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Radon levels and health risks in groundwater of Ferozepur district, Punjab

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ABSTRACT

Radon levels were measured in groundwater samples taken from Ferozepur district in Punjab, India. Radon concentration was recorded on-site using RAD7 detector. Activity concentration of radon ranged from 9.36 Bq/L to 25.36 Bq/L. Average value was 15.45 Bq/L with a Root Mean Square Deviation of 8.075 Bq/L. Twenty samples of ground water had radon concentrations higher than USEPA safety limit of 11 Bq/L, yet remained below alternative upper threshold of 148 Bq/L recommended by agency. However, all values were below action levels set by UNSCEAR, EC, and WHO, which are 40 Bq/L and 100 Bq/L respectively. Annual effective dose from inhalation varied between 0.000024 to 0.000064 mSv/y, while ingestion dose ranged between 0.023 to 0.064 mSv/y. Average annual effective dose was 0.000039 mSv/y for inhalation and 0.039 mSv/y for ingestion, with standard deviations of 0.000020 mSv/y and 0.020 mSv/y, correspondingly. Average annual effective dose from both ingestion and inhalation was lower than WHO recommended limit of 0.1 mSv/y. Most of measured values followed global guidelines set by WHO. However, in some cases, ingestion doses exceeded average taken over world i.e. 0.002 mSv/y given by UNSCEAR. Therefore, regular monitoring is advised. Excess lifetime cancer risk due to radon exposure in study area remained under permissible threshold of 1.45 × 10⁻³ specified by UNSCEAR.

Keywords: Cancer risk; Effective Dose; Exposure; Health Risk; Water consumption

INTRODUCTION

Radon (^{222}Rn), a noble gas, occurs naturally as part of uranium decay chain which is emitted through radioactive decay of radium-226 (^{226}Ra), available in uranium-bearing minerals within rocks and subsurface geological formations. This is a important cause of exposure to natural radiation for humans in everyday life. This gas lacks colour and smell and possesses a half-life of 3.8 days, and emits alpha particles. This is only gaseous constituent of uranium-238 (^{238}U) decay series and is continuously produced in environments containing ^{238}U or ^{226}Ra (Cothern, 1990; UNSCEAR, 2000, 2006; WHO, 2022). Granite rocks are typically rich in ^{238}U, which leads to the formation of its decay product, ^{226}Ra. This process influences the quality of the surrounding groundwater (Szabo *et al.,* 2012). Radon poses a health risk to the population when it moves from these geological formations to surface, especially through groundwater pathways (Duggal *et al.,* 2013). As a result, drinking water sources may become contaminated with radon. Radon activity levels can vary widely in groundwater. Surface water typically exhibits low levels of ^{222}Rn because it is exposed to the atmosphere, allowing radon to escape easily due to temperature changes. In contrast, groundwater often shows higher radon levels, especially when it flows through granite rocks (Ali *et al.,* 2010). Variations in radon levels in water are influenced by factors such as local geology, tectonic activity, weather conditions, and changes in soil structure (USEPA, 1999). According to USEPA (1999) permissible concentration of ^{222}Rn in drinking water should not exceed a threshold of 11 Bq/L. WHO(2008), EURATOM (2013) has set a reference level of 100 Bq/L for ^{222}Rn in water. ^{222}Rn is most significant radon isotope (Al-Nafiey *et al.,* 2014). Most of inhaled ^{222}Rn is exhaled quickly. However, its rapidly decaying byproducts, such as Polonium-218 and -214 act as sources of alpha radiation and can deposit on bronchial lining. This leads to internal exposure to alpha radiation. Radon inhalation has been established as a primary contributor to lung cancer and was classified as a carcinogenic substance by the WHO (1986). Epidemiological studies also suggest a possible link between ingested ^{222}Rn and stomach cancer (Ravi Kumar & Somashekar, 2014). Monitoring ^{222}Rn in water, particularly in groundwater, is essential to protect population from internal exposure through both

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inhalation and ingestion. Long-term exposure to radon can increase the risk of lung, blood, and stomach cancers (BEIR, 1999; UNSCEAR, 2006; Florou *et al.,* 2006; Nayak *et al.,* 2022; WHO, 2022). According to National Academy of Sciences, 89% of lung cancer cases linked to radon are due to inhalation of ^{222}Rn released from water, while 11% of stomach cancer cases are caused by ingesting water contaminated with ^{222}Rn (NASR, 1999). The groundwater quality is based on physical and chemical parameters which in turn are affected by climatic conditions, geological formations, and anthropogenic activities. Therefore, assessment of groundwater quality is important to ensure its safe use (Kumar *et. al.,* 2021). Regular auditing of radon levels in domestically used water is essential, particularly regions in which groundwater is main source of domestic purposes without any prior treatment. Present study assessed levels of ^{222}Rn in water samples, computed annual effective radiation dose, and estimated potential health risks linked to radon exposure through ingestion and inhalation pathways.

METHODOLOGY

Area of Investigation

Area considered in this study lies in Ferozepur District, situated at 31.0026° N latitude and 74.8741° E longitude. District covers a total area of 5,303 square kilometers, out of which 3,258.78 square kilometers fall under Bet region and 196.63 sq Km under Border area. It is situated east of Moga and Faridkot districts, and south of Muktsar. Twenty-two villages were selected to ensure complete coverage of district. The district was systematically divided into grids, and at least one sample was taken from each grid and investigated for concentration of Radon. Residents use this groundwater for domestic purposes without any prior treatment. Figure 1 depicts the grid map of district, indicating locations of sampling sites.

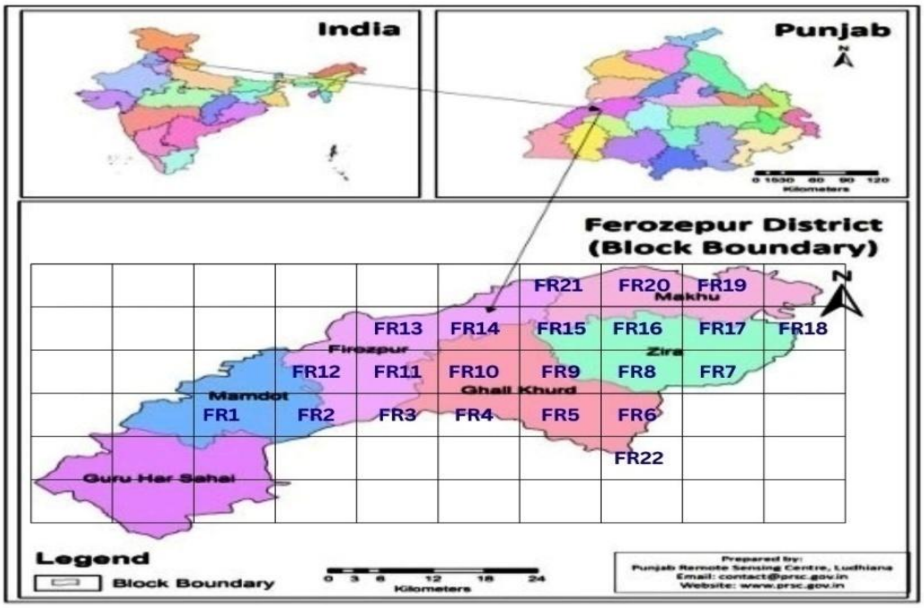

Figure 1: Location of Sampling Sites shown in Grid Map of District

Geological Characteristics of Study Area

Area under consideration is divided into three major belts that run roughly parallel to the Sutlej River. On the southwest side lies Bet region, locally called "Hittar," which has alluvial soil comprises of sand, silt, clay and often associated with kankar. Toward the southeast, Rohi and Mukhi Plains are characterized by sandy, light-textured soil, with brackish water commonly found in wells. In one part south of Sutlej River, within canal-irrigated and waterlogged zones of Ferozepur district. Soil pH increased with increase in soil depth (Gupta *et al.,* 2022). Groundwater under unconfined conditions is extracted using hand pumps (up to 30 meters deep), as well as shallow to medium-depth tubewells, reaching depths of up to 175 meters in northern region and up to 125 meters in central region of district. (Official report, Ferozepur District)

Sampling

Samples were drawn from borehole water sources in 22 villages using 250 ml reagent bottles. These samples were drawn from same water sources that residents use for their domestic needs. Collected water was untreated at time of sampling. Each bottle was filled carefully to avoid formation of air bubbles and then sealed tightly with a cap for ^{222}Rn analysis. Radon activity was determined using RAD7 electronic radon detector integrated with RAD H_2O attachment for water sample analysis (Durridge Co., USA). This detector uses semiconductor alpha sensor that enables direct conversion of alpha particle emissions into electrical signals. This detector can detect upto 4 pCi/L (equivalent to 0.148 Bq/L), with a 10% standard deviation. It comprises of multiple subsystems, including RAD7 monitoring unit for quantifying ^{222}Rn concentration emitted from water samples in gaseous form, sealed water container, fan-driven aeration setup, and a desiccant tube equipped with an integrated air particulate filter. Collected water samples reflect quality of tested sources. Geographic coordinates, along with date and time of sampling, were systematically recorded for each location. Table 1 lists details of sampling sites.

Table 1: Locations and details of Ferozepur districts sampling sites

Sample code	Description	Latitude (° N)	Longitude (° E)
FR1	Mudki	74.88	30.78
FR2	Kotkarur kalan	74.91	30.82
FR3	Wara bhai	74.81	30.82
FR4	Bhangar	74.73	30.84
FR5	Jhoke Hari har	74.61	30.87
FR6	JhokeTahal Singh	74.49	30.81
FR7	Lakho ke behram	74.15	30.83
FR8	Tibbi Khurd	74.51	30.90
FR9	Ferozepur	74.62	30.93
FR10	Sande Hasham	74.71	30.94
FR11	BambeLande	74.77	30.90
FR12	Hardasa	74.87	30.93
FR13	BandalePuana	74.98	30.95
FR14	Pandori Jattan	75.05	30.97
FR15	Lehrarahi	74.96	30.94
FR16	Alipur	74.90	31.01
FR17	Sarhali	74.92	31.10
FR18	Makhu	74.98	31.11
FR19	Malan wala	74.83	31.05
FR20	Dulchi Ke	74.62	30.99
FR21	Mahalam	74.67	31.01
FR22	Kohla	74.83	30.01

Estimation of ^{222}Rn concentration in Samples of Ground Water

Concentration of ^{222}Rn activity in collected samples of ground water was measured utilizing the RAD7 detector integrated with the RAD H_2O accessory unit. Figure 2 show experimental arrangement for water sample analysis.

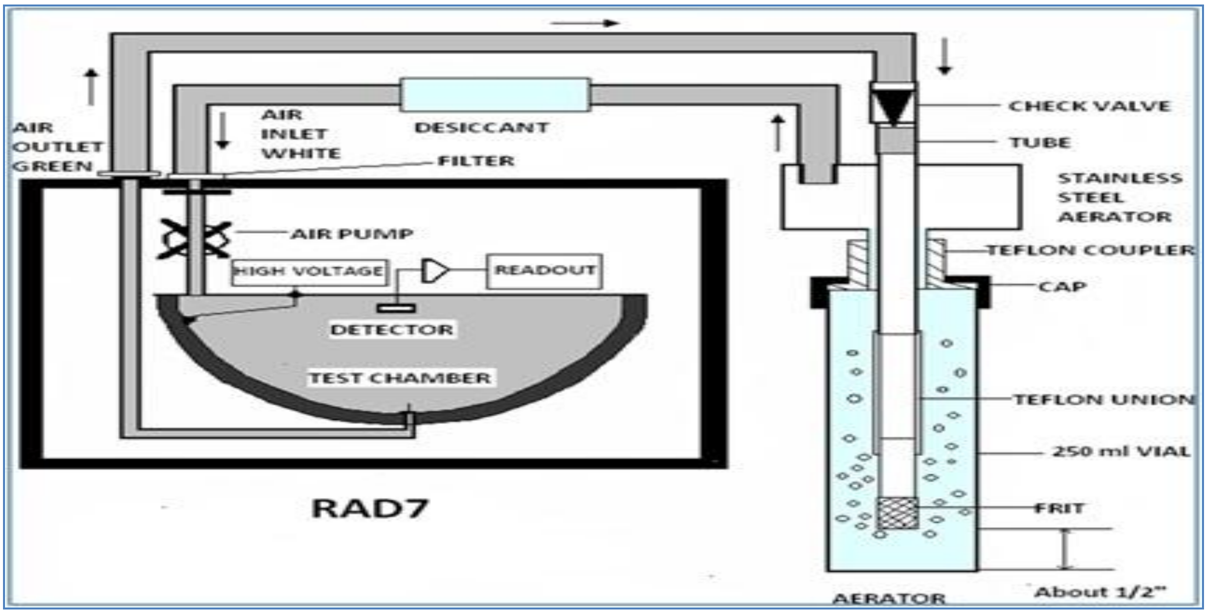

Figure 2: RAD H_2O assembly diagram (Kumar *et al.,* 2018)

Radon measurement procedure involves following steps: Initially, RAD7 radon detection chamber is purged to ensure cleanliness. Subsequently, sample bottle of 250 ml, along with fan assembly and drying tube, is connected to establish a closed-loop air circulation system equipped with an inline air filter. This setup keeps a consistent air-to-water volumetric ratio, ensuring that measurements are not affected by changes in airflow. When all components are joined together properly, RAD7 system is available to begin operation. During measurement, air circulation by internal pump aids in removing radon from water. This extraction process takes about five minutes. Once completed, released radon enters measuring chamber. RAD H_2O setup balances radon levels between water and air within five minutes. Device then takes four automatic readings and gives an average result. Each measurement cycle takes approximately 30 minutes. For a 250 mL sample, radon extraction efficiency is typically around 94% (Durridge Co., USA). All measurements were carried out immediately at sampling sites, with only a few minutes between sample collection and analysis. To ensure accurate readings, the RAD7 was thoroughly dried before each measurement to reduce relative humidity.

2.5. Annual Effective Dose

Total dose received from radon in groundwater has two components: (1) Radiation dose due to inhaled radon released into the atmosphere, and (2) Radiation dose due to consumption of radon-contaminated water. Average annual effective doses from radon ingestion and inhalation were evaluated using Eq. 1 and 2.

$E_{(Rn)Inh} = C_{(Rn)w} \times R_w \times T \times F \times D_f$ --------------------(1)

$E_{(Rn)Inh}$: Inhalation effective dose expressed in millisieverts per year (mSv/y).

R_w : Radon Levels in water samples (Bq/L).

$C_{(Rn)w}$: Radon Partition Ratio (Air/Tap Water) (10^{-4})

T : Mean residence stay of individuals in interior (7000 h/y).

F : Radon-Progeny Equilibrium Factor (0.4).

D_f : Radon exposure factor for dose conversion 9nSv $(Bqhm^{-3})^{-1}$.

$E_{(Rn)Ing} = C_{(Rn)W} \times WC \times D_f \times T$-------------- (2)

$E_{(Rn)Ing}$: Ingestion effective dose containing radon (Sv/y).

$C_{(Rn)W}$: Radon concentration in sampled water (Bq/L).

WC : Indicates annual water intake across different age groups. (e.g., 230 L/y for infants under year old, 330 L/y for children aged 2–17, and 730 L/y for adults over 17 years old) (Binesh, 2012; Charles, 2024).

DF : Ingestion dose conversion factors were 5.9 nSv/Bq for children, 3.5 nSv/Bq for adults and 23 nSv/Bq for infants. and 'T' is the time (1 year) (Pourshabanian et al., 2023).

The WHO has set a guideline limiting annual effective dose from drinking water to a maximum of 0.1 mSv/y (100 μSv/y) (Khan et al., *2022; Pourshabanian* et al., *2023; Ajibola* et al., *2021).*

2.6. Excess Lifetime Cancer Risk (ELCR)

To estimate the cancer risk from ionizing radiation exposure due to radon, equation provided by ICRP was used, as shown in Equation (3) (Cousin *et al.,* 2011).

$\text{Cancer Risk} = E \times LS \times CF \times 10^{-3}$ ----------(3)

Calculation of cancer mortality risk per unit of radiation exposure (in Sieverts) is based on three main parameters: mean annual effective dose (E) in mSv/y, average human lifespan (LS) of 70 years, and fatal cancer risk factor (CF), which is 5.5×10^{-2} per Sv (Eckerman *et al.,* 2012).

3. Observations and Analysis

This study aimed to evaluate radon levels in groundwater of Ferozepur District, Punjab, India, where local population depends heavily on groundwater for domestic and agricultural use. Radon concentrations were measured using active RAD7 detection technique. Results of radon measurements in groundwater are shown in Figure 3. Highest radon concentration was recorded at location FR10 with a value of 25.36 Bq/L, while lowest was observed at location FR20, measuring 9.36 Bq/L. Average concentration of radon was 15.45 Bq/L. Higher values observed in some areas may be linked to regional seismic activity or local geological formations.

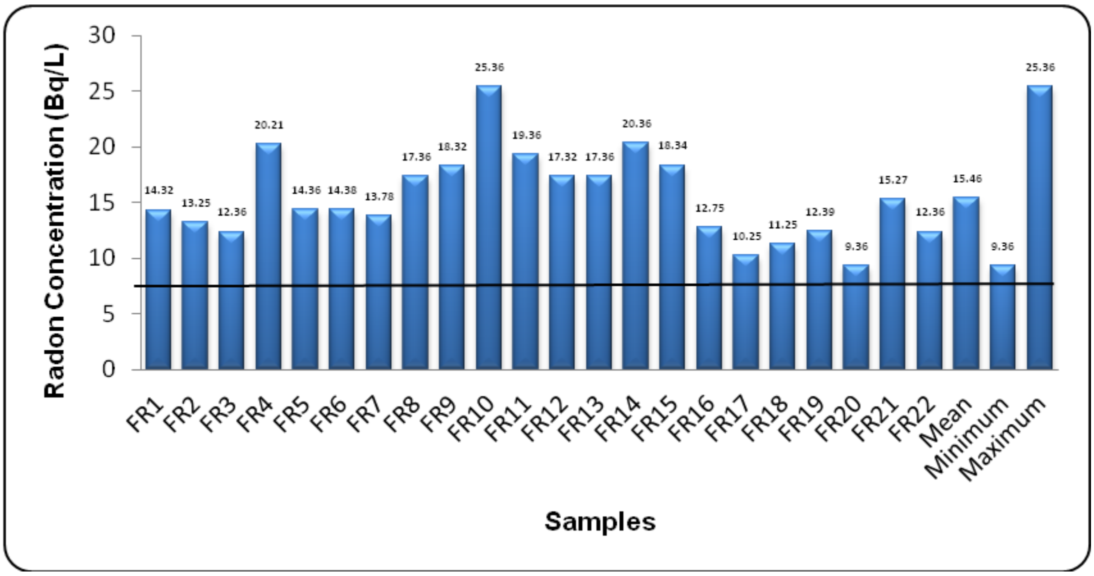

Figure 3: Values plotted for Radon concentration

Average radon concentration in 90% of samples exceeded USEPA guideline limit of 11 Bq/L. According to UNSCEAR (2008), recommended range of radon concentration in drinking water is between 4 and 40 Bq/L. All measured ^{222}Rn activity concentrations in this study were found to be below reference level of 100 Bq/L for drinking water, as specified by the European Commission guidelines (EC, 2001). Variations in radon levels in water are influenced by factors such as tectonic movement, local geology, weather conditions and changes in soil structure. Underlying geology and structural features of aquifers may also affect radon concentrations. Since residents of this district rely heavily on groundwater stored in aquifers for drinking and irrigation, continuous monitoring is essential to evaluate potential health risks from radon exposure. In areas with elevated radon levels, implementing mitigation measures can help minimize associated health risks for local population.

3.1. Health Implications of Radon Exposure 3.2.

Radon can enter human body by drinking contaminated water (ingestion) or by breathing air containing radon released from water (inhalation). In this study, effective radiation doses were estimated for both ingestion and inhalation for different age groups— adults, infants, and children. Figure 4 shows plotted results for: (a) inhalation dose, (b) ingestion dose for infants, and (c) ingestion dose for children and adults.

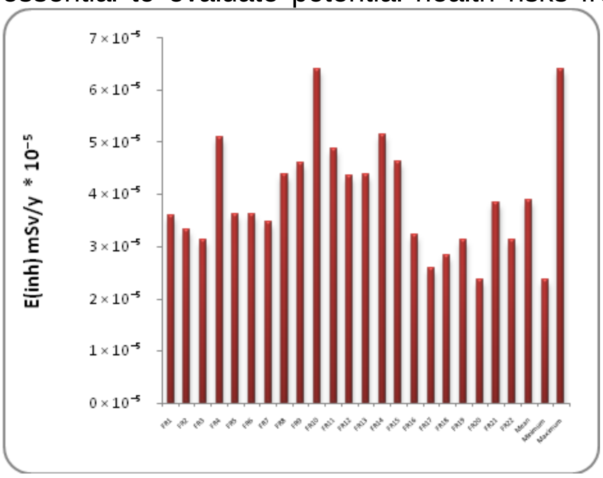

Figure 4(a): Plot for effectives doses of inhalation

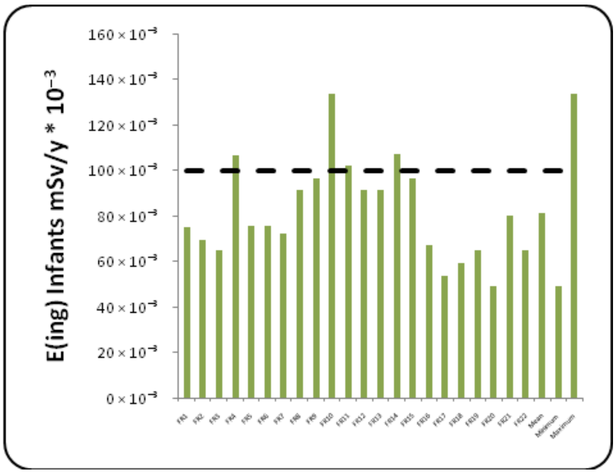

Figure 4(b): Plot for effectives ingestion doses for infants

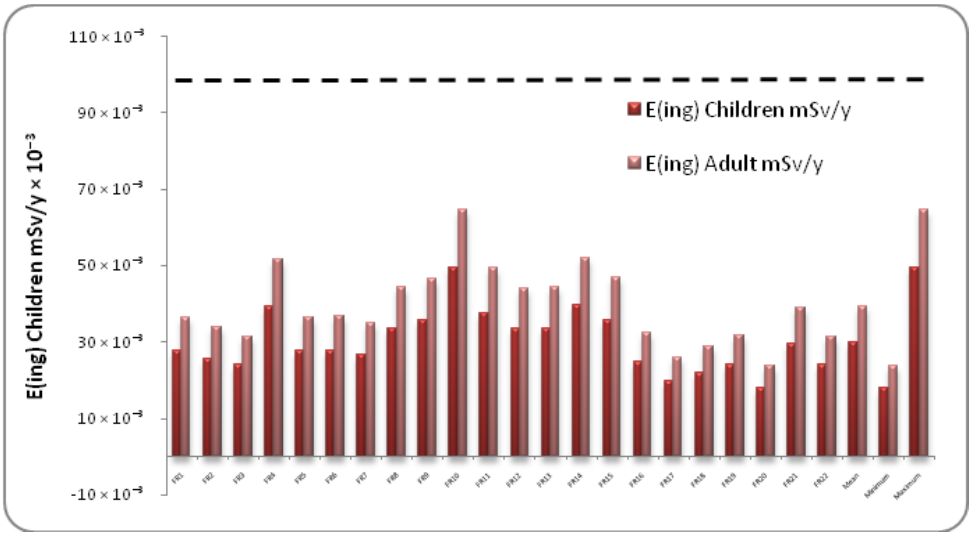

Figure 4(c): Plot for effectives ingestion doses for children and adults

As shown in Figure 4, highest effective dose from ingestion was recorded in infants, thereafter by adults, then children, with inhalation contributing least. Average effective dose from inhalation was 0.000039 mSv/y. For ingestion, mean effective dose was 0.030 mSv/y for children, 0.039 mSv/y for adults and 0.081 mSv/y for infants. According to WHO standards, the annual effective radiation dose from drinking water should not exceed 0.10 mSv/y. Number of samples went beyond the permissible ingestion level set by WHO, indicating potential health risks for infants. Infants had highest ingestion dose, followed by adults and then children. In some samples—FR4, FR10, FR11, and FR14—ingestion dose for infants was higher than recommended limit. However, ingestion doses for children and adults remained within WHO safety limits. Inhalation doses in all samples were also lower than recommended limit.

Cancer risk was calculated to assess potential carcinogenic effects of prolonged radon exposure. Results are shown in Figure 5 and compared with USEPA threshold of 1×10^{-4} (Shah *et al.,* 2024). Cancer risk values for locations FR17 and FR20 were within this limit. Mean Excess Lifetime Cancer Risk (ELCR) was 1.52×10^{-4}, which remains below safe limit of 1.45×10^{-3} recommended by (Taskin *et al.* 2009, UNSCEAR 2000).

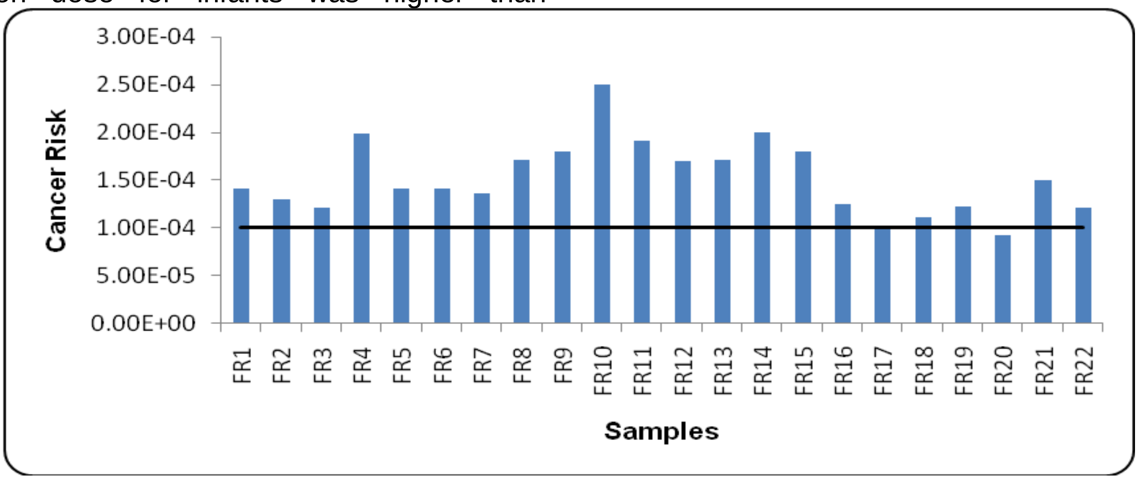

Figure 5: Graphical Representation of Cancer Risk from Radon Exposure

Radon exposure levels are affected by variables like variations in groundwater concentration, pre-sampling activities, and drinking water distribution system. Ignoring these factors may result in inaccurate exposure estimates and incorrect assessment of health risks for both adults and infants. Including site-specific parameters such as local geology and soil composition leads to more precise evaluations. This approach helps in creating specific plans to lower the possible health risks from radon exposure in the area.

3.3. Comparison with Other Studies

A comparison of radon concentrations from this study with global values was conducted and is presented in Table 3. Results of this study indicate that radon concentrations are generally low. In most regions of India, including present study area, levels remain below the USEPA action threshold of 11.1 Bq/L. However, Singh *et al.,* (2023) in Garhwal Himalaya, India reported some values that are above action level of 11.1 Bq/ L. Results of this study are nearly comparable to those found in Garhwal Himalaya region of India. Overall, results are under WHO action level of 100 Bq/L. This study reports higher radon concentrations compared to values observed in Romania, Brazil and Saudi Arabia. However, they are lower than levels reported in China and Pakistan, which showed higher radon concentrations. Overall, radon values measured in groundwater samples from this study fall within range reported by other researchers of India, shown in Table 3.

Table 3: Comparative Analysis of Radon Concentration with Global Studies

Additional Research	Radon Concentration(Bq/L)		References
	Range	Mean	
Romania	0.9 - 68.9	11.4	Nita *et al.,* (2024)
Brazil	0.95–36.00	2.35	Marques *et al.* (2004)
Saudi-Arabia	0.03 - 3.20	1.16	Mamun *et al.,* (2022)
China	0.71–3735	147.8	Zhuo *et al.* (2001)
Gilgit (Pakistan)	--------	250	Ullah *et al.,* (2022)
Northern Rajasthan, India	.5 -85.7	9.0	Rani *et al.,* (2013)
Bathinda, Punjab,India	.9-5.1	2.63	Duggal *et al.,* (2013)
Hanumangarh,Rajasthan,India	1.6-5.4	3.3	Duggal *et al.,* (2013)
Garhwal Himalaya, India	1.1-183.9	19.7	Singh *et al.,* (2023)
Ferozepur,Punjab ,India	9.36—25.36	15.45	Present investigations

CONCLUSIONS

This study presents the results of ^{222}Rn measurements from 22 groundwater samples collected across the Ferozepur district. Measurements were conducted using RAD7 radon detector, manufactured by Durridge Company Inc. Radon concentrations observed in groundwater from various areas of Ferozepur fall within safety limits suggested by UNSCEAR, European Commission (EC), and World Health Organization (WHO). However, in 90% of samples, radon concentrations exceeded maximum contaminant level of 11 Bq/L. Nevertheless, results remained within alternative maximum contaminant level of 148 Bq/L, as recommended by USEPA. To gain better insights into radon behavior, continuous monitoring in considered region is recommended. Total effective dose at all sampling sites was below safe limit of 0.1 mSv/y, as set by WHO and EU Council. Overall, findings indicate no considerable radiological or carcinogenic hazard from radon ingestion or inhalation for residents of studied areas.

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