Geomatics Based Appraisal on the Seismic Status of Southern India

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Abstract
The paper deals with the Geomatics based appraisal on the seismic scenario of South India. The tectonic linear features interpreted from satellite based remote sensing data were correlated with historical seismicity data using ArcGIS. The study reveals that N20^0 – 40^{0}W oriented lineaments and NE – SW to ENE – WSW lineaments are seismogenic and the later seems to be more risk prone. The frequency of moderate seismicities (4 to 5M) seems to have increased abruptly since 1971, which may be due to the up-gradation of seismic monitoring network, or due to their recurrence related to present day active tectonics in Southern India.

1. Introduction

The Indian Peninsular Shield, which has been thought as stable and inert to younger earth movements and related seismicities for quite long, has now turned out to be otherwise. The seismicities of Koyna (1967), Bhadrachalam (1969), Killari (1993), Jabalpur (1997) and Bhuj (2001) indicate that the peninsular region of India is not only vulnerable to seismicities but these could be disastrous too. In Southern Indian Peninsular also, a lot of earth tremors have been recorded (3 to > 5 M on Richter scale) since 1807 AD (Ramalingeswara Rao, 1992 and Anon, 1994). In addition, despite the strong belief of seismic inertness, many earlier workers (Vaidyanathan, 1971, Grady, 1971, Nair and Subramanian, 1989, Radhakrishna ,1992, Ramasamy and Balaji, 1995, Valdiya, 1998, Bendick and Bilham, 1999 and many others) have observed that South India is tectonically active since Jurassic period (210 million years). Further, the correlative studies carried out between lineaments / faults and seismicities by earlier workers indicate the coincidence of seismicities with lineaments / faults of different azimuthal frequencies in South India falling in parts of Karnataka, Andhra Pradesh, Kerala and Tamil Nadu states (Vemban et al., 1977, Ramalingeswara Rao and Sitapathi Rao, 1984, Singh and Raghavan, 1989, Ganesha Raj, 1990, Ramalingeswara Rao, 1992 and 2000, Banerjee et al., 2001, Valdiya, 2001, and many others). Ramalingeswara Rao (1992) further identified a new seismic zone in areas of low to high grade transition zone of South India and further stated that the diffused and weak seismicities could be attributed to the reactivation of adjoining shear zones. However, almost all the earlier workers suggested for further studies between the lineaments / faults and seismicities. Hence taking advantage of the availability of advanced technologies like high resolution satellite remote sensing which can aid in precise mapping of lineaments / faults and GIS which has advanced credential in spatial correlative modeling between lineaments and seismicities, the present study was undertaken to appraise the relation between seismicities and lineaments / faults using these technologies for parts of South India falling in Mangalore (M) – Chennai (C) – Cape Comorin (C) triangle (Figure 1A).

2. Methodology in Brief

In the present study, high resolution raw and digitally enhanced IRS satellite data were interpreted. In the case of raw data, all four bands of IRS 1C data having the spectral bands in visible and near infrared ranges were studied.

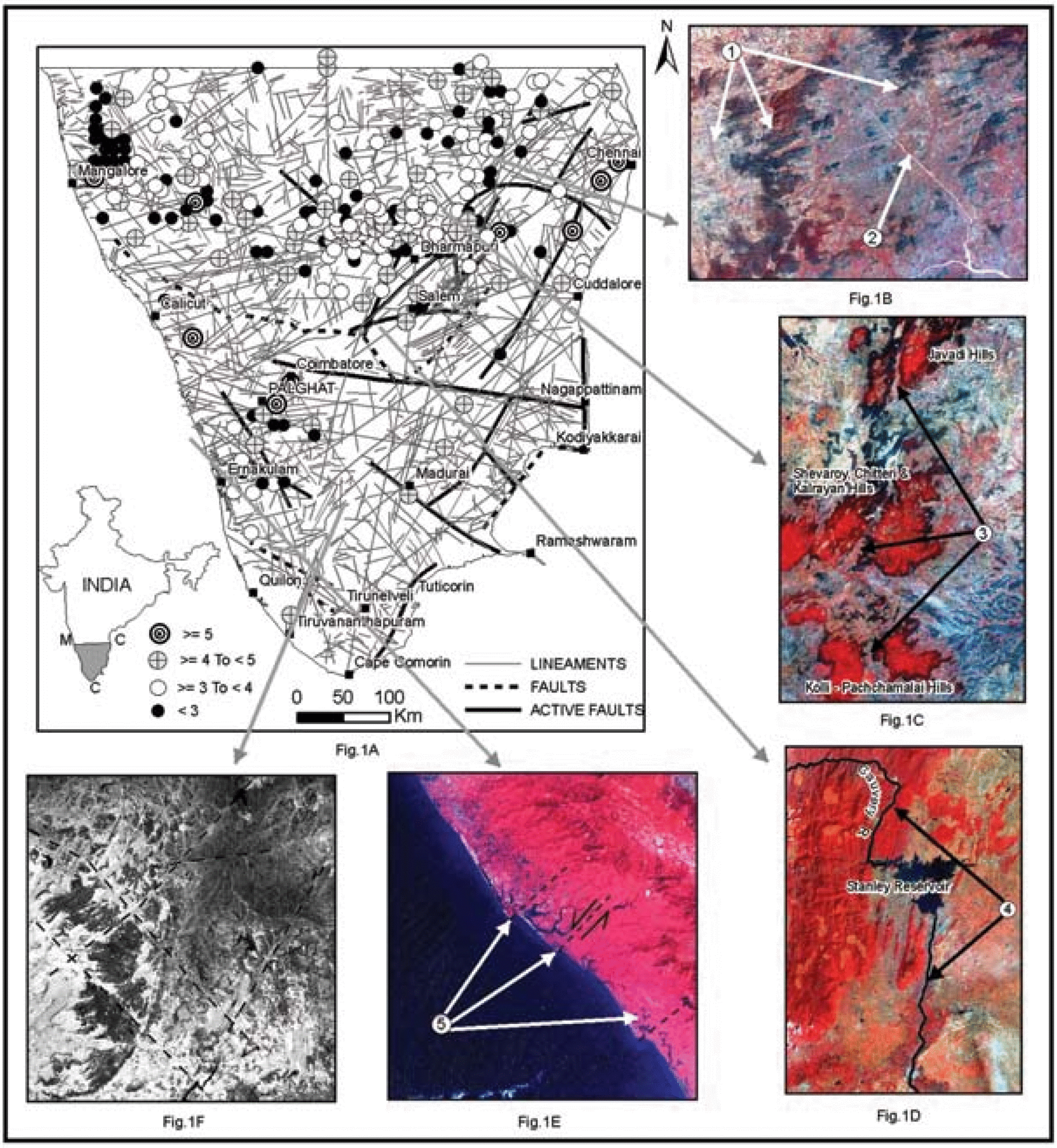

Figure 1: Lineaments/faults and seismicities

Figure 1A: Sketch showing the Lineaments and Seismicties, Figure 1B: IRS 1C FCC Imagery-Dyke Filled factures (1) and Fault controlled Pambar river (2) in Tiruttani region, Figure 1C: IRS 1C FCC Imagery –N-S Oriented major lineament /Fracture valley (3) bisecting Javadi hills in the north, Chitteri – Kalrayan hills in the center and Kolli – Pachchamalai hills in the south, Figure 1D: IRS 1C FCC Imagery – Cauvery River's rectangle southerly deflection along a systems of N-S Lineament (4) in the Stanley reservoir – Hogenekkal area, Figure 1E: IRS 1C FCC Imagery-Displaying a system of ENE-WSW/NE-SW lineaments expressing Sinistral Displacement (5) of coast in the part of Karnataka – Kerala Coast, Figure 1F: IRS 1C Rationed(3/4)Imagery – lineaments in the part of Kodaikamal Hillls

However, wherever linear features were faintly seen, False Color Composite (FCC) data, generated by exposing bands 2, 3&4 respectively under blue, green and red filters and deriving a single colored image (Figure 1B to 1E), and ratioed satellite pictures, generated by ratioing the reflectance values of four bands into six independent ratio outputs (1/2, 1/3, 1/4, 2/3, 2/4 and 3/4) were used (Figure 1F). From such satellite data sets, linear features were extracted using various photo recognition elements (Lillesand, 1989). In this case, dyke filled fracture systems and rectilinear flow of major drainages (1,2,Figure 1B), well defined linear fracture valleys and faultline escarpments in mountainous regions (3,Figure 1C), conspicuous and major deflections in rivers and drainages (4, Figure 1D), visibly seen faults along the coasts (5, Figure 1E) and other photo recognition elements like tonal, textural, vegetational and relief linearities and curvi linearities were interpreted. The linear features so interpreted for 20 number of individual satellite scenes were stitched/mosaiced and a single overlay was prepared using ArcGIS software and a planimetrically controlled map showing the linear features was thus prepared for the study area. These linear features were subjected to further analysis in conjunction with lithological, tectonic and geomorphic features interpreted from satellite images, inferred and active faults mapped and published by Geological survey of India (Anon, 2000) and the structural data collected from the field etc. Thus, the linear feature / lineaments related to tectonic origin were filtered from the linear feature map and the final lineament map was prepared (Figure 1A). Over this map, 238 historical seismicity data of more than M3 in Richter scale (Ramalingeswara Rao, 1992, Anon, 1994 and Ramalingeswara Rao, 2000) were plotted and the relation between the two was evaluated. To do so, the lineaments were further azimuthally classified into 18 groups of 10^0 each (N0^0-10^0W, N11^0-20^0W, N21^0-30^0W. ....and N0^0-10^0E, N11^0-20^0E, N21^0-30^0E, ...so on and so forth) and separate ID's were given for such 18 azimuthal groups of lineaments in ArcGIS environment. The epicenters / seismicities falling in each azimuthal group of lineaments were counted by overlaying the GIS layer having spatial distribution of seismicity data over lineament GIS layer. While counting so, the seismicities falling in the intersections of two or three lineaments were credited to all those intersecting lineaments and hence the 238 number of actual seismicities have accrued a total of 411 numbers called as "seismic counts" in this analysis. Subsequently various histograms were generated between the 18 azimuthal groups of lineaments and the corresponding seismic counts of the 411 counts. Similarly, individual histograms were also generated between the lineaments and 112 seismic counts of four block years (accrued from 96 seismic data) for which only years of occurrence was available as described below:

1. The histogram was generated between 18 azimuthal groups of lineaments and the corresponding seismic counts falling along each group of lineaments out of the total counts of 411 (Figure 2). This was done to evaluate the relation between the 18 azimuthal groups of lineaments and the historical seismicity data and to detect the seismic prone lineament group / groups.

2. Out of these 238 actual seismic data, the years of occurrence were available only for 96 seismic events that too restricted to the time span of 1807 to 1994 AD. This period was divided into four block years viz: 1807-1850, 1851-1900, 1901-1950 and 1951-1994 and the seismicities of these four block years falling along the 18 azimuthal groups of lineaments were independently counted and separate histograms were generated for each block year (Figure 3 to 6). This was again done to evaluate whether any possible changes are there in the lineament azimuths and the seismicities during these four block years. In this case too, the seismicities falling at the intersections of two or three lineaments were credited to all the intersecting lineaments. Hence 96 actual seismicities have accrued the seismic counts of 112.

3. The histogram was also generated between the same 18 azimuthal groups of lineaments and the highest magnitude of the seismic events witnessed along each azimuthal group of lineaments (Figure 7) to analyse which azimuthal groups of lineaments have witnessed seismicity of maximum magnitude.

4. Similar histogram was generated between the frequency of seismicities (number of seismicities) and the years of occurrence by using such 96 seismicities by grouping the years (1807 – 1994) into 18 block years of 10 years each (Figure 8).

5. In the same way, histogram between the magnitude of the 96 seismicities and the corresponding years of occurrence was also generated (Figure 9).

3. Discussions

Such analyses between the lineaments and the historical seismicity data have brought out certain newer information:

-The histogram between the 18 azimuthal group lineaments and the overall 411 seismic counts shows that 219 fell along NW – SE oriented lineaments and 192 fell along NE – SW aligned lineaments (Figure 2).

Though there appears to be a equal distribution of seismic counts both in NE – SW and NW – SE groups of lineaments, in the NW – SE groups maximum seismic counts were observed along $N21^0 – 40^0W$ oriented lineaments, whereas in the NE – SW groups seismic counts were spread over in the wider azimuthal spectrum of $N31^0 – 80^0E$ oriented lineaments (Figure 2 and Table 1).

- The histogram based correlative study between such 18 azimuthal groups of lineaments and the 112 seismic counts of four block years viz: 1807 – 1850 (Figure 3), 1851 – 1900 (Figure 4), 1901 – 1950 (Figure 5) and 1951 – 1994 (Figure 6) shows that from amongst 112 seismic counts 11, 30, 1 and 70 seismic counts occurred respectively in the above four block years.

Such block years wise analysis too (Figure 3, 4 and 6) shows a similar coincidence of maximum seismic counts along $N21^0 – 40^0W$ and $N31^0 – 80^0E$ lineaments except in block years (1901 – 1950) during which only one seismic count was recorded (Figure 5 and Table 1).

- The analysis between the above 18 azimuthal groups of lineaments and the highest magnitude of the seismic count witnessed in each group of lineaments shows no significant relation between the magnitudes and the lineament orientations (Figure 7). This means that magnitude wise the $N21^0–40^0$ W and $N31^0–80^0$ E lineaments do not show any conspicuous highs in seismic magnitude

Thus, the above analyses between the lineaments and the historical seismicity data show that NNW – SSE ($N21^0 – 40^0W$) groups and the NE – SW to ENE – WSW ($N31^0 – 80^0E$) groups of lineaments have more correlation with seismicities and hence these could be the probable seismogenic corridors. As such seismicities are found along restricted spectrum of lineaments in NW groups and wider spectrum of lineaments in NE – SW to ENE – WSW groups of lineaments may be more vulnerable for seismicities.

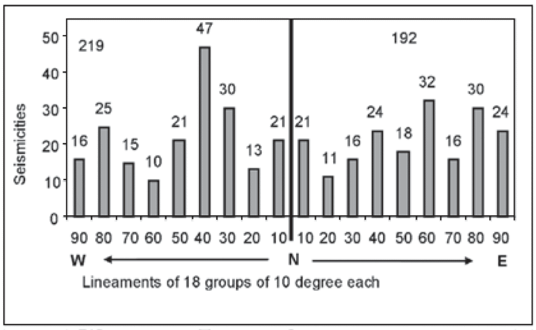

Figure 2: Histogram showing number of seismic counts falling in 18 Azimuthak groups of lineaments of 10^0 each

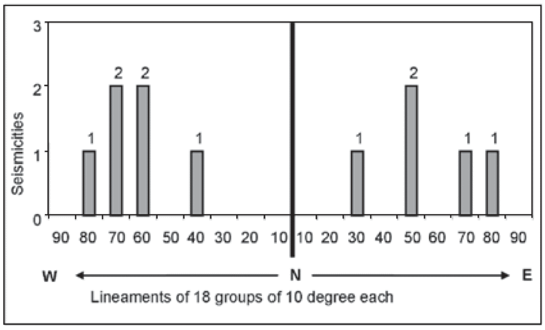

Figure 3: Histogram between number of seismic counts during 1807-1850 AD and 18 azimuthal group of lineaments

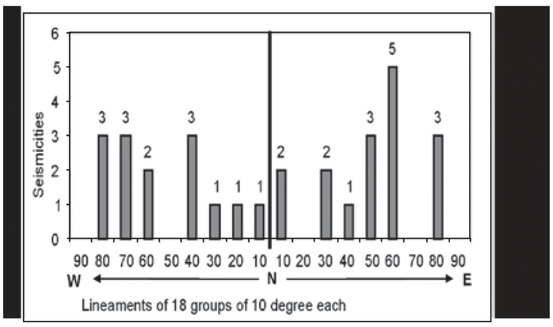

Figure 4: Histogram between Number of Seismic counts during 1850 – 1900 AD and 18 azimuthal groups of lineament

Table 1: Seismicities of different periods and corresponding lineaments of seismic maximas

Sl. No	Item	Lineament azimuths of seismic maximas	
		NW	NE
1	Historical Seismicities	$N21^0–50^0W$	$N31^0–90^0E$
2	Seismicities (1800–1850)	$N61^0–70^0W$	$N41^0–50^0E$
3	Seismicities (1850–1900)	$N31^0–80^0W$	$N41^0–80^0E$
4	Seismicities (1901–1950)	$N00^0–10^0W$	-----
5	Seismicities (1951–1994)	$N21^0–40^0W$	$N31^0–80^0E$

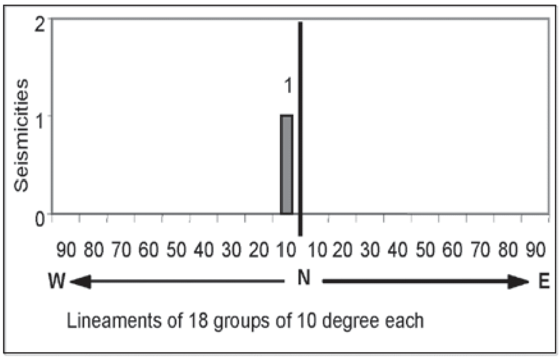

Figure 5: Histogram between number of Seismic counts during 1901-1950AD and 18 azimuthal groups of Lineaments

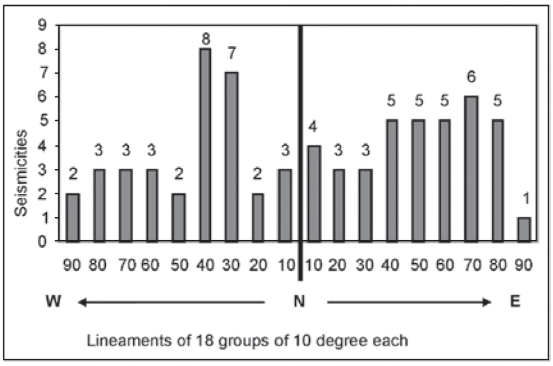

Figure 6: Histogram between number of seismic counts during 1951- 1994 AD and 18 azimuthal groups of lineaments

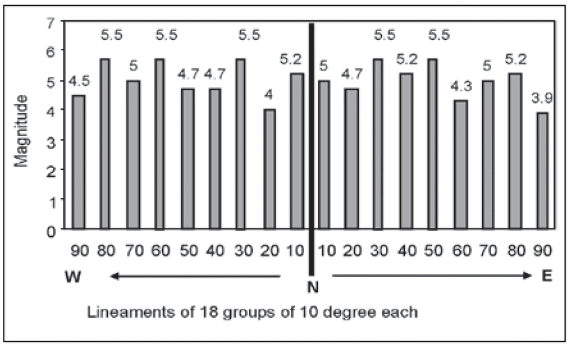

Figure 7: Histogram between the seismicity of highest magnitude and corresponding 18azimuthal groups of lineaments

The extraction of five azimuthal groups of lineaments (N31^0 – 40^{0}E, N41^0 – 50^{0}E, N51^0 – 60^{0}E, N61^0 – 70^{0}E and N71^0 – 80^{0}E) from the combined GIS data base on lineaments (Figure 1A), creation of single layer and its overlay with seismicity distribution also confirms the maximum coincidence of seismic events along this spectrum of N31^0 – 80^{0}E lineaments (Figure 10).

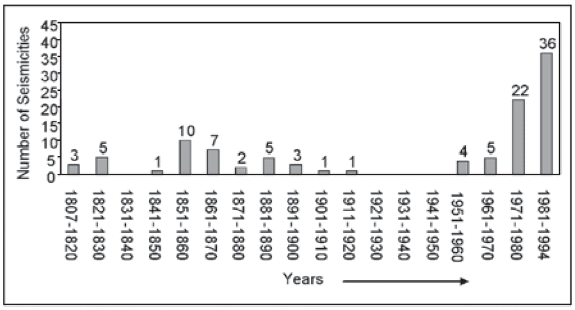

Figure 8: Histogram between the frequency of seismicties and the corresponding 18 azimuthal groups of lineaments

Further lineament density values were also worked out by measuring the total length of lineaments per 10 sq.km grid, plotting them in the respective grid centres. The X, Y data (coordinates of the grids) and the Z data (lineament density of the grids) were fed into Spatial Analyst module of ArcGIS and DEM was created. The overlaying of such 238 historical seismicity data over such lineament density DEM (Figure 11) also shows that the seismic locales predominantly fall along the maximas and the maxima axes of N31^0 – 80^{0}E lineament densities which are respectively represented by highs and elliptical domes in DEM. Grady (1971) has observed that the NE – SW faults in general are predominantly deep main faults having intimate relation with magmatism, metalogeny and seismicities. Ramasamy and Balaji (1995) have evolved Pleistocene tectonic model for South India in which they observed that the NW – SE faults/lineaments are Pleistocene dextral and the NE – SW are Pleistocene sinistral faults and these faults are respectively referable to right lateral and left lateral Wrench faults in the context of the north northeasterly aligned still prevalent compressive force in the Indian plate which only was responsible for the north northeasterly drifting of Indian plate. Again Ramasamy (1995) has observed that the NE – SW faults of Tamil Nadu are swinging west southwesterly and this system of faults has shifted the entire west coast of Kerala and Karnataka into an enechelon pattern (Figure 1D).

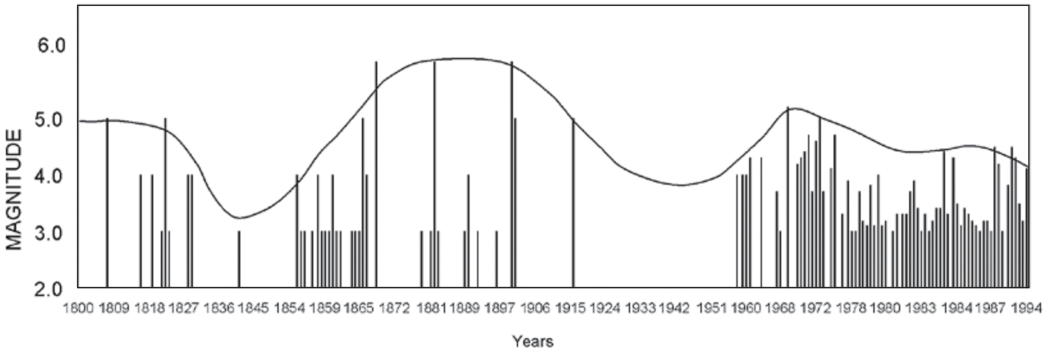

Figure 9: Histogram between the magnitude of seismicities and the years of occurrence

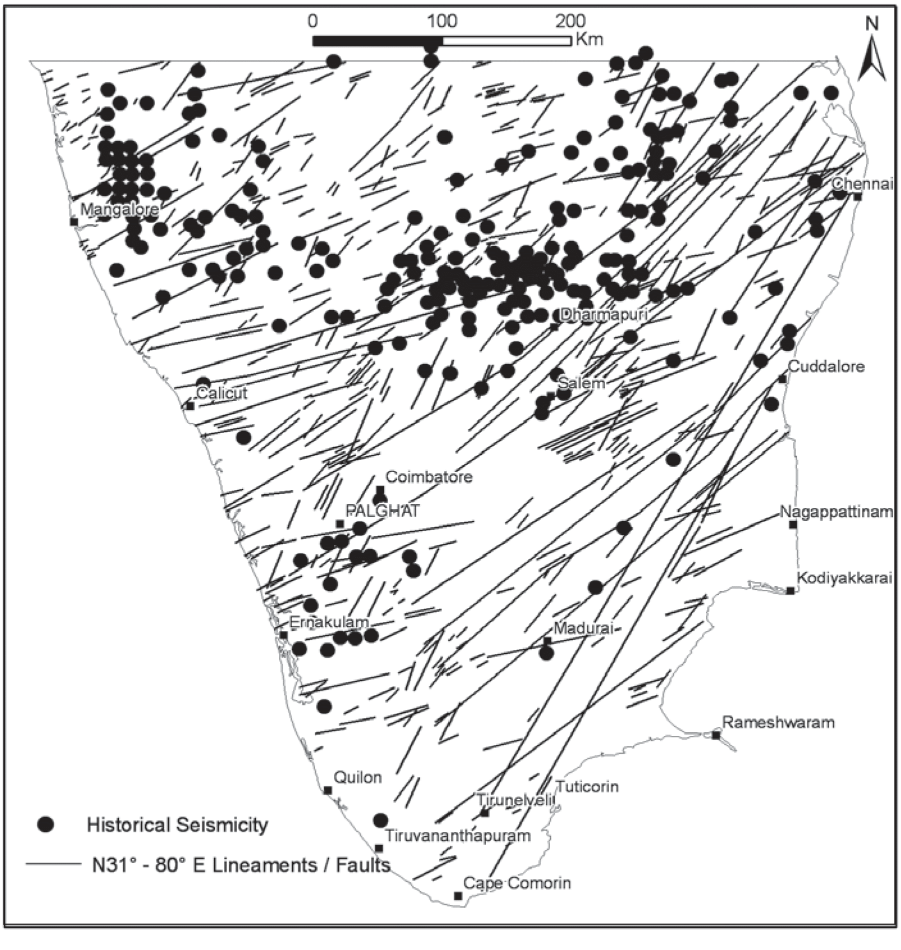

Figure 10: N31^0- 80^{0}E Lineaments/faults and seismicties

He has also observed that these faults continue right upto Laccadives and Maldives and shifted the N – S trending coral islands too into an enechelon pattern. Ramasamy (1995) further observed that the NE – SW to ENE – WSW faults are more active when compared to NW – SE faults. He has attributed the same to the additional compressive force incremented to these already active NE – SW sinistral faults by the rising Carlsberg ridge from the Arabian sea in the southwest, which is said to be rising at the rate of 1 to 3 mm per year (Le Pichon, 1968). In addition, the ENE – WSW faults of Kerala are also reported to be active and seismogenic (Nair, 1987, Nair and Subramanian 1989 and few more workers).

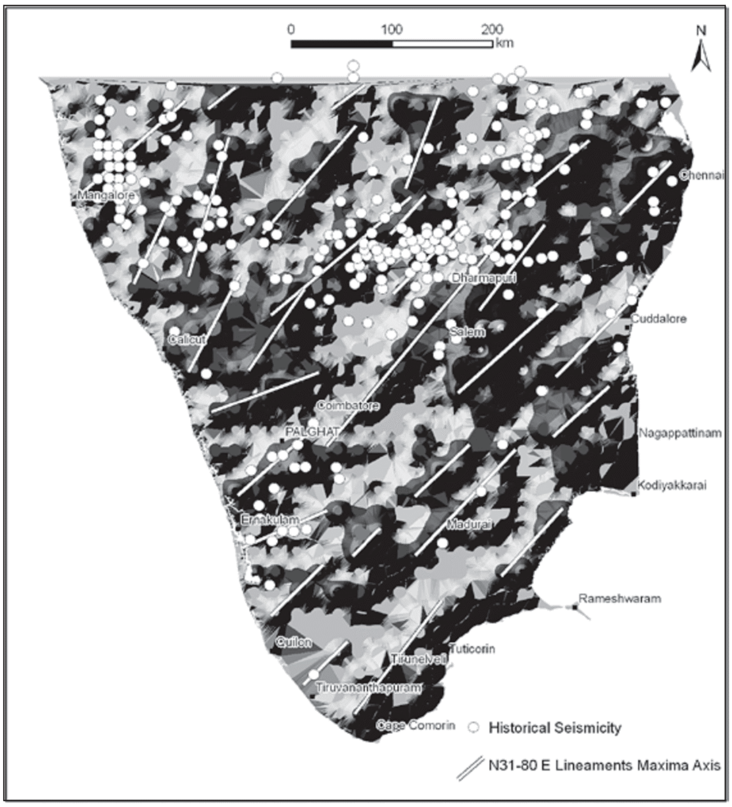

Figure 11: -3D Visualized GIS image of N31^{0}- 80^{0}E lineaments maximas versus seismicity

Further, Ramasamy and Karthikeyan (1998) have observed two major sub-parallel faults belonging to NE – SW group in-between Pondicherry in northeast and Kambam valley in southwest in Tamil Nadu showing varied anomalies indicating the Holocene grabening along these sinistral faults. Hence, it can be said that NE – SW to ENE – WSW faults are more seismogenic followed by NW – SE trending faults.

- The analysis between the frequency of seismicities and the years of occurrence (Fig.8) shows that there is moderate increase in frequency during 1851 – 1870 AD. Whereas the frequency of seismicities has steeply risen after 1971 that is after a time gap of 100 – 120 years. Due to the non availability of seismic data for considerable period, it cannot be conclusively said that the frequency of seismicity increases once in 100 – 120 years. On the contrary, the steep rise in the frequency of seismicities after 1971 could be probably attributed to the increase in seismic monitoring network. At the same time, as the higher magnitude / disastrous seismicities are occurring very frequently in the recent years in parts of Peninsular India, such increase in frequency due to the ongoing deformation of the Indian plate related to the still prevalent north northeasterly compressive force visualized by many earlier workers also cannot be ruled out.

- The histogram analysis between the years and magnitudes of seismicities shows a fluctuating pattern (Figure 9) with high magnitudes during 1854 – 1915 AD in the centre and the moderate magnitudes during 1800 – 1827&1960 – 1994 AD on either sides. This may possibly indicate the reoccurrence of high magnitude seismicities around 2040 – 2060 AD.

4. Conclusions

Thus, the present appraisal suggests the seismic vulnerability of NNW – SSE and NE – SW to ENE – WSW trending lineaments, with more probability along the latter group of lineaments. But these groups of lineaments, magnitude wise, do not show any contrasting seismic peaks which may, however, warrant some deeper studies. The frequency of seismicity seems to have increased from 1971 and also there are possibilities of high magnitude seismicities of 5 and above around 2040 – 2060 AD. However in the context of the increased seismic network and the availability of higher technologies, deeper studies in this direction may be rewarding in understanding seismic hazards and its mitigation in this part of the country.

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