CHAPTER: 3

MEASUREMENT OF INDOOR RADON/THORON, THEIR PROGENY CONCENTRATION AND ATTACHED/UNATTACHED FRACTIONS

This chapter describes the basic introduction and brief literature about the indoor radon/thoron and their progeny including attached and unattached fractions. The methodology of work for the measurement of these quantities using various instruments have been explained. Formulae used for calculations have been mentioned to compute equilibrium factors, annually effective inhalation doses for the assessment of harmful effects on residents of the studied area. In the last the results for various parameters have been shown in the form of tables and figures, which are then compared with the similar studies and finally conclusion has been presented.

3.1 INTRODUCTION

The modern lifestyle, in which people spend a significant percentage of their time indoors (houses, schools, workplaces, industry, and so on), makes radon/thoron entry, accumulation, and dispersion a critical issue. Radionuclides such as radon and thoron from the uranium and thorium decay series are produced by the decay of their immediate respective parent nuclides 226Ra and 224Ra. The gas is alone responsible for almost 50% of natural background radiation dose received by humans (UNSCEAR, 2008; Mehra et al., 2015; Chauhan et al., 2016). The radon/thoron and their progeny (Po-218, Pb-214, Pb-212, Bi-214, Bi-212) have a greater tendency to isolate themselves and move far away from their parent mineral by diffusion through soil and enters the indoor environment from surrounding air. Out of 2.2 mSv of dose received annually from natural sources of radiations, 1.27 mSv is due to radon isotopes and their short -lived progeny (IAEA, 1989; Kansal et al., 2011; Khan and Gibbons, 2014). Soil is the primary source of radon/thoron. Indoor radon/thoron levels are influenced by underground soil gas concentrations and are increased when high-source-content materials are used in construction (Kumar et al., 2014). Higher concentration of these gases in indoors is due to the low pressure inside the houses than outside which causes accumulation of radioactive isotopes from the building materials, soil and through cracks or gaps in walls and floors (Sahoo and Nathwani, 2007; Hassan et al., 2011; Soh et al., 2019).

The progeny of radon and thoron are the isotopes of heavy metals like polonium, bismuth and lead which exist as attached and unattached fraction (Mayya et al., 2010; Mishra et al., 2010). These progenies having positive charge combine with negatively charged air ions thereby shifting their charge to the gases and water vapours to form cluster (Eppan et al., 2007; Sapra et al., 2011). Due to the high diffusivities and tendency to attach with surfaces, these progeny get stick to existing fractions of aerosol particles, hence leads to rise in a continuous activity size distribution. Depending upon the aerosol size, their distribution has been categorized on the basis of their diameter, namely the unattached fractions (fine) having diameter of approx. 2 nm and the attached fractions (coarse) having diameter nearly equals to 100 nm. The unattached fraction is the ratio of unattached progeny concentration to total (attached + unattached) progeny concentration. The radon/thoron progenies with activity median below 10 nm are unattached progeny while with activity median between 10-10000 nm are attached progeny (Sharma et al., 2018). Some investigations show that due to the deposition velocities of the radon, progenies get more affected by the atmosphere and the attached fraction has less deposition velocity than unattached fraction. The deposition flux is related to ambient potential alpha energy concentration (PAEC) through effective deposition velocity which depends upon the existing concentration of aerosol particles (Rout et al., 2014). Unattached radon progenies undergo random motion like gas molecule, therefore these collide and stick to aerosol particles which is described as aerosol attachment (Mehra et al., 2015). During exhalation the traces of attached fractions passes the upper respiratory tract and leave the alveoli, while in case of unattached fractions their traces leave the upper respiratory tract but get deposited in the alveoli, this leads to the process of somatic transportation (Ramola et al., 2016). Also studies reveal the particle size is responsible for the accumulation of radon progeny in blood and it is evident that fine (unattached) fractions of progeny accumulate with blood with higher rate and delivers dose in the bronchial epithelium instead of coarse (attached) fraction (Chamberlin et al., 1956; Butterweck et al., 2002; Prahsad et al., 2017). Hence for precise dose assessment, it is imperative to know the attached/unattached progeny fractions.

The World Health Organisation has identified radon as a human carcinogen and has been directly linked to lung cancer (WHO, 2009). In United States alone, Radon is responsible for about 21,000 lung cancer deaths annually. About 2,900 of these deaths occur among people who have never smoked. According to an approximation, Radon is estimated to cause 1100 deaths per year in the United Kingdom (Milner et al., 2014) and 300 cases of lung cancer in Ireland every year can be linked to radon (Dowdall et al., 2017). Therefore, indoor radon monitoring is of fundamental importance.

Epidemiological studies by Henshaw revealed that indoor radon exposure associated with the risk of leukaemia and certain other cancers such as melanoma, kidneys and prostate cancer (Henshaw et al., 1990). The consequences from integrated analysis of seven North American case-control studies on the domestic radon and risk of lung cancer provide direct conformation of relation between residential radon and lung cancer risk and was reported using the data of miner and consistent with the results from animal and invitro studies (Krewski et al., 2005; Kansal et al., 2014). Darby's case-control studies shows that indoor radon is responsible for 2% of the deaths due to cancer in Europe (Hill et al., 2004). The existence of radon within the dwellings at higher levels causes significant risk of lung cancer (Lubin et al., 1995 and 1997).

The radon, thoron and their progeny get further attached to aerosols present in the air resulting in a significant radioactive hazard to human lungs. Radon progeny get deposited in the lungs during respiration and irradiate the tissues, thereby damaging the cells and may cause lung cancer (Fogler et al., 1994; BEIR VI, 1999; Mehra et al., 2009). Inhalation of high cumulative levels of radon and particularly its alpha emitting decay products has been linked to an increased risk of lung cancer among underground miners (BEIR IV, 1988; Sonakawde et al., 2003; Mishra et al., 2008; Pyngrope et al., 2020; Suman et al., 2020). It has been found that the inhalation dose received mainly from radon and thoron progeny and not from the gases themselves (Tsiyoglou et al., 1953; Mayya and Mishra, 2010; Kansal et al., 2011). The inhaled radon and its alpha emitting airborne progeny may cause lung cancer due to the absorbed dose in trachea bronchial epithelium (Garcis-Tobler 2018; Nazir et al., 2020). According to National Statistical office of Korea, lung cancer is the cause of highest death rate of 34.4 individual per 100,000 persons (Stastics Korea, 2013; Yoon et al., 2016).

A number of reputed international studies have been carried out for assessing activity concentration of radon, thoron and their progeny owing to their adverse health effects (Epinosa et al., 1999; Nikopolous et al., 2008; Chen et al., 2015; Al- Saleh 2017; Saini et al., 2018; Mirberg et al., 2018; Nguyen- Thu et al., 2019; Haussein et al., 2019).

The aim of present study is to determine the concentration of radon, thoron and their progeny and the attached/unattached progeny along with fraction of unattached radon and thoron using Single entry pinhole dosimeter, DRPS/DTPS and wiremesh DRPS/DTPS in the dwellings of Hanumangarh, Sri Ganganagar and Churu districts respectively in Northern Rajasthan and their health hazard to the various tissues and organs of human beings.

3.2 METHODOLOGY

To examine the concentration of radon/thoron gases, their progeny and fractions of attached/unattached; single entry pinhole dosimeter, deposition-based progeny sensors (DRPS/DTPS) and Wiremesh type deposition based progeny sensors, respectively were deployed in dwellings of different houses in the different villages of Hanumangarh (25 villages with 3 dosimeters in each village), Sri Ganganagar (21 villages with 4-6 dosimeters in each village) and Churu (20 villages with 5 dosimeters in each village) districts of Rajasthan. These dosimeters were calibrated with active working level monitors from tracer lab and grab filter paper sampling using radon and thoron sources (RN-1025 and TH-1025, Pylon, Canada) at BARC. The selection of location of the dwellings was based on a preliminary gamma survey carried out to assess surface contamination using a portable gamma survey metre (Polimaster, PM 1405, Belarus). A handheld GPS (Garmin GPSMAP-78S) was employed to ascertain the location of the dwellings. The data obtained from the gamma survey was categorised in two zones: Zone 1 (included villages with gamma level between 0-0.01 $\mu Svhr^{-1}$) and Zone-2 (included villages with gamma level between 0.01-0.02 $\mu Svhr^{-1}$).

3.2.1 Lab and Field Work

A) Preparation and Deployment of Dosimeters

In the lab, 100 pinhole dosimeters were prepared with LR-115 Type-II films of size 3×3 cm^2 (manufactured by Kodak Pathe, France) that were placed in the first and second compartments of the dosimeters to register tracks formed by alpha particles produced by the decay of radon and thoron gas, respectively. Similarly, 100 DRPS/DTPS and 100 Wiremesh DRPS/DTPS were prepared using LR-115 Type-II films with a size of 2.5×2.5 cm^2. An absorber of 37 µm thickness (25 µm aluminized mylar combined with 12 µm cellulose nitrate) has been installed above the detectors for DRPS, while an absorber of 50 µm aluminized mylar has been placed above the detectors for DTPS. The single entry pinhole dosimeter, DRPS/DTPS and Wiremesh DRPS/DTPS were deployed for one-year with the exposure period of 4 month each to study the seasonal variation of the concentration of radon, thoron and their progeny and unattached/attached fractions of radon/thoron. These were suspended overhead at a minimum distance of 1.5 meter from the ceiling and 10 cm away from the side walls (Figure 3.1). The reason of maintaining distance from the walls is behind the assumption that due to short half-life of thoron, exhaled thoron from buildings may get concentrated to the surface of walls (Ramola et al., 2016). To investigate seasonal changes, the full year has been divided into three seasons of four months each to cover the summer, winter, and rainy seasons. The deployed dosimeters were retrieved for further examination after each season and replaced with a new set of similarly prepared dosimeters. The houses in the research area were categorised depending on their ventilation conditions. A room with no windows is considered poorly ventilated, a room with one window and a door is considered somewhat ventilated, and a room with two or more windows and a door is considered well ventilated. The bulk of the houses in the neighbourhood is made up of cement and only has minor ventilation.

Figure 3.1: Deployed dosimeters, DRPS/DTPS and wiremesh in the dwellings

B) Etching and Counting of Tracks on The Detectors

Before etching the retrieved LR-115 films, the bulk etch rate of pristine films was standardized using a constant temperature etch bath. Then solution of 2.5 N of NaOH was prepared at room temperature and the exposed films were loaded into etching tank in the cartridges, then etching was carried out at 60 °C for 90 minutes. After etching, the etched films were washed with distilled water and left to dry.

The alpha tracks formed on films were counted using spark counter (model PSI-SCI) at pre-spark voltage of 900 V and optimized voltage 450 V. Spark counter is used to count the number of tracks on the films.

3.3 FORMULA USED FOR CALCULATIONS

3.3.1 Calculation of Indoor Radon and Thoron Concentration

The radon (C_R) and thoron (C_T) concentration in the filter compartment and the pinhole compartment can be calculated as (Sahoo et al., 2013):

$$C_R = \frac{(T_1 - B)}{(d \times k_R)} \qquad (1)$$

$$C_T = \frac{(T_2 - d \times C_R \times k_R' - B)}{(d \times k_T)} \qquad (2)$$

where, T_1 is the track density observed in ‘radon’ compartment,

k_R is the calibration factor of radon in ‘radon’ compartment for radon,

d is the number of days of exposure,

T_2 is the track density observed in the ‘radon + thoron’ compartment, k_R' and k_T are the calibration factors of radon and thoron in ‘radon + thoron’ compartment,

B is the background tracks arise due to intrinsic properties and exposure during transit period.

3.3.2 Calculation of Equilibrium Equivalent Concentration for Radon/Thoron (EERC/EETC)

According to UNSCEAR report (2008), the equilibrium equivalent radon and thoron progeny concentration is calculated using equation 3 and the equilibrium equivalent thoron concentration using equation (UNSCEAR, 2008; Mishra and Mayya, 2008):

$$\text{EERC (Bqm}^{-3}\text{)} = \frac{(T_{Rn} - B)}{d \times S_R} \qquad (3)$$

$$\text{EETC (Bqm}^{-3}) = \frac{T_T - B}{d \times S_T} \qquad (4)$$

Where, T_T (track cm^{-2} d^{-1}) is track density in DTPS,

S_T is sensitivity factor for thoron progeny (0.94 ± 0.0027 tr cm^{-2} d^{-1}/EETC (Bqm^{-1}),

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

d is number of days of exposure (120 days).

T_{Rn} (tracks cm^{-2}d^{-1}) is exact track density from radon progeny in DRPS using equation:

$$T_{Rn} = T_{DTPS} - \frac{\phi_{R_T}}{\phi_{T_T}} T_{DRPS} \qquad (5)$$

where, T_{DRPS} is total tracks in DRPS, T_{DTPS} is total track in DTPS,

ϕ_{RT} is track registration efficiency for thoron progeny in DRPS (0.01 ± 0.0004),

ϕ_{TT} is track registration efficiency for thoron progeny DTPS (0.083 ± 0.0004).

3.3.3 Calculation of Equilibrium Factor

The worldwide assumed value of equilibrium factor for radon and its progeny is 0.4 and the equilibrium factor for thoron and its progeny is 0.02 (UNSCEAR, 2000). However instead of using the assumed equilibrium factor for radon (F_R) and thoron (F_T) for each house was calculated from measured gas and progeny concentrations using the equations (UNSCEAR, 2000):

$$\text{Equilibrium Factor for radon } (F_R) = \frac{EERC}{C_R} \qquad (6)$$

$$\text{Equilibrium Factor for radon } (F_T) = \frac{EETC}{C_T} \qquad (7)$$

Since, EERC, EETC, C_R and C_T are all measured in Bqm^{-3}, equilibrium factors are less than one unit.

3.3.4 Calculation of Total Inhalation Dose

Inhalation effective dose due to radon and its progeny (D_R) is calculated by using following equation (UNSCEAR, 2000):

$$D_R\ (mSvy^{-1}) = [\ (C_R \times F_{CR}) + (EERC \times F_{EERC})] \times 8750 \times O_F \times 10^{-6} \quad (8)$$

Inhalation effective dose due to thoron and its progeny (D_T) is calculated by using following equation:

$$D_T\ (mSvy^{-1}) = [(C_T \times F_{CT}) + (EETC \times F_{EETC})] \times 8750 \times O_F \times 10^{-6} \quad (9)$$

Total Inhalation dose due to radon, thoron and their progeny (D_{Inh}) is calculated by using equation:

$$D_{Inh}\ (mSvy^{-1}) = D_R\ (mSvy^{-1}) + D_T\ (mSvy^{-1}) \quad (10)$$

where, F_{CR} is dose conversion factor for radon concentration (0.17 $nSvBq^{-1}h^{-1}m^3$), F_{CT} is dose conversion factor for thoron concentration (0.11 $nSvBq^{-1}h^{-1}m^3$), F_{EERC} is dose conversion factor for radon progeny concentration (9 $nSvBq^{-1}h^{-1}m^3$), F_{EETC} is dose conversion factor for thoron progeny (40 $nSvBq^{-1}h^{-1}m^3$) recommended by UNSCEAR (2000), and O_F is standard occupancy factor (0.8) for 1 year exposure period.

3.3.5 Calculation of Distribution of Dose to Individual Tissue and Organs

Distribution of dose to individual tissues and organs is calculated by using following equation (UNSCEAR, 2000; Khan et al., 2014):

$$\text{Dose to individual organ} = T_W \times D_{Inh}\ (mSvy^{-1}) \quad (11)$$

where T_W is tissue Weighing factor and D_{Inh} ($mSvy^{-1}$) is the total inhalation dose.

3.3.6 Calculation of Attached Equilibrium Equivalent Radon/Thoron Concentration ($EERC_A$/$EETC_A$)

$$EERC_A = \frac{T_r - b}{S_r \times d} - EETC_A \quad (12)$$

$$EETC_A = \frac{T_t - b}{S_t \times d} \quad (13)$$

Where, $EERC_A$, $EETC_A$ are attached equilibrium equivalent concentration of radon and thoron (Bqm^{-3}).

T_r and T_t are track densities (tracks cm^{-2}) of attached radon and thoron progeny in wiremesh DRPS/DTPS.
b is the background counts due to the exposure during transit period.
S_r (0.04 tracks $cm^{-2}d^{-1}$)/(Bqm^{-3})) is the sensitivity factor for $EERC_A$ and S_t (0.33 (tracks $cm^{-2}d^{-1}$)/(Bqm^{-3})) is the sensitivity factors for attached fraction for $EETC_A$.

3.3.7 Calculation of Attached and Unattached Fraction

The time-integrated unattached fraction for radon (F_r) and for thoron (F_t) was calculated as (Mayya et al., 2010)

$$\text{Unattached fraction of radon } (F_r) = \frac{EERC_U}{EERC} \qquad (14)$$

$$\text{Unattached fraction of thoron } (F_t) = \frac{EETC_U}{EETC} \qquad (15)$$

$$\text{Attached fraction of radon } (F^*_r) = \frac{EERC_A}{EERC} \qquad (16)$$

$$\text{Attached fraction of thoron } (F^*_t) = \frac{EETC_A}{EETC} \qquad (17)$$

Where, $EERC_U$ and $EETC_U$ are the equilibrium equivalent concentration of unattached radon and thoron progeny and has been calculated subtracting total (attached +unattached) EERC/EETC from attached EERC/EETC, respectively.
$EERC_A$ and $EETC_A$ are the equilibrium equivalent concentration of attached radon and thoron progeny.

3.3.8 Calculation of Dose Conversion Factors

The following models have been used for calculating the factors of dose conversion for mouth (DCF_m) and nasal breathing (DCF_n) for the estimation of effective dose (Porestendorfer, 1996):

$$DCF_m = 101 \times F_r + 6.7 \times (1-F_r) \qquad (18)$$

$$DCF_n = 23 \times F_r + 6.2 \times (1-F_r) \qquad (19)$$

Combined DCF is calculated by taking 60% mouth and 40% nasal breathing (Bennet WD et al., 2003)

$$DCF_c = 0.6 \times DCF_m + 0.4 \times DCF_n \qquad (20)$$

Where, DCF_c is the dose conversion factor for combined breathing (mSv WLM^{-1}).

3.3.9 Calculation of Inhalation Dose

Human respiratory tract model (HRTM) has been employed to calculate the inhalation dose because of mouth and nasal breathing (ICRP, 1993):

$$\text{IDH} = C_r \times \frac{F_r}{3700} \times \frac{7000\ ha^{-1}}{170} \times DCF_{(m,n)} \qquad (21)$$

Where, C_r is radon concentration.
F_r is the unattached fraction of radon.
The unattached fraction (F_r) is defined as the fraction of the potential alpha energy concentration (PAEC) of the short lived progeny that is not attached to the ambient aerosol. The F_r depends on the concentration of the particles of ambient aerosol (Z) and can be estimated by (Porstendofer, 2001):

$$Z\ (\text{cm}^{-3}) = \frac{414}{F_r} \qquad (22)$$

The measurement of Z is necessary to evaluate the impact of aerosol concentration on variation of radon short lived decay products.

3.3.10 Calculation of Annual Effective Dose

Due to exposure of radon/thoron progeny, the annual effective dose has been calculated as (UNSCEAR, 2000):

$$\text{AEDR (mSvy}^{-1}) = \text{EERC (Bqm}^{-3}) \times 8760\ \text{hy}^{-1} \times 0.8 \times 9\ \text{nSv (Bq.h/m}^{3})^{-1} \times 10^{-6} \qquad (23)$$

$$\text{AEDT (mSvy}^{-1}) = \text{EETC (Bqm}^{-3}) \times 8760\ \text{hy}^{-1} \times 0.8 \times 40\ \text{nSv (Bq.h/m}^{3})^{-1} \times 10^{-6} \qquad (24)$$

Where, EERC and EETC are the total (attached + unattached) equilibrium equivalent concentration of radon and thoron progeny, respectively.
0.8 is the factor for annual indoor occupancy, 8760 is hours per year.
9 nSv $(\text{Bq.h/m}^3)^{-1}$ and 40 nSv $(\text{Bq.h/m}^3)^{-1}$ are the dose conversion factor for radon and thoron progeny respectively (Mayya et al., 1998; UNSCEAR, 2006).

3.4 RESULTS AND DISCUSSION

3.4.1 Seasonal Variation of Radon/Thoron, Their Progeny (EERC/EETC) and Attached/Unattached Fractions in Indoor Air

The Table 3.1 shows the seasonal variation of radon, thoron and their progeny concentration (EERC/EETC) and attached/unattached fractions of radon/thoron in Hanumangarh, Sri Ganganagar and Churu Northern districts of Rajasthan.

In Hanumangarh district, total 75 dosimeters were deployed in 25 villages with 3 dosimeters in each village throughout the year for seasonal variation of radon and thoron and their progeny concentration. The radon concentration varies from 10.8 to 73.7 Bqm^{-3} with the average value of 32.5 Bqm^{-3} during rainy season. During summer season, it varies from 3.1 to 53.3 Bqm^{-3} with an average value of 16.8 Bqm^{-3}, while in winter season, it varies from 7.2 to 191.5 Bqm^{-3} with an average value of 47.3 Bqm^{-3}. The thoron concentration varies from 9.6 to 112.9 Bqm^{-3} with an average value of 37.9 Bqm^{-3} during the rainy season. During summer season the concentration varies from 7.3 to 54.7 Bqm^{-3} with an average value of 22.3 Bqm^{-3}. While in winter season, it varies from 11.7 to 258.2 Bqm^{-3} with an average value of 59.6 Bqm^{-3}. The EERC and EETC concentration varies from 0.6 to 24.6 Bqm^{-3} with an average value of 6.6 Bqm^{-3} and 0.2 to 1.3 Bqm^{-3} with an average value of 0.7 Bqm^{-3}, respectively during rainy season. During winter season the EERC and EETC concentration varies from 0.7 to 41.5 Bqm^{-3} with an average value of 12.7 Bqm^{-3} and 0.1 to 3.7 Bqm^{-3} with an average value of 0.9 Bqm^{-3}, respectively. While these varies from 1.7 to 12.8 Bqm^{-3} with an average value of 6.4 Bqm^{-3} and 0.1 to 1.1 Bqm^{-3} with an average value of 0.3 Bqm^{-3} respectively for summer season. The attached fractions of radon/thoron concentration ($EERC_A$/$EETC_A$) vary from 1.23 to 23.64 Bqm^{-3} with an average value of 5.82 Bqm^{-3} and 0.09 to 1.26 Bqm^{-3} with an average value of 0.36 Bqm^{-3} respectively in rainy season. During winter season, it varies from 0.12 to 16.40 Bqm^{-3} with an average value of 6.28 Bqm^{-3} and 0.10 to 1.39 Bqm^{-3} with an average value of 0.59 Bqm^{-3} respectively, while for summer season, these varies from 0.81 to 30.87 Bqm^{-3} with an average value of 5.70 Bqm^{-3} and 0.01 to 1.05 Bqm^{-3} with an average value of 0.34 Bqm^{-3} respectively.

In Sri Ganganagar district, total 100 dosimeters were deployed in 21 villages with 4-6 dosimeters in each village throughout the year for seasonal variation of radon and thoron and their progeny concentration. The radon concentration varies from 3.1 to 41.6 Bqm^{-3} with an average value of 15.5 Bqm^{-3} during rainy season. During summer season, it varies from 4.1 to 59.2 Bqm^{-3} with an average value of 13.8 Bqm^{-3}, while in winter season, it varies from 10.1 to 139.4 Bqm^{-3} with an average value of 22.8 Bqm^{-3}. The thoron concentration varies from 7.2 to 246.5 Bqm^{-3} with an average value of 26.6 Bqm^{-3} during the rainy season. During summer season the concentration varies from 7 to 99.4 Bqm^{-3} with an average value of 21 Bqm^{-3}. While in winter season, it varies from 9.1 to 126.6 Bqm^{-3} with an average value of 40.7 Bqm^{-3}. The EERC and EETC concentration varies from 1.8 to 23.3 Bqm^{-3} with an average value of 6.1 Bqm^{-3} and 0.3 to 1.2 Bqm^{-3} with an average value of 0.5 Bqm^{-3}, respectively during rainy season. During winter season the EERC and EETC concentration varies from 0.5 to 31.4 Bqm^{-3} with an average value of 7.4 Bqm^{-3} and 0.1 to 3.1 Bqm^{-3} with an average value of 0.7 Bqm^{-3}, respectively. While these varies from 1 to 13.6 Bqm^{-3} with an average value of 3.1 Bqm^{-3} and 0.1 to 0.7 Bqm^{-3} with an average value of 0.3 Bqm^{-3}, respectively for summer season. The attached fractions of radon/thoron concentration ($EERC_A/EETC_A$) vary from 0.06 to 17.44 Bqm^{-3} with an average value of 4.06 Bqm^{-3} and 0.04 to 1.43 Bqm^{-3} with an average value of 0.30 Bqm^{-3} respectively in rainy season. During winter season, it varies from 0.78 to 23.87 Bqm^{-3} with an average value of 4.12 Bqm^{-3} and 0.01 to 0.90 Bqm^{-3} with an average value of 0.34 Bqm^{-3} respectively, while for summer season, these varies from 0.53 to 10.90 Bqm^{-3} with an average value of 2.86 Bqm^{-3} and 0.04 to 0.98 Bqm^{-3} with an average value of 0.26 Bqm^{-3}, respectively.

In Churu district, total 100 dosimeters were deployed in 20 villages with 5 dosimeters in each village throughout the year for seasonal variation of radon and thoron and their progeny concentration. The radon concentration varies from 12.6 to 42.5 Bqm^{-3} with the average value of 20.7 Bqm^{-3} during rainy season. During summer season, it varies from 4.3 to 27.6 Bqm^{-3} with an average value of 15 Bqm^{-3}, while in winter season, it varies from 5.7 to 93.7 Bqm^{-3} with an average value of 22.9 Bqm^{-3}.

The thoron concentration varies from 8 to 56.8 Bqm^{-3} with an average value of 19 Bqm^{-3} during the rainy season. During summer season the concentration varies from 10.4 to 57.3 Bqm^{-3} with an average value of 17.9 Bqm^{-3}. While in winter season, it varies from 8 to 56.8 Bqm^{-3} with an average value of 19 Bqm^{-3}. The EERC and EETC concentration varies from 1.2 to 30.3 Bqm^{-3} with an average value of 6.2 Bqm^{-3} and 0.2 to 1.8 Bqm^{-3} with an average value of 0.4 Bqm^{-3}, respectively during rainy season. During winter season the EERC and EETC concentration varies from 0.5 to 30.1 Bqm^{-3} with an average value of 6.2 Bqm^{-3} and 0.2 to 3.7 Bqm^{-3} with an average value of 1.1 Bqm^{-3}, respectively. While these varies from 1.1 to 15.2 Bqm^{-3} with an average value of 3.9 Bqm^{-3} and 0.2 to 1.8 Bqm^{-3} with an average value of 0.4 Bqm^{-3} respectively for summer season. The attached fractions of radon/thoron concentration ($EERC_A/EETC_A$) vary from 0.09 to 24.30 Bqm^{-3} with an average value of 3.39 Bqm^{-3} and 0.13 to 1.25 Bqm^{-3} with an average value of 0.43 Bqm^{-3} respectively in rainy season. During winter season, it varies from 0.04 to 13.50 Bqm^{-3} with an average value of 3.77 Bqm^{-3} and 0.04 to 2.59 Bqm^{-3} with an average value of 0.47 Bqm^{-3} respectively, while for summer season, these varies from 0.01 to 29.54 Bqm^{-3} with an average value of 3.14 Bqm^{-3} and 0.03 to 1.60 Bqm^{-3} with an average value of 0.30 Bqm^{-3} respectively.

Figure 3.2 to 3.7 shows the average seasonal variation of radon, thoron and their progeny concentration (EERC/EETC) and attached fractions of radon/thoron concentration ($EERC_A/EETC_A$) in the indoor dwellings of Hanumangarh, Sri Ganganagar and Churu districts respectively.

The average seasonal radon, thoron and their progeny concentration (EERC/EETC) and attached fractions of radon/thoron ($EERC_A/EETC_A$) have been observed to be higher in the winter season as compared with summer and rainy seasons. This might be due to poor ventilation conditions inside dwellings, less air exchange between indoor and outdoor and therefore radioactive gases accumulate more in indoor environment during winter. The average seasonal concentration of radon, thoron and their progeny observed lowest in the summer season. In summer season, due to increased temperature and air mixing, these gases concentration is reduced.

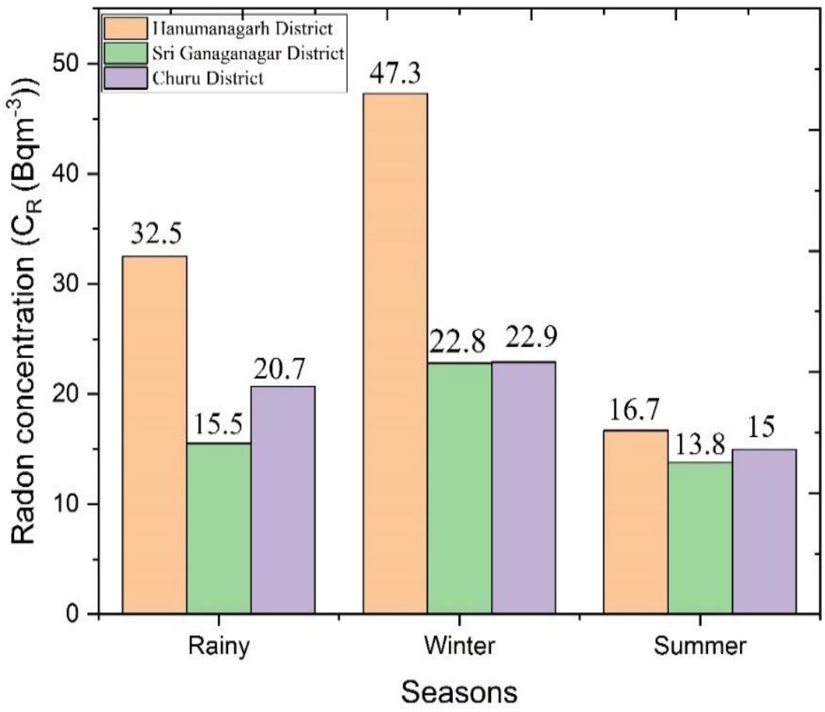

Figure 3.2: Average seasonal variation of indoor radon concentration in Hanumangarh, Sri Ganganagar and Churu districts of Northern Rajasthan

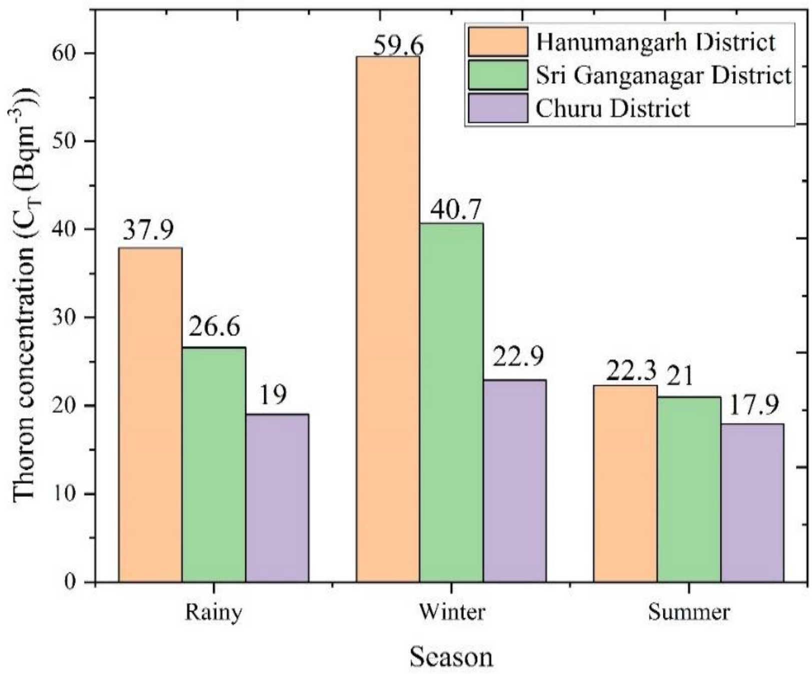

Figure 3.3: Average seasonal variation of indoor thoron concentration in Hanumangarh, Sri Ganganagar and Churu districts of Northern Rajasthan

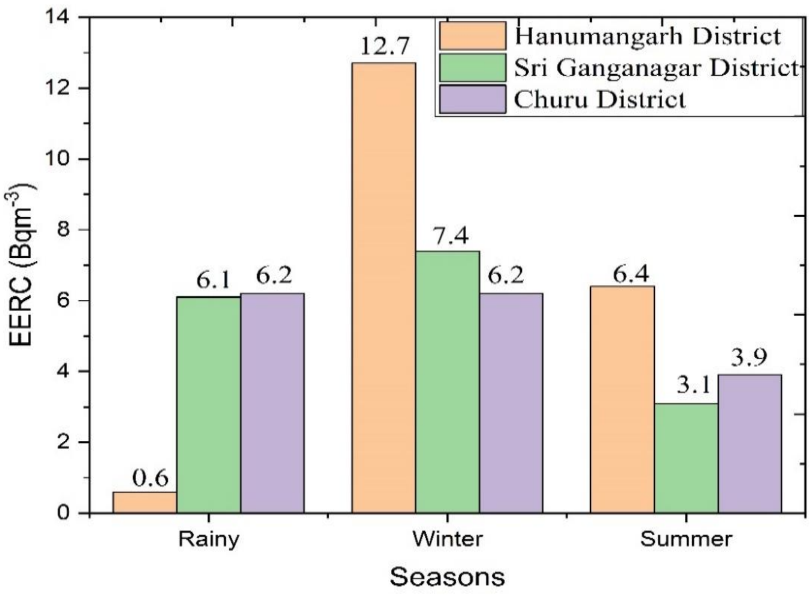

Figure 3.4: Average seasonal variation of indoor radon progeny concentration (EERC) in Hanumangarh, Sri Ganganagar and Churu districts of Northern Rajasthan

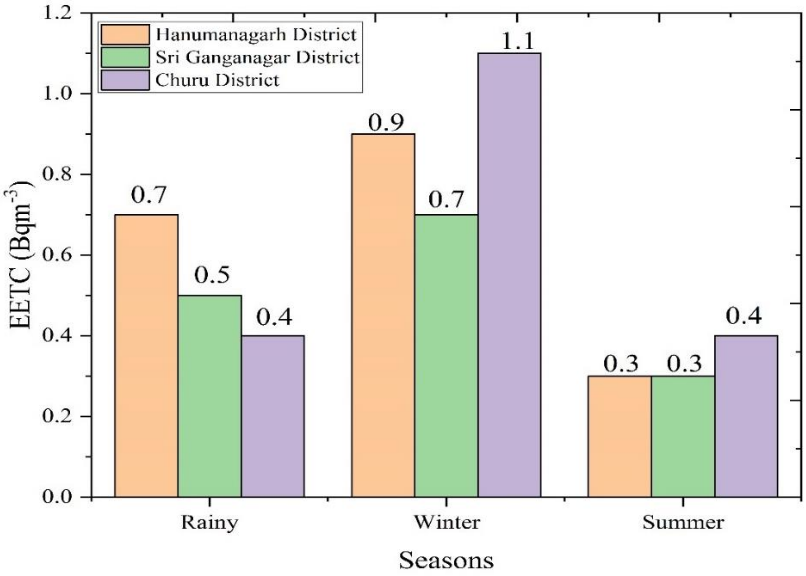

Figure 3.5: Average seasonal variation of indoor thoron progeny concentration (EETC) in Hanumangarh, Sri Ganganagar and Churu districts of Northern Rajasthan

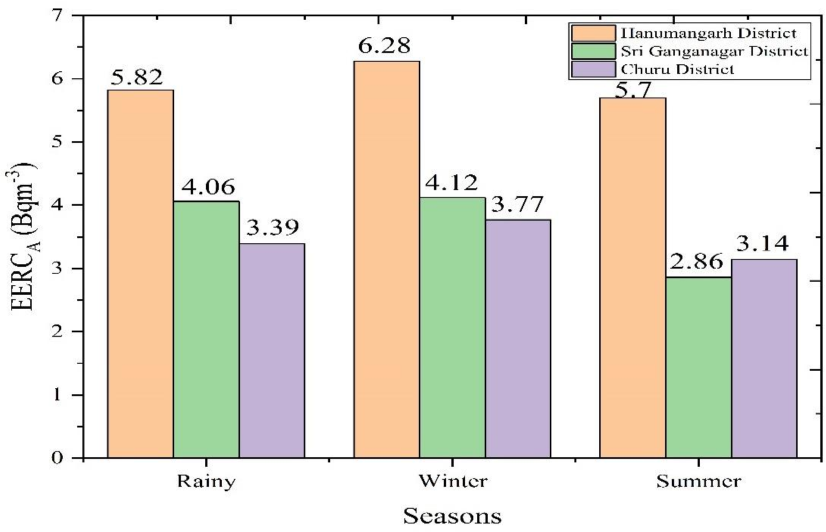

Figure 3.6: Average seasonal variation of indoor attached fraction of radon (EERC$_A$) in Hanumangarh, Sri Ganganagar and Churu districts of Northern Rajasthan

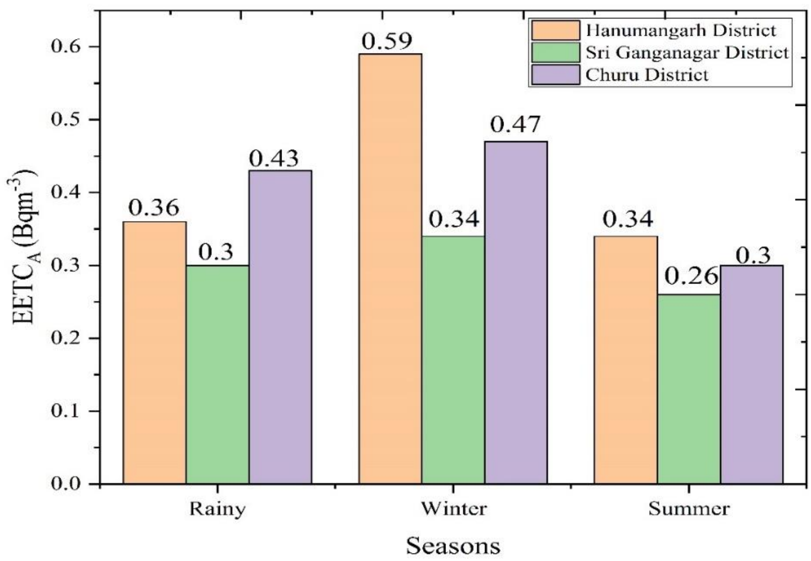

Figure 3.7: Average seasonal variation of indoor attached fraction of thoron (EETC$_A$) in Hanumangarh, Sri Ganganagar and Churu districts of Northern Rajasthan

3.4.2 Annual Average Concentration of Radon/Thoron, Their Progeny (EERC/EETC) and Attached/ Unattached Fractions in Indoor Air

Table 3.2 shows the values of average annual concentration of radon, thoron and their progeny concentration (EERC/EETC) and attached/unattached fractions of radon/thoron and Table 3.3 shows the total annual effective dose in Hanumangarh, Sri Ganganagar and Churu districts, respectively.

In Hanumangarh district, the values of average annual concentration of radon for all the three seasons which lie in the range of 9.55 to 84.94 Bqm^{-3} with an average value of 26.90 Bqm^{-3}. The values of average annual concentration of thoron lie in the range from 15.1 to 100 Bqm^{-3} with mean value of 39.9 Bqm^{-3}. The annual average concentration of radon progeny (EERC) has values from 2.7 to 17.6 Bqm^{-3} having an average of 8.6 Bqm^{-3}. The annual average concentration of thoron progeny (EETC) lies in the range from 0.5 to 8.7 Bqm^{-3} having an average of 2.7 Bqm^{-3}. The annual average attached concentration of radon progeny ($EERC_A$) has values from 1.36 to 15.31 Bqm^{-3} having an average of 5.93 Bqm^{-3}. The annual average concentration of thoron progeny ($EETC_A$) lies in the range from 0.17 to 0.84 Bqm^{-3} having an average of 0.43 Bqm^{-3}. The annual average unattached concentration of radon progeny ($EERC_U$) has values from 0.04 to 13.13 Bqm^{-3} having an average of 2.67 Bqm^{-3}. The annual average concentration of thoron progeny ($EETC_U$) lies in the range from 0.21 to 8.33 Bqm^{-3} having an average of 2.30 Bqm^{-3}.

It has been observed that the annual average equilibrium factor between radon and its progeny was 0.4 and for thoron and its progeny was 0.02 (UNSCEAR, 2008). The total annual effective dose for radon, thoron and their progenies vary from 1.52 to 8.63 µSvy^{-1} with an average value of 3.41 µSvy^{-1}. From attached/unattached fractions of radon/thoron values using dose conversion factors for mouth and nose, the inhalation dose for mouth and nose has been varied from 0 to 36.83 µSvy^{-1} with an average value of 4.74 µSvy^{-1} and from 0 to 8.56 µSvy^{-1} with an average value of 1.29 µSvy^{-1}, respectively.

In Sri Ganganagar district, the values of average annual concentration of radon for all the three seasons which lie in the range of 3.8 to 32.6 Bqm^{-3} with an average value of 9.8 Bqm^{-3}. The values of average annual concentration of thoron lie in the range from 9 to 96 Bqm^{-3} with mean value of 19 Bqm^{-3}. The annual average concentration of radon progeny (EERC) has values from 1.6 to 12.6 Bqm^{-3} having an average of 5.5 Bqm^{-3}. The annual average concentration of thoron progeny (EETC) lies in the range from 0.2 to 1.3 Bqm^{-3} having an average of 0.5 Bqm^{-3}. The annual average attached concentration of radon progeny ($EERC_A$) has values from 1.24 to 9.60 Bqm^{-3} having an average of 3.68 Bqm^{-3}. The annual average concentration of thoron progeny ($EETC_A$) lies in the range from 0.09 to 0.69 Bqm^{-3} having an average of 0.30 Bqm^{-3}. The annual average unattached concentration of radon progeny ($EERC_U$) has values from 0.01 to 8.33 Bqm^{-3} having an average of 1.83 Bqm^{-3}. The annual average concentration of thoron progeny ($EETC_U$) lies in the range from 0.01 to 0.98 Bqm^{-3} having an average of 0.20 Bqm^{-3}.

It has been observed that the annual average equilibrium factor between radon and its progeny was 0.4 and for thoron and its progeny was 0.02 (UNSCEAR, 2008). The total annual effective dose for radon, thoron and their progenies vary from 0.52 to 4.28 μSvy^{-1} with an average value of 1.88 μSvy^{-1}. From attached/unattached fractions of radon/thoron values using dose conversion factors for mouth and nose, the inhalation dose for mouth and nose has been varied from 0.01 to 294.53 μSvy^{-1} with an average value of 6.75 μSvy^{-1} and from 0.01 to 54.94 μSvy^{-1} with an average value of 1.49 μSvy^{-1}, respectively.

In Churu district, the values of average annual concentration of radon for all the three seasons which lie in the range of 12.5 to 40.6 Bqm^{-3} with an average value of 19.5 Bqm^{-3}. The values of average annual concentration of thoron lie in the range from 11.6 to 39 Bqm^{-3} with mean value of 19.9 Bqm^{-3}. The annual average concentration of radon progeny (EERC) has values from 1.4 to 21.4 Bqm^{-3} having an average of 5.4 Bqm^{-3}. The annual average concentration of thoron progeny (EETC) lies in the range from 0.3 to 1.8 Bqm^{-3} having an average of 0.6 Bqm^{-3}. The annual average attached concentration of radon progeny ($EERC_A$) has values from 1.34 to 18.95 Bqm^{-3} having an average of 3.43 Bqm^{-3}. The annual average concentration of thoron progeny ($EETC_A$) lies in the range from 0.16 to 1.03 Bqm^{-3} having an average of 0.40 Bqm^{-3}. The annual average unattached concentration of radon progeny ($EERC_U$) has values from 0.01 to 18.90 Bqm^{-3} having an average of 2 Bqm^{-3}. The annual average concentration of thoron progeny ($EETC_U$) lies in the range from 0.01 to 1.32 Bqm^{-3} having an average of 0.25 Bqm^{-3}.

It has been observed that the annual average equilibrium factor between radon and its progeny was 0.4 and for thoron and its progeny was 0.02 (UNSCEAR, 2008). The total annual effective dose for radon, thoron and their progenies vary from 0.75 to 3.09 μSvy^{-1} with an average value of 1.70 μSvy^{-1}. From attached/unattached fractions of radon/thoron values using dose conversion factors for mouth and nose, the inhalation dose for mouth and nose has been varied from 0 to 14.50 μSvy^{-1} with an average value of 2.49 μSvy^{-1} and from 0 to 3.55 μSvy^{-1} with an average value of 0.70 μSvy^{-1}, respectively.

For all the three districts of Northern Rajasthan, it has been observed that the measured concentration for indoor radon in the studied area was lower than the recommended action level of 200 – 300 Bqm^{-3} (ICRP, 2018) for all three districts. The average indoor values of thoron concentration are higher than the world average value of 10 Bqm^{-3} (UNSCEAR, 2008). The measured value for radon progeny concentration is well below the worldwide average value of 15 Bqm^{-3} while for thoron progeny concentration the value is comparatively higher than the world's average value of 0.5 Bqm^{-3} (UNSCEAR, 2008). The annual average effective dose for inhalation lies below than recommended value of 14 μSvy^{-1} (ICRP, 2018).

A wide variation in the concentration of radon, thoron, and their progeny has been observed in the present study. This variation was presumably due to topography, different ventilation conditions, geological locations and environmental parameters such as weather, humidity, temperature, pressure, wind speed and lifestyle of population. The concentration of thoron gas is higher in most of dwellings, this presumably due to use of thorium rich materials in construction of dwellings of this area. Moreover, the soil of Northern India is rich in thorium level and became a primary source of high indoor thoron.

3.4.3 Frequency Distribution

In Hanumangarh District, the frequency distribution graph shows (Figure 3.8a) that the thoron centration in 9.3% dwellings lies between 0-10 Bqm^{-3}, in 17.3% dwellings lies between 10-20 Bqm^{-3}, in 18.6% dwellings lies from 20-30 Bqm^{-3} and in rest of 54.8% dwellings lies between 30-120 Bqm^{-3}. It has been observed that the 9.3% dwellings have lower thoron concentration than the worldwide average value of 10 Bqm^{-3} as recommended by UNSCEAR (2008) denoted by blue dotted line.

The frequency distribution graph shows that the radon concentration in 62% dwellings lies between 0-20 Bqm^{-3}, in 29.3% dwellings lies between 20-40 Bqm^{-3} and in remaining 8% dwellings lies from 40-60 Bqm^{-3} (Figure 3.8b). It has been observed that the 8% dwellings have higher radon concentration than the worldwide average value of 40 Bqm^{-3} as recommended by UNSCEAR (2008) denoted by blue dotted line.

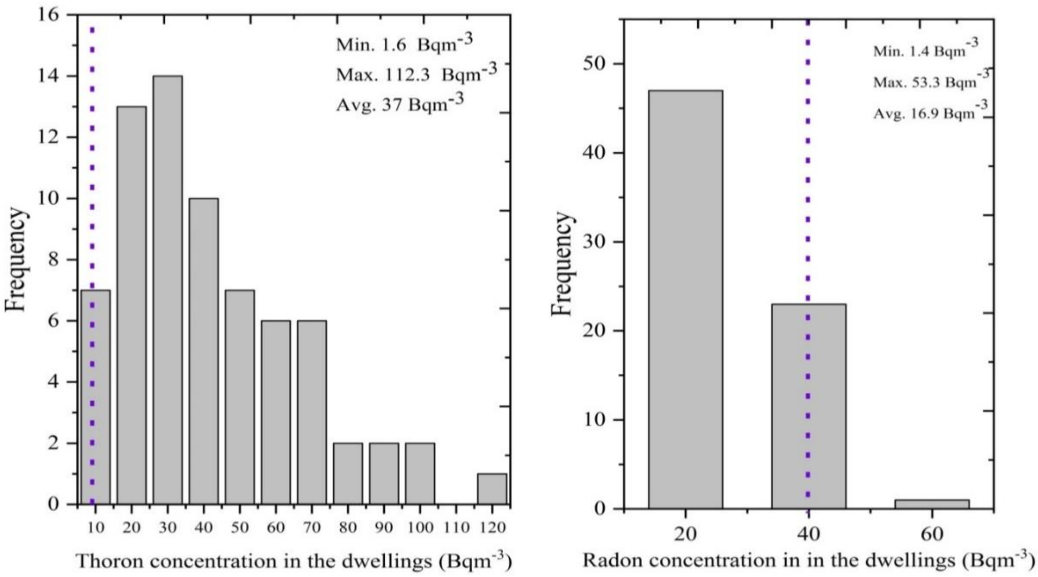

Figure 3.8: Frequency distribution for a) thoron concentration, b) radon concentration in Hanumangarh district

The frequency distribution graph shows (Figure 3.9a) that the frequency distribution graph shows that the radon progeny concentration in 21.3% dwellings lies between 0-5 Bqm^{-3}, in 49.3% dwellings lies between 5-10 Bqm^{-3} and in remaining 17% dwellings lies from 10-15 Bqm^{-3}. It has been observed that the 17% dwellings have higher radon progeny concentration than the worldwide average value of 15 Bqm^{-3} as recommended by UNSCEAR (2008) denoted by blue dotted line.

The thoron progeny centration in 44% dwellings lies between 0-0.5 Bqm^{-3}, in 46.6% dwellings lies between 0.5-1 Bqm^{-3}, in 0.93% dwellings lies from 1-1.5 Bqm^{-3} and in rest of 0.26% dwellings lies between 1.5-2 Bqm^{-3} (Figure 3.9b). It has been observed that the 44% dwellings have lower thoron progeny concentration than the worldwide average value of 0.5 Bqm^{-3} as recommended by UNSCEAR (2008) denoted by blue dotted line.

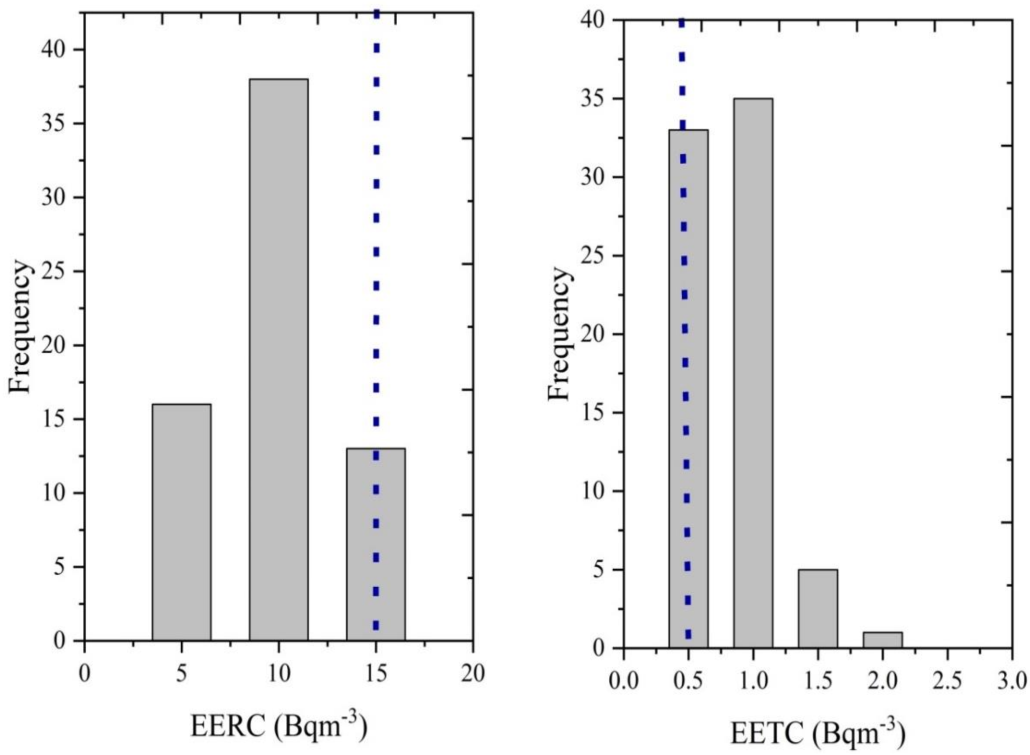

Figure 3.9: Frequency distribution for a) radon progeny concentration (EERC), b) thoron progeny concentration (EETC) in Hanumangarh district

In **Sri Ganganagar District**, the frequency distribution graph shows (Figure 3.10a) that the frequency distribution graph shows that the radon concentration in 77% dwellings lies between 0-20 Bqm^{-3}, in 18% dwellings lies between 20-40 Bqm^{-3} and in remaining 5% dwellings lies from 40-60 Bqm^{-3}. It has been observed that the 5% dwellings have higher radon concentration than the worldwide average value of 40 Bqm^{-3} as recommended by UNSCEAR (2008) denoted blue dotted line.

The thoron centration in 13% dwellings lies between 0-10 Bqm^{-3}, in 43% dwellings lies between 10-20 Bqm^{-3}, in 26% dwellings lies from 20-30 Bqm^{-3} and in rest of 18% dwellings lies between 30-120 Bqm^{-3} (Figure 3.10b). It has been observed that the 13% dwellings have lower thoron concentration than the worldwide average value of 10 Bqm^{-3} as recommended by UNSCEAR (2008) denoted blue dotted line.

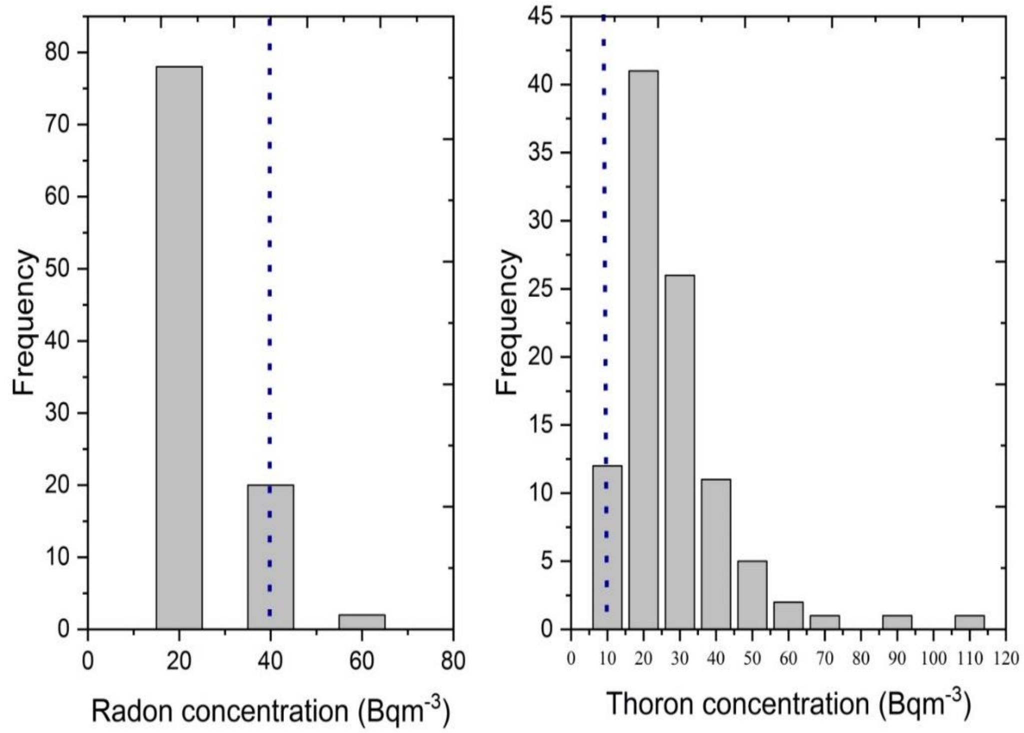

Figure 3.10: Frequency distribution for a) radon concentration, b) thoron concentration in Sri Ganganagar district

The frequency distribution graph shows (Figure 3.11a) that the thoron progeny centration in 68% dwellings lies between 0-0.5 Bqm^{-3}, in 28% dwellings lies between 0.5-1 Bqm^{-3}, in 4% dwellings lies from 1-1.5 Bqm^{-3}. It has been observed that the 68% dwellings have lower thoron progeny concentration than the worldwide average value of 0.5 Bqm^{-3} as recommended by UNSCEAR (2008) denoted by blue dotted line.

The frequency distribution graph shows that the radon progeny concentration in 54% dwellings lies between 0-5 Bqm^{-3}, in 42% dwellings lies between 5-10 Bqm^{-3} and in remaining 8% dwellings lies from 10-15 Bqm^{-3} (Figure 3.11b). It has been observed that the 0% dwellings have higher radon progeny concentration than the worldwide average value of 15 Bqm^{-3} as recommended by UNSCEAR (2008) denoted by blue dotted line.

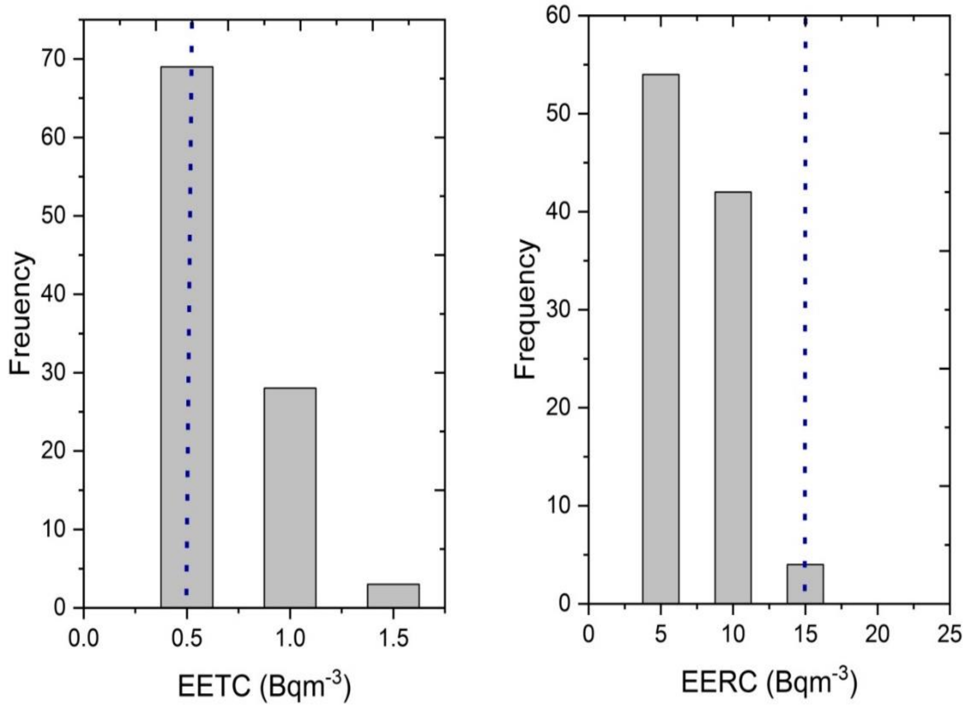

Figure 3.11: Frequency distribution for a) thoron progeny concentration (EETC), b) radon progeny concentration (EERC) in Sri Ganganagar district

In Churu District, the frequency distribution graph shows (Figure 3.12a) that the frequency distribution graph shows that the radon concentration in 72% dwellings lies between 0-20 Bqm^{-3}, in 25% dwellings lies between 20-40 Bqm^{-3} and in remaining 3% dwellings lies from 40-60 Bqm^{-3}. It has been observed that the 3% dwellings have higher radon concentration than the worldwide average value of 40 Bqm^{-3} as recommended by UNSCEAR (2008) denoted by blue dotted line.

The thoron centration in 83% dwellings lies between 0-10 Bqm^{-3}, in 15% dwellings lies between 10-20 Bqm^{-3}, in 1% dwellings lies from 20-30 Bqm^{-3} and in rest of 1% dwellings lies between 30-120 Bqm^{-3} (Figure 3.12b) It has been observed that the 20% dwellings have higher thoron concentration than the worldwide average value of 10 Bqm^{-3} as recommended by UNSCEAR (2008) denoted by blue dotted line.

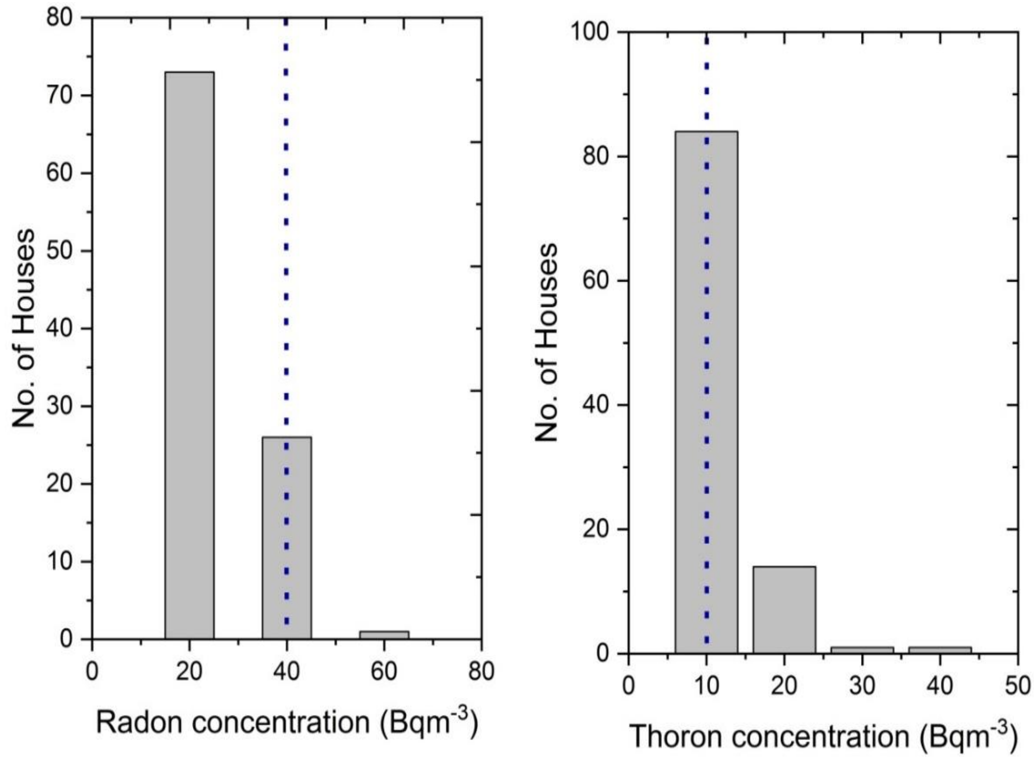

Figure 3.12: Frequency distribution for a) radon concentration, b) thoron concentration in Churu district

The frequency distribution graph shows (Figure 3.13a) that the thoron progeny centration in 48% dwellings lies between 0-0.5 Bqm^{-3}, in 36% dwellings lies between 0.5-1 Bqm^{-3}, in 16% dwellings lies from 1-1.5 Bqm^{-3}. It has been observed that the 48% dwellings have lower thoron progeny concentration than the worldwide average value of 0.5 Bqm^{-3} as recommended by UNSCEAR (2008) denoted by blue dotted line.

The frequency distribution graph shows that the radon progeny concentration in 68% dwellings lies between 0-5 Bqm^{-3}, in 22% dwellings lies between 5-10 Bqm^{-3} and in remaining 10% dwellings lies from 10-25 Bqm^{-3} (Figure 3.13b). It has been observed that the 5% dwellings have higher radon progeny concentration than the worldwide average value of 15 Bqm^{-3} as recommended by UNSCEAR (2008) denoted by blue dotted line.

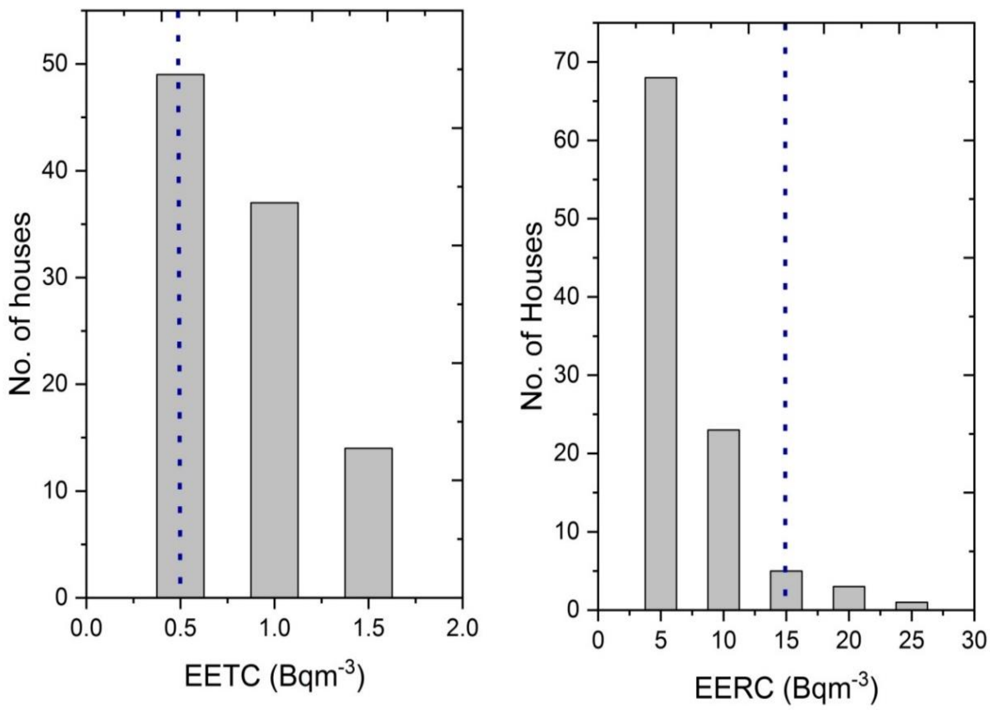

Figure 3.13: Frequency distribution for a) thoron progeny concentration (EETC), b) radon progeny concentration (EERC) in Churu district

3.4.4 Correlation Between Radon and Its Progeny and Thoron and Its Progeny in Studied Area

Figure 3.14a shows the positive correlation between radon and its progeny with pearson's value of 0.58 and Figure 3.14b shows the weak positive correlation between thoron and its progeny having pearson's value of 0.142 in Hanumangarh district of Rajasthan.

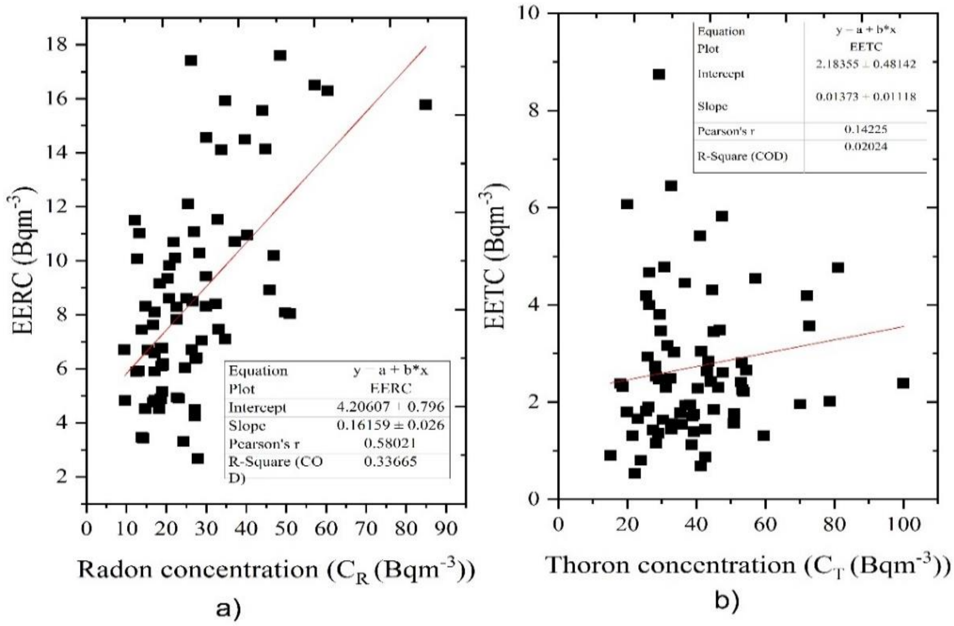

Figure 3.14: Correlation between a) radon and its progeny concentration (EERC) b) thoron and its progeny concentration (EETC) in Hanumangarh district

Figure 3.15a shows the weak positive correlation between radon and its progeny with pearson's value of 0.15 and Figure 3.15b shows the weak positive correlation between thoron and its progeny having pearson's value of 0.14 in Sri Ganganagar district of Rajasthan.

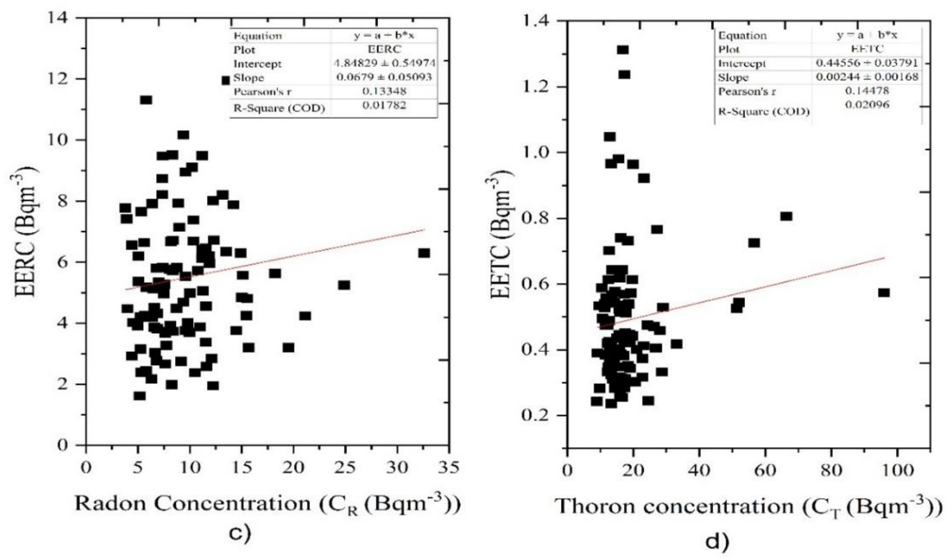

Figure 3.15: Correlation between a) radon and its progeny concentration (EERC) b) thoron and its progeny concentration (EETC) in Sri Ganganagar district

Figure 3.16a shows the positive weak correlation between radon and its progeny with pearson's value of 0.22 and Figure 3.16b shows the weak negative correlation between thoron and its progeny having pearson's value of -0.23 in Churu district of Rajasthan.

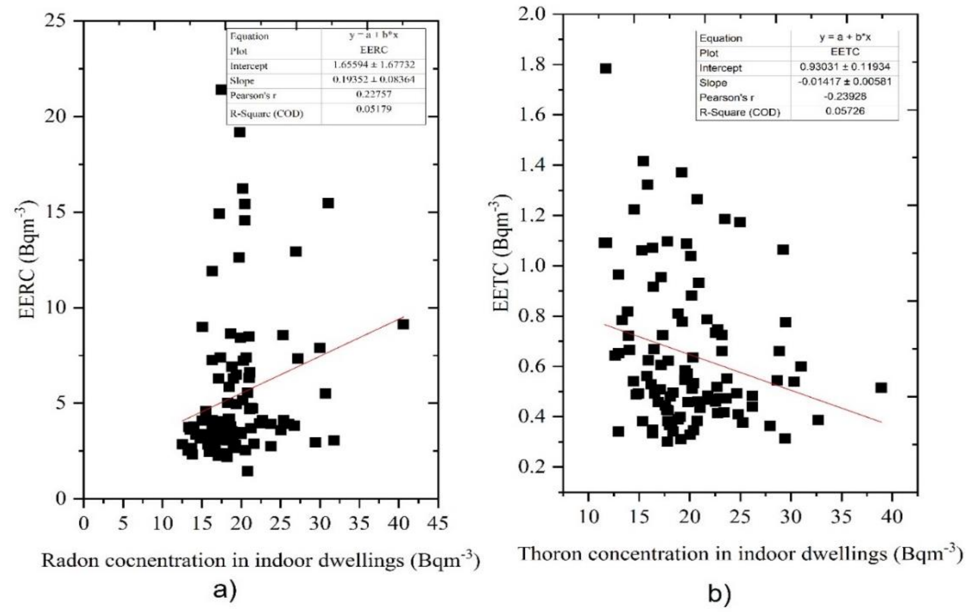

Figure 3.16: Correlation between a) radon and its progeny concentration (EERC) b) thoron and its progeny concentration (EETC) in Churu district.

Table 3.4 represents the comparison of the measured values of radon/thoron and their progeny concentration in the study area with other similar research workcarried 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), 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 being 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).

Table 3.5 shows the measured average attached equilibrium equivalent concentration for radon/thoron ($EERC_A/EETC_A$) has been compared with the similar investigations performed in other regions of India. These values are lower than 13 Bqm^{-3} and 1.3 Bqm^{-3} in Udhampur district, Jammu and Kashmir, Himalaya (Sharma et al., 2018), lower than 46 Bqm^{-3} and 2.2 Bqm^{-3} in Garhwal, Himalaya (Parsad et al., 2017), lower than the values of 26.2 Bqm^{-3} and 2.36 Bqm^{-3} of Hamirpur district, Himachal Pradesh, India (Singh et al., 2015) and also lower than 18 Bqm^{-3} and 1.2 Bqm^{-3} for radon/thoron respectively in the Jalandhar and Kapurthala district of Punjab (Mehra et al., 2016).

3.5 CONCLUSION

- Out of 275 dwellings, 12 dwellings (4.36%) having higher indoor annual average radon concentration (40.22 to 99.86 Bqm^{-3}) than the recommended value of 40 Bqm^{-3} (UNSCEAR, 2008).
- 99% of dwellings having higher indoor annual average thoron concentration (10.65 to 100 Bqm^{-3}) than the world average value of 10 Bqm^{-3} (UNSCEAR, 2008). The concentration of thoron gas is higher in most of dwellings, this presumably may be due to use of thorium rich materials in construction of dwellings of this area.
- 4.36 % dwellings having higher indoor annual average radon progeny concentration (15.42 to 21.4 Bqm^{-3}) than the worldwide average value of 15 Bqm^{-3}, while 201 dwellings (73%) having higher indoor annual average thoron progeny concentration (0.5 to 8.7 Bqm^{-3}) than the world's average value of 0.5 Bqm^{-3} (UNSCEAR, 2008).
- The measured average values for indoor radon, thoron and their progeny concentration in the studied area is higher in winter season as compared to rainy and summer season which may be because of the closed environment in winter and less exchange of gases between indoor and outdoor environments, thereby leading to accumulation of radon gas during winters. Also due to the similar reason, the dwellings with poor ventilation have higher concentration than the average and well ventilated dwellings in all the three seasons.
- The calculated annual average equilibrium factor between radon and its progeny was 0.4 and for thoron and its progeny was 0.02, which are as per the recommended value given by UNSCEAR (2008).
- The annual average effective dose for inhalation lies below than recommended value of 14 μSvy^{-1} for the residential places (ICRP, 2018). Therefore, it may not cause any health risk to the residents of the area.

- The concentration of indoor radon/thoron in some areas like Pillibanga, Jandawali, Sangria, Bhagatpura, Dhaba, Kharliya, Bhadra, Rawatsar, and Panniwala of Hanumangarh District and Ratangarh of Churu District of Rajasthan with higher values may be explored further for radiological health effects to the residents of the area.
- The data will contribute towards the national pool for mapping and for further studies.

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Table 3.1: Seasonal variation for indoor radon/thoron, their progeny concentration and attached/unattached fractions in the studied area

Parameter	Seasonal variation of Radon, Thoron, EERC, and EETC level (Bqm^{-3})								
	Rainy			Winter			Summer		
	Min.	Max.	Avg.	Min.	Max.	Avg.	Min.	Max.	Avg.
Hanumangarh district									
C_R	10.8	73.7	32.5	7.2	191.5	47.3	3.1	53.3	16.7
C_T	9.6	112.9	37.9	11.7	258.2	59.6	7.3	54.7	22.3
EERC	0.6	24.6	6.6	0.7	41.5	12.7	1.7	12.8	6.4
EETC	0.2	1.3	0.7	0.1	3.7	0.9	0.1	1.1	0.3
$EERC_A$	1.23	23.64	5.82	0.12	16.40	6.28	0.81	30.87	5.70
$EETC_A$	0.09	1.26	0.36	0.10	1.39	0.59	0.01	1.05	0.34
Sri Ganganagar district									
C_R	3.1	41.6	15.5	10.1	139.4	22.8	4.1	59.2	13.8
C_T	7.2	246.5	26.6	9.1	126.6	40.7	7	99.4	21
EERC	1.8	23.3	6.1	0.5	31.4	7.4	1	13.6	3.1
EETC	0.3	1.2	0.5	0.1	3.1	0.7	0.1	0.7	0.3
$EERC_A$	0.06	17.44	4.06	0.78	23.87	4.12	0.53	10.90	2.86
$EETC_A$	0.04	1.43	0.30	0.01	0.90	0.34	0.04	0.98	0.26

Parameter	**Seasonal variation of Radon, Thoron, EERC, and EETC level (Bqm^{-3})**								
	Rainy			**Winter**			**Summer**		
	Min.	**Max.**	**Avg.**	**Min.**	**Max.**	**Avg.**	**Min.**	**Max.**	**Avg.**
Churu district									
C_R	12.6	42.5	20.7	5.7	93.7	22.9	4.3	27.6	15
C_T	8	56.8	19	8	56.8	19	10.4	57.3	17.9
EERC	1.2	30.3	6.2	0.5	30.1	6.2	1.1	15.2	3.9
EETC	0.2	1.8	0.4	0.2	3.7	1.1	0.2	1.8	0.4
$EERC_A$	0.09	24.30	3.39	0.04	13.50	3.77	0.01	29.54	3.14
$EETC_A$	0.13	1.25	0.43	0.04	2.59	0.47	0.03	1.60	0.30

Table: 3.2: Annual average indoor radon/thoron, their progeny concentration and attached/unattached fractions in the studied area

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC $\pm \sigma$ (Bqm^{-3})	EETC $\pm \sigma$ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
Hanumangarh district							
1	**Hanumangarh Junction**	20.79 ± 3.46	22.22 ± 8.92	9.82 ± 0.88	0.53 ± 0.18	10.86	3.33
2		22.16 ± 3.58	26.32 ± 9.25	10.1 ± 0.98	4 ± 0.38	13.47	3.54
3	**Hanumangarh Town**	17.06 ± 3.22	28.07 ± 8.61	4.84 ± 0.7	2.74 ± 0.32	11.88	3.21
4		26.58 ± 3.6	25.44 ±10.19	8.51 ± 0.9	1.82 ± 0.27	11.92	3.79
5		29.9 ± 4.05	41.13 ±11.45	9.43 ± 0.95	5.42 ± 0.45	18.66	4.28
6	**Phephana**	22.51 ± 3.58	53.7 ± 10.29	8.3 ± 0.87	2.21 ± 0.28	21.41	3.81
7		28.82 ± 3.61	38.69 ± 1.38	7.05 ± 0.8	1.12 ± 0.19	15.62	4.13
8		20.39 ± 3.43	40.35 ± 11.18	9.36 ± 0.93	2.28 ± 0.3	17.33	4.14
9	**Jnania**	34.72 ± 4.06	30.7 ± 11.97	15.93 ± 1.15	2.47 ± 0.31	16.37	4.48
10		25.09 ± 3.73	39.38 ± 11.29	8.61 ± 0.9	1.75 ± 0.26	16.58	4.15
11		12.53 ± 2.85	41.42 ± 8.94	5.9 ± 0.79	3.04 ± 0.34	16.79	3.36
12	**Padampura**	19.01 ± 3.25	32.94 ± 10.6	6.76 ± 0.82	1.56 ± 0.25	13.75	3.89
13		27.1 ± 3.89	19.88 ± 11.16	4.5 ± 0.7	1.79 ± 0.27	8.72	4.04
14		13.22 ± 2.89	47.37 ± 10.32	11.03 ± 1.04	5.83 ± 0.47	21.41	3.94
15	**Dabli Rathan**	18.55 ± 3.26	70.08 ± 11.87	6.77 ± 0.84	1.96 ± 0.26	26.27	4.32

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
16		27.21 ± 3.86	35.38 ± 10.91	4.25 ± 0.69	1.78 ± 0.26	13.81	3.95
17		26.35 ± 3.85	26.22 ± 10.45	6.7 ± 0.83	1.89 ± 0.27	11.6	3.85
18	**Pilibanga**	20.73 ± 3.27	50.88 ± 11.7	8.61 ± 0.89	1.56 ± 0.23	20.35	4.27
19		45.84 ± 4.26	28.95 ±13.15	8.93 ± 0.89	1.36 ± 0.22	13.08	4.75
20		15.28 ± 2.94	18.03 ± 9.61	6.69 ± 0.85	2.38 ± 0.3	9.03	3.59
21	**Jandawali**	17.06 ± 2.99	26.41 ± 10.01	8.1 ± 0.89	4.67 ± 0.42	13.06	3.77
22		24.74 ± 3.54	28.27 ± 11.31	6.03 ± 0.79	2.53 ± 0.31	12.28	4.14
23		57.14 ± 5.09	44.54 ± 14.49	16.51 ± 1.19	4.31 ± 0.39	21.79	5.36
24	**Jorkiyan**	27.61 ± 3.93	33.53 ± 10.49	6.4 ± 0.78	3.02 ± 0.34	14.32	3.87
25		25.49 ± 3.79	57.12 ± 12.55	12.12 ± 1.11	4.55 ± 0.42	24.59	4.7
26		19.24 ± 3.26	53.31 ± 12.24	6.19 ± 0.76	2.25 ± 0.29	20.58	4.43
27	**Nagrana**	12.65 ± 2.65	36.84 ± 12.08	10.08 ± 1	1.94 ± 0.3	16.29	4.46
28		12.07 ± 2.81	32.85 ± 10.33	11.51 ± 1.02	1.43 ± 0.24	15.26	3.86
29		17 ± 3.09	27.49 ± 8.72	6.58 ± 0.78	1.43 ± 0.25	11.83	3.25
30	**Sangria**	39.31 ± 4.34	23.88 ± 11.34	4.03 ± 0.64	0.8 ± 0.19	9.57	4.06
31		44.75 ± 4.39	29.14 ± 11.73	14.13 ± 1.03	2.47 ± 0.3	15.25	4.35
32		23.14 ± 3.64	38.3 ± 9.76	4.9 ± 0.7	1.94 ± 0.28	15.05	3.58

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
33	**Bhagatpura**	49.74 ± 4.99	26 ± 11.5	8.09 ± 0.86	2.93 ± 0.33	12.34	4.23
34		84.94 ± 6.05	72.81 ± 14.77	15.78 ± 1.13	3.57 ± 0.36	30.72	5.42
35		33.12 ± 4.26	43.57 ± 10.34	7.47 ± 0.86	2.84 ± 0.34	17.96	3.84
36	**Dhaba**	46.82 ± 4.74	29.34 ± 11.58	10.19 ± 0.95	3.8 ± 0.38	14.44	4.3
37		60.35 ± 4.92	52.92 ± 12.76	16.3 ± 1.08	2.41 ± 0.29	23.88	4.71
38		19.01 ± 3.27	50.97 ± 9.45	5.15 ± 0.7	1.76 ± 0.25	19.29	3.47
39	**Kharliyan**	40.22 ± 4.47	72.03 ± 12.39	10.95 ± 1	4.19 ± 0.4	29.06	4.6
40		39.65 ± 4.13	45.13 ± 11.69	14.49 ± 1.01	1.84 ± 0.24	20.49	4.31
41		14.88 ± 3.04	39.28 ± 8.91	8.32 ± 0.88	1.39 ± 0.22	16.33	3.33
42	**Hansliyan**	37.13 ± 4.35	100 ± 12.74	10.72 ± 1.02	2.38 ± 0.27	37.7	4.68
43		33.69 ± 4.23	36.65 ± 11.18	14.11 ± 1.19	4.45 ± 0.42	18.4	4.26
44		16.72 ± 3.19	42.59 ± 11.44	4.75 ± 0.67	1.44 ± 0.24	16.26	4.12
45	**Goluwala**	22.51 ± 3.37	32.55 ± 11.96	7.82 ± 0.9	2.49 ± 0.31	14.29	4.39
46		18.84 ± 3.07	38.89 ± 9.81	6.1 ± 0.75	1.7 ± 0.26	15.56	3.61
47		19.18 ± 3.24	31.68 ± 10.42	6.12 ± 0.79	3.16 ± 0.34	13.65	3.85
48	**Bhadra**	50.95 ± 5.19	45.03 ± 13.29	8.05 ± 0.89	3.45 ± 0.38	18.84	4.85
49		29.96 ± 4.07	29.14 ± 11.47	14.58 ± 1.17	8.74 ± 0.56	17.49	4.4

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
50		13.11 ± 2.88	78.65 ± 11.3	5.91 ± 0.78	2.01 ± 0.28	28.86	4.12
51	**Dholpalia**	28.3 ± 3.98	31.29 ± 9.95	10.29 ± 0.97	2.29 ± 0.31	14.62	3.74
52		32.83 ± 4.21	30.8 ± 11.59	11.53 ± 1.03	4.78 ± 0.41	15.7	4.34
53		13.85 ± 2.89	42.59 ± 10.51	3.46 ± 0.61	0.87 ± 0.21	15.64	3.78
54	**Jogiwala**	34.72 ± 4.34	46.78 ± 11.77	7.1 ± 0.86	3.49 ± 0.37	19.12	4.33
55		16.66 ± 3.18	47.76 ± 10.61	7.63 ± 0.9	2.61 ± 0.33	19.33	3.95
56		26.87 ± 3.88	73.29 ± 12.1	11.08 ± 1.04	7.12 ± 0.51	30.5	4.55
57	**Rawatsar**	32.37 ± 4.05	53.12 ± 12.41	8.4 ± 0.91	2.81 ± 0.33	21.44	4.55
58		18.32 ± 3.21	46.3 ± 10.81	9.16 ± 0.94	2.3 ± 0.29	19.25	4.01
59		43.95 ± 4.69	20.08 ± 12.49	15.57 ± 1.21	6.07 ± 0.48	13.91	4.73
60	**25DWD**	21.88 ± 3.45	44.25 ± 10.84	10.7 ± 1	2.42 ± 0.3	19.12	4.05
61		22.68 ± 3.52	54.39 ± 11.43	4.93 ± 0.73	2.65 ± 0.33	20.66	4.16
62	**2KBM**	27.32 ± 3.89	15.11 ± 10.66	6.36 ± 0.79	0.91 ± 0.22	7.46	3.89
63		9.72 ± 2.56	30.41 ± 9.38	4.82 ± 0.71	1.64 ± 0.25	12.29	3.45
64	**Tibbi**	9.55 ± 2.58	43.18 ± 9.81	6.71 ± 0.83	2.63 ± 0.32	17.51	3.65
65		18.67 ± 3.14	28.36 ± 10.75	4.89 ± 0.69	1.16 ± 0.21	11.47	3.88
66		14.2 ± 2.96	35.77 ± 8.92	3.43 ± 0.6	1.55 ± 0.25	13.58	3.26

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
67		17 ± 3.13	23.1 ± 9.88	5.9 ± 0.76	1.66 ± 0.25	10.22	3.63
68	**Peerkambdia**	29.9 ± 3.98	18.71 ± 11.05	8.32 ± 0.92	2.32 ± 0.29	9.79	4.09
69		26.12 ± 3.61	81.09 ± 13.86	17.43 ± 1.28	4.77 ± 0.43	34.43	5.19
70		18.27 ± 3.07	29.73 ± 9.35	4.53 ± 0.65	3.47 ± 0.36	12.58	3.46
71		14.71 ± 3.03	59.55 ± 9.85	4.53 ± 0.68	1.31 ± 0.22	21.8	3.58
72	**Panniwala**	27.96 ± 3.77	21.54 ± 9.59	2.67 ± 0.53	1.31 ± 0.23	8.51	3.45
73		48.48 ± 4.51	32.75 ± 11.6	17.61 ± 1.23	6.45 ± 0.48	18.94	4.44
74		24.29 ± 3.63	41.33 ± 10.06	3.31 ± 0.55	0.69 ± 0.16	15.11	3.59
75		13.85 ± 2.94	25.54 ± 8.07	7.45 ± 0.85	4.19 ± 0.4	12.39	3.1
Minimum		4.45 ± 2.03	15.1 ± 8.1	2.7 ± 0.5	0.5 ± 0.2	7.46	3.1
Maximum		99.39 ± 6.8	100 ± 14.8	17.6 ± 1.3	8.7 ± 0.6	37.7	5.42
Average		26.9 ± 3.68	39.9 ± 11	8.6 ± 0.9	2.7 ± 0.3	17.06	4.05
Sri Ganganagar district							
1	**39 LNP**	15.71 ± 3.37	18.96 ± 9.7	3.21 ± 0.59	0.42 ± 0.06	0.27	2.8
2		15.54 ± 3.41	10.48 ± 8.82	4.82 ± 0.71	0.59 ± 0.07	0.15	4.4
3		15.14 ± 3.48	24.38 ± 9.97	5.58 ± 0.75	0.47 ± 0.06	0.45	1.56
4		9.8 ± 2.94	12.64 ± 8.14	4.01 ± 0.63	0.43 ± 0.06	0.37	3.35

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
5	Binjwala	11.18 ± 3.06	12.85 ± 7.99	9.49 ± 0.86	0.4 ± 0.06	0.33	8.29
6		9.4 ± 3.14	12.91 ± 7.96	10.17 ± 1.02	1.05 ± 0.09	0.45	8.78
7		7.34 ± 3.17	9.73 ± 7.93	8.22 ± 0.91	0.53 ± 0.07	0.35	4.77
8		8.89 ± 3.28	17.41 ± 8.6	7.94 ± 0.91	1.24 ± 0.1	0.46	6.44
9	47 LNP	12.27 ± 3.47	9.2 ± 9.14	8.02 ± 0.86	0.39 ± 0.06	0.36	4.07
10		32.62 ± 4.69	16.17 ± 11.93	6.3 ± 0.81	0.74 ± 0.08	0.3	3.46
11		6.36 ± 2.92	18.61 ± 8.64	7.92 ± 0.86	0.54 ± 0.07	0.28	3.99
12		14.91 ± 3.43	11.76 ± 9.06	6.3 ± 0.77	0.56 ± 0.07	0.22	3.14
13	Padampura	14.79 ± 3.52	15.84 ± 9.1	12.56 ± 1.05	0.45 ± 0.06	0.19	5.87
14		14.22 ± 3.41	10.65 ± 8.78	7.88 ± 0.86	0.49 ± 0.07	0.32	6.12
15		13.65 ± 3.43	15.96 ± 8.91	11.95 ± 0.91	0.35 ± 0.06	0.23	3.62
16		8.77 ± 3.04	17.68 ± 8.94	5.83 ± 0.76	0.51 ± 0.07	0.25	2.99
17	Gajsinghpur	6.99 ± 2.97	18.34 ± 8.16	5.36 ± 0.74	0.73 ± 0.08	0.58	4.58
18		9.57 ± 3.26	18.37 ± 8.59	8.95 ± 0.87	0.35 ± 0.06	0.09	8.28
19		12.33 ± 3.73	16.94 ± 9.61	6.72 ± 0.89	1.31 ± 0.1	0.34	5.19
20		19.09 ± 4.02	66.43 ± 11.8	11.45 ± 1.06	0.81 ± 0.08	0.27	9.6
21		24.88 ± 4.31	22.72 ± 11.17	5.25 ± 0.71	0.32 ± 0.05	0.17	3.14

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
22		18.23 ± 3.76	11.58 ± 9.52	5.63 ± 0.75	0.38 ± 0.06	0.33	4.99
23	**Fojuwala**	11.64 ± 3.41	13.4 ± 9.77	2.59 ± 0.52	0.24 ± 0.05	0.19	2.06
24		6.31 ± 2.81	20.03 ± 9.28	2.17 ± 0.56	0.96 ± 0.08	0.42	1.68
25		10.38 ± 3.84	33.17 ± 11.36	7.38 ± 0.77	0.42 ± 0.06	0.35	6.75
26		9.17 ± 3.8	56.7 ± 11.84	2.75 ± 0.58	0.73 ± 0.07	0.61	1.81
27	**70 RB**	6.59 ± 2.89	12.6 ± 8.08	4.51 ± 0.71	0.7 ± 0.07	0.69	3.94
28		9.57 ± 3.22	13.28 ± 8.93	5.54 ± 0.75	0.97 ± 0.08	0.43	3.47
29		5.85 ± 2.78	19.29 ± 8	5.18 ± 0.72	0.57 ± 0.07	0.39	2.43
30		11.87 ± 3.38	15.48 ± 8.93	6.21 ± 0.81	0.98 ± 0.08	0.22	2.8
31	**Rai Singh Nagar**	5.05 ± 2.87	16.73 ± 7.58	6.2 ± 0.74	0.29 ± 0.05	0.15	2.25
32		7.74 ± 2.98	16.64 ± 7.85	3.28 ± 0.57	0.26 ± 0.05	0.15	2.66
33		6.59 ± 2.87	9.91 ± 7.33	3.87 ± 0.62	0.28 ± 0.05	0.26	2.33
34		4.41 ± 2.54	12.22 ± 6.47	6.57 ± 0.75	0.33 ± 0.05	0.1	5.18
35		6.36 ± 2.89	13.06 ± 7.5	4.2 ± 0.66	0.36 ± 0.05	0.35	1.3
36		9.57 ± 3.06	15.93 ± 8.29	3.76 ± 0.61	0.26 ± 0.05	0.24	1.75
37	**Jorawar**	11.24 ± 3.44	29.08 ± 9.72	6.42 ± 0.81	0.53 ± 0.07	0.2	6.18
38		15.48 ± 3.45	19.15 ± 9.57	4.25 ± 0.64	0.34 ± 0.05	0.24	2.72

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC $\pm \sigma$ (Bqm^{-3})	EETC $\pm \sigma$ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
39		8.71 ± 2.98	20.6 ± 8.3	4.49 ± 0.66	0.3 ± 0.05	0.26	2.15
40		11.58 ± 3.27	12.52 ± 8.81	4.56 ± 0.67	0.35 ± 0.06	0.34	2.26
41	**Karanpur**	6.48 ± 2.85	12.55 ± 7.38	5.12 ± 0.71	0.61 ± 0.07	0.42	3.31
42		10.49 ± 3.13	12.31 ± 8.3	2.38 ± 0.51	0.42 ± 0.06	0.26	2.18
43		6.88 ± 3.5	15.1 ± 9.55	3.82 ± 0.63	0.4 ± 0.06	0.35	2.76
44		8.31 ± 3.19	14.15 ± 8.43	9.52 ± 0.95	0.37 ± 0.06	0.32	4.27
45		8.37 ± 2.97	18.85 ± 8.43	6.72 ± 0.79	0.45 ± 0.06	0.38	5.51
46		11.52 ± 3.17	19.73 ± 8.69	3.38 ± 0.61	0.44 ± 0.06	0.25	2.86
47	**52 F**	9.4 ± 3.13	13.63 ± 8.64	4.69 ± 0.68	0.57 ± 0.07	0.29	2.21
48		5.68 ± 2.66	16.56 ± 8.2	4.26 ± 0.64	0.28 ± 0.05	0.27	3.25
49		11.18 ± 3.31	17.01 ± 9.17	6.13 ± 0.76	0.38 ± 0.06	0.3	4.57
50		13.19 ± 3.65	22.76 ± 9.93	8.2 ± 0.85	0.37 ± 0.06	0.12	1.89
51		13.53 ± 3.11	14.48 ± 9.12	6.35 ± 0.76	0.38 ± 0.06	0.37	4.95
52		6.82 ± 2.98	13.34 ± 8.12	5.81 ± 0.73	0.41 ± 0.06	0.23	1.56
53	**Kachi Thedi**	3.78 ± 3.16	28.05 ± 9.21	7.78 ± 0.84	0.46 ± 0.06	0.29	4.38
54		5.33 ± 2.67	13.3 ± 6.98	7.66 ± 0.76	0.32 ± 0.05	0.29	2.98
55		8.2 ± 2.75	17.24 ± 7.6	6.68 ± 0.76	0.57 ± 0.07	0.22	2.75

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC $\pm \sigma$ (Bqm^{-3})	EETC $\pm \sigma$ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
56		7.34 ± 2.85	15.21 ± 7.7	8.74 ± 0.9	0.43 ± 0.06	0.4	4.69
57	**Lakhiyan**	7.57 ± 3.35	11.29 ± 8.35	5.28 ± 0.73	0.53 ± 0.07	0.21	5.07
58		10.38 ± 3.43	12.18 ± 9.19	6.7 ± 0.81	0.47 ± 0.06	0.1	4.72
59		7.4 ± 3.03	17.32 ± 8.3	5.83 ± 0.75	0.43 ± 0.06	0.34	5.13
60		8.14 ± 3.01	26.3 ± 8.76	3.93 ± 0.65	0.47 ± 0.06	0.27	3.28
61	**Aryan**	9.98 ± 3.1	21.13 ± 9.16	3.7 ± 0.63	0.4 ± 0.06	0.17	3.66
62		12.1 ± 3.2	16.07 ± 8.79	2.84 ± 0.57	0.51 ± 0.07	0.19	2.12
63		5.79 ± 2.75	11.6 ± 8.11	11.32 ± 0.97	0.48 ± 0.06	0.22	4.38
64		11.52 ± 3.16	17.41 ± 8.65	6.46 ± 0.77	0.29 ± 0.05	0.27	3.11
65		6.65 ± 2.78	15.68 ± 8.33	3.04 ± 0.58	0.52 ± 0.07	0.28	2.42
66		8.26 ± 2.91	16.27 ± 8.01	1.99 ± 0.48	0.39 ± 0.06	0.33	1.64
67	**Kesri Singhpur**	10.03 ± 3.36	23.14 ± 9.16	4.99 ± 0.69	0.41 ± 0.06	0.37	3.43
68		8.08 ± 3.08	27.25 ± 9.38	5.77 ± 0.77	0.77 ± 0.07	0.38	3.97
69		11.93 ± 3.73	23.18 ± 10.32	5.97 ± 0.81	0.92 ± 0.09	0.36	5.74
70		10.21 ± 3.56	96.05 ± 11.99	9.11 ± 0.89	0.57 ± 0.07	0.3	8.07
71		21.16 ± 4.1	26.8 ± 11.38	4.24 ± 0.63	0.41 ± 0.06	0.27	1.83
72		19.55 ± 3.8	15.79 ± 10.28	3.2 ± 0.59	0.4 ± 0.06	0.17	3

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
73	Ganganagar	6.82 ± 2.88	15.81 ± 8.1	2.78 ± 0.54	0.32 ± 0.05	0.17	2.55
74		8.37 ± 2.95	19.67 ± 8.43	5.74 ± 0.76	0.61 ± 0.07	0.33	4.11
75		3.9 ± 2.85	52.11 ± 8.59	7.42 ± 0.83	0.54 ± 0.07	0.39	4.55
76		4.99 ± 4.41	24.65 ± 11.23	3.91 ± 0.61	0.24 ± 0.05	0.19	3.75
77		11.01 ± 3.11	12.85 ± 8.04	3.88 ± 0.61	0.36 ± 0.05	0.14	3.03
78	Sadul Shehar	4.41 ± 2.52	13.71 ± 6.84	2.92 ± 0.55	0.31 ± 0.05	0.3	2.11
79		5.62 ± 2.91	17.08 ± 8.2	6.65 ± 0.8	0.53 ± 0.07	0.45	4.6
80		9 ± 3.17	14.4 ± 8.25	7.15 ± 0.81	0.58 ± 0.07	0.41	5.87
81		5.33 ± 2.81	14.46 ± 7.87	2.39 ± 0.49	0.28 ± 0.05	0.19	2.38
82		7.63 ± 2.94	17.48 ± 8.21	3.68 ± 0.61	0.45 ± 0.06	0.31	3.1
83	Gharsana	6.88 ± 2.87	12.35 ± 7.54	4.32 ± 0.66	0.55 ± 0.07	0.26	3.24
84		14.51 ± 3.4	14.33 ± 9.11	3.76 ± 0.64	0.54 ± 0.07	0.22	2.69
85		15.02 ± 3.34	15.89 ± 8.92	4.85 ± 0.72	0.62 ± 0.07	0.38	3.87
86		5.79 ± 2.82	14.79 ± 7.56	2.44 ± 0.52	0.4 ± 0.06	0.35	2.05
87	Anoopgarh	7.63 ± 3.07	26.99 ± 8.37	2.67 ± 0.54	0.41 ± 0.06	0.18	1.96
88		7.51 ± 2.87	12.75 ± 7.9	4.97 ± 0.68	0.49 ± 0.06	0.37	3.28
89		5.27 ± 2.7	17.56 ± 7.35	4.2 ± 0.64	0.31 ± 0.05	0.21	2.55

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
90		8.37 ± 2.98	13.84 ± 7.74	3.74 ± 0.63	0.38 ± 0.06	0.17	2.34
91		5.05 ± 2.78	13.53 ± 7.28	5.37 ± 0.73	0.64 ± 0.07	0.25	3.69
92		5.16 ± 2.59	16.52 ± 6.96	1.62 ± 0.43	0.31 ± 0.05	0.23	1.24
93	**Sadhan wali**	4.01 ± 2.86	11.46 ± 7.48	4.47 ± 0.68	0.54 ± 0.06	0.51	4.06
94		7.4 ± 3.05	16.63 ± 8.06	9.48 ± 0.95	0.64 ± 0.07	0.49	3.67
95		4.53 ± 2.68	17.11 ± 7.32	4.02 ± 0.62	0.31 ± 0.05	0.26	2.36
96		11.29 ± 3.11	51.33 ± 9.6	5.07 ± 0.69	0.53 ± 0.06	0.17	3.15
97	**Gulabewala**	12.27 ± 3.47	13.18 ± 8.88	1.96 ± 0.47	0.38 ± 0.06	0.34	1.37
98		7.74 ± 2.9	9.04 ± 7.63	3.74 ± 0.6	0.24 ± 0.05	0.21	3.13
99		10.78 ± 3.11	13.68 ± 8.32	5.72 ± 0.75	0.56 ± 0.07	0.54	5.52
100		5.27 ± 2.63	28.65 ± 7.91	3.15 ± 0.57	0.33 ± 0.05	0.32	2.57
Minimum		3.8 ± 2.5	9 ± 6.5	1.6 ± 0.4	0.2 ± 0	0.09	1.24
Maximum		32.6 ± 4.7	96 ± 12	12.6 ± 1.1	1.3 ± 0.1	0.69	9.6
Average		9.8 ± 3.2	19 ± 8.7	5.5 ± 0.7	0.5 ± 0.1	0.3	3.68
Churu district							
1	**Sardarshehar**	15.1 ± 3.04	16.43 ± 7.83	8.99 ± 0.95	0.92 ± 0.08	0.27	3.12
2		21.07 ± 3.47	12.66 ± 8.63	6.61 ± 0.83	0.64 ± 0.07	0.34	4.26

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
3		30.68 ± 4.01	17.79 ± 10.07	5.51 ± 0.8	1.1 ± 0.09	0.95	2.03
4		19.82 ± 3.37	14.5 ± 8.47	19.18 ± 1.35	1.22 ± 0.1	1.02	18.95
5		31.08 ± 3.95	19.72 ± 10	15.46 ± 1.19	1.09 ± 0.09	0.34	4.58
6	**Jasrasar**	19.73 ± 3.46	13.01 ± 8.62	12.62 ± 1.1	0.65 ± 0.08	0.48	4.13
7		20.44 ± 3.46	15.26 ± 8.74	14.57 ± 1.2	1.06 ± 0.09	0.73	7.62
8		27.2 ± 3.91	12.98 ± 9.65	7.33 ± 0.89	0.96 ± 0.09	0.52	5.44
9		17.35 ± 3.26	11.8 ± 8.1	7.38 ± 0.9	1.09 ± 0.09	0.45	5.34
10		19.39 ± 3.4	22.8 ± 8.95	6.49 ± 0.84	0.75 ± 0.08	0.57	5.83
11	**Malsar**	18.3 ± 3.32	18.87 ± 8.57	5.02 ± 0.71	0.39 ± 0.06	0.26	4.3
12		16.34 ± 3.18	17.1 ± 8.18	4.1 ± 0.67	0.51 ± 0.07	0.4	2.51
13		17.39 ± 3.35	17.91 ± 8.6	3.53 ± 0.66	0.62 ± 0.08	0.51	3.33
14		29.99 ± 4.15	14.7 ± 10.32	7.89 ± 0.91	0.49 ± 0.07	0.4	4.6
15		17.51 ± 3.36	23.18 ± 8.91	21.39 ± 1.38	0.66 ± 0.08	0.58	2.49
16	**Salasar**	21.04 ± 3.63	16.46 ± 9.17	6.32 ± 0.84	0.67 ± 0.08	0.45	2.92
17		20.49 ± 3.58	17.8 ± 9.14	15.42 ± 1.19	0.3 ± 0.05	0.24	5.9
18		20.19 ± 3.56	19.56 ± 9.18	16.22 ± 1.22	0.58 ± 0.07	0.42	5.78
19		17.18 ± 3.31	14.47 ± 8.36	14.91 ± 1.24	0.54 ± 0.07	0.43	5.97

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC $\pm \sigma$ (Bqm^{-3})	EETC $\pm \sigma$ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
20		19.05 ± 3.3	16.36 ± 8.43	6.29 ± 0.83	1.07 ± 0.09	0.4	4.81
21	**Asalrsar**	17.12 ± 3.25	20.72 ± 8.53	6.29 ± 0.85	1.27 ± 0.09	0.31	3.73
22		16.33 ± 3.25	11.59 ± 8.06	11.92 ± 1.09	1.09 ± 0.1	0.48	3.87
23		16.93 ± 3.27	30.98 ± 9.06	3.68 ± 0.66	0.6 ± 0.07	0.44	2.6
24		20.62 ± 3.5	21.71 ± 9.13	7.39 ± 0.88	0.79 ± 0.08	0.23	2.44
25		21.1 ± 3.59	13.85 ± 8.97	4.69 ± 0.75	0.82 ± 0.08	0.44	4.33
26	**Churu**	17.09 ± 3.2	13.34 ± 8.04	2.26 ± 0.55	0.78 ± 0.08	0.46	1.61
27		16.3 ± 3.13	12.95 ± 7.85	7.27 ± 0.82	0.34 ± 0.05	0.28	4.93
28		18.51 ± 3.31	16.18 ± 8.28	4.18 ± 0.67	0.53 ± 0.07	0.45	3.31
29		20.16 ± 3.41	19.24 ± 8.82	5.14 ± 0.8	1.37 ± 0.11	0.57	2.88
30		25.28 ± 3.74	20.4 ± 9.62	8.55 ± 0.91	0.53 ± 0.07	0.48	6.32
31	**Ratangarh**	22.72 ± 3.52	19.04 ± 9.03	4.11 ± 0.65	0.4 ± 0.06	0.32	3.26
32		40.63 ± 4.27	38.95 ± 11.1	9.12 ± 0.92	0.51 ± 0.06	0.39	8.03
33		17.83 ± 3.33	22.99 ± 8.78	3.6 ± 0.63	0.47 ± 0.07	0.37	3
34		19.28 ± 3.39	16.35 ± 8.62	2.81 ± 0.56	0.33 ± 0.05	0.32	2.49
35		23.82 ± 3.69	20.02 ± 9.5	2.75 ± 0.55	0.33 ± 0.05	0.28	1.35
36	**Motisar**	25.05 ± 3.73	21.01 ± 9.68	3.59 ± 0.63	0.44 ± 0.06	0.34	3.25

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
37		15.78 ± 3.14	15.36 ± 8	2.84 ± 0.56	0.38 ± 0.06	0.23	2.56
38		15.89 ± 3.16	23.39 ± 8.46	3.28 ± 0.6	0.42 ± 0.06	0.33	3.28
39		18.36 ± 3.32	15.92 ± 8.44	4.19 ± 0.68	0.62 ± 0.07	0.45	3.04
40		18.65 ± 3.34	18.08 ± 8.59	8.64 ± 0.89	0.48 ± 0.06	0.47	2.37
41	Dhadar	26.97 ± 3.9	13.98 ± 9.71	12.93 ± 1.09	0.72 ± 0.08	0.47	6.22
42		15.99 ± 3.15	17.2 ± 8.11	3.07 ± 0.6	0.61 ± 0.07	0.45	2.04
43		19.95 ± 3.54	17.6 ± 9.04	3.47 ± 0.63	0.45 ± 0.06	0.41	2.69
44		25.43 ± 3.93	18.01 ± 9.95	4.13 ± 0.67	0.37 ± 0.06	0.33	3.47
45		21.22 ± 3.64	23.6 ± 9.51	3.68 ± 0.65	0.47 ± 0.07	0.42	2.16
46	Bhojrasar	20.8 ± 3.61	18.22 ± 9.21	5.54 ± 0.77	0.38 ± 0.06	0.37	4.84
47		20.25 ± 3.55	23.19 ± 9.32	7.22 ± 0.87	0.72 ± 0.08	0.33	5.93
48		18.81 ± 3.38	19.82 ± 8.77	6.9 ± 0.79	0.46 ± 0.06	0.39	2.05
49		20.98 ± 3.61	17.34 ± 9.17	8.49 ± 0.9	0.72 ± 0.08	0.5	8.24
50		19.91 ± 3.86	29.48 ± 10.35	8.41 ± 0.98	0.78 ± 0.09	0.51	5.9
51	Bhanipur	17.48 ± 3.2	14.06 ± 8.15	3.66 ± 0.65	0.66 ± 0.08	0.28	3.39
52		16.72 ± 3.25	19.77 ± 8.51	2.7 ± 0.58	0.57 ± 0.07	0.29	1.94
53		26.74 ± 3.75	20.12 ± 9.67	3.83 ± 0.7	1.04 ± 0.09	1.03	1.34

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
54		21.26 ± 3.5	15.86 ± 8.84	4.74 ± 0.77	1.32 ± 0.1	0.74	3.2
55		31.82 ± 3.97	20.2 ± 10.2	3.05 ± 0.63	0.88 ± 0.08	0.68	1.66
56	**Aspalsar**	15.09 ± 3.11	16.89 ± 8.01	4.09 ± 0.67	0.46 ± 0.06	0.4	2.95
57		18.34 ± 3.26	17.21 ± 8.37	3.61 ± 0.63	0.95 ± 0.08	0.41	2.49
58		18.23 ± 3.28	23.49 ± 8.73	2.19 ± 0.59	1.18 ± 0.09	0.36	1.95
59		16.35 ± 3.13	19.53 ± 8.22	3.68 ± 0.62	0.55 ± 0.07	0.37	2.4
60		19.39 ± 3.42	18.34 ± 8.79	4.96 ± 0.72	0.5 ± 0.07	0.42	3.87
61	**Bhaghsar Purvi**	16.01 ± 3.09	29.44 ± 8.74	2.44 ± 0.52	0.31 ± 0.05	0.21	2.07
62		13.68 ± 2.97	28.84 ± 8.28	2.65 ± 0.57	0.66 ± 0.07	0.25	2.42
63		20.79 ± 3.5	11.7 ± 8.67	1.44 ± 0.61	1.79 ± 0.13	0.47	1.34
64		29.42 ± 3.98	16.55 ± 10.03	2.94 ± 0.58	0.49 ± 0.07	0.21	1.47
65		16.28 ± 3.15	21.82 ± 8.35	3.18 ± 0.59	0.48 ± 0.06	0.22	2.89
66	**Gudawadi**	19.03 ± 3.46	22.56 ± 9.09	2.87 ± 0.58	0.46 ± 0.06	0.29	1.86
67		14.28 ± 3.08	25.25 ± 8.43	3.36 ± 0.62	0.38 ± 0.06	0.36	2.43
68		12.52 ± 2.9	30.33 ± 8.26	2.86 ± 0.59	0.54 ± 0.07	0.32	2.86
69		18.3 ± 3.4	24.63 ± 9.12	3.57 ± 0.64	0.49 ± 0.07	0.42	2.46
70		18.18 ± 3.42	19.25 ± 8.84	3.04 ± 0.64	0.78 ± 0.08	0.24	1.43

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
71	Nakrasar	19.09 ± 3.49	15.42 ± 8.81	2.65 ± 0.67	1.42 ± 0.1	0.27	2.57
72		13.79 ± 2.98	29.24 ± 8.32	2.32 ± 0.59	1.06 ± 0.09	0.2	2.28
73		14.82 ± 3.13	22.57 ± 8.34	3.15 ± 0.63	0.73 ± 0.08	0.36	2.82
74		20.5 ± 3.49	20.91 ± 9.08	2.54 ± 0.58	0.93 ± 0.08	0.36	1.78
75		18.05 ± 3.29	18.83 ± 8.52	2.38 ± 0.57	0.81 ± 0.08	0.2	1.62
76	Sujangarh	16.13 ± 3.17	23.69 ± 8.48	2.63 ± 0.56	0.55 ± 0.07	0.41	2.61
77		13.27 ± 2.94	20.42 ± 7.82	2.53 ± 0.53	0.35 ± 0.06	0.25	1.87
78		19.98 ± 3.45	17.84 ± 8.83	3.4 ± 0.6	0.38 ± 0.06	0.37	2.32
79		21.61 ± 3.53	19.13 ± 9.03	2.87 ± 0.56	0.31 ± 0.05	0.2	1.9
80		26.04 ± 3.84	17.74 ± 9.72	3.91 ± 0.64	0.43 ± 0.06	0.29	2.2
81	Rajgarh	17.12 ± 3.22	16.35 ± 8.27	3.09 ± 0.58	0.35 ± 0.06	0.32	2.45
82		21.43 ± 3.53	20.81 ± 9.13	4.72 ± 0.7	0.46 ± 0.06	0.33	2.47
83		18.63 ± 3.35	21.81 ± 8.82	3.67 ± 0.64	0.47 ± 0.06	0.41	2.31
84		16.94 ± 3.24	18.34 ± 8.38	3.82 ± 0.62	0.34 ± 0.05	0.3	2.25
85		23.82 ± 3.69	22.7 ± 9.59	3.92 ± 0.65	0.52 ± 0.07	0.31	3.37
86	Shobasar	18.23 ± 3.32	26.17 ± 8.96	3.53 ± 0.62	0.48 ± 0.06	0.4	2.53
87		13.56 ± 2.96	20.72 ± 7.89	3.62 ± 0.62	0.38 ± 0.06	0.35	3.2

No. of dwellings	Villages	$C_R \pm \sigma$ (Bqm^{-3})	$C_T \pm \sigma$ (Bqm^{-3})	EERC ± σ (Bqm^{-3})	EETC ± σ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	$EERC_A$ (Bqm^{-3})
88		13.97 ± 3	20.22 ± 7.95	3.77 ± 0.64	0.51 ± 0.07	0.16	2.23
89		16.3 ± 3.18	15.76 ± 8.11	3.15 ± 0.61	0.56 ± 0.07	0.44	3
90		17.23 ± 3.26	26.17 ± 8.82	4.05 ± 0.66	0.44 ± 0.06	0.37	3.29
91	**loonch**	22.37 ± 3.61	14.97 ± 9.05	3.94 ± 0.66	0.49 ± 0.07	0.38	3.04
92		13.33 ± 2.95	32.71 ± 8.43	3.76 ± 0.63	0.39 ± 0.06	0.2	3.71
93		15.25 ± 3.11	22.8 ± 8.32	3.39 ± 0.61	0.41 ± 0.06	0.38	3.38
94		18.81 ± 3.37	20.32 ± 8.78	3.53 ± 0.64	0.64 ± 0.07	0.49	2.83
95		17.06 ± 3.23	24.78 ± 8.66	3.18 ± 0.59	0.41 ± 0.06	0.3	2.88
96	**Sawar**	17.29 ± 3.27	17.84 ± 8.42	2.4 ± 0.53	0.42 ± 0.06	0.37	1.77
97		18.46 ± 3.35	24.98 ± 8.95	5.85 ± 0.82	1.17 ± 0.1	0.72	5.31
98		15.49 ± 3.12	27.95 ± 8.59	4.58 ± 0.69	0.36 ± 0.06	0.33	2.64
99		18.87 ± 3.36	22.5 ± 8.87	3.2 ± 0.6	0.47 ± 0.06	0.37	3.13
100		18.63 ± 3.36	28.65 ± 9.16	3.78 ± 0.65	0.54 ± 0.07	0.49	3.22
Minimum		12.5 ± 2.9	11.6 ± 7.8	1.4 ± 0.5	0.3 ± 0.1	0.16	1.34
Maximum		40.6 ± 4.3	39 ± 11.1	21.4 ± 1.4	1.8 ± 0.1	1.03	18.95
Average		19.5 ± 3.4	19.9 ± 8.8	5.4 ± 0.7	0.6 ± 0.1	0.4	3.43

Table: 3.3: Annual effective dose (μSvy^{-1}) due to radon/thoron and their progeny concentration and also inhalation dose for mouth and nose due to fractions of radon/thoron

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
Hanumangarh district						
1	**Hanumangarh Junction**	0.64	1.75	2.39	2.91	0.90
2		0.66	2.83	3.49	5.11	1.45
3	**Hanumangarh Town**	0.33	2.08	2.41	1.17	0.42
4		0.57	2.55	3.12	0.51	0.25
5		0.63	3.82	4.45	14.95	3.75
6	**Phephana**	0.55	2.35	2.90	0.37	0.18
7		0.48	2.53	3.01	9.65	2.57
8		0.61	2.21	2.82	5.54	1.53
9	**Jnania**	1.04	3.36	4.41	18.58	4.62
10		0.57	2.42	2.99	9.36	2.45
11		0.39	1.82	2.20	0.35	0.15
12	**Padampura**	0.45	1.90	2.35	3.28	0.98
13		0.32	2.59	2.90	0.88	0.37
14		0.71	2.65	3.36	0.24	0.12
15	**Dabli Rathan**	0.45	1.98	2.43	0.03	0.02

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
16		0.30	2.59	2.90	0.33	0.18
17		0.45	2.56	3.01	0.07	0.05
18	**Pilibanga**	0.57	2.03	2.60	1.06	0.41
19		0.62	3.91	4.53	0.18	0.12
20		0.44	1.84	2.28	0.04	0.03
21	**Jandawali**	0.53	2.62	3.15	0.53	0.23
22		0.41	2.61	3.02	0.42	0.21
23		1.11	5.61	6.71	4.94	1.69
24	**Jorkiyan**	0.44	2.97	3.41	3.77	1.17
25		0.79	3.24	4.03	0.07	0.05
26		0.41	2.11	2.52	1.10	0.41
27	**Nagrana**	0.65	1.52	2.17	0.00	0.00
28		0.74	1.33	2.07	0.26	0.12
29		0.43	1.71	2.14	3.82	1.09
30	**Sangria**	0.30	3.25	3.55	6.53	1.96
31		0.94	4.14	5.08	35.13	8.33
32		0.34	2.33	2.66	8.29	2.19
33	**Bhagatpura**	0.57	4.65	5.22	2.71	1.02

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
34		1.09	7.54	8.63	10.84	3.42
35		0.51	3.35	3.86	0.35	0.19
36	**Dhaba**	0.70	4.67	5.37	4.46	1.49
37		1.10	5.32	6.42	20.54	5.46
38		0.35	1.96	2.30	0.53	0.23
39	**Kharliyan**	0.74	4.27	5.01	1.25	0.54
40		0.96	3.57	4.53	36.83	8.56
41		0.54	1.53	2.08	2.98	0.86
42	**Hansliyan**	0.72	3.53	4.25	12.43	3.31
43		0.93	3.84	4.77	1.32	0.54
44		0.32	1.69	2.01	0.87	0.33
45	**Goluwala**	0.52	2.43	2.95	8.18	2.15
46		0.41	1.93	2.33	0.65	0.27
47		0.41	2.36	2.77	0.07	0.05
48	**Bhadra**	0.57	4.89	5.46	1.38	0.61
49		0.95	4.75	5.71	12.28	3.17
50		0.39	1.57	1.96	0.24	0.12
51	**Dholpalia**	0.68	2.82	3.50	1.43	0.55

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
52		0.77	3.87	4.63	2.05	0.75
53		0.23	1.31	1.54	0.33	0.15
54	**Jogiwala**	0.49	3.65	4.14	1.70	0.66
55		0.50	2.01	2.51	0.11	0.07
56		0.73	4.06	4.79	20.03	4.78
57	**Rawatsar**	0.57	3.28	3.85	4.30	1.35
58		0.60	2.05	2.65	13.51	3.23
59		1.03	5.08	6.12	0.07	0.05
60	**25DWD**	0.70	2.36	3.06	2.50	0.81
61		0.34	2.49	2.83	5.51	1.55
62	**2KBM**	0.43	2.36	2.79	16.18	3.97
63		0.32	1.21	1.52	0.22	0.10
64	**Tibbi**	0.43	1.47	1.91	0.45	0.18
65		0.33	1.76	2.09	5.84	1.57
66		0.23	1.53	1.76	3.60	1.00
67		0.39	1.77	2.17	1.12	0.41
68	**Peerkambdia**	0.56	2.95	3.51	0.20	0.12
69		1.13	3.35	4.48	2.90	0.94

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
70		0.31	2.38	2.69	0.58	0.25
71		0.30	1.50	1.80	8.12	2.01
72	Panniwala	0.20	2.52	2.72	0.56	0.27
73		1.17	5.54	6.71	8.96	2.64
74		0.24	2.06	2.30	0.68	0.30
75		0.49	2.24	2.73	1.56	1.00
Minimum		0.20	1.21	1.52	0.00	0.00
Maximum		1.17	7.54	8.63	36.83	8.56
Average		0.57	2.84	3.41	4.74	1.29
Standard deviation		0.24	1.23	1.41	7.26	1.75
Geometric mean		0.52	2.61	3.16	1.42	0.54
Median		0.53	2.52	2.95	1.43	0.55
Sri Ganganagar district						
1	39 LNP	0.28	2.24	2.52	0.51	0.24
2		0.46	2.00	2.46	0.20	0.11
3		0.27	2.87	3.14	46.82	10.49
4		0.47	1.83	2.29	0.35	0.18
5	Binjwala	1.40	1.49	2.89	0.13	0.08

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
6		0.85	1.70	2.55	0.26	0.13
7		0.71	1.07	1.78	1.58	0.50
8		0.91	1.44	2.35	0.18	0.09
9	**47 LNP**	0.96	2.26	3.22	2.62	0.88
10		0.71	3.50	4.21	4.05	1.35
11		0.95	0.79	1.74	0.73	0.25
12		0.77	2.36	3.13	2.62	0.87
13	**Padampura**	1.46	2.49	3.95	3.38	1.09
14		0.60	2.66	3.26	1.76	0.66
15		2.01	2.27	4.28	2.67	0.90
16		0.62	1.05	1.67	1.26	0.41
17	**Gajsinghpur**	0.57	1.22	1.80	0.16	0.08
18		0.32	1.26	1.58	0.47	0.20
19		0.23	1.97	2.20	3.70	1.03
20		0.46	1.73	2.19	1.73	0.58
21		0.22	1.24	1.46	7.67	1.93
22		0.53	1.07	1.59	0.16	0.08
23	**Fojuwala**	0.18	1.99	2.17	1.70	0.61

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
24		0.05	1.49	1.55	7.78	1.89
25		0.27	1.83	2.10	0.93	0.38
26		0.13	2.21	2.35	8.69	2.27
27	**70 RB**	0.25	1.14	1.40	0.35	0.15
28		0.66	1.57	2.24	0.68	0.25
29		0.34	0.82	1.15	2.07	0.55
30		0.63	2.10	2.73	2.96	0.90
31	**Rai Singh Nagar**	0.79	0.50	1.29	0.73	0.23
32		0.32	1.13	1.46	0.36	0.16
33		0.39	1.09	1.48	1.19	0.40
34		0.90	0.53	1.43	0.09	0.05
35		0.29	1.05	1.33	6.65	1.66
36		0.39	1.77	2.16	3.41	1.04
37	**Jorawar**	0.63	1.54	2.18	0.04	0.03
38		0.40	2.97	3.37	3.57	1.19
39		0.43	1.25	1.68	2.52	0.76
40		0.43	2.12	2.55	4.29	1.29
41	**Karanpur**	0.32	1.02	1.33	2.25	0.67

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
42		0.25	2.17	2.41	0.21	0.12
43		0.21	1.19	1.39	2.03	0.62
44		0.76	1.13	1.89	3.20	0.90
45		0.85	1.72	2.57	0.32	0.16
46		0.19	1.88	2.07	1.20	0.45
47	**52 F**	0.58	0.72	1.30	0.66	0.22
48		0.34	0.89	1.23	0.60	0.23
49		0.64	1.65	2.28	0.77	0.31
50		1.18	1.80	2.99	3.36	1.03
51		0.79	0.64	1.42	0.13	0.06
52		0.75	1.06	1.81	2.02	0.61
53	**Kachi Thedi**	0.97	0.68	1.66	0.49	0.18
54		1.21	0.89	2.10	0.84	0.29
55		0.94	0.73	1.67	0.51	0.17
56		0.99	1.15	2.14	1.19	0.40
57	**Lakhiyan**	0.30	1.32	1.62	0.08	0.05
58		0.69	1.08	1.77	0.64	0.25
59		0.59	0.90	1.49	0.10	0.06

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
60		0.27	0.64	0.91	0.25	0.10
61	**Aryan**	0.26	1.50	1.76	0.02	0.02
62		0.19	1.65	1.84	1.87	0.62
63		0.08	0.77	0.84	294.53	54.94
64		0.44	1.51	1.95	5.59	1.51
65		0.26	0.95	1.20	0.34	0.14
66		0.05	1.20	1.24	7.81	1.93
67	**Kesri Singhpur**	0.12	1.43	1.55	18.53	4.23
68		0.35	1.21	1.56	1.30	0.40
69		0.41	2.66	3.06	0.13	0.08
70		0.06	0.96	1.01	26.86	5.68
71		0.07	1.12	1.19	116.75	22.94
72		0.15	1.51	1.65	0.31	0.15
73	**Ganganagar**	0.07	1.15	1.21	1.30	0.43
74		0.51	1.87	2.38	1.26	0.46
75		0.67	0.69	1.36	0.65	0.21
76		0.25	0.75	1.00	0.04	0.03
77		0.18	0.34	0.52	0.46	0.15

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
78	Sadul Shehar	0.20	0.41	0.61	0.36	0.12
79		0.46	0.62	1.08	0.52	0.17
80		0.80	1.67	2.46	0.33	0.16
81		0.08	0.89	0.97	0.01	0.01
82		0.42	1.28	1.70	0.21	0.11
83	Gharsana	0.50	1.23	1.73	0.38	0.16
84		0.34	2.71	3.06	2.15	0.78
85		0.47	3.39	3.86	1.32	0.56
86		0.14	0.95	1.08	0.59	0.22
87	Anoopgarh	0.13	0.87	1.00	1.69	0.50
88		0.63	1.36	1.99	0.65	0.26
89		0.37	0.58	0.95	0.63	0.21
90		0.34	1.44	1.78	1.77	0.58
91		0.18	0.89	1.08	4.02	1.03
92		0.10	0.77	0.87	0.92	0.30
93	Sadhan wali	0.27	0.80	1.07	0.11	0.05
94		0.96	1.28	2.24	2.36	0.70
95		0.07	0.63	0.71	21.47	4.50

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
96		0.55	0.88	1.42	0.50	0.18
97	Gulabewala	0.10	1.32	1.42	4.19	1.16
98		0.18	1.49	1.68	1.50	0.52
99		0.65	1.95	2.60	0.04	0.03
100		0.31	0.32	0.63	0.07	0.03
Minimum		0.05	0.32	0.52	0.01	0.01
Maximum		2.01	3.50	4.28	294.53	54.94
Average		0.48	1.40	1.88	6.75	1.49
Standard deviation		0.35	0.66	0.80	31.80	5.99
Geometric mean		0.37	1.25	1.72	0.95	0.35
Median		0.40	1.25	1.72	0.92	0.34
Churu district						
1	Jasrasar	0.58	1.18	1.76	5.93	1.49
2		0.44	1.59	2.02	2.89	0.88
3		0.36	1.42	1.79	6.75	1.71
4		1.22	1.37	2.59	0.01	0.01
5		0.99	1.50	2.49	8.87	2.19
6	Malsar	0.83	2.27	3.09	14.19	3.54

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
7		0.93	1.19	2.12	3.16	0.87
8		0.49	2.33	2.82	2.39	0.81
9		0.49	1.99	2.48	2.21	0.73
10		0.42	1.08	1.51	0.21	0.10
11	**Salasar**	0.34	1.48	1.82	0.57	0.24
12		0.28	1.30	1.58	2.84	0.83
13		0.24	1.13	1.37	0.10	0.06
14		0.51	1.16	1.68	2.84	0.82
15		1.36	1.25	2.62	12.29	2.87
16	**Asalrsar**	0.42	1.58	2.00	6.20	1.65
17		0.99	1.34	2.33	7.25	1.85
18		1.04	1.58	2.63	8.91	2.25
19		0.95	1.10	2.05	5.20	1.34
20		0.41	1.40	1.81	1.08	0.38
21	**Churu**	0.42	1.63	2.05	3.39	0.98
22		0.77	1.31	2.08	6.89	1.72
23		0.24	0.81	1.05	0.94	0.30
24		0.50	2.21	2.71	13.47	3.37

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
25		0.31	1.15	1.46	0.14	0.08
26	**Ratangarh**	0.16	1.36	1.52	1.62	0.53
27		0.47	0.95	1.42	1.47	0.46
28		0.28	1.54	1.83	1.11	0.41
29		0.34	1.45	1.79	3.25	0.92
30		0.56	1.40	1.96	1.48	0.50
31	**Motisar**	0.27	0.91	1.18	0.63	0.23
32		0.59	0.98	1.57	0.26	0.12
33		0.24	1.09	1.33	0.52	0.21
34		0.19	1.17	1.36	0.32	0.15
35		0.19	1.13	1.32	4.18	1.13
36	**Dhadar**	0.24	0.96	1.20	0.18	0.09
37		0.19	1.00	1.19	0.20	0.10
38		0.22	1.25	1.47	0.00	0.00
39		0.28	1.23	1.51	1.38	0.46
40		0.57	1.98	2.55	14.50	3.55
41	**Bhojrasar**	0.83	1.44	2.28	5.18	1.39
42		0.21	1.20	1.41	1.90	0.59

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
43		0.24	1.39	1.63	1.15	0.41
44		0.29	2.23	2.52	1.07	0.44
45		0.25	1.41	1.66	3.47	1.00
46	**Bhanipur**	0.37	1.40	1.77	0.44	0.20
47		0.48	2.14	2.63	1.18	0.46
48		0.46	1.72	2.18	11.77	2.90
49		0.56	1.92	2.48	0.07	0.05
50		0.55	1.58	2.13	2.05	0.66
51	**Aspalsar**	0.24	0.52	0.76	0.05	0.03
52		0.18	0.89	1.07	0.98	0.32
53		0.25	1.02	1.27	4.65	1.17
54		0.31	1.42	1.74	1.84	0.57
55		0.21	1.28	1.49	3.38	0.94
56	**Bhaghsar Purvi**	0.27	1.07	1.34	1.23	0.41
57		0.24	1.00	1.24	1.18	0.38
58		0.16	1.96	2.12	0.45	0.21
59		0.26	1.76	2.01	3.19	0.97
60		0.34	1.69	2.02	1.35	0.49

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
61	Gudawadi	0.17	1.27	1.45	0.55	0.23
62		0.18	0.99	1.17	0.16	0.08
63		0.11	1.58	1.68	0.14	0.08
64		0.20	0.95	1.14	3.15	0.85
65		0.21	0.98	1.19	0.17	0.08
66	Nakrasar	0.20	1.14	1.34	2.07	0.63
67		0.22	0.94	1.16	1.08	0.36
68		0.19	0.56	0.75	0.00	0.00
69		0.25	1.83	2.08	2.75	0.87
70		0.21	1.55	1.77	5.78	1.54
71	Sujangarh	0.19	1.94	2.13	0.07	0.05
72		0.16	1.04	1.20	0.02	0.01
73		0.21	1.04	1.25	0.21	0.10
74		0.19	2.34	2.53	3.15	1.01
75		0.16	0.99	1.16	1.29	0.41
76	Rajgarh	0.18	1.15	1.33	0.01	0.01
77		0.17	0.99	1.16	1.03	0.35
78		0.23	1.33	1.57	2.07	0.65

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
79		0.20	1.19	1.39	2.08	0.64
80		0.27	1.37	1.64	3.79	1.07
81	**Shobasar**	0.21	0.81	1.02	0.55	0.20
82		0.31	1.27	1.59	4.06	1.12
83		0.25	1.11	1.36	2.19	0.65
84		0.26	1.35	1.61	3.39	0.98
85		0.27	1.44	1.70	0.53	0.23
86	**loonch**	0.24	1.15	1.38	1.38	0.45
87		0.24	0.94	1.18	0.25	0.11
88		0.25	1.07	1.32	2.48	0.72
89		0.21	1.02	1.23	0.07	0.04
90		0.28	1.51	1.79	0.93	0.35
91	**Sawar**	0.27	1.26	1.52	1.05	0.37
92		0.25	1.09	1.34	0.02	0.01
93		0.23	1.27	1.51	0.00	0.00
94		0.24	1.52	1.77	0.98	0.37
95		0.21	1.03	1.24	0.19	0.10
96	**Sawar**	0.17	1.51	1.68	1.66	0.56

No. of dwellings	Villages	AEDR	AEDT	Total Dose	Inhalation dose for mouth	For nose
97		0.39	2.03	2.42	0.35	0.17
98		0.30	1.06	1.36	2.74	0.78
99		0.22	1.13	1.34	0.03	0.02
100		0.25	1.19	1.44	0.46	0.19
Minimum		0.11	0.52	0.75	0.00	0.00
Maximum		1.36	2.34	3.09	14.50	3.55
Average		0.36	1.34	1.70	2.49	0.70
Standard deviation		0.25	0.38	0.50	3.20	0.78
Geometric mean		0.31	1.29	1.63	0.86	0.32
Median		0.26	1.27	1.58	1.32	0.45

Table 3.4: Comparison of indoor radon/thoron and their progeny concentration with similar investigations in other areas

S. No.	Area of study	C_R (Bqm^{-3})	C_T (Bqm^{-3})	EERC (Bqm^{-3})	EETC (Bqm^{-3})	References
1.	Cyprus	14-17	-	-	-	Nikopolous et al., 2008
2.	Canada	7-1175	164	-	-	Chen et al., 2015
3.	Vietnam	-	2000	-	-	Nagyun et al., 2015
4.	Khasi Hills district of Meghalaya	55.9	60.6	20.9	1.4	Pyngrope et al., 2020
5.	Faridabad district of Haryana	26.3	38.1	38.1	5.15	Singh et al., 2019
6.	Mandya city of Karnataka	22.4	24.1	-	-	Narsimhamurthy et al., 2020
7.	Rajpur region of Uttarakhand Himalaya	89	38	35	2.14	Kandari et al., 2016
8.	Srinagar, J & K	35.61	64.15	9.30	0.57	Nazir et al., 2020
9.	Hamirpur district, Himachal Pradesh	63.8	86.9	29.3	2.7	Singh et al., 2015
10.	HBRA, Southeastern coast of Odisha	18	43	-	8	Ramola et al., 2015
11.	**Hanumangarh district, Rajasthan**	26.90	39.9	8.6	2.7	**Present study**
12.	**Sri Ganganagar District, Rajasthan**	9.8	19	5.5	0.5	
13.	**Churu District Rajasthan**	19.5	19.9	5.4	0.6	

Table 3.5: Comparison of attached fractions of radon/ thoron with similar investigations in other areas

S. No.	Area of study	$EERC_A$ (Bqm^{-3})	$EETC_A$ (Bqm^{-3})	Reference
1.	Udhampur	13	1.3	Sharma et al., 2018
2.	Garhwal, Himalya	46	2.2	Prasad et al., 2017
3.	Hamirpur, H.P.	26.2	2.36	Singh et al., 2015
4.	Jalandhar and Kapurthla of Punjab	18	1.2	Mehra et al., 2016
5.	**Hanumangarh district, Rajasthan**	8.69	0.66	**Present study**
6.	**Sri Ganganagar district, Rajasthan**	3.68	0.30	
7.	**Churu district, Rajasthan**	3.43	0.40	