Chapter 6
Results and Discussion

Identification of active tectonic signatures in continental interiors is a challenge because the erosional processes are faster than the generation of geomorphic evidences of active tectonism. Though many studies were carried out in such terrains to understand the nature of active tectonism, there are lacunas in characterizing active faults because of limitation in applicable methods. Thus, the present study utilized all the available methods/techniques in morphotectonic evaluation to arrive at a more realistic assessment of active tectonic signatures. The study carried out in a part of peninsular India lying in the south western terminus of Palghat gap, where there are instances of ongoing seismicity (Fig. 1.4).

The area is drained by four rivers namely Bharthapuzha, Vadakkancheripuzha, Karavannur river and Chalakudipuzha which are flowing towards west and debouching in the Arabian sea. The basement rocks mostly constitute charnockite with occasional occurrence of gneissic rocks. The NW-SE trending dolerite dykes are the other major basement geological unit in the area (Fig. 6.1). To evaluate the nature of active tectonism in the area, systematic geomorphic, morphometric study including the remote sensing data analysis and field investigation has been done.

6.1 Lineament Setup

In the study area five lineaments were marked earlier by GSI (2000). Off these Periyar lineament and Idamalayar lineament are prominent ones trending in NW-SE direction. GSI (2000) has also marked three faults in this region viz., Pattikkadu-Kollengol, Malayattur-Vadakkanetretti and Ottappalam-Kuttanpuzha fault. The north western continuity of Periyar fault is also marked as a major NW-SE trending lineament in the study area. Later studies identified a NW-SE trending SW dipping reverse fault (Desamangalam fault) based on the geomorphic and field studies (John and Rajendran, 2008; 2009).

In the present study the lineaments are delineated through visual image interpretation. Mostly they are segmented but are following the same trend. During the image analysis, no signature have been observed for Pattikkadu-Kollengol fault but there are the signatures of Ottappalam-Kuttanpuzha fault as discontinuous features. The Malayattur- Vadakkanetretti Fault is falling outside the study area.
Fig. 6.1 Regional Geology and Structure of the Area with Lineament Identified in the present Study (GSI, 1992)
The study area is dominated by NW-SE trending lineaments, though there are some lineaments trending E-W, NE-SW and N-S to NNE –SSW also observed (Fig. 3.1). The E-W lineaments are mostly confined to northern side, up to Bharathapuzha river and are part of Palghat Cauvery Shear zone of Proterozoic origin (Bhaskar Rao et al., 1996; D’cruz, et al., 2000). The NW-SE Idamalayar lineament has disturbed the Bharathapuzha river course at Ottappalam (Fig. 1.4, 6.1) and overprints on the original E-W trend in the northern side of the river (John and Rajendran 2008). These NW-SE patterns of lineaments controlled by emplacement of basic dykes connected with Deccan volcanism (Krishnaswamy, 1981; Nair, 1990).

The present study identified four sets of NW-SE trending lineaments in the area. Lineament ‘a’ represent Idamalayar fault/lineament and ‘b’ appears to be connecting Idamalayar and Desamangalam fault (Fig. 3.1).The lineament ‘c’ resembles continuity of Periyar lineament. The South eastern extension of the ‘c1’ and ‘d’ are appears to be merging with the Periyar lineament (lineament c). However, the signatures of the NW-SE trending lineament (‘d’) are feeble in the low lying coastal area. The lineaments ‘c’, ‘c1’ and ‘d’ are bisected by the two sub parallel segments of NE-SW trending lineaments, and are grouped as ‘e’ lineament in the central part of the study area. This ‘e’ lineament appears to be converges into a single lineament, in its north eastern extension. Further north eastern continuity of this lineament after ‘b’ lineaments is also not observed in the image studies.

In the north western part of the area some N-S, NE-SW, NNE-SSW, WNW-WSE trending lineaments have also been marked during the image studies. Since they have the limited regional extent and don’t have any affinity with any of the regional structure existing/identified, they have been kept as unnamed lineaments.

6.2 Observations From Morphometric Variables
A number of landscapes in different part of the world have been studied using conventional morphometric parameters to extract information for flood potential of an area (Horton, 1945; Strahler, 1952;1957; Leopold and Miller 1956). In recent time many of these parameters are found to be useful in understanding the presence of active tectonism (Ritz et al. 2016; Lin et al. 2015; Choi et al. 2015; Kothyari et al. 2016; Rao et al. 2015; Balen et al. 2015; Topal et al. 2016; Bhosle et al. 2007; Geothals et al. 2016; Silveira et al. 2009; John and Rajendran, 2008; Lunina et al. 2008; Giaconia et al. 2012; Bucci et al. 2013; Naccio et al. 2013; Fattahi et al. 2014;
Fig. 6.2 Distributions of Various Zones in the Study Area
Cultera et al. 2015; Gürbüz et al. 2015). The present study also attempted to evaluate the area through morphometric analysis. For this purpose the drainage system of the study area is divided into 135 sub basins having 3rd or 4th order streams (Fig. 3.2).

To understand the behavior of morphometric parameters with respect to the lineaments and relief, the area is further divided into six zones on the basis of the lineament disposition and relief (Fig. 6.2) and compared each other. Lineament ‘c1’ separates zone I from zone II and zone IV from zone V. Lineament ‘b’ separates zone III from zone II and IV. The NE–SW trending Pattikadu lineament (‘e’), running across the study area, separates zones I and II from zones IV and V. The zone VI is demarcated by ‘d’ lineament separating it from zone V. The zones I, II, III, IV, V and VI are having 9, 47, 9, 35, 31 and 4 number of basins respectively. The zones I and VI are lying in the coastal area while zone III is falling in the NE portion of the study area and representing the low lying terrains. The zones II and IV are falling in the central portion of the study area and representing the relief terrains while zone V is representing the moderate relief. For a comprehensive discussion the morphometric parameters are grouped into three categories viz., having 1) linear aspects 2) shape aspects and 3) relief aspects.

6.2.1 Linear Aspects

Bifurcation ratio ($R_b$), Stream frequency ($F_s$) and Drainage Density (DD) are the morphometric variable related with linear aspects. The frequency distribution of $R_b$ in the area shows that 64 % of the basins are falling in stable range of 3.0 to 5.0 (Strahler, 1964). It is to be noted that 20% of the basins are having the values lower and 16 % of the basins are showing values higher than the said stable range (Fig. 3.3). But the basins associated with low relief zones (III and VI) are showing the low average values for $R_b$ within the stable range. However, the low relief area in the north western side, close to coast (zone I), where a number of NW SE trending discontinuous lineaments are passing through, is showing $R_b$ equivalent to high relief zones of the area (Fig. 3.13). As the gradient is the main factor responsible for the high values of bifurcation ratio, the higher $R_b$ in zone may be indicating rejuvenation of the drainage system.

Stream frequency ($F_s$) calculated for the study area indicates that 45.9% (62) of the basins having the average or near average values, 26.7% (36) and 27.4% (37) are showing very low and very high stream frequency (Fig. 3.7). The qualitative
analysis using sample range diagram also indicate that the basins associated with lower relief zones (I, III and VI) are having very low average stream frequency (Fig. 6.2, 6.3). However, it is also observed that out of four basins having the highest stream frequency (between 8.1 -9.0), three of the basins (111, 112, 120) are associated with lower relief zone V. The high $F_s$ indicate larger surface runoff and steeper grounds (Vittala et al. 2004). The spatial distributions of the basins indicate that the above mentioned three basins are falling in the vicinity of NW-SE trending ‘c’ lineament (Fig. 3.17, 6.2). The other basin that shows high $F_s$ (45) is falling in the high relief zone II in the vicinity of lineament b (Fig. 3.17 and 6.2).

The values of drainage density (DD) indicate that 37.7% (51) of the basins are having the average or near average values (2.37). But 28.8% (39) and 33.3% (45) of basins are showing very high and very low drainage density respectively (Fig. 3.8). The sample range diagram shows that the basins associated with lower relief zones (I, III and VI) are having very low average drainage density and higher average values of DD is associated with high and moderate relief zones (II, IV and V) (Fig. 6.2, 6.3). It is also observed that the basin (112) having the highest drainage density (4.15) is associated with moderate relief zone V in the vicinity of NW-SE trending ‘c’ lineament (Fig. 3.18 and 6.3).

Constant of channel maintenance (C) indicate 72.5% (92) of the basins showing average or near average values (Fig. 3.9). Anomalous values of ‘C’, within the area, are observed for the basins located in the vicinity of ‘c’, ‘c1’ and ‘b’ lineament (Fig. 3.19, 6.2). The sample range diagram also shows that the basins associated with lower relief zones (I, III and VI) are having high average values as compared to the zones of high elevation (II, IV and V) (Fig. 6.3).

6.2.2 Areal Aspects
Form factor ($R_f$), elongation ratio ($R_e$), circularity ratio ($R_c$) are the morphometric variable related with areal aspects. All these variable represents the basin shape from circular to elongated.

The frequency distribution of form factor ($R_f$) in the area shows that 60% (81) of the basins are elongated (falling in the range of below 0.4) while 40% (54) of the basins have attained the oval shape (falling in the range of above 0.4) (Fig. 3.4, Table 3.3). Among the 81 elongated basins, 3 basins (63, 133, and 73) are observed as highly elongated (i.e values falling below 0.21) (Fig. 3.4). In the study area oval shaped
Fig. 6.3 Sample Range Diagrams for the Various Morphometric Variables
basins are associated with the low relief areas. The sample range diagram indicates that average values of form factor for all zones are falling in the elongated category (between 3 and 4). But the basins associated with zone I and VI are showing relatively lower values compared to other zones (Fig. 6.3). In the present study identified three extremely elongated basins and two of them (basin number 63 and 133) are associated with zone I and VI in the vicinity of NW-SE trending segments ‘c1’ and ‘d’ lineament respectively. The third extremely elongated basin (73) is falling in high relief zone IV in the vicinity of the segments of ‘b’ lineament (Fig. 3.14). The elongation of basins, in the direction of these lineaments may indicate the strong control of the lineament in determining the basin shape. The formula used for the calculation of $R_f$ also indicates that if the length of the basin is increased without change in the area, the shape of basin would become elongated provided the linearity of the main stream of the basin is maintained. This situation will happen only if a basin is falling along or in the vicinity of a lineament and having the strong structural control to the shape the basin.

The frequency distribution of elongation ratio ($R_e$) in the area indicate that 11.11% (15) basins are oval, 37.7% (51) of the basins are less elongated, 51.11% (69) of the basins are elongated (Fig. 3.5, Table 3.2, 3.2). Within the elongated category 3 basins (63, 133 and 73) are observed as highly elongated (in the range between 0.41-0.50) (Fig. 3.5). Based on the values of $R_e$, there are attempts to classify tectonic activity (Zuchiewicz, 1989; Keller and Pinter, 2002; Keller et al. 1999; Melosh and Keller, 2013). In the Sample range diagram it is also noticed that average values of elongation ratio is falling in the elongated category (between 6 and 7) for all zones. But the basins associated with zone I and VI are showing comparatively lower values (Fig. 6.3). In the study area out of three extremely elongated basins two of them (basin number 63 and 133) are associated with zone I and VI in the vicinity of NW-SE trending segments of ‘c1’ and ‘d’ lineament respectively which may indicate the strong structural control over the shape of the basin. The third extremely elongated basin (73) is falling in high relief zone IV in the vicinity of NW-SE trending ‘b’ lineament (Fig. 3.15 and 6.2). Similar to the form factor, elongation ratio is also depends on the area and the length of the basin. The basins would be elongated for those are falling along or in the vicinity of a lineament having the strong geological/structural control.

The values of circularity ratio ($R_c$) indicates that 77.7% (105 basins) are elongated (i.e falling in range of 0.41-0.70). However, 18.5% (25 basins) are circular
or oval (> 0.70) while 3.8 % (5 basins) are showing extreme elongation (< 0.4) (Fig. 3.6, Table 3.3). The sample range diagrams shows that basins associated with zone II, IV and V are having higher $R_c$ compared to the lower relief zones i.e I, III and VI (Fig. 6.3). Among the five extremely elongated basins identified in the area, basin nos. 63, 100 and 97 are falling in the vicinity of NW-SE trending ‘c1’ lineament and basins 133 and 73 is falling in the vicinity of the segments of NW-SE trending d and b lineaments respectively (Fig. 3.16 and 6.2). As per the formula this factor depends on the area and the perimeter of the basin. The increase in the perimeter with no change in the area will result in a less circular basin. This may indicate strong geological/structural control in the formation of the basin. The above mentioned five basins may indicate the strong structural control of lineaments confining to their respective zones.

6.2.3 Relief Aspects

Ruggedness number ($R_n$), Basin relief (H) and Relief ratio ($R_h$) are the morphometric variable related with relief aspects. In the coastal (zone I and VI) and the northeastern part (zone III) of the area the basin relief is only 10 m (Fig. 3.20). In the SE part of NW-SE elongated hilly terrain is having the maximum elevation of 848 meter while the area towards NW is moderately elevated (Fig. 3.20). In the study area the data shows that 65 % (89) basins are showing low $R_h$ while 35% (46) basins are showing higher values. The values of $R_n$ indicate that 75.5% (102) of the basins are having the average 0.80 or near average values. But there are 24.5% (33) of the basins are showing high values (<1.1) (Fig. 3.11, Table 3.3). The sample range diagram also shows that the basins associated with lower relief zones (I, III and VI) are having low average values as compared to the zones of higher and moderate elevation (II, IV and V) (Fig. 6.3). In addition to that, it is also observed that the average value of $R_n$ in zone V is much higher than the zone II higher elevation. The spatial distribution of the data also shows that basins having high ruggedness number are located in three pockets of high relief areas falling in the vicinity of ‘b’, ‘c’ and ‘c1’ lineaments (Fig. 3.21 and 6.2). Out of three pockets two are falling in the zone II and IV. The third pocket is falling in the zone V of moderate elevation, in the vicinity of ‘c’ lineament (Fig. 3.21 and 6.2).
6.3 Inter Relationship of Different Morphometric Variables
The above morphometric variables have also been correlated between them in different zones by using the sample range diagrams.

6.3.1 Bifurcation Ratio ($R_b$) vs Relief Ratio ($R_h$)
Generally the high bifurcation ratio is confined to the area of high relief ratio because the gradient plays an important role in the development of drainage. Thus, in general areas having high $R_h$ will be having high $R_b$ and low $R_h$ should have low $R_b$. But the present study observed that zone I being lower $R_h$ is showing the higher $R_b$ as compared to the other zones which are similar in the relief and relief ratio (zone III and VI) (Fig. 6.4). Since a small increase in the basin elevation can lead to the increase in the formation of new drainages the higher $R_h$ in zone I may be indicating terrain rejuvenation (Fig. 3.3, 3.13, 3.22).

6.3.2 Drainage Density vs Relief Ratio
As mentioned above since the higher drainage formation is associated with high relief, the drainage density should be also high in the areas of high $R_h$. Thus, it is important to understand the anomalies in interrelationship between these two parameters in different zones. The higher elevation difference facilitates the formation of new drainages within the basin depending on the subsurface lithology. It is observed that the zones having the high relief ratio (zone II, IV and V) showing relatively high DD compared to low relief zones (I, III and VI) (Fig. 6.4). It may indicate the presence of highly permeable/resistant subsoil material under dense vegetative cover though the lithology is mostly charnockite and gneiss. Though both zones I and VI falls in the coastal area, zone VI shows the high relief ratio and low DD as compared to zone I (Fig. 6.4). This may suggest that resistant rocks are shallower in zone VI as compared to zone I, though they are lying in the same coastal belt. Here too the basement rocks mostly constitute charnockite with occasional occurrence of gneissic rocks (Fig. 6.2, 6.1, 3.19).
Fig. 6.4 Representation of Correlation for Various Morphometric Variables.
6.3.3 Circularity Ratio ($R_c$), Elongation Ratio ($R_n$) and Form Factor ($R_f$)
Morphometric variables like Circularity ratio, Elongation ratio and Form Factor are used for defining the shape of the basins. But for a given basin, there exist a relation between these parameters viz., elongation ratio > circularity ratio > form factor (Talukdar, 2012).

Thus, correlation made between these three parameters to understand the interrelationship (Fig. 6.5). It is observed that for some basins the values of circularity ratio has exceeded from the values of elongation ratio. It is found that the basins with anomalous relations are observed only in the basins of higher relief zones. In zone II basin number 3, 16, 41, 42, 47 and 51, in zone IV basin number 83, 91, 93, 101 and 102, in zone V basin number 107, 108, 109, 111, 112, 188 and 122 are found to be associated with this anomaly (Fig. 3.16 and 6.3. Table 3.3). In the calculation of these parameters ($R_n$, $R_c$ and $R_f$), area of the basin is common component. Thus only with the reduction in the perimeter of the basin, with a given area, can result in higher circularity ratio compared to elongation ratio. The higher perimeter may be an indication of irregular basin boundary.

Thus the above anomaly may be indicating the youngness of the basins. It is observed that such anomalous basins are falling in the vicinity of either ‘c1’, ‘c’ or ‘b’ lineaments only in their respective zones and in turn indicate the structural control of them, over the basins falling in different zones (Fig. 3.16, 6.3).

6.4 Geomorphic Analysis
6.4.1 Asymmetry Factor (AF)
In the study area 64.4% (87) of the basins are showing the normal range for symmetry (AF values between 35-65) where as 36.6% (48) of the basins are showing higher basin asymmetry (either high or low normal range of AF values) (Fig. 4.1). It is observed that majority of the basin asymmetries are observed in the basins located in the high relief zones falling between ‘b’ and ‘c1’ lineament. The data indicates that the higher basin asymmetries are also observed in lower relief area too (basin no 28, 26, 29, 8, 9, 123 and 125) and these basins are falling in the vicinity of north western segment of ‘c1’ and south eastern segment of ‘c’ lineaments (Fig. 4.2). The higher basin asymmetry is generally considered as formed due to tilt of the terrain, if there
Fig. 6.5 Representation of Correlation for Various Morphometric Variables.
exist no geological or structural influence (Fig. 4.2). Thus, the association of higher asymmetry basins in the low relief zones in the vicinity of NW-SE trending segments of ‘c’ and ‘c1’ lineaments may be indicating the tectonic adjustments.

6.4.1 Transverse Topography Symmetry Factor (T)
The transverse topography symmetry analysis of the various 3rd and 4th order drainages indicate that the drainages falling between the Vadakkancheripuzha and Manali river shows very less shifting of drainages from the centre of the basin (Fig. 4.3).

However, the area bounded by northwestern part of Vadakkancheripuzha, the south eastern part of Manali river and Kurumalipuzha, shows the appreciable shift in the main drainage from the centre of the basin (Fig. 4.3). The direction of the shift indicate that the basins in the south eastern part of the Manali river and Kurumalipuzha are oriented in either southwest or northeast direction across the ‘c1’, ‘c’ and ‘d’ lineaments. In a natural setting, near the coastal area, the slope of the ground would be directed towards the sea. But in the present study, in the coastal region across d lineament, all the drainage changes are towards inland i.e NE (Fig. 4.3). Though the area bounded between c, c1 and b lineament is the area of moderate to high relief, the pattern of the deflections of the drainage in the northern side of ‘e’ lineament is different compare to the southern side (Fig. 4.3). These anomalous shifting of the drainages within the basins concentrated in the southern half of the study area may indicate the influence of ongoing tectonic adjustments along the segments of ‘c’, ‘c1’ and ‘b’ lineament.

6.4.2 River Sinuosity and Deflections
The river sinuosity values in the study area for different river stretches are ranging from 1.6 to 3.38 (Table 4.3). The rivers show changes in directions of flow and sinuosity values on either side of the NW–SE trending lineaments (Fig. 4.4, Table 4.3). Drainage deflections towards SW have been seen in the drainage course of Vadakkancheri and Manali river across the segments of NW-SE trending ‘c1’ lineament in SE of Kadangod and SW of Pattikadu (Fig. 4.4). Similar deflection has also been seen in the drainage course of Vadakkancheri (deflection directed towards SE), Manali river (deflection directed towards SE) and Kurumalipuzha (deflection directed towards NW) across the segments of NW-SE trending ‘c’ lineament in SW of
Kadangod, SE of Ollur and further SE of Ollur respectively (Fig. 4.4). In addition to that NW directed deflections are observed along the Manali river and Kurumalipuzha across ‘d’ lineament also (Fig. 4.4). This ‘d’ lineament appears to induce the meandering across the Chalakudipuzha. The above drainage segments are showing change in direction as well as variation in sinuosity values across the respective lineaments (stretch 4-5-6, 14-15-16, 17-18-19-20). According to Zamolyi et al. (2010) and Ramswamy et al. (2011), change in river sinuosity and deflection may be indicating the neotectonic adjustments.

6.4.3 Mountain Front Sinuosity ($S_{mf}$)

Mountain front sinuosity ratio shows that the values are raging between 1.11 and 2.41. As per the classification (Bull and McFadden, 1977; 2007; Keller and Pinter, 2002; Pérez-Peña et al. 2010; Silva et al. 2003), the $S_{mf}$ values are falling in highly tectonically active (1 -1.4) and less activity range (1.4 -3). The lower values (less than 1.4) of $S_{mf}$ is observed in the extreme north (4, 28 and 32) and extreme south (19, 20, 21, 22 and 23) of the study area and those are lying in the vicinity/ sympathetic to the segments of NW-SE trending ‘c1’, ‘d’, ‘c’ and ‘b’ lineaments (Fig. 4.5).

6.4.4 Valley Floor Valley Height Ratio ($V_f$)

The $V_f$ is calculated at 151 locations across different reaches of the drainage system (Fig. 4.12). In the study area valleys are trending in different directions viz E-W, NE-SW, N-S, NNW-SSE, NW-SE and WNW-ESE. The $V_f$ Data indicates that majority of the valleys in the study area are trending in NW-SE (Fig. 4.12).

According to Bull and McFadden, (1977) and Keller and Pinter, (1996) the ratio below 5 is indication of tectonic activity however below 1 is an indicator of vigorous activity (‘V’ shaped valley). The data shows most of the valleys along NW-SE trending lineaments (‘a’, ‘b’, ‘c’, ‘c1’and ‘d’) are showing $V_f$ less than 5.0 Further the $V_f$ <1.0 is observed along valleys corresponding to NW-SE trending ‘b’, ‘c1’, ‘c’ lineaments only (Fig. 4.19, Table 4.5). Since $V_f = <1$ corresponds to vigorous tectonic activity (Bull and MaFadden 1977, Keller and Pinter 1996, Pedrera et al. 2009, Pérez-Peña et al. 2010, Giaconia et al. 2012, Topal et al. 2016), it can be suggested that the NW-SE trending lineaments ‘b’, ‘c1’, and ‘c’ are active and responding to the present tectonic regime (Fig. 4.19).
6.5 Observation on Brittle Faults

During the field investigations signatures of the NW–SE trending lineaments are traced as brittle faults at many locations. At four locations i.e Erumapeti, Mannuti, Tayyor and Kadangod, brittle faults associated with damage zone and core are observed (Loc 1, 2, 3, 4 Fig. 5.1). The amount of displacement required to produce the gouge at each location have been calculated using the Scholz, (1990) empirical relation. It shows that 240cm, 250cm, 330cm, 262cm displacement might have occurred at Erumapeti, Mannuti, Tayyur and Kadangod respectively for the formation of gouge of respective thickness (Fig. 5.2E, 5.5D, 5.11B, 5.15c). At Erumapeti and Mannuti breccia engulfed within gouge is observed within the damage zone (Fig. 5.2D, 5.5A). At Tayyur and Kadangod gouge of two color (green and yellow) is observed at the fault core (Fig. 5.11 B, D. 5.15 B, C, D). Consolidated gouge is also observed in the fault at Kadangod. The Faults observed at all the four locations are trending NW-SE with a SW dip and have shown lateral continuity up to 100 to 500 in strike direction. The spatial distribution these four faults indicating that they are falling along or in the vicinity of NW-SE trending c1 lineament (Fig. 5.1).

In addition to the above four locations, 11 brittle fault, with different orientation, have been observed at nine other locations [viz. NW-SE trending fault at Velur, Puthur, Trikkur, Thannikkudam, Korattikkara, Kallavi; N-S trending fault at Trikkur; NE-SW trending fault at Kachitodu, Kundukad; E-W trending fault at Kundukad, Perumbpilau] (Fig. 5.1, 5.17, 5.19, 5.21, 5.22, 5.25, 5.27, 5.30, 5.34, 5.35, 5.36, 5.40, 5.42). At all these locations the width of the damage zones are very negligible or absent. Gouge formation along the slip planes of these faults are either trace or negligible, but all are associated with the slickensides. Though the faults identified in the area are oriented in different direction, but the spatial distribution shows that they are falling in the vicinity of NW-SE trending ‘c1’ and ‘c’ lineament (Fig. 5.1).

The Slip linear plot (Hoeppener, 1955; Marshak and Mitra, 1988) prepared for the individual locations shows the movement direction of the hanging wall blocks in either north west or south west direction (Fig. 5.4, 5.6, 5.7, 5.11, 5.12, 5.13, 5.16). The presence of the gouge zones also indicates the faulting in the near surface conditions Scholz, (1990). Since the displacement, style of deformation, movement direction, fault rocks observed at these individual locations and their spatial
distribution may indicate that these are the parts of a single regional structure (shear zone) (Fig. 5.1).

6.6 Discussion

Regionally this area has experienced an earthquake of M=6 in 1900 at Coimbatore, (Basu, 1964; John and Rajendran, 2008) and spatially it is located in the eastern side of the Palghat Gap. The 1994 Wadakkancheri event (M = 4.3) was the maximum magnitude observed in the area (Rajendran and Rajendran, 1996). The study area is a part of Peninsular India in which the moderate earthquakes are occurring as reactivation of pre-existing structures (e.g. Gowd et al. 1996). Thus the present study focused on identification of active tectonic structures as preliminary information for seismic hazard assessment.

The basement rocks of the study area mostly constitute charnockite with occasional occurrence of gneissic rocks (Fig. 6.1). The study identified systematic sets of lineaments oriented in NW-SE directions connected with well known structures of Kerala viz., Periyar fault, Idamalayar fault and Desamangalam fault (Fig. 6.1). A set of NE-SW trending lineaments are also observed in the central zone of the area. The lineaments associated with these structures are identified as segmented in nature (Fig. 3.1, 6.1). The study used morphometric parameters to evaluate the area (Table 3.1). The area then divided into six zones to compare the behavior of various morphometric parameters (Fig. 6.2). Geomorphic indices are also employed to delineate the subtle changes in geomorphology induced by tectonic activity through the adjustment along lineaments.

During the quantitative and qualitative analysis of the landforms using morphometric variables certain interesting observations were made. The higher values of bifurcation ratio ($R_b$) are observed in the NE part of zone I in the vicinity of NW–SE trending lineament ‘c1’, in NE and SE parts of zone II and in the vicinity of NW–SE trending lineament ‘b’ (southeastern continuity of Desamangalam Fault) (Fig. 6.4, 3.13). High bifurcation ratio ($R_b$) observed in a low relief zone (I), may be indicative of uplift in the vicinity of ‘c1’ lineament (Fig. 3.13 and 6.4). The high values of $R_b$ are an indication of terrain rejuvenation due to young tectonic movements (Panek, 2004; Zuchiewicz, 1989). The High stream frequency ($F_s$), observed in the basins of zone I in the vicinity of the lineament ‘c’ (Fig. 3.17, 6.3), is further supporting this theory.
The variables related to the areal aspects ($R_f$, $R_e$ and $R_c$) have identified the extreme elongation along three basins falling in the vicinity of northern segment of ‘c1’ and southern segment of ‘b’ and ‘d’ lineaments (Fig. 3.14, 3.15, 3.16). In addition to that $R_c$ indicates that area the basins are elongated along ‘c1’ lineament in the southern portion of the study area (Fig. 3.16). While comparing $R_f$, $R_e$ and $R_c$ it is observed that north western segment of ‘b’ and south western segments of ‘c’ and ‘c1’ lineaments are showing anomalies in the value of $R_c$ (zone II, IV and V) (Fig. 3.14, 6.5). The relief aspect variables indicate that the high $R_n$ values are concentrates in two pockets of higher relief (in zone II and IV) and one pocket in moderate relief (Zone V). This anomalous value of $R_n$ in the moderate relief zone is falling in the vicinity of ‘c’ lineament (Fig. 3.11, 6.3). Overall in the analysis of the various conventional morphometric variables it is observed that NW-SE trending c1 and the south western segments of ‘b’ and ‘c’ lineaments are mostly influencing the drainage basins of the area.

High basin asymmetry is observed mainly along ‘c’ and ‘c1’ lineaments. The low lying areas close to the coast (zone I) observed two highly asymmetrical basins where as no such basins observed in zone III which is also of low relief. Basins falling along or in the vicinity of south eastern segment of ‘b’ lineament are also indicating high basin asymmetry (Fig. 4.2). In addition to that some of the basins of low relief area have also shown the high asymmetry in the vicinity of south eastern segment of ‘c’ lineament (Fig. 4.2, 6.2). Thus the AF also indicates that the basins falling in the vicinity of ‘c1’ and the south eastern segments of ‘c’ and ‘b’ lineaments may be adjusting to tectonic movements (Fig. 4.2).

The transverse topography symmetry analysis has shows that the area falling along the coast (Zone I and VI ) is comparable in terms of the shifting of the main stream with the zone of same relief in inland portion (Zone III) (Fig. 4.3, 6.2). A noticeable difference in the degree of the shifting of the drainages is observed in the northern and southern portion, though they are of same relief. It is observed that the degree of drainage shift from the centre of basin has increased in the southern and extreme north portion of the study area as compared central portion in the study area (Fig. 4.3). These areas are bounded by ‘b’ & ‘c1’, as well as ‘c’ & ‘d’. The high ‘T’ observed in the zone of ‘c’ and ‘c1’ may be indicating the drainage adjustment due to ongoing tectonic disturbance.
The combination of $S_{mf}$ and $V_f$ have been used by the researchers globally to evaluate the mountain front by assigning the tectonic activity classes in terms of reduction in the uplift rates. (Bull and McFadden, 1977; Rockwell et al. 1984; Silva et al. 2003). In the present work also $S_{mf}$ and $V_f$ have been used to arrive a qualitative evaluation. The data shows that out of 33 stretches 8 (4, 28, 32, 23, 22, 19, 20, 21) are showing values $S_{mf}<1.4$ (high tectonic activity) while other 25 are also showing $S_{mf}<3$ (less tectonic activity) (Fig. 6.6, Table 4.5). In the quantitative evaluation of $V_f$, 14 out of 151 locations (81, 93, 98, 75, 76, 73, 103, 104, 105, 107, 114, 65, 68, 62) the values are <1.0 Table 4.5). Within these 14 location one location (98) is falling along the NE-SW trending valley 3 loc (93, 105, 62) are along WNW- ESE trending valley, remaining are falling along NW-SE trending valley (Fig. 4.14, 4.17, 4.18, Table 4.5).

The spatial distribution of $S_{mf}$ and $V_f$ indicate that majority of the lower values of $V_f$ and $S_{mf}$ are located in the SE part of the study area. It is observed that the mountain front stretch no 22 ($S_{mf}<1.4$, highly active range), is associated with ‘c’ lineament, the lowest value (<1.0) of $V_f$ (loc 65, 68) are observed along ‘c’ lineament (Fig. 6.6). At other locations in the south eastern part of area the mountain front stretch no 15 and 12 (related with ‘c’ and ‘c1’) are showing $S_{mf}<1.4$, (highly active range) at the same place the lowest value (<1.0) of $V_f$ (loc 76, 75, 76 and 114) are also observed (Fig. 6.6). In the northern part of the study area along NW-SE trending mountain front stretch no 6 is showing $S_{mf}<1.4$ (associated with ‘b’ lineament) at the same place, at location 81 the lowest value of $V_f$ (<1.0) is observed. This location ($V_f$ 81) is falling at the crossing point of northern segment of ‘b’ lineament. Mountain stretch no 6 is also indicating the tectonic adjustment along northern segment of ‘b’ lineament since it resembles to the possible SE extension of active fault (Desamangalam fault) identified in earlier studies (Fig. 6.6).

The quantitative evaluation of the $S_{mf}$ and $V_f$ indicates the coherency in the values, direction of valley and direction of mountain front with the direction of the lineaments supports the view of ongoing tectonic adjustment along the respective segments of the lineaments (c and c1) (Bull and McFadden 1977, Keller and Pinter 1996, Pedrera et al. 2009, Pérez-Peña et al. 2010, Giaconia et al. 2012, Topal et al. 2016). The observation from the transverse ‘T’ also shows the consistency with the observations from $S_{mf}$ and $V_f$ (Fig. 6.6, 4.3).
Fig. 6.6 Drainage and Lineament Map Showing the Coherency Between the Mountain Front Sinuosity and Valley Valley Floor Valley Height Data.
During analysis of the drainage system it is found that the courses of smaller rivers in the area are also controlled by the NW–SE trending lineaments and have resulted as the sharp deflections, anomalous sinuosity and compressed meandering. The spatial distribution the drainage courses of smaller river indicate lineament ‘c’ has induced a sharp turn towards SE consistently whenever it has crossed the rivers viz. Kurumalipuzha, Manali and Vadakkancheripuzha (Fig. 4.4). Drainage deflections are also observed along ‘c1’ lineament at Manali and Vadakkancheripuzha near Pattikadu and Kadangod. Similar kind of deflections can also be seen along ‘d’ lineament along the Kurumalipuzha and Manali river (Fig. 4.4). In the SE portion of the study area as Chalakudipuzha come in the vicinity of ‘d’ lineament, it starts meandering (Fig. 4.4). Similarly the compressed meandering is also observed along Manali river in the zone bounded by c1 and c lineaments (Stretch 4-5-6, 14-15-16, 17-18-19-20) (Table 4.3, Fig. 4.4). The above drainage segments are showing in change in direction as well as variation in sinuosity values. According to Zamolyi et al. (2010) and Ramswamy et al. (2011), change in river sinuosity and deflection may be indicating the neotectonic adjustments. The developed river courses also fitting to the model suggested by Zamolyi et al. (2010), for the drainage pattern in the hanging wall and foot wall, in case of Chalakudipuzha (Fig. 2.3 C) and Manali river (Fig. 2.3 C) in association with ‘d’ lineament, it appears that the south dipping hanging wall moved reversely (Fig. 4.4). The Vadakkancheripuzha (Fig. 2.3 D) which is associated with drainage deflection along ‘c’ lineament may be the result of oblique movement. These observations suggests, the ‘c’, ‘c1’ and ‘d’ lineament are south dipping weak zones and may be indicating the reverse to oblique movement. The NW–SE trending lineament (‘c1’) which is identified as one of the branch of Periyar lineament is associated with brittle faulting. At four locations these faults are developed into visible zones of faulting and damage zones that are dipping SW. In addition to the above four location brittle faulting has been observed at nine other locations (Fig. 6.7). Slickensides from these fault zones and faults indicate a consistent north-directed movement of respective hanging wall blocks. Majority of the brittle faults observed are trending NW-SE and dipping SW (Fig. 6.7). The faults trending in other directions may indicate the splays developed from the main fault (Fig. 6.7). The association of ongoing seismicity in the region with NW-SE trending lineaments further confirms tectonic disturbance along the north western side of the Periyar lineament (Fig. 6.7). There are incidences of earthquakes in the
Fig. 6.7 Map Representing the Seismicity, Faulting Location and Slip Linear Plots Associated with Faults in the Study Area.
southeastern end of Periyar Fault too (Rajendran et al. 2009). The low value of $S_{mf}$ and $V_f$ in these zones also support the fact that the area is tectonically active.

Peninsular India is suggested to be under compressional stress regime due to the continued northward movement of Indian landmass and the resistive forces from Himalayan collision zone. Studies by Gowd et al. (1992) identified that NW–SE trending structural weaknesses are one of the favorable directions that can facilitate movement in the present tectonic regime as strike slip or reverse faulting. Both field observations of fault and drainage deflections as well as the anomalies in the sinuosity may be indicating the same in this part of Peninsular India too. Thus the lineaments ‘c’, ‘d’ & ‘c1’ should also be considered as potential source for the future moderate earthquake.