ISSN: 2277-5536 (Print); 2277-5641 (Online)

GEOMORPHIC SUBZONES IN THE LANJA REGION, DISTRICT RATNAGIRI, FROM SOUTHERN KONKAN COASTAL BELT, MAHARASHTRA, INDIA USING DIGITAL ELEVATION MODEL ANALYSIS

Dikshit V.M. and Patil B.S.
Geology Department, D.B.F. Dayanand College of Arts and Science, Solapur. 413002, Maharashtra, India.

ABSTRACT
The Digital Elevation Model (DEM) analysis of the Lanja region, from southernmost Konkan plains was studied to recognize and demarcate three geomorphic subzones from west to east are Dissected Tableland (DTL), adjacent to coast, Low Relief Lowland (LRL), at middle and Escarpment Foothill (EFH). The DEM expressing landscape, lineaments, drainage pattern and various associated geomorphic features tends to infer that these subzones are bounded by faults.

KEY WORDS: Digital Elevation Model, Konkan Coastal Belt and Lineaments

INTRODUCTION

Morphotectonic mega-features of northern section of passive western continental margin of India from west to east are Konkan Coastal Belt (KCB), Western Ghat Scarp (WGS) and Deccan upland (Figure 1). North of $16^{0}30'$ N latitude of these mega-features are covered by horizontally disposed basaltic lava flows of Deccan Traps of Upper Cretaceous to Eocene age. The significant processes related to the effusion of flood basalts are the northward movement of Indian plate over the Reunion Hotspot resulting crustal arching, volcanism, rifting and down faulting of western arm of the rift (Cambell and Griffith, 1990 and Radhakrishnan, 1993). The basement of southern traps is composed of heterogeneous stratigraphic formations mainly include Dharwar Super group, (Rogers and Maudlin, 1994) Kaladgis and Bhima Groups and spans about 3000 million years of the earth's history. These basement rocks are exposed immediately south of Deccan Traps.

Topographic features on Survey of India topographic maps (47H/5,6,9 and 10) on 1:50,000 scale of the Lanja region in the southern KCB showing curvilinear lineaments (Figure 2a) and trellis drainage pattern (Figure 3) has inspired us to investigate and analyze its morphotectonic features. This paper highlights subdivisions of the KCB into three geomorphic subzones. This has been done by extracting the lineaments, geomorphic and structural features and their characterization by using DEMs and field investigations. For this purpose primary and secondary tectonic indicators suggested by Jordan et al., 2005 were considered.

Konkan Coastal Belt

The KCB in Maharashtra state stretches about 720 km from the River Tapi in the north up to the River Terekhol in the south. It is a coastal low-land forming narrow and elongated strip of land whose average width is about 50 km. Geomorphologically western part of this belt exhibits numerous small and short plateaus (butte and mesas) at different altitudes up to a width around 40km from coast line and further east a sudden rise in great heights forms scrap facing towards west and hence the region is traversed by numerous westerly flowing rivers. According to Peshwa and Kale (1997), KCB is characterized by residual hills of moderate to low relief, narrow plains and laterite plateaus. In the plains of KCB planar surfaces occur at 260-180m ASL, 130-100m ASL, 75-60m ASL and 15-3m ASL (Dikshit, 1993), while those in WGS and its adjacent foothills narrow flats occur at 750±50m ASL, and 300±50m ASL. KCB is traversed by several east-wests trending ridges and west flowing rivers and their tributaries with steep to low gradients. They are short and flow over a humid tropical landscape along narrow to broad 'V' shaped valleys. These streams display sub-dendritic and locally modified to form rectangular, braided and trellis to barbed type of drainage patterns as well as right angled bends suggesting structural control. The most common geomorphic features recognized are raised beaches, stabilized dunes, mud flats, drowned valleys, estuaries, laterite platforms, weathered hills, hilly interfluves, cliffs, 'V' shaped valleys, river terraces and nick points. According to Oldham (1894) the deep, narrow and steep sided streams are the result of active incising the landscape and increasing head-ward erosion are indicative of possible active uplift of the land and dictates the streams are striving to achieve counterbalance between erosion and uplift. Studies also indicate the presence of submergence and emergence coast formed due to sea level changes and tectonic movements (Dikshit, 1993). Northern part of the coastal KCB is dominated by submergence, while in the southern part the coastal landforms are indicative of emergence on an E-W pivot centered in the region of the Alibag (Powar, 1993). The West Coast Fault, Panvel lineament and offshore structures are the major tectonic features in the KCB. According to Powar (1980), the N-S trending lineaments are parallel to major structures in KCB indicate characteristic of vertical uplift. It is accepted that the west coast fault, runs parallel to the coast line (NNW-SSE) (Powar, 1981). Thus, it is presumed the west coast of India represents a fault. The Panvel lineament delineates the axis of the monoclinal flexure of Blanford (1867). This lineament has been traced by Auden (1949) for over 120km from Silvasa in Dadra from southern Gujarat to south of Panvel in Maharashtra. According to Das and Ray (1977), it is associated with the line of hot springs and has extension further south up to Rajapur. The basaltic flows east of the flexure axis are horizontal, while those on the western side are dipping towards west or southwest. The amount of dip is higher ($55^0 – 58^0$) in the Panvel region, (Powar, 1981) and it progressively decreases to the south of Savitri River (Powar, 1981) and Ratnagiri (Widdowson and Mitchell, 1999).

The KCB expresses dense network and complex pattern of lineaments. Lineament analysis by Powar and Patil (1980, 81); Deshmukh and Sehgal (1988); Widdowson and Mitchel (1999) indicate that the most common trend of lineaments are NNW-SSE to NNE-SSW, NW-SE and NE-SW. Most of lineaments are preferentially aligned with fracture zones, fault zones, dyke swarms (Powar, 1980; Deshmukh and Sehgal, 1988; Powar, 1993; Dessai and Bertrand, 1995 and Srinivasan, 2002). All these lineaments and the other major morphotectonic features of western India are intimately related to the series of events of intense intra-plate volcanism, the role of compression resulting from the collision of Indian plate and its subsequent subduction below the Eurasian plate and vigorous post-Deccan Trap history of cymatogenic uplift (Powar, 1980 and 1993). The N-S lineaments are related to the volcanism and rifting phenomena of the Deccan Volcanic Province. The NW-SE trending lineaments in the southern Deccan Traps coincide with the structural trends of Dharwar and hence indicate the rejuvenation of weak zones or faults in the basement (Powar, 1980; Widdowson and Mitchell, 1999). The reactivation and superimposition of weak zones in the basement upon the horizontally disposed lava flows of Deccan Traps, has also increased the density and complexity of lineaments in the KCB (Drury and Holt, 1980; Powar, 1981; and Kale and Rajguru, 1988).

MATERIALS AND METHODS

The Shuttle Radar Topography Mission (SRTM) elevation data on a near-global scale was used to generate digital topographic database. Filled and finished data of 3arc second WRS-2 of 90m resolution was downloaded from the GLCF site. Two tiles of height data of WRS-2 was used for the further preprocessing and generation of DEM. The tiles were mosaiced and image subset of study area was clipped from the whole scene. The gaps in data were filled and negative values and sea areas were removed in ArcGIS environment. The SRTM data (90m resolution) was then converted into grids of 30m resolution with the help of bicubic polynomial interpolation algorithm. The subzones were digitized using visual interpretation method in GIS platform (Figure 3). Several digital profiles were extracted in E-W direction and one of them is presented in figure 2b.

To enhance and isolate geomorphic features, the DEM data was reprocessed by using algorithms developed for Topographic Position Index (TPI) and terrain generalization. The former algorithm known as 'terrain sculptor' was developed Jennes (2006) while later by Leonowicz et al., (2010). TPI calculates the difference between a cell elevation value and average elevation values of neighborhood cells. Positive TPI value indicates the cell has higher elevation than its surroundings, whereas negative TPI value indicates lower elevation. TPI analysis provides spatial distribution of landforms in the study area such as, a hilltop, valley bottom, ridge lines, flat plains, slope segments etc. (Figure 4). The terrain sculptor is algorithm which removes unnecessary disturbing details and preserves major landforms. The terrain generalized four images shown in figure 5 were generated by using algorithms for a) low pass mean filter, b) exaggeration and sharpening of ridges, c) exaggeration of ridges and removal of their details with deepening of valleys and d) lowland image generated by widening of valleys to generate generalized lowland. Primary and secondary tectonic landforms (Stewart and Hancock, 1994) expressed by images of DEM, TPI and terrain generalization have been studied and compared on either side of the major lineaments. Similarly, Survey of India (SOI) topographic maps of the study region at scale 1:50,000 have been used for getting geo-information and carrying field visits for ground truths. The ground survey was carried out using hand held Global Positioning System (GPS) receiver and used for accuracy assessment, resampling of images, georeferencing and ground truths.

Dem Model

The DEM (Fig.2A) exhibit general increase in elevation from west to east. The model depicts the perspective view of the landscape, lineaments, associated topographic and landform features, such as the segment of WGS, change in the local relief, slope breaks and degree of dissection. The DEM (Figure 3) shows, variation of gradient and morphology over the area in the form of erosional surfaces, valley forms and their depths, drainages and its patterns of the westerly flowing Kajali, Machkundi, Kodavli and Vaghotan rivers, their tributaries and narrow and elongated drainage basins, linear and curvilinear valleys and ridges and depth of valleys. The DEM analysis helped to recognize secondary as well as primary tectonic indicators. Primary tectonic indicators recognized are; sharp linear and curvilinear valleys, triangular facets, linear ridges, slope breaks, while drainage network, drainage density, drainage patterns and modified valley slopes etc. are the secondary morphological indicators. Digital profile across the E-W line (Figure 2B) and DEM (Figure 3) exhibit three geomorphic subzones from west to east are; Dissected Tableland (DTL) adjacent to coast, Low Relief Lowland (LRL) at middle and Escarpment Foothill (EFH).

TPI and generalized images:

TPI image (Figure 4) discriminates terrain features such as ridges, steep slopes, and plain areas, 'U' shaped and deeply incised valleys. In the case of terrain generalized images, figure 5a and d depict the coastal belt, the WGS and its foot hills, while images in figure 5b and c demarcate ridges and valleys in the coastal belt. The combined mountain model (exaggerated ridges) and lowland model (deepened valleys) of shaded relief image is presented in figure 6. The image of TPI and that of generalized terrain were found useful to recognize various geomorphic features and delineate geomorphic subzones as in case of DEM. The analysis of TPI and terrain generalized images indicate that the EFH is characterized by rugged terrain with development of continuous ridges and deeply incised valleys. Most of well-developed major ridges in EFH are trending in E-W direction and others are in reticulate manner. DTL subzone is characterized by elevated and dissected plateau with number of mesas and associated steep slopes and 'U' and 'V' shaped valleys. In this subzone ridges are at developing stage. The middle LRL subzone is characterized by undulating terrain and broken or discontinuous ridges with steep slopes and 'U' shaped valleys. In this subzone ridges are disappearing as a result of fluvial erosional activities and frequent landslide events.

Lineaments, Geomorphic Subzones and Associated Features in the Lanja Region

Lineaments in the study area have been recognized (Figure 2a) on the basis of linear scarps and ridges, varying shapes of straight to curvilinear drainage segments and deep valleys and linear tonal variations. Lineaments are continuous and discontinuous varying in length from 5 to 85km and most of them have controlled drainage segments exhibiting trellis or asymmetrical drainage patterns. Orientation criteria helped to assemble them into three broad groups, viz., (i) N-S trend (L_1 to L_6), (ii) NW-SE trend (L_7 and L_8) and iii) ENE – WSW trend (L_9 and L_{10}). Detailed studies of DEM, TPI, generalized terrain images and field data indicate that the geomorphic features in three subzones are distinctly different from one another. The L_1 and L_4 lineaments isolate and assist to demarcate geomorphologically the KCB into three subzones.

N-S lineaments are coinciding linear coastal segments (L_5) and straight to curvilinear valleys (L_1 to L_4) and transverse the westward general slope of the KCB. The trends of curvilinear lineaments (L_1 to L_2) are changing from N40^{0}W, through N-S to N20^{0}E. The concavity of L_1 and L_2 lineaments is facing towards west and controlling the deep and strike parallel valleys of Agav and Palu, tributaries of Kajali River. The L_4 lineament is sinus and segmented. Its northern concave segment is facing towards east while its southern concave segment facing towards west. The L_4 lineament has controlled the N-S stream segments of tributaries of Kajali and Machkundi Rivers at west of Lanja and coincide the line of hot springs which extends from northern KCB to the Rajapur. L_5 lineament is segmented and coincide coast line. N-S lineaments are parallel to the regional structures, west coast fault and Panvel flexure, in the KCB. Waterfalls, potholes and 'V' shaped valleys along these lineaments are indicative of rejuvenation. NW-SE and ENE-WSW lineaments are mainly disposed in the eastern region. NW-SE lineaments are traceable in the scarp region and few of them are also extending in the upland region. L_8 extends from Sukh River valley from southeast up to Ratnagiri in northwest. The NW-SE lineaments control the sharp bends of rivers and streams hence indicate rejuvenation which is supported by along stream geomorphic features such as poundings, cascades, waterfalls and pot holes. Intense steep fracturing (Fig. 7A and C) and slicken sliding down the dip indicating vertical displacement was observed along L_1, L_2 and L_5 lineaments. These may be semi vertical extension fractures formed as a result of wide shatter zone in the dilatational hanging wall.

The EFH subzone is hilly exhibits one N-S curvilinear ridge bounded by L_1 and L_2 lineaments and a few numbers of alternate E-W trending ridges and valleys. The region between L_2 and L_3 lineaments has numerous E-W trending ridges and valleys. The height of these ridges decreases towards west and they are truncating at the L_2 lineaments. The zoomed view of these ridges shows triangular facets at their truncation along L_2 lineament indicates the presence of fault (Figure 6b) (Dikshit and Patil, 2012). The E-W trending streams between L_2 and L_3 exhibit higher channel gradients and terraces containing boulders to coarse sand at their lower reaches while gravel and sandy terraces in their upper reaches. Major streams joining L_2 lineament show presence of potholes at their lower reaches, especially Salpe stream exhibit giant potholes. The lava flow contact considered as marker in the eastern regions shows tilting towards east at 6^0 (Figure 7B). Similar type of tilting has been observed in the upland region in contrast to horizontal flow contacts in the subzones of western DTL and middle LRL. These geomorphic features indicate the uplift at subzone EFH with rotation of the block along N-S axis. Such rotation and curvilinear lineaments indicate the presence of listric type of normal faults along the L_2 lineament. If this is the case the L_1 to L_3 are also listric faults, hence they are contemporaneous. Thus, EFH and LRL subzones on either sides of L_1 lineament represent upthrown footwall and downthrown hanging wall respectively. The DTL and LRL subzones exhibit distinct geomorphic and physiographic features. These subzones are separated by L_4 lineament. Stream segments along L_4 lineament exhibits number of potholes in the lateritic bedrock indicating the presence of deep seated fault zone which is rejuvenated. According to Widdowson, 1993, laterites in the KCB are Tertiary. Therefore rejuvenation along L_4 lineament is post lateritization

ISSN: 2277-5536 (Print); 2277-5641 (Online)

during Quaternary. The DTL subzone is characterized by higher elevation, relative relief and degree of dissection than in the featureless LRL subzone (Figure 3). The Dhokachi River traverses the boundary (L_4) between these two subzones. In the LRL subzone, the Dhokachi river and its tributaries characteristically show shallow and wide channels and lower stream gradient whereas in DTL subzone they exhibit deep 'V' shaped valleys and higher gradient.

There are number of knick points along its channel in DTL subzone indicated by the presence of sudden change in gradient, cascades, waterfalls and giant potholes. Similarly, the Dhokachi River, just east of L_4 lineament is shallow with more sinuosity than in the western DTL with deep 'V' shaped valleys, support the deformation along this lineament. Thus, it tends to infer that the weak zone coinciding L_4 lineament is a deep seated normal fault in which the DTL block has upthrown and LRL block is downthrown. The L_5 lineaments are related with the west coast fault. Vertical cliff and associated steep to vertical highly fractured zone at number of locations along coast supports the deformation and presence of fault. The Arabian Sea at west of L_5 lineament represents the downthrown hanging wall while that of east is upthrown DTL. The off-shore seismic investigations and drilling data in the Arabian Sea reveal that the Deccan Traps occur at the depth of more than 150m below the MSL, indicating the down faulting along western margin of India (Dessai and Bartrand, 1995) and support a presence of fault along the coast line.

RESULTS

The N-S lineaments are dominating, seen throughout Lanja area, confirms the continuity and parallelism to mega structures as WCF, Panvel flexure and rift in the offshore. In this region, L_1 to L_4 lineaments are curvilinear, hence they are syn-tectonic, out of these L_1 to L_3 are parallel and their concave traces are towards west, while L_4 shows concavity towards east. L_2 lineament is inferred as a listric normal fault and hence L_1 and L_3 are also the listric faults and make one system. This inference is supported by the presence of triangular facets, asymmetrical and trellis drainage patterns in EFH subzone as well as presence of parallel intense fracturing (shatter zone), poundings, cascades, waterfalls, knick points and pot holes along these lineaments. L_4 lineament is inferred as deep seated fault which has upthrown western block and downthrown eastern blocks. Moreover, the length and depth of L_1 lineament valley is more than other curvilinear lineaments. Thus, L_1 is considered as a major fault and its adjacent L_2 and L_3 lineaments are synthetic faults while L_4 is antithetic fault. In this situation, eastern blocks of each lineament viz., L_1, L_2 and L_3 are upthrown while western block of L_4 is upthrown results in the formation of graben in between L_1 and L_4 lineaments. Such association of faults suggests the presence of half graben structure in the study area. The variation in elevation, relief, slope, gradient, drainage and landform patterns, degree of dissection etc. in these three subzones are as a result of tectonic activity responsible for the development of half graben structure.

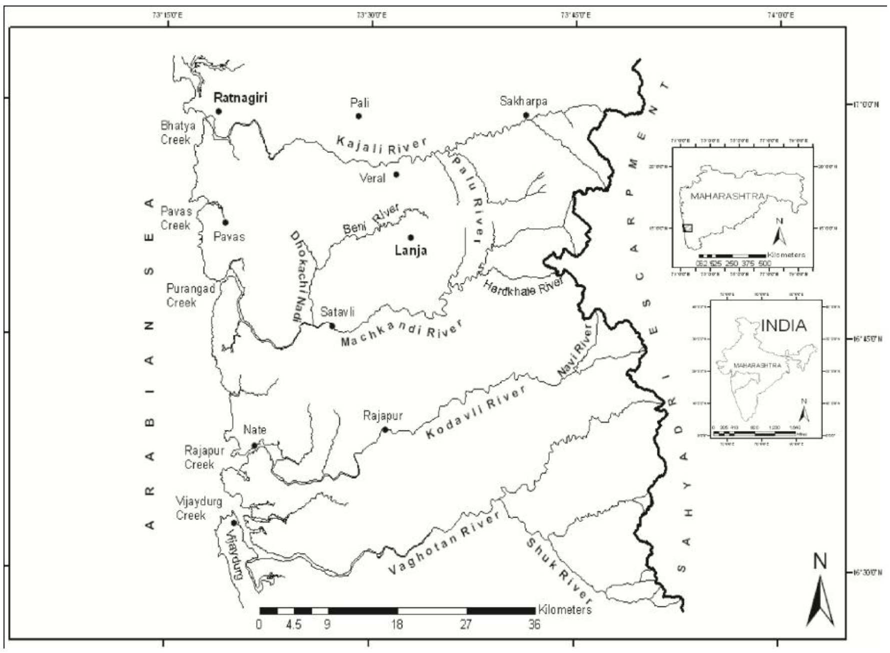

Figure1. Location map of the study area

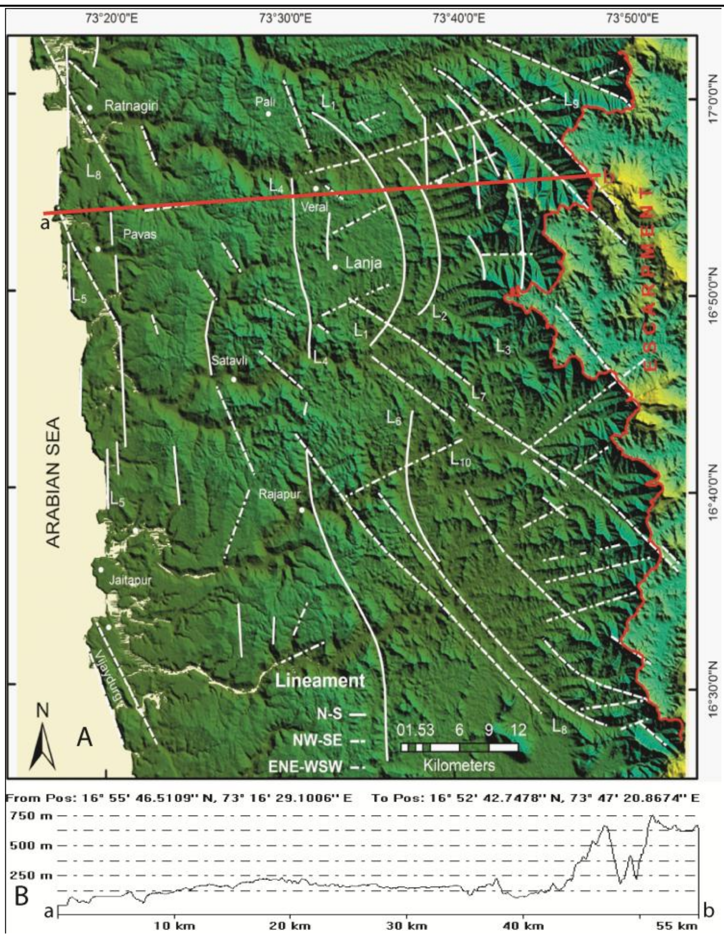

Figure 2. A) Colour coded DEM of the study area showing lineaments. B) Digital profile of the area through a-b (shown in above figure by red line).

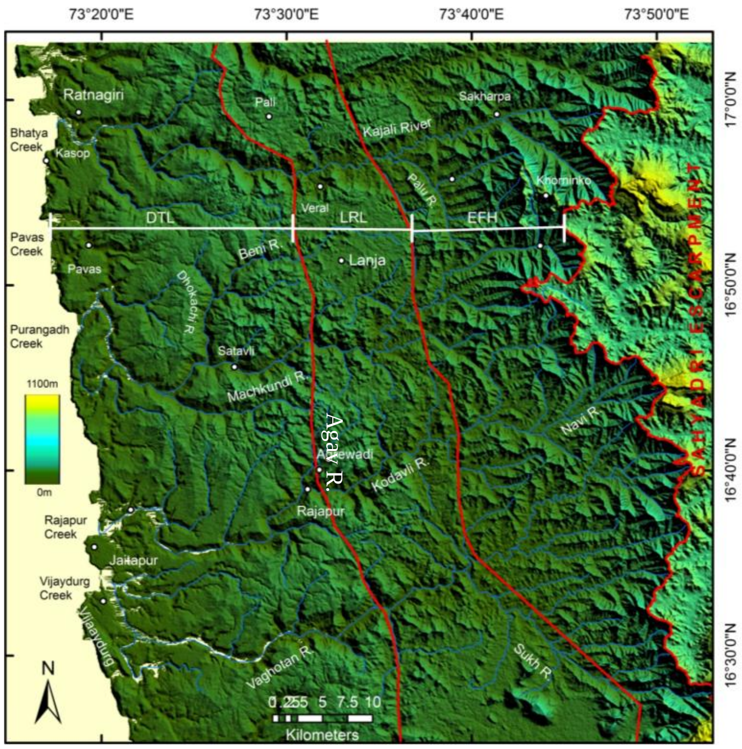

Figure 3. Colour coded DEM of the study area showing three geomorphic subzones and streams.

ISSN: 2277-5536 (Print); 2277-5641 (Online)

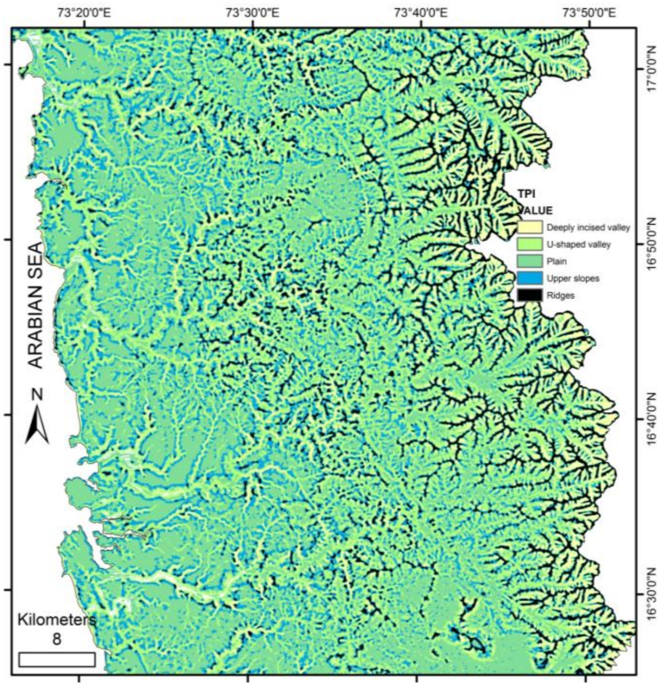

Figure 4: A TPI image map showing various landforms and sharply defines three domains.

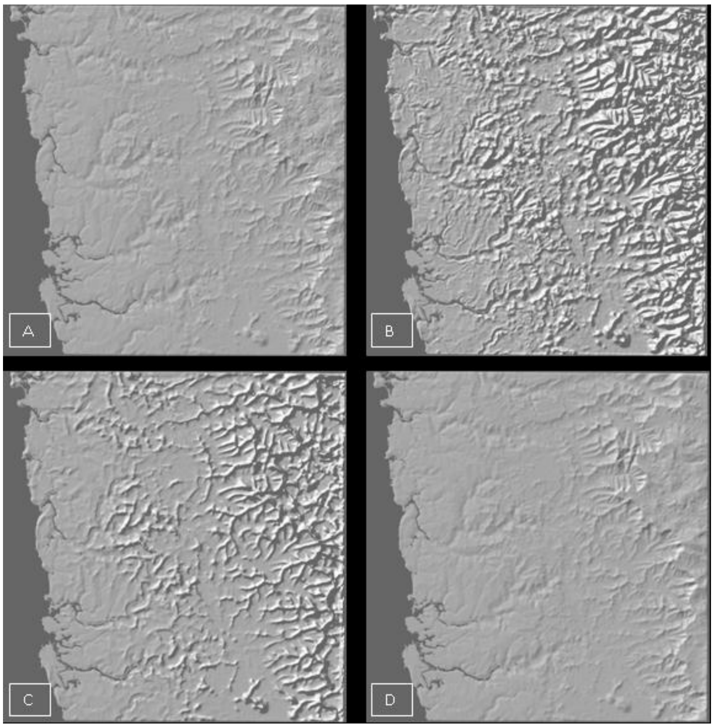

Figure 5. Steps of generalization method. A: low pass mean filtered image, B: ridges exaggerated and sharpened, C: ridges exaggerated, ridge details removed and valleys deepened, D: low-land image, valleys deepened and widened to generalize low areas.

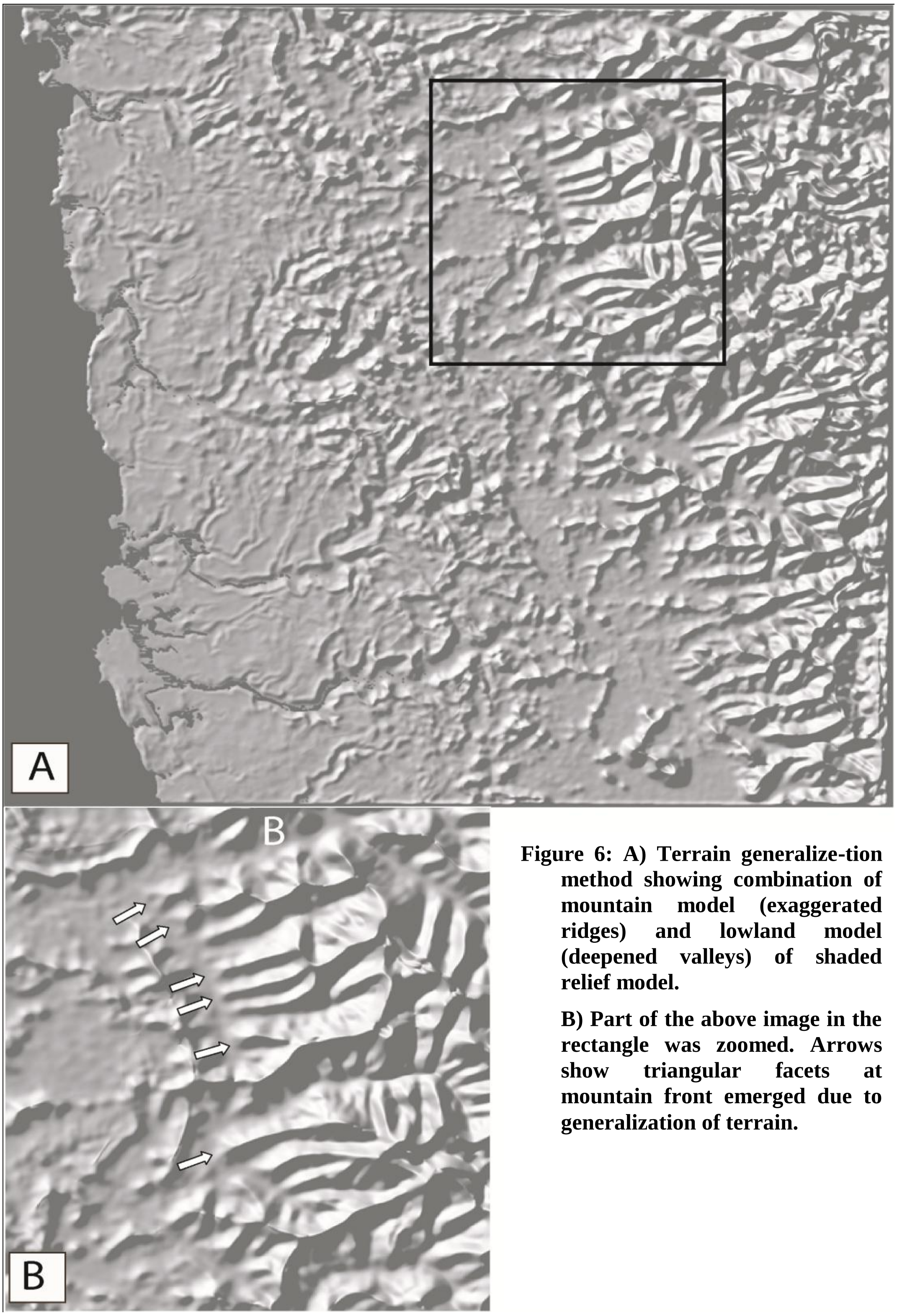

Figure 6: A) Terrain generalize-tion method showing combination of mountain model (exaggerated ridges) and lowland model (deepened valleys) of shaded relief model.

B) Part of the above image in the rectangle was zoomed. Arrows show triangular facets at mountain front emerged due to generalization of terrain.

Figure 7. Field photographs showing steep fracturing and dipping flow contact.

A. Steep N-S fracturing with dip >85^0 Location: Agrewadi

B.: Lava flow contact dip 6^{0}E. Location: Khorninko

C.: Sea cliff exhibiting intense steep N-S fracturing with dip >85^{0}E Location: Kasop

CONCLUSION

DEM analysis is found to be useful to recognize and demarcate three distinct trends of lineaments and three geomorphic subzones in the Lanja region from southern KCB. Three subzones from west to east are Dissected Tableland (DTL), adjacent to coast, Low Relief Lowland (LRL), at middle and Escarpment Foothill (EFH). TPI and terrain generalization image analysis also supports in demarcation of geomorphic subzones. The demarcated subzones are fault bounded blocks related to the uplift, subsidence and tilting.

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