesh, Chhattisgarh, and whole of the states of Maharashtra, Karnataka, Andhra Pradesh, Telengana, Tamil Nadu, Kerala, and Goa. The area of this rectangular tile of 15°X15° covering peninsular landmass is over 1.44 million km^2. The plateau is bounded on the east by Eastern Ghats and west by the Western Ghats and they meet at the plateau's southern tip. The Satpuda Range and Vindhya Range, which divide the Deccan plateau from the northern Indian alluvial plains, form the triangle's northern limit. The northwestern part of the plateau is made up of lava flows known as the Deccan Traps. The Deccan Traps were formed around 65 million years ago, at the end of the Cretaceous period (Radhakrishna 1993). These lava flows represent one of the world's greatest volcanic provinces. It covers the entire Maharashtra State, some areas of Gujarat and some parts of Madhya Pradesh. Up to 1.5 million km^2 was thought to have been initially covered by these lava flows (Cox 1980; Mitchell & Widdowson 1991), which is currently reduced to be around 512,000 km^2. An east-west trending deep-seated fault known as Narmada – Son lineament stands as the most conspicuous feature in the whole region with a total strike length of 1200 km, which is believed to mark the boundary between two regimes of contrasting geological history: The Bundelkhand Protocontinent to the north and Dharwar to the south (Anand & Rajaram 2004).

The average elevation of Deccan is about 600 m, sloping generally eastward. The east flowing principal rivers are Godavari, Krishna and Kaveri that start from the Western Ghats and drain into the Bay of Bengal. Another two major rivers, which do not drain into the Bay of Bengal but into Arabian Sea, are Tapi and Narmada River. The Narmada River originates from northeastern end of Satpura while the Tapi River originates in the eastern-central part of Satpura, before meeting the Arabian Sea. All rivers on the Deccan Plateau are rain fed and become dehydrated in the summer months. The plateau's climate is drier than that on the coasts and the rain shadow effect of the Western Ghats is prevailed to the east of the mountain and the precipitation improves further east under the effect of SW monsoon from the Bay of Bengal.

Morpho-tectonics Investigation - Overview

Morphotectonics is the relation between geomorphology and tectonics. It is fundamental to the understanding of landscape evolution. The use of morphometric indices to evaluate landscape stability and to interpret tectonic control on the landscape is well-known concept. Filosofov (1960) demonstrated utility of morphometric maps for tectonic analysis and since then, as new methodologies have been developed and the procedures for creating and evaluating morphometric parameters have been continually refined (Zuchiewicz 1991; Golts & Rosenthal 1993; Rodriguez 1993; Cox 1994; Salvador & Riccomini 1995; Grohmann 2004; Garrote *et al* 2008). Remote sensing data and Geographic Information Systems (GIS) have greatly improved these techniques, especially in the last ten years, making them more agile and precise in their interpretation (Jordan *et al* 2005; Guth 2006; Valeriano *et al* 2006; Grohmann *et al* 2007).

Peninsular India experienced tectonics in its geological past. It is alleged that some portions are still undergoing tectonic movements at a subtle rate. This is bound to impact the morphological expression. Morphometric studies around River Terna, post Killari earthquake incidence of 1994, have supported this belief. Morphometric analysis as a part of geomorphic investigations of Peninsular India, so far have been conducted at watershed or basin level and have remained inconclusive. Two adjacent basins can give contrasting results due to litho-structural diversity, morpho-tectonic units at variable activity levels, orientation of morphological unit vis-a-vis tectonic setup and subtle nature of tectonic movements. In order to enumerate regional tectonic setup and its regional variability, comprehensive morphometric investigation is undertaken to overcome the set limitations, as the analysis of indices at regional scale helps in understanding of a seesaw balance of a larger scale tectonic activity between and amongst the individual basins.

Digital elevation models (DEMs) offer a chance to measure the impact of tectonic behavior on the evolution of the terrain (Shahzad & Gloaguen, 2011a, 2011b). To extract the morphometric indices from digital elevation models and to study landscapes, an increasing variety of techniques and toolboxes have been created over the past ten years. The present morphometric analysis was carried out using ERDAS and ArcGIS, the available software packages for image processing and GIS applications. Additionally, by employing well-known algorithms and procedures, 'Viz-Morphotec', a package of software application programmes for morphometry, was created and used to generate indices for the present investigation. The quantified characteristics include basin's length, area, relief, slope, aspect, shape, stream-length, slope of the channel, density, stream-order, sinuosity and frequency.

Morphometric analysis

The area under present investigation comprises five major river basins i.e. Tapi, Godavari, Krishna, Pennar, Kaveri. The area also consists of parts of Narmada and Mahanadi catchment. Godavari and Krishna are of the highest order and as such comparison between them based on basinal morphometric indices cannot be justified. Hence it is more prudent to evaluate indices of basin of the same order. The statistical measures of the basins of various order defining deviations from the mean value can be used to enumerate scale of tectonics at regional as well as amplitude scale.

The Shuttle Radar Topographic Mission (SRTM) DEM of 15°X15° tile bound by 70ºE to 85ºE longitude and 8ºN to 23ºN latitude covering Peninsular India was used for the analysis. The dimension of SRTM DEM tile at 90-meter pixel resolution is 18000x18000 pixels. Processing of the tile, as a contiguous unit was not possible due to memory and processing time constrain. To overcome this; a tile of 3601x3601 at coarser pixel resolution of 450 meter (15 degree second) was created by resizing the larger tile by factor of one by five. As most of the natural systems are scale invariant and follow law of fractal distribution, it is presumed that computed morphometric indices would adhere fractal distribution thereby facilitating computation of indices at 450-meter pixel resolution without substantially affecting the morphometric analysis at regional scale. However, fractal nature of drainage network was verified by generating stream network by varying input DEM resolution. For this purpose, SRTM DEM tile of 3ºx3º bound by 70ºE to 73ºE longitude and 20ºN to 17ºN latitude of 3601x3601 pixel was used. The same tile was resized to nominal pixel resolution of 180, 270, 360 and 450 meters. The details of stream network computed using these tiles is given in Table 1.

It can be seen from the table that number of streams of given order increases as per DEM resolution and number of 9th and 10th order streams at 90-meter pixel resolution is comparable with number of 7th and 8th order streams at 360- or 450-meter pixel resolution. There is also a reasonable match between the basin shapes at these resolutions. The log-log plot DEM resolution verses number of streams for 5th to 8th order is demonstrated in Fig 2. The

Table 1: Details of Stream Network Computed Using Different Tiles

Stream Order	Pixel Resolution (seconds)				
	3"	6"	9"	12"	15"
	Stram No				
1	5621676	1406129	630108	358649	229448
2	1019093	260185	114281	63535	40635
3	206587	50382	21969	12220	7815
4	43478	10497	4646	2608	1678
5	9253	2314	1040	569	364
6	2058	493	219	118	76
7	445	99	45	28	16
8	97	27	14	6	3
9	22	4	2	1	0
10	4	1	0	0	0

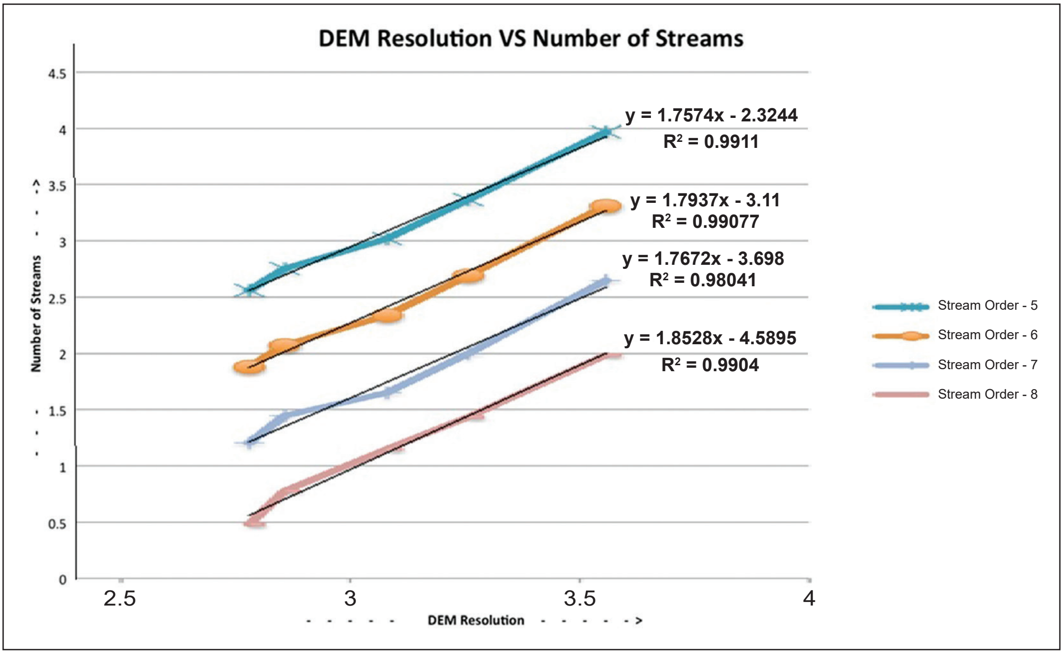

Fig. 2: Log-log plot DEM resolution verses number of streams for 5th to 8th order

R^2 of regression for all distribution is above 0.98. The slope of the regression line, i.e. fractal dimension (D) is 1.75 to 1.85 for 5th to 8th order respectively. The strong correlation between DEM resolution and stream numbers proves scale invariance of stream network thereby facilitating morphometric analysis at various DEM resolutions.

Computation of morphometric indices

There are over twenty-five basinal indices commonly used in morphometric studies. They can be grouped as, Network related - bifurcation ratio, length ratio, elongation ratio, sinuosity index etc.; Density related - drainage density, constant of channel maintenance etc.; Basin geometry - circularity index, form factor, asymmetry index etc.; and Relief related – hypsometric integral, relief index, mean relief etc.

In addition to these basinal indices, other morphometric measures for elucidating active tectonics are also used. These are computed over a grid or line / swath of varying sized – surface roughness, surface index or along a line – mountain front sinuosity index, valley width height ratio, stream knick points, swath profiles. These grid-based indices are then used to highlight morphometric anomaly in association with structural feature such as thrusts / faults, thereby suggesting tectonic activity along these structures. Eighteen morphometric measures, listed at Table 2, were computed for Peninsular India in the present investigation.

Basinal indices

The tectonically stable surface under geomorphic process will follow idealized development by gradual lowering of a surface and evolution of ideal geometric form. This uninterrupted evolution is reflected in morphometric measure to ideal range, such

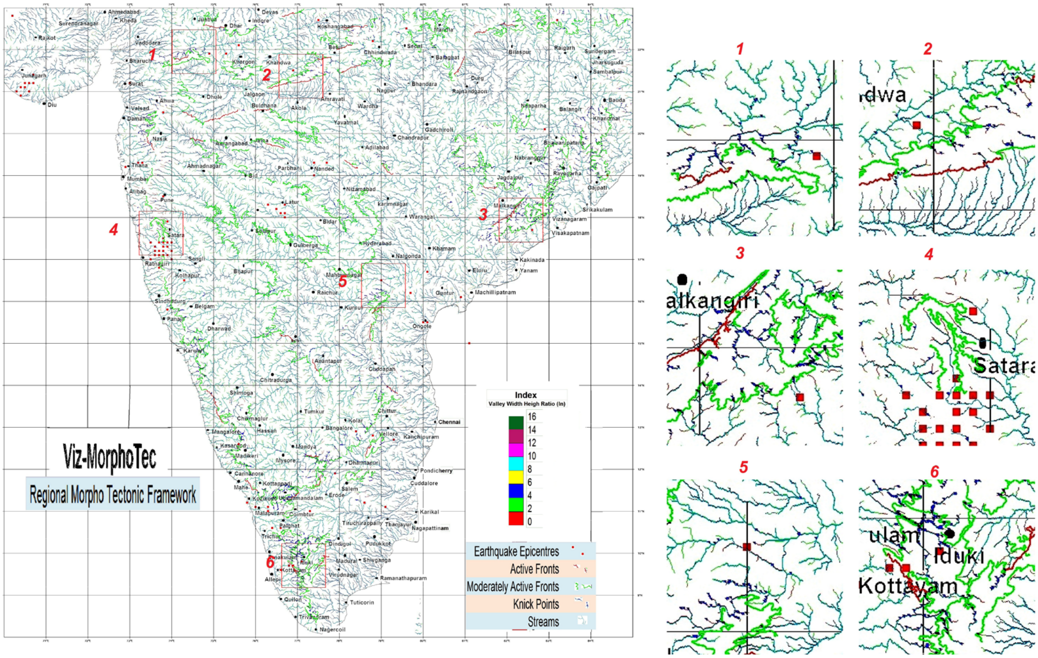

Fig. 3. As contour linearity, knick points, valley floor width height ratio and earthquake epicenters depict underlying tectonics; they are presented together in this figure.

as - bifurcation ratio (3-5), circularity index (around 0.7), asymmetry factor (around 50), low hypsometric integral (<0.3) - is indicative of long-term tectonic stability of the region. Additionally, extreme value for stream length ratio and bifurcation ratio for basin of given order was also reported as these extremes are indicative of structural / tectonic anomaly. Eleven basinal indices (no 1 to 11 listed in Table 2) were computed in the study. The analysis was carried out using Arc-GIS™ and ERDAS™ software utilities in addition to 'Viz-MorphoTec' application programs.

Non-basinal indices

These indices are computed along a line feature or over a grid. Mountain Front Sinuosity (SMF) is a measure of linearity of a contour line tentatively demarcating mountain / hill range from adjoining plain area. It has been frequently observed that tectonically active mountain fronts reveal more straight profiles than the mountain fronts that are inactive. The index value in range of 1.0 to 1.3 indicates active tectonics, while index values 1.3 to 3.0 suggest moderately active tectonics. Although SMF effectively identifies active tectonic lines, its use in morpho-tectonics is limited due to computational complexity arising out of identification of appropriate contour level and its segment wise linearity evaluation. This limitation was addressed by linearity evaluation of all contour lines generated from DEM at 50-meter contour interval. Using 'Viz-MorphoTec' program all contours were digitized and their linearity at 5 km segment length was evaluated. The segments at linearity range of 1.0-1.3 and

Table 2: Grid-based morphometric indices for Peninsular India

Index	Formula	Description	Reference
Mean stream length ratio (R1)	Mean of R1= Lu/ Lu - 1	Lu = stream length order u and Lu - 1 = total stream segment length of the next lower order	Horton (1945)
Maximum stream length ratio (Max_R1)	Maximum R1	Maximum of R1	
Mean bifurcation ratio (Rbm)	Mean of Rb = Nu/ Nu + 1	Rbm Nu = total number of stream segment of order 'u'; Nu+1=number of segment of the next higher order	Horton (1945)
Maximum bifurcation ratio (Max_Rbm)	Maximum Rb	Maximum of Rb	
Form factor (Rc)	$Rf = A/Lb^2$	A = ratio between area of basin; Lb^2 = squared of the basin length	Horton (1945)
Circularity ratio (Rc)	Rc = 4pA/P2	P = basin perimeter: A = area of the basin and 4 is a constant	Strahler (1964)
Elongation ratio (Re)	Rc = A/Lb	A = area of the basin; Lb = basin length	Schumm (1956)
Basin relief (R)	R = H - h	H= highest, h = lowest elevation of the sub-basin	Hadley and Schumm (1961)
Relief ratio (Rh)	Rh = H/Lb	H = basin relief; Lb = basin length	Schumm (1963)
Hypsometric integral (Hi)	Hi=(H_mean-H_min) / (H_max-H_min)	H_mean = Mean elevation H_Max = Maximum elevation H_min = Minimum elevation	
Asymmetry factor (Af)	Af = 100 (Ar/At)	Ar = area of the basin to the right of the trunk stream and At = total area of the drainage basin	Hare and Gardner (1985) and Keller and Pinter (1996)
Valley floor width to height ratio (Vf)	Vf = 2Vfw / (Eld - Esc) + (Erd_Esc)	Vfw = width of the valley floor; Eld and Erd = elevation of the left and right valley divides, respectively, and Esc = elevation of the valley floor	Bull and McFadden (1977) and Keller and Pinter (1996)
Surface index (SI)	SI	Mean Surface index of the basin	Andreani et al (2014)
Surface roughness (SR)	SR	Mean surface roughness of the basin	Andreani et al (2014)
Distance from nearest Earthquake epicenter (D-EQ)	D_EQ	Minimum distance from earthquake epicenter	
% of linear contours (D_L)	D_L	% pixels having linear contours with linearity index <1.3	
% of moderately linear contours (D_ML)	D_ML	% pixels having linear contours with linearity index >1.3 and <3.0	
% of Density of Knick points (D_Knick)	D_Knick	% pixels with Knick points	

@Mean of Grid-based / line-based index value for the basin.

at 1.3-3.0 were identified over DEM and mapped as linear contours and moderately linear contours. As procedure is applied on all contours rather than a specific contour denoting mountain front, the resultant index was named as Contour Linearity Index (CLI) and Moderately Contour Linearity Index (MCLI), congruent to Mountain Front Sinuosity Index.

Natural drainage systems are very sensitive to sudden tectonic deformations, and are the first element of the landscape to respond to such changes. These relief breaks are important drainage gradient anomalies that can be used in studies of regional neo-tectonics (Queiroz *et al* 2015). Using knick point utility of 'Viz-MorphoTec' knick points for Peninsular India were identified and mapped. In a rapidly uplifted region, the streams are incised, valleys are narrow and V-shaped, hence valley floor width to height ratio also is considered as a meaningful index to assess tectonic status of any region. Low values of Vf suggest narrow deep V shaped valleys and high values indicate wide floored valleys. The Vf value for streams continuously increases in downstream direction. Any interruption in this gradual change is indicative of tectonics. Valley floor width height ratio (Vf) and knick points locations over all 5th order streams were also mapped using 'Viz-MorphoTec' program. Vf was computed for all stream segments along its entire length, the ratio is expressed as natural logarithm so as to accommodate and map range of 2 to 20000. As contour linearity, knick points, valley floor width-height ratio and earthquake epicenters depict underlying tectonics; they are presented together in

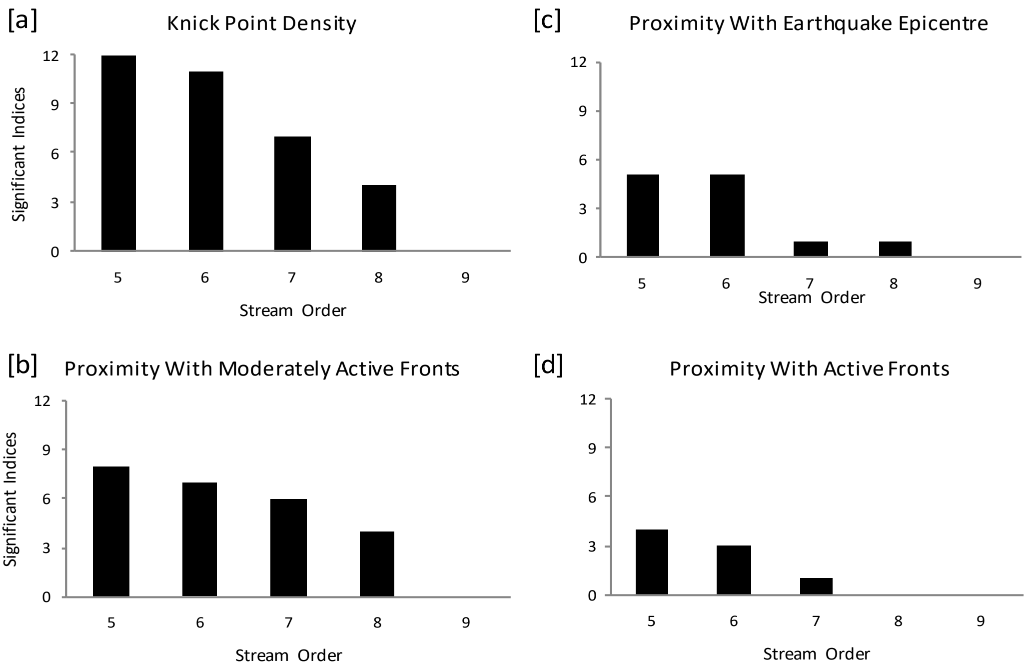

Fig. 4. Number of statistically significant indices verses tectonic indicator for 5th to 10th order

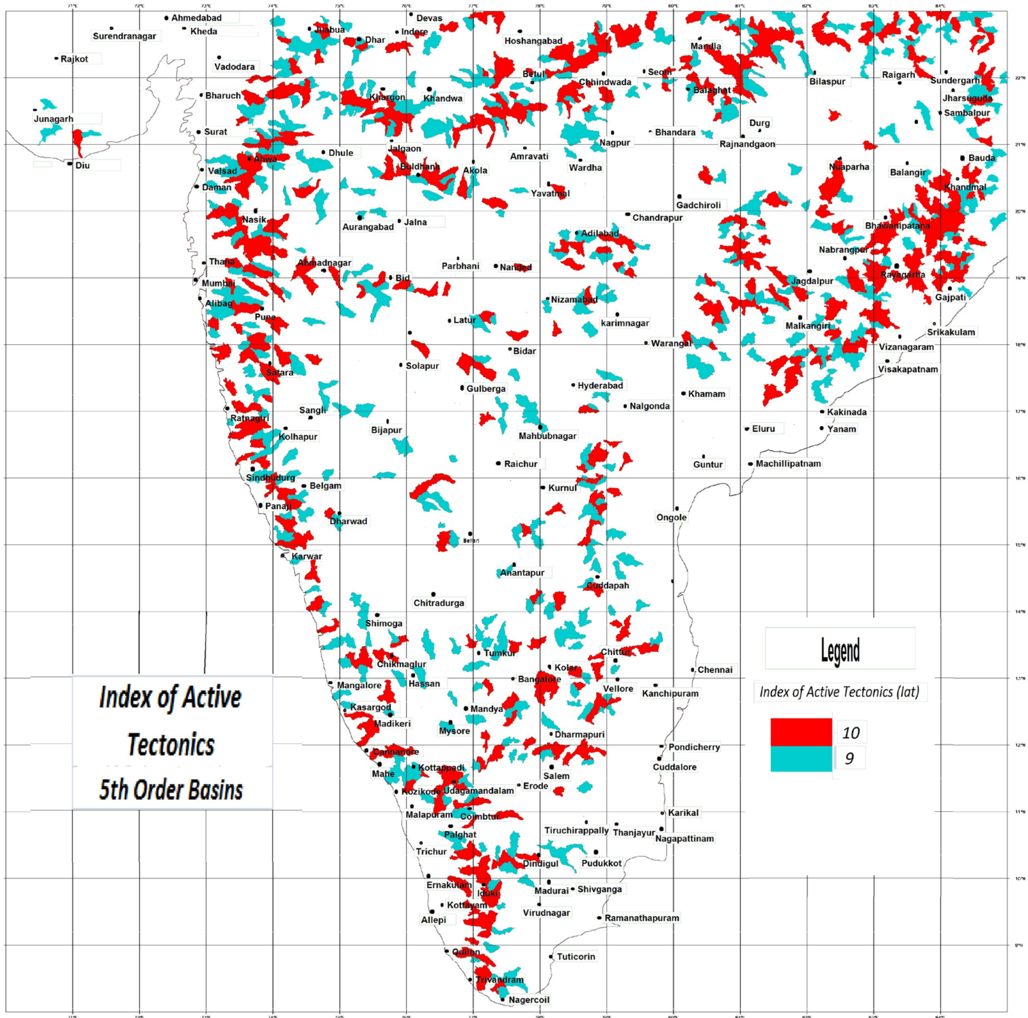

Fig. 5: 5[th] order basin at Iat rank of 9 and 10

Fig 3. Six insets highlighting the relation are also depicted on the same Fig 3. These are Narmada Graben [1], Satpuda hills near Khandwa [2], Eastern Ghat Mobile Belt [3], Koyna reservoir [4], Eastern Ghat Mobile Belt near Nalgonda [5] and Iduki reservoir [6]. These insets underline the association of tectonics and associated morphometric expressions in the form of knick point and Vf variability.

Surface index and surface roughness

The erosional discontinuity - in case of uniform lithology - could arise due to underlying tectonics, which selectively preserves these areas. Andreani *et al* (2014) demonstrated the relationship between erosional discontinuities with main tectonic framework for Ore Mountains and Eger Rift of East Germany and NW Czech Republic. The 'beleveled' planation surfaces of Peninsular India can also be indicative of polycyclic nature of the landscape evolution. In order to investigate erosional discontinuity vis-à-vis planation levels, Surface Index (SI) was calculated as per the procedure enumerated by Andreani *et al* (2014) for Peninsular India. The surface index was calculated by moving window of 25X25 pixels instead of 101x101 pixels. The range of SI for peninsula was found to be -0.86 to 0.86. The regions with SI values above 0.25 represent erosional discontinuity and were found to be associated with the planation levels mapped by earlier workers. The planation surfaces S0 to S3 as referred by Gunnel (1998) of south Indian peninsular shield around Palani, Annamalai and Nilgiri Hlls, Kurg, Karnataka Plateau have SI range of 0.25 – 0.6. Similarly, positive SI values in the similar range were observed for planation surfaces of western Maharashtra, i.e, Kas, Khanapur, Bhimashankar and Parner. Additionally, similar SI range was found over level surfaces of Satpuda, Ajanta and Balaghat ranges over plateau basalt. Some of these surfaces were also found to be in proximity with tectonic indicators like CLI, knick points etc. This implies the role of local tectonics in the development of the planation surfaces in addition to base-level changes. However, the role of tectonics in development of these erosional anomalies needs further investigations.

Morphometry and tectonics – Statistical test of significance

Role of tectonics on morphometric indices is mostly perceived in its deviance from normal range, though the complex relation is rarely verified by statistical techniques. Active tectonics is often deduced by frequent earthquake activity and the presence of numerous knickpoints in the streams can also be taken as the indicator of active tectonics. Active and moderately active mountain fronts are typical surficial expression of tectonics. Hence it is anticipated that the deviance morphometric indices will vary according to basin's proximity with these indicators. In this regard, the statistical significance of the relationship between morphometry and tectonic indicator is evaluated by Pearson's correlation coefficient (r). Pearson's correlation (r) of basinal morphometric indices and averaged non- basinal indices over basin area of for 5^{th} to 9^{th} order basins with tectonic indicators (basins proximity to earthquake epicenters, density of knick points, linear and moderately linear contours of basin) was computed along with its significance using SPSSTM package. The strength and significance were found to differ with basin order, morphometric indices and tectonic indicator. The results are given in Table 3. The statistically significant correlation can be observed with few morphometric indices and the strength of the tectonic indicators is found to vary from very weak to moderate. The strength and significance were found to differ with basin order, morphometric index and tectonic indicator. The main reason for this could be the area and geometry of the basin vis-à-vis intensity and alignment of tectonic activity. The number of statistically significant indices verses tectonic indicator for 5^{th} to 10^{th} order is presented in Fig 4. The lower order basins have a greater number of indices with statistically significant correlation than the basins of higher order. It can be seen that out of all tectonic indicators, the density of knickpoints have statistically significant correlation for maximum number of morphometric indices (Fig- 4a), followed by density of moderately straight contours, proximity with earthquake epicenters and density of linear contours in decreasing order (4b, c, d). High density of knick points indicates concomitant morphological adjustment amid tectonic disturbances, which is mirrored in these indices. Moderately linear contour hints tectonic event of the recent past, which is yet to manifest to the fullest morphometrically, as bared by a smaller number of statistically significant indices. In case of the other two tectonic indicators, those typically express ongoing tectonic activities; they are yet to cast its imprint on the morphometry. Hence it can be said that tectonic chronological adjustment sequence amongst tectonics and morphometry is depicted with respect to other two indicators. The statistical test of significance suggests association between tectonic indicators and morphometric indices and removes any doubt about the efficacy of morphometry in the assessment of tectonic activity at the regional scale.

Areas of active tectonics

Hamdouni *et al* (2007) presented a method to evaluate relative tectonic activity (Iat) over an area using six morphometric indices. Assessment of relative tectonic activity for 5th and 6th order streams for Peninsular India was carried out following the method outlined by Hamdouni *et al* (2007). However, for Iat computation, twelve index values were used instead of six. The Iat were ranked into ten sub-groups where rank 10 indicates highest Iat index. This has increased resolution of Iat and facilitated depiction of relative tectonic activity in otherwise tectonically torpid area. Fig 5 and 6 depict 5th and 6th order basins at Iat rank of 9 and 10. It can be observed that basins with high index of tectonic ~~tectonics~~ activity are associated with Western Ghat, Satpura Range, Gavilgarh Hills and Nilgiri, Kardmom and Anamalai Hills at the southern tip of the peninsula. The areas of high Iat can be found around Harishchandra, Balaghat, Mahadev and Ajantha Range, and around Dandalarayana and Nalmala Hills along Eastern Ghats. In the first instance, these areas appeared as anomaly however the earthquake incidences at Koyna and Killari in spatial proximity with Mahadev and Balaghat range explain high Iat values. In fact, large number of geomorphic evidence / observations in the form of fault scars, stream incision – tilting, fluctuating Valley width-height ratio, terrace upwarping, pointing towards tectonics are reported by a number of researchers.

Discussion and Conclusion

Good number of studies using morphometric indices was undertaken by earlier workers for Peninsular India to enumerate underlying structure and tectonics, however remained inconclusive. So far, almost all of these studies were conducted at watershed or basin level. Two basins can give two individual contrasting results when we try to compute the indices at the local scale but on a larger regional scale it can emerge as a scene that explains a seesaw balance of a larger scale tectonic activity between and amongst the individual basins. Hence, application of the indices on a regional scale can give a more meaningful interpretation of the landforms. Present investigations undertaken highlights variable morpho-tectonics of Peninsular

Table 3 (a): Pearson Correlation: Distance from Earthquake Epicenter

Order	N	Strm_ Lnth_Rto	Max_ Strm_ Lnth	Bifurn_ Rto	Max_ Bifurn_ Rto	Form_ Fact	Cir_Rto	Elong_ Rto	Bsn_Relf	Rlf_Rto	Hyp_ Int	Af	VF	SI	SR	Signi-ficant Indices
5	5305	-0.011	-0.011	-0.003	-0.003	-0.032*	-0.012	-0.031*	-0.123**	-0.134**	0.026	0.01	0.082**	0.085**	-0.137**	5
6	1201	-0.086**	-0.068*	-0.047	-0.034	0.026	0.003	0.023	-0.145**	-0.119**	0.047	0.007	0.067*	0.097**	-0.151**	5
7	279	-0.124*	-0.08	-0.116	-0.074	0.06	0.035	0.067	-0.11	-0.085	0.045	-0.031	0.033	0.055	-0.169**	1
8	56	-0.403**	-0.051	-0.012	0.008	0.175	0.268*	0.173	-0.276*	-0.24	0.011	-0.283*	0.021	0.144	-0.286*	1
9	11	-0.006	-0.093	-0.371	-0.113	0.375	0.25	0.378	-0.099	0.283	0.215	-0.121	0.396	-0.391	-0.079	0

** Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed)

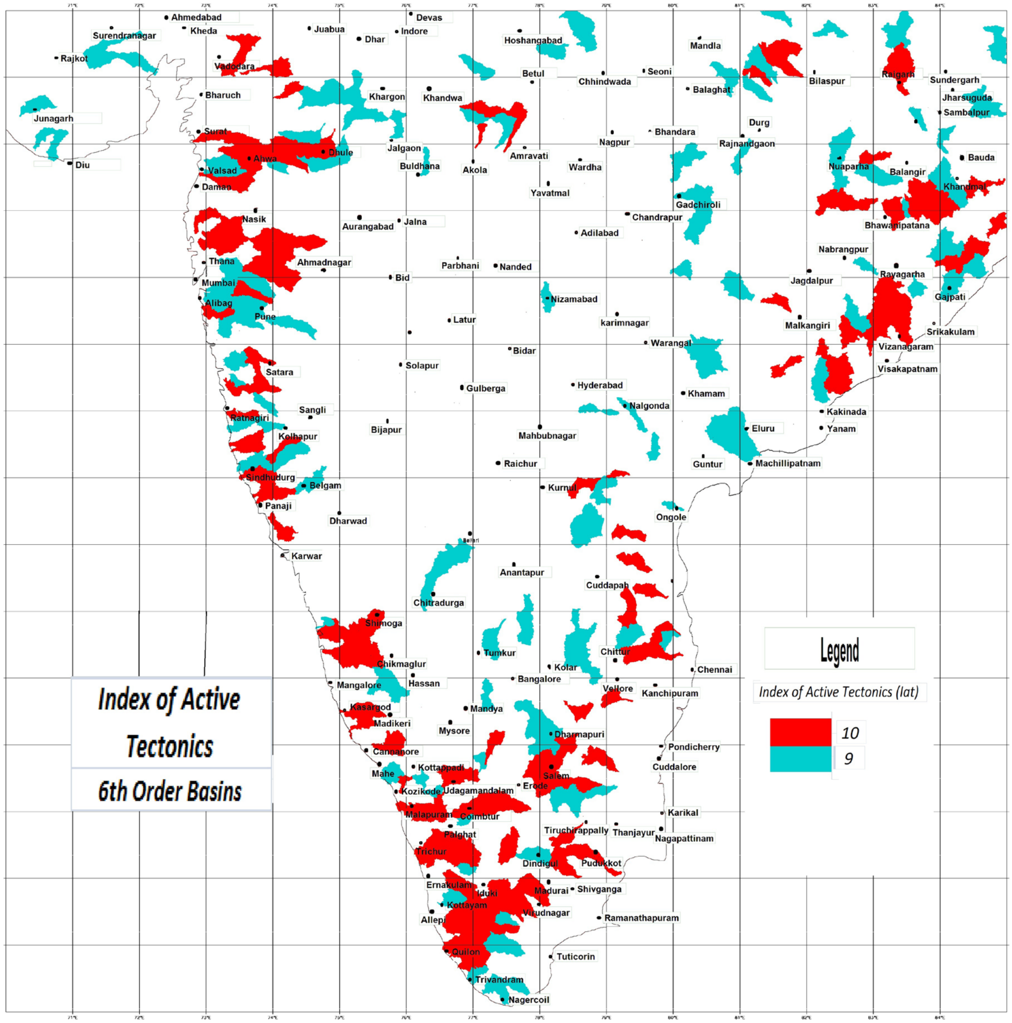

Fig. 6: 6^{th} order basin at Iat rank of 9 and 10

India in contrast with earlier investigations undertaken with limited areal coverage. The results presented in the study brought out the association of planation surfaces in the Deccan Basalt Province with active mountain fronts which is further strengthened by the statistically significant correlation between the earthquake epicenters and the active tectonic indices. The results are supportive of the tectonic activity this region in the past and basis for further investigations.

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