Morphometric and Seismic Hazard Analysis of Achankovil Shear Zone in Part of Kerala and Tamil Nadu States, India

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Research

Keywords: Shear zone, Faults, Morphometric Analysis, Peak Ground Acceleration

Posted Date: March 3rd, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-15892/v1>

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Abstract

Numerous studies have considered Achankovil shear zone as NW-SE trending Precambrian crustal scale structure. Two major faults namely Thenmala and Thenmala south faults are also identified as associated with this shear zone by earlier studies. The present study identified segmented lineaments in these zones. The major drainages in this zone are flowing in a general NW-SE trend. The rock units surrounding these faults are also trending in NW-SE direction. The present study applied both conventional and recent geomorphic parameters to identify anomalies in the terrain. Morphometric results suggest that the area between Thenmala fault and Thenmala South fault especially the central part exhibits anomalies in parameters for example elongation ratio, bifurcation ratio and stream frequency. Recent study identified continuities of NW-SE trending faults as brittle deformation in the southeastern continuity, away from hill ranges and identified as geologically young deformation. The M=6.0 Coimbatore earthquake of 1900 is the largest event reported in the region which occurred in Palghat Cauvery shear zone. The nearest seismic source zone identified is the one located in KKPT shear zone located 70-80 km from the study area which produced a M=5.0 event. There are also several instances of historic and recent earthquakes reported in the study area. Considering the general trend of the seismic source zone reported in the peninsular India the NW-SE trending faults can generate a Magnitude $M > 5.0$. We calculated peak ground acceleration for a magnitude of $M=5.5$ as the maximum credible earthquake that can generate by these two faults. The peak ground acceleration that Thirunelveli, the nearest city, would experience from Thenmala fault is of the range of 0.287-0.262.

1.0 Introduction

Peninsular India, though considered as tectonically stable, has witnessed several damaging earthquakes in the historical past. Several studies initiated subsequent to 1993 Killari earthquake, as a part of seismic hazard evaluation of Indian sub-continent. Number of studies conducted at continental interiors by various researchers, which are similar to prove the assumption that the earthquakes predominantly happen in the zones of weakness which are preexisting²⁰ and are favorably oriented to the ongoing tectonic stresses¹⁰. Due to long return period of damaging earthquakes, characteristic of intra cratonic settings, the events are occurring at least expected locations causing huge loss of life and property. An earlier study in peninsular India considered some of the shear zones in south India as weaker enough to produce damaging earthquakes²⁷. Two northwest-southeast (NW-SE) trending seismic sources identified in Peninsular India, one is Desamangalam fault and the other Periyar fault²⁸. The catalogue on earthquakes happened on Peninsular India is available for only 200 years, advance identification of potential zones which act as sources become important in order to evaluate the risk posed to the region.

To delineate tectonic features like lineaments and faults from Peninsular India, several studies are carried out by researchers like Grady (1971)¹¹, Vemban et al. (1977)⁴¹, Drury et al. (1984)⁹, Anon (1994)¹, Chetty (1996)⁶, GSI (2000)¹² etc and lead to the identification of numeral shear zones. Based on the findings of

Janardhan (1999)¹⁹, and the references therein continuities of these structures observed from some regions of Africa, Sri Lanka etc. The NW-SE trending Achankovil shear zone is one among them.

Several geomorphological studies conducted to the drainage system flowing along Achankovil shear zone (e.g. Manu 2008²³). Two faults are marked in the south eastern side of Achankovil shear zone in the Seismotectonic Map¹², first one is called as Thenmala fault and the second unnamed is later named as Thenmala South fault²⁵. An earlier study identified a geomorphic anomaly and attributed to active tectonism in the northwestern side of NW-SE trending Achankovil shear zone³⁰. Later, brittle faults are identified as the latest tectonic deformation observed along the southeastern terminus²⁵. However, no evidence is available from the area that falls between these two observations where the area is inaccessible due to thick forest cover. The present study evaluated the landforms of the area through morphometric analysis so as to identify subtle signatures of active tectonics, if any. The present study also accessed the seismic hazard of the area in the event of a probable magnitude from these structures.

2.0 Study Area

The area of study is a part of Precambrian crystalline terrain and falls in both Kerala and Tamil Nadu, where a major NW-SE trending shear zone named Achankovil is passing through in the Western Ghats (Fig. 1). This shear zone is clearly visible in both Landsat and Aeromagnetic images^{32,8}. The variation in lithology from northern part to the south is demarcated this as a different zone²⁹. This structure covers 120 km with a thickness of around 10–20 km, through Western Ghats and separating Trivandrum block from massif charnockites³⁴. Gravity studies indicate that Achankovil shear zone is thin along northern side compared to south^{2,40}. According to Radhakrishna et al. (1990)²⁶, current topography of this zone has developed later compared to the originally said shear zone. The two NW-SE trending faults mapped in the vicinity of this zone by GSI (2000)¹² are called Thenmala and Thenmala South fault²⁵.

The study area forms the NW-SE trending Khondalite belt of southern granulite terrain, mostly covered with garnet-biotite sillimanite gneiss and garnet-biotite gneiss^{13,14}. Charnockite, patches of quartzite, quatzo-feldspathic gneiss, calc granulites and limestone and pyroxene granulites are the other major geologic formations observed in the study area (Fig. 2). There are several drainages draining the area of which Kallada river and its tributary streams form the main drainage system flowing northwest. Thampraparni and its tributaries form the major southeast flowing river system in the area. Even though studies identified signature of neotectonism on either side of the structure, no significant study carried out for the central part of the shear zone in the hilly terrain.

Present Study

Most part of the study area comprises Precambrian crystalline rocks. The present study primarily focused on to identify geomorphic signatures of active tectonism in Achankovil shear zone and associated structures in the hilly terrain. It is also tried to access the seismic hazard expected to cause in the event of occurrence of a potential earthquake. Thus, the present study has two parts 1) identification of the

geomorphic signature of active faults through morphometric analysis and 2) to evaluate regional seismicity and hazard assessment.

3.0 Methodology

To understand the tectonic influence of the study area, primarily we demarcated the lineaments from satellite images. Morphometric analysis is done with the help of drainage network extracted from the topographic maps.

In tectonic geomorphology studies, geomorphic indices with their quantitative measurements are used as a common reconnaissance to recognize areas affecting tectonic deformation⁵. To study this anomalous evolution of drainage pattern, drainage basin morphometry and geomorphic indices are used after demarcating the area into 3rd and 4th order basins.

3.1 Lineament pattern

The lineaments identified from satellite image generally show dominant - sets of regional fracture pattern of an area. Some studies identified, NNE-SSW to NE-SW trending lineaments as prominent structures in the eastern side of Southern India¹¹. The orientation of five major group of lineaments observed in Kerala are i) WNW-ESE ii) NW-SE iii) NNE-SSW

24. iv) NNW-SSE & v) ENE-WSW²⁴.

Three sets of lineaments oriented in Northwest - Southeast, Northeast -Southwest and North-South are observed in the area of study (Fig. 2). The NW-SE lineaments dominate the area and are grouped into 4 sets. First set of lineaments oriented in NW-SE direction are observed along the N-E side of Thenmala fault and is named as L1. Second set of segmented lineaments are close to Thenmala fault and is named as L2. The third set of NW-SE trending segmented lineaments located close to Thenmala south fault and is named as L3. The fourth set lineaments falling along the S-W side of the study area is named as L4. Two parallel N-S trending lineaments falling in the S-E part of the study area, cutting across Thenmala south fault, is named as L5. The NE-SW trending segmented lineaments, cutting across both L1 and L2, is named as L6 and are confined to NE side of L3. Some lineaments are randomly oriented even in the western side.

3.2 Drainage network

Kallada, Ittikara, Vamanapuram, Karamana and Neyyar are the main west flowing rivers observed in the area. Thampraparni and its tributaries (Karungal River, Ramanadi and Manimuthar) constitute the east flowing drainage network. The west flowing rivers generally traveling along NW direction in the hilly terrain., a tributary of Kallada river, originates and flow along Thenmala South fault takes a turn towards north near Onthupacha to join Kallada river which is flowing along the Thenmala fault. Near Onthupacha

a tributary of Ittikara river flowing close to the main trunk of Kulattupula in the vicinity of Thenmala south fault.

3.3 Morphometric analysis

For detailed morphometric analysis the total river system of the area is extracted from topographic maps (1:50,000 scale) and assigned stream order to all the segments as per Strahler's (1952)³⁹ method. The study area then divided in to 273 basins of 3rd or 4th order. It is observed that the lengths of 3rd and 4th order streams are increasing towards the plain in the western side. Highest number of first order streams (163 nos.) is observed in basin no 28 which is falling close to the L3 segment of lineament, a tributary of Kulathupula. For morphometric analysis, linear, aerial and relief features of the basins were measured. The parameters calculated in the study are given in Table 1. The study identified that development of 1st and 2nd order streams are spatially closer in the eastern hilly terrain of the area compared to western plain land. Most of the basins of Karungal river in the northeastern side of lineament L1 are oriented in NE-SW direction but along the southern side some basins of Rama Nadi show NW-SE orientation. Near L2 most basins of Kallada River, Rama Nadi and Tambraparni river are oriented in NW-SE direction, however along northern side some basins of Kallada River show NE-SW orientation. Similarly, close to L3 most of the basins of Kallada river, Tambraparni River, Ittikara River and Manimuttar River oriented in NW-SE direction. Strong influence of lineament on basins of Karamana river, Tambraparni and Manimuttar River are observed for the lineament L4 and L6 whereas, influence of lineaments on basins appears to be limited for L5 in the basin formation. The following are the observations from the drainage morphometric analysis conducted in the area.

3.4 Bifurcation Ratio (Rb)

Bifurcation ratio of a basin can be computed by dividing stream number of a particular order with the stream number of the following higher order¹⁶. In the Precambrian terrain of peninsular India, Sreedevi et al. (2005)³⁶ reported the Rb value as 3.61 for a structurally controlled basin (in Cuddapah). Bifurcation ratio of Ist and IInd order drainages of the study area ranges between 11 and 2 for all the basins (Fig. 3). Out of 273 basins, 62 basins show values higher than 4. Basins of high Rb value (>5) observed as clusters in the study area. A cluster of 3 basins (>5 Rb) observed along the southern part of L1. Basin 160 with a Rb value of 11 is located along these lineament L1 (Table 2). Along the southern end of Thenmala fault another cluster of 4 basins of Tambraparni river (falling on lineament L2) is observed. A cluster of NE-SW oriented 5 basins of >5 Rb value is observed between L2 and L3. A large cluster of 10 basins (>5 Rb) is located along lineament L3 near the central part of Thenmala south fault. In this zone a low Rb value (<4) basin 10 is surrounded by high Rb value basins. High Rb value (>8) is observed in basins 125 and 115 of Karamana river falls in the vicinity of L4 (Refer table 2). There is a cluster of less Rb (<4) basins (seven basins;15, 27, 31, 38, 39, 40 and,42) observed in the west of north flowing segment of Kulathupula. It is also noted that some basins with >5 Rb value are scattered west of south Thenmala fault.

3.5 Drainage density (Dd)

The entire length of tributaries, distributaries and main stream in a **drainage basin** is calculated first. The ratio of this length with total area of the drainage basin is then computed to get drainage density value. It measures whether the watershed is well or poorly drained by stream channels¹⁷. The drainage density values calculated for 273 basins varies between 0.8 and 7.07 but the mean value is obtained as 2.87 (Table 2). In general, basins with high Dd values are oriented mainly towards NW-SE and NE-SW directions. Drainage density values will be normally low in those low relief regions where the subsoil is highly permeable or resistant with a thick vegetation cover. At the same time high relief regions with impermeable or weak subsoil and scanty vegetation cause high DD³⁸. Highest Dd value (D_d -7.07) is observed for the basin no 219 of Tambraparni River located between lineaments L2 and L3 with a basin orientation of NE-SW, whereas a Dd value of 6.52 is observed for basin 197 located along a small N-S oriented lineament observed along the Eastern side of the study area, having a main drainage orientation N-S, close to L3 (Fig. 5). There are 16 basins (of Kallada River, Ittikkara River, Tambraparni and Rama Nadi) located between L2 and L3, shows Dd value >4. Among them 7 basins are oriented towards NW-SE whereas 9 basins are oriented towards NE-SW direction including cluster of seven basins located in the central part. Another cluster of 4 basins showing high Dd values are observed in eastern side in the catchment area of Tambraparni/Manimuttar river. In the north western side, basins of Kulattupula and Ittikkara river generally show a low drainage density. In general, the source areas of Tambraparni and Kulathupula shows Dd values >3 with an exception for the basins 75,183 and 198. Two NE-SW basins (4 & 49) of Kallada River observed in the N-E side of L2 shows Dd value more than 4. Low Dd values (<3) except for the basins 239 and 118 observed in the western part. The highest value of Dd is observed in the three basins (basin no 219, 232 and 197) falling between L2 and L3 in south eastern side. The lowest values of Dd (<1) are observed for two basins in coastal zone as well as for a drainage trending NW-SE joining to Ittikkara river (basin no 246).

3.6 Stream Frequency (Sf)

Total number of streams observed in unit area of a river basin is called as Stream frequency¹⁶. Vittala, et al (2004)⁴² found that higher values of this parameter generally show steeper ground surfaces and larger surface runoff. The highest Sf value noted in the area is 12.1(basin no 71-located close to L3) and lowest value 0.06 with an average of 4.38 (Table 2). There are 19 basins showing Sf values >6 out of these 8 basins are clustered between L2 and L3 in the catchment area of Kulathupula river (Fig. 5). There are 6 more basins showing higher values (>6) close to this area apart from some isolated basins in both SE and NW side. Out of the high value cluster of basins between L2 and L3, three basins (basin no 7,8, and 11) shows high ruggedness number and drainage density. Basin no11 also shows high bifurcation ratio and basin asymmetry. In the southeastern corner of the L3 lineament another cluster of high stream density (>6) basins are observed in the catchment area of Manimuttar river. In this zone two low value basins (<4) are engulfed by the high value basins. Similar clusters of 8 basins of high Sf (>6) is observed in the S-E side of L3 in the catchment area of Neyyar river. However, there are two basins within the

cluster showing <4 . There is a cluster of three NW-SE oriented basins of Karungal river with >6 Sf in the vicinity of L1. Two of these basins (32 and 77) shows Dd value >4 . Basin 39 of north flowing segment of Kulattupula and NW-SE oriented basin 216 of Tambraparni river located between L2 and L3 shows surprisingly low Sf (<2) values (Refer Table 1). Comparatively lesser Sf values are observed in the northern side of L2, except for basin no 49 of Kallada River. Higher Sf value basins are concentrated mainly in the vicinity of lineaments L2 and L3 especially along the central and southern side, however low Sf values along northwestern side. Comparatively low Sf values are obtained in the eastern side near coastal zone.

3.7 Elongation ratio (Re)

To calculate this parameter, the diameter of a circle having the similar area of the basin is calculated first. This quantity is then divided with the maximum length of the basin³⁵. According to him, basins with an elongation ratio less than 0.7 are highly elongated. Re values of study area, range between 0.42 and 0.98. Low relief areas showing values near to 1.0 and between 0.6 and 0.8 are related with steep ground slope and high relief (Strahler, 1964). 13 elongated basins of Rama Nadi and Karungal rivers are observed in the vicinity of L1 (Fig. 4). Out of these 8 basins are oriented NW-SE and are clustered on either end of the lineament flowing outward. However, NE-SW trending basins are mostly located in the northern side of the lineament and are flowing towards northeast. There are 74 basins observed between L2 and L3. Out of these 36 basins are elongated and mostly observed in clusters. The central part of the area also having a cluster of 6 basins showing elongated basins. It is to be noted that there is a cluster of less elongated to circular basins (seven basins; 15, 27, 31, 37, 38, 39 and 40) observed in the west of north flowing segment of Kulathupula separating two clusters of highly elongated basins. The same set of basins also exhibit low bifurcation ratio and are more symmetrical though drainage density and ruggedness numbers of this basins are comparable with the cluster of highly elongated basins observed west of it (250, 251, 252, 257). Central part of the south Thenmala fault also exhibit a large cluster of elongated basins (16 nos.) which are spatially linked with the elongated basins observed between L2 and L3. This cluster of basins is also showing high bifurcation ratio compared to surroundings. It is also noted that the highly elongated basins scattered west of south Thenmala fault are mostly oriented along NW-SE direction with some exception close to west coast (oriented NE-SW).

3.8 Ruggedness Number (Rn)

Strahler (1968)³⁷ computed ruggedness number, by multiplying relief of the drainage basin with drainage density. As much as the steepness and length of the basin increases, that much ruggedness number values increase. It is to be observed that basins situated in the western side of the area shows Rn value <1 . Similarly, all basins situated in the north western side of north flowing segment of Kulathupula (north western part of Thenmala south fault) shows Rn value <1 . A large cluster of 26 basins of Rn value >3 is observed along the southern side of lineaments L1 and L2. This cluster is located at the central part of Thenmala fault (Fig. 3). A small cluster of 3 basins (181, 182 and 199) are also observed close to it between L2 and L3. Even though most of the basins located between the southern side of lineaments L2

and L3 shows medium to high Rn value, basins 180,193, 202, 217, 223,224,225,235 and 237 shows Rn values <1. Basin no 10, located along lineament L3 with >3 Rn value also shows high stream frequency, high drainage density with high elongation. Another cluster of 9 basins (80,81,87,91,92,101,133,134, 143,) located at the south western part of Thenmala south fault near Ponmudi. However, basin 299 located close to these cluster shows <1 Rn value. A small cluster of basins of >3 Rn value is observed near the southern end of Thenmala south fault

3.9 Asymmetry Factor (Af)

It is obtained by dividing the area of the watershed to the right side of the main river with the entire area of the catchment. If a stream system is progressed in a uniform lithology terrain with less structural disturbances, the asymmetry factor value will be equal to 50. However highly disturbed terrain associated with active structures would show deviation from this value (<50 or >50²²). The value of Af should be 50 for a continuous stream flowing over a uniform lithology in a stable setting, whereas value will be less than 50 or more than 50 for unstable settling²². The tectonic tilt of the basin area is detected by this factor¹⁵. In this area asymmetry values deviates up to 40 for some of the basins (Table 2). There are 50 basins showing deviation more than 20 in Af in the study area (Fig. 4). The basins with greater anomalous asymmetry factor (deviation more than 30) are mostly falling close to lineaments. However, basins related with lower relief area in the western side of the study are also showing anomalous values (deviation more than 20). The 16 basins located between L2 and L3 in the vicinity of L5 are showing basin asymmetry is the biggest cluster of asymmetric basins observed in the study area. Basin 25 of Karungal river with a high asymmetry (30) is located in the vicinity of lineament L1. Out of 273 basins of the study area, Af values of 138 basins shows > 10 deviation. Around 5 basins of Karungal river and Rama Nadi in the vicinity of L1 observed medium asymmetric values. High asymmetry values are observed in 3 basins of Kallada and Rama Nadi (Basin no 43,45,55,155 and 158) in the vicinity of L2. Out of these except basins 155 and 55, all basins are oriented in NW-SE direction. The highest asymmetry basin 55 of Kallada River (Af is 10) is located along lineament L2. A cluster of 5 basins of >20 deviation is observed at the southern end of Thenmala south fault. It is observed that most of the basins in the vicinity of L3 shows high to medium asymmetry and are situated in the central western side of L3. Basin no. 71 of Kallada River, basins 200,199,238,210 and 209 of Tambraparni River (shows an asymmetry more than 30 (values < 20 and > 80). Similarly, basins 246 of Ittikara and 276 of Vamanapuram Rivers shows high asymmetry. But most of the basins of high asymmetry oriented in NE-SW direction and some medium asymmetry basins are oriented in NW-SE direction. Most of the asymmetric basins are located along the southern part of L3 compared to northern part.

3.10 Valley floor width to valley height ratio (V_f)

This ratio obtained by dividing the width of river valley with the sum of the difference in height of the valley divides on the right & left of the stream floor and the elevations of the valley floor (Table 3.1). Broad floored valleys are differentiating from V shaped valleys by using this parameter⁵. Present study calculated the V_f for the valleys situated along and the vicinity of six lineaments as well as those not in

the vicinity of lineaments. In the study area drainages shows generally low Vf values indicating 'V' shaped valley, except for plain areas in the east and coastal areas in the west. The highest value of Vf observed in an E-W trending drainage of Vamanapuram River is 28.6 and lowest value located in NW-SE trending drainage of Tambraparni is 0.1 at location no 79 (along lineament L3) and 87 (along lineament L2) (Table 3) (Fig. 6). Out of 143 locations 135 locations, valley floor values are less than 10. According to Bull and McFadden (1977)⁵ and Keller and Pinter (2002)²² the locations where the ratio values observed below 10 indicate vigorous tectonic processes. Out of 66 locations selected in NW-SE trending drainages, only three values (locations 122,125,69&71) are >10. Out of these, location 121 and 125 are falling on Vamanapuram River along the western portion of the area of study, away from the lineament and other two located in Rama Nadi in the plains along the eastern side close to L1. The values are falling between 0.1-5 for the locations selected on Kallada River, Karungal River and Rama Nadi along lineament L1. Two values are < 1 and are located on Rama Nadi along the southern segment of L1. Valley floor locations selected along L2 for NW-SE trending drainages of Kallada River and Rama Nadi lies in between 0.1-5. All values are less than 1 along the southern side of L2 in Rama Nadi and Kallada River. Similarly, valley floor value for the points selected in Kallada River and Tambraparni River along L3 varies between 0.1 and 5. Most of the points selected on Tambraparni River along the southern side of L3 except one, shows Vf value less than one. Locations selected for valley floor calculations in Tambraparni River between L2 and L3 shows values <5. Most of the lower values are observed along the southern side of L2 and L3. Northern side of L5 shows lower Vf value compared to southern side. Locations selected in the NE-SW trending drainages of Karungal and Kallada River along lineament L6 also shows <5 Vf values except one. Some drainages of Vamanapuram River selected to calculate valley floor values in plain areas, away from the lineament to find out the condition of valleys in this terrain. None of them show less than one but are mostly within 10. This may indicate that development of 'V' shape valley may be due to high erosional resistance of hard rock terrain. Thus, we consider <1 value of Vf may be indicating the evidence of active tectonism in this study area. The value <1 is mostly falling in the drainages of Kallada River, Tambraparni River, Karungal River and Rama Nadi along L1, L2 & L3.

3.11 Transverse Topographic Symmetry Factor (T)

This value is obtained by dividing total distance of the river channel from the middle of the watershed with the distance measured from the central line to the basin boundary. T shows the relocation of stream channel right angled to the drainage basin axis⁷. Transverse topography symmetry factor calculated for the drainages in the study area shows that the drainages close to the lineaments show definite pattern. NW-SE trending drainages of Kallada River, Karungal river and Rama Nadi located along as well as in the vicinity of lineament L1 shows deviation towards south west (Fig. 6). At the same time most of the NE-SW oriented drainages of these rivers close to L1, shows deviation towards northwest. But the magnitude of deviation is comparatively more for NW-SE trending drainages. In the same way most of the NW-SE flowing drainages of Kallada river and Rama Nadi along the lineament L2 and its vicinity are showing deviation towards southwest and the NE-SW tributaries of these rivers shows deviation towards north west. NW-SE oriented drainages of Manimuttar River, Tambraparni River, and Kulattupula located along

and close to lineament L3 shows deviation towards north east. Similarly, NW-SE oriented drainages of Ittikara river located between Thenmala fault and Thenmala South fault shows deviation towards north east, but those located in the western side of South Thenmala fault shows deviation towards south west. NW-SE oriented drainages of Karamana river falling along and vicinity of lineament L4 shows deviation towards northeast. Similarly, NW-SE oriented tributaries of Tambraparni falling along and vicinity of L5 shows north east deviation. However, drainages of kulattupula, Kallada and Karungal Rivers falling along the lineament L6 is not showing any definite pattern towards any particular direction. In general, most of the NW-SE trending drainages located near lineaments showing a deviation towards south west. But exceptions are observed in NW-SE flowing drainages located close to lineament L3, they show a deviation towards north east. However, drainages situated in the western side of the study area shows a deviation towards south and southwest. Between L2 and L3 the drainages seldom show deviations towards south east.

4.0 Regional Seismicity

Considering the recent and historic earthquakes of south India, the most important one is the 1900 Coimbatore earthquake³. There are several incidence of low magnitude earthquakes in Kerala²⁸. Geological studies succeeding to 1994 Wadakkancheri earthquake (M=4.3) identified a NW-SE trending potential fault²¹. The earthquake sequence of 2000-2001 (M=5.0 & 4.8) in central Kerala⁴, which is occurred about 70-80 km from the study area, suggest NW-SE trending fault as the possible causative fault. The temporary local network in 2011-12 in Kerala³³ further confirmed that the NW-SE system of central Kerala is adjusting in the present stress regime. Historically too this area had been experiencing low magnitude earthquakes with the isoseismals elongated in NW-SE and are spatially close to NW-SE trending faults/lineaments²⁸.

In the study area too, there are many occurrences of low magnitude earthquakes in the vicinity of Thenmala and Thenmala south faults (Table 4). The biggest of them (M 4.5) on 07/06/1988 is located near Aryanadu, falling in the south western side of Thenmala south fault in the vicinity of lineament L4 followed by another one (M=4.3) in the same location after 12 hours (Fig.7). Another event is reported in the next day (08/06/1988) with a magnitude of 3.5 near Idaikkal, located in the eastern side of Thenmala fault. After two months, one more event is reported with a magnitude of 3.2 in the north eastern side of Thenmala fault which is followed by another event of M=3 near Chembur. after 6 days an earthquake of magnitude of 3.6 was occurred on 14/11/1993 is located close to Thenmala South fault between Mannur and Nellimudu.

Historically too this region experienced events in closely spaced time period. In the year 1881 an event was reported with an intensity of 3 close to lineament L2. The other two significant events are reported during 1856 within a span of 15 days felt an intensity of IV near Panayamuttam. The other events (2 nos) are falling in the drainage basin area of Vamanapuram River. These five tremors are reported around Thenmala fault and Thenmala south fault with in a span of 3 months. The results indicate that the study area subjected to greater frequency of low magnitude earthquakes. However, accuracy of location is not

good enough to confidentially connect them to any specific lineament, the enduring seismicity may due to the tectonic modification along these NW-SE oriented structures.

4.1 Seismic hazard evaluation

From the regional study it is understood that the maximum earthquake occurred in the regional vicinity is $M=5$ (2000-2001 Kottayam events) though Killari earthquake of $M=6.3$ is the maximum occurred in peninsular India. Considering the probability of reactivation, the Thenmala and Thenmala south fault are favorably oriented¹⁰ (NW-SE) for movement in the present stress regime. The focal mechanism available for various events in Central Kerala are also suggest adjustments in NW-SE trending structures^{31,33,4}. Based on the nearest bigger event it can be considered that a magnitude $M=5.0$ is quite possible from these structures and for a safer side we need to prepare for an eventual $M=5.5$ magnitude as maximum credible earthquake from these sources.

Considering the population existing near this fault we attempted to calculate the Peak Ground Acceleration (PGA) in the level of bed rock at various nearby cities. The widely accepted attenuation relation for calculating PGA in peninsular India is formulated by Iyengar and Raghukanth (2004)¹⁸. Equation is given below:

$\ln y = c_1 + c_2 (M-6) + c_3 (M-6)^2 - \ln R - c_4 R + \ln \epsilon$, Where y refers to Peak Ground Acceleration in g , M refers to magnitude of earthquake and R refers to hypo central distance. Since PGA is known to be attributed nearly as a lognormal random variable $\ln y$ would normally distribute with the average of $(\ln \epsilon)$ being almost zero and the constants for the South Indian province are $c_1=1.7816$, $c_2 = 0.9205$, $c_3 = 0.0673$ and $c_4 = 0.0035$.

From the available information focal depth of the moderate events in peninsular India is found to be between 7 to 10 km. Based on this the PGA at rock level that would experience to the four nearby cities, in the event of moderate earthquake ($M=5.5$) from these two potential sources, has been calculated (Table 5). Thirunelveli is the nearest city located only 15 km from the Thenmala fault and Trivandrum located farthest (47 km) from the same fault. On the other hand, Trivandrum is the nearest city (33 km) from Thenmala south fault. It found that the city of Thirunelveli would experience a PGA of the order of 0.287-0.2627 in the event of a moderate event form Thenmala fault and Trivandrum would experience a PGA of the order of 0.1475-0.1296 for similar event from Thenmala south fault.

5.0 Discussion

The NW-SE trending Thenmala fault and Thenmala south fault are the prominent regional features observed in the study area. The major drainages in this zone are flowing in a general NW-SE trend. Study identified the presence of 6 set of lineaments, oriented in NW-SE, NE-SW and N-S with a segmented nature. Results indicate that the basins located along the central part of Thenmala fault and Thenmala south fault shows more anomalies for the morphometric parameters calculated in the study.

Basins with high R_b values are observed in clusters in the vicinity of Thenmala fault and Thenmala south fault near lineaments L2 and L3. Even though D_d is low, some basins located between Thenmala fault and Thenmala south fault (between lineaments L2 and L3) shows relatively high R_b values. Basins with high D_d values are concentrated between Thenmala fault and Thenmala south fault. The basins of the study area are mostly elongated and a large cluster of elongated basins observed along Thenmala south fault. It is also noted that the highly elongated basins scattered west of south Thenmala fault are mostly oriented along NW-SE direction with some exception close to west coast (oriented NE-SW). Basins with high R_n are observed in majority near Thenmala fault and Thenmala south fault. Higher S_f value basins are concentrated mainly in the vicinity of lineaments L2 and L3 especially along the central and southern side, however low S_f values are observed in the northwestern side.

Three more geomorphic parameters (A_f , T and V_f) employed in order to have more quantitative evidences. Both A_f and T are generally used to detect the tilting of a region ²². In the study area asymmetry factor deviates up to 40 for some basins. There are 50 basins showing deviation more than 20 A_f in the study area. The basins with higher anomalous asymmetry factor (deviation more than 30) are mostly falling close to lineaments. Because of the high erosional resistance of the hard rock terrain, < 1 value of V_f is considered as the evidence of active tectonism in this study area. The value < 1 is mostly falling in the drainages of Kallada River, Tambraparni River, Karungal River and Rama Nadi along lineaments L1, L2 & L3. The V_f calculated for different drainages indicate that the magnitude of deviation is comparatively more for NW-SE trending drainages. In general, most of the NW-SE trending drainages located near lineaments showing a deviation towards south west. But exceptions are observed in NW-SE flowing drainages located close to lineament L3, they show a deviation towards north east. However, drainages situated in the western side of the study shows a deviation towards south and southwest. Few seismic events are also reported in this region. Between L2 and L3 the drainages seldom show deviations towards south east. The NW-SE trending lineaments and related anomalies representing that these may developed from neotectonics movements.

The results indicate that the study area subjected to greater frequency of notable earthquakes. The twin earthquakes observed near Aryanadu ($M = 4.5$ and $M = 4.3$) on 07/06/1988 is followed with another event on the next day at Idakal with a magnitude of 3.5. After two months, one more event is reported (on 26/08/1988) with a magnitude of 3.2 in the north eastern side of Idakal followed with an event (on 02/09/1988) of $M = 3$ at Chembur after 5 days. This frequent earthquake with in short duration around Thenmala fault and Thenmala south fault indicate that the above-mentioned structures may be tectonically active and can produce a maximum credible earthquake of $M = 5.5$ which would generate a PGA between 2.6–2.8 in the town of Thirunelveli.

6.0 Conclusion

Present study proves the control of Thenmala and Thenmala south fault over the area and its drainages. The anomalies observed in the drainage density, bifurcation ratio, stream frequency etc. are mainly observed along and the vicinity of the NW-SE trending four lineaments. The anomalies observed are

specifically matching with the values observed in tectonically active basins. The remaining geomorphic indices like transverse topographic symmetry factor, asymmetric factor and valley floor width to height ratio showing data supporting this conclusion. The ground motions calculated from the recorded shakes as peak ground acceleration and expected magnitudes. These values are considered from the nearby two active sources, Thenmala and Thenmala south faults. Morphometric outcomes suggest that the above said NW-SE trending faults influenced the drainage network of the area. Latest study recognized continuities of NW-SE trending faults as brittle deformation in the southeastern continuity, away from hill ranges and identified as geologically young deformation. The region also experienced earthquakes of magnitude up to M=5, prompting to consider the potential hazard from moderate earthquake.

Abbreviations

PGA	Peak Ground Acceleration
AKSZ	Achankovil Shear Zone
NW-SE	North West- South East
NE-SW	North East- South West
N-S	North -South
DD	Drainage Density
BR	Bifurcation Ratio
SF	Stream Frequency
ER	Elongation Ratio
RN	Ruggedness Number
AF	Asymmetry Factor
TTS	Transverse Topographic Symmetry Factor
VR	Ratio of Valley Floor Width to Valley Height
KKPT	Karur Kamban Painavu Trichur Shear Zone
SEISAT	Seismotectonic atlas of India
GSI	Geological survey of India

Declarations

- Availability of data and materials- Research data from own PhD work. The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.
- Competing interests-NA
- Funding-NA
- Authors' contributions-PE analyzed and interpreted the study area data. Dr. Ganapathy-Guide of PE helped to synthesis the data. All authors read and approved the final manuscript.
- Acknowledgements-The authors are express the gratitude to Dr. Biju John, senior scientist, NIRM, Bangalore for his encouragement, support and extended facilities for this study. Support given by Centre for Disaster Mitigation and Management, Vellore Institute of Technology (VIT), Vellore, India is gratefully acknowledged.

References

1. Annon (1994) Geoscientific analysis, database creation and development of GIS for parts of Indian Peninsular Shield, Project Vasundhara.
2. Balakrishnan T S, Unnikrishnan P, Murthy AV S (2009) The Tectonic Map of India and contiguous areas. Jour. Geol. Soc. India 74:158-170.
3. Basu K L (1964) A note on the Coimbatore earthquake of 8th February 1900. Indian J. Meteor. Geophys 15 :281– 286.
4. Bhattacharya S N , Dattatrayam R S (2002) Earthquake sequences in Kerala during December 2000 and January 2001. Sci.82 :1275-1278.
5. Bull W B , McFadden L (1977) Tectonic geomorphology North and South of the Garlock fault Geomorphology in Arid Regions :115–138.
6. Chetty T R K (1996) Proterozoic shear zones in southern granulite terrain India. Gondwana Research Group Memoir-3: The Archaean and Proterozoic terrains in Southern India within East Gondwana :77-89.
7. Cox R T (1994) Analysis of drainage basin symmetry as a rapid technique to identify areas of possible Quaternary tilt block tectonics: An example from the Mississippi Embayment. Soc. Am. Bull 106 :571-581.

8. Drury S A, Harris N B W, Holt R W, Reeves-Smith G J , Wightman R T(1984) Precambrian tectonics and crustal evolution of south India. *Geol* 92 :3-20.
9. Drury S A, Holt R W (1980) The tectonic framework of the south Indian craton: a reconnaissance involving LANDSAT imagery. *Tectonophysics* 65 :71–75.
10. Gowd T N, S V Srirama Rao, V. K. Gaur (1992) Tectonic stress field in the Subcontinent. *J. Geophys* :11879–11888.
11. Grady C (1971) Deep main faults in south India. *Jour. Geol. Soc. India* 12 : 56–62.
12. GSI Seismotectonic Atlas of India and its Environs. *Surv. India Spec. Publ.*, 2000, no.59.
13. , Quadrangle Geological Map 58D, 1970.
14. , Quadrangle Geological Map 58H, 1969.
15. Hare P W, Gardner T W (1985) Geomorphic indicators of vertical neotectonism along converging plate margins, Nicoya Peninsula, Costa Rica. *Tectonic Geomorphology* :75–104.
16. Horton R E (1985) Erosional development of streams and their drainage basins; hydro physical approach to quantitative morphology. *soc. Am. Bull* 56: 275-370.
17. Horton R E (1932) Drainage basin characteristics. *Trans. Amer. Geophys* :350-361.
18. Iyenger R N, Raghukanth (2004) Attenuation of Strong Ground Motion in Peninsular India. *S.T.G. Seismological Research Letters* 75: 530-540.
19. Janardhan A S (1999) Southern Granulite Terrain, South of the Palghat–Cauvery Shear Zone: implications for India– Madagascar connection. *Gondwana Res.*2(3) : 463–469.
20. John B, Rajendran C P (2009) Evidence of episodic brittle faulting in the cratonic part of the Peninsular India and its implications for seismic hazard in the slow deforming regions. *Tectonophysics* 471: 240-252.
21. John B Rajendran C P (2008) Geomorphic indicators of Neotectonism from the Precambrian terrain of Peninsular India: a study from the Bharathapuzha Basin Kerala *Geol. Soc. India* 71: 827–840.
22. Keller E A, Pinter N (2002) *Active Tectonics: Earthquakes, Uplift, and Landscape*. Prentice Hall, New Jersey.
23. Manu M S, Anirudhan S (2008) Drainage characteristic of Achankovil river basin. *Journal of Geological Society of India* 71:841-850.
24. Nair M M (1990) Structural trend line patterns and lineaments of the Western Ghats, South of 130 latitude. *Geol. Soc. India* 35: 99-105.
25. Praseeda E, John B, Srinivasan C, Singh Y, Divyalakshmi K S, Samui P (2015) Thenmala Fault System, Southern India: Implication to Neotectonics. *Geol. Soc. India* 86:391-398.
26. Radhakrishna T, Mathai J, Yoshida M (1990) Geology and structure of the high-grade rocks from Punalur - Achankovil sector South India. *Geol. Soc. India* 35: 263-272.
27. Rajendran, C. P., Rajendran, K., & John, B., The 1993 Killari (Latur), Central India, Earthquake: An Example of Fault Reactivation in the Precambrian Crust', *Geology*, 1996, v. 24, pp.651-654.

28. Rajendran C P, John B, Sreekumari K, Rajendran K (2009) Reassessing the earthquake hazard in Kerala based on historical and current seismicity. *Geol. Soc. India* 73 :785-802.
29. Rajesh k, Chetty T R K (2006) Structure and Tectonics of the Achankovil Shear zone Southern India. *Gondwana Research* 10:86-98.
30. Ramasamy S M, Kumaran C J, Selvakumar R, Saravanavel J (2011) Remote sensing revealed drainage anomalies and related tectonics of South India. *Tectonophysics* 501: 41-51.
31. Rastogi B K, Chadha RK, Sarma C S P(1995) Investigations of June 7, 1988 earthquake of magnitude 4.5 near Idukki Dam in southern India :109-122.
32. Reddi A G B, Mathew M P, Singh B, Naidu P S (1988) Aeromagnetic evidences of crustal structure in the Granulite terrain of Tamil Nadu- Kerala. *Jour.Geol. Soc. India* 32:368-381.
33. Saikia U, Rai S S, Subrahmanyam M, Satyajit D, Somasis B, Kajal J B, Rishikesh M(2014) Accurate location and focal Mechanism of small earthquakes near Idukki Reservoir Kerala: Implication for earthquake genesis. *Current Science*107:1885-1891.
34. Santosh M, Morimoto T, Tsutsumi Y (2006) Geochronology of the khondalite belt of Trivandrum Block, Southern India: electron probe ages and implications for Gondwana tectonics *Gondwana Research* 9:261–278.
35. Schumm S A (1956) Evolution of Drainage systems and slopes in bad lands at Perth, Amboy, New Jersey. *Bull. Soc. America* 67:597-646.
36. Sreedevi P D, Subrahmanyam K, Shakeel Ahammed (2005) The significance of morphometric analysis for obtaining ground water potential zones in a structurally controlled terrain. *Environmental Geology* 47: 412-420.
37. Strahler A N (1968) Quantitative geomorphology. In:Fairbridge RW (ed) *The encyclopaedia of geomorphology*. Reinhold Book Crop, New York.
38. Strahler A N (1964) Quantitative geomorphology of drainage basins and channel networks, In: *Handbook of applied Hydrology*, McGraw-Hill Book Cooperation, New York: 4-39-4-76.
39. Strahler A (1952) Dynamic Basis of Geomorphology. *Geological Society of America Bulletin* 63 : 923-938.
40. Sunil P S, Radhakrishna M, Kurian P J, Murty B V S , Subrahmanyam C, Nambiar C G, Arts K P, Arun S K, Mohan S K (2010) Crustal structure of the western part of the Southern Granulite Terrain of Indian Peninsular Shield derived from gravity data. *Asian Earth Sciences* 39:551–564.
41. Vemban N A, Subramanian K S, Gopalakrishnan K, Rao V V (1977) Group Discussion on lineament tectonics and regional tectonic analysis. *Surv. India Misc. Publications* 31:53-56.
42. Vittala S R, Govindaiah S, Gowda H H (2004) Morphometric analysis of sub watersheds in the Pavagada area of Tumkur District, South India using Remote sensing and GIS Techniques. *Indian. Soc. Remote sensing* 32 : 351-362.

Tables

Figures

Figure 1

.Seismotectonic Map of the peninsular India showing study area adopted from SEISAT(GSI 2000). 1 and 2 are Thenmala and Thenmala south fault respectively.

Figure 2

. Geology and lineament of study the area(from GSI 1969 and 1970 quadrangle maps). Thenmala and Thenmala south fault are marked. The lineament from the present study shows segmented nature of surface expression of faults.

Figure 3

Drainage basin map showing distribution of ruggedness number and Bifurcation ratio (between first and second order streams) in the study area.

Figure 4

Drainage basin map showing distribution of elongation ratio and asymmetry factor in the study area.

Figure 5

Drainage basin map showing distribution of stream frequency and drainage density in the study area.

Figure 6

Drainage basin map showing distribution of valley floor width to height ratio and transverse topographic symmetry factor in the study area.

Figure 7

Historical seismicity of the area between latitude 80 30' - 90 0' and longitude 760 45' - 77 030'.

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