Chapter - 4

TECTONIC GEOMORPHOLOGY

The study area is drained by deeply incising south to southwest flowing rivers from west to east. The major rivers draining are the Hiran, Saraswati, Singwada, Sangawadi, Rupen, Machundri, Rawal, Malan, Raidi and Dhantarvadi River. All the rivers are flowing almost southwards from the rugged topography of trappean rocks to the gently sloping surface of Quaternary miliolite deposits up to coast meeting Arabian Sea. Moreover, the topography observed in the satellite images and SOI toposheets include the formation of sharp meanderings, sudden gradient change, knickpoints, rapids, slope breaks, straight channels, deep incisions and valleys. However, the major contrast in the geomorphological characteristics and topography is observed in the eastern and western side of the Rawal river basin. The division of the morphotectonic domains were considered on the basis of geology, geomorphology, structural control and topography. These morphotectonic domains were investigated separately to understand the morphotectonic setting and neotectonic evolution of the present study area.

The morphotectonic domain-I includes three major river basins Malan, Raidi and Dhantarvadi River in the eastern part of the study area covering the approximate area of about 1183 km^2 (Figure 4.1). The morphotectonic domain-I consists of rocks of Deccan Trap Formation, Gaj Formation of Tertiary and Miliolite Formation of Quaternary deposits (Merh, 1995). This domain comprises the region around Rajula and consists of mainly the rugged hilly topography developed over the Deccan Traps and the south sloping coastal segment with miliolite deposits of late Quaternary age with present day mudflats. The Tertiary rocks occurs in a coast parallel thin belt to the south of Rajula between the Deccan Traps and miliolite while further west they are buried under miliolites. The area also comprises of an extensive zone of structurally controlled dykes which have been studied mainly for petrology and geochemistry (Chatterjee and Bhattacharji, 2001, 2004; Sheth et al., 2013). However, no structural data or previously mapped faults responsible for uplift or earthquake swarm are known from the area.

4.1 TOPOGRAPHIC ANALYSIS

Several topographic topographical profiles were drawn from Survey of India topographical map on 1:50000 scale. The topographic section were drawn along the river basin trends covering all the geomorphic zones and structural attributes from highland to coastal plain (Figure 4.1). The cross profiles of three sections from NW to SE are made to understand overall landscape. The largest basin in this domain, Dhantarvadi river basin, flows eastward from the undulated hilly source region. The river flows between dissected hills and valleys in the upland zone (Figure 4.1, A-A′). These area also comprises of fault zones, shear zones, tilted lava flows and knickpoints in the channels. The river flows between the highly dissected hilly region and ENE to NE trending dyke swarms. Flowing towards east, there is a sudden bend in the main channel towards SSE in the middle reaches (Figure 4.1). At this river bend, a very thin cover of alluvial deposits were observed near Dhantarvadi dam in the middle course up to the lower reaches of the river. The middle part of the basin is entirely covered by dyke swarms at right angles to the channel and its tributaries. The dyke covered upland zone consists of uneven terrain and low dissected ridges. The change in topography is noticeable at the base of mountain front with gentle slope (Figure 4.1, A-A′). The pediment cover is observed where gently coastward dipping surface comprises of eroded trappean rocks overlain by Tertiary rocks. The gently sloping planar surface covers the area up to coastal zone. The Quaternary miliolites are observed in the coastal zone shows ~20 to 25m high coastal cliffs. The intertidal flats were observed between the pediment surface and coastal cliffs.

The topographic section B-B′ is towards west of section A-A′ which a distinct variation in the landscape. The upland zone covered by trappean rocks shows undulating high elevated terrain consisting of dissected dykes and cuesta ridges (Figure 4.1, B-B′). The topography is less rugged in the middle reaches of Raidi River, however, few scattered dykes trending NE-SW cuts the river at places. The dyke ridge near Katar ridge is observed at the retreating mountain front in the upland zone (Figure 4.1, B-B′). The pediment surface covers small area where by Tertiary deposits dipping gently towards coast. The coastal zone is extensive with large intertidal zone and ~20 m high marine cliffs are observed near Jafarabad coast (Figure 4.1, B-B′).

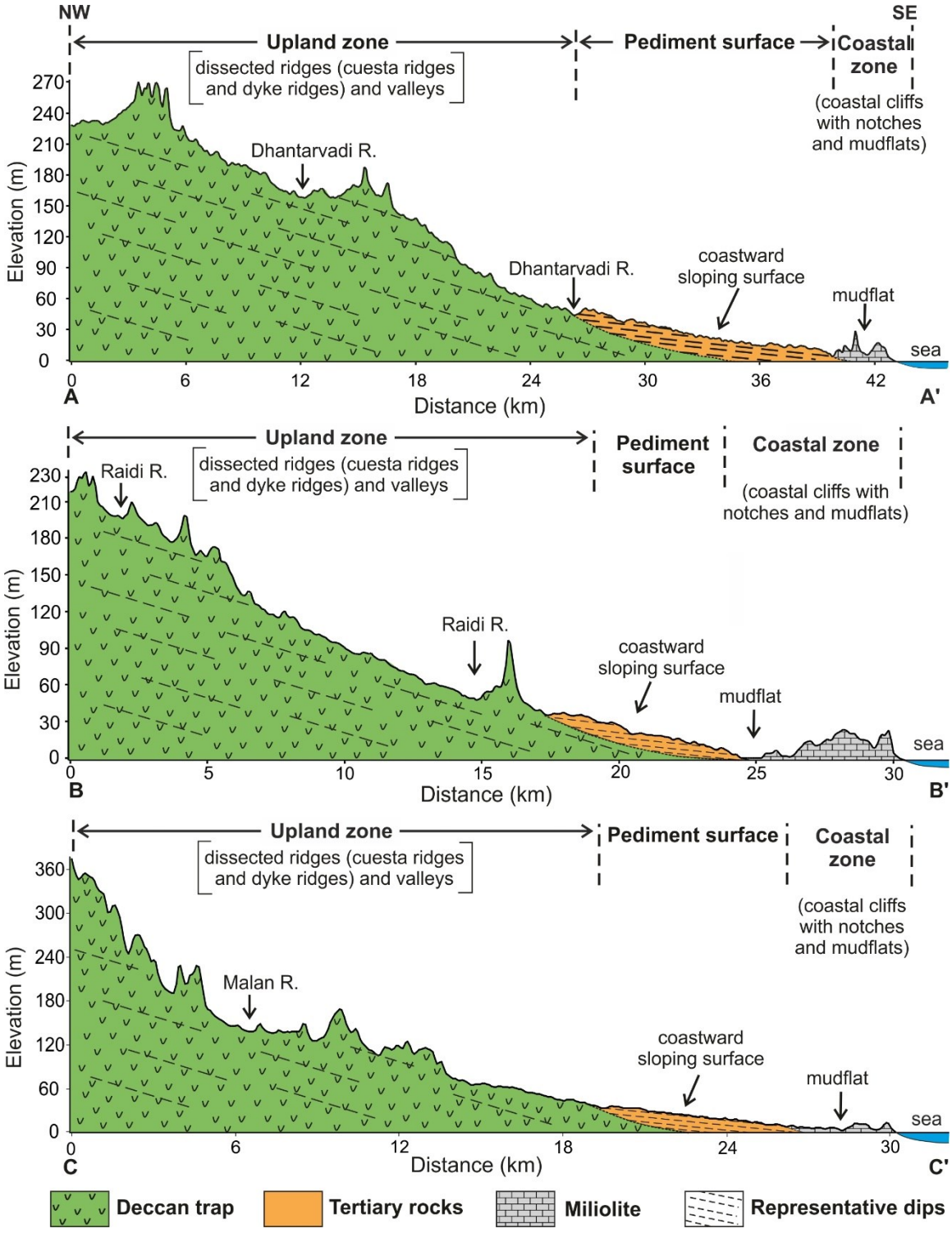

Figure 4.1 NW-SE Topographic profiles along three major rivers Dhantarvadi (section A-A'), Raidi (section B-B') and Malan (section C-C') showing distinct geomorphic zones along with various geomorphic features. Cross-sections are shown in figure 3.2.

The morphotectonic domain II divides from domain-I to the west of Malan basin. The topographic profile obtained from the section C-C′ shows three distinct features:

highly dissected hills and valleys, steep fault scarp and zone of dyke swarm. The upland zone in the profile shows rugged topography till the gentle slope towards coast. This cross section shows hilly topography in the upland zone having maximum elevation of 360m compared to other sections (Figure 4.1 C-C′). The dyke swarms terminates here due to the presence of fault. The fault scarp in the profile is clearly observed between dyke swarm zone and hilly terrain. The main channel flows along with the fault towards south till the pediment cover. The gently sloping pediment surface covers large area accumulating alluvium from the small streams and major channels merging the intertidal flats. The Tertiary rocks are exposed widespread underlying the alluvial deposits. The coastal zone comprises of mudflats and miliolite cliffs (Figure 4.1, C-C′). However, the cliffs observed towards the west of the Jafarabad are of ~5 to 15m high. The Quaternary deposits are mainly beach dune complexes, mudflats of Holocene age which covers limited area near Malan basin. In this domain, the change in overall topography is observed from north to south, i.e., rugged to planar landscape. Moreover, from east to west, the variation in geomorphology and structural attributes were evident. The complexity of the terrain in morphotectonic domain-I is mainly due to the presence of dyke swarms, shear zones and fault scarps.

4.2 DIGITAL ELEVATION MODEL (DEM) ANALYSIS

The DEM analysis of this domain shows mainly ~NE trending dykes and linear ridges with shows various prominent structures, deeply incised rivers, sharp meandering, fault line/fault scarp and aeolinite ridges near coast. The west part of the Malan River basin shows clearly the uneven topography with sudden gradient change forming mountain front. This is due to the presence of probably a large fault or lineament which extends from far north near Khambha village to coastal zone at south trending NNE to NE. This fault line is observed in the headland region of Dhantarvadi drainage basin where the extension of the mountain front is observed trending ~NE-SW. The Dhantarvadi River has larger basin compared to other major river basin in the study area. The river eroded maximum terrain of trappean rocks and ~NE trending dykes and hence the area is observed as partly rugged/partly plain terrain. The main trunk stream of Raidi River flows towards east making the basin completely asymmetric. The Katar Fault (F1) as observed is the drainage divide of the Raidi river basin and small rivers flowing

southwards. This fault extends towards east up to the mudflats, east of Dhantarvadi river basin. The ~NE trending dykes terminates near the probable Katar Fault extension observed in Dhantarvadi river basin also. Observing all topographical changes, slope map and aspect map were made to understand the regional gradient and the direction of slopes.

4.2.1 Slope data

The slope map generated for this domain shows the variation in color change that exhibits the different degree of slopes (Figure 4.1a). The sudden gradient changes is mainly due to the topographic variation and behavior of river on the trappean surface. To understand the variation in degrees of slope, the area is separated into three divisions: 0º to 45º (gentle slope), 45º to 75º (moderate slope) and >75º (steep slope) (Figure 4.5). The upland zone of the domain shows steep to moderate slope due to several hills, lineaments, ridges and scarps. This because of to the presence of structural features like faults, dykes or joints. Moreover, the slope abruptness is also observed along with Malan River dividing the basin evidently by hills and linear dykes on either sides. The rivers eroding the pediment surface forming moderate to gently sloping surface up to the coastal zone. These moderate slope area observed mainly near the coastal zone due to the presence of vertical sea facing miliolite cliffs. Considering the channel and tributaries, the large cliff sections, fluvial terraces and deep channel incision also shows moderate to steep slope.

4.2.2 Aspect data

The aspect map shows varied pixels with the majority of the area is sloping towards south and southwest (Figure 4.2b). The ~NE-SW trending linear dykes and cuesta ridges are mainly showing west, north and northwest slope and the pixels observed such that the termination of the dykes is seen. The Malan River flowing ~ SSW terminates the dyke swarms. The cuesta ridges trending parallel to the dyke swarms exhibits the west and northwest gently slope. The trappean lava flows observed in this study area shows south to southwest tilting. This slope direction is a result of the southward draining of the major rivers. The upland zone as well as pediment surface reveals the northwest and northward gradient while the coastal zone displays a variations in pixels. However, the pixels showing north and northwest slope parallel to the coastline indicating the aeolinite ridges of Quaternary age. Such type of aeolinite ridges and coastal cliffs with the slope towards inland explains the coastal uplift which is observed all along the S and SW coastline.

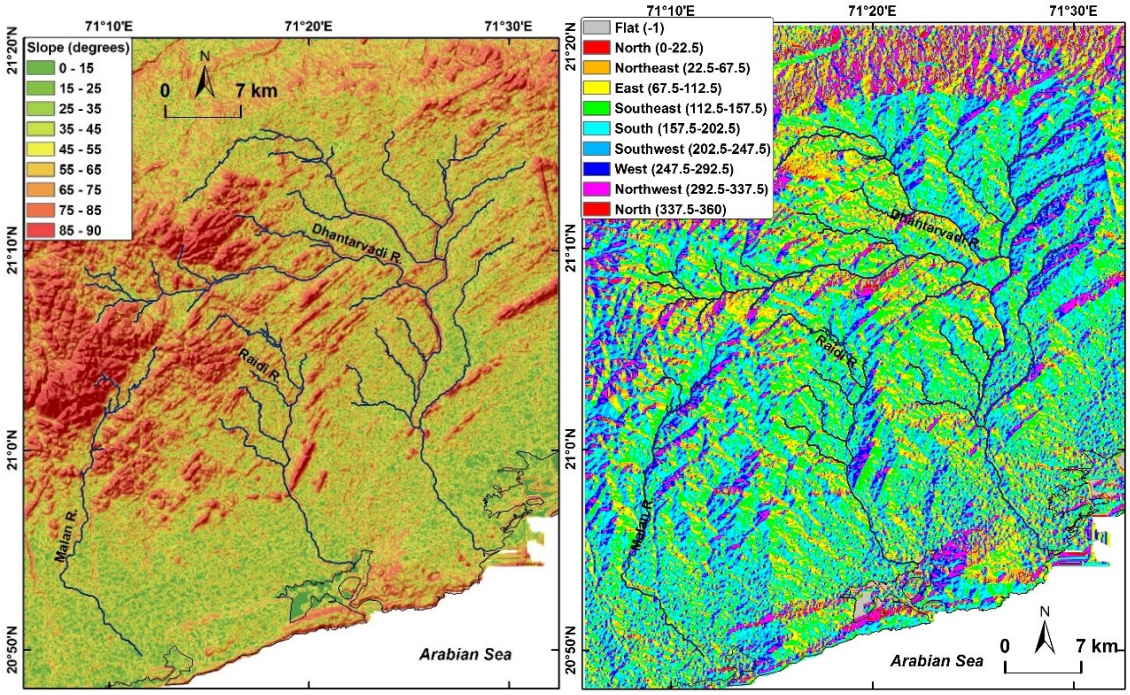

Figure 4.2. Slope map (left) and aspect map (right) of morphotectonic domain-I. Slope map showing steep slopes in the upland zone on dyke swarm and cuesta ridges. Note the north to northwest facing escarpments and southeastward gentle slopes due to tilted lava flows. Aspect map showing the direction of gradient with majority of area is sloping towards southwest.

4.3 LINEAMENT ANALYSIS

The morphotectonic domain-I covers >1500 km^2 with dense lineaments observed on the trappean surface due to the presence of dyke swarms (Figure 4.3). Three major rivers viz., Malan, Raidi and Dhantarvadi flowing southwards on the trappean lava flows, cutting dykes and merging in the coast (Figure 3.1, 4.3a). The spatially distributed lineaments observed all along this domain. The linear features are mainly dykes, cuesta ridges, fault scarps, straight channels, mountain fronts and coast parallel dunes and ridges. Total 390 lineaments were traced in this domain and the total length is about 1196.13 km (Figure 4.3). The maximum length of the lineament is about 12.05 km while the minimum lineament length is about 0.53 km. These lineaments extends from Talaja at the east area up to the south flowing main trunk stream of Rawal River at the west of the domain (Figure 4.3). In this zone, the dyke swarms observed from the easternmost part extending towards west up to Malan river channel and swings southward and later ends near coastal zone.

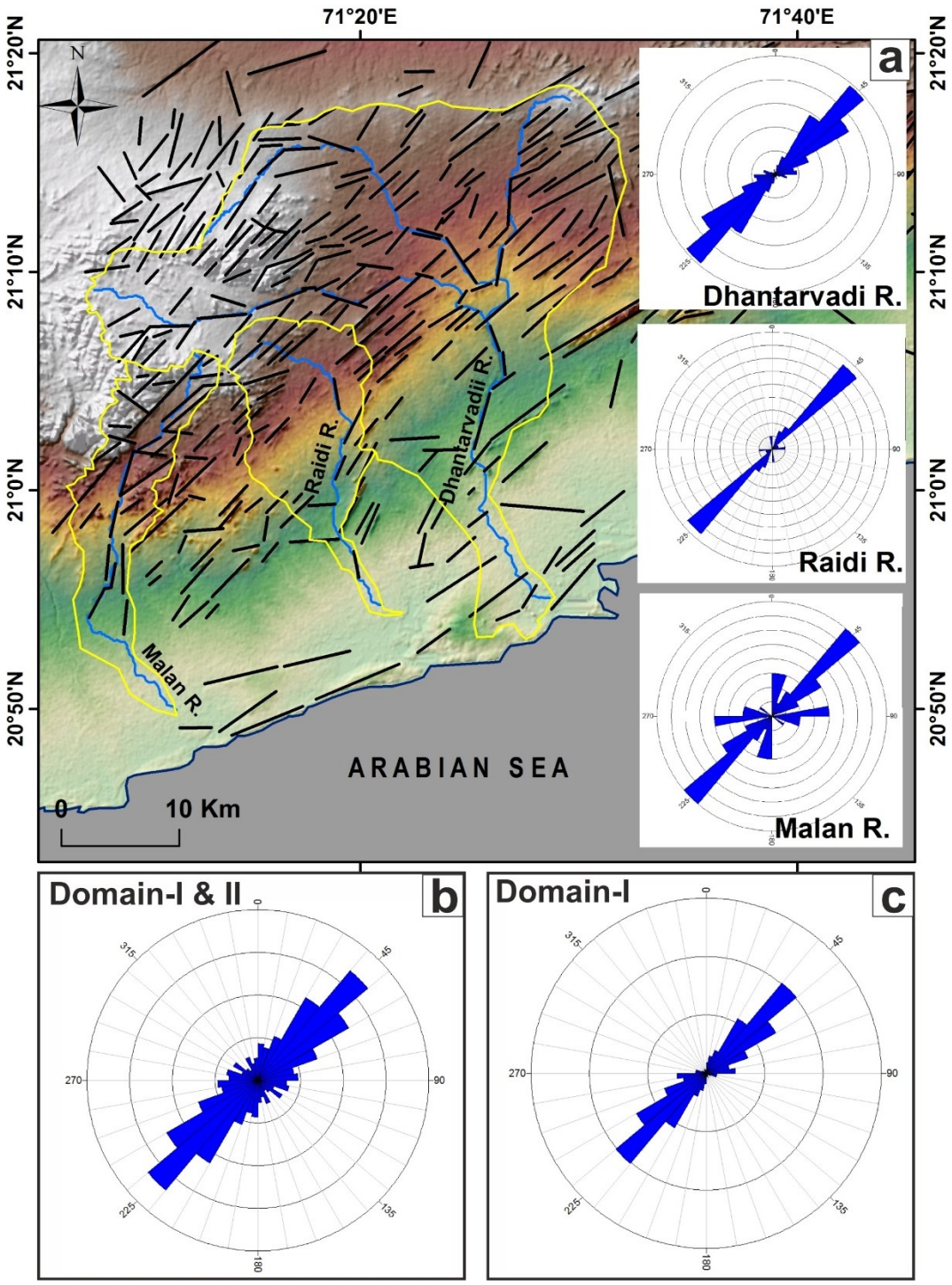

Figure 4.3 a) Lineament Map of the morphotectonic domain-I showing three river basin. Rose diagrams of lineaments observed in individual basin showing NE-SW as major trend. Note that the lineament trend near Malan River shows ENE-WSW trend. b) Rose diagram of lineaments of study area showing three dominant trend: NE-SW, ENE-WSW and NNE-SSW. c) Rosette of domain-II showing majority of lineaments trending NE-SW and few ENE-WSW following dyke swarm trend.

The Dhantarvadi river basin covers ~867 km^2 with about 175 lineaments traced showing two major trends i.e. NE-SW and ENE-WSW (Figure 4.3 a). This is due to the ENE to NE trending dyke swarms extending from the further east towards this zone. The lineament density is mainly observed on the rugged terrain of trappean rocks while in Quaternary coastal plain, the density of these feature is very less. The area with less dense linear features consists of Quaternary sediment cover over the tertiary deposits underlying the traps. The lineaments observed on the coastal zone is almost parallel to the present day shoreline i.e. ~NE. The Raidi river basin covers ~162 km^2 and 31 lineaments shows ~NE-SW prominent trend (Figure 4.3a). The orientation of the lineaments changes from ENE-WSW to NE-SW when extends towards west. This clearly signifies the change in lineament orientation towards west due to the variation in dyke swarm pattern. Some ~E trending ridges also observed in the Raidi river basin. The Malan river basin covers ~154 km^2 to the west of the domain where dyke swarm swings southward towards coast. About 32 lineaments traced in this basin shows three trends, viz., ~NNE-SSW, NE-SW and ENE-WSW. These lineament directions is due to the presence of ~NNE-SSW to ~ENE-WSW trending fault scarps obstructing the westward extension of ~NE-SW trending dyke swarms.

The noteworthy variation observed in the trend of the lineaments is from east to west towards Malan River. The dykes swings towards SSW near Malan River due to Girnar intrusive (Vanik et al., 2018) where the morphotectonic domains were distributed. The three lineament trends in Malan basin is NE-SW, E-W and NNE-SSW of dyke swarms. The swing of the dykes is evident in the lineament map as the shows three different trends in this domain. Comparing this with the major structural lineaments of domain-I and II, the NE-SW shows prominent trend (Figure 4.3 b, c). However, multiple trends in the entire study area also noticeable. This infers that the morphotectonic domain-I is structurally controlled by the dyke ridges and cuesta ridges showing dominant ENE to NE trend.