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^{222}Rn and ^{220}Rn levels of Mansa and Muktsar district of Punjab, India

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In this study ^{222}Rn (Radon) measurement were performed in water and soil gas and also both ^{222}Rn and ^{220}Rn concentrations were determined in air of Mansa and Muktsar district of Punjab, India. The data then used for calculation of the annual effective dose for health risk assessment of public. Totally 35 locations have been selected for the measurements. All measurements (^{222}Rn and ^{220}Rn) were done with RAD7 detection system. The ^{222}Rn concentration in the water of studied area varies from 0.4 ± 0.2 Bq l^{-1} to 17 ± 2.8 Bq l^{-1}. The average value of ^{222}Rn concentration in soil, ^{222}Rn and ^{220}Rn concentrations in indoor air are 8 ± 3 kBq m^{-3}, 47 ± 21 Bq m^{-3}, and 39 ± 19 Bq m^{-3}, respectively. The total average annual effective dose for water samples is 13 µSv a^{-1} and for indoor air samples is 2.3 mSv a^{-1}. It has been observed that ^{222}Rn concentration in water has increased with depth of groundwater.

Keywords: ^{222}Rn (radon), ^{220}Rn (thoron), ingestion, inhalation, annual effective dose, PAEC

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Introduction

^{222}Rn is a radioactive inert gas that is a decay product of radium in the naturally occurring uranium series. The measurement of ^{222}Rn in the environment is of great interest due to its alpha emitting nature. A certain fraction of the ^{222}Rn escapes into the air, where in the outdoors; it is quickly diluted and is of no further concern. However, in confined spaces such as homes and office buildings, ^{222}Rn can accumulate to harmful levels. The main source of indoor ^{222}Rn and ^{220}Rn levels are the building material, soil and tap water. ^{222}Rn monitoring in soil involves either measuring ^{222}Rn in soil or measuring the ^{222}Rn flux from a soil, but the former measurement is more easy and quick by using the active technique of ^{222}Rn monitoring (Ruckerbauer and Winkler, 2001). ^{222}Rn is responsible for about half of the radiation dose received by the general population (UNSCEAR, 1994). The inhalation of ^{222}Rn and its progeny contributes more than 50% of the total dose from natural sources (UNSCEAR, 2000). A high value of the ^{222}Rn concentration in the particular geological area can be health hazard and will be the cause of lung Cancer for the residents of that area (Sevc et al., 1976; Khan, 2000). The ^{222}Rn from water contributes to the total inhalation risk associated with ^{222}Rn in indoor air. The high values of ^{222}Rn concentration in drinking water also lead to significant risk of stomach and gastrointestinal Cancer (Zhuo et al., 2001; Kendal and Smith, 2002).

As reported in earlier studies the concentration of Th, U, Pb, Cr, Ni, F and SO_4 are higher than the permissible limits in soil of South western Punjab (Kochhar et al., 2006; Mehra, 2009), so a study has been carried out in the Mansa and Muktsar area to make assessment of ^{222}Rn exposure for screening purpose and for investigating the geographical variation of the ^{222}Rn concentration as well as for the health-related hazards of the locality if any.The main objective of this work is to assess the indoor ^{222}Rn and ^{220}Rn Concentrations, soil gas concentration, ^{222}Rn concentration in water and the average annual effective dose to the population.

Geology

The scattered outcrops of the Aravali-Delhi Subgroup occur at Tosham (Haryana) just south of the study area i.e., Mansa and Muktsar districts as shown in **Figure 1**. The soil in the study area falls in the arid and moisture regime. The soils associated with alluvial planes shows better indurations and mature development of soil profile. They are composed of different layers of clay, sticky clay and fine to coarse grained micaceous sandstone (Kochhar et al., 2006).

Experimental Setup

An active technique RAD-7 in different modes has been used to measure the ^{222}Rn and ^{220}Rn concentration in air, water and soil of 35 locations in vicinity of Mansa and Muktsar districts of Punjab, India.

^{222}Rn and ^{220}Rn Measurement in Air

The measurement of ^{222}Rn and ^{220}Rn concentration in indoor air has been taken using RAD7 air accessories for continues 48 h protocol. EPA test protocols have been used for operating the RAD7 in indoor air (USEPA, 1993). The doors and windows of the houses were closed for at least 12 h before the measurement of ^{222}Rn and ^{220}Rn in air. The detector has an ability to distinguish alpha particles from ^{218}Po and ^{214}Po with energies of 6.0 and 7.9 MeV. RAD7 can measure the ^{222}Rn concentration > 0.4 Bq m^{-3} and $< 750{,}000$ Bq m^{-3}.

^{222}Rn Measurement in Water

The sampling locations of studied area have been chosen with great care and an attempt has been made to cover most of the area of study region. The in situ measurement of water samples was made using RAD- H_2O accessories. The RAD-H_2O uses a standard pre-calibrated degassing system and preset protocols, built into the RAD-7 which gives direct reading of ^{222}Rn concentration in water. A 250 ml vial has been used to collect the samples of water from various locations. A Wat– 250 protocol and grab mode with 5 min cycle and four recycles have been used to run the instrument for the estimation of ^{222}Rn in Water. The water samples have been collected from each village by varying the depth of ground water, surface water and tap water.

Soil Gas Measurement

For analysis of ^{222}Rn concentration in soil gas the measurements were done in same 35 locations and four measurements were done at each location. The pilot rod has been hammered into the ground to the depth required for sampling. Once the rod has been successfully driven to the required depth, the pilot rod has been removed for the penetration of drive rod along with probe more easily to sampling site. The drive rod has been positioned inside the probe and continuously hammered the rods together into the sampling site. When drive rod along with probe has come to be required depth then removed the drive rod from the sampling site and connects the probe with RAD7 soil accessories for sucking the soil gas

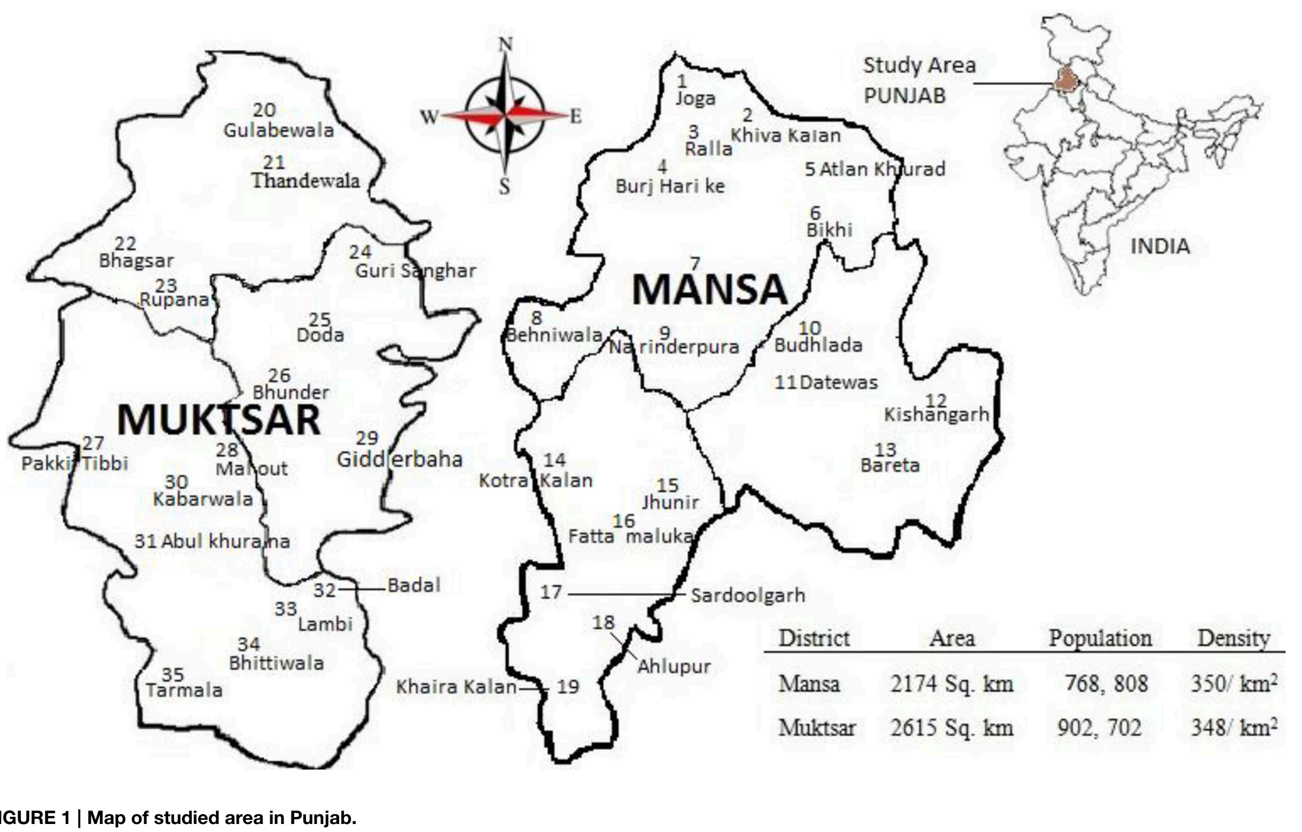

FIGURE 1 | Map of studied area in Punjab.

from deep soil. The soil gas sucked through the tube pipe into the measuring instrument for 5 min. The gab mode and sniff protocol were used for the soil gas sampling on the measuring instrument at each site. The measurement of ^{222}Rn and ^{220}Rn concentration in indoor air has been taken using RAD7 air accessories for continues 48 h protocol. EPA test protocols have been used for operating the RAD7 in indoor air (USEPA, 1993).

TABLE 1 | Average ^{222}Rn concentration data and annual effective dose of different water sources in Mansa and Muktsar Districts of Punjab.

S. no	Gps coordinates		Depth (m)	^{222}Rn (Bq l^{-1})	T (°C)	Annual effective dose of adults (μSv a^{-1})		
	Latitude	Longitude				Stomach	Lung	Total
1	30° 10′ 09.3″ N	75° 25′ 52.0″ E	27.4	17 ± 2.8	28.3	3.6	42.8	46.4
2	30° 06′ 3.2″ N	75° 34′ 11.3″ E	15.2	4 ± 0.7	24.9	0.8	10.1	10.9
3	30° 07′ 06.1″ N	75° 26′ 01.8″ E	13.7	7 ± 2.8	26.1	1.6	18.7	20.3
4	30° 05′ 10.6″ N	75° 20′ 55″ E	7.6	4 ± 0.9	26.8	0.8	10.1	10.9
5	30° 05′ 9.8″ N	75° 30′ 3.7″ E	18.2	1 ± 0.5	26.1	0.2	2.5	2.7
6	29° 57′ 45.1″ N	75° 32′ 75″ E	27.4	5 ± 1.4	24.9	1.1	12.6	13.7
7	29° 58′ 22″ N	75° 23′ 04.3″ E	10.7	2 ± 0.4	27.7	0.4	4.3	4.6
8	29° 55′ 35.7″ N	75° 11′ 49.6″ E	10.6	4 ± 0.7	27.1	0.7	8.9	9.6
9	29° 56′ 49.9″ N	75° 27′ 43.2″ E	12.1	6 ± 1.3	32.1	1.2	14.7	15.9
10	29° 56′ 22″ N	75° 33′ 18.1″ E	TW*	3 ± 0.5	26.8	0.6	7.1	7.7
11	29° 54′ 14.6″ N	75° 37′ 31.5″ E	27.4	3 ± 0.2	26.4	0.7	8.2	8.9
12	29° 54′ 19.4″ N	75° 44′ 11.3″ E	21.3	4 ± 1.5	26.4	0.8	10.1	10.9
13	29° 52′ 32.8″ N	75° 40′ 48.6″ E	13.7	4 ± 0.9	26.4	0.8	10.1	10.9
	29° 52′ 89″ N	75° 40′ 56.1″ E	12.1	6 ± 1.1	29.1	1.3	15.9	17.2
14	30° 03′ 42″ N	75° 33′ 34″ E	TW	2 ± 0.1	26.8	0.3	4.1	4.5
15	29° 47′ 50″ N	75° 19′ 59″ E	9.1	5 ± 0.4	28.3	1.1	12.6	13.7
	29° 47′ 41″ N	75° 19′ 56, , E	15.2	4 ± 0.9	27.9	0.8	9.0	9.7
	29° 47′ 45″ N	75° 19′ 53, , E	36.6	3 ± 0.5	27	0.6	7.6	8.2
	29° 47′ 48.4″ N	75° 19′ 58″ E	213.4	8 ± 2.4	27.2	1.8	21.1	22.9
16	29° 46′ 4.64″ N	75° 18′ 11.4″ E	TW	1 ± 0.5	24.2	0.3	3.3	3.6
17	30° 10′ 208″ N	74° 49′ 131″ E	24.3	3 ± 0.5	26.4	0.7	7.9	8.6
	30° 10′ 435″ N	74° 49′ 705″ E	13.7	4 ± 0.2	26.8	0.8	10.1	10.9
18	29° 40′ 11.5″ N	75° 19′ 10.3″ E	21.3	3 ± 0.8	24.3	0.5	6.4	6.9
19	29° 38′ 26.1″ N	75° 16′ 42.3″ E	TW	0.4 ± 0.2	28.3	0.1	1.0	1.1
20	30° 3′ 362″ N	74° 36′ 732″ E	10.6	8 ± 2.1	32.8	1.6	19.3	20.9
21	30° 47′ 824″ N	74° 51′ 514″ E	25.9	12 ± 2.4	27.7	2.6	31.1	33.7
22	30° 12′.001″ N	74° 29′.904″ E	12.1	2 ± 0.6	27.7	0.5	6.0	6.5
23	30° 24′ 26.8″ N	74° 31′ 52″ E	TW	1 ± 0.7	22.2	0.2	2.9	3.1
24	30° 12′ 41.1″ N	74° 9′ 51.6″ E	17.0	2 ± 0.3	27.1	0.5	5.4	5.9
25	30° 38′ 367″ N	74° 63′ 963″ E	15.2	6 ± 1.7	27.1	1.4	16.2	17.6
	30° 22′ 920″ N	74° 63′ 618″ E	TW	2 ± 0.6	27.7	0.4	5.0	5.5
26	30° 18′ 40.5″ N	75° 31′ 45.1″ E	21.3	14 ± 1.4	27.7	3.0	35.7	38.6
	30° 18′ 23.9 ″ N	74° 23′ 80″ E	TW	2 ± 0.2	26.8	0.4	5.0	5.5
27	30° 10′ 0.45″ N	74° 21′ 7.7″ E	TW	1 ± 0.4	23.5	0.2	2.4	2.6
28	30° 10′ 54.5″ N	74° 30′ 8.7″ E	10.6	3 ± 0.8	32.5	0.7	8.2	8.9
29	30° 12′.6.8″ N	74° 39′ 42″ E	7.6	4 ± 1.3	29.2	0.8	9.1	9.9
30	30° 04′ 32.3″ N	75° 20 ′38.2″ E	10.6	2 ± 0.8	28.6	0.5	5.7	6.1
31	30° 8′ 31.5″ N	74° 32′ 18.5″ E	7.6	4 ± 1.4	29.5	0.9	10.8	11.7
32	30° 4′ 35″ N	74° 40′ 3.6″ E	12.1	5 ± 0.6	32	1.0	11.4	12.4
33	30° 03′ 55.9″ N	74° 37′ 204″ E	12.1	4 ± 0.8	25.8	0.8	10.1	10.9
	30° 03′ 80.2″ N	74° 37′ 52.4″ E	10.6	7 ± 1.2	27.4	1.5	17.4	18.9
34	29° 58′ 39.4″ N	74° 30′ 20.1″ E	12.1	4 ± 1.5	32.8	0.9	10.8	11.7
35	30° 056′ 603″ N	74° 61′ 221″ E	27.4	10 ± 3.6	33.2	2.2	26.1	28.3
	30° 056′ 191″ N	74° 61.′ 443″ E	15.2	8 ± 1.2	27.7	1.7	20.2	21.8

TW = Tap Water.*

Theoretical Formalism

The ingestion, inhalation and annual effective dose have been calculated by Equations (1) and (2) (UNSCEAR, 2000).

$$E_{WIg}(\mathrm{mSva}^{-1}) = \mathrm{C}_{Rn\mathrm{W}} \times \mathrm{C_w} \times (\mathrm{EDC}) \quad (1)$$

Where E_{WIg} is the effective dose for ingestion, C_{RnW} is ^{222}Rn concentration in water (kBq m^{-3}) and C_w is weighted estimate of water consumption (60 la^{-1}), respectively and EDC is the effective dose coefficient for ingestion 3.5 nSv Bq^{-1}.

$$E_{WIh}(\mathrm{mSva}^{-1}) = \mathrm{C}_{Rn\mathrm{W}} \times \mathrm{R_{aW}} \times \mathrm{F(Rn)} \times \mathrm{O} \times (\mathrm{DCFR}) \quad (2)$$

where E_{WIh} is the effective dose for inhalation, R_{aW} is the ratio of ^{222}Rn in air to ^{222}Rn in tap water (10^{-4}), $F(Rn)$ is the equilibrium factor (0.4) between ^{222}Rn and its decay products, O is the average indoor occupancy time per person (7000 h y^{-1}) and $DCFR$ is the dose conversion factor for ^{222}Rn exposure 9 nSv h^{-1} (Bq $m^{-3})^{-1}$. The average annual effective dose for indoor ^{222}Rn is calculated by Equations (3) and (4) using parameters introduced in report by UNSCEAR (2008).

$$AEDR(\mathrm{mSva}^{-1}) = {}^{222}\mathrm{Rn_{air}} \times \mathrm{F}(Rn) \times \mathrm{O} \times (\mathrm{DCFR}) \quad (3)$$

Where $AEDR$ (mSva^{-1}) is annual the effective dose for ^{222}Rn, $^{222}Rn_{air}$ is the indoor ^{222}Rn concentration (Bq m^{-3}) and remaining factors have been explained above.

$$AEDT(\mathrm{mSva}^{-1}) = {}^{220}Rn_{\mathrm{air}} \times \mathrm{F(Th)} \times \mathrm{O} \times (\mathrm{DCFT}) \quad (4)$$

Where $AEDT$(mSva^{-1}) is the annual effective dose for ^{220}Rn, $^{220}Rn_{air}$ is the indoor ^{220}Rn concentration (Bq m^{-3}), $DCFR$ is the dose conversion factor for ^{222}Rn exposure 40 nSv h^{-1}(Bq $m^{-3})^{-1}$ and $F(Th)$ is the equilibrium factor (0.1) between ^{220}Rn and its decay products UNSCEAR (2008).

The daughter concentration of ^{222}Rn and ^{220}Rn in terms of Potential Alpha Energy Concentration (PAEC) in mWL has been calculated using Equation (5).

$$Rn_{air}\ or\ {}^{220}Rn_{air} = \frac{PAEC\ (WL)\ \times\ 3700}{F\ (Rn)\ or\ F\ (Th)} \quad (5)$$

Results and Discussion

Table 1 summarizes the results of measurement of ^{222}Rn concentration in collected water samples of 35 villages. The ^{222}Rn concentration in water samples of studied area varies from 0.4 ± 0.2 Bq l^{-1} to 16.7 ± 2.8 Bq l^{-1} with an average value of 4.7 Bq l^{-1}, which is lower than the recommended value of USEPA (1991). The USEPA recommended the maximum contamination level (MCL) for ^{222}Rn concentration in water as 11 Bql^{-1} (USEPA, 1991). The measured values of ^{222}Rn in water of studied area are well within the safe limit of 4–40 Bq l^{-1} (UNSCEAR, 2008).

The ^{222}Rn concentration in water is lower as compared to higher value of uranium content in the nearby region of the studied area (Kochhar et al., 2006). It may be because of the solubility of ^{222}Rn in water is relatively low and with its short radio-active half life much of it will decay before it has opportunity of release from the ground water. When ^{222}Rn-containing groundwater reaches the surface by natural or man-made forces, the ^{222}Rn will inevitably be out gassed into the atmosphere. In some villages, the samples of ground water have been collected from different depth of ground water and tap water. It has been observed that ^{222}Rn concentration in water has increased with depth of groundwater (**Figure 2**). The level of ^{222}Rn concentration in tab water has been found to be lower than the level of ^{222}Rn concentration in ground water. Tab water is actually stored ground water and ^{222}Rn gas escapes out when it stored. This may be due to the surface water typically containing very low concentrations of ^{222}Rn, with activities below 4 Bq l^{-1} (Hopke et al., 2000). However, concentrations of ^{222}Rn in ground water may be high, depending on the aquifer or hydrogeology of the region. In most of the cases the ground water concentration is higher than the tap water. The increase in the value of ^{222}Rn concentration in water with depth has been reported by many researchers as given in **Table 2.**

The ^{222}Rn in the drinking water is the main source of the radiation doses for stomach (Ingestion dose) and lungs (Inhalation dose). The ingestion and inhalation doses in the studied area vary from 0.1 μSva^{-1} to 3.6 μSv a^{-1} and 1.0 μSva^{-1} to 42.8 μSv a^{-1} and are less the worldwide average annual of Inhalation (1.26 mSv a^{-1}) and Ingestion (0.29 mSv a^{-1}) recommended by UNSCEAR (2008). The total average annual effective dose for ^{222}Rn in water is 13 μSva^{-1}. The annual effective dose of 0.1 mSv a^{-1} is the safe limit of drinking water from three radioisotopes viz. ^{222}Rn, ^{3}H, and ^{40}K recommended by European Commission and world health organization (European Commission, 1998; WHO, 2004).

It can be seen from **Table 3** that the average Value of indoor ^{222}Rn and^{220}Rn concentration in the vicinity of these districts are 47 ± 21 Bq m^{-3} and 39 ± 19 Bq m^{-3}, respectively. These values are within the range of intervention level (200–300 Bq m^{-3}) recommended by International commission on Radiological

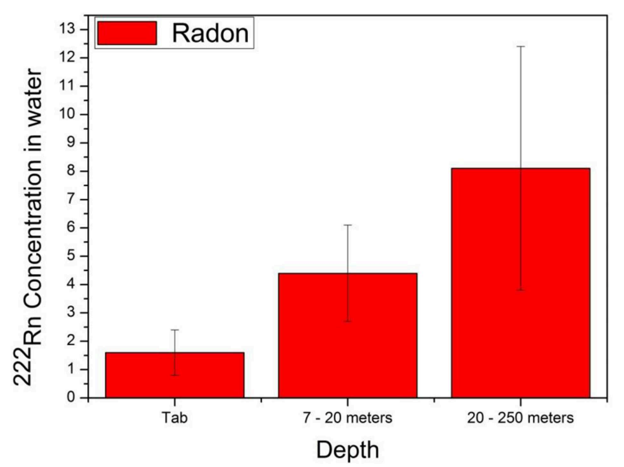

FIGURE 2 | Variation of radon concentration in water with depth.

TABLE 2 | The comparison of mean ^{222}Rn concentrations in indoor air, water, and soil gas samples from different countries.

Country	State/Districts	^{222}Rnin air (Bq m^{-3})	C_{RnW}		^{222}Rn conc. in soil (kBq m^{-3})	Ref.
			Depth	(Bq l^{-1})		
USA		29.0–422	Ground water	34.2 kBq m^{-3}	12.5-280	Colmenero Sujo et al., 2004
			Tap water	27.3 kBq m^{-3}		King and Minissale, 1994
China		222.2–230.4	10 m	24	2.0-14	Sun et al., 2004
		12.0–41.0	10–30 m	34		Xinwei, 2006
			>30 m	56		Zuoyuan et al., 2002
Kenya	Nairobi	170.3 ± 39.6	Water works	1.8 ± 0.3		Mustapha et al., 2002
			Well water	29.0 ± 6.0		
			Spring	53.1 ± 2.5		
			River	6.5 ± 0.7		
Brazil		30.2–315	Ground water	0.95–36.00		Marques et al., 2004
			Public water	2.35		Magalhaes et al., 2003
			Tap water	0.39–0.45		
Pakistan	Islamabad	43.26–97.04		25.90–158	17.34–75.52	Ali et al., 2010
	Muree	18.48–42.08		1.64–10.2	0.61-3.89	
India	Uttrakhand/					
	Budhakedar	8 ± 1 to 79 ± 5	Ground water	510 ± 10.0	1.10 ± 0.2 to 31.8 ± 1	Prasad et al., 2008
	Eastern doon valley	28.4–63.7	Hand pump (6–51.9 m)	44.8		Choubey et al., 2003
			Tube well (7.6–156 m)	52.45		
India	Punjab/		Tap water	1.95	3.2–17.2	Present investigation
	Mansa/Muktsar	47 ± 21	7–20 m	4.5		
			>21 m	7.41		

TABLE 3 | Statistical Parameters of ^{222}Rn and ^{220}Rn concentration in indoor air samples, ^{222}Rn concentration in soil samples.

Parameters	^{220}Rn in air (Bq m^{-3})	^{220}Rn (mWL)	AEDT (mSv a^{-1})	^{222}Rn in air (Bq m^{-3})	^{222}Rn (mWL)	AEDR (mSv a^{-1})	Total dose	Ratio	^{222}Rn in soil (kBq m^{-3})
Min	11.7	0.32	0.33	17.1	1.8	0.4	0.81	0.06	3.2
Max	84.3	2.28	2.36	95.7	10.3	2.4	4.02	0.46	17.2
Average	39 ±19	1.05	1.09	47 ± 21	5 ± 2	1.2	2.33	0.22	8 ± 3
GM	34.2	0.92	0.96	44.7	4.8	1.1	2.1	0.19	7.1
Median	34.7	0.94	0.97	44.8	4.84	1.1	1.99	0.19	7.3
t-test	33.3 – 45.2	–		48.9 – 54.9	–	–	–	–	6.8 – 8.7

Protection (ICRP, 2009). The present average indoor ^{222}Rn values are lower in comparison to the values reported in USA, China, Brazil, Kenya and Uttrakhand region of India but greater than Muree region of Pakistan as reported in **Table 2.**

The ratio of PAEC of ^{220}Rn to that of ^{222}Rn is in the range of 0.06–0.46. Stranden and Dixon have reported measurements on a variety of underground mines and enclosures in Norway and UK (Dixon et al., 1985; Stranden, 1985). The estimated ratios of PAEC (^{220}Rn)/PAEC (^{222}Rn) are usually within the range of 0.1–1.0. The *AEDR* (mSv a^{-1}) and *AEDT* (mSv a^{-1}) in the studied area are varied from 0.4 mSv a^{-1} to 2.4 mSv a^{-1} and 0.3 mSv a^{-1} to 2.3 mSv a^{-1}, respectively. In all the villages studied, the average *AEDR* (mSv a^{-1}) was 1.24 mSva^{-1} which is slightly less than the worldwide average annual dose (1.26 mSv a^{-1}) recommended by UNSCEAR (2008). The ^{222}Rn concentration in soil of studied area has been varied from 3.2 kBq m^{-3} to 17.2 kBq m^{-3}. **Figure 3** shows the correlation coefficient for measured ^{222}Rn concentration in air (Rn_{air}) and soil (Rn_{soil}). It has been found that a positive correlation ($R^2 = 0.57$) exits between ^{222}Rn concentration in air and soil gas. The value of

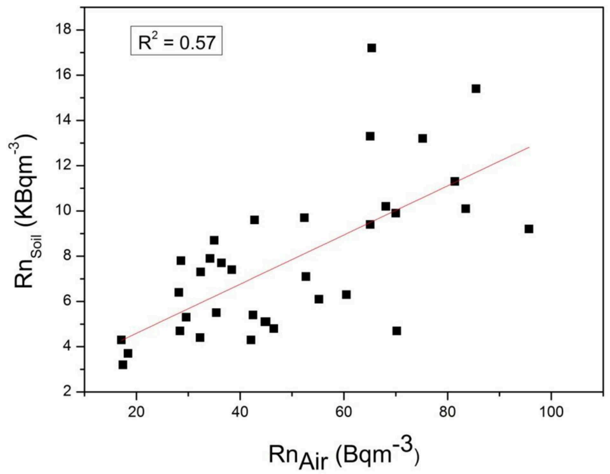

FIGURE 3 | Correlation of radon concentration in air and soil.

^{222}Rn concentration in soil is lower than the values reported in USA, Islamabad region of Pakistan and almost equivalent to china as given in **Table 2.** Using student's t–distribution with 95% confidence limit as shown in Equation (6).

$$m \pm \frac{t_{0.975}(\sigma)}{\sqrt{n-1}} \quad (6)$$

Where σ is the standard deviation, m is arithmetic mean and (n - 1) is degree of freedom. The calculated 95% confidence limits for ^{222}Rn and ^{220}Rn in indoor air is 33.3–4.2 Bq m^{-3} and 48.9–54.9 Bq m^{-3}, respectively. The calculated 95% confidence limits for ^{222}Rn in soil and water are 6.8–8.7 kBq m^{-3} and 3.8–5.6 Bq l^{-1}, respectively.

Conclusion

It has been seen that ^{222}Rn concentration in water samples are well below the recommended value. The total average annual effective dose for ^{222}Rn in water is lower than reference level (0.1 mSv a^{-1}) recommended by EC and WHO organization (European Commission, 1998; WHO, 2004). It is observed that there is a positive correlation between ^{222}Rn concentration in air and soil, so the soil of the study area has significant contribution to the indoor ^{222}Rn concentration. The average Indoor values of ^{222}Rn and ^{220}Rn concentration in the studied areas are greater than the world average value of 40 Bq m^{-3} (UNSCEAR, 2000), but the values are in general within the range of recommended action level 200–300 Bq m^{-3} (ICRP, 2009). The estimated ratios of PAEC (^{220}Rn)/PAEC (^{222}Rn) are usually within the range of 0.1–1.0. The average annual effective dose in indoor air received by the residents of the study area is lower than the recommended action level of 1.26 mSv a^{-1} (UNSCEAR, 2008).

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