Low Order Earthquake activity on Groundwater quality and its implications in Ongole domain of Eastern Ghat Mobile Belt, South India

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ABSTRACT

Hydrogeologic responses to earthquakes have been known for decades, and have occurred both close to, and thousands of miles from earthquake epicentres. Water wells have become turbid, dry or begun flowing, discharge of springs and groundwater to streams has increased and new springs have formed, and well and surface – water quality have become degraded as a result of earthquakes. Earthquakes affect our Earth's intricate plumbing system. The potential effect of a large earthquake on groundwater in Ongole domain of Eastern Ghat mobile belt, South India has been studied in the paper. This paper will assess the groundwater levels and water quality affected after earthquakes. For this study hydrological data were collected at 21 monitoring sites from 2004 – 2010. Earthquakes induced groundwater level changes in 21 piezometers. Changes in water levels to restore to normally took nearly 6 months to 18 months. There is a lot of change observed in water quality, particularly of some elements. This type of case studies were initiated in Russia, China and Japan in recent time. Frequent low order earthquakes were noticed in recent months in Nellore, Prakasam and Srikakulam areas of Andhra Pradesh may throw some light on the future seismic activity in the region. An attempt has been made to portray the seismic picture of central coastal area of Andhra Pradesh and its effect on water quality has been presented.

Keywords: Hydrogeological response, groundwater quality, earthquake prediction, health hazards

Introduction

Seismicity occurs in response to specific changes in stress or pore pressure, entails the amount of seismic deformation that results. The most straightforward factor influencing the potential for seismic deformation is the size of the region over which an activity (gas production) takes place.

Dense networks of seismometers are required to determine both the temporal evolution of seismicity, including the time - dependent spatial patterns of earthquake locations. Because the onset of triggered seismicity may involve subtle changes in micro earthquakes, it is important to have a monitoring system with adequate sensitivity and high location accuracy, so that low - magnitude events can be well recorded. In particular, seismic source parameters including source dimension, seismic moment, stress drop, and radiated energy (Hanks and Kanimori, 1979) can provide useful insights for relating industrial operations to the resulting seismicity. In view of seismic activity close monitoring of earthquake recording stations have been planned and established.

Seismicity monitoring in and around Southern Peninsular shield

The southern peninsular shield is found to have low to moderate seismicity with a slow rate of stress accumulation. Unfortunately, the peninsula is also very sparsely instrumented till late 90's to study its seismicity in greater detail. Due to the occurrence of micro to moderate earthquakes in the peninsular region over the past few decades. The region should not longer be regarded, as totally aseismic in value and its seismicity requires close study.

Earthquake monitoring stations have been established both by IMD, and NGRI. Using data recorded during the years (2007-2010), by Andhra Pradesh seismic network (APSENET). Mapping of seismically active faults from this shall also help in reassessing the seismic hazard of this region. The earthquakes which were recorded with less than 3 magnitude (M) were registered from a focal depth of less than 5 km as stated by scientists of NGRI (personal communication). Some of the earthquakes with focal depths are tabulated here in table 1.

The Ongole and its surroundings are subject to structural deformation for the past 3000Ma as mentioned plate tectonic history of the area. There are several faults in this region, which are seismically active since long time. The river courses in the region reflect conspicuous changes, supporting the confluence of fault system in the region. The region is drained by Gundlakamma, Musi, Paleru and Manneru rivers. The confirmed seismicity of this area can be attributed to a combination of neotectonic activity coupled with the effects of Indo- Antarctica breakup and periodically reactivation of faults, since geologic past. The tectonic activity in the region clearly reflects the reactivation of older faults and new ones developed by the northeastward drift of the Indian plate. As it was mentioned earlier the water levels, rainfall and quality of water are studied for post and pre monsoon for the years 2009, 2010 and 2011. However, the relation of geological weathering and water quality along with meteorological parameters were discussed. In the present study after visualizing the seismic activity in the region an attempt has been made to correlate the seismic activity with rainfall and water levels. According to previous researchers and maps of the Geological Survey of India, several faults and fractures are reported.

An attempt has been made to explain the seismicity of the Ongole region that comes under zone III by the Bureau of Indian standards (BIS 2002) and surrounding regions in terms of tectonic frame wok of Indo-Antarctica breakup. For this study historical earthquake data were collected from different sources and plotted on Google earth map shown in figure 1 and analyze the number of earthquake events in year wise, and domain shown in figure 2 &3. From this analysis, it is clearly understood that, in recent days the area is very much subjected to earthquakes. Keeping in view of the history of seismicity of this area, an attempt is made to study the water quality and water levels in the borewells with respect to earthquakes, relation to rainfall and water table pattern with special reference to the years 2009, 2010 and 2011 has been studied in the Ongole region.

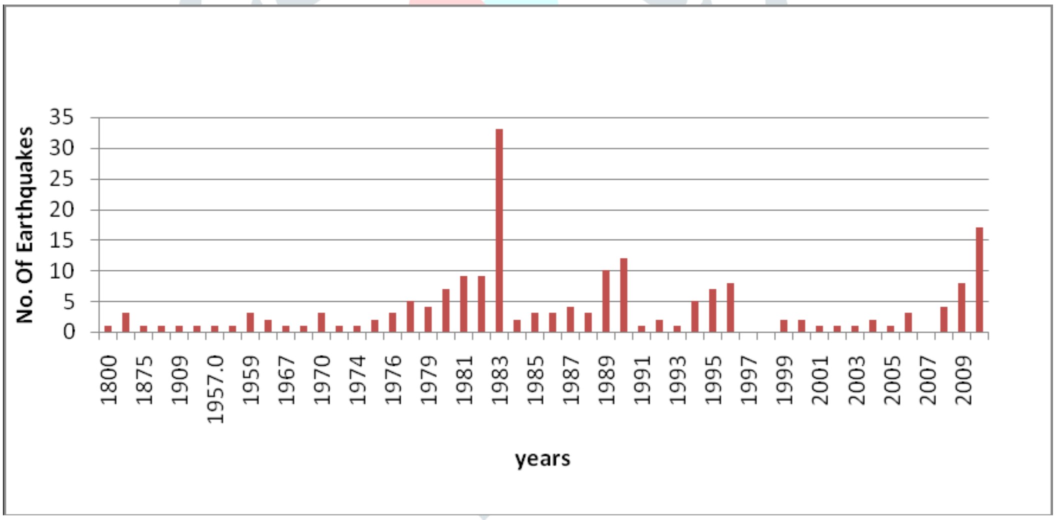

Figure 1. Seismicity in the Ongole area past 25 decades

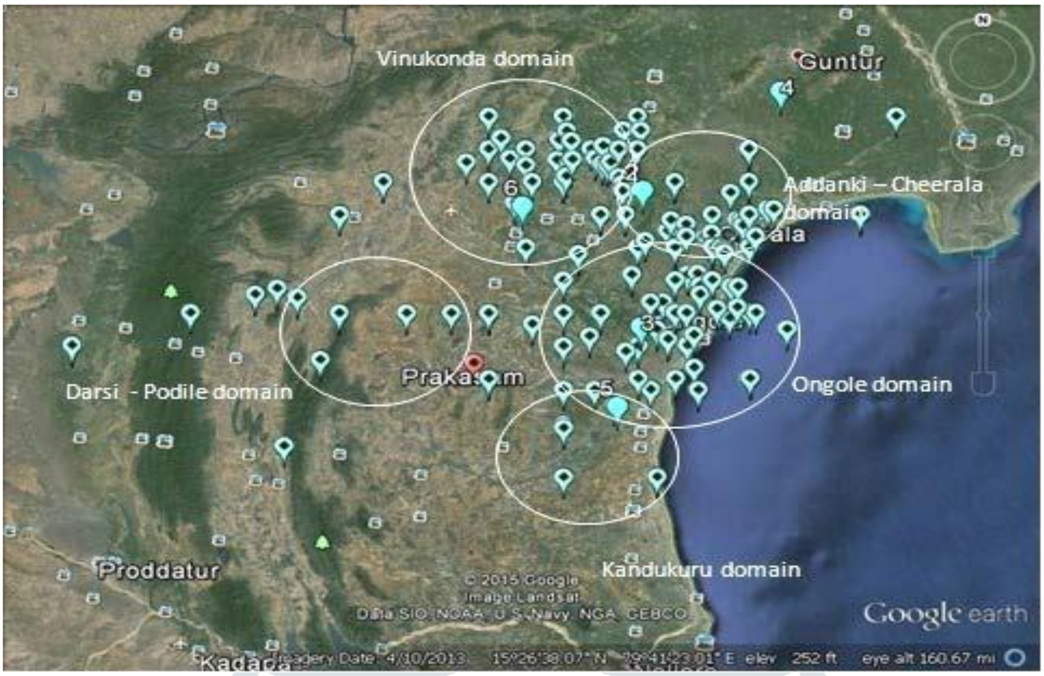

Figure 2. Earthquake epicentres plotted over a Google earth map

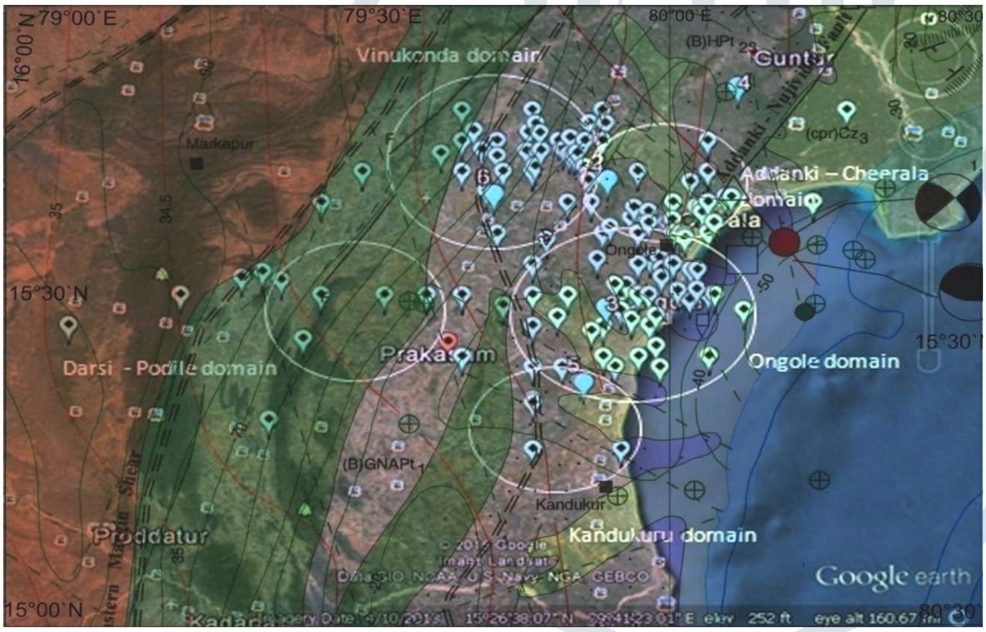

Figure 3. Epicentres plotted over geology/tectonic map

Table1: Earthquake catalogue

YYYY	Date		Origin time(UTC)								
	MM	DD	Hr	Mn	Sec	Latitude	Longitude	Depth (km)	RMS	Mag	Source
2008	11	25	9	46	24. 3	15. 872	79. 959	3	0. 5	2. 2	HYB6
2009	4	17	3	3	24. 3	15. 392	80. 074	9	0. 4	2. 7	HYB18
2009	7	21	14	54	44. 6	15. 569	79. 014	10. 8	0. 4	1. 9	HYB24
2009	9	12	14	58	53. 4	15. 832	79. 669	3. 3	0. 5	2. 5	HYB32
2009	11	7	10	50	52	15. 954	79. 909	8. 8	2	2	HYB36
2009	11	12	21	55	45. 4	15. 968	79. 825	3. 1	0. 3	1. 6	HYB40
2009	11	24	16	48	55	15. 997	79. 856	0. 5	0. 3	2	HYB43

Discussion

Scientists have been able to find changes in several water quality parameters associated with earthquakes in Russian, Japan and ChinaS. These changes have been observed both before and after the occurrence of earthquakes. Some of these chemical changes are subtle while others are more prominent and conspicuous. Changes in water quality parameters after earthquake have been widely studied and well understood by scientists. However, changes in water quality parameters as a precursor to earthquake hasn't been sufficiently studied and lacks enough data to make any firm claims. Ongole domain as a seismic-risk zone (III) carries a great significance in earthquake-related researches, because of frequently occurring earthquakes (< 3 magnitude) in the area, especially the ones related to water quality changes. These changes when occurred before the occurrence of earthquake can hint an impending disaster, i.e. the changes act as precursory phenomena. Moreover, the same changes can also pose threat to human and other living beings who consume the water. As a key to earthquake prediction as well as a threat to human health, groundwater conditions (hydrochemistry) in Ongole domain in regards to earthquake is taken seriously and the same has been discussed belo**w.**

Possibility of Short-term Earthquake Prediction

Earthquake is a natural disaster which every one wish could predict but even modern science and technology fails to do so with significant accuracy, as of now. However, in the past three decades several researches has been carried out and the results have indicated that changes in chemistry of water carries a clue to predictability of earthquakes. Different researches have used different parameters to check the chemical changes in water such as ion concentrations [12], stable isotope ratio [11], radon count rates [6], pH [7], and electrical conductivity. Some of these parameters changes several months before earthquake occurs. Anomalies in groundwater quality have been observed four to six months prior to two earthquakes of 5+ magnitudes [11]. Although, these parameters have shown possibility of prediction of earthquake, scientists, on the other hand agree that the data they have obtained are insufficient to establish any claims.

A long term data is required to establish any correlation between water quality and upcoming earthquake; this is exactly where Nepal fits in. Frequently occurring earthquakes and uncountable number of natural springs sprouting out from underneath the rocks of Himalayas is what makes this country a white-spot for earthquake research. Within the lengths of Nepal, sufficient data on pre-earthquake water quality changes may be obtained within a short period of time due to frequent occurrence of earthquakes of significant magnitudes. While it's not certain that what water quality parameters are likely to help in advancement of earthquake prediction science, multiple parameters can be monitored to detect precursory changes in groundwater. The larger number of parameters monitored higher is the chance of discovering the lucrative precursor of earthquake. In addition to this, studies on different types of geology are also crucial because the water quality parameter changes in one part of the world may not match with the changes in other part of the world. And it's very important to understand how one of the youngest and most seismically active systems gives away hints to an upcoming earthquake.

Wells in the study area during 2009 – 2011

Due to inattention of concerned parties no assessment of groundwater quality changes has been administered in the post-earthquake scenario. As we know that groundwater quality is changed seasonally but in some conditions like seismic history of the area may play a vital role in changing of water quality. In fact, existence of this phenomenon is not even realized by many.

Around 120 ground water bore wells were considered which were drilled into crystalline basement rocks. Each mandal consists of 25 villages on an average. The water levels among each mandal are carefully reduced to single well and data is shown in the table. The area of investigation falls in the Proterozoic magmatic arc of the Ongole domain, Eastern ghat mobile belt, which is covered by granite, gneisses, shales and schists. The study area is surrounded by an upland consisting of fractured bedrock metamorphic schist. Water level data were collected in all the wells. Submersible pressure transducers were used to measure the water level data with an accuracy of 0. 3 mm. The water level in wells measures the fluid pressure at depths the well is open to the surrounding formations.

Groundwater quality changes and risk to public health in the study area

Groundwater quality is also influenced by earthquakes as studies by Tsunogai and Wakita (1995). The earthquake probably increased the turbidity of all well water, although the increase in many wells was so slight that it was not visible (Cooper et al.,1965). It was found that there was increase in different parameters such as Ba, Ca, K, Li, Mo, Na, Rb, S, Si, Sr, Cl^- and $SO4^{2-}$ (Claesson et al.,2004). However in this study, major ions were dealt.

Fluctuations of groundwater chemistry after the earthquake could be mainly due to different factors as follows: a) change in water levels as a result of earthquake, b) change in water temperature that will cause more solubility, c) change in water pressure trapped in rocks and aquifers and d) mixing with water of neighboring aquifers. The water quality in the study area has been analyzed and observed that the elements which are influenced by the earthquakes. In the study area, water samples from Kurcherapalli village in Podili mandal, has shown, continuing increase in chloride concentration in the year 2009 from 300 ppm to 1900 ppm chloride.

Analyses of water samples from the above said well had shown, continuing increase in chloride, sodium concentration. However, radon studies were not carried out. The rate of increase of chloride concentration accelerated after the earthquake, the concentration increased, in the year 2009 near by 600 ppm to 1500 ppm chloride, 100ppm to 300 ppm sodium has been observed apart from the other elements. Especially Fluoride ion concentration is also observed. Darsi, Podili, Kanigiri mandals shows high fluoride ion concentrations between 1.2 ppm to 20 ppm. Table 2 shows the variation of chemical ion concentrations in the study area before and after earthquakes.

Table 2: Comparison of ground water chemistry before and after earthquakes

S.No	Mandal	Average Ionic concentrationsYear 2009							Average Ionic concentrations before Year 2007					
		No of samples (n)	HCO_3	Cl	SO_4	F	Na	Ca	HCO_3	Cl	SO_4	F	Na	Ca
1	Donakonda	10	459	1097	52	1. 20	50	760	200	350	10	2. 40	35	250
2	Konkana mitla	10	600	540	110	1. 40	371	120	180	220	50	3. 20	120	100
3	Kondepi	10	400	592	120	2. 40	100	220	250	280	60	2. 80	80	150
4	Hanumanthuni padu	10	500	249	90	1. 10	120	292	220	130	50	2. 20	60	100
5	Darsi	10	249	284	42	4. 20	46	168	112	140	40	3. 00	40	150
6	Podili	10	420	1160	42	4. 40	80	136	300	350	45	3. 50	50	120
7	Kanigiri	10	544	218	100	5. 20	336	144	250	130	40	4. 00	120	100
8	Talluru	10	480	320	100	2. 60	72	288	200	350	10	2. 40	35	250
9	Cheemakurthy	10	248	440	74	1. 4	100	120	180	220	50	3. 20	120	100
10	Nagulauppaladu	10	1170	760	178	3. 6	278	48	550	480	120	2. 80	160	150
11	Ongole	10	2700	6600	151	3. 4	391	270	1000	3500	80	2. 20	200	100
12	Tangutur	10	900	980	152	2. 3	352	160	112	140	40	3. 00	40	150
13	Addanki	10	700	1000	200	3. 8	260	240	400	350	45	3. 50	50	120
14	Ponnaluru	10	400	550	120	2. 1	100	160	250	300	80	1. 9	50	100
All the values are in ppm														

Due to the earthquakes, in the subsurface, this process (microfracturing) would greatly increase the surface area of the effected rock in contact with groundwater and thus allow the release of gases and dissolved ions from the rock into the groundwater, changing its chemical composition. Development of micro cracks into larger fractures may connect hydraulically isolated aquifers, causing both changes in the hydraulic heads and mixing of groundwater with, initially distinct hydrogeochemistry. However the study area is enriched with fluoride rich rocks. Fluoride occurs in primary minerals, especially giotites and amphiholes, where it substitutes for hydroxyl positions in the mineral structure. An example is biotite ($K2(Mg,Fe)4(Fe,Al)2[Si6Al2O20](OH)2(F,Cl)2$). Other high-temperature fluorine minerals such as topaz are less soluble. Apatite ($Ca5(CI,F,OH) (PO4)3$), which may form at both high and low temperatures, is another important source of fluorine. Substituted apatites with high fluorine and more soluble than purer (hightemperature) apatites. Fluorite ($CaF2$,) is the main fluorine mineral, which occurs in localized secondary hydrothermal vein deposits and as a relatively rare authigenic mineral in sediments. On weathering, the fluorine tends to be released preferentially from these minerals. Where biotite and amphiboles are abundant, such as in granite, a major source of fluoride in water bodies is formed. Due to this reason study area groundwater is enriched with fluoride concentration. Fluorine occurrence in natural waters is closely related to its abundance in the local minerals and rocks.It is also strongly associated with mineral solubility and in this regard the mineral fluorite, which is less soluble and has favorable dissolution kinetics at low temperature, exerts the main control of aqueous concentrations in the natural environment.

In this issue, a hydrochemical study of the study area is located in the Prakasam district favours dissolution of F-bearing silicates (Muscovite and biotite react with dissolved carbon dioxide to form kaolinite, releasing dissolved K, Na, Mg, silicate and bicarbonate) than dissolution of fluorite as source of F of ground water. The literature states that the source for F-in groundwater from the biotite, sericite, and mica containing fractured bedrock aquifer in the Darsi- Podili – Kanigiri contain very high F contents. Concentrations of Ca, as well as Na + K, increase with groundwater F concentrations. Because fluorite dissolution in a soda-water environment tends to result in the association of high F water with low Na water, the authors interpret the opposite association here as supporting evidence for lack of fluorite dissolution. However, because the mixed cations and SO4 – Cl type water is more consistent with an earlier stage of groundwater evolution than those characterized by soda–water chemistry, additional evidence is necessary to rule out the dissolution of fluorite.

Countries like India where groundwater is almost exclusively used for domestic purpose, including drinking; changes in quality of water may have severe effects on public health. Ongole domain has suffered frequently occurring earthquakes (magnirude < 3). When the intense shaking of an earthquake occurs, an influx of sediments from the host rock geochemistry can influence water quality for surface and groundwater systems. Particles within the host rock could leach nitrates, fluoride, sulphate, carbonate, arsenic and radon compounds into well sources. There may be an additional risk of bacterial contamination in raw water supplies. According to research conducted in many other cases of major earthquakes, it's has been found that various chemical alterations in ground water takes place, some of which can create significant toxicity [5]. With high silicon content in Nepalese rocks, stress induced electrification of rocks [4, 3] cause to generate Hydrogen peroxide [12] and free hydroxyl radical and toxic materials such as hydroxyl radicals that are formed prior to major earthquakes can help inactivate important enzymes required for biological functioning [2].

Considering the magnitude of earthquake and the series of aftershocks, it is highly likely that chemical properties of ground water has significantly changed and is going to cause several harms to public health, if not soon, then at least in the long term. Earthquake can be attributed to numerous types of diseases that include infectious and parasitic diseases, Neoplasms.

Conclusion

Installation of water quality monitoring systems along the Ongole domain can provide useful information on pre and post earthquake water quality parameters changes. Information on these changes is crucial to public health safety as well as to the advancement in earthquake prediction science. Its urgency for assessing possible risks in public health caused by recent earthquakes in the region, but in a long term these monitoring systems can provide data that can help us in finding our way to prediction of earthquake. Observation of abrupt changes in water quality certainly won't help in accurate prediction as of now but it certainly tells us that an earthquake is occurring soon. This level of information can be of great help for early preparations.

References

[1] Avouac JP, Meng L, Wei S, Wang T and Ampuero JP (2015), Lower edge of locked Main Himalayan Thrust unzipped by the 2015 Gorkha earthquake. Nature Geoscience, 8 : 708-711.

[2] Balka M, Boseb M, Ertemc G, Rogoffd DA, Rothschilda LJ and Freund FT (2009), Oxidation of water to hydrogen peroxide at the rock–water interface due to stress-activated electric currents in rocks. Earth and Planetary Science Letters, 283 : 87-92.

[3] Freund F (2002), Charge generation and propagation in igneous rocks. Journal of Geodynamics, 33 : 543-570.

[4] Freund F (2010), Toward a unified solid state theory for pre-earthquake signals. Acta Geophysica,58 : 719-766.

[5] Grant RA, Halliday T, Balderer WP, Leuenberger F, Newcomer M, Cyr G and Freund FT (2011), Ground Water Chemistry Changes before Major Earthquakes and Possible Effects on Animals. International Journal of Environmental Research and Public Health, 8 : 1936-1956. Earthquake - Science in Himalayas: Ground Water Quality Change and its Implications

[6] Igarashi G, Saeki S, Takahata N, Sumikawa K, Tasaka S, Sasaki Y, Takahashi M and Sano Y (1995), Ground-water radon anomaly before the kobe earthquake in Japan. Science, 269 : 60-61.

[7] Malakootian M and Nouri J (2010), Chemical Variations of Ground Water Affected by the Earthquake in bam region. International Journal of Environmental Research, 4 : 443-454.

[8] Molden D, Sharma E and Acharya G (2015), Lessons from Nepals's Gorkha Earthquake 2015. International Centre for Integrated Mountain Development (ICIMOD).

[9] Nepal Disaster Report. Edited by Dangal R (2015), Government of Nepal Ministry of Home Affairs.

[10] Shitov AV (2010), Health of people living in a seismically active region. In: Florinsky, I.V. (Ed.), Man and the Geosphere. Nova Science Publishers, New York, USA.

[11] Skelton A, Andrén M, Kristmannsdóttir H, Stockmann G, Mörth C-M, Sveinbjörnsdóttir Á, Jónsson S, Sturkell E, Guðrúnardóttir HR and Hjartarson H (2014), Changes in groundwater chemistry before two consecutive earthquakes in Iceland. Nature Geosciences, 7 : 752-756.

[12] Tsunogai U and Wakita H (1995), Precursory chemical changes in ground water: kobe earthquake, Japan. Science, 269 : 60-63.

[13] United States Geological Survey (2015), earthquake.usgs.gov.

[14] Wood H (2014), The Effects of Earthquakes on Groundwater in Santa Clara County. Banjara and Paudel