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Characteristic behavior of water radon associated with Wenchuan and Lushan earthquakes along Longmenshan fault

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HIGHLIGHTS

- Long trend of water radon measured in China during 2003–2014 at six stations round Longmenshan fault.
- Water radon shows characteristics behavior associated with Wenchuan and Lushan earthquakes.
- Water radon shows one to one relation with rainfall and ground water level variations.
- Sharp increase or decrease in water radon concentrations are found few days prior to the earthquake.

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ABSTRACT

In China, numerous subsurface, surface water well and spring parameters are being monitored through a large network of stations distributed in China sponsored by China Earthquake Administration (CEA). All the data from these network is managed by China Earthquake Network Center (CENC). In this paper, we have used numerous data (water radon, gas radon, water level, water temperature) available through CENC for the period 2002–2014 and studied the behavior and characteristics of water ^{222}radon [Rn(w)]. The observed parameters were also complemented by rainfall data retrieved from Tropical Rainfall Measuring Mission (TRMM) satellite. Our detailed analysis shows pronounced changes in the observed parameters (especially water and gas radon) prior to the earthquake. The changes in water radon, ground water level and rainfall showing characteristics behavior for Wenchuan and Lushan earthquakes. The long term data analysis of water radon and water level at various locations around epicenters of two major earthquakes along Longmenshan fault show a positive and negative relation of water radon and water level prior to these earthquakes. It is difficult to find any trend of water radon and changes in water radon pattern with these two earthquakes that could prove as a reliable precursor of earthquakes. Changes in the water radon concentrations from one location to other may be associated with the changes in ground water regime and geological settings in the epicentral and surrounding regions.

1. Introduction

Wenchuan (Ms = 8.0) and Lushan (Ms = 7.0) earthquakes occurred along Longmenshan fault, the southern part of which was associated with the triggering of Lushan and central part was associated with Wenchuan with separation of 85 km. Both the earthquakes (Wenchuan – Ms = 8.0 and Lushan – Ms = 7.0) occurred along Longmenshan fault confirm that Longmenshan fault is one of the active faults. In China, efforts are being made to monitor numerous subsurface, water well and spring parameters through a large network of stations distributed in China sponsored by China Earthquake Administration (CEA). All the data from these network is managed by China Earthquake Network Center (CENC). Water and gas radon are also being monitored in China since more than one decade. We have considered water radon data during 2002 until February 2014 from 6 stations located around the Longmenshan fault. Wenchuan earthquake occurred at the steep eastern margin of the Tibetan plateau in the Sichuan province of China on May 12, 2008, which killed about 70000 lives, 18000 people were missing, damaged millions of infrastructure,

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widespread surface manifestations and landslides were observed in epicentral and surrounding regions. About 257 landslides and rock avalanches were triggered by the earthquake which were distributed along the fault rupture zone and river channels (Cui et al., 2009; Xu et al., 2009; Yin et al., 2009). After four years of this deadly Wenchuan earthquake, Lushan (Ms = 7.0) earthquake occurred in the southwest of Longmenshan fault on April 20, 2013. Liu et al. (2013) and Shan et al. (2013) are of the opinion that the occurrence of Lushan earthquake was aftershock of the deadly Wenchuan earthquake.

Water and gas radon are being monitored around different seismically active locations in the world to get an early signal of an earthquake since last several decades (Teng, 1980; Hauksson, 1981; Igarashi et al., 1995; Virk and Singh, 1994; Virk et al., 1995, 2001; Singh et al., 1999; Virk and Walia, 2001; Richon et al., 2003; Walia et al., 2003, 2005a,b, 2006, 2008; 2013, Einarsson et al., 2008; Kumar et al., 2012). Anomalous changes in subsurface radon concentrations are expected prior to earthquakes according to the dilatancy-diffusion model for earthquake occurrence (Scholz et al., 1973). Holub and Brady (1981) initiated radon measurements under a large water reservoir in order to investigate the possible influence of changing water loads, resulting in changing volumetric stresses. The elastic properties of rocks, the local fracture system and the compressibility of rock pores are related to the magnitude of stress-strain-induced variations. Kies et al. (1999) studied the influence of earth tides on underground radon concentrations. Various atmospheric, ground and subsurface parameters (pressure, temperature, soil moisture, underground stress and earth tide) control the underground degassing process that influence the water and gas radon emissions (Toutain and Baubron, 1999; Immè and Morelli, 2012). Trique et al. (1999) carried out analysis of long term radon emanation and electric potential measurements in the vicinity of two artificial lakes in the French Alps and found repeatedly association of electric potential variations and radon emanations with transient deformation events induced by variations in the lake level. In a high stress region, the radon levels increase prior and decrease after the earthquake (Tarakç et al., 2014). Such changes could be related with the enhancement of permeability due to fracturing of rocks and pore pressure diffusion in response to observed seismicity, increase in in-situ temperature (Talwani et al., 2007), upflow velocity and gas flux that may be associated with the significant correlation of ^{222}Rn concentrations with earthquakes (Koike et al., 2014a). These changes can also lead to co-seismic changes in ground water levels (Parvin et al., 2014). A pronounced change in gas and water radon were observed associated with Wenchuan earthquake (Ren et al., 2012). The water radon concentrations at various locations were not found to be significant to use as a reliable precursor of strong earthquake. Radon anomalies are not only influenced by the magnitude and epicentral distance of earthquakes but also by the mechanism of radon migration (Walia et al., 2003, 2005a,b, 2008).

Long term measurements of water and gas radon are required to understand the variations of water and gas radon with the seismicity. Understanding of various parameters associated with earthquakes is a complex and challenging task, since the earthquakes occur in different in-situ geophysical and tectonic environment and the characteristics of these earthquakes differ from one earthquake to other one. Many studies in tectonic areas have shown a possible correlation of soil-gas anomalies with tectonic activity (Ciotoli et al., 1998; Yang et al., 2003; Fu et al., 2005; Walia et al., 2005, 2006; Koike et al., 2014a,b; Parvin et al., 2014). Variation in radon concentrations is not only due to the tectonic structures but also due to changes in lithology (Walia et al., 2008). The water and gas radon emissions from the epicentral region depend on the numerous parameters, such as in-situ configurations, tectonic regime, hydrological regime, and land and ocean proximity etc. Water and gas radon concentrations could be one of the possible early indicators for an impending earthquake depending on earthquake magnitude and earthquake regime (geology, geophysical, tectonic and hydrological regime) (Yan et al., 2011). An anomalous increase in radon concentration was measured at the Nakaizu observatory on the Izu Peninsula prior to the 2011 Tohoku earthquake using a custom-made radon counter. Tsunomori and Tanaka (2014) have found exponential decrease in the radon concentrations from the background level after the earthquake. Richon et al. (2003) have found an anomalous increase in soil gas radon, 22 days prior to the Mindoro earthquake (M = 7.1), In numerous earthquakes, an anomalous soil-gas and water radon were recorded prior to the earthquake (Hatuda, 1953; Hirotaka et al., 1988; Arora et al., 2012; Immè and Morelli, 2012; Friedmann, 2012). The changes in the radon concentrations could be one of the potential precursors for an impending earthquakes which are being monitored around the world in seismic prone areas (Ciotoli et al., 1998; Yang et al., 2003; Fu et al., 2005; Walia et al., 2005, 2006, 2013; Kuo et al., 2010a,b; Koike, et al., 2014a,b; Negarestani et al., 2014; Parvin et al., 2014).

Recent studies using ground and satellite observations have shown an existence of strong coupling between lithosphere-hydrosphere-atmosphere associated with earthquakes (Singh et al., 2007, 2010a,b; Tronin, 2010). Numerous ground, atmosphere and ionosphere parameters have shown anomaly prior to the earthquake.

Number of studies have shown association of a single parameter with an impending earthquake and all these studies claim to use single parameter for reliable earthquake precursor. However, long term variations of individual parameter show such anomalous behavior without its association with earthquake. Singh (2013) and Singh et al. (2007, 2010a,b) suggested complementary nature of multi parameters may be considered as the reliable early warning of earthquake. Efforts are being made by scientists to have multi parameter stations in earthquake regions to get an early information about an earthquake (Verma and Bansal, 2012). In China, efforts have been made to monitor multi parameters in search of reliable precursors for earthquakes. In this paper, we present long term variations of water radon measured at various locations surrounding the Longmenshan fault along which two major earthquakes occurred recently. Long term variations of ground water level and water temperature measured at the same water radon stations have been analyzed to study complementary nature with the observed seismicity along the Longmenshan fault.

2. Experimental method

Numerous sensors for measuring water and gas radon, water level, water temperature and many other parameters are deployed at the same location and its vicinity for precursor studies. Such parameters are monitored at 778 locations in China.

2.1. Water and gas radon monitoring

Radon is an inert gas generated from radioactive decay of the ^{238}U, ^{232}Th and ^{235}U series. ^{222}Rn which come from decay ^{238}U series has a half life of 3.8 days, ^{220}Rn which generate from decay of ^{232}Th has a half life of 54.5s, ^{219}Rn which is the member of ^{235}U series has a half life of 3.92s (Yan et al., 2011; Immè and Morelli, 2012; Ren et al., 2012). The measurement of ^{222}Rn concentrations in ground water is measured through water wells that are found to be associated with the changes in the stress of the earth's crust or build up stress in the seismically active regions (Nazaroff and Nero, 1988). Radon is dissolved in water and organic matter which is