CHAPTER 3

RADON/THORON AND THEIR PROGENY CONCENTRATION IN THE DWELLINGS

This chapter deals with the measurement of radon/thoron and their progeny concentration in the dwellings of the studied area using active and passive techniques. The detailed introduction about the topic, measurement procedure, formulae used for calculations of equilibrium factors, annual effective inhalation and ingestion dose for the assessment of the hazardous effects to the residents, discussion and conclusion has been presented in this following section.

3.1 INTRODUCTION

Radiological pollution is a severe health hazard to worldwide population due to continuous exposure of radiations. Natural and artificial radioactivity are the sources of radioactive pollution in the atmosphere and indoor environment (Eisenbud, 1963). Soil and rocks contain radioactive element uranium/thorium which decays to radon/thoron gases which further penetrate into the indoor environment. The term "indoor" applies to a wide range of locations including houses, offices and workplace structures as well as sporting venues. The vast majority of people spend up to 90% of their time indoors and up to 60% of the workers work in offices (Andersson and Setterwall, 1996). The radon and thoron gases enter into the indoor air through exhalation from soil and building materials used in construction of walls and floors (Nazaroff and Nero 1988). These gases can relocate from soils and rocks and have tendency to accumulate in surrounding environment such as houses and underground mines. Radon gas accumulates to the levels that are detrimental to one's health, especially in inadequately ventilated buildings (Deborah et al., 2020). There are some factors like topographical, geological conditions, type of houses, ventilation conditions and wind speed which affect the activity concentration of radon, thoron and their progeny (Subba et al., 1988; Martz et al., 1991; Ramola et al., 2000; Mehra et al., 2013). Radon is continuously emitted from the earth's surface via faults and fractures, making it useful as a geophysical tracer, for geological exploration and earthquake precursor (Fleshier et al., 1975).

From the available literature the radon, thoron and their progeny have been considered as potentially serious indoor pollutants. These get attached to aerosols present in ambient air which constitutes significant radioactive hazards to human lungs. While breathing, the progenies get sticks to alveoli and could expose cells of bronchial and pulmonary epithelium in the lungs to radiation, thereby damaging the cells, DNA and may cause to lung cancer (Butterweck et al., 2002). Radon and its progeny leads to about 69% of the total annual effective dose in contrast to another natural sources (Khan 1993; Mehra et al., 2015). For non-smokers radon is the primary cause of lung cancer while for smokers it is secondary, encompassing an approximated 3-20% of deaths due to lung cancer globally (WHO, 2009). Henshaw (1990) claimed that indoor radon exposure has been linked to the development of leukaemia and other malignancies such as melanoma, kidney and prostate cancers, as well as lung cancer among miners (BEIR VI, 1999; UNSCEAR, 2000; Kansal et al., 2011). A pooled study of eight epidemiological studies (Lubin and Boice 1997), seven North American case-control studies (Krewski et al., 2005) and thirteen European case-control studies (Darby et al., 2005) found a direct link between household radon and lung cancer risk (Sonkawde et al., 2003). Investigations on cellular mutagenesis, animal experiments and occupational studies have all proven radon as a human carcinogen (BEIR VI, 1999). There is 16 percent increase in relative lifetime lung cancer risk per 100 Bqm^{-3} of chronic radon inhalation (Fintan et al., 2019). Indoor radon causes 21,000 (13.4%) lung cancer deaths in the United States each year, with 2900 of these being non-smokers (EPA, 2003). A radon concentration of 50 Bqm^{-3} can cause 25% of leukaemia cases in children and adults of all ages (Richardson et al., 1991).

The studied area falls in the Malwa region of Punjab which is known for having highest cancer rate in the country. So, the present study has been carried out for the first time to find out the activity concentration of these radiations and their associated carcinogenic health effects for the residents of the area. The field work has been done for various seasons throughout the year in the dwellings under different ventilation conditions. It would also help to find the areas where concentration is high and provide data for the national pool.

3.2 METHODOLOGY

3.2.1 Lab and Field Work: Using Passive Technique

The time integrated passive technique, single entry pinhole dosimeters and deposition-based direct radon/thoron progeny sensors (DRPS/DTPS) have been used for the measurement of the concentration of radon/thoron and their progeny respectively, on the basis of the grid pattern to cover the whole studied area. The study has been carried out year wise in each of the two districts for indoor measurement. These dosimeters have been developed by BARC, Mumbai, India and calibrated with radon/thoron sources (RN-1025 and TH-1025, Pylon, Canada) by using active monitors from tracer lab and grab filter sampling (Sahoo et al., 2013). Dosimeters were prepared (as shown in Figure 3.1) in the lab. Single entry pinhole dosimeter was prepared using LR-115 Type-II films (manufactured by Kodak Pathe, France) of size 3×3 cm^2, which were placed in first and second compartment of dosimeters to register tracks formed due to alpha particles produced from the decay of radon and thoron gas respectively. DRPS/DTPS were prepared using LR-115 Type-II films of size 2.5×2.5 cm^2 in each section. For DRPS an absorber of 37 μm thickness (25 μm aluminised mylar combined with 12 μm cellulose nitrate) and for DTPS an absorber of 50 μm aluminized mylar has been placed above the detectors.

Figure 3.1: Preparation of dosimeters

(Radiation Physics Lab, Department of Physics, MRSPTU, Bathinda)

Then these dosimeters were deployed in 50 villages with 4 dosimeters in each village covering 25 villages in each district (100 dosimeters were deployed in 25 villages of Barnala district and 100 dosimeters were deployed in 25 villages of Moga district) throughout the year in different seasons. The entire year has been divided into three seasons of four months each to cover the summer, winter and rainy seasons to study the seasonal changes. After completion of each season, the deployed dosimeters were retrieved for further analysis and were replaced with the new set of similarly prepared dosimeters. The houses in the studied area were divided into categories based on ventilation conditions. A room without a window is regarded as poorly ventilated, a room with one window and a door are considered as partially ventilated and a room with more than two windows and a door is considered as well ventilated. The majority of the dwellings in this area are made of cement and are only partially ventilated. These dosimeters were suspended from the ceiling at a distance of 10 cm from the walls and at a minimum height of 1.5 meters from the ground (as shown in Figure 3.2). Because most of the thoron is assumed to be exhaled from building materials due to its short half-life (55 seconds) and thus it accumulates close to wall surfaces. Hence the above distance from the wall was chosen (Ramola et al., 2016).

Figure 3.2: Dosimeters suspended from the roof of building

After four months of exposure, the detectors (LR-115 films) were removed from the retrieved dosimeters and then chemically etched using 2.5 NaOH solution at 60° C for 90 minutes using a constant temperature bath to develop the clear tracks of alpha particles on the detectors. Spark counter was used to count the tracks at pre-spark voltage of 900V and optimized at 450 V from which track density was calculated. Further radon, thoron and their progeny concentration has been calculated using standard formulae.

3.2.2 Field Work: Using Active Technique

For measurement of radon/thoron gas concentration, Smart RnDuo (for active technique) has been used on the basis of the grid pattern to cover the whole studied area. The radon/thoron concentration measurements were made in closed-building conditions maintained for 12 hours prior to the start of the measurement to maximum build-up of radon/thoron. Internal- external air exchange systems, windows and fans were not operated during measurements. Houses were selected in such a way that there was no disturbance during the measurement period and adequate room for the device. Smart RnDuo has been placed at least 90 cm (3 feet) away from windows or other potential openings in the exterior walls and also placed at least 50 cm (20 inches) from the floor and at least 10 cm (4 inches) from other objects. For radon was sampled in RnDuo using flow mode of sampling for measurement duration of 24 hours having cycle period of one hour while, for thoron gas, RnDuo using flow mode for measurement duration of one hour having a cycle period of 15 minutes.

3.3 FORMULAE USED

3.3.1 To Calculate Indoor Radon (C_r) and Thoron (C_t) Gas Concentration

The radon and thoron concentrations have been calculated using the following equations (Sahoo et al., 2013):

$$C_r\left(Bqm^{-3}\right)=\frac{\left(t_1-b\right)}{\left(d\times k_r\right)} \tag{1}$$

$$C_t\left(Bqm^{-3}\right)=\frac{\left(t_2-d\times C_r\times k_r^{'}-b\right)}{\left(d\times k_t\right)} \tag{2}$$

Where, t_1 (tr.cm^{-2}) is the track density in the ‘radon’ compartment,

k_r (0.017 ± 0.002 tr.cm^{-2}(Bqm^{-3}d)$^{-1}$) is the calibration factor in radon compartment for radon,

d is the number of exposure days (120 days),

b is the background tracks that arises due to intrinsic properties and exposure during transit period (4 tr.cm^{-2}),

t_2 (tr.cm^{-2}) is the track density in the ‘radon + thoron’ compartment,

k_r*’* (0.0172 ± 0.002 tr.cm^{-2}(Bqm^{-3}d)$^{-1}$) is the calibration factor of radon and k_t (0.01 ± 0.001 tr.cm^{-2}(Bqm^{-3}d)$^{-1}$) is the calibration factor of thoron.

3.3.2 To Calculate Equivalent Radon/Thoron Progeny Concentration (EERC/EETC)

Equivalent radon and thoron progeny concentration was calculated by using following equations (Mishra and Mayya, 2008):

$$EERC(Bqm^{-3}) = \frac{(t_r - b)}{d \times S_r} \qquad (3)$$

$$EETC(Bqm^{-3}) = \frac{(t_t - b)}{d \times S_t} \qquad (4)$$

Where, S_r is radon progeny sensitivity factor (0.09 ± 0.0036 $tr.cm^{-2}d^{-1}$/EERC (Bqm^{-3})),

t_r ($tr.cm^{-2}d^{-1}$) is exact track density from radon progeny in DRPS using equation:

$$t_r = t_{DRPS} - \frac{\phi_r}{\phi_t} t_{DTPS} \qquad (5)$$

Where, t_{DRPS} is total tracks in DRPS,

t_{DTPS} is total tracks in DTPS,

$\emptyset_r$ is track registration efficiency for radon progeny in DRPS (0.01 ± 0.0004),

$\emptyset_t$ is track registration efficiency for thoron progeny DTPS (0.083 ± 0.0004) (Mishra and Mayya, 2009).

t_t ($tr.cm^{-2}d^{-1}$) stands for track density in DTPS,

For thoron progeny S_t is sensitivity factor (0.94 ± 0.0027 $tr.cm^{-2}d^{-1}$/EETC (Bqm^{-3})).

3.3.3 To Calculate Equilibrium Factor

Equilibrium factor is defined as the ratio of equilibrium equivalent concentration to parent gas concentration. The average equilibrium factor for the studied area has been calculated by measuring the same for each dwelling from the radon/thoron gas and their progeny concentration using following equations (UNSCEAR, 2000):

Equilibrium Factor for radon (f_r) = $\frac{EERC}{C_r}$ (6)

Equilibrium Factor for radon (f_t) = $\frac{EETC}{C_t}$ (7)

3.3.4 To Calculate Annual Effective Inhalation Dose Due to Radon/Thoron and Their Progeny Concentration (AEDR/AEDT)

Annual effective inhalation dose (AEDR/AEDT) has been calculated by using the equations as given below (UNSCEAR, 2000):

$$\text{AEDR}\ (\text{mSvy}^{-1}) = [(C_r \times f_{cr}) + (\text{EERC} \times f_{\text{EERC}})] \times 8750 \times o_f \times 10^{-6} \qquad (8)$$

$$\text{AEDT}\ (\text{mSvy}^{-1}) = [(C_t \times f_{ct}) + (\text{EETC} \times f_{\text{EETC}})] \times 8750 \times o_f \times 10^{-6} \qquad (9)$$

Total annual effective inhalation dose (AD) due to exposure of radon, thoron and their progeny has been calculated by using equation:

$$\text{AD}\ (\text{mSvy}^{-1}) = \text{AEDR}\ (\text{mSvy}^{-1}) + \text{AEDT}\ (\text{mSvy}^{-1}) \qquad (10)$$

Where, f_{cr} is dose conversion factor for radon concentration (0.17 $\text{nSvBq}^{-1}\text{h}^{-1}\text{m}^3$),
f_{EERC} is dose conversion factor for radon progeny concentration (9 $\text{nSvBq}^{-1}\text{h}^{-1}\text{m}^3$),
f_{ct} is dose conversion factor for thoron concentration (0.11 $\text{nSvBq}^{-1}\text{h}^{-1}\text{m}^3$),
f_{EETC} is dose conversion factor for thoron progeny (40 $\text{nSvBq}^{-1}\text{h}^{-1}\text{m}^3$) recommended by UNSCEAR (2000),
and o_f is standard indoor occupancy factor (0.8) for 1year exposure period.

3.4 RESULTS AND DISCUSSION

3.4.1 Radon/Thoron and Their Progeny Concentration Using Passive Technique

3.4.1.1 Seasonal Variations. Table 3.1 represents the seasonal variations of the activity concentration of radon, thoron and their progeny (EERC/EETC) using passive technique. **In Barnala district,** the measured value of indoor radon concentration lies in the range of 4.92 ± 1.52 to 98.49 ± 7.09 Bqm^{-3} with an average value of 26.78 ± 3.74 Bqm^{-3} during rainy season, in winter season it lies in the range of 4.06 ± 1.98 to 142.00 ± 8.46 Bqm^{-3} with average value of 30.34 ± 3.99 Bqm^{-3} and in summer season it lies in the range from 2.58 ± 1.81 to 83.76 ± 6.56 Bqm^{-3} having an average value of 23.77 ± 3.58 Bqm^{-3}.

The measured value of thoron concentration lies in the range from 10.53 ± 6.01 to 520.18 ± 25.90 Bqm^{-3} having an average value of 57.31 ± 11.43 Bqm^{-3} during rainy season, in winter season it lies in the range from 7.89 ± 5.74 to 634.80 ± 26.12 Bqm^{-3} having an average value of 64.90 ± 11.23 Bqm^{-3} and in the summer season, it lies in the range from 8.77 ± 5.34 to 133.33 ± 8.82 Bqm^{-3} having an average value of 39.22 ± 10.03 Bqm^{-3}.

The measured concentration of radon progeny (EERC) lies in the range of 0.48 ± 0.27 to 43.84 ± 2.10 Bqm^{-3} with an average value of 10.02 ± 0.98 Bqm^{-3} during rainy season, in winter season it lies in the range from 0.44 ± 0.25 to 92.94 ± 2.94 Bqm^{-3} having an average value of 11.14 ± 1.00 Bqm^{-3} and in summer season, it lies in the range from 1.24 ± 0.46 to 23.27 ± 1.56 Bqm^{-3} having an average value of 7.48 ± 0.86 Bqm^{-3}.

The thoron progeny (EETC) concentration has been calculated and lies in the range from 0.10 ± 0.03 to 2.82 ± 0.16 Bqm^{-3} having an average value of 0.90 ± 0.08 Bqm^{-3} during rainy season, in winter season it lies from 0.17 ± 0.04 to 9.25 ± 0.29 Bqm^{-3} having an average of 1.11 ± 0.09 Bqm^{-3} and in summer season, it lies in the range from 0.07 ± 0.03 to 2.60 ± 0.15 Bqm^{-3} with an average value of 0.77 Bqm^{-3}.

In Moga district, the measured value of indoor radon concentration lies in the range of 10.32 ± 2.82 to 109.39 ± 7.58 Bqm^{-3} with an average value of 40.31 ± 4.64 Bqm^{-3} during winter season, in rainy season it lies in the range of 10.32 ± 2.70 to 94.26 ± 7.00 Bqm^{-3} with average value of 36.75 ± 4.47 Bqm^{-3} and in summer season, it lies in the range from 1.38 ± 0.35 to 67.94 ± 6.04 Bqm^{-3} having average value of 22.37 ± 3.61 Bqm^{-3}.

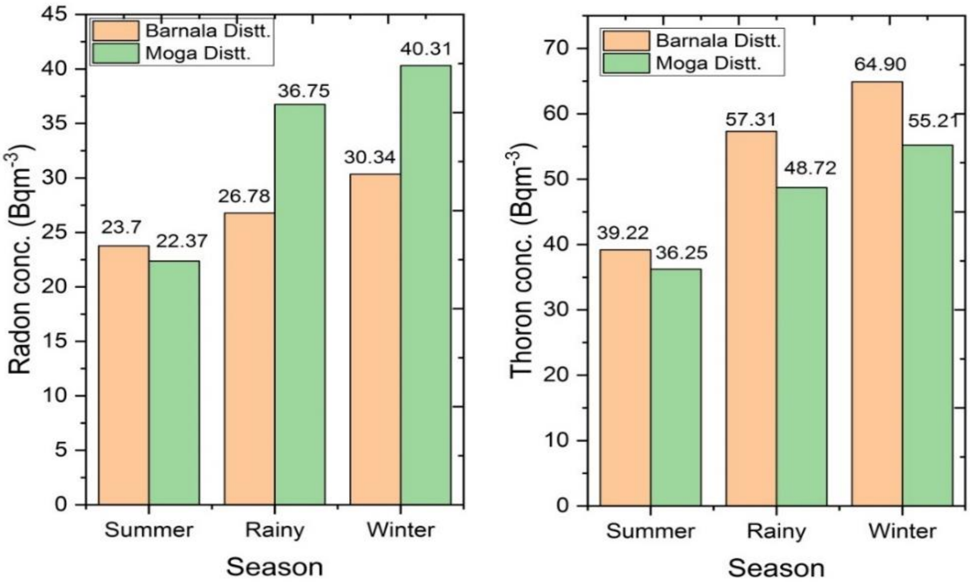
The measured value of thoron concentration lies in the range from 15.95 ± 8.02 to 298.16 ± 22.16 Bqm^{-3} having an average value of 55.21 ± 12.90 Bqm^{-3} during winter season, in rainy season it lies in the range from 4.76 ± 0.53 to 267.72 ± 18.70 Bqm^{-3} having an average value of 48.72 ± 12.28 Bqm^{-3} and in the summer season, it lies in the range from 6.36 ± 4.79 to 137.10 ± 16.44 Bqm^{-3} having an average value of 36.25 ± 9.99 Bqm^{-3}.

The measured radon progeny (EERC) concentration lies in the range of 3.33 ± 0.63 to 39.45 ± 2.13 Bqm^{-3} with an average value of 13.72 ± 1.21 Bqm^{-3} during winter season, in rainy season it lies in the range from 3.34 ± 0.63 to 26.30 ± 1.68 Bqm^{-3} having an average value of 12.10 ± 1.15 Bqm^{-3} and in summer season, it lies in the range from 0.23 ± 0.07 to 23.51 ± 1.62 Bqm^{-3} having an average value of 9.70 ± 0.99 Bqm^{-3}.

The thoron progeny (EETC) concentration has been calculated and lies in the range from 0.23 ± 0.05 to 5.48 ± 0.23 Bqm^{-3} having an average value of 1.13 ± 0.10 Bqm^{-3} during winter season, in rainy season it lies from 0.15 ± 0.04 to 2.41 ± 0.15 Bqm^{-3} having an average value of 0.90 ± 0.09 Bqm^{-3} and in summer season, it lies in the range from 0.03 ± 0.01 to 1.71 ± 0.13 Bqm^{-3} having an average value of 0.62 ± 0.07 Bqm^{-3}.

Table 3.1 also represents the probability distribution of radon/thoron and their progeny (EERC/EETC) which shows positive skewness from normal distribution towards right tail. The kurtosis value shows heavily tailed distribution in the rainy and winter season while in summer it shows slightly light tail distribution for radon concentration and radon/thoron progeny concentrations.

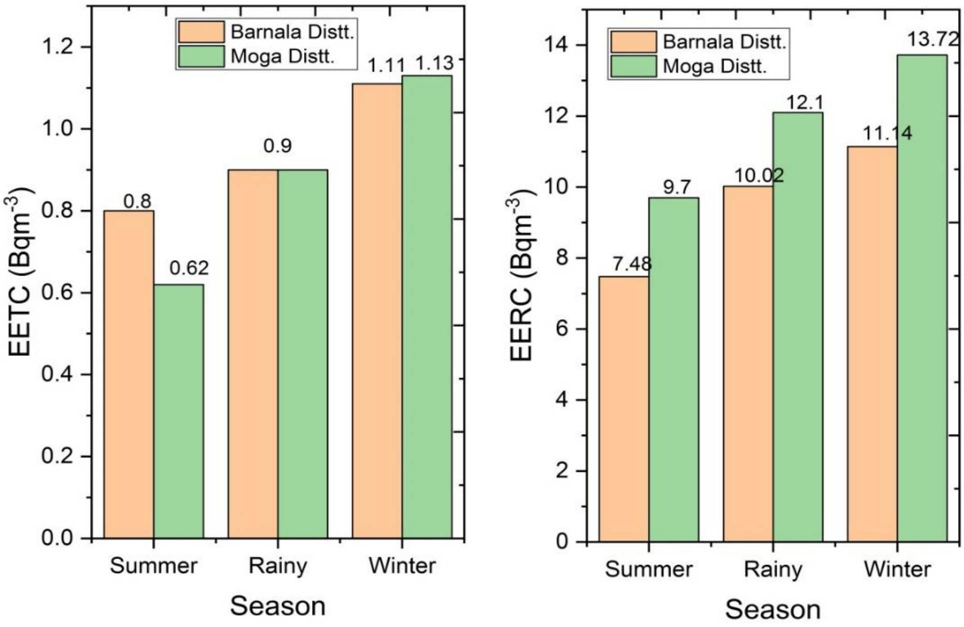
It has been observed that the average concentration of radon, thoron and their progeny in the studied area (Barnala and Moga districts) is higher in the winter season than in the summer and rainy seasons. This may be due to the poor ventilation condition in winter season which results in less exchange of gases between indoor and outdoor environments, thereby leading to accumulation of radon gas during winters. Figure 3.3 (a & b) shows that the radon and thoron concentration have higher values in winter season as compared to rainy and summer season in the studied area, respectively.



a) b)

Figure 3.3: Seasonal variation of a) radon and b) thoron concentration in the dwellings

Figure 3.4 (a & b) shows that the EERC and EETC have higher concentration in winter season as compared to rainy and summer season in the studied area, respectively.



a) b)

Figure 3.4: Seasonal variation of a) Radon progeny concentration (EERC) and b) thoron progeny concentration (EETC) in the dwellings

3.4.1.2 Annual Average Concentration. Table 3.2 shows the annual average radon/thoron and their progeny concentration in the studied area. **In Barnala district,** the measured values of annual average concentration of radon using passive technique lies in the range of 9.59 ± 2.57 to 63.13 ± 5.53 Bqm^{-3} with an average value of 26.96 ± 3.77 Bqm^{-3}. The measured average for radon concentration is below than the recommended level of 40 Bqm^{-3} (UNSCEAR, 2008). The values of annual average concentration of thoron lies in the range from 12.57 ± 6.53 to 230.21 ± 16.50 Bqm^{-3} with an average value of 53.81 ± 10.90 Bqm^{-3} which is higher than the worldwide average value of 10 Bqm^{-3} (UNSCEAR, 2000). The annual average concentration of radon progeny (EERC) has values from 1.94 ± 0.44 to 33.30 ± 1.79 Bqm^{-3} having an average value of 5.31 ± 0.22 Bqm^{-3} which is lower than the worldwide value of 15 Bqm^{-3} (UNSCEAR, 2006; 2008). The annual average concentration of thoron progeny (EETC) lies in the range from 0.24 ± 0.05 to 3.62 ± 0.15 Bqm^{-3} having an average value of 0.94 ± 0.09 Bqm^{-3}. The measured average value for thoron progeny concentration is higher than worldwide value of 0.5 Bqm^{-3} (UNSCEAR 2006; 2008).

In Moga district, the measured values of annual average concentration of radon for all the lies in the range of 15.88 ± 3.28 to 64.61 ± 5.64 Bqm^{-3} with an average value of 33.14 ± 4.24 Bqm^{-3}. The measured average value for radon concentration is below than the recommended level of 40 Bqm^{-3} (UNSCEAR, 2000). The values of annual average concentration of thoron lie in the range from 16.64 ± 9.02 to 114.05 ± 14.96 Bqm^{-3} with average value of 46.73 ± 11.72 Bqm^{-3} which is higher than the worldwide average value of 10 Bqm^{-3} (UNSCEAR, 2000). The annual average concentration of radon progeny (EERC) has values from 6.91 ± 0.85 to 21.76 ± 1.50 Bqm^{-3} having average value of 11.84 ± 1.12 Bqm^{-3}, which is lesser than the worldwide value of 15 Bqm^{-3} (UNSCEAR, 2006; 2008). The annual average concentration of thoron progeny (EETC) lies in the range from 0.39 ± 0.06 to 2.45 ± 0.14 Bqm^{-3} having an average value of 0.88 ± 0.09 Bqm^{-3}. The measured average value for thoron progeny concentration is higher than worldwide value of 0.5 Bqm^{-3} (UNSCEAR 2006; 2008).

3.4.1.3 Equilibrium Factor. In Barnala district, the average equilibrium factor between radon and its progeny for rainy, winter and summer season varies as 0.40, 0.42 and 0.37 respectively and for thoron and its progeny the average equilibrium factor is found to be 0.02, 0.02 and 0.02, respectively. The annual average equilibrium factor between radon and its progeny is 0.4 and for thoron and its progeny is 0.02.

In Moga district, the average equilibrium factor between radon and its progeny for rainy, winter and summer season varies as 0.44, 0.39 and 0.37 respectively and for thoron and its progeny the average equilibrium factor is found to be 0.02, 0.02 and 0.02, respectively. The annual average equilibrium factor between radon and its progeny is 0.4 and for thoron and its progeny is 0.02.

In the studied area, the annual average value of the radon equilibrium factor is 0.37, which is lower than the recommended value of 0.4 (UNSCEAR, 2008). The annual average value of equilibrium factor for thoron is found to be 0.02 which is same with the recommended limit of 0.02 (UNSCEAR, 2008).

3.4.1.4 Frequency Distribution. In Barnala district, Figure 3.5 shows the frequency distribution graph for the radon concentration according to which in 5% dwellings it lies between 0-13 Bqm^{-3}, in 41% dwellings it lies between 13-26 Bqm^{-3}, in 45% dwellings it lies from 26-39 Bqm^{-3}, in 3% it lies from 39-52 Bqm^{-3}, in 6% dwellings it lies from 52-65 Bqm^{-3}.

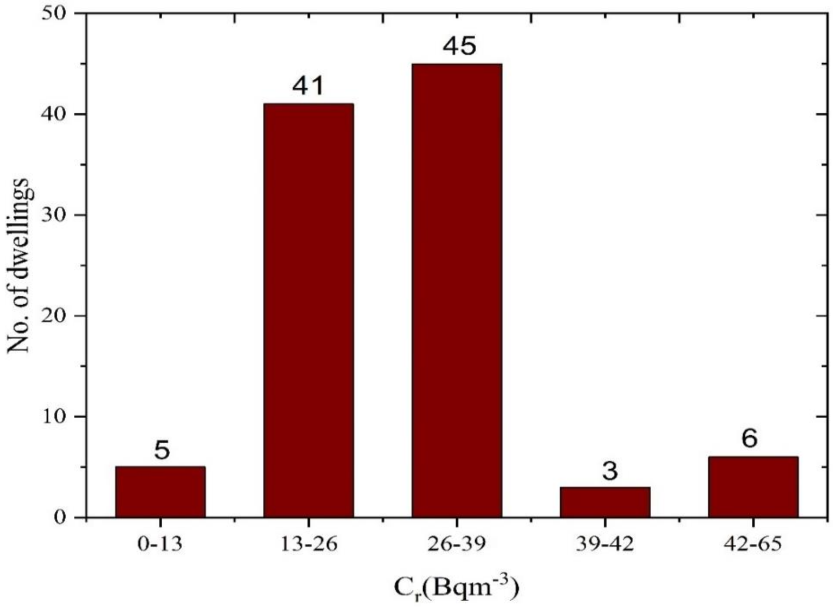


Figure 3.5: Frequency distribution of radon concentration (C_r) in Barnala district

Figure 3.6 shows the frequency distribution for the thoron concentration according to which in 57% dwellings it lies from 0 to 50 Bqm^{-3}, in 39% dwellings it lies from 50-100 Bqm^{-3}, in 2% it lies from 100-150 Bqm^{-3}, in 1% it lies from 150-250 Bqm^{-3} respectively.

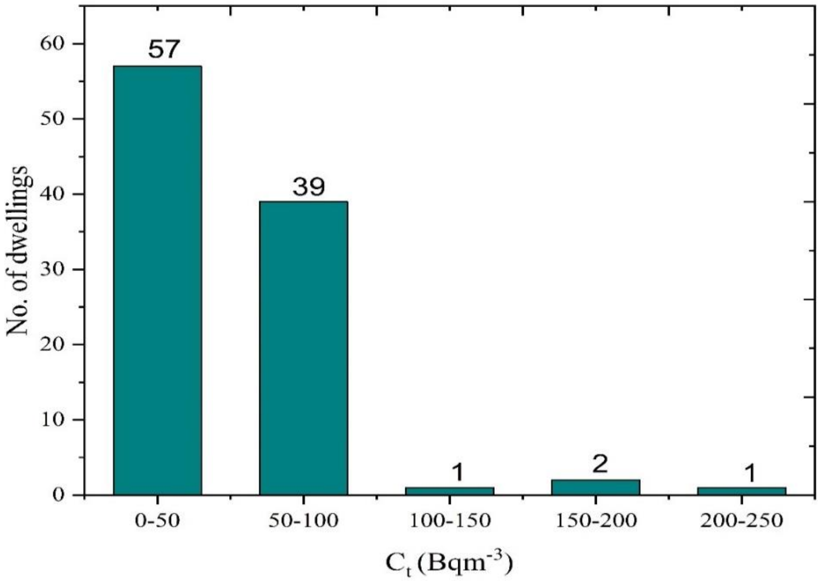


Figure 3.6: Frequency distribution of thoron concentration (C_t) in Barnala district

Figure 3.7 shows the frequency distribution for EETC according to which in 65% dwellings it lies from 0-1 Bqm^{-3}, in 32% dwellings it lies from 1-2 Bqm^{-3}, in 2% dwellings it lies from 2-3 Bqm^{-3}, in 1% dwellings it lies from 3-4 Bqm^{-3}.

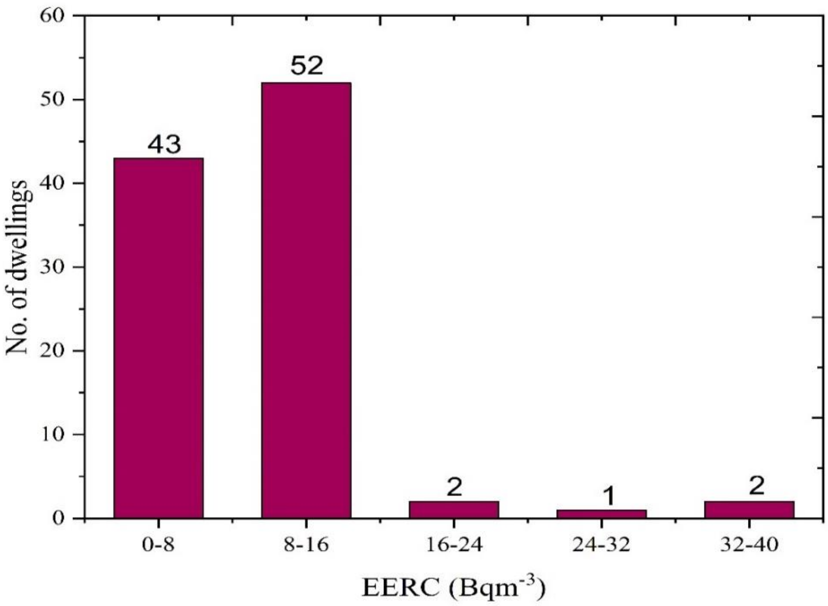


Figure 3.7: Frequency distribution of radon progeny concentration (EERC) in Barnala district

Figure 3.8 shows the frequency distribution for EERC according to which in 43% dwellings it lies from 0-8 Bqm^{-3}, in 52% dwellings it lies from 8-16 Bqm^{-3}, in 2% dwellings it lies from 16-24 Bqm^{-3} and rest of 3% dwellings it lies from 24-40 Bqm^{-3}.

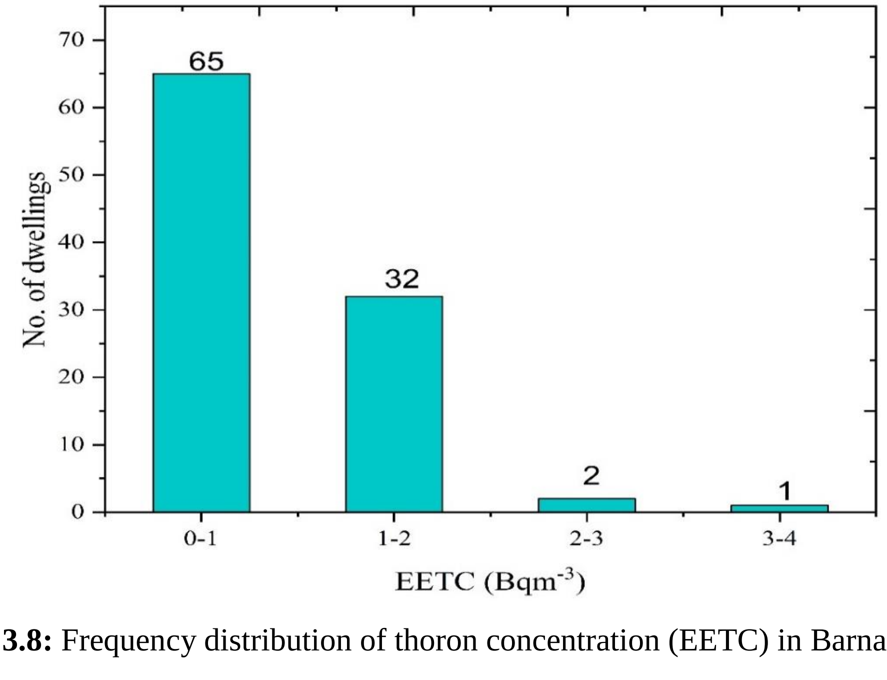


Figure 3.8: Frequency distribution of thoron concentration (EETC) in Barnala district

In Moga district, Figure 3.9 shows the frequency distribution graph for the radon concentration according to which in 2% dwellings it lies between 0-16 Bqm^{-3}, in 51%

dwellings it lies between 16-32 Bqm^{-3}, in 37% dwellings it lies from 32-48 Bqm^{-3}, in 8% it lies from 48-64 Bqm^{-3}, in 2% dwellings it lies from 64-80 Bqm^{-3}.

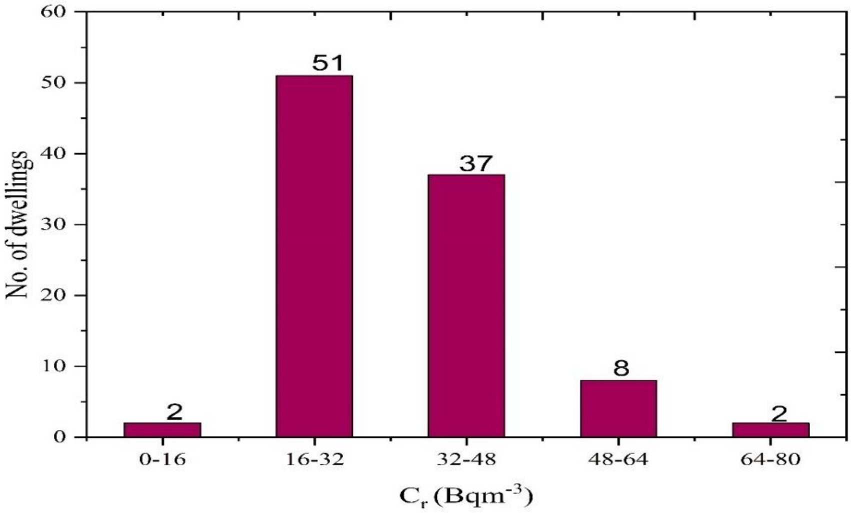


Figure 3.9: Frequency distribution of radon concentration (C_r) in Moga district

Figure 3.10 shows the frequency distribution for the thoron concentration according to which in 15% dwellings it lies from 0-30 Bqm^{-3}, in 71% dwellings it lies from 30-60 Bqm^{-3}, in 9% it lies from 60-90 Bqm^{-3}, in 5% it lies from 90-120 Bqm^{-3} respectively.

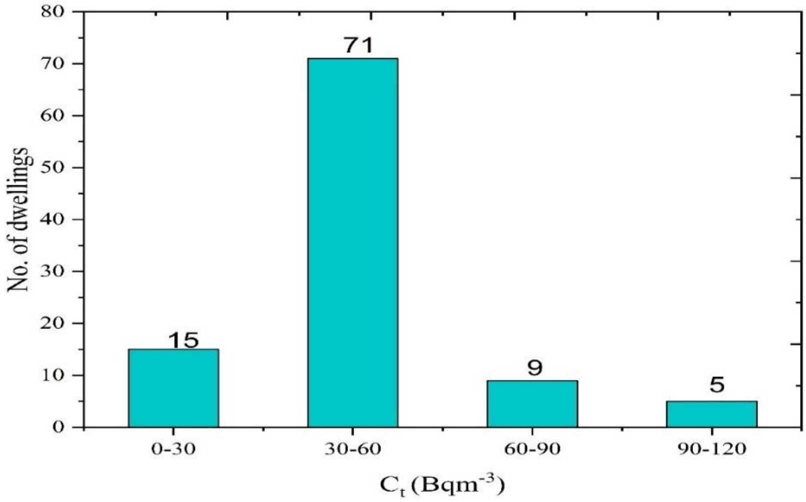


Figure 3.10: Frequency distribution of thoron concentration (C_t) in Moga district

Figure 3.11 shows the frequency distribution for EERC according to which in 9% dwellings it lies from 0-8 Bqm^{-3}, in 83% dwellings it lies from 8-16 Bqm^{-3}, in 8% dwellings it lies from 16-24 Bqm^{-3}.

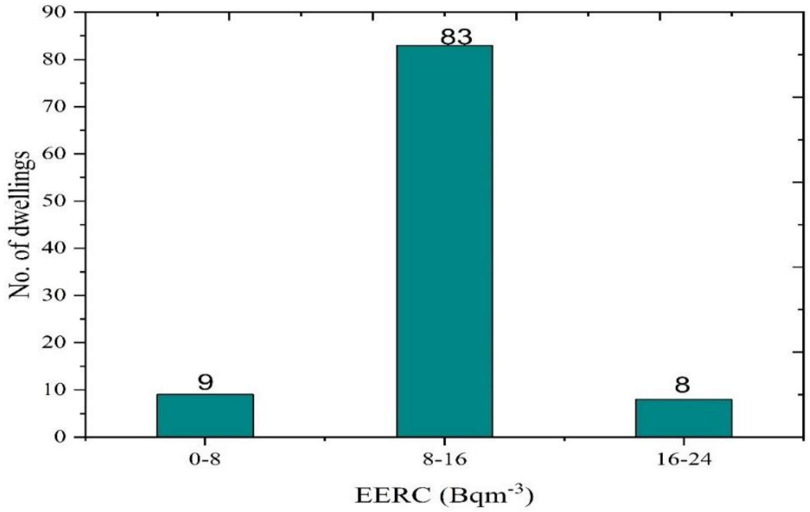


Figure 3.11: Frequency distribution of radon progeny concentration (EERC) in Moga district

Figure 3.12 shows the frequency distribution for EETC according to which in 70% dwellings it lies from 0-1 Bqm^{-3}, in 28% dwellings it lies from 1-2 Bqm^{-3}, in 2% dwellings it lies from 2-3 Bqm^{-3}.

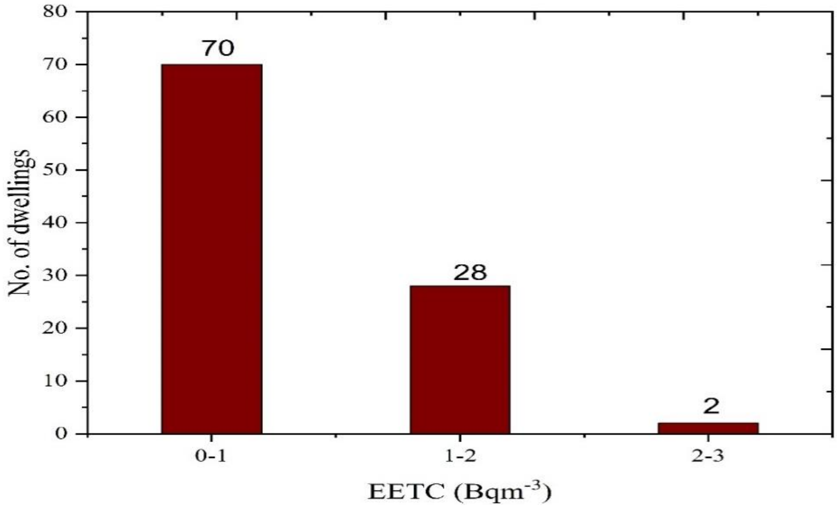
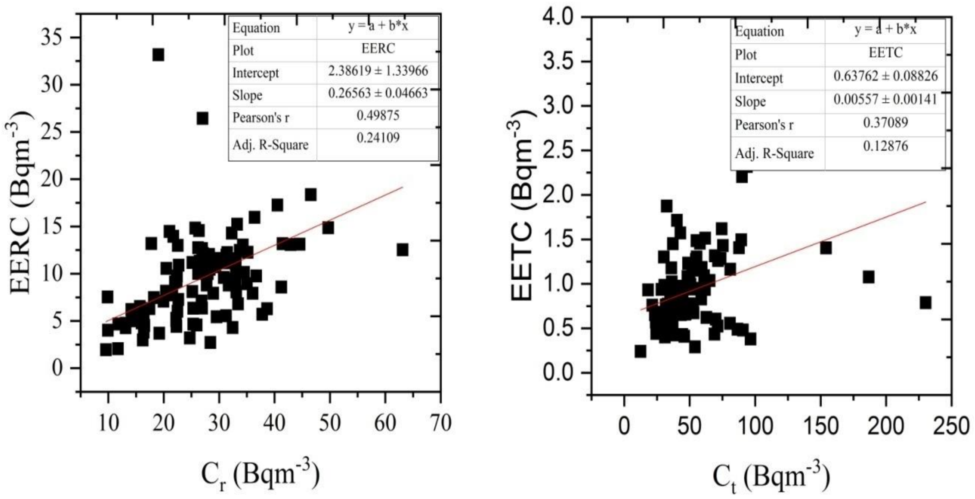


Figure 3.12: Frequency distribution of thoron progeny concentration (EETC) in Moga district

3.4.1.5 Correlation between Radon/Thoron and Their Progeny Concentration. Analysis has been done to find out the correlation between radon and its progeny concentration. The plot between these two quantities, linear fitting using least square regression is shown in Figure 3.13a.

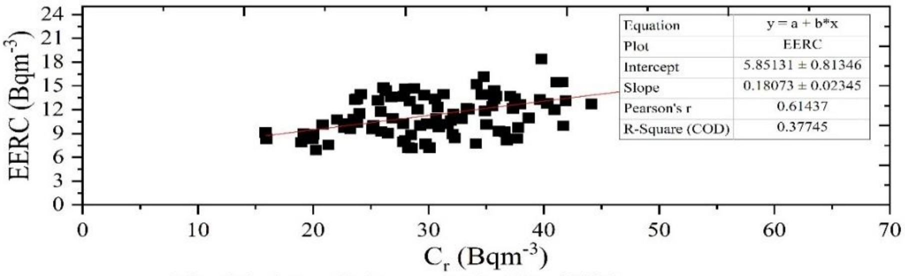


a) b)

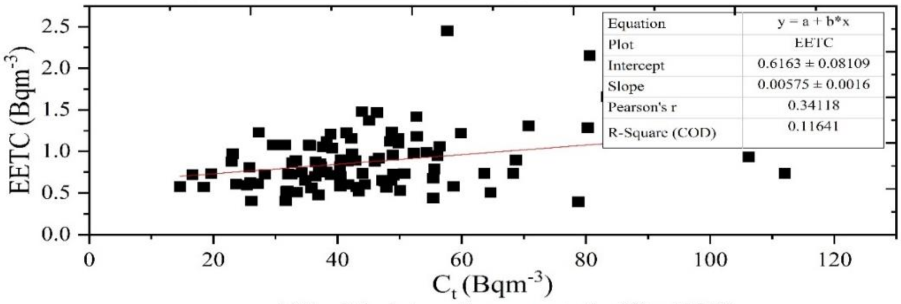
Figure 3.13: Correlation between a) Radon concentration (C_r) and EERC and b) thoron concentration (C_t) and EETC in Barnala district

For Barnala district, the linear fit has an R^2 value of 0.24 and Pearson's r value (which quantifies linear dependency) of 0.49, indicating a modest connection between the two quantities. Also, the analysis was done to study the correlation between thoron concentration and its progeny concentration. Same correlation was done between thoron and its progeny concentration. Figure 3.13b shows that the linear fit has an R^2 value of 0.12 and Pearson's r value (which quantifies linear dependency) of 0.37, indicating a modest connection between the two quantities.

For Moga district, (as shown in Figure 3.14a) the linear fit has an R^2 value of 0.37 and Pearson's r value (which quantifies linear dependency) of 0.61, indicating a modest connection between the two quantities. Also, the analysis was done to study the correlation between thoron and its progeny concentration. The plot between these two quantities, linear fitting using least square regression is shown in Figure 3.14b. The linear fit has an R^2 value of 0.11 and Pearson's r value (which quantifies linear dependency) of 0.34, indicating a modest connection between the two quantities.



a) Correlation between Radon concentration (Cr) and EERC



b) Correlation between thoron concentration (C_t) and EETC

Figure 3.14: Correlation between a) radon concentration (C_r) and EERC and b) thoron concentration (C_t) and EETC in Moga district

3.4.1.6 Box whisker plots. Figure 3.15 to 3.17 shows the box-whisker plots of variations in seasonal distribution of radon/thoron and their progeny concentration. Box plots effectively describe the symmetry, tightness and distribution of data points. The length (vertical) of the box marks the inter-quartile range, i.e., the difference between third (75%) and first quartile (25%). The lines extending parallel from the boxes are known as 'whiskers', whose upper end denotes 90% values and lower end 10% values. '×' represents maximum and minimum datapoints (outliers) while '-' represents 99% and 1% values. The horizontal line inside the box stands for the median and '▪' stands for the mean value. The individual data points are presented on right side of each box.

For Barnala district, the radon concentration for winter season shows highest variability of as longer inter quartile range (IQR) of 37.08 Bqm^{-3} (Figure 3.15) and for thoron the IQR is of 68.42 Bqm^{-3} (Figure 3.16). This shows the variability of thoron is much higher than radon in winter season.

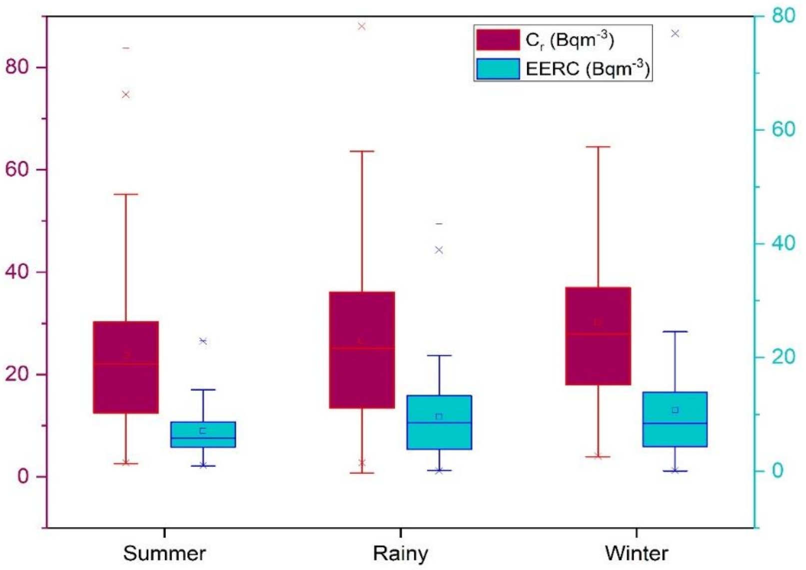


Figure 3.15: Box-whisker plot for radon concentration (C_r) and EERC in Barnala district

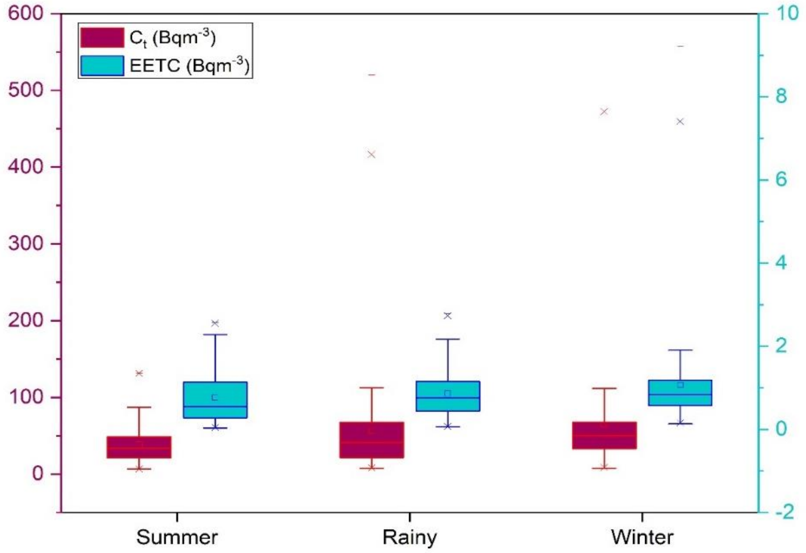


Figure 3.16: Box-whisker plot for thoron concentration (C_t) and EETC in Barnala district

For Moga district, the radon concentration for winter season shows highest variability of as longer inter quartile range (IQR) of 40.02 Bqm^{-3} (Figure 3.17) and for thoron the IQR is of 63.21 Bqm^{-3} (Figure 3.18).

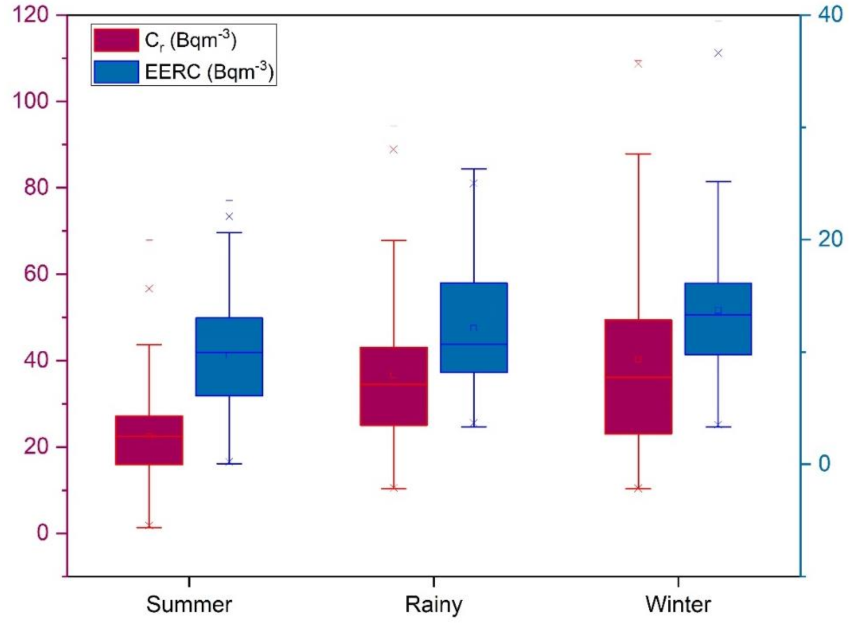


Figure 3.17: Box whisker plot for radon concentration (Cr) and EERC in Moga district

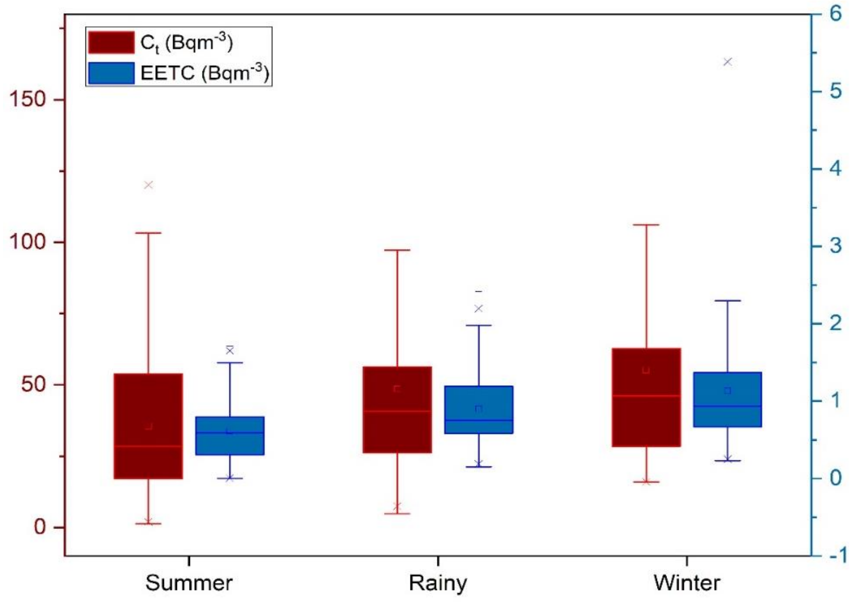


Figure 3.18: Box whisker plot for thoron concentration (Ct) and EETC in Moga district

3.4.1.7 Annual Effective Dose. In Barnala district, the average annual effective inhalation dose for radon and its progeny lies in the range from 0.13 to 2.17 mSvy^{-1} with an average value of 0.63 mSvy^{-1} and it lies in the range from 0.08 to 1.12 mSvy^{-1}

with an average value of 0.30 mSvy^{-1} for thoron and its progeny. The total annual average effective inhalation dose for radon/thoron and their progeny lies in the range from 0.21 to 2.59 mSvy^{-1} with mean value of 0.94 mSvy^{-1} which is lower than the safe limit of 14 mSvy^{-1} at residential places as recommended by ICRP, 2018. Figure 3.19 shows the box whisker plot for annual effective inhalation dose due to radon/thoron and their progeny concentration.

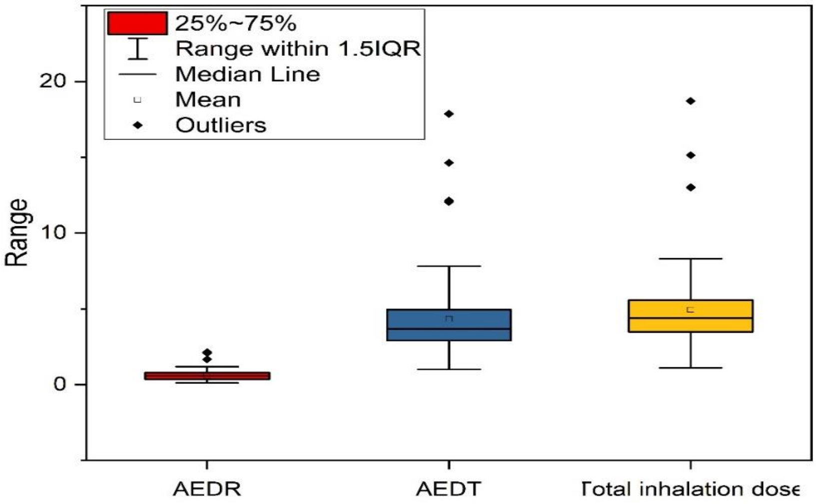


Figure 3.19: Box- whisker plot for total annual inhalation dose in Barnala district

In Moga district, the average annual effective inhalation dose for radon and its progeny lies in the range from 0.46 to 1.44 mSvy^{-1} with an average value of 0.79 mSvy^{-1} and it lies in the range from 0.13 to 0.73 mSvy^{-1} with an average value of 0.28 mSvy^{-1} for thoron and its progeny. The total annual average effective inhalation dose for radon/thoron and their progeny lies in the range from 0.63 to 2.17 mSvy^{-1} with mean value of 1.07 mSvy^{-1} which is lower than the safe limit of 14 mSvy^{-1} at residential places as recommended by ICRP, 2018. Figure 3.20 shows the box whisker plot for annual effective inhalation dose due to radon/thoron and their progeny concentration.

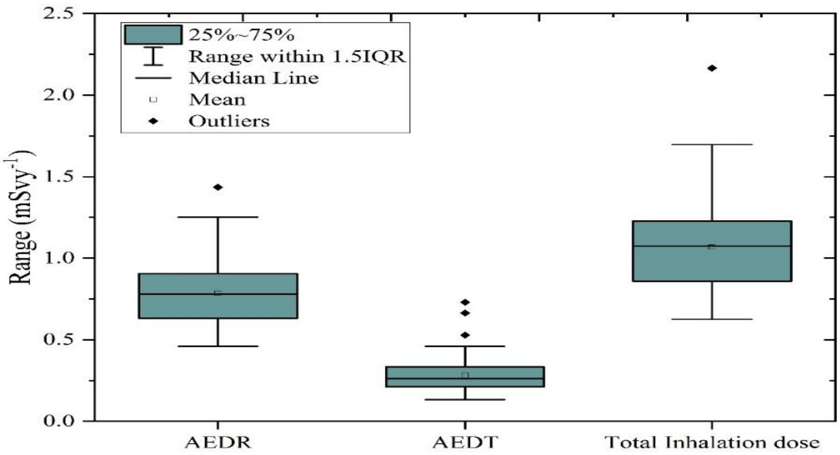


Figure 3.20: Box- whisker plot for total annual inhalation dose in Moga district

3.4.2 Radon/Thoron Gas Concentration Using Active Technique

Table 3.3 shows the measurement of radon/thoron gas concentration in the studied area using active technique. **In Barnala district,** the average value of radon concentration in the dwellings lie in the range of 6.82 ± 0.76 to 59.75 ± 2.54 Bqm^{-3} with average value of 22.86 ± 1.63 Bqm^{-3} and having 20.74 ± 1.57 Bqm^{-3} geometric mean. These values are below the recommended level of 40 Bqm^{-3} (UNSCEAR, 2008). The average value of thoron concentration lies in the range from 8.48 ± 3.05 to 224.34 ± 7.98 Bqm^{-3} with average value of 49.44 ± 5.26 Bqm^{-3} and having 42.76± 5.18 Bqm^{-3} geometric mean which is higher than the worldwide average value of 10 Bqm^{-3} (UNSCEAR, 2000).

In Moga district, the average value of radon concentration lies in the range of 8.23 ± 0.32 to 60.56 ± 3.24 Bqm^{-3} with an average value of 27.94 ± 2.01 Bqm^{-3} and having 26.20 ± 1.93 Bqm^{-3} geometric mean these values are below the recommended level of 40 Bqm^{-3} (UNSCEAR, 2008). The values of average annual concentration of thoron lie in the range from 11.32 ± 3.15 to 110.9 ± 8.76 Bqm^{-3} with average value of 42.01 ± 5.75 Bqm^{-3} and having 38.02 ± 5.68 Bqm^{-3} geometric mean which is higher than the worldwide average value of 10 Bqm^{-3} (UNSCEAR, 2000).

Table 3.4 represents the comparison of the measured values of radon/thoron and their progeny concentration in the studied area with other similar research work carried out in other states. The values of radon/thoron and their progeny concentration respectively, are lower than that of Srinagar, J & K (Nazir et al., 2020), Hanumangarh district, Rajasthan (Singla et al., 2021a), Hamirpur district, Himachal Pradesh (Singh et al., 2015), Khasi Hills district of Meghalaya (Pyngrope et al., 2020), Rajpur region of

Uttarakhand Himalaya (Kandari et al., 2016) and Una (Mehra et al., 2013) while are higher than that of Faridabad district of Haryana (Singh et al., 2019), Mandya city of Karnataka (Narsimhamurthy et al., 2020), Moradabad district of Uttar Pradesh (Singh et al., 2016) and HBRA South Eastern coast of Odisha (Ramola et al., 2015).

3.5 CONCLUSION

- Out of 200 samples, 32.5% of the dwellings have higher annual average radon concentration than the recommended value of 40 Bqm^{-3} (UNSCEAR, 2008).
- 100% of the dwellings have higher annual average thoron concentration than the world average value of 10 Bqm^{-3} (UNSCEAR, 2008), this presumably may be due to the use of thorium rich materials used in construction of dwellings of this area (Mishra 1972; Sankarn et al., 1986).
- 9% of the dwellings have higher annual average radon progeny concentration (EERC) than the worldwide average value of 15 Bqm^{-3} while 96% of the dwellings have higher annual average thoron progeny concentration (EETC) than the world average value of 0.5 Bqm^{-3} (UNSCEAR, 2008).
- The measured average radon, thoron and their progeny concentration in the studied area have been found to be higher in winter season as compared to rainy and summer season due to exchange of gases.
- The annual average equilibrium factor between radon and its progeny is 0.37 which is slightly less than world average value of 0.4 and for thoron and its progeny is 0.02, which is same as recommended by UNSCEAR (2008).
- The total annual effective inhalation dose received to the local population is well below the recommended level by ICRP, 2018. Hence the presence of these radiations may pose no carcinogenic risk to the residents of the studied area.
- The area where higher concentration values may be explored further for radiological risk assessment to the residents of the studied area.
- The data will contribute towards the national pool for mapping and for further studies.

Table 3.1: Statistical analysis of Seasonal variation of radon, thoron, and their progeny (EERC/EETC) concentration using passive technique

Seasons	**Summer**				**Rainy**				**Winter**			
Statistics	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})	**EETC ± σ** (Bqm^{-3})	**EERC ± σ** (Bqm^{-3})	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})	**EETC ± σ** (Bqm^{-3})	**EERC ± σ** (Bqm^{-3})	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})	**EETC ± σ** (Bqm^{-3})	**EERC ± σ** (Bqm^{-3})
Barnala District												
Minimum	2.58 ± 1.81	8.77 ± 5.34	0.07 ± 0.03	1.24 ± 0.46	4.92 ± 1.52	10.53 ± 6.01	0.10 ± 0.03	0.48 ± 0.27	4.06 ± 1.98	7.89 ± 5.74	0.17 ± 0.04	0.44 ± 0.25
Maximum	83.76 ± 6.56	133.33 ± 8.82	2.60 ± 0.15	23.27 ± 1.56	98.49 ± 7.09	520.18 ± 25.90	2.82 ± 0.16	43.84 ± 2.10	142.00 8.46	634.80 ± 26.12	9.25 ± 0.29	92.94 ± 2.94
Average	23.77 ± 3.58	39.22 ± 10.03	0.80 ± 0.08	7.48 ± 0.86	26.78 ± 3.74	57.31 ± 11.43	0.90 ± 0.08	10.02 ± 0.98	30.34 ± 3.99	64.90 ± 11.23	1.11 ± 0.09	11.14 ± 1.00
Standard deviation	14.78 ± 0.94	25.19 ± 2.35	0.63 ± 0.03	4.56 ± 0.22	16.45 ± 1.00	64.04 ± 2.88	0.56 ± 0.03	7.45 ± 0.33	17.87 ± 0.96	72.40 ± 3.03	1.15 ± 0.04	11.61 ± 0.40
Skewness	1.23 ± 0.50	1.57 ± 0.74	1.18 ± 0.62	1.67 ± 1.09	1.36 ± 0.48	4.78 ± 1.57	1.00 ± 0.22	1.85 ± 0.60	2.72 ± 1.00	5.58 ± 1.57	4.76 ± 2.55	4.49 ± 1.50
Kurtosis	2.16 ± 0.20	3.04 ± 1.07	0.56 ± -0.52	3.33 ± 1.63	3.10 ± 0.33	29.76 ± 6.35	1.10 ± -0.33	5.41 ± 1.32	14.48 ± 3.83	39.97 ± 5.60	28.42 ± 10.3	27.61 ± 5.91
Geometric Mean	19.37 ± 3.46	32.57 ± 9.77	0.59 ± 0.07	6.35 ± 0.84	22.23 ± 3.61	41.94 ± 11.11	0.72 ± 0.08	7.42 ± 0.92	26.12 ± 3.88	49.63 ± 10.87	0.86 ± 0.09	7.73 ± 0.92
Moga District												
Minimum	1.38 ± 1.65	6.36 ± 4.79	0.03 ± 0.01	0.23 ± 0.07	10.32 ± 2.82	15.95 ± 8.02	0.23 ± 0.05	3.33 ± 0.63	10.32 ± 2.70	4.76 ± 0.53	0.15 ± 0.04	3.34 ± 0.63
Maximum	67.94 ± 6.04	137.1 ± 16.44	1.71 ± 0.13	23.51 ± 1.62	109.39 ±7.58	298.16 ± 22.16	5.48 ± 0.23	39.45 ± 2.13	94.26 ± 7.00	267.72 ± 18.70	2.41 ± 0.15	26.30 ± 1.68

Seasons	**Summer**				**Rainy**				**Winter**			
Statistics	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**	**EETC ± σ (Bqm^{-3})**	**EERC ± σ (Bqm^{-3})**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**	**EETC ± σ (Bqm^{-3})**	**EERC ± σ (Bqm^{-3})**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**	**EETC ± σ (Bqm^{-3})**	**EERC ± σ (Bqm^{-3})**
Average	22.37 ± 3.61	36.25 ± 9.99	0.62 ± 0.07	9.70 ± 0.99	40.31 ± 4.64	55.21 ± 12.90	1.13 ± 0.10	13.72 ± 1.21	36.75 ± 4.47	48.72 ± 12.28	0.90 ± 0.09	12.10 ± 1.15
Standard deviation	10.37 ± 0.73	24.84 ± 2.22	0.42 ± 0.03	4.99 ± 0.29	22.11 ± 1.10	45.34 ± 2.93	0.82 ± 0.03	5.84 ± 0.24	15.95 ± 0.85	39.73 ± 2.42	0.44 ± 0.02	4.78 ± 0.24
Skewness	0.93 ± -0.02	1.18 ± 0.14	0.62 ± -0.24	0.03 ± -0.71	1.20 ± 0.61	3.34 ± 0.82	3.31 ± 2.02	1.37 ± 0.49	1.08 ± 0.60	3.35 ± 0.48	0.93 ± 0.31	0.50 ± 0.15
Kurtosis	2.92 ± 0.92	1.59 ± 0.31	-0.15 ± -0.37	-0.20 ± 0.35	1.47 ± 0.10	14.15 ± 0.94	14.49 ± 6.72	3.88 ± 1.92	1.36 ± 0.31	14.48 ± -0.07	0.57 ± -0.55	-0.39 ± 0.81
Geometric Mean	19.56 ± 3.54	28.69 ± 9.74	0.39 ± 0.07	7.54 ± 0.94	34.96 ± 4.51	45.07 ± 12.59	0.96 ± 0.10	12.57 ± 1.19	33.62 ± 4.40	39.56 ± 12.05	0.80 ± 0.09	11.16 ± 1.12

Table 3.2: Annual average radon/thoron and their progeny concentration and total annual effective inhalation dose using passive technique

Dosimeter No.	Village/ Town	Ventilation conditions	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	Total annual effective inhalation dose ($mSvy^{-1}$)
Barnala District							
1	Dhanola	Partially	24.72 ± 3.73	56.63 ± 11.07	0.95 ± 0.09	3.18 ± 0.63	0.54
2		Poor	42.90 ± 4.75	230.21 ± 16.50	0.79 ± 0.08	13.07 ± 1.14	1.27
3		Well	16.01 ± 3.11	35.38 ± 8.95	0.59 ± 0.07	4.79 ± 0.72	0.51
4		Poor	61.53 ± 5.53	73.68 ± 15.35	1.28 ± 0.10	33.30 ± 1.79	2.59
5	Bhadaur	Well	19.96 ± 3.41	41.03 ± 9.69	0.74 ± 0.07	7.08 ± 0.82	0.71
6		Well	15.72 ± 3.05	40.35 ± 8.94	0.92 ± 0.08	6.17 ± 0.80	0.70
7		Partially	17.78 ± 3.12	44.44 ± 9.26	0.43 ± 0.06	13.17 ± 0.99	1.01
8		Poor	19.05 ± 3.35	24.07 ± 8.91	0.57 ± 0.07	33.16 ± 1.38	2.29
9	Jangiana	Partially	25.35 ± 3.77	39.18 ± 10.47	0.82 ± 0.08	6.33 ± 0.80	0.69
10		Partially	22.31 ± 3.55	96.49 ± 11.67	0.38 ± 0.06	4.42 ± 0.67	0.49
11		Partially	22.26 ± 3.56	28.36 ± 9.49	0.46 ± 0.06	5.02 ± 0.68	0.49
12		Poor	25.98 ± 3.73	41.42 ± 10.38	0.73± 0.08	4.56 ± 0.71	0.55
13	Channa	Partially	25.18 ± 3.65	186.74 ± 14.43	1.08 ± 0.10	8.10 ± 0.94	0.99
14		Poor	27.02 ± 3.89	36.45 ± 10.58	1.02 ± 0.09	26.43 ± 1.45	2.01
15		Partially	25.70 ± 3.80	37.23 ± 10.43	1.45 ± 0.11	14.82 ± 1.24	1.40
16		Well	21.74 ± 3.49	57.89 ± 10.68	1.45 ± 0.11	13.94 ± 1.21	1.36

Dosimeter No.	**Village/ Town**	**Ventilation conditions**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**	**EETC ± σ (Bqm^{-3})**	**EERC ± σ (Bqm^{-3})**	**Total annual effective inhalation dose ($mSvy^{-1}$)**
17	Nainewal	Partially	26.21 ± 3.83	55.56 ± 11.23	1.15 ± 0.10	12.74 ± 1.14	1.20
18		Poor	32.92 ± 4.21	48.44 ± 11.68	1.08 ± 0.09	9.44 ± 0.98	0.97
19		Well	21.05 ± 3.47	51.95 ± 10.37	1.18 ± 0.09	14.46 ± 1.16	1.31
20		Poor	34.30 ± 4.24	30.70 ± 11.15	0.98 ± 0.09	13.03 ± 1.12	1.16
21	Tapa	Poor	33.44 ± 4.28	65.30 ± 12.22	1.04 ± 0.09	6.81 ± 0.86	0.81
22		Partially	30.86 ± 4.08	80.80 ± 12.55	0.55 ± 0.07	9.59 ± 0.96	0.86
23		Partially	22.03 ± 3.55	55.36 ± 10.57	1.30 ± 0.10	9.11 ± 0.99	1.01
24		Poor	31.72 ± 4.08	36.55 ± 11.15	0.68 ± 0.08	8.79 ± 0.93	0.81
25	Draj	Well	16.52 ± 3.12	33.63 ± 8.94	0.46 ± 0.06	4.50 ± 0.69	0.46
26		Well	11.82 ± 2.78	35.96 ± 8.28	0.86 ± 0.08	4.66 ± 0.71	0.58
27		Partially	18.24 ± 3.27	23.49 ± 9.37	0.65 ± 0.08	7.45 ± 0.88	0.69
28		Partially	17.44 ± 3.24	27.10 ± 8.80	0.65 ± 0.08	6.29 ± 0.82	0.62
29	Mehta	Poor	33.04 ± 4.15	36.06 ± 10.99	1.18 ± 0.10	11.58 ± 1.07	1.13
30		Poor	36.07 ± 4.39	69.88 ± 12.60	0.60 ± 0.07	7.92 ± 0.90	0.76
31		Partially	27.70 ± 3.87	43.76 ± 10.67	0.93 ± 0.09	10.75 ± 1.03	1.01
32		Partially	27.13 ± 3.88	18.32 ± 9.86	0.93 ± 0.09	12.11 ± 1.11	1.07
33	Dhurkot	Poor	46.57 ± 4.95	32.55 ± 12.76	1.87 ± 0.13	18.36 ± 1.39	1.76
34		Poor	44.56 ± 4.86	30.31 ± 12.44	1.30 ± 0.11	13.11 ± 1.17	1.27

Dosimeter No.	**Village/ Town**	**Ventilation conditions**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**	**EETC ± σ (Bqm^{-3})**	**EERC ± σ (Bqm^{-3})**	**Total annual effective inhalation dose (mSvy^{-1})**
35		Partially	40.55 ± 4.66	42.98 ± 12.43	1.57 ± 0.12	17.26 ± 1.33	1.61
36		Well	36.42 ± 4.44	55.26 ± 12.44	1.48 ± 0.11	15.96 ± 1.28	1.51
37	Sanghere	Partially	41.23 ± 4.51	40.35 ± 12.14	0.97 ± 0.09	8.57 ± 0.91	0.89
38		Poor	63.13 ± 5.24	154.19 ± 16.22	1.40 ± 0.11	12.52 ± 1.12	1.38
39		Well	33.09 ± 4.22	61.79 ± 12.04	0.94 ± 0.09	8.06 ± 0.87	0.86
40		Well	26.84 ± 3.85	81.09 ± 12.12	1.16 ± 0.10	7.10 ± 0.88	0.87
41	Wajid Ke	Well	27.99 ± 3.93	90.73 ± 12.50	0.48 ± 0.06	10.00 ± 0.96	0.87
42		Partially	31.72 ± 4.18	53.73 ± 11.77	1.16 ± 0.09	9.13 ± 0.99	0.98
43		Partially	35.04 ± 4.35	21.54 ± 10.99	0.76 ± 0.08	8.92 ± 0.95	0.83
44		Partially	35.16 ± 4.37	47.08 ± 11.94	0.67 ± 0.08	12.26 ± 1.09	1.04
45	Chahuan Ke	Well	16.41 ± 2.96	58.88 ± 9.41	0.83 ± 0.08	3.82 ± 0.66	0.54
46		Poor	32.46 ± 3.97	69.01 ± 12.12	0.43 ± 0.06	4.30 ± 0.64	0.48
47		Partially	22.49 ± 3.55	26.32 ± 9.45	0.46 ± 0.06	6.01 ± 0.78	0.55
48		Partially	22.26 ± 3.58	28.46 ± 9.54	0.94 ± 0.09	5.27 ± 0.77	0.64
49	Sehjra	Partially	28.96 ± 3.92	93.76 ± 12.57	2.32 ± 0.12	7.91 ± 1.01	1.25
50		Partially	26.21 ± 3.82	90.06 ± 12.24	2.21 ± 0.13	10.01 ± 1.10	1.35
51		Well	22.37 ± 3.58	89.47 ± 11.96	1.49 ± 0.10	9.27 ± 1.01	1.10
52		Poor	31.20 ± 4.07	74.46 ± 12.46	1.62 ± 0.12	11.14 ± 1.10	1.25

Dosimeter No.	Village/ Town	Ventilation conditions	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	Total annual effective inhalation dose ($mSvy^{-1}$)
53	Bhadalwad	Partially	29.37 ± 4.03	75.44 ± 12.31	1.43 ± 0.11	10.73 ± 1.07	1.17
54		Poor	33.72 ± 4.27	61.89 ± 12.29	1.51 ± 0.12	12.45 ± 1.16	1.30
55		Well	22.72 ± 3.60	71.64 ± 11.30	1.26 ± 0.10	10.88 ± 1.07	1.12
56		Well	28.33 ± 3.97	54.78 ± 11.47	1.27 ± 0.11	10.46 ± 1.07	1.09
57	Barnala	Well	16.24 ± 3.11	40.35 ± 8.99	1.71 ± 0.12	2.97 ± 0.70	0.72
58		Well	11.76 ± 2.74	86.55 ± 10.33	0.49 ± 0.06	2.05 ± 0.49	0.35
59		Poor	29.31 ± 3.78	45.03 ± 10.64	0.73 ± 0.08	11.60 ± 1.02	1.00
60		Poor	33.26 ± 4.09	144.25 ± 13.87	3.62 ± 0.15	15.23 ± 1.21	2.12
61	Mehal Kalan	Poor	49.72 ± 5.12	35.19 ± 13.22	0.90 ± 0.09	14.85 ± 1.19	1.27
62		Partially	27.76 ± 3.76	52.44 ± 10.52	0.77 ± 0.08	8.79 ± 0.92	0.84
63		Well	14.17 ± 2.97	24.46 ± 8.09	0.44 ± 0.06	6.20 ± 0.79	0.55
64		Well	25.35 ± 3.76	31.09 ± 10.12	0.40 ± 0.06	4.65 ± 0.67	0.46
65	Kurar	Well	9.59 ± 2.57	12.57 ± 6.53	0.24 ± 0.05	1.94 ± 0.44	0.21
66		Well	9.87 ± 2.59	40.35 ± 8.20	0.88 ± 0.09	7.52 ± 0.90	0.76
67		Well	14.47 ± 2.63	25.05 ± 7.59	0.55 ± 0.07	5.79 ± 0.78	0.55
68		Well	9.93 ± 2.59	48.34 ± 8.60	1.08 ± 0.10	4.00 ± 0.71	0.60
69	Aspal Kalan	Poor	25.18 ± 3.77	87.72 ± 12.25	1.40 ± 0.11	11.17 ± 1.09	1.19
70		Partially	20.42 ± 3.24	50.78 ± 9.70	0.99 ± 0.09	8.14 ± 0.90	0.85

Dosimeter No.	**Village/ Town**	**Ventilation conditions**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**	**EETC ± σ (Bqm^{-3})**	**EERC ± σ (Bqm^{-3})**	**Total annual effective inhalation dose (mSvy^{-1})**
71		Partially	20.48 ± 3.35	59.26 ± 10.42	1.18 ± 0.10	10.56 ± 1.03	1.07
72		Partially	22.54 ± 3.53	48.34 ± 10.30	0.74 ± 0.08	12.98 ± 1.12	1.09
73	Dangarh	Partially	26.38 ± 3.81	24.66 ± 9.93	0.68 ± 0.08	14.55 ± 1.18	1.16
74		Poor	31.49 ± 4.17	50.00 ± 11.56	0.70 ± 0.08	12.22 ± 1.10	1.04
75		Well	26.96 ± 3.87	35.58 ± 10.50	0.68 ± 0.08	12.64 ± 1.12	1.05
76		Well	26.50 ± 3.80	49.90 ± 10.86	1.03 ± 0.09	11.29 ± 1.06	1.07
77	Harigarh	Well	29.02 ± 3.91	42.88 ± 10.87	0.94 ± 0.09	11.30 ± 1.04	1.04
78		Poor	41.46 ± 4.71	44.64 ± 12.64	0.88 ± 0.08	13.16 ± 1.15	1.16
79		Poor	36.70 ± 4.45	46.69 ± 12.10	0.66 ± 0.08	9.75 ± 0.99	0.88
80		Well	33.04 ± 4.13	52.63 ± 11.63	0.76 ± 0.08	10.33 ± 1.01	0.94
81	Bheni Dessa	Well	14.52 ± 3.00	28.75 ± 8.37	0.50 ± 0.06	6.09 ± 0.79	0.56
82		Poor	37.79 ± 4.17	61.11 ± 11.77	1.09 ± 0.09	5.69 ± 0.81	0.76
83		Well	14.23 ± 2.98	33.24 ± 8.58	0.77 ± 0.08	5.00 ± 0.74	0.57
84		Well	16.41 ± 3.15	34.89 ± 8.89	0.76 ± 0.08	5.42 ± 0.77	0.60
85	Attar Singh Wala	Partially	28.22 ± 3.84	30.21 ± 10.26	0.57 ± 0.07	12.02 ± 1.03	0.98
86		Poor	31.32 ± 4.15	69.20 ± 12.27	1.31 ± 0.10	11.95 ± 1.13	1.21
87		Partially	22.66 ± 3.49	30.21 ± 9.55	0.45 ± 0.06	7.26 ± 0.85	0.63
88		Well	13.14 ± 2.89	53.41 ± 9.33	0.94 ± 0.09	4.28 ± 0.72	0.59

Dosimeter No.	**Village/ Town**	**Ventilation conditions**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**	**EETC ± σ (Bqm^{-3})**	**EERC ± σ (Bqm^{-3})**	**Total annual effective inhalation dose ($mSvy^{-1}$)**
89	Diwana	Poor	29.54 ± 4.05	48.83 ± 11.40	1.23 ± 0.10	5.44 ± 0.80	0.76
90		Poor	38.65 ± 4.40	71.44 ± 13.01	0.52 ± 0.06	6.28 ± 0.78	0.64
91		Bad	19.22 ± 3.29	62.77 ± 10.53	0.62 ± 0.07	3.68 ± 0.61	0.48
92		Partially	22.43 ± 3.55	53.02 ± 10.65	0.67 ± 0.07	9.74 ± 0.97	0.87
93	Kattu	Well	15.72 ± 3.00	44.05 ± 9.11	0.66 ± 0.08	6.52 ± 0.80	0.65
94		Well	21.57 ± 3.48	37.04 ± 9.80	0.56 ± 0.07	7.74 ± 0.88	0.70
95		Partially	28.45 ± 3.71	31.68 ± 10.02	0.76 ± 0.08	2.71 ± 0.58	0.44
96		Poor	31.26 ± 3.83	37.52 ± 10.50	0.43 ± 0.06	5.54 ± 0.70	0.53
97	Handiaya	Partially	26.96 ± 3.70	43.37 ± 10.62	0.65 ± 0.07	6.36 ± 0.82	0.65
98		Poor	34.53 ± 4.32	54.09 ± 12.08	0.29 ± 0.05	10.13 ± 0.99	0.80
99		Bad	13.14 ± 2.83	45.91 ± 8.69	0.41 ± 0.06	4.74 ± 0.64	0.46
100		Poor	32.29 ± 3.82	43.37 ± 10.96	0.65 ± 0.07	14.28 ± 1.05	1.15
Minimum			9.59 ± 2.57	12.57 ± 6.53	0.24 ± 0.05	1.94 ± 0.44	0.21
Maximum			63.13 ± 5.53	230.21 ± 16.50	3.62 ± 0.15	33.30 ± 1.79	2.59
Average			26.96 ± 3.77	53.81 ± 10.90	0.94 ± 0.09	9.55 ± 0.95	0.94
Standard deviation			9.97 ± 0.60	32.31 ± 1.73	0.48 ± 0.02	5.31 ± 0.22	0.41
Geometric Mean			25.17 ± 3.72	47.61 ± 10.76	0.84 ± 0.08	8.35 ± 0.92	0.86

Dosimeter No.	**Village/ Town**	**Ventilation conditions**	**C_r ± σ (Bqm^{-3})**	**C_t ± σ (Bqm^{-3})**	**EETC ± σ (Bqm^{-3})**	**EERC ± σ (Bqm^{-3})**	**Total annual effective inhalation dose (mSvy^{-1})**
Kurtosis			1.90 ± 0.21	11.48 ± 1.08	8.83 ± 0.20	7.06 ± 1.19	3.13
Skewness			0.89 ± 0.22	2.90 ± 0.51	2.19 ± 0.52	2.05 ± 0.50	1.39
1st Quartile			20.46 ± 3.39	35.53 ± 9.65	0.64 ± 0.07	5.95 ± 0.79	0.63
2nd Quartile			26.67 ± 3.80	45.47 ± 10.66	0.83 ± 0.08	9.01 ± 0.96	0.87
3rd Quartile			32.52 ± 4.15	61.28 ± 12.12	1.18 ± 0.10	12.14 ± 1.10	1.16
Moga District							
1	Bhagapurana	Partially	32.16 ± 4.04	25.96 ± 10.44	0.63 ± 0.07	11.42 ± 1.04	0.95
2		Partially	41.91± 4.49	112.03 ± 3.40	0.74 ± 0.07	13.12 ± 1.08	1.17
3		Well	21.33 ± 3.46	47.04 ± 9.92	0.52 ± 0.07	7.56 ± 0.87	0.68
4		Poor	64.04 ± 5.57	39.36 ± 14.31	0.70 ± 0.07	14.70 ± 1.20	1.23
5	Marhi	Poor	35.72 ± 4.31	29.40 ± 11.17	0.88 ± 0.08	14.42 ± 1.20	1.21
6		Well	23.22 ± 3.72	41.64 ± 10.37	0.88 ± 0.09	9.57 ± 1.01	0.91
7		Well	19.15 ± 3.33	47.18 ± 9.81	0.65 ± 0.07	8.98 ± 0.93	0.81
8		Well	23.79 ± 3.72	48.65 ± 10.73	0.65 ± 0.07	10.41 ± 1.04	0.90
9	Rode	Partially	37.09 ± 4.43	18.17 ± 11.12	0.58 ± 0.07	13.69 ± 1.18	1.08
10		Poor	44.15 ± 4.80	106.23 ± 14.96	0.93 ± 0.09	12.69 ± 1.12	1.19
11		Partially	29.07 ± 4.04	48.93 ± 11.41	0.73 ± 0.08	12.02 ± 1.10	1.03
12		Partially	37.67 ± 4.47	43.40 ± 12.05	0.58 ± 0.07	8.36 ± 0.95	0.76

Dosimeter No.	Village/ Town	Ventilation conditions	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	Total annual effective inhalation dose (mSvy^{-1})
13	Khokhrana	Partially	27.98 ± 4.18	111.33 ± 13.84	1.19 ± 0.11	14.61 ± 1.30	1.37
14		Poor	34.11 ± 4.48	50.10 ± 12.66	0.53 ± 0.07	7.71 ± 0.94	0.71
15		Poor	34.17 ± 4.44	37.72 ± 11.83	1.05 ± 0.10	15.21 ± 1.30	1.32
16		Partially	22.93 ± 3.85	63.67 ± 11.76	0.74 ± 0.09	10.26 ± 1.09	0.93
17	Nathuwala	Well	25.86 ± 4.04	52.31 ± 11.75	0.98 ± 0.10	11.74 ± 1.17	1.09
18		Poor	32.91 ± 4.40	37.35 ± 11.79	0.81 ± 0.09	10.89 ± 1.11	0.98
19		Partially	29.64 ± 4.26	48.92 ± 11.90	0.95 ± 0.09	13.84 ± 1.24	1.21
20		Poor	31.93 ± 4.04	42.83 ± 11.02	0.89 ± 0.09	10.62 ± 1.02	0.99
21	Samalsar	Partially	30.90 ± 4.18	44.02 ± 11.48	0.73 ± 0.08	9.79 ± 1.00	0.89
22		Partially	31.65 ± 4.32	64.67 ± 12.69	0.50 ± 0.07	10.21 ± 1.06	0.87
23		Well	20.24 ± 3.63	33.32 ± 10.05	0.89 ± 0.09	6.91 ± 0.94	0.73
24		Poor	35.03 ± 4.36	19.67 ± 11.06	0.73 ± 0.08	10.14 ± 1.05	0.90
25	Smadh Bhai	Partially	28.27 ± 4.10	35.79 ± 11.21	0.56 ± 0.08	7.21 ± 0.93	0.67
26		Partially	28.55 ± 3.87	32.08 ± 10.48	0.73 ± 0.08	7.14 ± 0.86	0.71
27		Partially	25.23 ± 3.75	23.67 ± 9.77	0.61 ± 0.07	9.99 ± 1.01	0.85
28		Poor	29.87 ± 3.99	32.64 ± 10.68	0.72 ± 0.08	10.22 ± 1.02	0.91
29	Chrik	Poor	39.79 ± 4.56	43.94 ± 12.25	1.48 ± 0.11	18.40 ± 1.38	1.65
30		Poor	39.67 ± 4.58	68.31 ± 13.00	0.73 ± 0.08	13.28 ± 1.15	1.14

Dosimeter No.	Village/ Town	Ventilation conditions	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	Total annual effective inhalation dose (mSvy^{-1})
31		Partially	30.56 ±4.06	38.28 ± 11.02	1.11 ± 0.10	13.34 ± 1.17	1.22
32		Partially	27.98 ±3.91	26.15 ± 10.26	0.40 ± 0.06	8.11 ± 0.87	0.68
33	Nihal Singhwala	Poor	60.66 ± 5.21	48.49 ± 13.56	1.12 ± 0.11	18.59 ± 1.45	1.59
34		Poor	64.61 ± 5.64	56.12 ± 14.68	0.95 ± 0.11	13.65 ± 1.36	1.25
35		Partially	59.63 ± 5.62	46.37 ± 14.77	1.47 ± 0.12	18.75 ± 1.43	1.70
36		Partially	49.31 ± 5.14	52.72 ± 13.91	1.42 ± 0.11	18.74 ± 1.41	1.68
37	Himatpura	Poor	49.48 ± 5.06	110.51 ± 14.74	1.34 ± 0.11	17.78 ± 1.37	1.64
38		Partially	47.07 ± 4.63	59.88 ± 12.92	1.22 ± 0.09	15.89 ± 1.18	1.44
39		Poor	51.66 ± 5.06	48.77 ± 13.46	1.23 ± 0.11	12.56 ± 1.17	1.23
40		Well	28.49 ± 4.40	38.90 ± 11.44	0.72 ± 0.09	8.82 ± 1.10	0.82
41	Dharamkot	Well	27.81 ± 3.72	78.78 ± 11.53	0.39 ± 0.06	7.94 ± 0.85	0.70
42		Well	26.77 ± 3.81	54.34 ± 10.99	0.99 ± 0.08	13.61 ±1.06	1.21
43		Partially	36.81 ± 3.86	31.91 ± 9.86	0.52 ± 0.07	8.13 ± 0.89	0.73
44		Poor	40.94 ± 4.95	55.42 ± 13.77	0.68 ± 0.08	12.00 ± 1.17	1.04
45	Chotian Kalan	Partially	30.79 ± 4.37	31.55 ± 11.60	1.08 ± 0.10	12.31 ± 1.20	1.14
46		Partially	30.10 ± 4.13	31.66 ± 10.93	0.40 ± 0.06	7.19 ± 0.87	0.63
47		Poor	32.28 ± 4.39	21.09 ± 11.22	0.57 ± 0.08	8.43 ± 0.99	0.74
48		Well	26.89 ± 3.94	34.26 ± 10.62	0.75 ± 0.08	10.91 ± 1.04	0.95

Dosimeter No.	Village/ Town	Ventilation conditions	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	Total annual effective inhalation dose (mSvy^{-1})
49	Poorhni	Well	18.98 ± 3.41	80.61 ± 11.19	2.15 ± 0.12	7.88 ± 0.97	1.18
50		Partially	26.49 ± 4.73	83.39 ± 14.77	1.66 ± 0.13	9.04 ± 1.28	1.13
51		Partially	24.02 ± 3.89	80.32 ± 12.45	1.28 ± 0.11	11.52 ± 1.18	1.18
52		Poor	37.32 ± 4.68	70.79 ± 13.83	1.31 ± 0.11	12.16 ±1.22	1.23
53	Buttar	Partially	27.81 ± 3.89	49.74 ± 11.11	1.16 ± 0.10	10.25 ± 1.01	1.04
54		Partially	28.78 ± 4.02	41.43 ± 11.14	1.22 ± 0.11	14.68 ± 1.27	1.33
55		Well	26.09 ± 3.78	52.79 ± 10.87	1.18 ± 0.10	14.77 ± 1.24	1.33
56		Poor	31.30 ± 4.22	29.59 ± 11.10	1.08 ± 0.10	13.95 ± 1.24	1.24
57	Moga	Partially	41.11 ± 4.55	27.35 ± 11.72	1.23 ± 0.10	15.45 ± 1.26	1.39
58		Well	34.80 ± 4.13	37.22 ± 11.08	0.85 ± 0.09	16.16 ± 1.25	1.33
59		Poor	51.08 ± 5.05	45.08 ± 13.28	1.37 ± 0.11	16.87 ± 1.32	1.54
60		Poor	54.35 ± 5.17	57.68 ± 13.74	2.45 ± 0.14	21.76 ± 1.50	2.17
61	Pooroowal	Poor	55.96 ± 5.22	40.60 ± 13.69	0.90 ± 0.09	15.26 ± 1.24	1.31
62		Poor	47.93 ± 4.71	56.45 ± 13.02	1.06 ± 0.09	12.25 ± 1.11	1.17
63		Well	25.91 ± 3.85	16.64 ± 9.78	0.72 ± 0.08	9.24 ± 0.99	0.83
64		Partially	29.76 ± 4.12	33.42 ± 11.05	0.51 ± 0.07	7.68 ± 0.90	0.69
65	Mahna	Well	19.95 ± 3.45	31.76 ± 9.52	0.51 ± 0.07	8.29 ± 0.93	0.71
66		Well	15.94 ± 3.28	25.41 ± 9.02	0.59 ± 0.08	8.33 ± 0.95	0.73

Dosimeter No.	**Village/ Town**	**Ventilation conditions**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**	**EETC ± σ (Bqm^{-3})**	**EERC ± σ (Bqm^{-3})**	**Total annual effective inhalation dose ($mSvy^{-1}$)**
67		Well	15.88 ± 3.30	27.17 ± 9.09	0.61 ± 0.08	9.14 ± 1.04	0.79
68		Poor	37.95 ± 4.67	46.02 ± 12.93	0.88 ± 0.09	12.67 ± 1.20	1.12
69	Ajitwal	Well	23.79 ± 3.84	114.05 ± 13.04	1.14 ± 0.11	13.35 ± 1.26	1.27
70		Partially	27.86 ± 4.05	38.92 ± 11.29	1.21 ± 0.11	13.67 ± 1.28	1.26
71		Well	24.14 ± 3.90	35.38 ± 10.68	1.08 ± 0.11	13.94 ± 1.29	1.24
72		Poor	28.38 ± 4.04	42.32 ± 11.15	0.97 ± 0.10	13.06 ±1.19	1.16
73	Dina	Well	23.62 ± 3.82	37.05 ± 10.59	0.76 ± 0.09	13.28 ± 1.22	1.11
74		Well	29.30 ± 4.07	50.78 ± 11.49	0.73 ± 0.08	9.99 ± 1.03	0.91
75		Well	34.63 ± 4.40	39.17 ± 11.83	1.04 ± 0.10	13.89 ± 1.22	1.24
76		Poor	37.50 ± 4.58	42.23 ± 12.36	1.16 ± 0.10	13.40 ± 1.20	1.25
77	Kokri kokri	Poor	35.72 ± 4.46	37.59 ± 11.78	1.07 ± 0.10	13.38 ± 1.21	1.21
78		Partially	30.67 ± 4.12	38.18 ± 11.19	0.75 ± 0.08	10.88 ± 1.08	0.96
79		Poor	36.12 ± 4.48	48.99 ± 12.24	0.71 ± 0.08	9.28 ± 1.01	0.86
80		Partially	35.55 ± 4.46	32.72 ± 11.79	0.86 ± 0.09	12.45 ± 1.16	1.09
81	Rajiana	Well	20.81 ± 3.53	44.42 ± 10.14	0.60 ± 0.08	10.11 ± 1.04	0.86
82		Partially	23.51 ± 3.70	36.47 ± 10.23	0.87 ± 0.09	10.81 ± 1.08	0.98
83		Poor	25.11 ± 3.84	41.70 ± 10.74	0.60 ± 0.08	9.55 ± 1.00	0.83
84		Partially	22.07 ± 3.64	40.40 ± 10.23	0.82 ± 0.09	10.75 ± 1.08	0.96

Dosimeter No.	Village/ Town	Ventilation conditions	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	Total annual effective inhalation dose ($mSvy^{-1}$)
85	Karyal	Poor	35.89 ± 4.49	43.04 ± 12.19	0.57 ± 0.07	13.70 ± 1.20	1.10
86		Partially	33.31 ± 4.33	68.73 ± 12.76	0.89 ± 0.09	12.15 ± 1.13	1.11
87		Poor	37.78 ± 4.60	47.88 ± 12.57	0.56 ± 0.07	9.74 ± 1.02	0.85
88		Well	25.63 ± 3.84	46.66 ± 10.96	0.92 ± 0.09	13.16 ± 1.19	1.15
89	Babiha Bhaike	Poor	33.48 ± 4.36	49.82 ± 12.13	1.10 ± 0.10	12.06 ± 1.14	1.14
90		Poor	32.11 ± 4.09	58.71 ± 11.86	0.58 ± 0.07	8.92 ± 0.96	0.81
91		Well	22.70 ± 3.64	34.83 ± 10.13	0.65 ± 0.08	9.73 ± 1.03	0.85
92		Well	23.16 ± 3.70	40.47 ± 10.43	0.70 ± 0.08	10.18 ± 1.05	0.90
93	Gill	Well	26.32 ± 3.92	37.39 ± 10.74	0.80 ± 0.09	14.38 ± 1.23	1.19
94		Partially	34.92 ± 4.42	25.81 ± 11.38	0.81 ± 0.09	11.82 ± 1.12	1.03
95		Poor	38.70 ± 4.49	26.13 ± 11.61	0.97 ± 0.10	10.95 ± 1.10	1.03
96		Poor	41.68 ± 4.76	55.60 ± 13.24	0.79 ± 0.09	9.95 ± 1.04	0.94
97	Ludhai Ke	Partially	36.64 ± 4.49	55.41 ± 12.68	0.44 ± 0.07	9.22 ± 0.99	0.79
98		Poor	40.31 ± 4.73	47.54 ± 12.81	0.64 ± 0.08	12.80 ± 1.16	1.07
99		Well	20.01 ± 3.45	36.93 ± 9.66	0.48 ± 0.07	8.88 ± 0.97	0.75
100		Poor	41.62 ± 4.53	28.31 ± 11.83	0.72 ± 0.08	15.48 ± 1.17	1.25
Minimum			15.88 ± 3.28	16.64 ± 9.02	0.39 ± 0.06	6.91 ± 0.85	0.21
Maximum			64.61 ± 5.64	114.05 ± 14.96	2.45 ± 0.14	21.76 ± 1.50	2.59

Dosimeter No.	**Village/ Town**	**Ventilation conditions**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**	**EETC ± σ (Bqm^{-3})**	**EERC ± σ (Bqm^{-3})**	**Total annual effective inhalation dose (mSvy^{-1})**
Average			33.14 ± 4.24	46.73 ± 11.72	0.88 ± 0.09	11.84 ± 1.12	0.94
Standard deviation			10.31 ± 0.51	20.04 ± 1.38	0.34 ± 0.02	3.03 ± 0.14	0.41
Geometric Mean			31.71 ± 4.21	43.30 ± 11.65	0.83 ± 0.09	11.47 ± 1.11	1.04
Kurtosis			1.13 ± 0.17	3.33 ± -0.34	4.78 ± 0.09	0.32 ± -0.34	3.13
Skewness			1.06 ± 0.52	1.69 ± 0.47	1.64 ± 0.53	0.65 ± 0.27	1.39
1st Quartile			26.04 ± 3.85	34.69 ±10.74	0.65 ± 0.08	9.56 ± 1.01	0.63
2nd Quartile			30.85 ± 4.18	42.57 ± 11.49	0.81 ± 0.09	11.78 ± 1.11	0.87
3rd Quartile			37.54 ± 4.53	52.41 ± 12.68	1.08 ± 0.10	13.69 ± 1.22	1.16

Table 3.3: Radon/thoron gas concentration in the dwellings using active technique

Dosimeter No.	**Village/Town**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**
Barnala district			
1	Dhanola	20.79 ± 1.23	52.89 ± 7.03
2		38.7 ± 2.24	224.34 ± 7.98
3		12.32 ± 1.11	31.56 ± 4.12
4		56.54 ± 2.43	69.32 ± 7.23
5	Bhadaur	15.43 ± 1.32	37.43 ± 4.67
6		11.21 ± 1.02	36.45 ± 4.44
7		13.24 ± 1.04	40.02 ± 4.68
8		15.56 ± 1.15	22.13 ± 4.27
9	Jangiana	22.45 ± 1.32	31.93 ± 5.21
10		19.81 ± 1.36	92.43 ± 6.32
11		11.43 ± 1.25	24.13 ± 6.12
12		20.34 ± 1.62	37.12 ± 4.23
13	Channa	21.54 ± 1.71	183.54 ± 6.34
14		22.57 ± 1.42	32.15 ± 5.12
15		20.46 ± 1.9	35.14 ± 5.43
16		17.14 ± 1.36	53.76 ± 4.87
17	Nainewal	20.15 ± 1.47	52.36 ± 5.62
18		27.89 ± 2.02	42.14 ± 5.36
19		16.24 ± 1.34	46.23 ± 5.13
20		30.64 ± 2.12	25.64 ± 5.23
21	Tapa	29.87 ± 2.15	62.53 ± 6.79
22		27.87 ± 2.02	75.76 ± 5.72
23		17.98 ± 1.13	52.35 ± 5.5
24		26.75 ± 2.12	32.64 ± 6.16
25	Draj	12.63 ± 1.03	29.13 ± 3.6
26		7.58 ± 0.97	30.54 ± 4.13
27		13.65 ± 1.02	18.93 ± 4.23
28		13.78 ± 1.06	21.72 ± 4.4
29	Mehta	28.68 ± 2.1	32.14 ± 5.2
30		32.77 ± 2.13	64.82 ± 5.12
31		25.96 ± 1.74	39.14 ± 5.14

Dosimeter No.	**Village/Town**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**
32		24.05 ± 1.13	13.77 ± 4.56
33	Dhurkot	42.11 ± 2.14	28.92 ± 6.32
34		39.23 ± 2.18	26.35 ± 5.23
35		37.46 ± 2.34	38.92 ± 5.67
36		32.15 ± 2.2	51.72 ± 6.61
37	Sanghere	36.81 ± 2.24	36.91 ± 5.76
38		59.75 ± 2.12	150.72 ± 7.14
39		28.76 ± 2.11	56.36 ± 6.35
40		23.12 ± 1.56	78.81 ± 6.31
41	Wajid Ke	22.75 ± 1.62	83.23 ± 5.78
42		26.36 ± 2.09	48.52 ± 5.34
43		31.76 ± 2.12	18.49 ± 5.78
44		30.23 ± 2.14	42.04 ± 5.34
45	Chahuan Ke	12.14 ± 1.46	48.22 ± 4.43
46		26.17 ± 1.67	64.53 ± 5.67
47		17.42 ± 1.78	22.75 ± 4.87
48		16.23 ± 1.56	23.67 ± 4.56
49	Sehjra	24.12 ± 1.74	89.91 ± 6.13
50		22.65 ± 1.45	84.78 ± 5.16
51		17.57 ± 1.63	85.88 ± 5.17
52		29.56 ± 2.01	70.97 ± 6.28
53	Bhadalwad	25.74 ± 2.1	70.64 ± 6.13
54		28.63 ± 2.14	58.87 ± 6.5
55		17.72 ± 1.3	68.34 ± 5.73
56		24.98 ± 1.67	49.43 ± 5.87
57	Barnala	12.58 ± 1.04	35.67 ± 4.33
58		7.32 ± 1.02	82.53 ± 4.98
59		27.45 ± 1.23	40.62 ± 5.55
60		30.97 ± 2.04	139.51 ± 6.73
61	Mehal Kalan	45.46 ± 2.54	31.78 ± 6.14
62		28.81 ± 1.87	47.56 ± 5.98
63		11.32 ± 1.64	18.72 ± 4.12
64		20.34 ± 1.04	27.56 ± 5.03

Dosimeter No.	Village/Town	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})
65	Kurar	7.54 ± 0.95	8.48 ± 3.89
66		7.98 ± 1.1	37.81 ± 3.99
67		10.42 ± 1.13	21.94 ± 3.54
68		6.82 ± 0.76	43.75 ± 3.56
69	Aspal Kalan	24.12 ± 1.34	84.36 ± 5.79
70		15.23 ± 1.23	46.89 ± 4.25
71		16.91 ± 1.15	55.73 ± 5.25
72		17.32 ± 1.82	43.64 ± 5.34
73	Dangarh	21.42 ± 1.06	20.76 ± 4.13
74		29.34 ± 2.1	45.65 ± 5.76
75		21.35 ± 1.46	31.88 ± 5.87
76		22.65 ± 1.9	46.52 ± 5.15
77	Harigarh	24.78 ± 1.45	39.72 ± 5.34
78		37.32 ± 2.14	38.65 ± 6.78
79		32.53 ± 2.16	42.44 ± 6.12
80		30.47 ± 2.05	47.98 ± 5.32
81	Bheni Dessa	10.67 ± 1.5	23.76 ± 4.68
82		32.65 ± 2.1	57.84 ± 5.78
83		11.24 ± 1.45	37.89 ± 3.98
84		12.57 ± 1.25	26.98 ± 3.67
85	Attar Singh Wala	22.98 ± 1.78	26.24 ± 5.12
86		27.86 ± 2.04	64.76 ± 5.16
87		17.42 ± 1.56	25.89 ± 4.15
88		10.34 ± 1.04	48.63 ± 3.78
89	Diwana	24.56 ± 2.01	42.55 ± 5.12
90		34.48 ± 2.2	65.32 ± 6.1
91		15.33 ± 1.43	57.29 ± 5.13
92		19.27 ± 1.64	48.23 ± 5.23
93	Kattu	11.62 ± 1.5	39.21 ± 4.03
94		17.36 ± 1.23	34.53 ± 3.05
95		23.78 ± 1.34	27.54 ± 4.78
96		26.54 ± 1.73	34.08 ± 5.45
97	Handiaya	21.62 ± 1.67	37.12 ± 4.98

Dosimeter No.	**Village/Town**	**C_r ± σ (Bqm^{-3})**	**C_t ± σ (Bqm^{-3})**
98		30.92 ± 2.13	47.14 ± 6.12
99		8.45 ± 1.45	41.36 ± 4.02
100		26.89 ± 1.02	34.12 ± 5.05
Minimum		6.82 ± 0.76	8.48 ± 3.05
Maximum		59.75 ± 2.54	224.34 ± 7.98
Average		22.86 ± 1.63	49.44 ± 5.26
Standard deviation		9.97 ± 0.44	32.24 ± 0.94
Geometric Mean		20.74 ± 1.57	42.76 ± 5.18
Kurtosis		1.78 ± -1.24	11.41 ± -0.15
Skewness		0.92 ± 0.05	2.90 ± 0.12
1st Quartile		15.53 ± 1.25	31.86 ± 4.56
2nd Quartile		22.61 ± 1.62	40.99 ± 5.22
3rd Quartile		28.70 ± 2.09	56.59 ± 5.81
Moga district			
1	Bhagapurana	27.5 ± 2.01	18.56 ± 5.34
2		34.8 ± 2.24	107.4 ± 6.32
3		18.73 ± 1.34	42.8 ± 4.92
4		59.65 ± 3.24	34.64 ± 6.45
5	Marhi	31.84 ± 2.41	23.75 ± 5.56
6		18.38 ± 1.65	24.67 ± 5.34
7		16.49 ± 1.54	41.7 ± 4.65
8		19.96 ± 1.87	42.5 ± 4.98
9	Rode	32.06 ± 2.13	11.83 ± 6.62
10		40.83 ± 2.24	102.4 ± 6.78
11		25 ± 2.01	44.36 ± 6.32
12		34.77 ± 2.19	38.74 ± 6.12
13	Khokhrana	21.64 ± 2.12	108.67 ± 7.35
14		26.86 ± 2.21	46.98 ± 5.67
15		30.04 ± 2.22	32.89 ± 6.32
16		17.57 ± 1.78	59.31 ± 5.34
17	Nathuwala	22.45 ± 1.98	49.74 ± 5.97
18		29.31 ± 2.2	30.9 ± 4.78
19		25.1 ± 2.13	42.74 ± 6.23

Dosimeter No.	**Village/Town**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**
20		23.84 ± 2.13	37.43 ± 5.36
21	Samalsar	24.14 ± 1.12	39.38 ± 6.12
22		22.98 ± 2.15	60.24 ± 5.78
23		16.32 ± 1.67	28.79 ± 4.87
24		31.79 ± 1.18	14.23 ± 5.23
25	Smadh Bhai	23.05 ± 2.04	30.76 ± 5.36
26		23.55 ± 1.84	27.57 ± 4.78
27		22.13 ± 1.79	17.68 ± 4.43
28		26.29 ± 1.47	28.76 ± 5.15
29	Chrik	35.18 ± 2.68	39.63 ± 5.26
30		32.36 ± 2.59	63.7 ± 6.27
31		25.57 ± 2.57	35.72 ± 5.29
32		23.12 ± 1.85	23.87 ± 4.67
33	Nihal Singhwala	54.31 ± 2.89	42.56 ± 6.24
34		60.56 ± 2.78	53.85 ± 6.83
35		53.24 ± 2.54	41.63 ± 6.26
36		45.75 ± 2.86	47.45 ± 5.94
37	Himatpura	44.26 ± 2.77	106.32 ± 6.24
38		42.37 ± 2.64	55.84 ± 5.39
39		46.25 ± 2.79	43.75 ± 6.24
40		21.34 ± 2.78	33.56 ± 6.82
41	Dharamkot	24.81 ± 1.89	72.57 ± 5.5
42		20.35 ± 1.34	50.23 ± 4.98
43		33.23 ± 1.78	27.42 ± 3.85
44		34.96 ± 2.92	50.5 ± 8.54
45	Chotian Kalan	25.23 ± 2.2	27.84 ± 5.88
46		27.31 ± 2.71	27.35 ± 5.32
47		26.12 ± 1.98	17.4 ± 6.12
48		20.42 ± 1.74	29.25 ± 5.04
49	Badhni	14.73 ± 1.88	76.53 ± 6.05
50		22.04 ± 2.25	78.44 ± 6.88
51		17.45 ± 1.73	76.47 ± 7.32
52		30.52 ± 1.56	64.3 ± 6.36

Dosimeter No.	Village/Town	$C_r \pm \sigma$ (Bqm^{-3})	$C_t \pm \sigma$ (Bqm^{-3})
53	Buttar	22.72 ± 1.37	43.69 ± 5.57
54		26.48 ± 2.1	37.23 ± 5.38
55		21.25 ± 1.47	49.56 ± 5.14
56		26.31 ± 2.71	23.85 ± 6.81
57	Moga	37.12 ± 2.23	21.57 ± 5.37
58		27.93 ± 1.56	32.75 ± 5.2
59		47.23 ± 2.73	42.68 ± 3.15
60		49.14 ± 2.56	52.77 ± 5.23
61	Badoowal	50.27 ± 2.23	36.41 ± 4.21
62		42.87 ± 2.67	52.73 ± 5.37
63		22.34 ± 1.78	11.32 ± 5.42
64		19.86 ± 2.86	29.46 ± 5.93
65	Mahna	16.96 ± 1.76	28.53 ± 5.23
66		12.35 ± 1.18	21.67 ± 4.03
67		13.68 ± 1.5	22.48 ± 4.25
68		34.41 ± 1.34	42.87 ± 5.29
69	Ajitwal	17.51 ± 1.23	110.9 ± 6.27
70		23.24 ± 2.04	35.83 ± 5.32
71		20.19 ± 1.68	32.06 ± 5.51
72		21.32 ± 1.97	38.3 ± 5.83
73	Dina	16.46 ± 1.45	32.47 ± 5.94
74		25.81 ± 1.03	44.72 ± 5.72
75		30.62 ± 2.2	33.76 ± 5.81
76		32.67 ± 2.3	39.3 ± 5.36
77	Kokri	24.27 ± 2.23	35.04 ± 5.71
78		25.72 ± 1.75	35.21 ± 6.23
79		32.13 ± 2.24	43.63 ± 6.83
80		30.78 ± 2.31	27.98 ± 5.26
81	Rajiana	15.23 ± 1.32	40.05 ± 5.48
82		18.32 ± 1.51	32.84 ± 5.91
83		20.5 ± 1.64	28.16 ± 6.26
84		16.43 ± 1.96	36.27 ± 4.99
85	Karyal	30.32 ± 2.23	37.15 ± 6.34

Dosimeter No.	**Village/Town**	**$C_r \pm \sigma$ (Bqm^{-3})**	**$C_t \pm \sigma$ (Bqm^{-3})**
86		29.51 ± 2.07	64.79 ± 5.29
87		31.45 ± 2.3	43.46 ± 6.3
88		23.26 ± 1.45	41.25 ± 6.32
89	Babiha Bhaike	29.41 ± 2.16	46.87 ± 7.24
90		26.78 ± 2.05	55.23 ± 6.35
91		17.45 ± 1.42	30.06 ± 4.3
92		16.24 ± 1.31	35.93 ± 6.2
93	Gill	21.86 ± 1.74	32.76 ± 5.77
94		27.55 ± 2.21	20.78 ± 5.36
95		34.56 ± 2.72	22.36 ± 6.23
96		38.27 ± 2.48	51.23 ± 6.48
97	Ludhai Ke	32.93 ± 2.21	48.95 ± 5.89
98		37.23 ± 2.05	42.53 ± 8.76
99		18.21 ± 1.21	34.68 ± 6.87
100		8.23 ± 0.32	20.84 ± 5.76
Minimum		8.23 ± 0.32	11.32 ± 3.15
Maximum		60.56 ± 3.24	110.9 ± 8.76
Average		27.94 ± 2.01	42.01 ± 5.75
Standard deviation		10.41 ± 0.52	20.36 ± 0.87
Geometric Mean		26.20 ± 1.93	38.02 ± 5.68
Kurtosis		1.11 ± 0.1	3.33 ± 1.85
Skewness		1.07 ± -0.21	1.67 ± 0.34
1st Quartile		21.06 ± 1.67	29.14 ± 5.28
2nd Quartile		25.65 ± 2.05	37.87 ± 5.74
3rd Quartile		32.44 ± 2.30	47.83 ± 6.26

Table 3.4: Comparison of radon/thoron and their progeny with the similar investigation in other states of India

S. No.	Area of study	C_r (Bqm^{-3})	C_t (Bqm^{-3})	EERC (Bqm^{-3})	EETC (Bqm^{-3})	Reference
1.	Srinagar, J & K	35.61 ± 2.04	64.15 ± 4.23	9.30 ± 0.51	0.57 ± 0.004	Nazir et al., 2020
2.	Hanumangarh district, Rajasthan	32.16 ± 4.01	39.93 ± 10.97	8.69 ± 0.88	0.66 ± 0.07	Singla et al., 2021
3.	Hamirpur district, Himachal Pradesh	63.8	86.9	29.3	2.7	Singh et al., 2015
4.	Khasi Hills district of Meghalaya	55.9 ± 24	60.6 ± 34	20.9 ± 11	1.4 ± 0.9	Pyngrope et al., 2020
5.	FaridaPoor district of Haryana	26.3 ± 1.2	38.1 ± 1.6	38.1 ± 1.6	5.15 ± 0.23	Singh et al., 2019
6.	Mandya city of Karnataka	22.4 ± 1.5	24.1 ± 1.8	-	-	Narsimhamurthy et al., 2020
7.	Rajpur region of Uttarakhand Himalaya	89	38	35	2.14	Kandari et al., 2016
8.	MoradaPoor district of Uttar Pradesh	19.9	14.9	-	-	Singh et al., 2016
9.	Una, HP, India	98.65 ± 1.9	388.19 ± 11	-	-	Mehra et al., 2013
10.	HBRA, Southeastern coast of Odisha	18	43	-	8	Ramola et al., 2015
11.	Nalgonda district, Telangana state, India	122 ± 98	166 ± 159	-	-	Suman et al., 2021
12.	Barnala district, Punjab	26.96 ± 3.77	53.81 ± 10.90	5.31 ± 0.22	0.94 ± 0.09	**Present study**
13.	Moga district, Punjab	33.14 ± 4.24	46.73 ± 11.72	11.84 ± 1.12	0.88 ± 0.09	