DETECTION OF EARTHQUAKE HAZARD IN SOUTHWEST PENINSULAR INDIA - SPURT OF VARIOUS UNUSUAL GEOLOGICAL INCIDENTS

Presented by

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Natural Disasters would keep happening, we cannot avoid them, so let's prepare ourselves. Join our effort to build a Disaster Management Information System.
The city is underlain by significant thickness of sedimentary formations of which thickness and geological conditions are known and it would help establish empirical relationships between the site amplifications and basin configuration.
Kerala is an integral segment of the South Indian Shield and tectonically very stable landmass. The region comprises Precambrian crystalline rocks, metamorphosed to the granulite grade under high temperature and pressure conditions. The dominant rock type is massive charnockite, a medium to coarse grained ortho-pyroxene bearing anhydrous granulite, and is texturally very compact. The rocks are variably weathered and lateritised up to 5 m of laterite capping at places.
Unusual Geological Incidents in Kerala During 2001

1. Micro-earthquake Activity (EQ)
2. Building Cracks (BC)
3. Ground Fissures (GF)
4. Land Subsidence (LS)
5. Well Collapse (WC)
6. Trees/Bushes Shaking (TBS)
7. Bubbling/Muddying and Gas Emission (BMG)
8. Wavy Motion in Well Water (WM)
9. Well Water Level Increase (WLI)
10. Well Water Level Decrease (WLD)
11. Well/ Pond Dry (WD)
12. Leaf Fall (LF)
13. Coloured Rain (CR)
14. Well Water Colour Change (WWC)

Fig. 2a: Unusual geological incidents that have occurred in Kerala state during 2001.
Active Phases of Unusual Geological Incidents in Kerala During 2001

February-02 March 2001

- Micro-earthquake Activity (EQ)
- Building Cracks (BC)
- Ground Fissures (GF)
- Wavy Motion in Well Water (WM)
- Well Water Level Increase (WLI)
- Well Water Level Decrease (WLD)
- Trees/Bushes Shaking (TBS)

June-November 2001

- Micro-earthquake Activity (EQ)
- Building Cracks (BC)
- Ground Fissures (GF)
- Wavy Motion in Well Water (WM)
- Well Water Level Increase (WLI)
- Well Water Level Decrease (WLD)
- Well/ Pond Dry (WD)
- Bubbling/ Muddying and Gas Emission (BMG)
- Land Subsidence (LS)
- Well Collapse (WC)
- Leaf Fall (LF)
- Coloured Rain (CR)
- Well Water Colour Change (WWC)

Fig.2b: Unusual geological incidents and their active phases that have occurred in Kerala state during 2001.
Fig. 3: Histograms showing district wise (a) and incident wise (d) number of various unusual geological incidents that have occurred in Kerala state during 1996 to November 2001; January to March, and April to November 2001. District wise (b & c) and incident wise (e & f) distribution of individual incident occurred during January to March, and April to November are also shown as radar chart. The distribution patterns show that the incidents during January to March (b) were confined to certain districts only whereas the activity during April to November (c) were spread almost throughout the state (Abbreviations: EQ (micro-earthquakes); WM (wavy motion in well water); WLI (well water level increase); TBS (trees/bushes shaking); WLD (well water level decrease); BC (building cracks); GF (ground fissures); WC (well collapse); BMG (bubbling/muddying and gas emission); LS (land subsidence); WD (well/pond dry); LF (leaf fall); WWC (well water colour change); CR (coloured rain); TRV (Trivandrum); KOL (Kollam); PAT (Pathanamthitta); ALE (Alleppey); KOT (Kottayam); IDU (Idukki); ERN (Ernakulam); TRI (Trichur); PAL (Palakkad); MAL (Malappuram); CAL (Calicut); KAN (Kannur); KAS (Kasaragod); WAY (Wayanad)).
Fig. 4: Temporal distribution (daily occurrence) of all the unusual geological incidents (a) that have occurred in Kerala from (1) September 1996 to November 2001; (2) 2000 to November 2001; (3) January to November 2001; (4) January to March 2001; and (5) April to November 2001. Temporal patterns of individual fourteen incidents that have occurred from February to November 2001 are shown in Figure b. Vertical lines are histograms of daily number, and solid curves are the cumulative number of the incidents. The distribution pattern clearly indicates that the spurt in activities has taken place in two active phases starting from February and June, and are separated by a quiescence period of about three months. The active phase from February to 02 March has shorter duration as compared to the active phase started from 01 June 2001.
Fig. 5: Cumulative number of individual total incidents with time that have occurred in Kerala from September 1996 to November 2001 (a); January to March 2001 (b); January 2000 to November 2001 (c); April to November 2001 (d); January to November 2001 (e) and June to November 2001 (f). Prior to February 2001, only a few earthquakes have occurred which include both the moderate sized earthquakes of 12 December 2000 and 7 January 2001 around Irattupettah in Kottayam district. Spurt in unusual geological incidents have taken place mainly in two active phases starting from February and June 2001 during which a total of 14 different types of incidents have occurred. The active phases beginning from February and June are separated by a quiescence phase of about three months duration (03 March to 31 May 2001). (Abbreviations: EQ (micro-earthquakes); WM (wavy motion in well water); WLI (well water level increase); TBS (trees/bushes shaking); WLD (well water level decrease); BC (building cracks); GF (ground fissures); WC (well collapse); BMG (bubbling/ muddying and gas emission); LS (land subsidence); WD (well/ pond dry); LF (leaf fall); WWC (well water colour change); CR (coloured rain)).
Fig. 6: Map of Kerala state showing spatial (a) and temporal (b) distribution of various unusual geological incidents that have occurred from September 1996 to November 2001. A total of 14 different types of incidents have occurred during the period which are shown over the major geological features, drainage and lineament patterns of the state. Most of these geological incidents have occurred from February to November 2001. Arrows indicate the time of either increase in the number of continuing incidents or onset of new incidents (Abbreviations: EQ (micro-earthquakes); WM (wavy motion in well water); WLI (well water level increase); TBS (trees/bushes shaking); WLD (well water level decrease); BC (building cracks); GF (ground fissures); WC (well collapse); BMG (bubbling/muddying and gas emission); LS (land subsidence); WD (well/pond dry); LF (leaf fall); WWC (well water colour change); CR (coloured rain)).
Fig. 7: Map of Kerala state showing spatial (a) and temporal (b) distribution of various unusual geological incidents that have occurred from January to November 2001. A total of 14 different types of incidents have occurred during the period. Most of these geological incidents have occurred from February to November 2001 and the weekly rates of occurrence of individual incident during the period is shown in Figure c. Arrows indicate the time of either increase in the number of continuing incidents or onset of new incidents (Abbreviations: EQ (micro-earthquakes); WM (wavy motion in well water); WLI (well water level increase); TBS (trees/bushes shaking); WLD (well water level decrease); BC (building cracks); GF (ground fissures); WC (well collapse); BMG (bubbling/ muddying and gas emission); LS (land subsidence); WD (well/ pond dry); LF (leaf fall); WWC (well water colour change); CR (coloured rain).
Fig. 8: Spatial (a) and temporal (b) distribution of various unusual geological incidents that have occurred in Kerala state from January to March 2001. During this period, a total of seven different types of incidents (micro-earthquakes, wavy motion, water level increase, water level decrease, shaking of trees/bushes, ground fissures, and building cracks) have occurred, which are mostly clustered in Calicut, Malappuram and Palakkad districts in the north; and Trivandrum, Kollam and southern parts of Alleppey districts in the south. Arrows indicate the time of either increase in the number of continuing incidents or onset of new incidents (Abbreviations: EQ (micro-earthquakes); WM (wavy motion in well water); WLI (well water level increase); TBS (trees/bushes shaking); WLD (well water level decrease); BC (building cracks); GF (ground fissures).
Fig. 9: Spatial (a) and temporal (b) distribution of various unusual geological incidents that have occurred in Kerala state from April to November 2001. During this period, a total of 13 different types of incidents (including all the incidents except trees/bushes shaking during January to March) have occurred, which are distributed throughout the state irrespective of geology and topography. Arrows indicate the time of either increase in the number of continuing incidents or onset of new incidents (Abbreviations: EQ (micro-earthquakes); WM (wavy motion in well water); WLI (well water level increase); WLD (well water level decrease); BC (building cracks); GF (ground fissures); WC (well collapse); BMG (bubbling/ muddying and gas emission); LS (land subsidence); WD (well/ pond dry); LF (leaf fall); WWC (well water colour change); CR (coloured rain).
Fig. 10: Cumulative number of individual unusual geological incidents in Kerala that have occurred from **January to November 2001** (a); **January to March 2001** (b); and **April to November 2001** (c). The distribution patterns clearly indicate two sets of active phases separated by a quiescence phase for about 3 months from March to May 2001. The spurt in activity had taken place in the beginning of February with occurrence of seven different types of incidents over the preceding normal background, and it continued till March 02 beyond which the activity reduced to background till May end. The second active phase had initiated with well collapse incident followed by 12 additional incidents and continued till November with reduced frequency. *(Abbreviations: EQ (micro-earthquakes); WM (wavy motion in well water); WLI (well water level increase); TBS (trees/bushes shaking); WLD (well water level decrease); BC (building cracks); GF (ground fissures); WC (well collapse); BMG (bubbling/muddying and gas emission); LS (land subsidence); WD (well/pond dry); LF (leaf fall); WWC (well water colour change); CR (coloured rain)).*
Fig. 11: Spatial distribution of earthquakes in Kerala state that have occurred since historical past till April 2002 (a). It is evident from temporal patterns that number of earthquakes have been very low prior to 1983 and there is gradual increase in the seismicity in the recent past which is confined to certain localities. Seismicity in Kerala state occurred from 2000-April 2002 (b); and 2001- April 2002 (c) show its significant fluctuations in two active phases from February to 02 March, and August to September 2001. Magnitude relationships of micro-earthquakes occurred during February to November 2001 (d) indicates that the magnitude of none of the earthquakes exceeded 3.5, and this active phase is preceded by two moderate sized earthquakes of 12 December 2000 and 07 January 2001 of M 5 & 4.8 respectively.
Fig. 12: Spatial (a) and temporal patterns (b) of earthquakes in Kerala state that have occurred from 1900 to April 2002. During this period, most of the earthquakes are clustered in eight localities as delineated in the map. Temporal distribution is restricted till April 2002 and patterns of seismicity variation are shown from 1900 to April 2002 (b) and 1978 to April 2002 (c). Histograms of daily number of earthquakes are also shown in both the figures. a and b denotes active phases of recent seismicity in Kerala from February to March, and from June to November 2001 respectively.
Fig. 13: Seismicity of Kerala from 1996 to April 2002 (a). Only three earthquakes have occurred during 1996 to 2000 which include recent largest earthquake of M 5 on 12 December 2000 around Erattupettah in Kottayam district. Temporal patterns of seismicity from 1996-April 2002 (b); 2000-April 2002 (c); and 2001- April 2002 (d) show significant fluctuations of seismicity in two active phases from February to 02 March, and August to September 2001. Histograms of daily and cumulative number of earthquakes are shown in these figures. The active phase starting from February 2001 is preceded by two moderate sized earthquakes of 12 December 2000 and 07 January 2001 of M 5 & 4.8 respectively.
Fig. 14: Spatial (a) and temporal (b & c) distribution of daily number of well collapse incident that have occurred from June to November 2001 in Kerala state. The incident is mostly confined in southern districts, Malappuram and Calicut with sparse distribution in remaining parts of the state. It is evident that there was no well collapse incident prior to June (b), and the spurt in incident had taken place from the beginning of June which continued till November with reduced rate. Maximum occurrences is recorded during the third week of June 2001 (WC: well collapse).
Fig. 15: Spatial distribution of affected regions (a) and temporal patterns due to well collapse incident that have occurred from June to November 2001 in Kerala state. District wise distribution of percent of well collapses shown in the radar chart (b) indicate that maximum collapses have occurred in Malappuram district (~25% of the total) followed by Trivandrum, Kollam, Alleppey, Kottayam, Calicut and Palakkad districts. It is evident that the spurt in the incident that had initiated from 01 June with a weekly frequency of about eight well collapses, which increased to a maximum of 57 during the third week of June beyond which the rate reduced slowly to normal till the end of November 2001 (c).
Fig. 17: Typical forms of well collapses and other related incidents that have occurred in Kerala from June to November 2001, and associated geological conditions (Photographs by Dr. H.N. Singh and Mr. John Mathai).
Fig. 18: Typical forms of well collapses that have occurred in various parts of Kerala from June to November 2001 (pictures by Dr. H.N. Singh & Mr. John Mathai).
Various Forms of Ground Deformations in Kerala During 2001

Building Cracks/Displacement of Wooden Beam

Ground Fissures

Fig 19. Building cracks, displacement of the wooden beam and ground fissures observed in various parts of the Kerala state during February to March 2001. The pictures of ground fissures and building cracks/displacement of wooden beams presented here are from Malappuram and Palakkad districts where extensive ground deformations in various forms have occurred during the period. Some ground fissures were measured more than 500 m long especially in Mamgara area in Nilambur. Multiple ground cracks observed in Chittur Taluk occupy the epicentral tract of Coimbatore earthquake of 1900 (pictures by Dr. H.N. Singh).
Fig. 16: Cumulative Number of unusual geological incidents occurred in Kerala from January to November (a); and cumulative rainfall pattern recorded at eight observatories in Kerala state from March to August 2001 as against normal for the same periods (b). The total rainfall during June to August 2001 is compared with the total rainfall during the same period in the high rainfall year of 1991 (Source: IMD rainfall data for 2001 as reported in Mathrubhoomi daily; Normal rainfall and the rainfall for the 1991 is taken from Hand Book on Watershed based development, State Planning Board Publication, December 1999). Several incidents have occurred during the period of scanty rainfall and hence there is no positive correlation between rainfall and occurrence of unusual geological incidents.
Untimely Leaf Fall

Field pictures showing untimely leaf fall which have occurred during the monsoon period from June to November 2001 in Kollam and Trivandrum districts in Kerala. Similar phenomena are also observed in Malappuram and Trichur districts. This incident has taken place during the active period of other unusual geological incidents such as well collapses, earthquakes, wavy motion in well water etc (Pictures by John Mathai).
Fig. 18: Spatial (a) and temporal (b) Pattern of WM, WLI, WLD, WD and BMG that have occurred in Kerala state
Spatial (a) and temporal (b) patterns of CR, LF, WWC that have occurred in Kerala during June to November 2001. All these incidents have occurred during II active phase and coincide on time scale. Duration of these incidents is observed to be shorter as compared to other incidents during the same period.
Fig. I-1: Spatial (a, b & c) and temporal (d) patterns of all the incidents that have occurred in Kerala during January to November 2001.
Comparison
Comparison
Comparison
Temporal patterns of microearthquake activity (EQ) and well collapse (WC) incidents in Kerala that have occurred from January to November 2001. Note that the spurt in seismic activity had taken place in two active phases starting from the beginning of February and from the last week of August 2001 and are separated by a long quiescence period of 6 months whereas spurt in well collapse activity had initiated from the beginning of June when there was no seismic activity.
**Kerala Region**

- Monthly Number
- Cumulative
- A: Normal Seismicity
- B: Precursory Swarm
- C: Gap Events/period
- D: Mainshock and aftershocks

**Latur Earthquake**

- Daily
- Cumulative
- A: Normal Seismicity
- B: Precursory Swarm
- C: Gap Events/period

**Dilatancy Model**

- Vp/Vs
- 1.75
- 10-20% change

- Electrical Resistivity
  - ~15% change

- Rate of flow of water
  - (or Radon Emission)

- Geodetic Measurements
  - Vertical motion ~several cm
  - Tilts ~10^{-6} rad
  - Volumetric Strain ~10^{-5} -10^{-6}

- Number of Seismic Events
  - Stage I: Elastic Strain Buildup
  - Stage II: Dilatancy Dominant
  - Stage III: Influx Water Dominant
  - Stage IV: Aftershocks

- Time:
  - Stage I: Elastic Strain Buildup
  - Stage II: Dilatancy Dominant
  - Stage III: Influx Water Dominant
  - Stage IV: Aftershocks
  - Stage V: Earthquake and Sudden Stress Drop
A Model showing an elliptical area (dotted) trending east-west in the Central Kerala region is delineated as potential zone for the probable location of future significant earthquake using the most direct manifestations of various unusual geological incidents during 2001 (land deformation, ground water anomalies in open wells, past and recent seismic events and fault zones, and available historical seismicity data since 1900),
Conclusions

• A total of 612 unusual geological incidents at 499 different locations have occurred in Kerala state from February to November 2001.

• A database is created incorporating all the important occurrence features related to these incidents and spatio-temporal patterns are studied. No such incidents prior to February 2001 and beyond November 2001 are observed in the state.

Under normal geological conditions, such widespread unusual geological incidents can not occur in a region. No surficial causative factor such as rainfall activity during 2001 was found to play role in triggering these incidents.
Conclusions (Contd………..)

• Peculiar character of temporal patterns (short duration) and widespread occurrence of these incidents without showing spatio-temporal inter-relationships indicate that the incidents are caused by a single causative factor of internal geodynamic processes in Kerala region.

• Enhanced seismic activity during February- March and August-October 2001 also indicate towards the vital role of internal geodynamic processes in triggering these incidents.

• In short, except three incidents (coloured rain, well water colour change and untimely leaf fall), the remaining incidents can be considered as macroscopic precursors (under the category of land deformation) to an impending large earthquake in Kerala.
Conclusions (Contd.)

• Similar to some of these incidents had occurred in China and its surrounding areas prior to large earthquakes and have been regarded as earthquake precursors.

• The present chain of events, if viewed in terms of the dilatancy diffusion model, can be manifestations of preparatory stage of an earthquake.

• Based on sudden spurt in various unusual geological incidents and seismic activity during Feb. to Nov. 2001 and past significant earthquakes, a potential area trending east-west and enclosed by latitude 10.7-10.9° N and longitude 76.0-76.8° E have been delineated for the impending large earthquake.
THANK YOU