Radon Concentration in Water and Health Threat to Region of Balakot-Bagh (B-B) Fault Line, Lesser Himalayas, North Pakistan

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Abstract

The current study was carried out near and surrounding fault line areas of Balakot-Bagh (B-B). The study aimed to find radon concentration levels in drinking water sources near and away from the fault line. The comparison was carried out for the radon level in those samples taken from the area near with those taken away from the fault line. Also, to evaluate health hazard from these drinking water to the people of the area. This area had received an earthquake of magnitude 7.6 in 2005. An active technique, RAD-7, based on alpha spectroscopy was used. The study period for the current study was three months, from 16th May to 15th August 2020. Radon concentrations were found higher in bore water with the mean value of 20.6 BqL$^{-1}$. These were 19.5 BqL$^{-1}$ and 9.3 BqL$^{-1}$ in spring and surface water, respectively. The mean value in all type of sources in the study area was 16.5 BqL$^{-1}$ which is higher than the maximum contaminated level of 11.1 BqL$^{-1}$ recommended by the U.S. The calculated doses from the radon levels were 0.0532 mSv, 0.0562 mSv and 0.0254 mSv and 0.0449 mSv, respectively.

1. Introduction

Radon is a radioactive, non-reactive gas. It exists in nature as unscented and flavorless gas (Cevik et al. 2011). It is found inside Earth's crust in elemental form (Cevik et al. 2011). There are three natural isotopes of radon: radon 222Rn, thoron 220Rn, and actinon 219Rn with half-lives of 3.82 days, 55.6s and 3.6s, respectively belong to the natural decay series of 238U, 232Th and 235U (Cevik et al. 2011; IARC 1988). 222Rn is essential isotope of radon due to their longer half-life; compared to the other two isotopes, it can travel long distances inside the earth in geological formations. Once it comes to the outdoor air environment, it can mount up and ultimately reaches a dangerous level, especially indoor environments. It has been reported that isotope 222Rn (named as radon) has seriously influenced the human health because of its longer half-life and the large quantity of its parent component (238U) in earth crustal materials compare with the other two isotopes. As indicated by the review, radon follows tobacco smoking as a reason for lung cancer (IARC 1988).

In three significant segments, radon levels can be evaluated as to their measurement concerns air, one indoor, the other outdoor, and the third one in the mining of various types. For indoor radon and its daughters, the sources can be inside or outside or both. The inside sources comprise building materials, water, cellar air, soil (Richard and Rebers 1991), while the outside air is just known as the outside source. High indoor radon levels by and large outcome from prominent radon creation and versatility in soils. The pores in building foundations and cracks in floor slabs are also responsible for indoor radon built-up (Nielson et al. 1994). The ventilation rate, temperature and pressure factors inclinations are the center elements liable for changes in indoor radon fixation levels (Rahman et al. 2010; Rafique et al. 2011). The air exchange among indoor and open-air conditions is affected by ventilation rate; the high ventilation rate decreases the indoor radon concentration, and poor ventilation built elevated radon in the inner environment. While the presence of radon in the outside environment depends on time, climatic conditions, and the origin from where the air sample is taken (Ali et al. 2011). Radon can be the measurement in air, both by passive and active techniques. However, the passive/integrated methods are
generally considered appropriate for field study and for appraisal of radon focuses throughout extended time scales (Miles 2001; Martinez et al. 2001; Sesana and Begnini 2004; Al-Jarallah et al. 2008). In these techniques, a detector will capitulate a single measurement of the radioactivity of radon in air, averaged over some selected period from a few months to a year or even for a more extended time from which seasonal and annual variations of radon concentrations can be measured. For this purpose, many detectors, be installed at each place exclusive of lost a solo measurement on a day. These detectors can also be helpful for such sites where active techniques either not possible or error in its measurement.

In the Himalayan region of Pakistan, two essential earthquakes occur: in 1965 and October 2005 in Kohistan District and Balakot Region, respectively. Besides that, these earthquakes cause damages, also responsible for the high level of radon emanation from geological faults and fractures (Khan et al. 2010; Khan et al. 2021).

The variation in radioactivity in rocks depends on amount of radioactive elements (Serra 1984; Khan et al. 2021). Different types of rocks, i.e., sedimentary, igneous, and metamorphic, have varying radioactivity values based on the number of radioactive minerals. Clay minerals in mud rocks like shale/clay regulate radioactivity. The radiation levels are high (50%) in mud rocks due to thorium and potassium (Serra 1984). In clastic rocks such as sandstones, uranium is abundant in arkose (> 25 % feldspar), whereas thorium and potassium are abundant in glauconitic form (Serra 1984; Khan et al. 2021). In carbonate rocks such as limestone and dolomite, radioactivity is low (thorium and uranium). Carbonate's radioactivity is proportional to the amount of argillaceous material present. If the carbonates have a higher argillaceous content, higher will be radioactivity (Serra 1984; Khan et al. 2021). organic sedimentary rocks such as coal, the radioactivity is low. Still, when the organic material is present in shale, i.e., organic shale, radioactivity is high due to clay minerals (Serra 1984; Khan et al. 2021).

Radioactivity (potassium) is abundant in salt, gypsum, and anhydrite (together known as evaporites), but other radioactive elements are present in a smaller amount. There are three different types of igneous rocks: acidic, mafic, and ultramafic. From acidic to mafic to ultramafic, the radioactivity (uranium, thorium, and potassium) decreases due to different chemical composition (Serra 1984; Khan et al. 2021).

The Himalayas was affected by a significant earthquake in the last century, for instance, Kangra (1905), Bihar-Nepal (1934), Assam (1950), and Kashmir (2005) earthquake. These earthquakes occurred in Sub-Himalayas (Thakur 2008; Kaneda et al. 2008; Sapkota et al. 2013). In Lesser and Higher Himalayas, several moderate earthquakes occur Nepal (2006), India, Kohistan, and Kashmir (1965) (Kumahara and Nakata 2006; Kaneda et al. 2008). Kashmir seismic tremor happens on eighth October 2005 of size 7.6, and around 80,000 lives were lost (Mona Lisa et al. 2007). Such quakes typically bring about the increased radon radiation from faults and fractures. The fault during this quake lies from the north of Balakot (Tanda Fault) toward the northwest of Bagh (Muzaffarabad Fault) (Mona Lisa et al. 2007) collectively called Balakot-Bagh Fault (B-B Fault).

2. Geology And Tectonics
The high seismicity in Pakistan is attributed to Indo-Pakistani, Eurasian, and Arabian Plates (Bilham 2005; Wheeler et al. 2005). In northern Pakistan, the Himalayan fold and thrust belt are responsible for active faults, high seismicity and thrust fabric (Molnar and Tapponnier 1975; Nakata et al. 1990; Khattak et al. 2017). These thrusts, i.e., Salt Range Thrust (SRT), Main Boundary Thrust (MBT), Main Central Thrust (MCT), and Main Karakorum Thrust (MKT), divides the Himalayas into Sub, Lesser, and Higher Himalayas (Mona Lisa et al. 2007). The region being investigated in the current research lies in Hazara Kashmir Syntaxis (HKS), Lesser Himalayas (lies between MBT and MCT) in Northern Pakistan (Fig. 1b).

In Northern Pakistan, the Lesser Himalayas starts from the northwest and continues further south due to bending of the MBT forms HKS (DiPietro and Pogue 2004; Wadia 1931; Khattak et al. 2017) (Fig. 1b). Calkins et al. 1975 named MBT as the Panjal and Murree thrust westward where the MBT and MCT diverge. As a result of this divergence in the Lesser Himalayas thick sequence of rocks occur in Hazara and Attock–Cherat range (Panjal thrust is called Khairabad thrust in the Attock–Cherat Range; MCT of the Lesser Himalaya) south of Peshawar (Yeats and Hussain 1987) (Fig. 1b). In the north of the Panjal thrust, Lesser Himalayas contains Precambrian meta-sediments, metamorphosed sequence of Paleozoic and Mesozoic age of Peshawar Basin (DiPietro 1991; Hussain et al. 2004a). The Precambrian rocks include the Salkhala, Gandaf, Manki, and Tanawal formations. Several intrusive bodies present in this area, i.e., Mansehra Granite and Swat Gneiss of Cambrian age and Peshawar Plain Ambela alkaline complex of Late Paleozoic age (DiPietro et al. 1999; Hussain et al. 2004 b). Towards the south of the Panjal thrust, the Lesser Himalaya contains Precambrian age Hazara Slate overlain by Abbottabad Group (Latif 1974; Yeats and Hussain 1987) (Fig. 1b).

The B–B Fault is a reverse fault emerges from Main Boundary Thrust (MBT) (Fig. 1c). In the Muzaffarabad area, the B-B Fault distinguished Precambrian strata (northeast) from Miocene Murree Formation (southwest). Towards the southeast, the B-B Fault separates Murree and Kamlial formations (Yeats et al. 2006; Kumahara and Nakata 2006; Kaneda et al. 2008) (Fig. 1c).

3. Materials And Methods

Radon concentrations were measured at various places in the study area. The study area lies south of the main Himalayan Range (Lesser Himalayas) and is one of Pakistan's wettest parts. From the study area total of 60 samples was collected, 20 each from spring, borehole, and surface water; the sources were drinking water. The current study was carried out in Balakot in the 16 km length and 7.8 km width section along an active fault line which lies in 34.50°–34.58° N latitude and 73.28°–73.38° E longitude, with almost of 125 square kilometres area.

The bore/well water samples were taken through a tube fixed to the tap at a procribed flow rate. The spring and surface water samples were directly taken and managed in the bottles. These bottles dipped in the water, filled, and capped tightly within the sources to avoid any outside air entry into these bottles. Several replacement/duplicate samples were collected from arbitrary sites to examine the steadiness and strength of the method. For the preservation and to transfer these samples to a laboratory to measure
radon, some amount of concentrated acid of HNO$_3$ was added to each water sample. However, in situ measurement, there is no need for acidification; the sampling collection period was chosen in summer for three months from mid-May to the middle of August in 2020. It is easy to survey the area in this season in another nine months, the area either under snowfall or under snow bed, so difficult for movement. However, the impact of the weather on radon levels in water has no significant effect, so not considered in the current survey. These samples were analyzed for radon level through active technique by using RAD-7.

Durridge Company makes RAD-7 is a solid-state $\alpha$ detector, as shown in Fig. 3. through which radon is detected in an electronic way (Durridge Co. 2009). A silicon semiconductor material is used in it. Silicon converts alpha particle radiation which falls on it, to an electrical signal directly; it consists of a 0.7-litre hemisphere cell, layered on the inner side with an electrical conductor. A semiconductor solid-state planar silicon alpha detector, ion ingrained at the center of the hemisphere. The inner conductor can be charged to a voltage of 2000–2500 V compared to a silicon detector which creates an electric field throughout the volume of the cell. The repulsive force on the positive charge (alpha particle) due to the electric field pushes these particles onto the silicon detector.

The detector measured the radon levels in water samples as already set conversion arithmetic which directly gives the results in printed and recorded in a soft form. However, preset for the conversion factor needed according to the sample volume; for example, the conversion factor for 250ml water is 4. If base data is available for the area, then the sample volume is selected for sampling. For more radon in the water in the area, 100ml sample is suitable; however, in general, 25ml samples are standard.

Those samples of water for which in field measurement are not possible by one or other reason and the measurement to be taken in the laboratory take more than 10 hours from collection to the laboratory. In such cases, the measurement is corrected by using the term decay conversion factor (DCF), by using equation (Ali et al. 2010, Cho et al. 2020):

$$ DCF = e^{\left(\frac{T}{132.4}\right)} \text{ Eq. 1} $$

$T$ is that time taken by a sample from collection to the lab for analyzing for radon concentration in hours, while 132.4 is the mean life of $^{222}Rn$.

The detector RAD-7 can also be used for soil gas radon measurement using accessories of the instrument such as a probe of length 90cm, which is immersed in the soil through the entire length of 90 cm or less per soil nature/requirement for the soil collection of samples. It sucks the gas from the soil sample, and this gas is transfer to a silicon detector where radon level measure in the soil sample. It gives the result in the same way as in the case of water in the form of a chart bar printed on paper and in the recorded soft form. Two protocols are standard for using RAD-7; these are sniff protocol and Grab mode.

4. Results And Discussion
The radon level in all three types of media of drinking sources is shown in Table 1. The values range from 15.0 to 22.9 BqL$^{-1}$ from 17.2 to 24.5 BqL$^{-1}$ and from 7.4 to 11.8 BqL$^{-1}$ with average values of 19.5 ± 2.8 BqL$^{-1}$, 20.6 ± 2.9 BqL$^{-1}$ and 9.2 ± 1.4 BqL$^{-1}$ in spring, borehole and in surface water, respectively. In all types of drinking sources, radon concentration ranges from 7.4 to 24.5 BqL$^{-1}$ with an average value of 16.6 ± 2.4 BqL$^{-1}$. Table 2 shows the mean calculated doses from these radon concentrations. Table 3 gives a statistical analysis of the results. It indicates almost 68% of samples; radon concentrations were higher than MCL and 32% below this level in surface water. Figure 3 reveals the mean values of the radon concentrations in all three types of sources. Figure 4 shows the mean calculated doses from the radon level. While Fig. 5 demonstrates the frequency distribution of water radon concentrations in the study area. The doses calculated from the radon level in the limit of ICRP-65 (0-3mSv) (ICRP-60 1990). The borehole samples mainly were from the urban area like Balakot city and surrounding while the spring water samples were taken from rural area hilly area. The surface water samples mainly were consisting of River Kunhar and various ponds (lakes).
Table 1
Radon concentrations in sources of drinking water in (BqL$^{-1}$)

| S. No | Spring    | Borehole  | Surface  |
|-------|-----------|-----------|----------|
| 1.    | 21.9 ± 3.1| 22.5 ± 3.2| 10.0 ± 1.6|
| 2.    | 16.6 ± 2.2| 20.5 ± 3.1| 11.0 ± 1.8|
| 3.    | 19.7 ± 2.5| 21.1 ± 3.3|  8.9 ± 1.4|
| 4.    | 18.4 ± 3.2| 23.8 ± 3.6|  8.6 ± 1.3|
| 5.    | 15.0 ± 2.1| 19.8 ± 3.0|  8.1 ± 1.3|
| 6.    | 19.8 ± 3.6| 17.5 ± 2.9|  9.5 ± 1.7|
| 7.    | 20.3 ± 3.8| 17.8 ± 3.0|  9.1 ± 1.5|
| 8.    | 20.9 ± 3.3| 18.7 ± 2.8|  8.8 ± 1.2|
| 9.    | 22.9 ± 3.7| 17.2 ± 3.1| 10.3 ± 1.7|
|10.    | 21.4 ± 3.0| 19.3 ± 2.9|  9.1 ± 1.6|
|11.    | 19.6 ± 3.1| 22.8 ± 3.1| 11.8 ± 1.9|
|12.    | 22.1 ± 3.7| 21.8 ± 3.9| 10.3 ± 1.7|
|13.    | 19.1 ± 2.9| 22.3 ± 4.0|  7.9 ± 1.3|
|14.    | 16.8 ± 2.5| 22.9 ± 3.2| 10.7 ± 1.7|
|15.    | 18.9 ± 2.6| 20.6 ± 3.3|  8.4 ± 1.3|
|16.    | 16.7 ± 2.1| 19.7 ± 3.0|  7.8 ± 1.2|
|17.    | 20.2 ± 3.4| 19.2 ± 2.9|  9.7 ± 1.5|
|18.    | 18.8 ± 2.3| 24.5 ± 3.4|  8.0 ± 1.3|
|19.    | 22.5 ± 3.9| 20.1 ± 3.5|  7.4 ± 1.3|
|20.    | 18.6 ± 2.6| 20.5 ± 3.2| 10.2 ± 1.8|
|A.M   | 19.5       | 20.6       |  9.3      |
|S.D.  | 2.8        | 2.9        |  1.4      |
|Maximum| 22.9       | 24.5       | 11.8      |
|Minimum| 15.0       | 17.2       |  7.4      |
|Range | 15.0–22.9  | 17.2–24.5  | 7.4–11.8  |
Table 2
Mean calculated doses from radon concentrations in sources of drinking water (mSv)

| S. No | Spring | Borehole | Surface |
|-------|--------|----------|---------|
| A.M   | 0.0532 | 0.0562   | 0.0254  |
| S.D   | 0.0076 | 0.0079   | 0.0038  |
| Maximum | 0.0625 | 0.0669   | 0.0322  |
| Minimum | 0.0412 | 0.0469   | 0.0202  |
| Range | 0.0412–0.0625 | 0.0469–0.0669 | 0.0202–0.0322 |

Table 3
Sample data statistics for all types of drinking water sources.

| Range of $^{222}$Rn content (BqL$^{-1}$) | Frequency | Percentage frequency | Cumulative frequency |
|-----------------------------------------|-----------|----------------------|---------------------|
| 0–3                                     | 0         | 0                    | 0                   |
| 3.1–6                                   | 0         | 0                    | 0                   |
| 6.1–9                                   | 9         | 15                   | 15                  |
| 9.1–12                                  | 11        | 18.33                | 33.33               |
| 12.1–15                                 | 1         | 1.6                  | 35                  |
| 15.1–18                                 | 6         | 10                   | 45                  |
| 18.1–21                                 | 20        | 15                   | 78.33               |
| 21.1–24                                 | 12        | 20                   | 98.33               |
| 24.1–27                                 | 1         | 1.6                  | 100.00              |

5. Conclusions

High radon values were found in the vicinity of the fault line compared to the following parts, which are away from the fault line even of the same climatic and geological character with a positive correlation of radon level with ruptured rocks. Radon level also depends on the depth of bore. The radon concentration increases with the depth of the bore. High radon in spring and bore water compared to surface water the reason for elevated radon was aeration, as the surface water is exposed to air while spring and bore water is not unexposed. The average values of the radon level in both spring water 19.5 BqL$^{-1}$ and borehole water 20.6 BqL$^{-1}$ and even average value in all types of drinking water sources 16.5 BqL$^{-1}$ are well above the Maximum contaminated limit (MCL) of 11 BqL$^{-1}$ set by US EPA (1991). only the surface water sources mean value of 9.3 BqL$^{-1}$ is below this level; however, most of the area’s inhabitants use the bore...
and spring water for drinking. Therefore, it is recommended that drinking water not be used before proper treat meant like granular activated carbon (GAC) (Cho et al. 2020). The other conventional method is not using the water for drinking purpose immediately taken out from the bore or spring and leaving it unexposed for few days so that radon activity decreases as being half-life of radon 3.82 days after first half-life enough radon decayed. Then these water sources can be used for drinking.

**Declarations**

**Declaration of conflicting interests**

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Figures
Figure 1

a). Shows the location of Pakistan b). The map shows tectonic units and geology of northwest Himalayas (Yeats and Hussain 1987) c). Map shows the location and geology of B–B Fault in HKS (Kaneda et al. 2008).
Figure 2

Schematic of RAD-7 active detector
Figure 3

Average value of radon level in various drinking water sources.
Figure 4

Average value of radon level in all samples of water sources.
Figure 5

Frequency distribution of radon concentration in all samples of water in the study area