CHAPTER 5

RADON CONCENTRATION IN WATER AND DOSE ESTIMATION

In this chapter, the measurement of radon concentration in underground and surface water has been done in the studied area using Smart RnDuo developed by BARC, Mumbai. Further, the correlation between radon concentration in underground water with depth (in meters) has been discussed. The inhalation and ingestion doses have been calculated to study the radiological risk assessment for the residents of the studied area. The detailed introduction about the topic, measurement procedure, formulae used for calculations, results and discussion and conclusion have been discussed in this following section.

5.1 INTRODUCTION

Exposure of humans to radon gas is a cause of concern. Many pooled as well as individual studies have been carried out to find the radiation levels and so that the radiological health risk to the general public can be assessed. The world is naturally radioactive, with natural sources such as cosmic radiation, radon gas exposure and terrestrial radiation accounting for over 90% of human radiation exposure (Kansal et al., 2015). Among the various sources of natural ionizing radiations present on the earth, radon alone contributes to more than 50% of the total dose received by the general public (UNSCEAR 2000; Singh et al., 2015) and is known to be the second largest cause of lung cancer after smoking (WHO, 2009; Al-Zabadi et al., 2015). Radon, a progeny of uranium, is an inert, colourless and odourless gas found in numerous kinds of rocks like granites, metamorphic rocks and sedimentary rocks containing phosphate (Lowerence et al., 1991; Linda et al., 1992; Carvalho et al., 2007). Radon gas is fifteen times more soluble in water than other noble gases like helium and neon, which gets dissolved and transported with the water when underground water moves through radium rich soil and rocks. The existence of natural radioactivity in water is based on the local geological conditions of the source, soil or rocks (Fatima et al., 2007). Dissolved radon in water may enter into indoor air through de-emanation when this water is used for showering or laundry purposes (UNSCEAR, 2000).

A report by the National Research Council of the United States attributed 3,000 to 32,000 lung cancer deaths per year (with a mean of about 19,000 deaths annually) to Rn-222 and its short-lived progeny in indoor air (NCBI, 1999). Furthermore, there is a plethora of literature suggesting that there is no safe level for stochastic (probabilistic) effects to occur (Tsoulfanidis et al., 2015). Several studies on radon and its correlation with geology have been attempted in different parts of the world (Tanner, 1986; Ramola et al., 1989; Choubey et al., 1994). From various epidemiological combined investigation of seven North American case-control studies, it was established that radon in homes increases the risk of lung cancer to the local population (Lubin et al., 1995, 1997; Krewski et al., 2005). In a study by Henshaw, it was revealed that indoor radon concentration is related with leukaemia and certain different malignancies (Henshaw et al., 1990). According to USEPA 1991, consumption of water causes 168 cancer deaths every year, 89% of lung cancer deaths were caused by breathing in radon released to the indoor air from water and 11% of stomach cancer deaths were caused by consuming water containing radon (USEPA, 1991). Radioactive contamination can lead to various life-threatening diseases like cancer and renal failures (Kurttio et al., 2006; Skeppstorm et al. 2007; Kansal et al., 2011). Radon progenies can also stick to aerosol particles thereby exposing indoor occupants to elevated radon exposure (Mishra and Mayya, 2008). These progenies deliver most of the dose to tissues, thereby damaging the genetic material and leading to mutations. ICRP recommends a threshold exposure limit of 1 mSv per year for general public and 20mSv per year for radiation workers for the total dose received for all sources (ICRP 2010). However, as per the United States Nuclear Regulatory Commission (US-NRC), exposure levels to individuals must be kept ‘as low as reasonably achievable’ (principle of ALARA). Besides acting as an indicator for uranium deposits, radon has some unique properties due to which it finds its use as a geophysical tracer for locating faults and geological structures (Tanner, 1986). However, the most important aspect of studying radon is the radiological hazard it poses to general public.

Water, being a basic component of all life forms, is essential for the survival of all living beings. It is therefore imperative to test water for such toxic and radiological components. Keeping in view the significance of the adverse health effects of radon, many studies have been carried out worldwide for quantifying radon in water. The present study in Barnala and Moga districts of Punjab, India has been carried out for the first time using Smart RnDuo to find the radiological risk assessment to the public. The ingestion and inhalation doses for various age groups like infants (1-2 year), children (8-12 year) and adults (above 17 year) have also been calculated. The data obtained in this study will add to the relevant scientific data pool for the radon mapping of country.

5.2 METHODOLOGY

5.2.1 Field Work

The studied area is divided into grid pattern for uniform mapping. Total 200 underground water samples were procured from 50 different villages with four samples (2 underground and 2 surface water) from each village. The underground water samples were collected from different sources like handpump, submersible and borewell while, the surface water samples were collected from different sources like canal, water works tanks and ponds. The samples were collected in 60 mL airtight, cleaned glass bottles. The samples were collected underwater by putting the sampling water bottles in the water container/ bucket so that radon could not escape during the sample collection (Figure 5.1). All sampling bottles were fully filled up to the top ensuring no bubble formation in the sample. Glass bottles have been preferred over other materials as they have more radon retention ability (Vesterbacka et al., 2010).

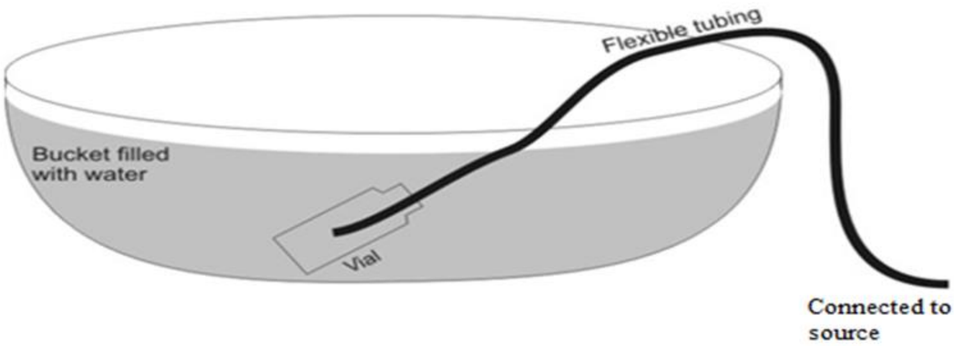

Figure 5.1: A schematic representation of water sample collection from source

To measure radon concentration in the collected water samples in real time, a scintillation-based radon monitor, Smart RnDuo developed by Radiation Protection & Advisory Division (RP&AD) at Bhabha Atomic Research Centre (BARC), Mumbai, India (Gaware et al., 2011), has been used. The inbuilt pump was made to turn on for

5 minutes to flush out air from the detector, after that RnDuo monitor along with bubbler attachment was connected to the sampling bottle using flexible tubing (Figure 5.2). Then pump was turned on manually for 2-3 minutes by putting pump setting “ON” in radon mode in closed setup. Then it was turned “OFF” in pump settings. Measurement of radon was taken in 15minute cycle each for 1hour operation at constant temperature. Gas was collected from the water sample into a scintillation cell (150 cc) for radon measurement using a diffusion method. The gas is passed via a "progeny filter" and a "thoron discriminator" during diffusive sampling, which removes radon/thoron progenies and thoron. The radon measurements in RnDuo are based on the continuous counting of alpha particles generated from radon and its decay products formed inside a cell volume by the PMT and the associated counting electronics. The collected alpha counts are processed by a microprocessor unit using a devised algorithm to display the radon concentration. For the measurement of radon concentration in water samples and radiological risk assessment following formulae has been used:

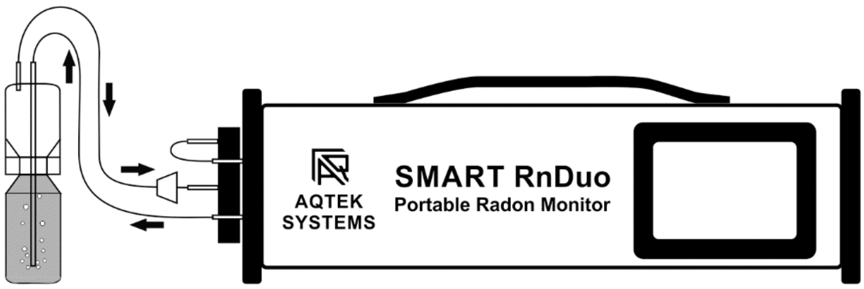

Figure 5.2: Set-up for measurement of radon in liquid sample

5.3 FORMULAE USED

5.3.1 To Calculate Radon in Water

The following formulae has been used to measure the radon concentration in liquid (C_{liq}) from the measured concentration of radon in air (C_{air}) in water samples is given by Smart RnDuo (Gaware et al., 2011):

$$C_{liq} = C_{air}(k + \frac{V_{air}}{V_w}) \quad (1)$$

Where, C_{air} is concentration of radon in air (Bqm^{-3}), C_{liq} is concentration of radon in water (Bqm^{-3}),

V_{air} and V_w are the air and water volume and k (=0.25) is partition coefficient between air and water.

5.3.2 To Calculate Annual Effective Dose Due to Ingestion and Inhalation

The dose exposure due to ingestion and inhalation from the Radon in water has been calculated by the parameters given in UNSCEAR report (2000).

5.3.2.1 To Calculate Ingestion Dose. The ingestion dose has been calculated Due to Radon Concentration in Water given by UNSCEAR, 2000:

$$I_D = C_{liq} \times A_{DWI} \times 365 \times DF \qquad (2)$$

Where I_D is the ingestion dose per year (μSvy^{-1}),

C_{liq} is the radon concentration in water,

A_{DWI} is the age-wise daily water intake (for infants (0-2 year) (0.8 L), for children (8-12 year) (2.5 L) and for Adult (above 17 years) (3L)) (WHO, 2004).

and DF is the dose conversion factor for radon (3.5 $nSvBq^{-1}$) for adults, (5.9 $nSvBq^{-1}$) for children and (23 $nSvBq^{-1}$) for infants (UNSCEAR, 2000).

5.3.2.2 To Calculate Inhalation Dose. The inhalation dose due to consumption of radon in drinking water is given by UNSCEAR, 2000:

$$Inh_D = C_{liq} \times R_w^a \times \phi_{Rn_{222}} \times o \times DF \qquad (3)$$

Where Inh_D is the inhalation dose per year (μSvy^{-1}),

C_{liq} is the radon concentration in water,

R_w^a is the ratio of radon in air and water/ transfer coefficient (10^{-4}),

$\phi_{Rn_{222}}$ is the equilibrium factor between radon and its progeny (0.4) (equilibrium factor is when radon is secular equilibrium with its progeny),

o is the time of individual average indoor occupancy (7000 hy^{-1}),

(ICRP assumes 80% annual indoor occupancy (ICRP, 1993), and DF is the dose conversion factor for inhalation of radon (33nSv (Bq h $m^{-3})^{-1}$) for infants, (31.4 nSv (Bq h $m^{-3})^{-1}$) for children and (28.3 nSv (Bq h $m^{-3})^{-1}$) for adults (Brudecki et al., 2014).

5.4 RESULTS AND DISCUSSION

5.4.1 Radon Concentration in Water

In Barnala district, Table 5.1 shows the measured radon concenration in all 100 water samples. The concentration varies from a minimum value of 0.17 ± 0.01 BqL^{-1} (Sehra, surface water) to maximum value of 9.84 ± 0.59 BqL^{-1} (Dhanula, surface water) with an average value of 3.01 ± 0.29 BqL^{-1}. The measured average values are lower than 11 BqL^{-1} as recommended by USEPA (1991), 100 BqL^{-1} by WHO (2004) and 4-40 BqL^{-1} by UNSCEAR (2008).

Table 5.1 also shows the annual effective dose due to ingestion and inhalation of radon in drinking water for various age groups. The annual effective dose due to ingestion for infants (0-2 year) lies in the range of 5.51 ± 0.43 to 56.55 ± 3.41 μSvy^{-1} with a mean value of 21.93 ± 1.36 μSvy^{-1}, for children (8-12 year) it lies in the range of 4.41 ± 0.35 to 45.25 ± 2.74 μSvy^{-1} with a mean value of 17.55 ± 1.09 μSvy^{-1} and for adults (above 17 years) it lies in the range of 3.14 ± 0.25 to 32.21 ± 1.95 μSvy^{-1} with a mean value of 12.49 ± 0.77 μSvy^{-1}. The annual inhalation dose varies from 7.57 ± 0.60 to 77.67 ± 4.70 μSvy^{-1} with a mean value of 30.11 ± 1.87 μSvy^{-1} for infants, 7.20 ± 0.57 to 73.90 ± 4.47 μSvy^{-1} with a mean value of 28.65 ± 1.78 μSvy^{-1} for children and 6.49 ± 0.51 to 66.60 ± 4.03 μSvy^{-1} with a mean value of 25.82 ± 1.60 μSvy^{-1} for adults. The calculated dose values are well below the annual effective dose of 100 μSvy^{-1} recommended by WHO (2004, 2008).

In Moga district, Table 5.2 shows the measured radon concentration in all 100 water samples of Moga district. The concentration varies from a minimum value of 0.82 ± 0.06 BqL^{-1} (Moga, surface water) to maximum value of 8.41 ± 0.51 BqL^{-1} (Marhi, surface water) with an average value of 3.26 ± 0.20 BqL^{-1}. The measured average values are lower than 11 BqL^{-1} as recommended by USEPA (1991), 100 BqL^{-1} by WHO (2004) and 4-40 BqL^{-1} by UNSCEAR (2008).

Table 5.2 also shows the annual effective dose due to ingestion and inhalation of radon in drinking water for various age groups. The annual effective dose due to ingestion for infants (0-2 year) lies in the range of 7.57 ± 0.60 to 77.67 ± 4.70 μSvy^{-1} with a mean value of 30.11 ± 1.87 μSvy^{-1}, for children (8-12 year) it lies in the range of 7.20 ± 0.57 to 73.90 ± 4.47 μSvy^{-1} with a mean value of 30.11 ± 1.87 μSvy^{-1} and for adults (above 17 years) it lies in the range of 6.49 ± 0.51 to 66.60 ± 4.03 μSvy^{-1} with a mean value of 25.82 ± 1.60 μSvy^{-1}. The annual inhalation dose varies from 5.51 ± 0.43 to 56.55 ± 3.41 μSvy^{-1} with a mean value of 21.93 ± 1.36 μSvy^{-1} for infants, 4.41 ± 0.35 to 45.25 ± 2.74 μSvy^{-1} with a mean value of 17.55 ± 1.09 μSvy^{-1} for children and 3.14 ± 0.25 to 32.21 ± 1.95 μSvy^{-1} with a mean value of 12.49 ± 0.77 μSvy^{-1} for adults. The calculated dose values are well below the annual effective dose of 100 μSvy^{-1} recommended by WHO (2004, 2008).

5.4.2 Frequency Distribution

For Barnala district, Figure 5.3 shows a frequency distribution graph for radon concentration. It has been observed that concentration in 31% of the samples lie between 0-2 BqL^{-1}, in 32% samples it lies between 2-4 BqL^{-1} and in 37% samples it lies between 4-10 BqL^{-1}.

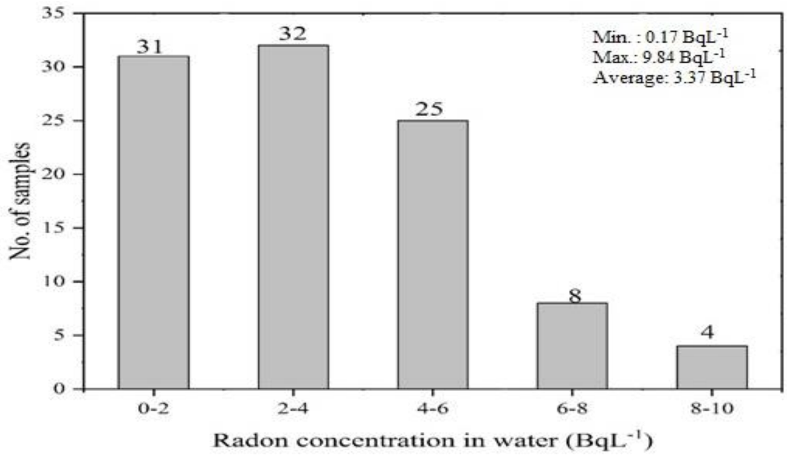

Figure 5.3: Frequency distribution of radon concentration in Barnala district

For Moga district, Figure 5.4 shows a frequency distribution graph for radon concentration. It has been observed that concentration in 25% of the samples lie between 0-2 BqL^{-1}, in 41% samples it lies between 2-4 BqL^{-1} and in 34% samples it lies between 4-10 BqL^{-1}.

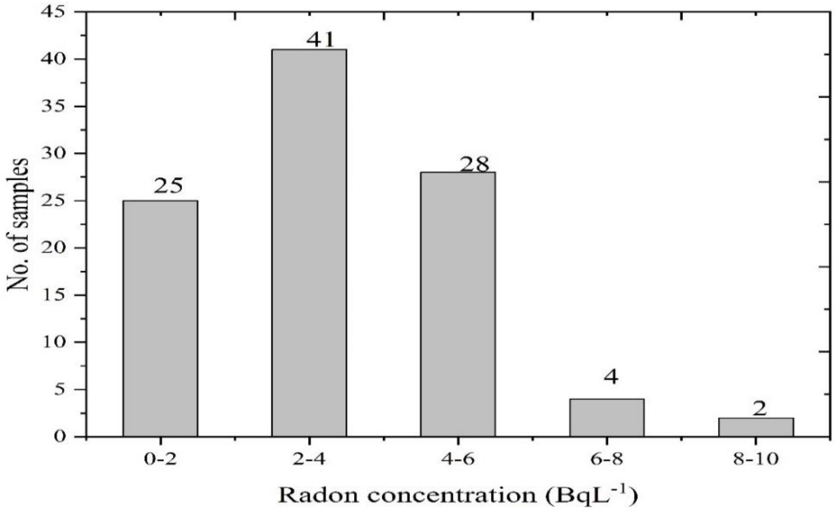

Figure 5.4: Frequency distribution of radon concentration in Moga district

5.4.3 Correlation between Radon Concentration in Underground Water with Depth (in Meters)

From the measured values, a weak correlation ($R^2 = 0.01$) has been found for the radon concentration in groundwater samples with the depth of well (24-183 meter) as shown in Figure 5.5.

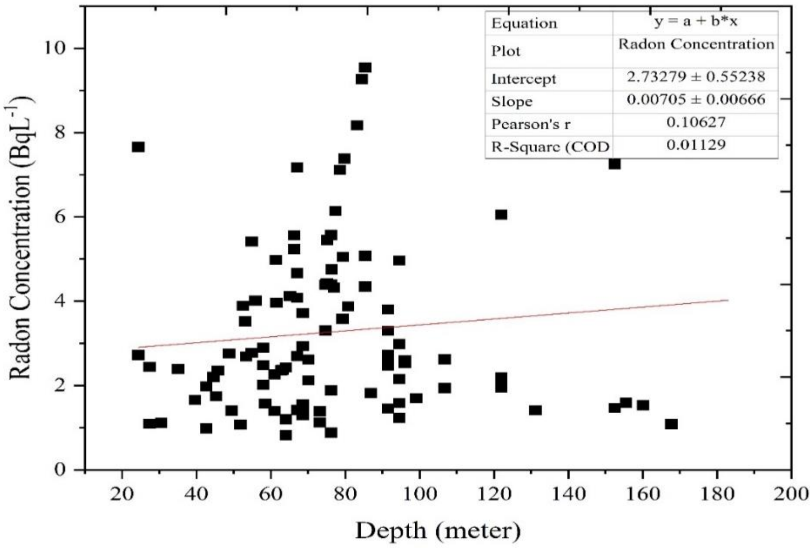

Figure 5.5: Correlation of radon concentration in under groundwater with depth (in metres) in studied area

Since the source of underground water in studied is mainly the unconfined aquifer, the increase in concentration of dissolved radon with depth can be attributed to the higher solubility under greater hydrostatic pressure and longer time spent by water in contact with surrounding earth while seeping to the greater depths. The higher concentration of radon in samples of groundwater from depths below 60 m may also be due to the greater radioactivity in rocks of confined aquifers in the studied area.

A normality test using Origin Lab 8.5, at a significance level of 0.01, revealed that the surface water data was not significantly drawn from a normally distributed population although the groundwater data was significantly drawn from a normally distributed population. Table 5.3 shows a comparative descriptive statistical analysis of drinking water from surface and underground water (100 samples each) using IBM-SPSS.

5.4.4 Comparison between Radon Concentration in Surface Water with Underground Water

The minimum and maximum radon concentration in surface water and groundwater ranged from 0.17 – 9.84 BqL^{-1} and 1.40 – 9.54 BqL^{-1}, respectively with a standard deviation of 1.62 Bqm^{-3} and 1.66 BqL^{-1}, respectively. The mean radon concentration (± SE) for surface and groundwater were found to be 2.23 ± 0.16 BqL^{-1} and 4.37 ± 0.29 BqL^{-1} respectively. Table 5.3 shows the descriptive statistics using SPSS, from which it has been found that the underground water sources have higher levels for radon than surface water sources and the same has been shown in Figure 5.6. This may be because of the reason that underground water directly encounters U-238 rich rocks that release radon in water and cannot escape to atmosphere (Skeppstorm et al., 2007; Voronov et al., 2004). Also, radon levels are generally higher in underground water as compared to surface water because of presence of granite, sand and gravels in the bedrock (Stojkovic et al., 2015). In contrast, radon in surface water samples can easily escape to atmosphere due to aeration and agitation in water. The variation in radon concentration in surface water and underground water depends upon geological factors and topography (Fonollosa et al., 2016; Parshad et al., 2018). The results show that the average radon concentration in underground water samples is 4.37 ± 0.29 BqL^{-1} which is higher than the average concentration of radon in surface water sources is 2.23 ± 0.16 BqL^{-1}.

For surface water, a positive value of 2.06 for skewness shows that the distribution is highly skewed and a high kurtosis value of 6.53 shows that the distribution is leptokurtic. Compared to a normal distribution, its tails are longer and fatter and often its central peak is higher and sharper. Similarly, for groundwater, a value of 0.73 for skewness shows that the data is moderately skewed while a negative value of kurtosis indicate that a distribution is platykurtic that is, the distribution is flat and has thin tails.

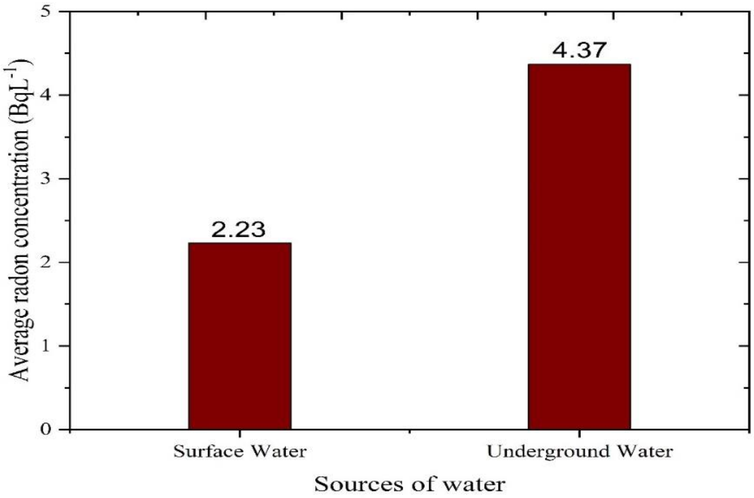

Figure 5.6: Inter comparison for radon concentration between surface water and underground water in studied area

It has been found that the borewell water samples have higher radon concentration than submersible and handpump samples for both the districts (Figure 5.7).

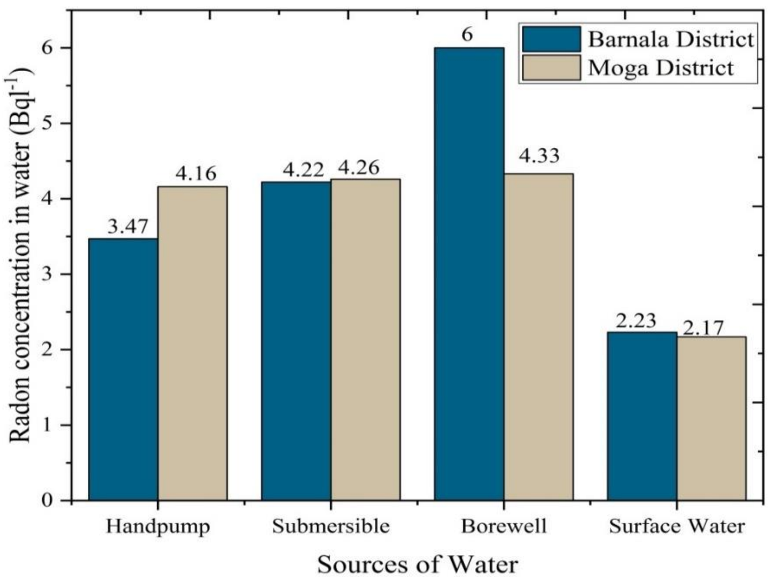

Figure 5.7: Comparison between radon concentration in water samples collected from different sources of underground water sources in studied area

Table 5.4 shows the comparison of measured radon concentration in water samples in the studied area with worldwide values and has been found to be lesser than these values. The average value in the studied area is slightly more than the 2.72 BqL^{-1} in Bathinda district, (Mehra et al., 2015) but less than 3.63 BqL^{-1} in Faridkot district, 4.7 BqL^{-1}in Mansa and Muktsar district, Punjab, India (Mehra et al., 2015). The measured radon concentration (0.17 to 9.84 BqL^{-1}) in the studied area are lower than that of Cyprus (0.3 to 20 BqL^{-1}) (Nikolpoulos et al., 2008), Greece (0.8 to 20 BqL^{-1}) (Nikolpoulos et al., 2008), Brazil (0.95 to 36) (Marques et al., 2004), Turkey (1.46 to 53.64 BqL^{-1}) (Tarim et al., 2010), South Korea (300 BqL^{-1}) (Cho et al., 2014), Iran (0.064 to 49.1 BqL^{-1}) (Banish et al., 2011), Sweden (5 to 3470 BqL^{-1}) (Salih et al., 2004).

5.4 CONCLUSION

- The measured values of radon concentration in all the samples have been found to be below the recommended limit of 100 BqL^{-1} by WHO (2004), 11 BqL^{-1} by USEPA, 1991 and within the range of 4-40 BqL^{-1} by UNSCEAR, 2008.
- The annual effective dose due to ingestion and inhalation for infants has been found to be higher than the dose received by children and adults, while overall dose is well below the safe limit of 100 μSvy^{-1} recommended by WHO (2008).
- The underground water samples have slightly higher values of radon concentration than in surface water is because the radon easily escapes from surfaces while as underground water retains.
- A weak positive correlation has been observed between radon concentration in underground water with depth. Since the source of underground water in studied is mainly the unconfined aquifer, the increase in concentration of dissolved radon with depth can be attributed to the higher solubility under greater hydrostatic pressure and longer time spent by water in contact with surrounding earth while seeping to the greater depths. The higher concentration of radon in samples of groundwater from depths below 60 m may also be due to the greater radioactivity in rocks of confined aquifers in the studied area.
- As the measured values in the studied area are below the recommended safe limits, so it can be concluded that radon in water may not pose any significant radiological risk to the public.

Table 5.1: Radon concentration and Annual effective dose due to ingestion and inhalation for various age groups in Barnala district.

S. No.	Place	Source	$C_{liq} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17 yr)	Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17yr)
1	Dhanula	SW	2.94 ± 0.31	27.19 ± 2.84	25.87 ± 2.7	23.32 ± 2.43	19.8 ± 2.06	15.84 ± 1.65	11.28 ±1.18
2		UG	8.17 ± 0.21	75.49 ± 1.94	71.82 ± 1.72	64.74 ± 1.66	54.96 ± 1.41	43.99 ± 1.13	31.13 ± 0.8
3		UG	4.39 ± 0.37	40.59 ± 3.38	38.62 ± 3.22	34.81 ± 2.9	29.55 ± 2.46	23.65 ± 1.97	16.83 ± 1.4
4		SW	9.84 ± 0.56	90.89 ± 5.14	86.48 ± 4.89	77.94 ± 4.41	66.17 ± 3.74	52.95 ± 2.99	37.7 ± 2.13
5	Bhaduar	UG	9.54 ± 0.55	88.16 ± 5.1	83.89 ± 4.85	75.6 ± 4.37	64.19 ± 3.71	51.37 ± 2.97	36.57 ± 2.11
6		UG	9.27 ± 0.47	85.65 ± 4.34	81.5 ± 4.13	73.46 ± 3.72	62.36 ± 3.16	49.91 ± 2.53	35.53 ± 1.8
7		SW	5.65 ± 0.44	52.19 ± 4.02	49.66 ± 3.82	44.76 ± 3.45	38 ± 2.92	30.41 ± 2.34	21.65 ± 1.67
8		SW	4.09 ± 0.37	37.81 ± 3.42	35.98 ± 3.26	32.42 ± 2.94	27.53 ± 2.49	22.03 ± 1.99	15.68 ± 1.42
9	Jangiana	UG	6.05 ± 0.43	55.9 ± 4	53.19 ± 3.81	47.94 ± 3.43	40.7 ± 2.91	32.57 ± 2.33	23.19 ± 1.66
10		UG	5.45 ± 0.34	50.36 ± 3.14	47.92 ± 2.99	43.19 ± 2.69	36.66 ± 2.28	29.34 ± 1.83	20.89 ± 1.3
11		SW	7.47 ± 0.49	69.05 ± 4.5	65.7 ± 4.28	59.22 ± 3.86	50.27 ± 3.27	40.23 ± 2.62	28.64 ± 1.87
12		SW	1.63 ± 0.22	15.07 ± 2.07	14.34 ± 1.97	12.92 ± 1.77	10.97 ± 1.5	8.78 ± 1.2	6.25 ± 0.86
13	Channa	UG	7.17 ± 0.48	66.28 ± 4.44	63.06 ± 4.23	56.84 ± 3.81	48.25 ± 3.23	38.62 ± 2.59	27.49 ± 1.84
14		UG	6.14 ± 0.39	56.73 ± 3.6	53.98 ± 3.43	48.65 ± 3.09	41.31 ± 2.62	33.06 ± 2.1	23.53 ± 1.49
15		SW	4.98 ± 0.42	46.04 ± 3.89	43.81 ± 3.7	39.49 ± 3.33	33.52 ± 2.82	26.83 ± 2.26	19.1 ± 1.61

S. No.	Place	Source	$C_{liq} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17 yr)	Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17yr)
16		SW	2.39 ± 0.41	22.06 ± 3.82	20.99 ± 3.64	18.92 ± 3.28	16.06 ± 2.78	12.85 ± 2.23	9.15 ± 1.59
17	Nainewal	SW	2.75 ± 0.3	25.42 ± 2.77	24.19 ± 2.63	21.8 ± 2.37	18.51 ± 2.01	14.81 ± 1.61	10.54 ± 1.15
18		UG	7.25 ± 0.47	66.98 ± 4.36	63.74 ± 4.15	57.44 ± 3.74	48.77 ± 3.17	39.03 ± 2.54	27.78 ± 1.81
19		UG	7.11 ± 0.42	65.7 ± 3.88	62.51 ± 3.69	56.34 ± 3.33	47.83 ± 2.82	38.26 ± 2.26	27.25 ± 1.61
20		SW	1.41 ± 0.35	13.05 ± 3.21	12.41 ± 3.05	11.19 ± 2.75	9.5 ± 2.33	7.6 ± 1.87	5.41 ± 1.33
21	Saina	UG	7.66 ± 0.49	70.74 ± 4.49	67.31 ± 4.27	60.66 ± 3.85	51.5 ± 3.27	41.22 ± 2.62	29.34 ± 1.86
22		UG	7.38 ± 0.37	68.19 ± 3.42	64.88 ± 3.25	54.48 ± 2.93	49.65 ± 2.48	39.73 ± 1.99	28.28 ± 1.42
23		SW	5.85 ± 0.45	54.08 ± 4.17	51.46 ± 3.97	46.38 ± 3.58	39.38 ± 3.03	31.51 ± 2.43	22.43 ± 1.73
24		SW	2.22 ± 0.32	20.49 ± 2.96	19.49 ± 2.82	17.57 ± 2.54	14.92 ± 2.15	11.94 ± 1.73	8.5 ± 1.23
25	Tapa	UG	2.48 ± 0.28	22.93 ± 2.59	21.82 ± 2.46	19.67 ± 2.22	16.7 ± 1.88	13.36 ± 1.51	9.51 ± 1.07
26		UG	2.37 ± 0.31	21.9 ± 2.86	20.84 ± 2.73	18.78 ± 2.46	15.94 ± 2.08	12.76 ± 1.67	9.08 ± 1.19
27		SW	1.29 ± 0.21	11.94 ± 1.9	11.36 ± 1.81	10.24 ± 1.63	8.69 ± 1.38	6.95 ± 1.11	4.95 ± 0.79
28		SW	0.92 ± 0.16	8.54 ± 1.48	8.13 ± 1.41	7.33 ± 1.27	6.22 ± 1.08	4.98 ± 0.86	3.54 ± 0.61
29	Draj	UG	3.8 ± 0.34	35.12 ± 3.18	33.41 ± 3.02	30.11 ± 2.72	25.57 ± 2.31	20.46 ± 1.85	14.57 ± 1.32
30		UG	4.12 ± 0.48	38.07 ± 4.44	36.22 ± 4.22	32.65 ± 3.8	27.72 ± 3.22	22.18 ± 2.58	15.79 ± 1.84
31		SW	1.44 ± 0.25	13.26 ± 2.3	12.62 ± 2.19	11.37 ± 1.97	9.66 ± 1.67	7.73 ± 1.34	5.5 ± 0.96

S. No.	Place	Source	$C_{liq} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17 yr)	Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17yr)
32		SW	1.07 ± 0.23	9.89 ± 2.12	9.41 ± 2.01	8.48 ± 1.82	7.2 ± 1.54	5.76 ± 1.23	4.1 ± 0.88
33	Mehta	UG	1.88 ± 0.22	17.36 ± 2.07	16.52 ± 1.97	14.89 ± 1.77	12.64 ± 1.5	10.12 ± 1.2	7.2 ± 0.86
34		UG	1.74 ± 0.17	16.08 ± 1.57	15.3 ± 1.49	13.79 ± 1.35	11.71 ± 1.14	9.37 ± 0.92	6.67 ± 0.65
35		SW	3.19 ± 0.3	29.46 ± 2.79	28.03 ± 2.65	25.27 ± 2.39	21.45 ± 2.02	17.17 ± 1.62	12.22 ± 1.16
36		SW	0.97 ± 0.11	8.97 ± 1.06	8.54 ± 1.01	7.7 ± 0.91	6.53 ± 0.77	5.23 ± 0.62	3.72 ± 0.44
37	Dhurkot	UG	1.41 ± 0.2	13.07 ± 1.81	12.43 ± 1.72	11.2 ± 1.55	9.51 ± 1.32	7.61 ± 1.05	5.42 ± 0.75
38		UG	1.57 ± 0.36	14.51 ± 3.33	13.8 ± 3.17	12.44 ± 2.85	10.56 ± 2.42	8.45 ± 1.94	6.02 ± 1.38
39		SW	0.25 ± 0.08	2.28 ± 0.73	2.17 ± 0.69	1.96 ± 0.63	1.66 ± 0.53	1.33 ± 0.43	0.95 ±0.3
40		SW	0.34 ± 0.1	3.14 ± 0.93	2.98 ± 0.88	2.69 ± 0.79	2.28 ± 0.67	1.83 ± 0.54	1.3 ± 0.38
41	Sanghere	SW	0.24 ± 0.07	2.2 ± 0.69	2.09 ± 0.66	1.89 ± 0.59	1.6 ± 0.5	1.28 ± 0.4	0.91 ± 0.29
42		SW	3.15 ± 0.32	29.14 ± 2.94	27.73 ± 2.8	24.99 ± 2.52	21.22 ± 2.14	16.98 ± 1.71	12.09 ± 1.22
43		UG	4.98 ± 0.46	46.02 ± 4.25	43.78 ± 4.04	39.46 ± 3.65	33.5 ± 3.09	26.81 ± 2.48	19.09 ± 1.76
44		UG	5.57 ± 0.59	51.44 ± 5.41	48.95 ± 5.15	44.11 ± 4.64	37.45 ± 3.93	29.97 ± 3.15	21.34 ± 2.24
45	Wajidke	SW	0.28 ± 0.08	2.56 ± 0.78	2.44 ±0.74	2.2 ± 0.67	1.86 ± 0.57	1.49± 0.46	1.06 ± 0.32
46		UG	5.23 ± 0.49	48.33 ± 4.53	45.98 ± 4.31	41.44 ± 3.88	35.18 ± 3.29	28.16 ± 2.64	20.04 ± 1.88
47		UG	4.34 ± 0.37	40.07 ± 3.41	38.13 ± 3.25	34.36 ± 2.93	29.18± 2.48	23.35 ± 1.99	16.62 ± 1.42

S. No.	Place	Source	C_{liq} ± σ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17 yr)	Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17yr)
48		SW	4.73 ± 0.38	43.7 ± 3.54	41.58 ±3.36	37.48 ± 3.03	31.82 ± 2.57	25.46 ± 2.06	18.13 ± 1.47
49	Sehra	UG	1.46 ± 0.23	13.45 ± 2.1	12.79 ± 2	11.53 ± 1.8	9.79 ± 1.52	7.83 ± 1.22	5.58 ± 0.87
50		UG	1.4 ± 0.21	13.94 ± 1.94	12.31 ± 1.85	11.09 ± 1.66	9.42 ± 1.41	7.54 ± 1.13	5.37 ± 0.8
51		SW	0.32 ± 0.07	2.95 ± 0.68	2.81 ± 0.65	2.53 ± 0.58	2.15 ± 0.49	1.72 ± 0.4	1.22 ± 0.28
52		SW	0.17 ± 0.08	1.54 ± 0.71	1.47 ± 0.67	1.32 ± 0.61	1.12 ± 0.52	0.9 ± 0.41	0.64 ± 0.29
53	Chuhanke	SW	3.39 ± 0.32	31.29 ±2.97	29.78 ± 2.83	26.84 ± 2.55	22.78 ± 2.16	18.23 ± 1.73	12.98 ± 1.23
54		UG	2.35 ± 0.29	21.71 ± 2.68	20.66 ± 2.55	18.62 ± 2.3	15.81 ± 1.95	12.65 ± 1.56	9.01 ± 1.11
55		UG	2.15 ± 0.26	19.87 ± 2.38	18.91 ± 2.27	17.04 ± 2.05	14.47 ± 1.73	11.58 ± 1.39	8.24 ± 0.99
56		SW	0.75 ± 0.07	6.96 ± 0.66	6.62 ± 0.63	5.97 ± 0.56	5.07 ± 0.48	4.06 ± 0.38	2.89 ± 0.27
57	Barnala	SW	1.34 ± 0.18	12.36 ± 1.68	11.76 ± 1.59	10.6 ± 1.44	9 ± 1.22	7.2 ± 0.98	5.13 ±0.7
58		UG	1.82 ± 0.22	16.8 ± 2.05	15.98 ± 1.95	14.41 ± 1.75	12.23 ± 1.49	9.79 ± 1.19	6.97 ± 0.85
59		UG	2.2 ± 0.26	20.33 ± 2.4	19.34 ± 2.29	17.43 ± 2.06	14.8 ± 1.75	11.84 ± 1.4	8.43 ± 1
60		SW	2.35 ± 0.21	21.71 ± 1.97	20.66 ± 1.88	18.62 ± 1.69	15.81 ± 1.43	12.65 ± 1.15	9.01 ± 0.82
61	Kurar	SW	0.23 ± 0.1	2.16 ± 0.97	2.05 ± 0.92	1.85 ± 0.83	1.57 ± 0.7	1.26 ± 0.56	0.9 ± 0.4
62		SW	0.27 ± 0.1	2.54 ± 0.88	2.42 ± 0.84	2.18 ± 0.76	1.85 ± 0.64	1.48 ± 0.52	1.05 ± 0.37
63		UG	2.36 ± 0.38	21.81 ± 3.51	20.75 ± 3.34	18.7 ± 3.01	15.88 ± 2.55	12.71 ± 2.05	9.04 ± 1.46
64		UG	2.42 ± 0.26	22.4 ± 2.38	21.31 ± 2.27	19.21 ± 2.05	16.31 ± 1.73	13.05 ± 1.39	9.29 ± 0.99

S. No.	Place	Source	$C_{liq} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17 yr)	Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17yr)
65	Mehal Kalan	SW	0.2 ± 0.08	1.87 ± 0.77	1.78 ± 0.73	1.6 ± 0.66	1.36 ± 0.56	1.09 ± 0.45	0.78 ±0.32
66		SW	4.02 ± 0.16	37.15 ± 1.48	35.35 ± 1.41	31.86 ± 1.27	27.05 ± 1.08	21.65 ± 0.86	15.41 ± 0.61
67		UG	5.56 ± 0.42	51.37 ± 3.88	48.88 ± 3.69	44.06 ± 3.33	37.4 ± 2.82	29.93 ± 2.26	21.31 ± 1.61
68		UG	5.41 ± 0.38	50 ± 3.55	47.58 ± 3.37	42.88 ± 3.04	36.41± 2.58	29.13 ± 2.07	20.74 ± 1.47
69	BheniDesa	UG	3.58 ± 0.33	33.09 ± 3.09	31.49 ± 2.94	28.38 ± 2.65	24.09 ± 2.25	19.28 ± 1.8	13.73 ± 1.28
70		UG	3.89 ± 0.42	35.94 ± 3.88	34.2 ± 3.69	30.82 ± 3.33	26.17 ± 2.82	20.94 ± 2.26	14.91 ± 1.61
71		SW	2.15 ± 0.22	19.87 ± 1.99	18.91 ± 1.9	17.04 ± 1.71	14.47 ± 1.45	11.58 ± 1.16	8.24 ± 0.83
72		SW	0.55 ± 0.11	5.09 ± 1.04	4.84 ± 0.99	4.36 ± 0.89	3.7 ± 0.75	2.96 ± 0.6	2.11 ± 0.43
73	Dangarh	UG	3.3 ± 0.32	30.45 ± 2.98	28.97 ± 2.84	26.11 ± 2.56	22.17 ± 2.17	17.74 ± 1.74	12.63 ± 1.24
74		UG	3.52 ± 0.36	32.52 ± 3.33	30.95 ± 3.17	27.89 ± 2.85	23.68 ± 2.42	18.95 ± 1.94	13.49 ± 1.38
75		SW	2.25 ± 0.19	20.81 ± 1.79	19.8 ± 1.7	17.84 ± 1.53	15.15 ± 1.3	12.12 ± 1.04	8.63 ± 0.74
76		SW	0.56 ± 0.06	5.2 ± 0.59	4.95 ± 0.56	4.46 ± 0.5	3.79 ± 0.43	3.03 ± 0.34	2.16 ± 0.24
77	AspalKala	UG	4.08 ± 0.35	37.69 ± 3.26	35.86 ± 3.1	32.32 ± 2.79	27.44 ± 2.37	21.96 ± 1.9	15.63 ± 1.35
78		UG	4.01 ± 0.32	37.05 ± 2.96	35.26 ± 2.81	31.78 ± 2.54	26.98 ± 2.15	21.59 ± 1.72	15.37 ± 1.23
79		SW	1.13 ± 0.23	10.47 ± 2.17	9.96 ± 2.06	8.97 ± 1.86	7.62 ± 1.58	6.1 ± 1.26	4.34 ± 0.9
80		SW	2.91 ± 0.16	26.91 ± 1.51	25.61 ± 1.44	23.08 ± 1.3	19.59 ± 1.1	15.68 ± 0.88	11.16 ± 0.63

S. No.	Place	Source	$C_{liq} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17 yr)	Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17yr)
81	Attar Singh Wala	UG	3.88 ±0.23	35.81 ± 2.13	34.07 ± 2.02	30.71 ± 1.82	26.07 ± 1.54	20.86 ± 1.24	14.85± 0.88
82		UG	3.96 ± 0.25	36.59 ± 2.31	34.82 ± 2.2	31.38 ± 1.98	26.64 ± 1.68	21.32 ± 1.35	15.18 ± 0.96
83		SW	2.59 ± 0.32	23.9 ± 2.93	22.74 ± 2.79	20.5 ± 2.51	17.4 ± 2.13	13.93 ± 1.71	9.91 ± 1.22
84		SW	1.58 ± 0.47	14.58 ±4.37	13.87 ± 4.16	12.5 ± 3.75	10.61 ± 3.18	8.49 ± 2.55	6.05 ± 1.81
85	Handiaya	UG	4.35 ± 0.37	40.18 ± 3.42	38.24 ± 3.26	34.46 ± 2.94	29.26 ± 2.49	23.41 ± 1.99	16.67 ± 1.42
86		UG	4.42 ± 0.39	40.84 ± 3.6	38.86 ± 3.43	35.02 ± 3.09	29.74 ± 2.62	23.8 ± 2.1	16.94 ± 1.49
87		SW	2.75 ± 0.5	25.44 ± 4.6	24.21 ± 4.37	21.82 ± 3.94	18.52 ± 3.34	14.82 ± 2.68	10.55 ± 1.91
88		SW	1.37 ± 0.3	12.66 ± 2.81	12.05 ± 2.67	10.86 ± 2.41	9.22 ± 2.04	7.38 ± 1.64	5.25 ± 1.16
89	Harigarh	SW	4.12 ± 0.36	38.07 ± 3.31	36.22 ± 3.15	32.65 ± 2.84	27.72 ± 2.41	22.18 ± 1.93	15.79 ± 1.37
90		UG	4.66 ± 0.38	43.08 ± 3.54	40.99 ± 3.36	36.95 ± 3.03	31.37 ± 2.57	25.1 ± 2.06	17.87 ± 1.47
91		UG	4.75 ± 0.4	43.89 ± 3.7	41.76 ± 3.52	37.64 ± 3.17	31.96 ± 2.69	25.57 ± 2.15	18.2 ± 1.53
92		SW	2.01 ± 0.28	18.59 ± 2.58	17.69 ± 2.46	15.94 ± 2.21	13.53 ± 1.88	10.83 ± 1.5	7.71 ± 1.07
93	Kattu	UG	4.39 ± 0.1	40.54 ± 0.04	38.58 ± 0.04	34.77 ± 0.03	29.52 ± 0.03	23.62 ± 0.02	16.82 ± 0.02
94		UG	4.32 ± 0.01	39.92 ± 0.09	37.98 ± 0.09	34.23 ± 0.08	29.06 ± 0.07	23.26 ± 0.05	16.56 ± 0.04
95		SW	3.67 ± 0.01	33.9 ± 0.03	32.26 ± 0.03	29.07 ± 0.03	24.68 ± 0.02	19.75 ± 0.02	14.06 ± 0.01
96		SW	2.17 ± 0.01	20.02 ± 0.02	19.04 ± 0.02	17.16 ± 0.02	14.57 ± 0.01	11.66 ± 0.01	8.3 ± 0.01

S. No.	Place	Source	$C_{liq} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17 yr)	Infants (0-2 yr)	Children (8-12 yr)	Adults (above 17yr)
97	Diwana	UG	4.96 ± 0.01	45.86 ± 0.05	43.64 ± 0.04	39.33 ± 0.04	33.39 ± 0.03	26.72 ± 0.03	19.02 ± 0.02
98		UG	5.05 ± 0.31	46.66 ± 2.86	44.4 ± 2.73	40.02 ± 2.46	33.97 ± 2.08	27.19 ± 1.67	19.35 ± 1.19
99		SW	3.63 ± 0.01	33.58 ± 0.03	31.96 ± 0.03	28.8 ± 0.03	24.45 ± 0.02	19.57 ± 0.02	13.93 ± 0.01
100		SW	1.97 ± 0.01	18.24 ± 0.02	17.35 ± 0.02	15.64 ± 0.02	13.28 ± 0.01	10.63 ± 0.01	7.56 ± 0.01
Minimum			0.17 ± 0.01	1.54 ± 0.09	1.47 ± 0.09	1.32 ± 0.08	1.12 ± 0.07	0.9 ± 0.05	0.64 ± 0.04
Maximum			9.84 ± 0.59	90.89 ± 5.41	86.48 ± 5.15	77.94 ± 4.64	66.17 ± 3.93	52.95 ± 3.15	37.7 ± 2.24
Average			3.37 ± 0.29	31.13 ± 2.68	29.62 ± 2.53	26.69 ± 2.3	22.66 ± 1.95	18.14 ± 1.56	12.91 ± 1.11
Standard Deviation			2.27	20.92	19.91	17.94	15.23	12.18	8.67
Kurtosis			0.22± -0.82	0.22 ± -0.82	0.22 ± -0.82	0.22 ± -0.82	0.22 ± -0.82	0.22 ± -0.82	0.22 ± -0.82
Skewness			0.75± -0.04	0.75 ± -0.04	0.75 ± -0.01	0.75 ± -0.04	0.75 ± -0.04	0.75 ± -0.04	0.75 ± -0.04
1st Quartile			1.57 ± 0.19	14.52 ± 1.79	13.82 ± 1.62	12.46 ± 1.54	10.57 ± 1.3	8.46 ± 1.05	6.02 ± 0.74
2nd Quartile			3.05 ± 0.31	28.17 ± 2.82	26.8 ± 2.66	24.16 ± 2.42	20.51 ± 2.05	16.41 ± 1.64	11.68 ± 1.17
3rd Quartile			4.71 ± 0.38	43.55 ± 3.54	41.43 ± 3.37	37.34 ± 3.04	31.71 ± 2.58	25.37 ± 2.06	18.06 ± 1.47

Table 5.2: Radon concentration and Annual effective dose due to ingestion and inhalation for various age groups in Moga district

S. No	Place	Types	$C_{liq} \pm \sigma$	Annual Effective Dose due to Inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
			(BqL^{-1})	Infants	Children	Adults	Infants	Children	Adults
1	Bhagapurana	UG	3.11 ± 0.29	28.70 ± 2.65	27.31 ± 2.00	24.61± 2.27	20.90 ± 1.93	16.72 ± 1.55	11.90 ± 1.10
2		SW	1.94 ± 0.15	17.91 ± 1.35	17.04 ± 1.46	15.36 ± 1.15	13.04 ± 0.98	10.43 ± 0.78	7.43 ± 0.56
3		SW	0.88 ± 0.09	8.11 ± 0.87	7.72 ± 0.83	6.96 ± 0.75	5.91 ± 0.64	4.73 ± 0.51	3.36 ± 0.36
4		UG	2.68 ± 0.26	24.81 ± 2.36	23.60 ± 2.25	21.27 ± 2.03	18.06 ± 1.72	14.45 ± 1.38	10.29 ± 0.98
5	Marhi	UG	8.39 ± 0.51	77.56 ± 4.70	73.80 ± 4.47	66.52 ± 4.03	56.47 ± 3.41	45.19 ± 2.74	32.17 ± 1.95
6		SW	8.41 ± 0.49	77.67 ± 4.49	73.90 ± 4.27	66.60 ± 3.85	56.55 ± 3.27	45.25 ± 2.62	32.21 ± 1.86
7		SW	5.07 ±0.38	46.87 ± 3.56	44.59 ± 3.38	40.19 ± 3.05	34.12 ± 2.59	27.31 ± 2.07	19.44 ± 1.48
8		UG	7.03 ± 0.45	64.92 ± 4.19	61.77 ± 3.99	55.67 ± 3.60	47.27 ± 3.05	37.82 ± 2.44	26.93 ± 1.74
9	Rode	UG	3.72 ± 0.31	34.35 ± 2.88	32.68 ± 2.74	29.45 ± 2.47	25.01 ± 2.09	20.01 ± 1.68	14.25 ± 1.19
10		SW	1.95 ± 0.18	18.03 ± 1.63	17.16 ± 1.56	15.46 ± 1.40	13.13 ± 1.19	10.51 ± 0.95	7.48 ± 0.68
11		SW	1.08 ± 0.20	10.02 ± 1.87	9.54 ± 1.78	8.60 ± 1.60	7.30 ± 1.36	5.84 ± 1.09	4.16 ± 0.78
12		UG	4.18 ± 0.15	38.60 ± 1.43	36.73 ± 1.36	33.10 ± 1.23	28.11± 1.04	22.49 ± 0.83	16.01 ± 0.59
13	Khokhrana	UG	4.57 ± 0.45	42.19 ± 4.15	40.14 ± 3.95	36.18 ± 3.56	30.72 ± 3.02	24.58 ± 2.42	17.50 ± 1.72
14		SW	2.70 ± 0.30	24.91 ± 2.76	23.70 ± 2.62	21.36 ± 2.36	18.14 ± 2.00	14.51 ± 1.61	10.33 ± 1.14
15		SW	1.53 ± 0.11	14.11± 1.02	13.43 ± 0.97	12.10 ± 0.87	10.28 ± 0.74	8.22 ± 0.59	5.85 ± 0.42
16		UG	4.11 ± 0.25	37.95 ± 2.29	36.11 ± 2.18	32.55 ± 1.97	27.63 ± 1.67	22.11 ± 1.34	15.74 ± 0.95
17	Nathuwala	UG	4.95 ± 0.34	45.70± 3.17	43.49 ± 3.01	39.20 ± 2.72	33.28 ± 2.30	26.63 ± 1.84	18.96 ± 1.31
18		SW	2.93 ± 0.15	27.11± 1.37	25.79 ± 1.30	23.25 ± 1.17	19.74 ± 0.99	15.79 ± 0.80	11.24 ± 0.57
19		SW	1.47 ± 0.18	13.54 ± 1.68	12.88 ± 1.59	11.61 ± 1.44	9.86 ± 1.22	7.89 ± 0.98	5.62 ± 0.70
20		UG	4.62 ± 0.30	42.72 ± 2.81	40.65 ± 2.67	36.64 ± 2.41	31.11 ± 2.04	24.89 ± 1.64	17.72 ± 1.16
21	Samalsar	UG	6.41 ± 0.48	59.22 ± 4.43	56.35 ± 4.22	50.79 ± 3.80	43.12 ± 3.22	34.51 ± 2.58	24.56 ± 1.84
22		SW	3.71 ± 0.33	34.31 ± 3.03	32.65 ± 2.89	29.43 ± 2.60	24.98 ± 2.20	19.99 ± 1.77	14.23 ± 1.26

S. No	Place	Types	$C_{liq} \pm \sigma$ (BqL^{-1})	Annual Effective Dose due to Inhalation (μSvy^{-1}) Infants	Children	Adults	Annual effective dose due to ingestion (μSvy^{-1}) Infants	Children	Adults
23		SW	2.62 ± 0.25	24.21 ± 2.35	23.04 ± 2.24	20.76 ± 2.02	17.63 ± 1.71	14.11 ± 1.37	10.04 ± 0.98
24		UG	6.01 ± 0.27	55.50 ± 2.51	52.81 ± 2.39	47.60 ± 2.15	40.41 ± 1.82	32.34 ± 1.46	23.02 ± 1.04
25	Smadh Bhai	UG	4.39 ± 0.28	40.61 ± 2.60	38.64 ± 2.47	34.82 ± 2.23	29.56 ± 1.89	23.66 ± 1.52	16.84 ± 1.08
26		SW	2.72 ± 0.20	25.13 ± 1.83	23.92 ± 1.74	21.55 ± 1.57	18.30 ± 1.33	14.64 ± 1.07	10.43 ± 0.76
27		SW	1.09 ± 0.09	10.06 ± 0.86	9.58 ± 0.82	8.63 ± 0.74	7.33 ± 0.63	5.86 ± 0.50	4.17 ± 0.36
28		UG	4.06 ± 0.16	37.47 ± 1.45	35.65 ± 1.38	32.13 ± 1.24	27.28 ± 1.05	21.83 ± 0.84	15.54 ± 0.60
29	Chrik	UG	3.80 ± 0.31	35.10 ± 2.88	33.39 ± 2.74	30.10 ± 2.47	25.55 ± 2.09	20.45 ± 1.68	14.56 ± 1.19
30		SW	2.76 ± 0.22	25.47 ± 2.00	24.24 ± 1.91	21.85 ± 1.72	18.55 ± 1.46	14.84 ±1.17	10.57 ± 0.83
31		SW	2.01 ± 0.21	18.61 ± 1.97	17.70 ± 1.88	15.96 ± 1.69	13.55 ± 1.43	10.84 ± 1.15	7.72 ± 0.82
32		UG	3.2 ± 0.23	29.81 ± 2.13	28.37 ± 2.02	25.57 ± 1.82	21.71 ± 1.55	17.37 ± 1.24	12.37 ± 0.88
33	Nihal Singhwala	UG	5.79 ± 0.19	53.52 ± 1.75	50.92 ± 1.66	45.90 ± 1.50	38.97 ± 1.27	31.18 ± 1.02	22.20 ± 0.72
34		SW	3.30 ± 0.23	30.49 ± 2.15	29.01 ± 2.04	26.15 ± 1.84	22.20 ± 1.56	17.77 ± 1.25	12.65 ± 0.89
35		SW	1.98 ± 0.14	18.27 ± 1.30	17.38 ± 1.23	15.67 ± 1.11	13.30 ± 0.94	10.64 ± 0.75	7.58 ± 0.54
36		UG	5.09 ± 0.23	47.04 ± 2.10	44.76 ± 2.00	40.34 ± 1.80	34.25 ± 1.52	27.41 ± 1.22	19.51 ± 0.87
37	Himatpura	UG	4.91 ± 0.17	45.39 ± 1.53	43.19 ± 1.46	38.92 ± 1.31	33.04 ± 1.11	26.44 ± 0.89	18.82 ± 0.64
38		SW	2.4 ± 0.12	22.88 ± 1.07	21.77 ± 1.02	19.62 ± 0.92	16.66 ± 0.78	13.33 ± 0.62	9.49 ± 0.44
39		SW	1.39 ± 0.10	12.83 ± 0.97	12.21 ± 0.92	11.00 ± 0.83	9.34 ± 0.70	7.48 ± 0.56	5.32 ± 0.40
40		UG	4.81 ± 0.13	44.45 ± 1.24	42.30 ± 1.18	38.12 ± 1.07	32.36 ± 0.90	25.90 ± 0.72	18.44 ± 0.52
41	Dharamkot	UG	4.64 ± 0.18	42.90 ± 1.68	40.82 ± 1.59	36.79 ± 1.44	31.23 ± 1.22	25.00 ± 0.98	17.79 ± 0.70
42		SW	2.98 ± 0.29	27.52 ± 2.64	26.19 ± 2.51	23.60 ± 2.27	20.04 ± 1.92	16.03 ± 1.54	11.41 ± 1.10
43		SW	1.70 ± 0.12	15.71 ± 1.10	14.95 ± 1.05	13.47 ± 0.94	11.44 ± 0.80	9.15 ± 0.64	6.52 ± 0.46

S. No	Place	Types	$C_{liq} \pm \sigma$ (BqL^{-1})	Annual Effective Dose due to Inhalation (µSvy^{-1})			Annual effective dose due to ingestion (µSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
44		UG	4.08 ± 0.11	37.74 ± 1.04	35.91 ± 0.99	32.36 ± 0.89	27.48 ± 0.75	21.99 ± 0.60	15.65 ± 0.43
45	Chotian Kalan	UG	3.72 ± 0.20	34.42 ± 1.82	32.75 ± 1.73	29.52 ± 1.56	25.06 ± 1.32	20.05 ± 1.06	14.28 ± 0.75
46		SW	2.16 ± 0.10	19.94 ± 0.95	18.98 ± 0.90	17.10 ± 0.81	14.52 ± 0.69	11.62 ± 0.55	8.27 ± 0.39
47		SW	1.41 ± 0.13	13.01 ± 1.17	12.38 ± 1.12	11.16 ± 1.01	9.48 ± 0.85	7.58 ± 0.68	5.40 ± 0.49
48		UG	3.71 ± 0.12	34.31 ± 1.08	32.65 ± 1.03	29.43 ± 0.93	24.98 ± 0.78	19.99 ± 0.63	14.23 ± 0.45
49	Badhni	UG	3.07 ± 0.15	28.38 ± 1.35	27.01 ± 1.28	24.34 ± 1.15	20.67 ± 0.98	16.54 ± 0.78	11.77 ± 0.56
50		SW	1.59 ± 0.18	14.71 ± 1.69	14.00 ± 1.60	12.62 ± 1.45	10.71 ± 1.23	8.57 ± 0.98	6.10 ± 0.70
51		SW	0.98 ± 0.14	9.07 ± 1.28	8.63 ± 1.22	7.78 ± 1.10	6.60 ± 0.93	5.28 ± 0.75	3.76 ± 0.53
52		UG	3.16 ± 0.11	29.24 ± 0.99	27.82 ± 0.94	25.07 ± 0.85	21.29 ± 0.72	17.03 ± 0.58	12.13 ± 0.41
53	Buttar	UG	3.60 ± 0.29	33.24 ± 2.70	31.62 ± 2.57	28.50 ± 2.32	24.20 ± 1.97	19.36 ± 1.58	13.79 ± 1.12
54		SW	2.69 ± 0.14	24.82 ± 1.34	23.61 ± 1.27	21.28 ± 1.15	18.07 ± 0.97	14.46 ± 0.78	10.29 ± 0.55
55		SW	1.11 ± 0.09	10.24 ± 0.81	9.74 ± 0.77	8.78 ± 0.70	7.45 ± 0.59	5.97 ± 0.47	4.25 ± 0.34
56		UG	3.29 ± 0.12	30.44 ± 1.15	28.96 ± 1.10	26.10 ± 0.99	22.16 ± 0.84	17.74 ± 0.67	12.63 ± 0.48
57	Moga	UG	5.46 ± 0.19	50.50 ± 1.78	48.05 ± 1.69	43.30 ± 1.53	36.76 ± 1.29	29.42 ± 1.04	20.94 ± 0.74
58		SW	2.89 ± 0.23	26.72 ± 2.09	25.42 ± 1.99	22.91 ± 1.79	19.45 ± 1.52	15.57 ± 1.22	11.08 ± 0.87
59		SW	0.82 ± 0.08	7.57 ± 0.72	7.20 ± 0.68	6.49 ± 0.62	5.51 ± 0.52	4.41 ± 0.42	3.14 ± 0.30
60		UG	5.85 ± 0.15	54.02 ± 1.35	51.40 ± 1.28	46.33 ± 1.15	39.33 ± 0.98	31.48 ± 0.78	22.41 ± 0.56
61	Badoowal	UG	3.71 ± 0.48	34.29 ± 4.40	32.63 ± 4.19	29.41 ± 3.77	24.97 ± 3.20	19.98 ± 2.56	14.22 ± 1.82
62		SW	2.12 ± 0.14	19.6 ± 1.26	18.65 ± 1.2	16.81 ± 1.08	14.27 ± 0.92	11.42 ± 0.74	8.13 ± 0.52
63		SW	1.2 ± 0.10	11.36 ± 0.96	10.81 ± 0.91	9.74 ± 0.82	8.27 ± 0.69	6.62 ± 0.56	4.71 ± 0.4
64		UG	4.02 ± 0.16	37.18 ± 1.49	35.38 ± 1.42	31.89 ± 1.28	27.07 ± 1.08	21.66 ± 0.87	15.42 ± 0.62
65	Mehna	UG	3.04 ± 0.07	28.11 ± 0.62	26.74 ± 0.59	24.1 ± 0.53	20.46 ± 0.45	16.38 ± 0.36	11.66 ± 0.26
66		SW	2.18 ± 0.07	20.17 ± 0.65	19.19 ± 0.62	17.3 ± 0.56	14.68 ± 0.47	11.75 ± 0.38	8.37 ± 0.27

S. No	Place	Types	$C_{liq} \pm \sigma$ (BqL^{-1})	Annual Effective Dose due to Inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
67		SW	1.12 ± 0.09	10.35 ± 0.86	9.85 ± 0.82	8.88 ± 0.74	7.54 ± 0.63	6.03 ± 0.5	4.29 ± 0.36
68		UG	2.99 ± 0.10	27.62 ± 0.89	26.28 ± 0.85	23.69 ± 0.77	20.11 ± 0.65	16.09 ± 0.52	11.46 ± 0.37
69	Ajitwal	UG	5.01 ± 0.36	46.27 ± 3.34	44.03 ± 3.18	39.68 ± 2.87	33.69 ± 2.43	26.96 ± 1.95	19.19 ± 1.39
70		SW	2.72 ± 0.14	25.13 ± 1.27	23.92 ± 1.21	21.55 ± 1.09	18.3 ± 0.93	14.64 ± 0.74	10.43 ± 0.53
71		SW	1.30 ± 0.08	12 ± 0.76	11.42 ± 0.72	10.29 ± 0.65	8.73 ± 0.55	6.99 ± 0.44	4.98 ± 0.32
72		UG	2.61 ± 0.13	24.1 ± 1.24	22.93 ± 1.18	20.66 ± 1.07	17.54 ± 0.9	14.04 ± 0.72	9.99 ± 0.52
73	Dina	UG	3.41 ± 0.30	31.49 ± 2.78	29.96 ± 2.64	27 ± 2.38	22.93 ± 2.02	18.35 ± 1.62	13.06 ± 1.15
74		SW	2.60 ± 0.19	23.98 ± 1.75	22.82 ± 1.66	20.57 ± 1.5	17.46 ± 1.27	13.97 ± 1.02	9.95 ± 0.72
75		SW	1.07 ± 0.06	9.89 ± 0.6	9.41 ± 0.57	8.48 ± 0.51	7.2 ± 0.43	5.76 ± 0.35	4.1 ± 0.25
76		UG	3.66 ± 0.15	33.78 ± 1.41	32.14 ± 1.34	28.97 ± 1.21	24.59 ± 1.02	19.68 ± 0.82	14.01 ± 0.58
77	Kokri kokri	UG	4.0 ± 0.37	37.17 ± 3.46	35.37 ± 3.3	31.88 ± 2.97	27.06 ± 2.52	21.66 ± 2.02	15.42 ± 1.44
78		SW	2.44 ± 0.20	22.52 ± 1.88	21.43 ± 1.79	19.32 ± 1.61	16.4 ± 1.37	13.12 ± 1.1	9.34 ± 0.78
79		SW	1.55 ± 0.12	14.29 ± 1.09	13.6 ± 1.04	12.25 ± 0.93	10.4 ± 0.79	8.33 ± 0.63	5.93 ± 0.45
80		UG	4.08 ± 0.11	37.74 ± 1.03	35.91 ± 0.98	32.36 ± 0.88	27.48 ± 0.75	21.99 ± 0.6	15.65 ± 0.43
81	Rajiana	UG	6.03 ± 0.23	55.7 ± 2.11	53 ± 2.01	47.76 ± 1.81	40.55 ± 1.53	32.45 ± 1.23	23.1 ± 0.87
82		SW	2.77 ± 0.29	25.61 ± 2.68	24.37 ± 2.55	21.96 ± 2.3	18.64 ± 1.95	14.92 ± 1.56	10.62 ± 1.11
83		SW	1.66 ± 0.20	15.31 ± 1.83	14.56 ± 1.74	13.13 ± 1.57	11.14 ± 1.33	8.92 ± 1.07	6.35 ± 0.76
84		UG	2.7 ± 0.22	25.31 ± 2.05	24.08 ± 1.95	21.7 ± 1.75	18.43 ± 1.49	14.75 ± 1.19	10.5 ± 0.85
85	Karyal	UG	4.62 ± 0.35	42.7 ± 3.27	40.63 ± 3.11	36.62 ± 2.8	31.09 ± 2.38	24.88 ± 1.9	17.71 ± 1.36
86		SW	2.2 ± 0.14	20.88 ± 1.3	19.87 ± 1.23	17.91 ± 1.11	15.2 ± 0.94	12.17 ± 0.75	8.66 ± 0.54
87		SW	1.29 ± 0.11	11.92 ± 1.01	11.35 ± 0.96	10.23 ± 0.86	8.68 ± 0.73	6.95 ± 0.59	4.95 ± 0.42
88		UG	4.77 ± 0.23	44.04 ± 2.17	41.9 ± 2.06	37.77 ± 1.86	32.06 ± 1.58	25.66 ± 1.26	18.27 ± 0.9
89		UG	4.82 ± 0.26	44.53 ± 2.38	42.37 ± 2.27	38.19 ± 2.05	32.42 ± 1.73	25.95 ± 1.39	18.47 ± 0.99

S. No	Place	Types	$C_{liq} \pm \sigma$ (BqL^{-1})	Annual Effective Dose due to Inhalation (μSvy^{-1}) Infants	Children	Adults	Annual effective dose due to ingestion (μSvy^{-1}) Infants	Children	Adults
90	Babiha Bhaike	SW	2.5 ± 0.23	23.43 ± 2.16	22.29 ± 2.05	20.09 ± 1.85	17.06 ± 1.57	13.65 ± 1.26	9.72 ± 0.9
91		SW	1.20 ± 0.11	11.08 ± 0.98	10.54 ± 0.93	9.5 ± 0.84	8.07 ± 0.71	6.46 ± 0.57	4.6 ± 0.41
92		UG	4.6 ± 0.21	42.61 ± 1.9	40.54 ± 1.81	36.54 ± 1.63	31.02 ± 1.38	24.83 ± 1.11	17.67 ± 0.79
93	Gill	UG	4.41 ± 0.28	40.76 ± 2.56	38.78 ± 2.44	34.95 ± 2.2	29.68 ± 1.86	23.75 ± 1.49	16.91 ± 1.06
94		SW	2 .39 ±0.12	22.08 ± 1.15	21.01 ± 1.1	18.94 ± 0.99	16.08 ± 0.84	12.87 ± 0.67	9.16 ± 0.48
95		SW	1.40 ± 0.10	12.89 ± 0.94	12.27 ± 0.89	11.06 ± 0.8	9.39 ± 0.68	7.51 ± 0.55	5.35 ± 0.39
96		UG	4.10 ± 0.18	37.85 ± 1.71	36.02 ± 1.62	32.46 ± 1.46	27.56 ± 1.24	22.05 ± 0.99	15.7 ± 0.71
97	Ludhai Ke	UG	4.03 ± 0.18	37.25 ± 1.69	35.45 ± 1.6	31.95 ± 1.45	27.12 ± 1.23	21.71 ± 0.98	15.45 ± 0.7
98		SW	2.62 ± 0.13	24.17 ± 1.21	23 ± 1.15	20.73 ± 1.04	17.6 ± 0.88	14.08 ± 0.71	10.02 ± 0.5
99		SW	1.58 ± 0.12	14.63 ± 1.14	13.92 ± 1.09	12.54 ± 0.98	10.65 ± 0.83	8.52 ± 0.66	6.07 ± 0.47
100		UG	4.28 ± 0.16	39.54 ± 1.51	37.62 ± 1.44	33.91 ± 1.3	28.79 ± 1.1	23.04 ± 0.88	16.4 ± 0.63
Minimum			0.82 ± 0.06	7.57 ± 0.60	7.20 ± 0.57	6.49 ± 0.51	5.51 ± 0.43	4.41 ± 0.35	3.14 ± 0.25
Maximum			8.41 ± 0.51	77.67 ± 4.70	73.90 ± 4.47	66.60 ± 4.03	56.55 ± 3.41	45.25 ± 2.74	32.21 ± 1.95
Average			3.26 ± 0.20	30.11 ± 1.87	28.65 ± 1.78	25.82 ± 1.60	21.93 ± 1.36	17.55 ± 1.09	12.49 ± 0.77
Standard Deviation			1.61	14.91	14.19	12.79	10.86	8.69	6.19
Kurtosis			0.65 ± 0.88	0.65 ± 0.88	0.65 ± 0.88	0.65 ± 0.88	0.65 ± 0.88	0.65 ± 0.88	0.65 ± 0.88
Skewness			0.75 ± 1.14	0.75 ± 1.14	0.75 ± 1.14	0.75 ± 1.14	0.75 ± 1.14	0.75 ± 1.14	0.75 ± 1.14
Mode			3.71 ± 0.15	34.31 ± 1.35	32.65 ± 1.46	29.43 ± 1.15	24.98 ± 0.98	19.99 ± 0.78	14.23 ± 0.56
1st Quartile			1.98 ± 0.12	18.27 ± 1.14	17.38 ± 1.09	15.67 ± 0.98	13.30 ± 0.83	10.64 ± 0.66	7.58 ± 0.47
2nd Quartile			2.99 ± 0.18	27.62 ± 1.68	26.28 ± 1.59	23.69 ± 1.44	20.11 ± 1.22	16.09 ± 0.98	11.46 ± 0.70
3rd Quartile			4.28 ± 0.26	39.54 ± 2.36	37.62 ± 2.25	33.91 ± 2.03	28.79 ± 1.72	23.04 ± 1.38	16.40 ± 0.98

Table 5.3: Radon concentration in water samples of different sources of water in studied area

Sources of water	Radon concentration in water (BqL^{-1})			
	Barnala District		Moga District	
	Range ± σ	Average ± σ	Range ± σ	Average ± σ
Surface water	0.17 ± 0.01 to 9.84 ± 0.56	2.23 ± 0.56	0.82 ± 0.06 to 8.41 ± 0.49	2.17 ± 0.17
Underground water	1.40 ± 0.01 to 9.54 ± 0.59	4.35 ± 0.29	2.61 ± 0.07 to 8.39 ± 0.51	4.28 ± 0.24
Handpump	1.40 to 7.66	3.47	3.16 to 5.09	4.16
Submersible	1.57 to 5.56	4.22	2.61 to 6.41	4.26
Borewell	3.30 to 9.27	6	2.68 to 8.39	4.33

Table 5.4: Worldwide comparison of radon concentration in water samples

S. No.	Area	Radon in water (BqL^{-1})		Reference
		Range	Mean Value	
1.	Iran	0.064 – 49.1	16.2	Banish et al., 2011
2.	Cyprus	0.3- 20	5.9	Nikolopoulos et al., 2008
3.	Greece	0.8- 24	5.4	Nikolopoulos et al., 2008
4.	Brazil	0.95- 36	36	Marques et al., 2004
5.	Turkey	1.46-53.64	-	Tarim et al., 2012
6.	South Korea	0-300	-	Cho et al., 2014
7.	China	0.71– 3735	-	Zhuo et al., 2001
8.	Sweden	5-3470	-	Salih et al. 2004
9.	Saudi Arabia	0.04-67.44	-	Alabudula'aly et al. 2014
10.	Barnala district Punjab	0.17 - 9.84	3.01	**Present study**
11.	Moga district Punjab	0.82-8.41	3.26	