On investigations of the observed thermal anomaly in earthquake precursors: A case study from the 1993 Latur earthquake prone area in western India

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Abstract

We report and discuss monitoring of short-term variations of widely used multi-geophysical parameters in Latur-Killari area in western India, the region that faced a major devastating earthquake in 1993. An abnormal rise in atmospheric temperature of more than 20°C at 11200 m height was observed in the air-flight just 100 km away from Latur during a monsoon period. To investigate the causes of such temperature rise, we studied seismicity of the area in relation to the 1993 Latur event, and continuously monitored ground-water level and soil Helium gas for one week immediately following this observation under a precursory 'quick please' operation in the study area. There are no precursory seismic signals associated with this temperature rise; hence the operation was suspended after one week time. Although this thermal anomaly is not followed by any major earthquake over the area, it has larger implications in atmosphere research area. While a detailed investigation of such anomaly is beyond the scope this paper, we report here the possibility that the satellite thermal sensor cannot penetrate thick clouds to accurately retrieve the temperature. We are cautious of arriving at a firm conclusion, but the findings of this study certainly call for continuous monitoring of temperature over the earthquake prone areas to gain insight into the physics of short-lived variation in temperature over

spatially limited extent, especially over the earthquake prone areas for improved seismic hazard assessment.

Keywords: 1993 Latur earthquake, Earthquake precursor, Helium, Tropospheric temperature, Ground water level.

Introduction

Earthquake precursors are difficult to recognize because of the complex processes occurring in the Earth's crust, various types of earthquake mechanisms, and the lack of extensive and continuous geophysical and geochemical monitoring in most earthquake prone areas. A variety of earthquake precursors, including geophysical, geochemical (Barsukov et al. 1985; King 1986), geodetic, biophysical, thermal (Guangmeng 2008), and other phenomena have been identified preceding major earthquakes. Some of these precursors include: the sudden change in seismicity characterized by seismic *b*-value characterizing the magnitude-frequency distribution, and fractal dimension of spatio-temporal distribution of epicenetrs (Dimri 2005a, 2005b; Ravi Prakash and Dimri, 2000), fluctuation in ground-water levels due to change in stress (Yuce and Ugurluoglu 2003), change of gravity and magnetic field of earth and electrical resistivity of sub-surface rock materials, including self-potential values (Hayakawa and Fujinawa 1994; Noritomi 1978; Hayakawa and Fujinawa 1994), release of Radon and Helium gas (Wakita et al. 1978), rise in skin surface and atmospheric temperature (Choudhury et al. 2006; Guangmeng 2008), atmospheric storm-related wind drag on continents, fault zone rock layer heating associated with the solar and geomagnetic storms, difference in electromagnetic emission (ULF/VLF).

Creation of micro-fractures due to the slow build-up of strain resulting in escape of radiogenic helium and radon provides the basis of geochemical methods of earthquake prediction (Barsukov et al. 1985; Virk et al. 2001). Geochemical and hydrological signals preceding the major earthquakes have been used for earthquake prediction, especially in China, Japan, the former Soviet Union, and the United States (King 1986). Yuce and Ugurluoglu (2003) have shown the ground water level changes in 19 exploration wells and recorded pre-seismic, co-seismic, and post-seismic water level changes during the Izmit and Duzce earthquakes in the Eskisehir region, Turkey. Comparing the precursory anomalies associated with the 1995 Kobe earthquake and the 1978 Izo-Oshima earthquake, Silver and Wakita (1996) concluded that many pre-seismic anomalies are true precursors, although the anomalies may exhibit some response heterogeneity. Wakita et al (1978) observed a high concentration of helium up to 350 ppm in soil gas along a fault during the 1966 Matsushiro earthquake swarm in Japan. Choubey et al. (1999) observed radon variation in spring water before and after the 1999 Chamoli earthquake, Garhwal Himalaya, India.

Anomalous changes in various geo-electrical parameters were observed before several earthquakes in different parts of the world (Noritomi 1978; Hayakawa and Fujinawa 1994). Thus, anomalous changes in various precursory parameters have been documented in different parts of the world. However, there is no consensus on the statistical significance of these precursors and their reliability, due to the lack of reproducibility and understanding of the underlying physical mechanisms. For example, a successful prediction of an earthquake based on some of these precursory studies was carried out by China for the 1975 Haicheng, China earthquake (M 7.3), but another prediction in 1976 using the similar precursory studies was considered as a failure in Tangshan (Ludwin 2004). Similarly, as another example in India, it was observed that the temporal variations in dissolved helium cannot be ascribed to the contemporary enhanced seismic activity in Bhavnagar in Gujarat, India (Gupta and Deshpande 2003). In the same way, although there are evidences for many thermal anomalies in National Centers for Environmental Prediction (NCEP) data, but not all cases of thermal anomaly correspond to the earthquake occurrence. So, it appears that different precursors may appear at different stages in different places of earthquake preparation zones. Then, the rule of game is 'leave nothing to chance' to probe further if one or two precursors appear. We, therefore, need to improve how to reduce such false alarm in earthquake precursor studies. To this end, we think multi-geophysical data, together with possibly temperature, pressure, humidity of the atmosphere and seismicity and so on may be used to correlate the sub-surface processes like occurrence of earthquakes with atmospheric phenomena. We made a very first attempt to understand such a correlation between these parameters with the help of data obtained by conducting short-term multi-parametric geophysical experiments in the Latur-Killari earthquake prone area of western India.

Methods/ Experimental

Precursor observed

On 18 June 2007 at 7.20 am during monsoon period, the digital display of an aircraft from Mumbai to Hyderabad flight showed that outside temperature at 11,272 m was -17°c to -18°c on its usual path near the Sholapur-Gulberga sites (see **Fig. 1a** for site locations) and up to a location where aircraft started descending for landing at Hyderabad airport. **Table 1** shows the details of temperature displayed on the Sholapur-Gulberga-Hyderabad sector. It was a normal Mumbai-Hyderabad flight during monsoon environment, except the abnormal outside temperature at 11272 meters height, with the atmospheric temperature at such height normally in the range of -38°c to -42°c in the Sholapur-Gulberga area, as recorded by the Global Positioning System (GPS) radio occultation technique.

In order to understand whether there exists a correlation between this event and changes in any sub-surface geophysical parameters and investigate possible causes of such a conspicuous rise in temperature, we conducted a short-term multi-parametric geophysical experiment in the study area. The experiment includes monitoring seismicity of the area, fluctuations of ground water level, and soil gas helium, which are discussed in detail in the 'Results and Discussion' section.

Results and discussion

The results of our investigations based on the monitoring of each of the geophysical parameters are discussed as follows.

Precursory parameters

(i) Seismicity of the Latur-Killari area

The main shock of the 1993 Latur earthquake occurred in the Deccan Plateau, a typical stable continental region (**Fig. 1a**). Geologically the area belongs to the Deccan Trap Plateau basalts of the Paleocene age that are composed of a series of lava-flows in western and central India. There are evidences for the occurrence of earthquake in this region in historical times (Rajendran et al. 1996; Gupta et al. 1999). A maximum intensity of VIII+ (MSK scale) was assigned to the 1993 earthquake. The aftershocks were monitored by a network of up to 21 stations between October 8, 1993 and January 31, 1994. A majority of the aftershocks occurred within a 10 km radius from the main shock. On the basis of the location of aftershocks in the first few days, a plane dipping at 45° towards the southwest and striking at 135° is inferred to be the fault plane (**Fig**. **1b**) for this event. The fault plane solution of the main shock, as reported by the USGS, reveals a reverse faulting mechanism.

The 1993 main shock was preceded by immense swarm activities about a year back in 1992; the swarms were followed by a quiescent period until a major earthquake took place in September 1993. Twenty six events were recorded by the CSIR-NGRI seismological observatory at Hyderabad from 18 October to 15 November 1992 in the Latur-Killari region. The largest magnitude earthquake (M 4.0) was recorded on 18 October, 1992. Since then the area is quiescent except the two earthquakes of magnitude 3.0 and 3.4 in January 2006. Dissimilarity between the swarm activity in 1992 and two earthquakes in January 2006 was not the enough reason to stop further probing, in spite of the fact that a time span of 14 years (from

1993 until 2007) is too short to build up the stress for a major earthquake; however, possibility of smaller to moderate earthquakes cannot be ruled out. Moreover, an earthquake of magnitude 3.8 was observed in the study area on 6 September 2007, although its occurrence in relation to the observed thermal anomaly is not yet clear.

Based on earthquake precursor studies, it is possible that the observed anomaly could result from (i) the thermal sensors cannot penetrate thick clouds, as expected in a monsoon time to accurately retrieve the temperature at such height, (ii) changes in meteorological phenomena, and (iii) changes in sub-surface properties, as inferred from geophysical phenomena. Although less likely, but we cannot exclude to mention that if none of the above parametric variations exhibits precursory signature, the temperature sensor of aircraft may malfunction, a case of aviation hazard and a matter of great concern for the safety of passengers. Since the Sholapur-Gulberga region is about 100 km from the Latur-Killari area, where an earthquake of magnitude 6.3 occurred on 29 September, 1993 killing more than 10000 people with heavy damage to property (Rajendran et al. 1996), it was then decided to probe other precursors in the vicinity of the area under operation ‘quick please’ to get relevant information from several agencies in India or abroad as quickly as possible.

(ii) Fluctuations in ground water level (20 to 23 June, 2007)

A continuous water-level monitoring was conducted by CSIR-National Geophysical Research Institute (CSIR-NGRI) during the period 20-23 June 2007 around the Latur-Killari area. Fluctuations in water level are worked out by taking care of rain fall recharge and withdrawal of ground water by the pumping. Eleven bore as well as dug wells were selected for continuous monitoring of water level, as shown in **Fig. 2**. The depth of these bore wells varies from 80 m to 170m, whereas the depth of dug wells varies from 10 m to 30 m. Finding a precursory signal in terms of fluctuation of ground water level during rainy seasons is a very challenging scientific exercise, which was carried out during the monitoring period. Initially, well inventory was carried out for about 50 tube/bore/dug wells in and around the study area as well as along the national highway to Latur. The water levels were monitored continuously with an interval of 1 to 4 hours for four days. The depth of water level in bore wells varies from 11 m to 38 m below ground level (bgl) and in dug wells it varies from 6 m to 11 m bgl. The water levels in most of the wells are in rising order, as shown in **Fig. 3(a-c)**. It has raised up to 3.34 m in bore well and 5.09 m in dug well during the period 20-23 June 2007. The rise in water level is mainly due to heavy rainfall in the area.

Fig. 3a shows the change in the water level in bore wells L1 and L5 and dug wells L3 and L9. The wells show an increase in water level except L1, which shows an apparent decline of 0.39 m over a period of 3 hr 15 min at 3.25 pm (on 21st June 2007 from 8.30 AM to 11.45 AM at the rate of 0.12 m/hr) during which there has not been any pumping of water neither from the observation well nor from the vicinity. Had there not been a rise in water level due to rain (at the rate of 0.047 m/hr), the true decline would have been 0.54 m in this well. This well is situated near Killari, as shown in **Fig. 2**.

Fig. 3b shows the variation in water level in bore well L2 and dug well L4. The bore well shows an initial rise in water level, which may be due to rain. However, the decline shown in the hydrograph is due to pumping of water from the well. The dug well shows an initial rise of 5.09 m followed by a continuous decline. The decline may be due to drainage that flows in the vicinity that did not allow rain water into the well L4.

Fig. 3c shows the variation in water level in four bore wells namely L7, L8, L9, and L10. Bore well L7 shows a rise, whereas the other three show apparent decline. Bore well L8 shows a steady decline of 0.03 m over a period of 21 hr 29 m (from 21st June 07, 11.24 AM to 22nd June 07, 08.55 AM), while most of the other wells during this period show rise in water level. The other two bore wells L10 and L11 do not show any significant rise or fall in spite of rain. In brief, the bore wells L10 and L8 show fluctuation in water level that might be related to pumping. In principle, such fluctuations in water level can be modeled using stochastic methods to understand the change in sub-surface medium properties. But, it is worth mentioning that monitoring of water level during rain and its withdrawal by pumping is a difficult task to be performed by any signal processing technique, such as the widely used wavelet analysis (Kang and Lin 2007); hence we did not attempt for such detailed study, except for investigating the presence or absence of significant precursory signature that is the main goal of this study.

(iii) Monitoring of Soil Gas Helium (21st, 24th and 25th June 2007)

Soil-helium surveys were carried out over the surface rupture zone along the three profiles 1, 2, and 3, along and either side of the bore well for helium. The profile 2 is shown in **Fig. 2** and the other two profiles 1 and 3 on either side of the bore well, while not shown in figure for clarity in presentation, are located with 50 m spacing.

Soil-gas data were sampled by drilling a metal probe to a depth of 1 m. The Alcatel Model ASM 100 T helium leak detector was used for soil-gas analysis. Helium concentration was measured to a precision of 0.02 ppm at 5 ppm level.

After the 1993 Latur earthquake, helium surveys were carried out in the vicinity of Latur in an area of 300 x 200 sq m, indicating elevated helium levels characterizing the surface ruptures (Rao et al. 1994; Reddy et al. 1994). In order to monitor the long-term changes in the helium field in an area, periodic measurements have been carried out in 1993, 1994, 1995, 1996, 1997, 2005, and 2006. The results of the soil-gas helium monitoring, as shown in **Table 2,** show that there is a rapid decline in the helium signal from 20,000 ppb (after the earthquake occurrence) to 2000 ppb during the period 1993-95, whereas the signal gradually declined thereafter. From the results of helium monitoring during 2005-2007, it is observed that the signal is further declined to around 400 ppb.

As a precursory element, these three soil-gas helium profiles 1, 2 and 3 (**Fig. 4**) were conducted on 21st, 24th and 25th June, 2007. **Table-2** compares the helium values for the years 2005, 2006 and June 2007, showing almost the same values during the three-year period. Based on such constant helium value for a relatively long period of three years, it can be inferred that the fault in the seismogenic part of the crust is dormant.

Summarizing the results of the three geophysical studies described above, we find no noticeable change in the precursors behavior related to the observed thermal anomaly. Accordingly, we suggest that the use of maximum possible numbers of precursor data correlation and interpretation is very useful to avoid the seismic hazards taking place in future. Although analyzing the monitoring of meteorological/ atmospheric parameters is outside the scope of such study, but their inclusion with sub-surface geophysical parameters will give some insight into a possible link between the two different phenomena (sub-surface and atmospheric).

Conclusions

We investigated the observed rise in atmospheric temperature by more than 20°c at 11272 meters altitude above the Sholapur-Gulberga region, which is close to the 1993 Latur-Killari earthquake prone area of western India. Our primary conclusions show that following this thermal anomaly, there are no precursory signals, such as change in (i) seismicity, (ii) ground-water level, and (iii) release of helium gas observed in the study region. The anomaly could rather be attributed to formation and movement of severe local storm under low-level convergence and upper-level divergence, or to lightening oxygen getting converted into ozone, being a potential absorber of UV light, or possibly the thermal sensor could not penetrate thick clouds during monsoon time to accurately retrieve the temperature. These findings suggest that conventional geophysical methods alone cannot explain the atmospheric temperature perturbations. A continuous monitoring of temperature over the region could resolve such short-lived temperature variations in upper atmosphere and its relation to the occurrence of major earthquakes. Studies of this kind involving conspicuous thermal anomaly over a limited spatial extent are very useful for better understanding of the atmosphere and terrestrial physics of spatial variation in temperature.

Abbreviations

NCEP: National Centers for Environmental Prediction; GPS: Global Positioning System; CSIR-NGRI: Council of Scientific and Industrial Research - National Geophysical Research Institute.

Declarations

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Authors' contributions

VPD conceived, designed, supervised the experiment, and revised the text. SP analyzed the seismicity data and wrote the paper. NCM, VSS, SRK, and CS conducted field experiments on changes in ground water level and processed the data. GKR and GR conducted the heat flow studies and processed the data. All authors read and approved the final manuscript.

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Availability of data and materials

Data supporting the conclusions can be made available on reasonable request to the Director, CSIR-NGRI (director@ngri.res.in) and the corresponding author.

Competing interests

The authors declare they have no competing interests.

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Figure Captions

Figure 1. (a) Map showing the locations of Mumbai, Sholapur, Gulberga, Hyderabad, and Latur areas. Star represents the main shock of 1993 Killari earthquake. Small shaded area in the inset represents the study area. (b) Epicentral map of the recorded aftershocks. The events marked in red are assumed to have occurred on the rupture plane of the 1993 Killari earthquake. The few scattered events marked in blue occurred on secondary faults (after Baumbach et al. 1994).

Figure 2. Map showing the location of bore wells L1 to L11 and bore well for helium survey. Three helium profiles 1, 2, 3 are taken along (2-2) and the other two (1-1, 3-3 not shown here for clarity in presentation) on either side of the bore well. Other two profiles are not shown to avoid overlapping of all the three profiles at a profile spacing of 50 m, that is smaller compared to the scale of the figure shown. The location of fault in the source area of the 1993 event is shown with solid line in the inset map, where the mainshock and aftershocks on the fault plane are shown with star and circles, respectively (modified after Baumbach et al. 1994).

Figure 3. Fluctuation in water level in bore wells (a) L1, L3, L5, L9, (b) L2, L4, and (c) L7, L8, L10, L11. All the three plots are shown at the same scale; the time scale for Figure 3c is shown at the middle of the figure for convenience in plotting.

Figure 4. Soil-gas helium concentrations observed along (a) profile-1, (b) profiles - 2 and 3 in the rupture zone of the 1993 Latur earthquake near Killari during the period 2005-07. Note almost the constant helium value during the whole three-year period.

Table Captions

Table 1 Temperature versus height displayed on the airline flight Mumbai-Hyderabad on 18th June 2007. Star (*) indicates descending height with temperature before landing at airport Hyderabad where surface temperature was 29°c.

Table 2 Soil-gas helium concentrations. Data are observed over **a,** profile-1, **b,** profile-2 and 3 in the rupture zone of Latur earthquake near Killari during the period 2005-07 which remain almost same. Location of profile 2 is shown in **Fig. 4** and profiles 1 and 3 are on either side of profile 2; 50 m apart.

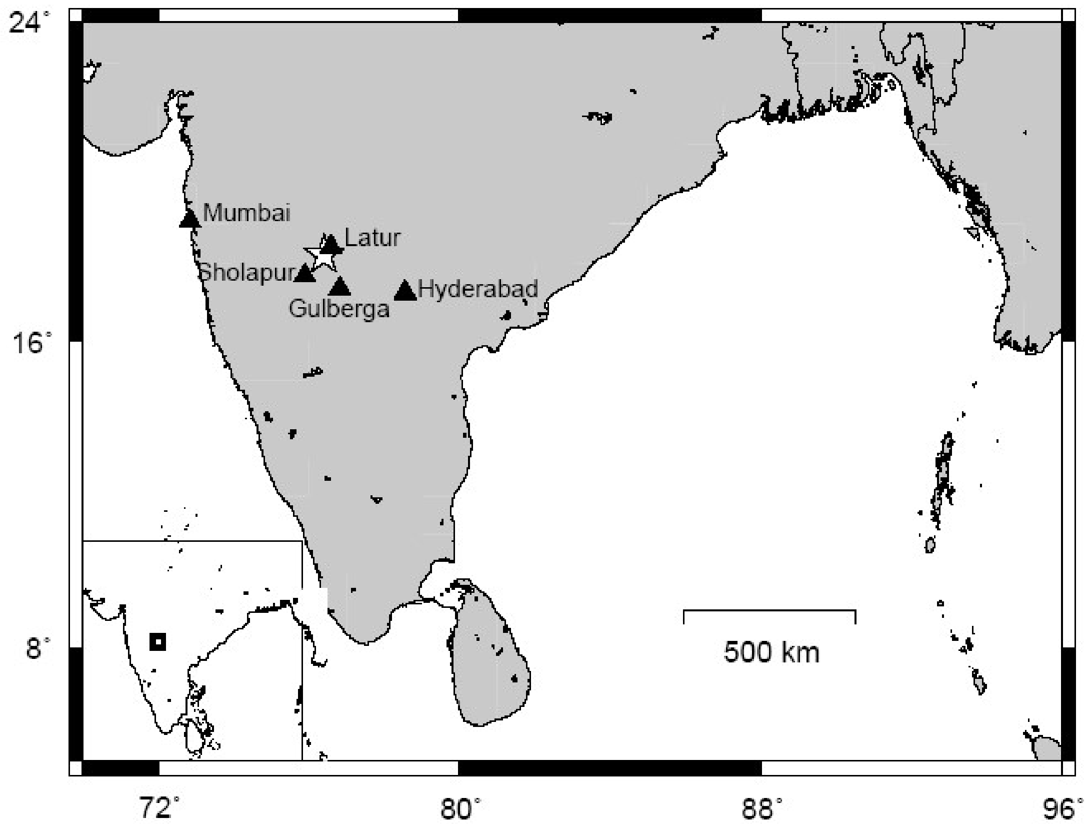

24°
16°
8°
72°
80°
88°
96°
Mumbai
Latur
Sholapur
Gulberga
Hyderabad
500 km

Figure 1a

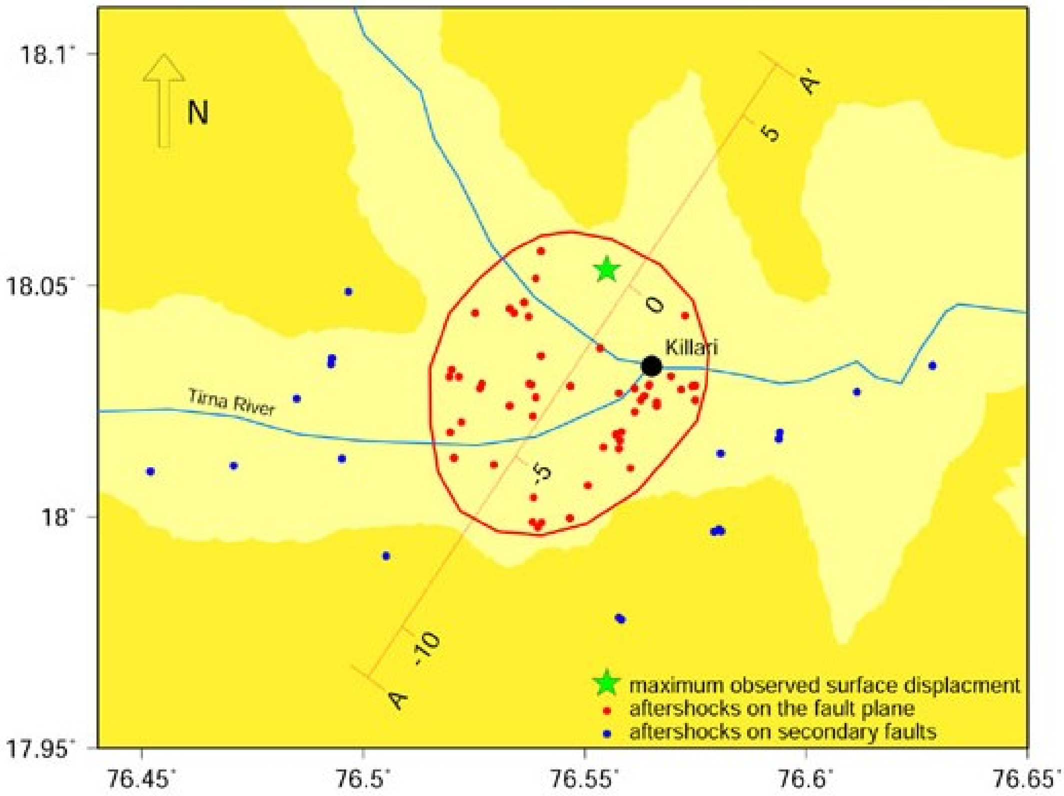

N
18.1°
18.05°
18°
17.95°
76.45°
76.5°
76.55°
76.6°
76.65°
A'
5
0
-5
-10
A
Killari
Tirna River
maximum observed surface displacment
aftershocks on the fault plane
aftershocks on secondary faults

Figure 1b

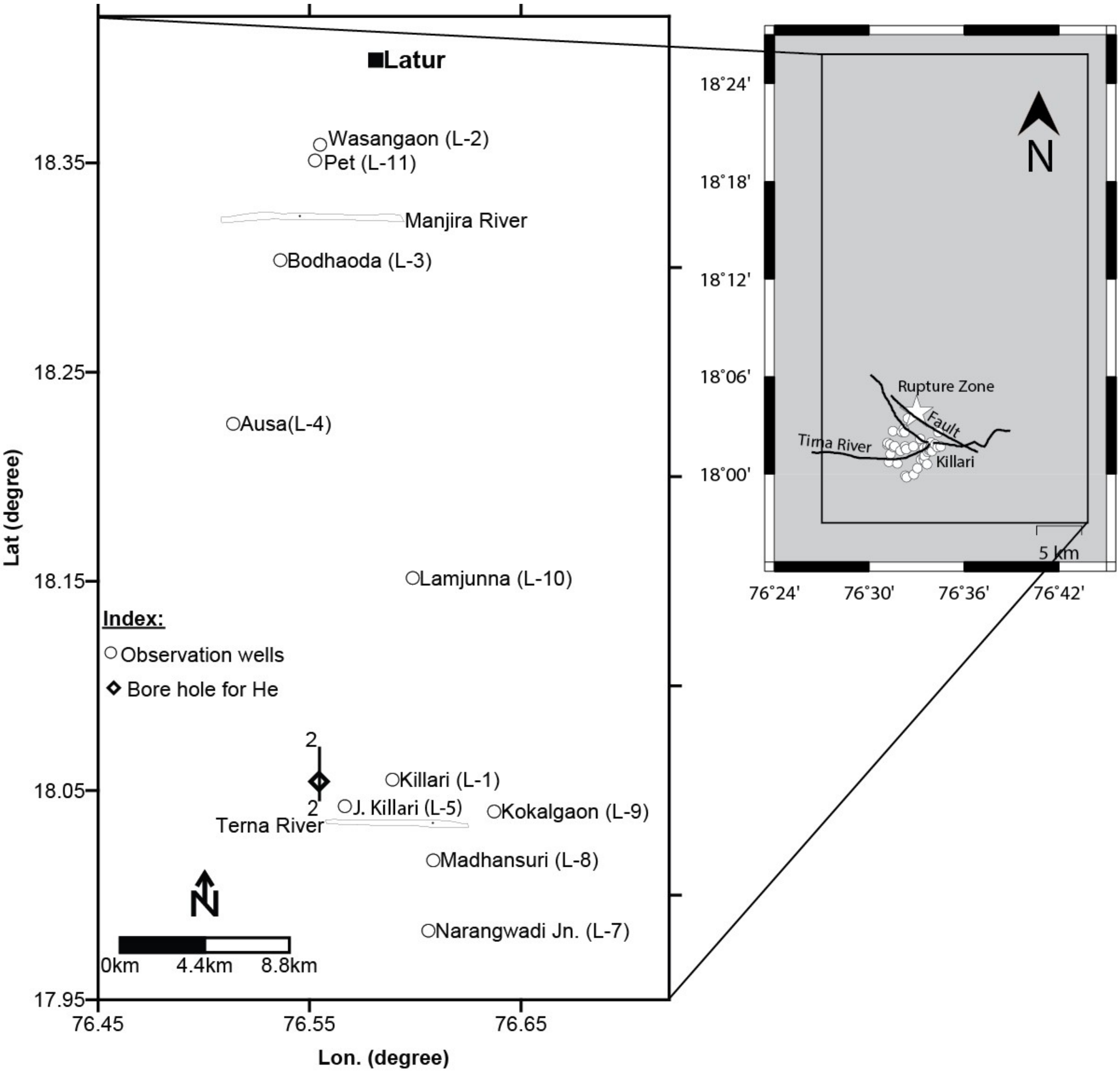
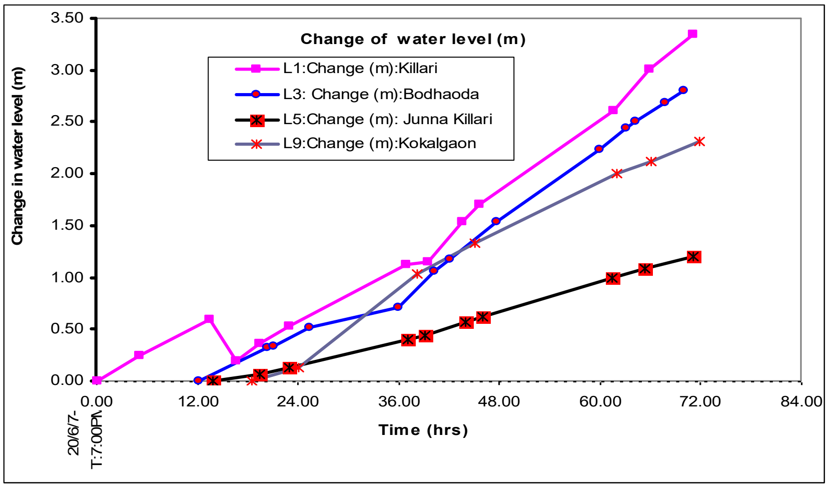
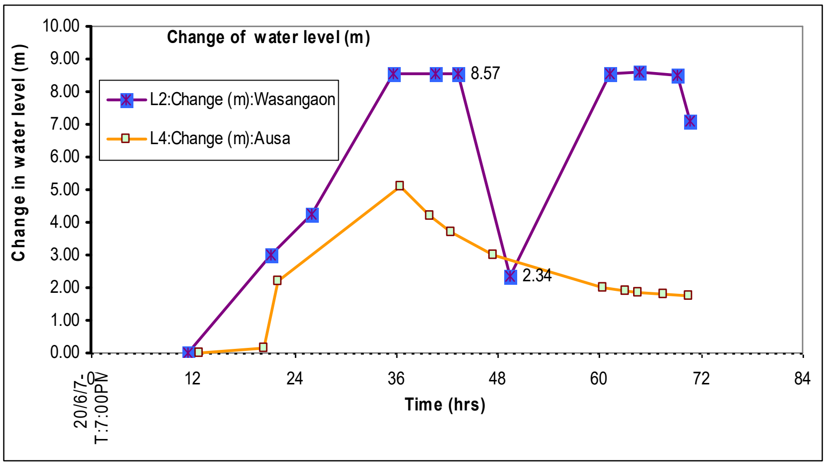

Latur
Wasangaon (L-2)
Pet (L-11)
Manjira River
Bodhaoda (L-3)
Ausa(L-4)
Lamjunna (L-10)
Index:
Observation wells
Bore hole for He
Killari (L-1)
J. Killari (L-5)
Kokalgaon (L-9)
Terna River
Madhansuri (L-8)
Narangwadi Jn. (L-7)
0km 4.4km 8.8km
N
Lat (degree)
Lon. (degree)
18.35
18.25
18.15
18.05
17.95
76.45
76.55
76.65
2
2
18°24'
18°18'
18°12'
18°06'
18°00'
76°24'
76°30'
76°36'
76°42'
Rupture Zone
Fault
Tirna River
Killari
5 km

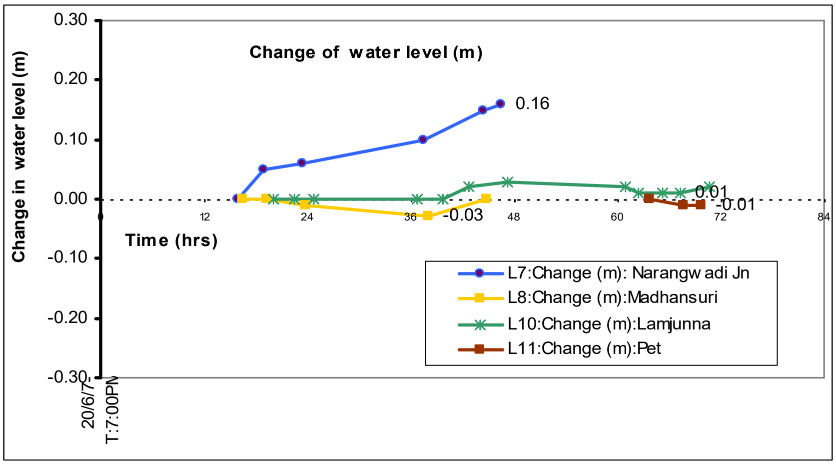
Figure 2



(a)



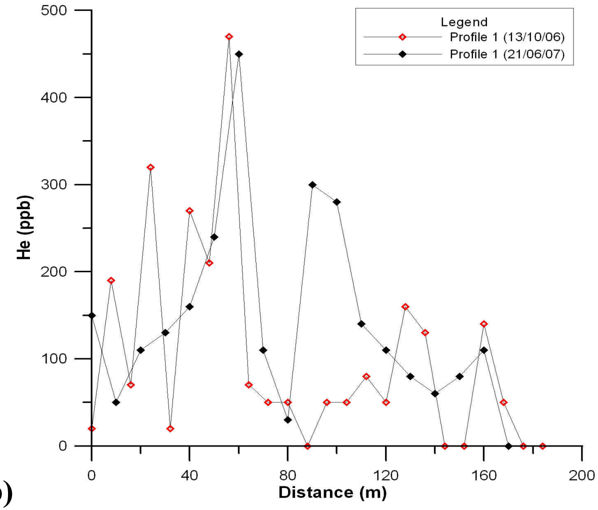
(b)



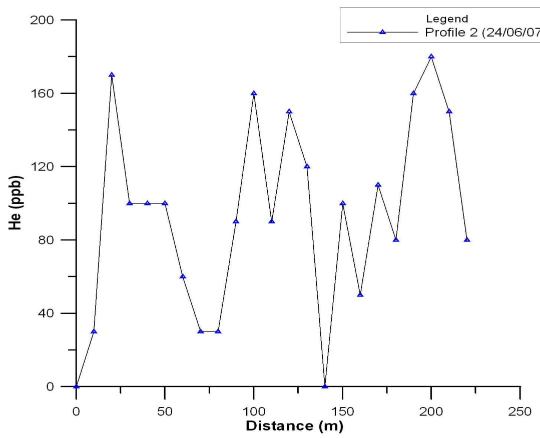
(c)

Figure 3 (a-c)

(a)


Legend
Profile 1 (13/10/06)
Profile 1 (21/06/07)
He (ppb)
Distance (m)
0
100
200
300
400
500
0
40
80
120
160
200

(b)


Legend
Profile 2 (24/06/07)
He (ppb)
Distance (m)
0
40
80
120
160
200
0
50
100
150
200
250

(c)

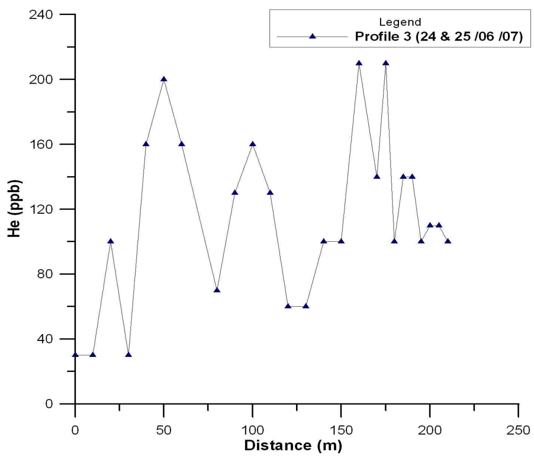

Legend
Profile 3 (24 & 25 /06 /07)
He (ppb)
Distance (m)
0
40
80
120
160
200
240
0
50
100
150
200
250

Fig. 4 (a-c)

Table 1

Serial No.	Height (m)	Temperature ($^{\circ}c$)	Approx. Location
1	11272	-17	Sholapur
2	11272	-17	Gulberga
3	9740	-9	*
4	7400	5	*
5	7200	6	*
6	5585	12	*
7	4500	17	*
8	3500	21	*

Table 2

dd/mm/yyyy 10/02/2005 Profile 1		dd/mm/yyyy 13/10/2006 Profile 1		dd/mm/yyyy 21/06/2007 Profile 1		dd/mm/yyyy 24/06/2007 Profile 2		dd/mm/yyyy 24 & 25/06/2007 Profile 3	
Dist. (m)	He (ppb)	Dist. (m)	He (ppb)	Dist. (m)	He (ppb)	Dist. (m)	He (ppb)	Dist. (m)	He (ppb)
0	60	0	20	0	150	0	0	0	30
12	60	10	190	10	50	10	30	10	30
		20	70	20	110	20	170	20	100
27	90	30	320	30	130	30	100	30	30
37	90	40	20	40	160	40	100	40	160
52	320	50	270	50	240	50	100	50	200
		60	210	60	450	60	60	60	160
67	170	70	470	70	110	70	30	70	
82	440	80	70	80	30	80	30	80	70
		90	50	90	300	90	90	90	130
97	260	100	50	100	280	100	160	100	160
112	150	110	0	110	140	110	90	110	130
		120	50	120	110	120	150	120	60
		130	50	130	80	130	120	130	60
142	290	140	80	140	60	140	0	140	100
		150	50	150	80	150	100	150	100
157	270	160	160	160	110	160	50	160	210
		170	130	170	0	170	110	170	140
		180	0			180	80	175	210
187	0	190	0			190	160	180	100
202	80	200	140			200	180	185	140
217	0	210	50			210	150	190	140
		220	0			220	80	195	100
232	0	230	0					200	110
								205	110
247	0							210	100