# Chapter VII

# SUMMARY AND CONCLUSION

Drainage basins are durable geomorphic features that provide insights into the long term evolution of the landscape. River basin geometry develop response to the nature and distribution of uplift and subsidence, the spatial arrangement of lineaments (faults and joints), the relative resistance of different rock types and to climatically influenced hydrological parameters (Burbank and Anderson, 2001). For developing a drainage basin evolution history, it is necessary to understand physiography, drainage patterns, geomorphic features and its structural control and erosion status.

The present study records evidences for active tectonic activities which were found to be responsible for the present day geomorphic set up of the study area since the Western Ghat evolution. A model was developed to explain the evolution of Chaliar River drainage basin based on detailed interpretation of morphometry and genesis of landforms with special emphasis on tectonic geomorphic indices and markers.

## 7.1 Summary and Conclusion

This thesis integrates morphometric analyses, drainage and morphostructural analyses, geomorphic studies, quantitative tectonic geomorphology and sedimentology to arrive at a conclusion for the evolution of Chaliyar River drainage basin and Nilambur valley.

In the present study, the role of linear, areal and relief aspects and development of drainage system are revealed through the geomorphic processes on the basis of morphometric analysis. Spatial analysis of the morphometric parameters has provided the topographic expression and has represented the interim phase during the quantification of morphology and tectonics of Chaliyar River drainage basin.

Sub-basins of Chaliyar River drainage basin have moderate to high channel dimension and stream discharge. Well developed lower order streams might have reduced the sheet flow and about 100 $km^2$ drainage area is sufficient to main 265 km of channel in the basin. Low drainage density and stream frequency indicate high precipitation, low runoff and low incidence of flooding. Average size, irregular and elongated nature of the sub-basins and that of Chaliyar River drainage basin also shows that the basins have longer lag time and low peak flow.

Comparatively higher values of bifurcation ratio, low values of elongation ratio, form factor, compactness factor and circularity index of the sub-basins and that of Chaliyar River drainage basin as a whole reflects the elongated nature of the basins and points to the role of younger tectonic activity that controls the drainage architecture of the basins. Mean length of the lower order streams are higher than the next higher order in sub-basins 4, 5, 7 and 8 indicating the change in stream gradient due to tectonic uplifting and tilting of the drainage basins.

Highly dissected nature, high relief and steep slopes as explained by the relief aspects of Chaliyar River drainage basin and its sub-basins reflect the active nature of the upland zone of the drainage basins. It also indicates that the upper reaches of the basin is structurally complex mountain landscape. Hypsometric analysis of the sub-basins suggests variation in the evolutionary history. Hypsometric curve of these sub-basins show that the streams have attained its old age of evolutionary history while the hypsometric integral computed for these sub-basins shows matured stage of evolution. This variation can be attributed to the concurrent tectonism and high rate of erosional activities within the drainage basins.

A brief study on the drainage characteristics and geomorphologic set up of the Chaliyar River drainage basin is attempted in the present study. Chaliyar River drainage basin is marked by geomorphological diversity manifested in terms of morphological and hydrological characteristics. Chaliyar River flows 169 km before it debouches into Lakshadweep Sea and attains its $7^{th}$ order when it flows 45 km from its source. Chaliyar River generally exhibits dendritic, sub-dendritic and rectangular drainage patterns. Trellis pattern is observed in the sub-basin of Punnapuzha tributary. $3^{rd}$ and $4^{th}$ order streams follow the general structural trend and exhibit rectangular pattern. Overprint of rectangular drainage pattern over dendritic pattern is quite common in the northern part of Nilambur valley and can be attributed to the right angle fault system. Deranged or contorted drainage pattern is observed in the Cherupuzha and Iruvahnipuzha sub-basins. Radial pattern is observed around isolated hills. Parallel drainage pattern is observed in the northern part of Iruvahnipuzha and Cherupuzha sub-basins. Anabranching drainage pattern observed in the middle reaches of Punnapuzha and Karimpuzha throw light on the upliftment and subsidence of river profiles due to block faulting.

Classification of streams based on stream behaviour and source area is attempted during the present study. Based on the proxies like valley slope, sinuosity, valley width to depth ratio, median size of the stream bed material and entrenchment ratio 10 km long, 17 segments of Chaliyar River from the source to river mouth is classified into A, B, C, E and F type (after Rosgen, 1994). Based on source area (after Sinha and Friend, 1996), Chaliyar River and its tributaries are classified into (i) mountain-fed, (ii) foot hill-fed, (iii) plain-fed and (iv) mixed-fed streams.

Geomorphological map of the Chaliyar River drainage basin is prepared depicting the spatial distribution of various landforms. Different geomorphic units are delineated on the basis of observation made from Survey of India toposheets, aerial photographs and satellite imagery and field observations. Geomoprhic units thus delineated are grouped based on the geomorphic processes into (i) depositional landforms, (ii) erosional landforms and (iii) structural landforms. Depositional landforms delineated from the study area are active channel belt with point bars, braided bars and channel bars, channel fills, palaeochannels, palaeo-alluvial fans, terraces of different levels ($T_0$, $T_1$, $T_2$ and $T_3$), and marshes and back swamps. Erosional landforms in the study area include denudational and residual hills, valleys and interfluves, and pediments. Structural landforms include structural hills and valleys.

Extensive field work was carried out and the observations of lithological, structural and geomorphological features in the study area ise explained. Evidences of active tectonism observed during field studies have been specially recorded.

Geological milieu of Chaliyar River drainage basin is comparable with any other parts of the Southern Granulite Terrane (SGT). Charnockite Group of rocks makes up the high hills and slopes and is the most widely distributed rock type of the study area. Wayanad Supracrustals represented by amphibolite, fuchsite quartzite, magnetite quartzite, are the oldest rock types and occurs as enclaves within the Charnockite and Migmatite Group of rocks. Migmatites are represented by hornblende-biotite gneiss, biotite gneiss and garnet-biotite gneiss. Younger acid and basic intrusive cut across the older rocks and are highly fractured. Quartz veins in the Chaliyar river basin are the primary source for gold and contribute to the alluvial placer gold deposit of Nilambur valley. Extensive lateritization has obliterated the general lithologic characteristics.

Field relationship of structural aspects of the Chaliyar River drainage basin represents three phases of deformation. Gneissosity with a general trend in NNW-SSE direction is the result of first stage of deformation ($D_1$). The secondary composition banding in gneisses and migmatites is a transposition structure represented by rootless tight isoclinal folds ($F_1$). Small scale appressed near isoclinal folds with thickened hinges ($F_2$) with NNW-SSE planar fabric represents the second stage of deformation ($D_2$). Open folds or warps represent the third stage of deformation ($D_3$) where the first two deformation structures get refolded. Field evidences supporting shearing (ductile and brittle) such as mylonites, lineation, slicken-slides, scarp lines, pseudotachylite veins could be traced out.

Field evidences that support the role of active tectonics in carving out the present day Chaliyar River drainage basin are unpaired terraces, strath terraces, channel migration and river incision, palaeochannels and palaeo-alluvial fans. Scars of palaeo-landslides and recent landslides indicates the reactivation of lineaments. Reactivation of lineaments with pseudotachylite veins along the fault scarp throw light on the seismic activity that occurred within the drainage basin.

Palaeo alluvial fan morphology acts as an indicator of active tectonics as it reflects varying rate of tectonic processes such as uplift of the source mountain along a range-bounding fault or tilting of the fan surface. Westward tilting and normal faulting produced segmented alluvial fan at Karadikundu - Chekuthankundu area. On the western side of Nilambur valley, alluvial fans are relatively small and steep. Active normal faulting produces straight mountain front with single fan head.

Stream profile analysis of Chaliyar River and its tributaries display uneven longitudinal profiles with numerous knickpoints along the profiles. Analysis of river concavity and river morphology has been carried out to better understand the influence of tectonics and rock uplift on the fluvial and topographic system in Chaliyar River drainage basin. Concavity derived from the river longitudinal profiles is independent of lithology of the study area. Wide variability in the concavity index of the tributaries of Chaliyar River reflects the role of tectonism in carving the present river profiles and is inconsistent with the findings of Whipple and Tucker (2002). Steepness indices and concavity indices computed for the longitudinal profiles show that the rate of uplift is higher than the rate of incision.

River incision is not uniform in Chaliyar River. It varies from 2 m to 20 m. Terraces are discontinuous, and number and altitude of terraces vary downstream and linking of different terrace fragments is difficult. From the field studies, it is clear that uplift has triggered river incision and lateral migration of stream channels at many places especially within the Nilambur valley. Simultaneous occurrence of tectonism and incision in which valley depth is equal to the amount of uplift can be compared with the suggestions made by Meritts et al., 1994; Bonnet et al., 1998; Bull, 1999 and Hovius (2000).

Morphotectonic parameters viz., mountain front sinuosity, stream length-gradient index and valley floor width to height ratio allow the quantification of tectonic deformation along the river profile. Anomalous stream length gradient index observed along the river profiles of Kurumanpuzha, Punnapuzha and Karimpuzha are attributed to the rock resistance and tectonics. Mountain front sinuosity computed indicates tectonically active to less active mountain fronts reflecting the comparatively older tectonic event in the drainage basin. Valley floor width to valley height ratio shows wide variation in the upper reaches of Chaliyar River and its tributaries. Low width to depth ratio in the upper reaches of Chaliyar River shows that the valleys are narrow and V-shaped, actively incising with high uplift rates. High values of valley floor width to height ratio in the lower reaches and in Nilambur valley is manifested in the broad U-shaped nature of the valleys.

Asymmetry Factor and Transverse Topographic Symmetry Factor could establish the lateral tilting of the drainage basins with respect to the main water course. Sub- basin 1 (Cherupuzha basin) has tilted towards east while sub-basins 2 and 5 (Iruvahnipuzha and Chaliyarpuzha basins) have tilted towards west. Sub-basins 3 and 4 (Kurumanpuzha and Kanjirapuzha basins) have tilted towards south while sub-basin 8 (Karimpuzha) has tilted towards north. Sub-basins 6 and 7 (Karakodupuzha and Punnapuzha basins) have tilted towards southeast and sub-basin 9 (Kuthirapuzha basin) has tilted towards NE. Considering Chaliyar River drainage basin as a single unit, the lateral tilting of the basin is towards south.

River response to active tectonics produces geomorphic anomalies within the drainage basin and are known as geomorphic markers of active tectonics. Such morphologic manifestations observed in Chaliyar River drainage basins are unpaired terraces, palaeo-alluvial fans, beheaded and deflected streams, compressed meanders, angular drainages, landslides and river ponding.

Based on the values of geomorphic indices of active tectonics, classification of sub-basins of Chaliyar River drainage basin is attempted as applied by Keller and Pinter, 1996 and El Hamdouni et al, 2007. As per Keller and Pinter's classification the sub-basins 2, 7, 8 and 9 belong to class 2, where the sub-basins are tectonically active. Sub-basins 1, 3, 4, 5, 6 belong to class 3 and are less tectonically active. According to the classification method of El Hamdouni et al., 2007, the sub-basins 3, 4, 7 and 8 belongs to class 2 of high tectonic activity and sub-basins 1, 2, 5, 6 and 9 belongs to moderate active tectonics.

The imprints of tectonic features are delineated in the form of lineaments and verified during field studies. Morphostructural analysis of drainage network and lineaments show that N-S, NE-SW, ENE-WSW, NNW-SSE and NW-SE trending lineaments mark the major drainage network of Chaliyar River drainage basin. Lower order streams generally follow NE-SW and NNW-SSE trending lineaments and higher order streams follow NW-SE trending lineaments.

Sedimentological aspects of the Quaternary fluvial sediments deposited in the Nilambur valley are studied to determine the depositional environment and rate of weathering. Sediment samples collected from the present day stream beds of Chaliyar River and its tributaries and from younger ($T_1$) and older terraces ($T_2$) are used to represent the sedimentological and geochemical characteristics of sediments of Nilambur valley. Texturally, the stream sediments from Nilambur valley belong to sand and sandy facies while the terraces are represented by the loam facies. Sandy stream sediments are well-sorted, matured to sub-matured, and coarse- to medium-grained. Younger $T_1$ terrace consists of matured, fine- to medium-grained, moderate to poorly sorted sand. Older terrace ($T_2$) consists of fine- to medium-grained poorly sorted sand. From the bivariate plots of Tanner (1991) and Friedman (1961; 1967), it is observed that the depositional environment of the stream sediments and terrace samples generally show episodic fluvial and stream regimes. CM plot (Passega, 1972) for stream sediments characterize the rolling of sediments during the depositional process. Younger terrace samples ($T_1$) were transported by uniform suspension and deposited by graded suspension, while older $T_2$ terrace samples were transported by rolling process and deposited by suspension. The chemical index of alteration (CIA) has been used to quantify the degree of weathering of stream sediments and terrace samples and the values range between 68 and 96 on a scale of 40-100, indicating a high degree of alteration. Similar geochemical properties and CIA values of $T_1$ and $T_2$ terrace samples indicate that there is no time gap between the development of these two terraces. Formation of two levels of terraces simultaneously can occur only due to tectonism.

The Chaliyar River drainage basin is in a transient state of response to regional Quaternary exhumation. The examination of morphological evidence of tectonics and morphometric and morphostructural characteristics shows that the geomorphological evolution of the Chaliyar River drainage basin is strongly affected by active tectonics.

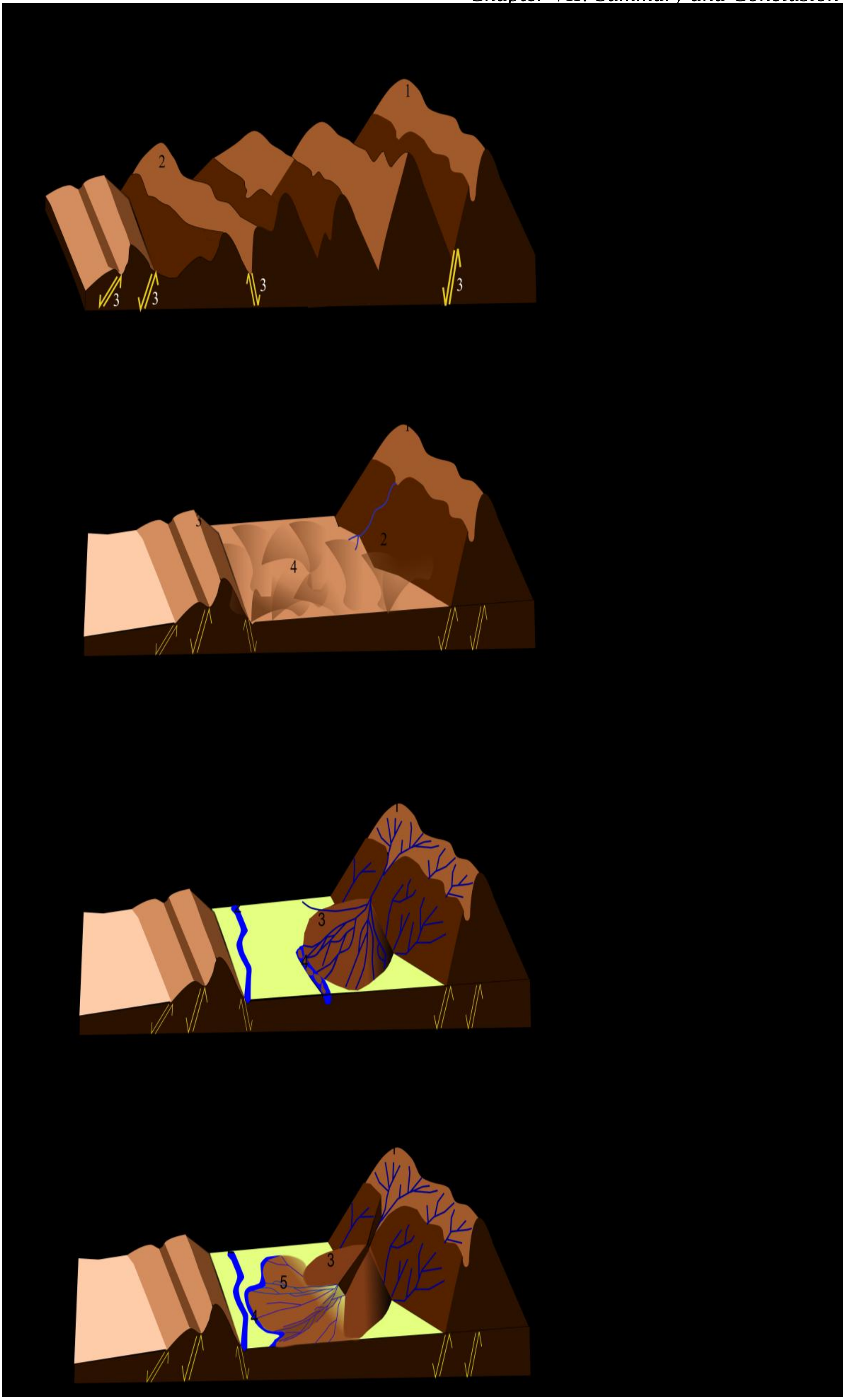
- Two different regional hydrographic domains have been distinguished on the basis of the geometry of the drainage network located roughly to the north and south of the drainage basin. Almost all the main tributaries of Chaliyar River belong to the northern domain, where the stream flow is generally oriented southwards cross cutting the regional structural trend of different lithofacies. The southern domain is characterized by a river network being drained to N and NNW and is almost parallel to the general structural trend. The drainage network of Chaliyar River drainage basin is tectonically controlled and frequent knickpoints along the longitudinal stream profiles of uniform lithology indicate neotectonic activity along lineaments. Active tectonic movements have been determining river segment development patterns or drainage network, in which correlation between river segment azimuth and lineament azimuth significantly confirms this process.
- V-shaped valleys with low valley floor width to depth ratio develops in the upper reaches of Chaliyar River and its tributaries in response to active uplift and broad U-shaped valleys in the lower reaches and in Nilambur valley indicate major lateral erosion due to the stability of base level or to tectonic quiescence.

- Down cutting induced by faulting has left the older channel remnants much higher than the present day channel. This explains the displacement of Quaternary pebble beds and reveals recent tectonic activity along normal faults. Frequent and recurring landslides at lineament junctions can be related to the reactivation of lineaments accelerated by heavy rain. River adjustment to active uplift on the river flanks are reflected in the formation of different levels of terraces like unpaired strath terraces, paired and unpaired fill terraces. The differential movements along the faults have resulted in the tilting of the basin that triggered channel avulsion and shifted the river flow from west to south and then to southwest direction.

- Active strike-slip faulting in Chaliyar River drainage basin produced characteristic assemblages of landforms that are considered as geomorphic markers of active tectonism like deflected and beheaded streams, shutter ridges, river ponding (sag pond), faults scarps, small horst and graben (microtopography). Presences of these geomorphic markers give strong evidence for tectonic creep or moderate earthquakes to have occurred in the past few thousand years. There have been no large earthquakes in historical time (few hundred years) but the morphostructural features in the basin suggests that earthquakes are likely to be generated.

- Many of the topographic features associated with active strike-slip faulting like fault scarp, river ponding can be explained by the simple shear that produced contraction and extension  or can be explained by extension and contraction associated with releasing or restraining bends or step fault traces (after Sylvester and Smith, 1976; Dibble, 1977; Keller, 1996). Thus it is assumed that two tectonic phase existed in the study area. The first phase was compressive in nature and occurred on a regional scale. This phase was responsible for the development of folded structures, over thrust, reverse faults and strike slip faults. The second, a neotectonic phase related with general uplift produced normal faults which displaced the geological structures formed during the compressive tectonic phase. These later structures have displaced the fluvial terraces and are responsible for the sharp fluvial channel deviation within the basin.

- From the foregoing geomorphic and tectonic setting, a model of evolution of Nilambur valley is proposed (Fig. 7.1). Block faulting sequel to the evolution of Western Ghat escarpment initiated in the evolution of Nilambur Valley. Block faulting resulted in the development of horst and graben. Initiation of the development of drainage system along the fault scarps and sudden deposition of boulders and gravels into the graben resulted in the formation of alluvial fan. Development of drainage systems in the Wayanad plateau resulted in Chaliyarpuzha flowing south and antecedent stream developed along the margin of the alluvial fan. Fan growth shifted the antecedent stream further west with a number of streamlets through the fan joining the main stream. Normal faulting almost perpendicular to the earlier fault scarp faces resulted in the upliftment of part of the alluvial fan deposit there by detaching the massive alluvial deposit. The antecedent river shifted the flow direction from south to WSW direction long the fault plane. New drainage systems were developed from the upthrown block in the south eroding Quaternary alluvial deposits there by exposing the bedrock. These streamlets have combined together and resulted in the development of the Karimpuzha River and the earlier antecedent river formed the Punnapuzha tributary. Localized normal faults within the valley resulted in the development of terraces and channel migration. These faulted blocks have been evolved and modified to present form by subsequent denudational processes.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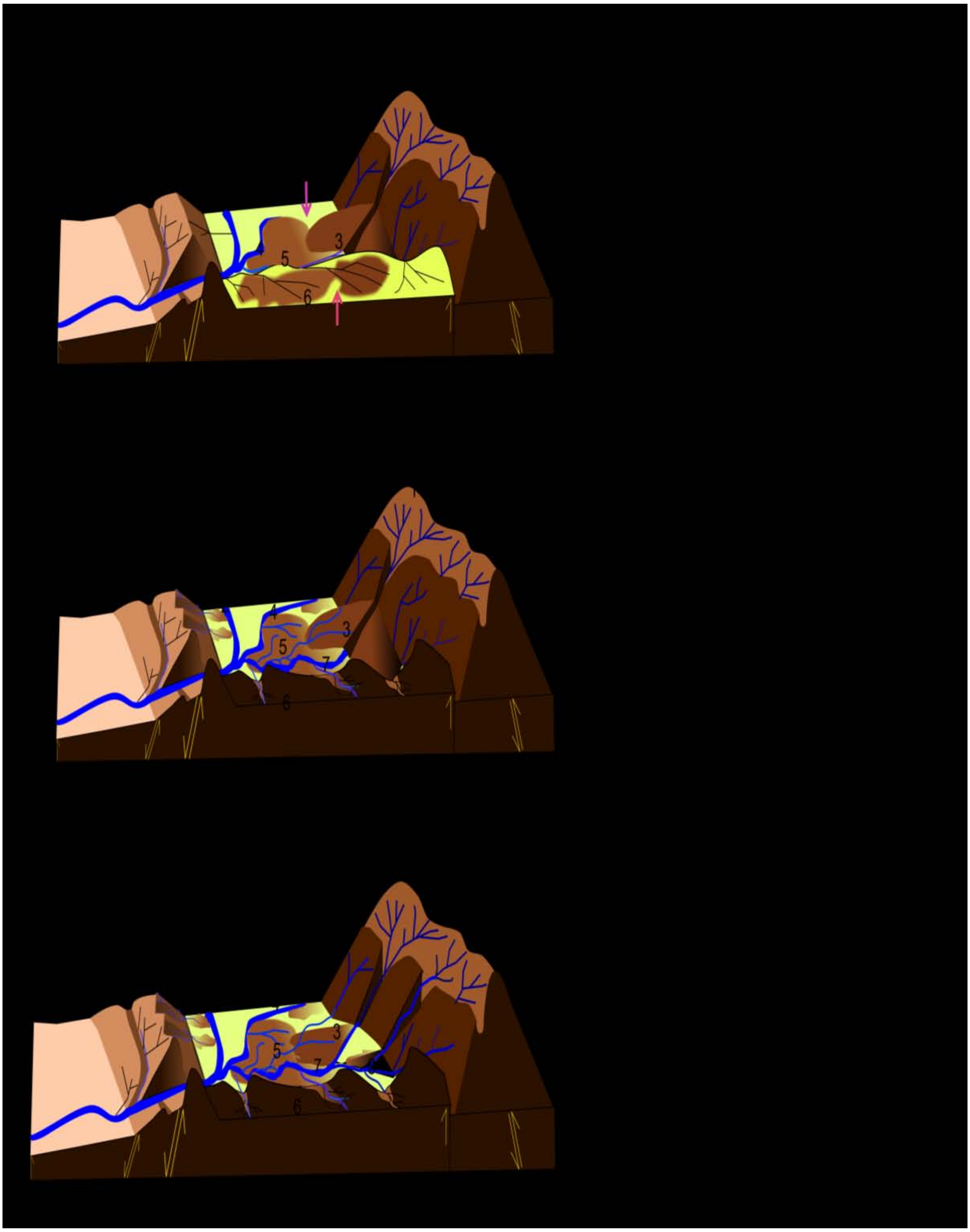

Fig. 7.1 Schematic block diagram showing the evolution of Nilambur valley (a) Western Ghat escarpment, (b) Step faulting that resulted in the development of horst and graben, and fault scarp faces, (c) Development of drainages and alluvial fan, (d) Reactivation of the alluvial and development of antecedent river, (e) ENE-WSW trending normal faulting resulting the upliftment of fan materials and development of streams through the uplifted part of the fan, (f) Erosion and development new river system and the antecedent river joining south flowing Chaliyar River and (g) Present day Nilambur valley with remnants of alluvial fan deposit and numerous rivers and streamlets and thick layer of alluvium.

## 7.2 Recommendations

This comprehensive study has provided the necessary foundation and paved the way for taking up further research on a wide range of applied aspects involving geomorphology. Some of the aspects that has not been dwelt upon in the present study can be pursued in the future to build up on the existing knowledge gained from this study,

- In the present study, dating of the terraces of different levels is not attempted. Thermoluminiscence dating can provide an excellent relative chronology of the terrace sediments. It enables to establish a correlation between sedimentation episodes of fluvial systems and can throw light on the climatic cycles in the Quaternary age.

- To understand the tectonic evolution and palaeo-seismicity of the study area, dating ($^{40}Ar/^{39}Ar$) of pseudotachylite is very useful since it is fault-related rock composed of friction-derived melt material interspersed with clasts and crystals from the host rock and is thought to be formed in response to seismic activity, meteoric impact, rapid tectonic faulting or landslides.