CHAPTER: 4

QUANTIFICATION OF RADON IN WATER

This chapter deals with the measurement of radon concentration in underground and surface water using Smart RnDuo indigenously developed by BARC, Mumbai, India. The radiological risk assessment for the population of the study area has been determined by calculating inhalation and ingestion doses using standard formulae. In the following section, introduction about the topic, measurement process, formulae used for calculations, results and conclusion has been discussed.

4.1 INTRODUCTION

Water is an important natural resource essential for survival of humans. The main sources for drinking water are underground sources (handpumps, borewell etc.), surface water (rivers, lakes ponds etc.) and precipitation (rains, hail, snow, etc.). Because of its 'universal solvent' nature water contains many substances which can be categorised as pollutants, including radioactive substances which may expose people consuming it to radiation. The radionuclides found predominantly in water are those belonging to naturally occurring decay chains of primordial radionuclides uranium, thorium and actinium (Love 1951; Hess et al., 1985; Nuccetelliet al., 2012; WHO, 2018). Radon is one such radionuclide whose radiological significance, especially the carcinogenic nature, is well studied and established (UNSCEAR, 1993 and 2000; WHO, 2008). It is a chemically inert gas emitting alpha radiation and having ubiquitous presence over earth. Of its three isotopes, namely radon (Rn-222), thoron (Rn-220) and action (Rn-219), only radon has a sufficiently long radioactive half-life (3.8 days) to be able to reach human bodies through natural environments, in particular through water.

Radon is produced by natural radioactive decay of radium (Ra-226), present in the lithosphere. It enters into water as a result of diffusion and dissolution from the rocks and other materials in its contact or by decay of radium dissolved in water from surrounding earthen material and to a lesser extent from dissolution of radon present in air in its contact (Andrews and Woods, 1972; Tanner, 1980; Bonotto and Caprioglio, 2002). The ingestion of radon bearing water results in radiation exposure to tissues and organs of digestive system, leading to an enhanced risk of stomach and gastrointestinal cancer (Ye et al., 1998; Auvinen et al., 2005; WHO, 2009; Nazir et al., 2020; Singla et al., 2021a). The stomach accounts for the highest fraction (90 per cent) of the total ingestion dose due to radon (Kendall and Smith, 2003). Some of the radon can also escape from water and add to the inhalation dose due to radon already present in the environment. The increasing concern about the quality of drinking water across the world has led to setting up of different standards and regulations for the control of various pollutants in it. Considering the potential health risk of radon in water, regulations have been set for it too. The United States Environmental Protection Agency (USEPA, 2000) has set a maximum contaminant level of radon in drinking water of 11.1 Bq/l (300 pCi/l), for European Union countries the E-DWD (EURATOM Drinking Water Directive) (EURATOM, 2013) has set range for guidance levels of radon in drinking water between 100 and 1000 Bq/l and The World Health Organization set the guidance level to 100 Bq/l (WHO, 2008 (drinking water guidelines)). In case of country like India the presence of radon in water assumes a greater significance as most of the daily water requirement of the body is met by direct consumption of drinking water.

Knowledge of the concentration of radon in drinking waters is necessary to determine its risk to public health. Different studies have shown that the concentration of radon in water varies greatly depending upon factors like the radioactive content, lithology and morphology of rocks in contact with water, the flow of water, and duration of the contact of water with rocks. Besides these factors which affect the source term of radon in water, the concentration of radon also depends on the processes which cause loss of radon from water like degassing and radioactive decay (Brutsaert et al., 1981; Loomis 1987; Ball et al., 1991; Otton 1992; Ilani et al., 2006). In general groundwater has a higher concentration of radon as the water is in contact with surrounding geological environment for a greater extent and duration and that too in a closed system where the dissolved radon cannot escape. In case of surface water, the loss of dissolved radon to the atmosphere leads to a lower concentration. Besides, the variation amongst the individual categories of water has also been found to be high (Frédéric Girault et al., 2016; Chen, 2019).

In case of India many studies pertaining to measurement of radon in drinking water have been published in recent times (Bajwa et al., 2005; Kansal et al., 2011; Sharma et al., 2017; Srinivasa et al., 2018; Singla et al., 2021b; Rani et al., 2021). However, in context of the vast size of the country and the large diversity in terms of geographic, geological, atmospheric, anthropogenic and other physical parameters, the data is still scarce. In the present study the radon concentration has been measured in drinking water from different groundwater and surface water sources for the district of

Hanumangarh, Sri Ganganagar and Churu in Rajasthan state of India. Though a couple of studies have been done in past for concentration of radon in water for Hanumangarh district, they have targeted only groundwater sources and cover too few locations to be considered representative of the district spread over a very large area (Duggal et al., 2012; Duggal et al., 2013; Rani et al., 2013). The present study attempts to cover the district comprehensively by having much more sampling locations which are spread all across the district. The method for measurement of radon in drinking water used in this study is more sensitive. Moreover the standard protocol recommended by Bhabha Atomic Research Centre (BARC), Mumbai (Sapra et al., 2016) used in nearly all radon in water studies done in India recently has been strictly followed, making it possible to have reliable direct comparisons with them.

4.2 METHODOLOGY

4.2.1 Field Work

In the present study, total 230 water samples were collected from different locations across Hanumangarh (50 samples), Sri Ganganagar (100 samples) and Churu (80 samples) districts. The water was sampled from different sources like taps, hand pumps, tube wells etc. which were being used to obtain surface water or underground water for drinking. The GPS coordinates for each sampling location was obtained by (GPSMAP 78S, Garmin Inc.). The gamma radiation field strength was also measured by (PM1405 Survey Meter, Polimaster Inc.). In case of underground water samples, the information about the depth of underground sources was obtained and noted.

The samples were collected in 60 mL airtight, cleaned glass bottles. These were collected underwater by putting the sampling water bottles in the water container/ bucket so that radon could not escape during the sample collection. 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).

On the spot measurement of radon in water sample has been carried out using SMART RnDuo monitor (AQTEK System, India) as per the protocol prescribed by BARC Radon Handbook (Sapra et al., 2016). 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 4.1). 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.

Figure 4.1: Set-up for measurement of radon in water sample at field work

4.3 FORMULAE USED FOR CALCULATIONS

4.3.1 Calculation of Radon Concentration in Water

The radon concentration in water (C_{wat}) (BqL^{-1}) was then calculated from the value of C_{air} using equation 1 (BARC Radon Handbook).

$$C_{wat} = C_{air}\left(K + \frac{V_{air}}{V_{wat}}\right) \qquad (1)$$

Where K is partition coefficient of radon in water with respect to air (= 0.25),
V_{air} (m^3) is (Bubbler + tubings + detector) volume of air enclosed in the closed loop and V_{wat} is liquid in sampling bottle (m^3) volume.

4.3.2 Calculation of Radiological Dose Due to Radon in Water

The radon present in water will impart radiation dose to humans through the exposure pathways of ingestion following consumption of the water by drinking; and by inhalation of the radon released from the water to indoor environment. Considering the different ages of the members of the population, the annual effective dose due to radon in water was calculated for infants (1 year), children (10 year) and adults (above 18 years) to see how the difference in doses for them.

The annual effective dose due to ingestion, D_{ing} (μSvy^{-1}) was calculated by using equation 2 (UNSCEAR, 2000) as:

$$D_{ing} = C_{wat} \times I \times F_{ing} \qquad (2)$$

Where, C_{wat} (BqL^{-1}) is the radon concentration in water, I (m^3y^{-1}) is the annual intake of water by subject,
F_{ing} ($\mu SvBq^{-1}$) is dose conversion factor for exposure by radon ingestion.
The annual water intake values of 150 l, 350 l and 500 l; and
the ingestion dose coefficient values of 23 $nSvBq^{-1}$, 5.9 $nSvBq^{-1}$ and 3.5 $nSvBq^{-1}$ were used for infants, children and adults respectively with required unit conversions (UNSCEAR 2000).
The water intake values used are those recommended for drinking water only, and not for water intake through other food materials.

The annual effective dose due to inhalation, D_{inh} (µSvy^{-1}) was calculated by using equation 3 (UNSCEAR, 2000) as:

$$D_{inh} = C_{wat} \times R_{a/w} \times EF \times T \times F_{inh} \qquad (3)$$

Where, C_{wat} (Bq/m^3) is the Radon concentration in water samples, $R_{a/w}$ is the ratio of radon in air to Radon in water (=10^{-4}) (UNSCEAR, 1993),

EF is equilibrium factor between Rn-222 and its progenies (= 0.4),

T is average annual time of exposure for radon released from water to air (350 h),

F_{inh} (nSv(Bq(m^3.h)$^{-1}$)$^{-1}$) is dose conversion factor for radon (decay product) inhalation by the subject.

The dose conversion factor for inhalation of radon of 33.0 nSv(Bq(m^3.h)$^{-1}$)$^{-1}$ for infants, 31.4 nSv(Bq(m^3.h)$^{-1}$)$^{-1}$ for children and 28.3 nSv(Bq(m^3.h)$^{-1}$)$^{-1}$ for adults was used (Brudecki et al., 2014) with required unit conversions.

These dose conversion factors have been calculated by using the dosimetric approach recommended by ICRP, 137, using ICRP bio-kinetic models and recommended parameters for concerned subjects (ICRP, 66).

4.4 RESULTS AND DISCUSSION

In Hanumangarh district, the radon concentration has been measured in 50 water samples taken from different sources of water (which includes 33 from surface water samples and 17 underground water) samples) as shown in Table 4.1. The concentration of radon in water samples have minimum value of 0.11 ± 0.06 BqL^{-1} and maximum value of 8.73 ± 0.50 BqL^{-1} with an average value 2.07 ± 0.21 BqL^{-1}. The measured values of radon concentration in water are lower than the safe limit of 11 BqL^{-1} as recommended by USEPA (1991), 100 BqL^{-1} by WHO (2004) and 4-40 BqL^{-1} recommended by UNSCEAR (2008). The frequency distribution graph shows that radon concentration in 33 samples (66%) lie between 0-2 BqL^{-1}, in 8 samples (16%) lie between 2-4 BqL^{-1} and in the rest of the 9 samples (18%) lie between 4-10 BqL^{-1} (Figure 4.2).

Table 4.1 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 0.37 to 30.77 µSvy^{-1} with a mean value of 7.14 µSvy^{-1}, for children (8-12 year) it lies in the range of 0.22 to 18.02 µSvy^{-}

[1] with a mean value of 4.27 μSvy^{-1} and for adults (above 17 years) it lies in the range of 0.19 to 15.27 μSvy^{-1} with a mean value of 3.62 μSvy^{-1}. The annual inhalation dose varies from 0.05 to 3.46 μSvy^{-1} with a mean value of 0.91 μSvy^{-1} for infants, 0.05 to 3.46 μSvy^{-1} with a mean value of 0.82 μSvy^{-1} for children and 0.19 to 15.27 μSvy^{-1} with a mean value of 3.62 μSvy^{-1} for adults. The calculated dose values are well below the annual effective dose of 100 μSvy^{-1} recommended by WHO (2004 and 2008).

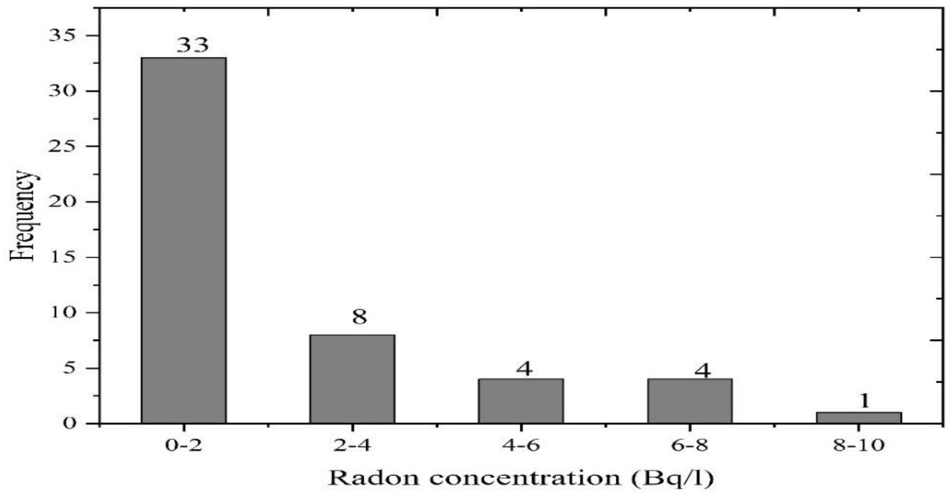

Figure 4.2: Frequency distribution for concentration of radon in water samples of Hanumangarh district

It can be observed that the concentration of radon in ground water samples was higher than those of surface water samples. The comparison can be better understood from the radon concentrations in the two types of water samples, shown in Figure 4.3. This can be explained by the fact that since surface water is in contact with atmosphere for a longer time, the probability of escape of radon dissolved in it to the atmosphere is higher in the light of a more favourable radon partition coefficient towards air ($K_{wat/air}$ = 0.3). On the contrary groundwater is in direct contact with rocks surrounding the aquifer resulting in transfer of radon from these rocks and a limited avenue for this dissolved radon to escape to air.

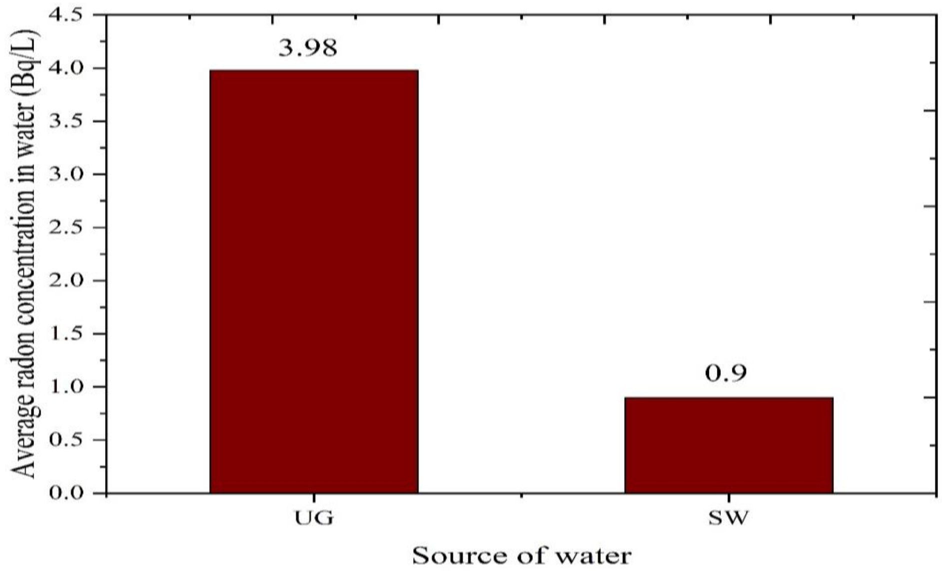

Figure 4.3: Comparison of radon concentration in surface water (SW) and underground water (UG) in Hanumangarh district

Analysis was done to see if there was any correlation between radon concentration in ground water and the depth of bore well. The plot between the two quantities and a linear fitting using least square regression is shown in Figure 4.4. A lose correlation was observed between the two quantities with the R^2 value of 0.17 for the linear fit and Pearson's *r* value (which quantifies the linear dependence) as 0.41. Since the source of groundwater 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 region.

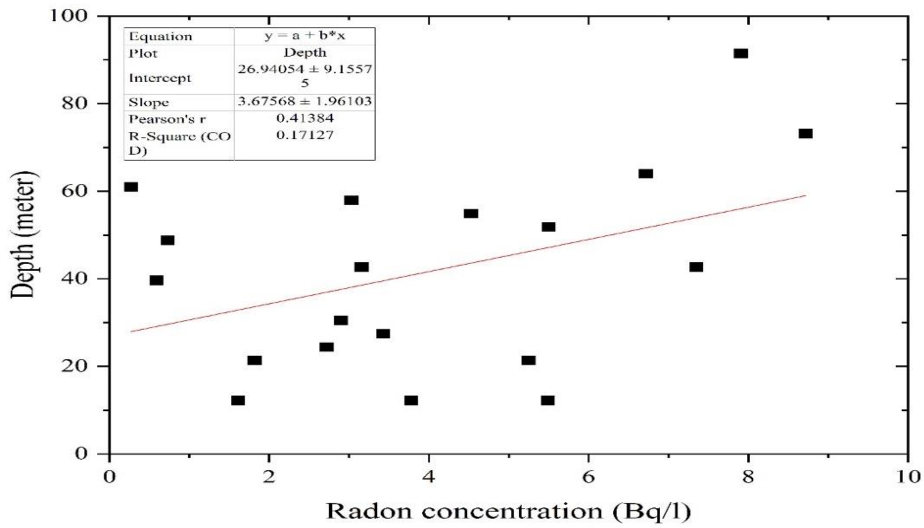

Figure 4.4: Correlation between concentration of radon in underground water with depth in Hanumangarh district

In Sri Ganganagar district, the radon concentration in water samples has been measured in 100 water samples (51 water samples are taken from surface water and 49 samples from Underground water) from 25 different villages. Table 4.2 shows the Radon concentration in all 100 water samples with minimum value of 0.13 ± 0.04 BqL^{-1} (Kesri Singhpur, canal water) and maximum value of 3.74 ± 0.26 BqL^{-1} (Fojuwala, Underground water) with an average value of 0.92 ± 0.12 BqL^{-1}. The measured readings from different water sources have also been shown and for underground samples it lies between 0.39 ± 0.06 to 3.74 ± 0.26 BqL^{-1} with an average value of 1.52 ± 0.15 BqL^{-1}, for surface water it lies between 0.13 ± 0.06 to 1.87 ± 0.22 BqL^{-1} with an average value of 0.43 ± 0.10 BqL^{-1}. The frequency distribution graph shows (Figure 4.5) that concentration of radon in 63% of water samples (63) lie between 0-1 BqL^{-1}, in 28% samples (28) lie between 1-2 BqL^{-1}, in the rest of 9% samples (9) lie between 2-4 BqL^{-1}. All the measured values of radon concentration lie within the recommended safe values of 11 BqL^{-1} by USEPA (1991), 100 BqL^{-1} by WHO (2004) and 4-40 BqL^{-1} recommended by UNSCEAR (2008).

The annual effective dose due to ingestion for infants (0-2 year) lies in the range of 0.85 to 25.13 μSvy^{-1} with a mean value of 6.19 μSvy^{-1}, for children (8-12 year) it lies in the range of 0.68 to 20.11 μSvy^{-1} with a mean value of 4.95 μSvy^{-1} and for adults (above 17 years) it lies in the range of 0.49 to 14.32 μSvy^{-1} with a mean value of 3.53 μSvy^{-1}. The annual inhalation dose varies from 1.17 to 34.52 μSvy^{-1}

with a mean value of 8.50 µSvy^{-1} for infants, 1.12 to 32.85 µSvy^{-1} with a mean value of 8.09 µSvy^{-1} for children and 1.01 to 29.60 µSvy^{-1} with a mean value of 7.29 µSvy^{-1} for adults. The calculated dose values are well below the annual effective dose of 100 µSvy^{-1} recommended by WHO (2004 and 2008).

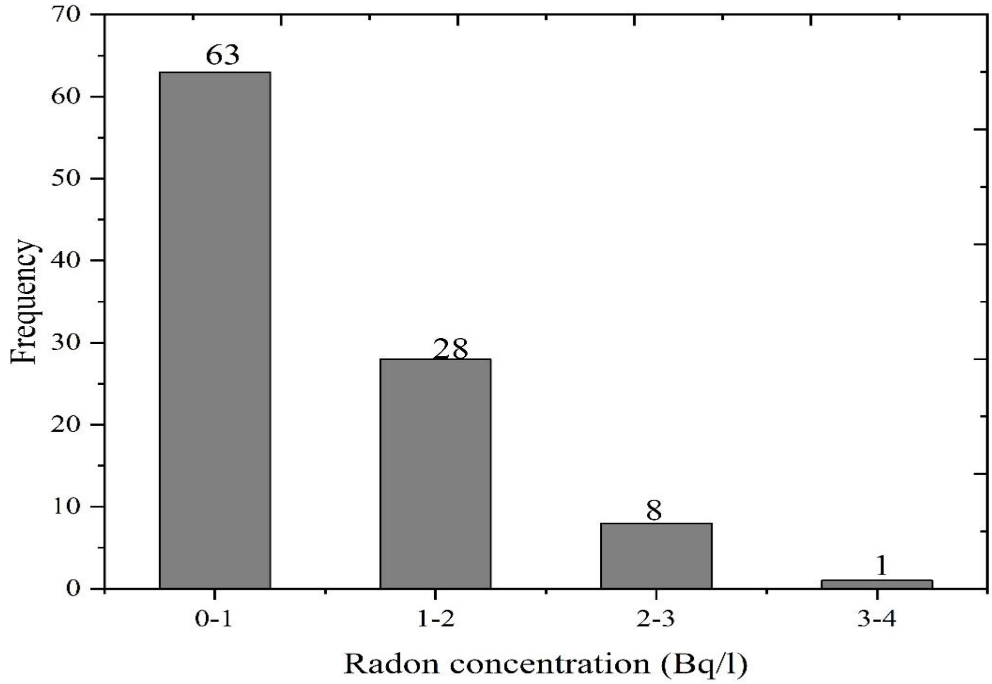

Figure 4.5: Frequency distribution for concentration of radon in water samples of sri Ganganagar district

This study states that the radon concentration in collected underground water samples had much higher value than collected from surface water as shown in Figure 4.6. This may be because of the subterranean water is in direct contact with the bedrock which may be rich in radium. On the other hand, aeration or agitation of water can easily remove the radon from the water (Singh et al., 2018). The higher value of radon concentration in subsurface water samples may be because of deep water which lead to enhance the time of interaction between moving water with a greater extent of aquifer. Also, higher sponginess of soil along with rocks at extreme depth ease the exchange of water and dissolve radon, which results into the higher radon concentration in subterranean water sources (Bourai et al., 2012).

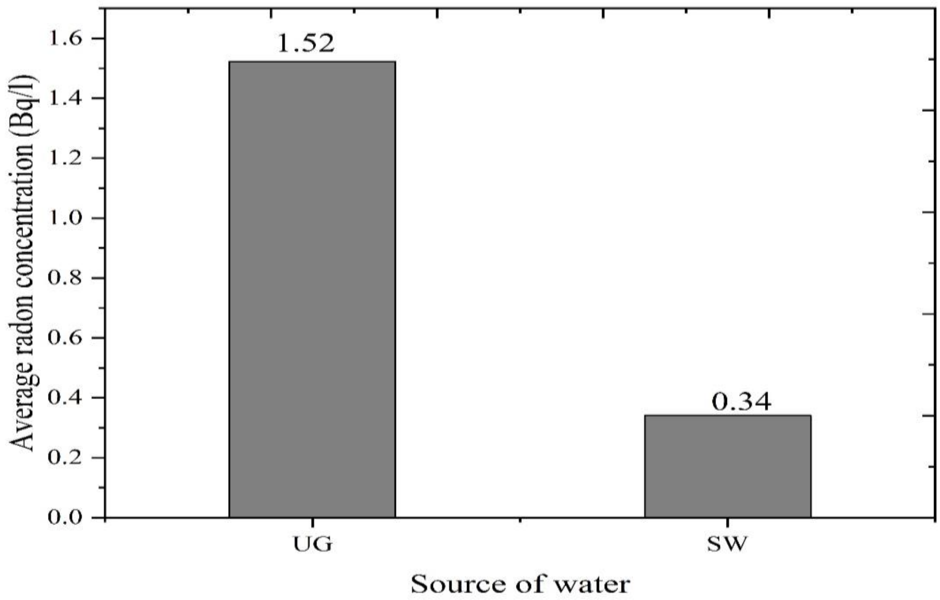

Figure 4.6: Comparison of radon concentration in surface water (SW) and underground water (UG) in Sri Ganganagar district

Figure 4.7 shows the moderate correlation between depth and radon concentration in water with adjusted R-square value of 0.54 and person value of 0.73, which are collected between the range of 53–183 m.

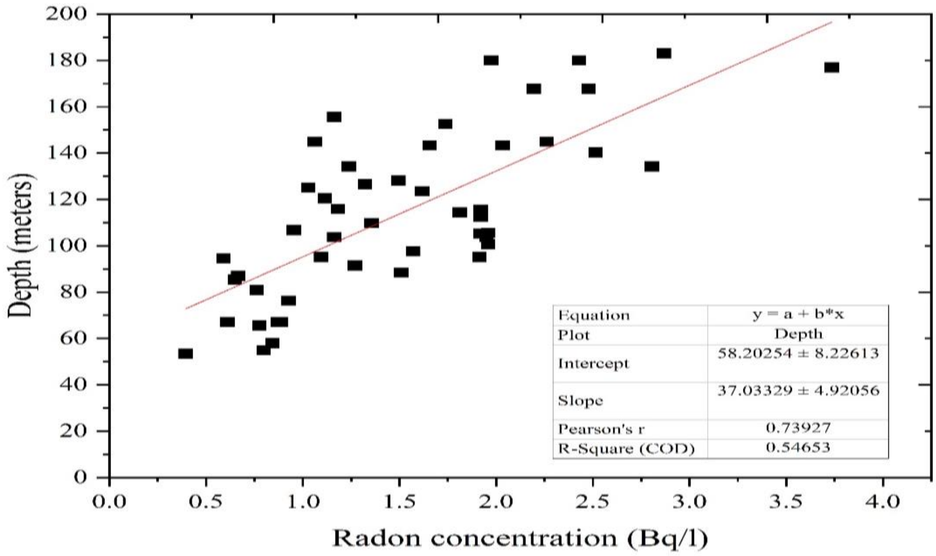

Figure 4.7: Correlation between radon concentration in underground water with depth of Sri Ganganagar district

In Churu district, the Radon concentration in water samples has been measured in 80 water samples (41 samples from surface water and 39 samples from underground water) from 25 different villages. Table 4.3 shows the Radon concentration in all 100 water samples with minimum value of 0.23 ± 0.04 BqL^{-1} and maximum value of 4.74 ± 0.23 BqL^{-1} with an average value of 1.79 ± 0.12 BqL^{-1}. The frequency distribution graph shows that concentration of radon in 31% of water samples (25) lie between 0-1 BqL^{-1}, in 33% samples (27) lie between 1-2 BqL^{-1}, in 22% samples lie (18) between 2-3 BqL^{-1} and in the rest of 14% samples (10) lie between 4-6 BqL^{-1} as shown in Figure 4.8. All the measured values of radon concentration lie within the recommended safe values of 11 BqL^{-1} by USEPA (1991), 100 BqL^{-1} by WHO (2004) and 4-40 BqL^{-1} recommended by UNSCEAR (2008).

The annual effective dose due to Ingestion for infants (0-2 year) lies in the range of 1.57 to 31.91 µSvy^{-1} with a mean value of 12.05 µSvy^{-1}, for children (8-12 year) it lies in the range of 1.26 to 25.54 µSvy^{-1} with a mean value of 9.64 µSvy^{-1} and for adults (above 17 years) it lies in the range of 0.50 to 18.18 µSvy^{-1} with a mean value of 6.86 µSvy^{-1}. The annual inhalation dose varies from 2.16 to 43.83 µSvy^{-1} with a mean value of 16.55 µSvy^{-1} for infants, 2.05 to 41.71 µSvy^{-1} with a mean value of 15.75 µSvy^{-1} for children and 1.85 to 37.59 µSvy^{-1} with a mean value of 14.19 µSvy^{-1} for adults. The calculated dose values are well below the annual effective dose of 100 µSvy^{-1} recommended by WHO (2004 and 2008).

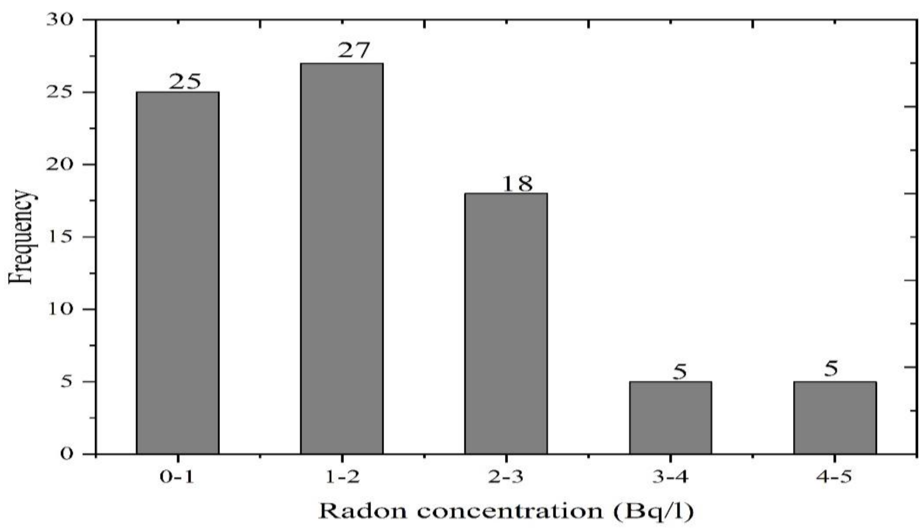

Figure 4.8: Frequency distribution for concentration of radon in water samples of Churu district

It can be observed that the concentration of radon in ground water samples was higher than those of surface water samples. The comparison can be better understood from the radon concentrations in the three types of water samples, shown in Figure 4.9.

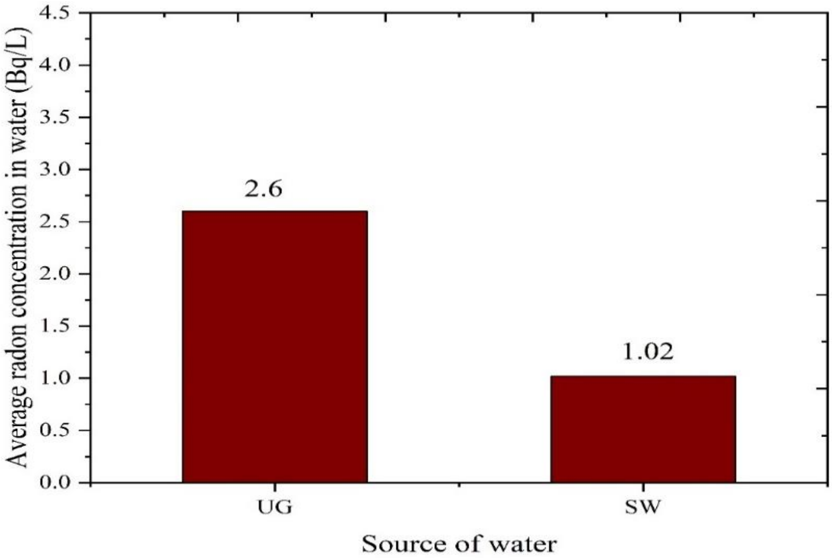

Figure 4.9: Comparison of radon concentration in surface water (SW) and underground water (UG) of Churu district.

Figure 4.10 shown the poor correlation between depth and radon concentration in water with adjusted R-square value of 0.64 and person value of 0.8, which are collected between the range of 67-198 meter.

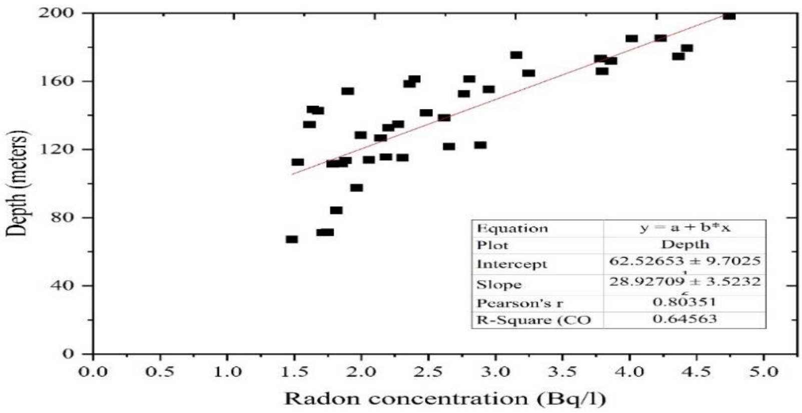

Figure 4.10: Correlation between radon concentration in underground water with depth in Churu district

Comparison with Values in Surrounding Areas and Other Parts of India

Table 4.4 shows the range of the values of radon in groundwater samples measured in this study was similar to values reported for Hanumangarh district in previous studies but the average value was slightly higher than the values of 3.7 BqL^{-1} (Duggal et al., 2012), 3.3 BqL^{-1} (Duggal et al., 2013) and 4.2 BqL^{-1} (Rani et al., 2013) of these studies. The concentration of radon in ground water samples reported in studies for other districts around study region are compared here. For immediate neighbouring districts, Rani et al., 2013 have reported the range of radon concentration for Churu district as 0.5 to 4.9 BqL^{-1} with a mean value of 2.6 ± 0.6 BqL^{-1}. The radon concentration in groundwater of Bikaner and Jhunjhunu was reported by Mittal et al., (2015) which vary in range of 0.50 to 22 BqL^{-1} with an average of 4.42 BqL^{-1}. Similarly, the range of radon concentration in groundwater samples from adjoining districts in state of Punjab was reported as 1 to 14 BqL^{-1} for Mansa and Muktsar districts (Mehra et al., 2015). The corresponding range of values for radon in groundwater was 0.6 to 7.8 BqL^{-1} for Sirsa district of Haryana which share borders with Hanumangarh (Sharma et al., 2017). It can be seen that the measured values of radon in groundwater was consistent with the values reported for these other districts in the region known to have similar geology and more specifically the similar content of radioactivity in soil. This range of radon concentration is lower than those reported for areas with higher earthern radioactivity content in other parts of India like Karnataka, (Srinivas et al., 2015; 2019), Jammu and Kashmir (Nazir et al., 2020) and Uttarakhand (Bourai et al., 2012).

In case of measurement of Radon in samples from surface water sources, comparatively less data is available in literature. There were no previous measurements for radon in surface water for Hanumangarh, Sri Ganganagar and Churu districts. In the available literature the concentration of radon in surface water has been reported to vary from 0.3 to 3.3 BqL^{-1} (average 1.7 BqL^{-1}) for Faridabad district, Haryana (Singh et al., 2019) and an average concentration of 1.95 BqL^{-1} for Mansa and Muktsar districts of Punjab (Mehra et al., 2015). Kaur et al., (2017) have reported the concentration of radon in water in Faridkot district was vary from 1 ± 0.12 to 6 ± 0.14 BqL^{-1} with an average value of 3.63 BqL^{-1}. Mehra et al., (2015) reported that the concentration of radon in water of Bathinda district was found to vary between 0.3 ± 0.09 (Bathinda) to 6.62 ± 0.4 $kBqm^{-3}$ (Gehri Butter) with an average value of 2.72 $kBqm^{-3}$. Bajwa et al., (2005) reported that the radon concentration in water of Himachal Pradesh lies from 1 ± 0.3 to 48 ± 2.2 BqL^{-1}. Kumar et al., (2022) reported that the concentration of radon in water in the surrounding regions of the National Capital Power Cooperation (NTPC), Dadri varies from 17 ± 1 to 68 ± 3 BqL^{-1} with an average value of 33 ± 13 BqL^{-1}.

The measured values of radon in surface water samples of this study were consistent with these values reported for surrounding regions, especially when considering the fact that a large variability in dissolved radon can occur for surface water depending on the time available to the water for aeration, which further depends on the depth of water source, the mobility of water etc.

4.5 CONCLUSION

- The average concentration of radon in all the water samples have lower concentration than recommended value of 11 BqL^{-1} by USEPA (1991), 100 BqL^{-1} by WHO (2004) and 4-40 BqL^{-1} recommended by UNSCEAR (2008).
- The annual effective dose for various age groups like infants, children and adults lies below the safe 100 μSvy^{-1} recommended by WHO (2008). For a given concentration of radon in drinking water, the dose was highest in case of infants and followed a decreasing trend with age.
- The concentration of radon in underground water have higher value than concentration in surface water which may be because of presence of granite, sands, gravel in the bedrock (Stojkovic et al., 2015) and also for the reason that underground water directly encounters U-238 rich rocks that releases radon in water and cannot escape to atmosphere, whereas in contrast radon in surface water samples can easily escape to atmosphere due to aeration and agitation in water (Voronov et al. 2004; Skeppstorm et al. 2007).
- Hence, the water in the studied area is safe for drinking purposes from the radiological risk point of view.
- The data will contribute towards the national pool for mapping and for further studies.

Table 4.1: Radon concentration and annual effective dose in water samples of Hanumangarh district

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
1	Hanumangarh Jn. Factory Road	SW	0.12 ± 0.06	0.05	0.05	0.05	0.40	0.24	0.20
2	Hanumangarh Jn.	SW	0.14 ± 0.06	0.06	0.06	0.05	0.47	0.28	0.24
3	Phephana	SW	0.16 ± 0.07	0.07	0.07	0.06	0.56	0.33	0.28
4	Phephana	SW	0.16 ± 0.07	0.07	0.07	0.06	0.55	0.33	0.28
5	Janania	UG	5.25 ± 0.39	2.43	2.31	2.08	18.12	10.85	9.19
6	Janania	SW	1.10 ± 0.19	0.51	0.48	0.44	3.80	2.28	1.93
7	Padampura	SW	0.11 ± 0.07	0.05	0.05	0.04	0.37	0.22	0.19
8	Padampura	SW	0.11 ± 0.06	0.05	0.05	0.04	0.38	0.23	0.19
9	Dabli Rathan	SW	0.12 ± 0.06	0.05	0.05	0.05	0.41	0.25	0.21
10	Dabli Rathan	UG	0.28 ± 0.09	0.13	0.12	0.11	0.96	0.57	0.49
11	Pilibanga	UG	1.61 ± 0.22	0.75	0.71	0.64	5.57	3.33	2.82
12	Pilibanga	SW	0.55 ± 0.13	0.25	0.24	0.22	1.89	1.13	0.96
13	Jodkya	UG	1.82 ± 0.22	0.84	0.80	0.72	6.29	3.77	3.19
14	Jandawali	UG	0.60 ± 0.14	0.28	0.26	0.24	2.07	1.24	1.05
15	Jandawali	SW	0.30 ± 0.10	0.14	0.13	0.12	1.04	0.62	0.53

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
16	Nagrana	SW	0.19 ± 0.07	0.09	0.09	0.08	0.67	0.40	0.34
17	Sangria	SW	0.36 ± 0.10	0.17	0.16	0.14	1.25	0.75	0.63
18	Sangria	UG	2.90 ± 0.29	1.34	1.28	1.15	10.01	5.99	5.08
19	Bhagatpura	SW	0.81 ± 0.16	0.38	0.36	0.32	2.81	1.68	1.43
20	Dhaba	SW	0.28 ± 0.10	0.13	0.12	0.11	0.96	0.57	0.49
21	Kharliya	SW	0.15 ± 0.07	0.07	0.07	0.06	0.51	0.31	0.26
22	Hansliya	SW	0.14 ±0.07	0.06	0.06	0.06	0.48	0.29	0.24
23	Hansliya	UG	4.54 ± 0.37	2.10	1.99	1.80	15.66	9.37	7.94
24	Goluwala	SW	1.43 ± 0.22	0.66	0.63	0.57	4.93	2.95	2.50
25	Goluwala	UG	6.72 ± 0.41	3.11	2.96	2.66	23.19	13.88	11.76
26	Bhadra	SW	0.22 ± 0.08	0.10	0.10	0.09	0.77	0.46	0.39
27	Bhadra	UG	5.50 ± 0.40	2.54	2.42	2.18	18.98	11.36	9.63
28	Dholpalia	SW	2.16 ± 0.24	1.00	0.95	0.86	7.47	4.47	3.79
29	Jogiwala	SW	0.48 ± 0.13	0.22	0.21	0.19	1.65	0.99	0.84
30	Jogiwala	UG	3.43 ± 0.32	1.59	1.51	1.36	11.84	7.09	6.00
31	Rawatsar	SW	1.00 ± 0.18	0.46	0.44	0.40	3.47	2.07	1.76
32	Rawatsar	UG	8.73 ± 0.50	4.03	3.84	3.46	30.11	18.02	15.27

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
33	25 DWD	UG	3.78 ± 0.34	1.75	1.66	1.50	13.06	7.82	6.62
34	25 DWD	SW	1.78 ± 0.25	0.82	0.78	0.71	6.15	3.68	3.12
35	2 K.B.M.	SW	0.96 ± 0.17	0.44	0.42	0.38	3.30	1.98	1.68
36	2 K.B.M.	UG	5.49 ± 0.40	2.54	2.41	2.18	18.95	11.34	9.61
37	Tibbi	SW	1.13 ± 0.19	0.52	0.50	0.45	3.89	2.33	1.97
38	Tibbi	UG	2.72 ± 0.28	1.26	1.20	1.08	9.39	5.62	4.76
39	Pir Kamria	SW	0.99 ± 0.17	0.46	0.44	0.39	3.43	2.05	1.74
40	Pir Kamria	UG	0.73 ± 0.15	0.34	0.32	0.29	2.53	1.51	1.28
41	Panni Wala	SW	0.93 ± 0.18	0.43	0.41	0.37	3.22	1.93	1.64
42	Panni Wala	UG	3.03 ± 0.29	1.40	1.33	1.20	10.47	6.27	5.31
43	Hanumangarh	UG	3.16 ± 0.31	1.46	1.39	1.25	10.91	6.53	5.53
44	Satipura	SW	1.18 ± 0.19	0.55	0.52	0.47	4.09	2.45	2.07
45	Satipura	SW	2.67 ± 0.28	1.23	1.17	1.06	9.22	5.52	4.68
46	Chak Jawala Singh	UG	7.35 ± 0.46	3.40	3.23	2.91	25.36	15.18	12.86
47	Chak Jawala Singh	SW	7.65 ± 0.48	3.54	3.36	3.03	26.41	15.81	13.40
48	Hanumangarh Town	SW	0.29 ± 0.09	0.13	0.13	0.11	0.99	0.59	0.50
49	Hanumangarh Town	SW	0.21 ± 0.08	0.10	0.09	0.08	0.74	0.44	0.37

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
50	Hanumangarh Town	UG	7.92 ± 0.49	3.66	3.48	3.14	27.31	16.35	13.85
Minimum			0.11 ± 0.06	0.05	0.05	0.04	0.37	0.22	0.19
Maximum			8.73 ± 0.5	4.03	3.84	3.46	30.11	18.02	15.27
Average			2.07 ± 0.21	0.96	0.91	0.82	7.14	4.27	3.62
Standard deviation			2.41	1.12	1.06	0.95	8.33	4.99	4.22
Geomatric mean			0.92 ± 0.17	0.43	0.41	0.37	3.21	1.92	1.63

Table 4.2: Radon concentration and annual effective dose in water samples of Sri Ganganagar district

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
1	Sri Ganganagar	UG	1.74 ± 0.22	16.06	15.28	13.77	11.69	9.36	6.66
2	39 LNP	UG	1.36 ± 0.13	12.53	11.92	10.75	9.12	7.30	5.20
3	Binjwala	UG	2.20 ± 0.16	20.28	19.30	17.39	14.77	11.82	8.41
4	RaiSingh Nagar	UG	1.16 ± 0.10	10.74	10.22	9.21	7.82	6.26	4.46
5	70 RB	UG	0.8 ± 0.12	7.79	7.41	6.68	5.67	4.54	3.23
6	Fojuwala	UG	2.87 ±0.22	26.50	25.22	22.73	19.30	15.44	10.99
7	GujSinghwala	UG	1.51 ± 0.21	13.95	13.27	11.96	10.16	8.13	5.79
8	Kesri Singh Pur	UG	0.61 ± 0.16	5.64	5.37	4.84	4.11	3.29	2.34
9	Jorawar	UG	0.93 ± 0.26	8.56	8.15	7.34	6.23	4.99	3.55
10	Aryan	UG	1.03 ± 0.20	9.50	9.04	8.15	6.92	5.53	3.94
11	Lakhiyan	UG	1.24 ±0.24	11.44	10.89	9.81	8.33	6.67	4.75
12	Karanpur	UG	0.65 ±0.12	6.00	5.71	5.15	4.37	3.50	2.49
13	Sadul Shehar	UG	1.11 ± 0.16	10.30	9.80	8.83	7.50	6.00	4.27
14	Roop Nagar	UG	0.59 ± 0.06	5.46	5.19	4.68	3.97	3.18	2.26
15	Gulabewala	UG	0.67 ± 0.07	6.16	5.86	5.28	4.48	3.59	2.55
16	Gharsana	UG	1.0 ± 0.16	9.83	9.35	8.43	7.16	5.73	4.08

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
17	Netewala	UG	0.8 ± 0.12	7.37	7.01	6.32	5.37	4.29	3.06
18	AnoopGarh	UG	1.5 ± 0.16	14.53	13.82	12.46	10.58	8.46	6.02
19	Kalwasia	UG	0.3 ± 0.06	3.65	3.47	3.13	2.66	2.13	1.51
20	Banda Colony	UG	1.2 ± 0.17	11.74	11.17	10.07	8.55	6.84	4.87
21	Padampura	UG	0.7 ± 0.12	7.04	6.70	6.04	5.13	4.10	2.92
22	Khaliwala	UG	1.18±0.21	10.93	10.40	9.37	7.96	6.37	4.53
23	Sadhawali	UG	0.89 ± 0.13	8.21	7.82	7.04	5.98	4.79	3.41
24	Ghumadwali	UG	1.5 ± 0.13	13.82	13.15	11.85	10.06	8.05	5.73
25	39 LNP	UG	2.43 ± 0.16	22.44	21.35	19.25	16.34	13.08	9.31
26	Binjwala	UG	1.91 ± 0.15	17.69	16.83	15.17	12.88	10.31	7.34
27	RaiSingh Nagar	UG	1.95 ± 0.15	18.02	17.15	15.45	13.12	10.50	7.47
28	70 RB	UG	1.62 ± 0.19	14.98	14.25	12.84	10.91	8.73	6.21
29	Fojuwala	UG	3.74 ± 0.21	34.52	32.85	29.60	25.13	20.11	14.32
30	GujSinghwala	UG	2.4 ± 0.22	22.90	21.79	19.64	16.68	13.35	9.50
31	Kesri Singh Pur	UG	0.8 ± 0.09	8.06	7.67	6.91	5.87	4.70	3.34
32	Lalgarh	UG	1.62 ± 0.13	14.95	14.22	12.82	10.88	8.71	6.20
33	Aryan	UG	2.03 ± 0.12	18.80	17.89	16.12	13.69	10.96	7.80

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
34	Lakhyan	UG	1.66 ± 0.12	15.31	14.56	13.13	11.14	8.92	6.35
35	Karanpur	UG	1.16 ± 0.10	10.74	10.22	9.21	7.82	6.26	4.46
36	Sadul Shehar	UG	1.97 ± 0.19	18.25	17.36	15.65	13.29	10.63	7.57
37	Roop Nagar	UG	0.95 ± 0.09	8.82	8.39	7.56	6.42	5.14	3.66
38	Gulabewala	UG	1.32 ± 0.12	12.21	11.62	10.47	8.89	7.12	5.07
39	Gharsana	UG	2.2 ± 0.17	20.90	19.89	17.92	15.22	12.18	8.67
40	Netewala	UG	1.92 ± 0.09	17.74	16.88	15.22	12.92	10.34	7.36
41	AnoopGarh	UG	1.96 ± 0.16	18.11	17.24	15.53	13.19	10.55	7.51
42	Kalwasia	UG	0.78 ± 0.06	7.17	6.82	6.14	5.22	4.17	2.97
43	Banda Colony	UG	1.81 ± 0.12	16.75	15.93	14.36	12.19	9.76	6.95
44	Padampura	UG	1.09 ± 0.08	10.12	9.63	8.67	7.36	5.89	4.20
45	Khaliwala	UG	1.92 ± 0.16	17.74	16.88	15.22	12.92	10.34	7.36
46	Sadhawali	UG	1.92 ± 0.11	17.74	16.88	15.22	12.92	10.34	7.36
47	Ghumadwali	UG	2.5 ± 0.09	23.23	22.11	19.92	16.92	13.54	9.64
48	Sri Ganganagar	UG	2.8 ± 0.21	25.93	24.67	22.23	18.88	15.11	10.75
49	Lalgarh	UG	1.9 ± 0.22	18.10	17.23	15.52	13.18	10.55	7.51
50	39 LNP	SW	0.4 ± 0.11	4.10	3.90	3.52	2.99	2.39	1.70

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
51	RaiSingh Nagar	SW	0.22 ± 0.08	2.04	1.94	1.75	1.48	1.19	0.84
52	Fojuwala	SW	0.3 ± 0.09	3.03	2.89	2.60	2.21	1.77	1.26
53	Binjwala	SW	0.58± 0.12	5.37	5.11	4.60	3.91	3.13	2.23
54	GujSinghwala	SW	0.2 ± 0.08	2.00	1.91	1.72	1.46	1.17	0.83
55	Kesri Singh Pur	SW	0.21 ± 0.07	1.92	1.83	1.65	1.40	1.12	0.80
56	Sri Ganganagar	SW	0.30 ± 0.08	2.77	2.63	2.37	2.01	1.61	1.15
57	Aryan	SW	0.27 ± 0.08	2.54	2.42	2.18	1.85	1.48	1.05
58	Lakhyan	SW	0.25 ± 0.08	2.28	2.17	1.96	1.66	1.33	0.95
59	Karanpur	SW	0.24 ± 0.07	2.20	2.09	1.89	1.60	1.28	0.91
60	Sadul Shehar	SW	0.31± 0.09	2.85	2.71	2.44	2.07	1.66	1.18
61	Roop Nagar	SW	0.20 ± 0.07	1.84	1.75	1.58	1.34	1.07	0.76
62	Gulabewala	SW	0.25 ± 0.08	2.35	2.24	2.02	1.71	1.37	0.98
63	Gharsana	SW	0.20 ± 0.07	1.89	1.80	1.62	1.38	1.10	0.78
64	Netewala	SW	0.23 ± 0.10	2.16	2.05	1.85	1.57	1.26	0.90
65	AnoopGarh	SW	0.20 ± 0.08	1.87	1.78	1.60	1.36	1.09	0.78
66	Kalwasia	SW	0.15 ± 0.07	1.38	1.31	1.18	1.00	0.80	0.57
67	Banda Colony	SW	0.15 ± 0.07	1.40	1.33	1.20	1.02	0.81	0.58

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
68	Padampura	SW	0.22 ± 0.07	2.00	1.91	1.72	1.46	1.17	0.83
69	Khaliwala	SW	0.23 ± 0.06	2.11	2.01	1.81	1.53	1.23	0.87
70	Sadhawali	SW	0.13 ± 0.04	1.21	1.15	1.04	0.88	0.71	0.50
71	Ghumadwali	SW	0.20 ± 0.07	1.88	1.79	1.61	1.37	1.10	0.78
72	Lalgarh	SW	0.35± 0.06	3.27	3.11	2.80	2.38	1.90	1.36
73	70 RB	SW	0.23 ± 0.10	2.13	2.02	1.82	1.55	1.24	0.88
74	Jorawar	SW	0.15 ± 0.05	1.39	1.32	1.19	1.01	0.81	0.58
75	39 LNP	SW	0.55 ± 0.12	5.12	4.87	4.39	3.73	2.98	2.12
76	Binjwala	SW	0.92 ± 0.15	8.52	8.11	7.31	6.20	4.97	3.53
77	RaiSingh Nagar	SW	0.27 ± 0.07	2.47	2.35	2.12	1.80	1.44	1.02
78	70 RB	SW	0.30 ± 0.09	2.81	2.67	2.41	2.04	1.64	1.16
79	Fojuwala	SW	1.87 ± 0.22	17.24	16.40	14.78	12.55	10.04	7.15
80	GujSinghwala	SW	0.49 ± 0.11	4.54	4.32	3.90	3.31	2.65	1.88
81	Kesri Singh Pur	SW	0.13±0.07	1.24	1.18	1.07	0.91	0.72	0.52
82	Jorawar	SW	0.40 ± 0.10	3.67	3.49	3.15	2.67	2.14	1.52
83	Jorawar	SW	0.28 ± 0.09	2.57	2.45	2.20	1.87	1.50	1.07
84	Sri Ganganagar	SW	0.42 ± 0.13	3.85	3.67	3.31	2.81	2.25	1.60

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
85	Lakhyan	SW	0.32± 0.10	2.99	2.85	2.57	2.18	1.74	1.24
86	Aryan	SW	0.34 ± 0.10	3.14	2.98	2.69	2.28	1.83	1.30
87	Karanpur	SW	0.28± 0.08	2.56	2.44	2.20	1.86	1.49	1.06
88	Sadul Shehar	SW	0.32 ± 0.07	2.95	2.81	2.53	2.15	1.72	1.22
89	Roop Nagar	SW	0.30 ± 0.09	2.81	2.67	2.41	2.04	1.64	1.16
90	Gulabewala	SW	0.16 ± 0.07	1.51	1.44	1.30	1.10	0.88	0.63
91	Gharsana	SW	0.41 ± 0.10	3.82	3.64	3.28	2.78	2.23	1.59
92	Netewala	SW	0.27 ± 0.10	2.54	2.42	2.18	1.85	1.48	1.05
93	AnoopGarh	SW	0.48 ± 0.07	4.43	4.22	3.80	3.23	2.58	1.84
94	Kalwasia	SW	0.13± 0.06	1.17	1.12	1.01	0.85	0.68	0.49
95	Banda Colony	SW	0.51± 0.11	4.74	4.51	4.06	3.45	2.76	1.97
96	Padampura	SW	0.21 ± 0.08	1.96	1.87	1.68	1.43	1.14	0.81
97	Khaliwala	SW	0.41 ± 0.10	3.78	3.60	3.24	2.75	2.20	1.57
98	Sadhawali	SW	0.27 ± 0.10	2.50	2.38	2.14	1.82	1.46	1.04
99	Ghumadwali	SW	0.50 ± 0.08	4.65	4.42	3.98	3.38	2.71	1.93
100	Lalgarh	SW	0.57 ± 0.10	5.25	5.00	4.50	3.82	3.06	2.18
Minimum			0.13 ± 0.04	1.17	1.12	1.01	0.85	0.68	0.49

S. No.	Place	Source of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to inhalation (μSvy^{-1})			Annual effective dose due to ingestion (μSvy^{-1})		
				Infants	**Children**	**Adults**	**Infants**	**Children**	**Adults**
Maximum			3.74 ± 0.26	34.52	32.85	29.60	25.13	20.11	14.32
Average			0.92 ± 0.12	8.5	8.09	7.29	6.19	4.95	3.53
Standard deviation			0.26	2.43	2.32	2.08	1.77	1.42	1.01
Geometric mean			0.29 ± 0.09	2.70	2.57	2.32	1.97	1.58	1.12

Table 4.3: Radon concentration and annual effective dose in water samples of Churu district

S. No.	Place	Sources of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to Inhalation (μSvy^{-1})			Annual effective dose due to Ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
1	Sardarshehar	SW	2.99 ± 0.16	27.67	26.33	23.73	20.15	16.12	11.48
2		UG	4.74 ± 0.20	43.83	41.71	37.59	31.91	25.54	18.18
3		UG	4.23 ± 0.23	39.11	37.21	33.54	28.47	22.78	16.22
4		SW	1.27 ± 0.12	11.73	11.16	10.06	8.54	6.83	4.87
5	Jasrasar	SW	0.94 ± 0.13	8.67	8.25	7.43	6.31	5.05	3.59
6		SW	2.95 ± 0.09	27.22	25.90	23.34	19.82	15.86	11.29
7		UG	3.86 ± 0.17	35.68	33.95	30.60	25.98	20.79	14.80
8		UG	4.43 ± 0.22	40.92	38.94	35.10	29.80	23.84	16.97
9	Malsar	SW	0.60 ± 0.13	5.56	5.29	4.77	4.05	3.24	2.31
10		UG	2.31 ± 0.15	21.32	20.29	18.28	15.52	12.42	8.84
11		UG	2.65 ± 0.20	24.53	23.34	21.03	17.86	14.29	10.17
12		SW	1.57 ± 0.08	14.47	13.77	12.41	10.54	8.43	6.00
13	Salasar	SW	1.18 ± 0.10	10.92	10.39	9.36	7.95	6.36	4.53
14		SW	0.42 ± 0.07	3.92	3.73	3.36	2.85	2.28	1.62

S. No.	Place	Sources of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to Inhalation (μSvy^{-1})			Annual effective dose due to Ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
15		UG	1.96 ± 0.12	18.15	17.27	15.57	13.22	10.58	7.53
16		UG	2.06 ± 0.08	19.01	18.09	16.30	13.84	11.07	7.88
17	Asalrsar	SW	1.74 ± 0.22	16.06	15.28	13.77	11.69	9.36	6.66
18		UG	3.79 ± 0.14	35.06	33.36	30.07	25.53	20.43	14.54
19		SW	0.51 ± 0.07	4.73	4.50	4.06	3.44	2.76	1.96
20		SW	1.62 ± 0.13	14.98	14.25	12.84	10.91	8.73	6.21
21	Churu	SW	2.67 ± 0.11	24.68	23.49	21.17	17.97	14.38	10.24
22		SW	0.90 ± 0.14	8.28	7.87	7.10	6.03	4.82	3.43
23		UG	4.02 ± 0.12	37.11	35.31	31.83	27.02	21.62	15.39
24		UG	4.36 ± 0.14	40.32	38.36	34.58	29.35	23.49	16.72
25	Ratangarh	SW	0.54 ± 0.08	5.01	4.76	4.29	3.65	2.92	2.08
26		SW	0.85 ± 0.09	7.87	7.49	6.75	5.73	4.59	3.27
27		UG	2.28 ± 0.11	21.02	20.00	18.03	15.31	12.25	8.72
28		UG	1.99 ± 0.11	18.43	17.54	15.81	13.42	10.74	7.65
29		SW	1.05 ± 0.10	9.71	9.24	8.33	7.07	5.66	4.03

S. No.	Place	Sources of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to Inhalation (μSvy^{-1})			Annual effective dose due to Ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
30	Motisar	SW	0.30 ± 0.08	2.76	2.62	2.36	2.01	1.61	1.14
31		UG	1.53 ± 0.08	14.10	13.42	12.10	10.27	8.22	5.85
32		UG	1.81 ± 0.07	16.76	15.94	14.37	12.20	9.76	6.95
33	Dhadar	SW	1.32 ± 0.11	12.15	11.56	10.42	8.85	7.08	5.04
34		SW	0.36 ± 0.08	3.34	3.18	2.87	2.43	1.95	1.39
35		UG	1.75 ± 0.08	16.15	15.37	13.85	11.76	9.41	6.70
36		UG	1.71 ± 0.05	15.81	15.04	13.56	11.51	9.21	6.56
37	Bhojrasar	SW	0.82 ± 0.06	7.57	7.20	6.49	5.51	4.41	3.14
38		SW	0.45 ± 0.04	4.12	3.92	3.54	3.00	2.40	1.71
39		UG	1.48 ± 0.12	13.69	13.03	11.74	9.97	7.98	5.68
40		UG	2.20 ± 0.10	20.34	19.36	17.45	14.81	11.85	8.44
41	Bhanipur	SW	0.55 ± 0.07	5.09	4.84	4.36	3.70	2.96	2.11
42		SW	1.40 ± 0.10	12.96	12.33	11.12	9.44	7.55	5.38
43		UG	2.89 ± 0.10	26.68	25.38	22.88	19.42	15.54	11.06
44		UG	2.62 ± 0.07	24.19	23.02	20.74	17.61	14.09	10.03

S. No.	Place	Sources of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to Inhalation (μSvy^{-1})			Annual effective dose due to Ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
45	Aspalsar	SW	0.60 ± 0.11	5.58	5.31	4.79	4.06	3.25	2.32
46		SW	0.23 ± 0.05	2.16	2.05	1.85	1.57	1.26	0.90
47		UG	1.64 ± 0.10	15.14	14.41	12.99	11.02	8.82	6.28
48		UG	1.79 ± 0.09	16.51	15.71	14.16	12.02	9.62	6.85
49	Bhaghsar Purvi	SW	1.54 ± 0.15	14.23	13.54	12.20	10.36	8.29	5.90
50		SW	0.58 ± 0.06	5.33	5.07	4.57	3.88	3.10	2.21
51		UG	3.25 ± 0.12	30.01	28.55	25.73	21.85	17.48	12.45
52		UG	3.78 ± 0.17	34.96	33.27	29.98	25.46	20.37	14.50
53	Gudawadi	UG	2.77 ± 0.22	25.56	24.32	21.92	18.61	14.89	10.60
54		UG	2.48 ± 0.21	22.96	21.84	19.69	16.71	13.37	9.52
55		SW	1.52 ± 0.18	14.02	13.34	12.02	10.21	8.17	5.82
56		SW	0.87 ± 0.10	8.00	7.61	6.86	5.82	4.66	3.32
57	Nakrasar	UG	3.16 ± 0.20	29.16	27.75	25.01	21.23	16.99	12.10
58		UG	2.95 ± 0.15	27.25	25.93	23.37	19.84	15.88	11.30
59		SW	0.92 ± 0.18	8.52	8.11	7.31	6.20	4.97	3.53

S. No.	Place	Sources of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to Inhalation (μSvy^{-1})			Annual effective dose due to Ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
60	Sujangarh	SW	1.51 ± 0.10	13.92	13.24	11.94	10.13	8.11	5.77
61		UG	2.80 ± 0.17	25.92	24.66	22.22	18.87	15.10	10.75
62		UG	2.36 ± 0.22	21.80	20.75	18.70	15.88	12.70	9.04
63		SW	0.64 ± 0.08	5.90	5.61	5.06	4.30	3.44	2.45
64		CW	1.11 ± 0.15	10.27	9.77	8.81	7.48	5.98	4.26
65	Rajgarh	SW	0.60 ± 0.07	5.52	5.25	4.73	4.02	3.22	2.29
66		SW	1.22 ± 0.11	11.30	10.75	9.69	8.23	6.58	4.69
67		UG	2.40 ± 0.15	22.16	21.09	19.01	16.14	12.91	9.19
68		UG	1.90 ± 0.10	17.55	16.70	15.05	12.78	10.22	7.28
69	Shobasar	UG	1.62 ± 0.15	14.93	14.20	12.80	10.87	8.70	6.19
70		UG	1.68 ± 0.08	15.49	14.74	13.29	11.28	9.03	6.43
71		SW	0.84 ± 0.11	7.78	7.40	6.67	5.67	4.53	3.23
72		SW	0.41 ± 0.05	3.81	3.63	3.27	2.78	2.22	1.58
73		UG	2.18 ± 0.18	20.18	19.20	17.31	14.69	11.76	8.37
74		UG	1.85 ± 0.14	17.14	16.31	14.70	12.48	9.98	7.11

S. No.	Place	Sources of water	$C_{wat} \pm \sigma$ (BqL^{-1})	Annual effective dose due to Inhalation (μSvy^{-1})			Annual effective dose due to Ingestion (μSvy^{-1})		
				Infants	Children	Adults	Infants	Children	Adults
75	loonch	SW	0.85 ± 0.08	7.81	7.43	6.70	5.69	4.55	3.24
76		SW	0.52 ± 0.05	4.77	4.54	4.09	3.47	2.78	1.98
77	Sawar	SW	0.32 ± 0.05	2.93	2.79	2.51	2.13	1.71	1.22
78		SW	0.69 ± 0.07	6.40	6.09	5.49	4.66	3.73	2.66
79		UG	2.14 ± 0.10	19.82	18.86	17.00	14.43	11.55	8.22
80		UG	1.88 ± 0.15	17.39	16.55	14.92	12.66	10.13	7.21
Minimum			0.23 ± 0.04	2.16	2.05	1.85	1.57	1.26	0.90
Maximum			4.74 ± 0.23	43.83	41.71	37.59	31.91	25.54	18.18
Average			1.79 ± 0.12	16.55	15.75	14.19	12.05	9.64	6.86
Standard deviation			0.89	8.29	7.89	7.11	6.04	4.83	3.44
Geometric mean			1.25 ± 0.10	11.58	11.02	9.93	8.42	6.75	4.80

*UG- Underground water, SW- Surface water.

Table 4.4: Comparison of radon concentration in water with similar investigations in other areas

S. No.	Area	Radon concentration in water (BqL^{-1})		Reference
		Range	Mean Value	
1.	Romania	0.9 – 68.9	11.4	Nita et al. 2013
2.	Garhwal Himalaya	1.7 – 57.7	20	Kandari et al. 2015
3.	Chihuahua, Maxico	-	16.1	Villalba et al. 2005
4.	Finland	27 – 460	-	Vesterbacka et al. 2004
5.	Australia	0.14-20.33	-	Antinks et al. 2016
6.	Srinagar, NW Himalaya	0.2 - 38.5	8.9	Nazir et al. 2020
7.	Brazil	0.95– 36	36	Marques et al., 2004
8.	Jhunjhunu, Bikaner	0.5-22	4.42	Mittal et al., 2015
9.	Churu district	0.5- 4.9	2.6	Rani et al., 2013
10.	Mansa and Mukutsar	1-14	-	Mehra et al., 2015
11.	Sirsa, Haryana	0.6-7.8	-	Sharma et al., 2017
12.	NTPC, Dadri	17-68	33	Kumar et al., 2022
13.	**Hanumangarh district, Rajasthan**	0.11- 8.73	2.07	**Present study**
14.	**Sri Ganganagar district, Rajasthan**	0.13 – 3.74	0.92	
15.	**Churu district, Rajasthan**	0.23 – 4.74	1.79	