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The Study of Radon/Thoron and Progeny Concentration in the District Muzaffarnagar, Uttar Pradesh, India Using SSNTDs

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The study aimed to measure indoor concentrations of radon, thoron, and their progeny in populated areas across seven locations in Muzaffarnagar using dosimeters, DTPS, and DRPS. The data collected over one year across four quarters revealed significant variability in concentration between locations and seasons. The highest average concentration of radon was found in Charthawal from November to January (92.3 Bq/m³), while the highest average concentration of thoron was observed in Mansoorpur from August to October (84.9 Bq/m³). The average concentration of radon progeny was highest in Rohana from November to January (24.7 Bq/m³), while the average concentration of thoron progeny was highest in Tirupadi from August to October (2.9 Bq/m³). Significant variations were observed in the concentration of radon, thoron, and their progeny between locations, which can be due to geological differences, building materials, and ventilation rates. The data also revealed seasonal variation, with November to January having the highest average concentrations of radon, thoron, and their progeny. The total effective dose of radon + EERC varied considerably across locations, with Tirupadi having the highest total effective dose of 0.89 mSv/year, and Muzaffarnagar having the lowest total effective dose of 0.62 mSv/year and similarly for thoron + EETC having the highest of 0.42 mSv/ year. the lowest of 0.07 mSv/ year in Rohana.

Keywords: Environmental monitoring, LR-115 (SSNTDs); Radiation monitoring; Twin Pinhole Dosimeter; Total equivalent dose

1 Introduction

Radium, a radioactive material, is found in the Earth's crust, and it emits radiation that produces radon, the only radioactive gas in its decay chain. Radon rises in the air and attaches itself to dust particles. Its half-life is 3.8 days, and it decays with an α (alpha) particle of 5.5 MeV[1]. When inhaled, radon can cause health risks, and its decay products may lead to lung cancer[2]. In heavy concentrations, the chances of the particles' solids (Po, Pb, Bi) getting attached to the lungs increase. Several research papers, including those from IARC (International Agency for Research on Cancer) and WHO (World Health Organization)[3], confirm with evidence the risks of radon exposure, particularly for miners[4,5]. Western countries focus on and inform the general public about the causes of cancer due to radon.

In modern society, people spend most of their time indoors, so it is essential to ensure that all materials used to build buildings are safe. Indoor radon can come from cooking gas, coal, and building materials[6,7]. Research suggests that indoor radon concentration is generally higher than outdoor concentration, primarily because of building materials and other relative causes[8,9]. In addition, the percentage of inhaled radon indoors is always higher than outdoors because mapped radon has more chances to be inhaled than free-moving radon. Basements are also at risk of higher concentration due to cracks that allow radon to enter and stay for extended periods. The pressure difference to the surrounding atmosphere can also cause higher concentrations. Newly constructed buildings may have high indoor radon levels because of decreased air entry or exit.

The study of radon and thoron concentration in specific areas helps to identify the risk associated with exposure to these gases and develop appropriate mitigation strategies to reduce the risk[10]. In the present study, the concentration of ^{222}Rn (radon) and ^{220}Rn (thoron) and their progeny in the Muzaffarnagar district of Uttar Pradesh were measured using radon/thoron pinhole-based discriminating dosimeters and DRPS/DTPS (Direct Radon and Thoron progeny sensors).

2 Study Areas and Samples

The present study is focused on the district of Muzaffarnagar in Uttar Pradesh, India, which is located near Saharanpur and Haridwar.

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Muzaffarnagar is known as the Sugar Bowl of Uttar Pradesh and is situated in the highly fertile upper Ganga Yamuna Doab region between Meerut and Saharanpur. Its borders touch the state of Uttarakhand. It is located approximately 125 kilometers northeast of the national capital, New Delhi, and roughly 200 kilometers southeast of Chandigarh.

Muzaffarnagar has a humid monsoon climate, with extremely hot summers and seasonal temperature variations. The monsoon season affects the atmosphere from June to September. June is the hottest month in Muzaffarnagar, with an average temperature of $30.2^{\circ C}$. The lowest temperature in Muzaffarnagar is in January, with an average temperature of around $12.5^{\circ C}$ throughout the year. The annual average temperature in Muzaffarnagar is $24.2^{\circ C}$. The district of Muzaffarnagar comprises approximately 266 villages, and it shares borders with Haryana on the western part and Uttarakhand on the eastern part. The focus of this study involves assessing the levels of ^{222}Rn (radon), ^{220}Rn (thoron), and their progeny concentrations within designated villages depicted in Fig. 1.

3 Methodology

More than 50 dwelling houses were selected to measure the concentration of ^{222}Rn, ^{220}Rn, and their progeny. Twin-cup pinhole dosimeters and DRPS/DTPS were placed in these areas for a year. The year-long study was divided into four quarters: The first quarter (February to April), the second quarter (May to July), the third quarter (August to October), and the fourth quarter (November to January). The internal structure of the twin pinhole dosimeter is shown in Fig. 2.

The twin cup-pinhole dosimeter is a cylindrical plastic device with an aluminium coating and painted outer surface. The system consists of a central disc that separates it into two chambers of equal size. Each chamber has a length and radius of 4.1 cm and 3.1 cm, respectively. The central disc features four pinholes measuring 2 mm in length and 1 mm in diameter, which serve to differentiate ^{222}Rn. The initial chamber, referred to as the radon thoron chamber, has a glass fiber filter that the gas passes through before entering. Following diffusion, the gas enters the second chamber through the central disk's pinholes, called the radon chamber. Compared to radon's half-life of 3.8 days, thoron's half-life is only 55.6 seconds.

LR-115 films (cellulose nitrate film) are placed at the center of both chambers in a size of 3.00 cm x 2.5 cm. This device was made by the Bhabha Atomic Research Centre (BARC) in Mumbai. The twin cup-pinhole dosimeter was placed indoors, 12 cm away from the walls and 2.5 m above the ground, for a three-month session in the study areas. The pinholes in the LR-115 track detector films of the first and second chambers were made by the exposure of gas (radon + thoron) according to their lifetime. After three months, the LR-115 track detector films from all selected areas were safely removed.

The chemical etching process is crucial for properly embossing the track onto the LLR film. First, distilled water was made from simple water using a water distillation assembly, and samples collected from the location were taken to the laboratory. Next, a 2.5 N NaOH solution was prepared for chemical etching. The films were submerged in the solution and subjected to chemical etching for 90 minutes in a

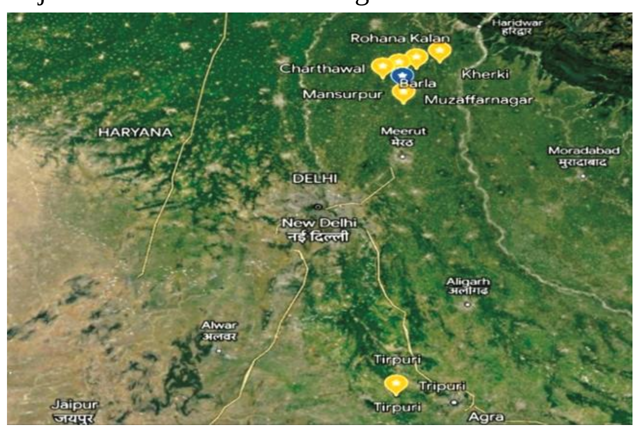

Fig. 1 — Geological map showing sample location. (*The map is only intended to be used as a visual aid and do not indicate any view on the legal positionof any country or territory or the delimitation frontiers or boundaries.)

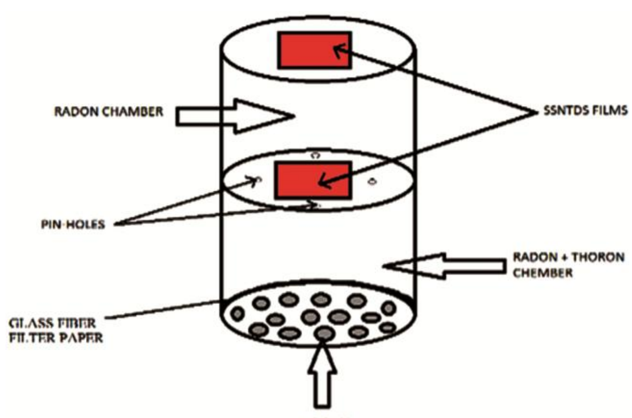

Fig. 2 — Internal schematic diagram of pinhole dosimeter.

water bath at a constant temperature of 60 °C. Alpha tracks on the films were easily visible and were counted with a spark counter. Pre-sparking the undeveloped holes twice to the operating voltage helped to highlight them.

The concentration of $^{222}Rn(C_R)$ and concentration of $^{220}Rn(C_T)$ are given by the following equations 1[11,16,17,18,19] and 2[11,16,17,18,19]:

$$C_R = \frac{T_1 - B}{d\ K_R} \quad \text{... (1)}$$

$$C_T = \frac{T_2 - d\ C_R\ K'_R - B}{d\ K_T} \quad \text{... (2)}$$

Where,

T_1=Track density in the radon chamber

T_2 = Track density in the ‘radon + thoron’ chamber

K_R=Calibration factor of radon in the 'radon' chamber (0.017 tr.cm^{-2}.d^{-1}/Bq m^{-3})16,17,18,19

d = Days of exposure

K_R`=Calibration factor of radon in ‘radon+thoron’ chamber (0.0172 tr.cm^{-2}.d^{-1}/Bq m^{-3})[16,17,18,19]

K_T=Calibration factor of thoron in 'radon+thoron' chamber (0.010 tr.cm^{-2}.d^{-1}/Bq m^{-3})[16,17,18,19].

B = background tracks

3.1 Measurement of Po-214(radon progeny) and Po-212 (thoronprogeny) concentration

DRPS/DTPS was utilized to assess the concentration of Radon progeny Po-214 and Thoron progeny Po-212. Fig. 3 displays the schematic diagram of DRPS and DTPS. The direct progeny sensors selectively record α traces generated by the deposition activity of progeny in LR115 solid-state nuclear detectors. An appropriate absorber thickness is used to detect different α particle energies. For radon and thoron progeny, the effective absorber thickness is 37 micrometers (25 aluminized mylar+12 cellulose nitrate) and 50 micrometers (aluminized mylar), respectively. These selectively record the tracks due to α particles emitted by Po-214 (α energy 7.69 MeV) + Po-212 (α energy 8.78 MeV) and Po212 (α energy 8.78 MeV), respectively.

Since the film in DRPS is exposed to both radon and thoron progeny, the tracks generated by the radon and thoron progeny are removed to calculate EERC and EETC, respectively. The system is designed to operate in deposition mode, making it important to prevent uncontrolled static deposition. The aluminized face of the LLR film was therefore used as the deposition surface to prevent uncontrolled static deposition (Mishra, 2014).

The formulas used to calculate EERC and EETC (equilibrium equivalent concentration for radon and thoron progeny) are given as follows[12]:

$$EERC(Bq\ m^{-3}) = \frac{T_3}{k_R\ d} \quad \text{... (3)}$$

$$EETC\ (Bq\ m^{-3}) = \frac{T_4}{k_T\ d} \quad \text{... (4)}$$

Where,

T3 Track density in DRPS due to radon progeny.

T_4=Track density in DTPS due to thoron progeny.

k_R= Calibration factor for radon progeny,0.09 tracks cm^{-2}d^{-1}per EERC (Bq m^{-3}).

k_T =calibration factor for thoron progeny, 0.94 tracks cm^{-2}d^{-1}per EETC (Bqm^{-3}).

To calculate the total annual effective dose due to radon, thoron, and their progeny concentration, the following formulas are given in equations5[20]and 6[20]:

$$AED\ (mSv/\ y) = (0.17C_{Rn} + 9EERC) x\ 8760\ x\ O_F\ x\ 10^{-6} \quad \text{... (5)}$$

$$AED\ (mSv/y) = (0.11C_T + 40\ EETC) x\ 8760\ x O_F\ x\ 10^{-6} \quad \text{... (6)}$$

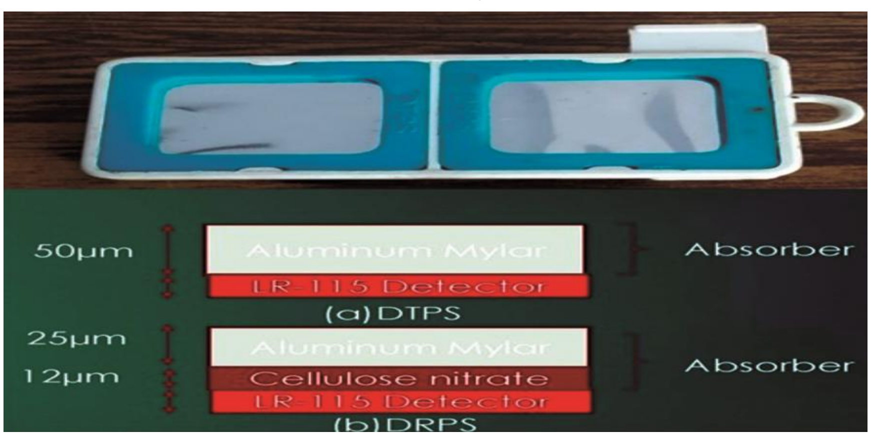

Fig. 3 — Schematic diagram of the DRPS and DTPS.

Table 1 — Radon and Thoron Concentration

S.N.	Location	Average of C_R session				Average of C_T session			
		I	II	III	IV	I	II	III	IV
1	Tirupadi	30.9	33.7	49.6	30.1	28.2	17.2	31.4	19.56
2	Kherkee	18.9	7.6	75.1	13.8	12.7	3.5	41.3	11.0
3	Rohana	5.5	14.7	5.3	34.4	4.00	13.4	4.6	22.4
4	Barla	14.6	44.3	17.0	79.8	9.6	28.5	15.5	48.0
5	Mansoorpur	10.2	20.5	88.5	18.9	8.7	19.7	84.9	15.9
6	Charthawal	21.3	26.1	33.9	92.3	15.8	9.9	30.9	47.2
7	Muzaffarnagar	14.4	23.0	17.4	71.2	12.1	16.6	15.6	33.0
	AVG	16.5	24.3	41.0	48.7	13.0	15.5	32.0	28.2
	MAXI	30.9	44.3	88.5	92.3	28.2	28.5	84.9	48.0
	MINI	5.5	7.6	5.3	13.81	4.00	3.5	4.6	11.0
	GM	14.6	21.4	29.1	39.2	11.2	13.3	23.3	24.8
	SD	8.2	12.1	31.5	31.7	7.7	7.9	26.4	14.9

Table 2 — DRPS and DTPS Concentration

S.N.	Location	Average of DRPS session				Average of DTP Ssession			
		I	II	III	IV	I	II	III	IV
1	Tirupdi	8.3	4.1	9.8	6.9	1.0	1.1	2.9	1.1
2	Kherkee	1.9	6.1	5.1	5.8	0.4	0.2	0.9	0.2
3	Rohana	0.7	1.0	2.8	24.7	0.1	0.2	0.2	0.4
4	Barla	0.4	5.3	1.4	5.4	0.1	0.3	0.1	0.5
5	Mansoorpur	0.8	1.2	18.3	1.2	0.1	0.2	2.4	0.2
6	Charthawal	2.1	0.8	3.3	8.9	0.1	0.1	0.5	1.9
7	Muzaffarnagar	2.3	1.5	2.9	8.7	0.2	0.7	0.3	1.7
	AVG	2.4	2.9	6.2	8.8	0.3	0.4	1.0	0.8
	MAXI	8.3	6.1	18.3	24.7	1.0	1.1	2.9	1.9
	MINI	3.1	0.8	1.4	1.2	0.1	0.09	0.1	0.2
	GM	9.9	2.1	4.4	6.5	0.2	0.3	0.6	0.6
	SD	6.1	2.2	6.0	7.5	0.3	0.4	1.1	0.7

Where,

C_R = The average concentration of radon

C_T = The average concentration of thoron

EERC =Progeny concentration of radon

EETC = progeny concentration of thoron

0.17 = Dosed conversation factor for Radon,

0.11 = Dosed conversion factor for thoron,

9 mSv(Bq.h.m^{-3})$^{-1}$ = Dose conversion factor (DCF) of radon

40 mSv(Bq.h.m^{-3})$^{-1}$ = Dose conversion factor (DCF) of radon

8760 = stay time of human in the year

O_F = 0.8 indoor occupancy factor

4 Results and Discussion

Table 1 and Table 2 summarize the resultant values of indoor ^{222}Rn and ^{220}Rn, and their progeny concentrations obtained using dosimeters, DTPS, and DRPS over the course of a year. Figs. 4 & 5 depict the corresponding graphs. The locations include Tirupadi, Kherkee, Rohana, Barla, Mansoorpur, Charthawal, and Muzaffarnagar. The concentration with the highest average value of radon is observed in Charthawal from November to January (92.3 Bq/m³), while the concentration with the highest average value of thoron is observed in Mansoorpur from August to October (84.9 Bq/m³). The concentration with the highest average value of radon progeny is observed in Rohana from November to January (24.7 Bq/m³), while thoron progeny is observed in Tirupadi from August to October (2.9 Bq/m³). November through January had the greatest average of ^{222}Rn with value of 92.33Bq/m³ and its progeny with value of 24.7 Bq/m³ while August through October had the greatest average of ^{220}Rn and their progeny with value of 84.9 Bq/m³ and 2.9 Bq/m³ respectively.

The data also shows a significant variation in the concentration of ^{222}Rn, ^{220}Rn, and their progeny between the different locations. For example, the average concentration of radon in Charthawal is much higher than in Mansoorpur, while the concentration with the highest average of radon progeny in Rohana

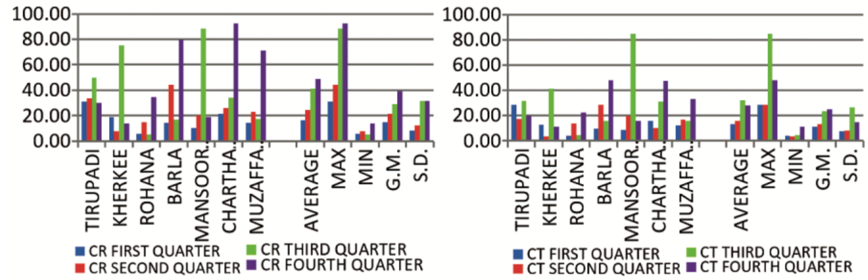

Fig.4 — Average C_R and C_T concentration throughout the year.

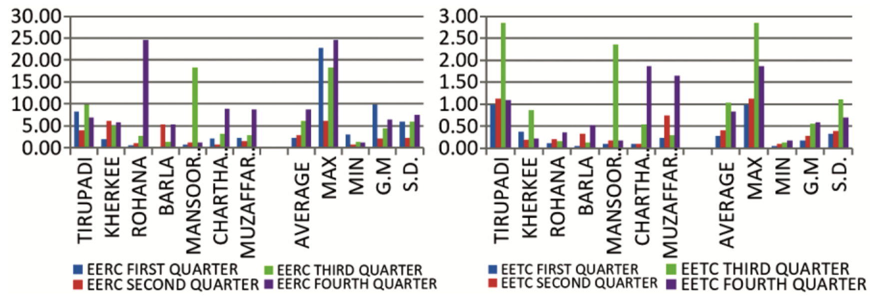

Fig. 5 — Average EERC and EETC concentration throughout the year.

is much higher than in Mansoorpur. Such variations can be due to geological differences, building materials, and ventilation rates.

Seasonal variation is also observed in the concentration of ^{222}Rn, ^{220}Rn, and their progeny. The average concentration of radon is highest with a value of 48.7 Bq/m³ from November to January, while it is lowest at 16.5 Bq/m³ from February to April. The concentration of thoron is highest during August to October with 32.0 Bq/m³ while it is lowest during February to April with 13.0 Bq/m³. The concentration of radon progeny is highest with 8.8 Bq/m^3 from November to January, while it is lowest from February to April. The concentration of thoron progeny is highest at 1.0 Bq/m³from August to October, while it is lowest at 0.3 Bq/m³ from February to April.

Overall, the data indicate that the concentration of ^{222}Rn, ^{220}Rn, and their progeny varies significantly both between locations and seasons [13–15].

The concentration of ^{222}Rn, ^{220}Rn, and their progeny may vary seasonally due to several factors. Variations in temperature, humidity, and atmospheric pressure can impact the diffusion and dispersion of these gases in the air. During the winter months, cooler and denser air can lead to higher concentrations of radon indoors. The composition of soil and geology can also differ across regions, affecting the release and concentration of these gases. Furthermore, the ventilation systems in buildings can play a role in determining the concentration of these gases. Activities such as mining, drilling, and excavation can emit radon and thoron into the air, while agricultural practices and the use of fertilizers may also influence the concentration of these gases.

Table 3 — Radon + Eerc, and Thoron + Eetc Concentration

Location	AED of Radon+EERC (mSv/y)	AED of Thoron+EETC, (mSv/y)
TIRUPADI	0.89	0.42
KHERKEE	0.64	0.12
ROHANA	0.64	0.07
BARLA	0.66	0.11
MANSOORPUR	0.75	0.22
CHARTHAWAL	0.76	0.19
MUZAFFARNAGAR	0.62	0.21
AVERAGE	0.70	0.19
MAX	0.89	0.42
MIN	0.62	0.07
G.M	0.70	0.17
S.D	0.O9	0.12

The total effective dose, radon progeny concentration, and thoron progeny concentration for various sites are all included in Table 3. It is evident from the data in the table that there is a sizable variance in the total effective dosage between various places. The place with the greatest total effective dose for Radon + EERC Tirupadi had a total effective dose of 0.89 mSv/year, more than twice as high as the next-highest location, Chartawal, which had a total

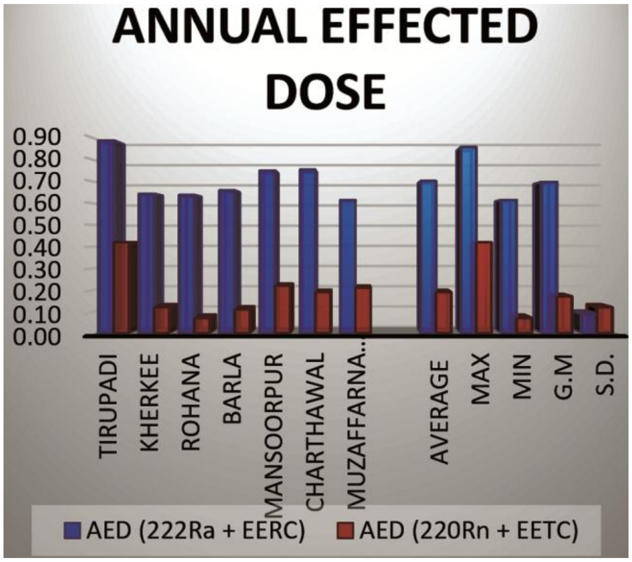

Fig. 6 — Annual effected dose or radon+EERC, and thoron+EETC.

effective dose of 0.76 mSv/year. The lowest total effective dose was found in Muzaffarnagar, which was only 0.62 mSv/year and Thoron + EETC Tirupadi had the highest effective dose of 0.42 mSv/year and Rohana had the lowest effective dose of 0.07 mSv/year. The total average value of Radon + EERC and Thoran + EETC during the whole year are 0.70 mSv/year and 0.19 mSv/year respectively.

The graphical variations of annual effective doses for all one year are shown in Fig. 6. The graph shows the annual effective dose Radon+EERC(mSv/year) is higher than the annual effective dose of Thoron+EETC, which shows the Radon concentration and their progeny have higher concentration than Thoron and thoron progeny concentration.

5 Conclusion

The findings emphasize the need for regular monitoring of ^{222}Rn, ^{220}Rn, and progeny concentrations in various environments and over various seasons. It is evident that seasonal change significantly affects the concentration of these gases, with summer showing the highest amounts of these gases. This variation in concentration could be due to changes in atmospheric pressure, temperature, and humidity. It is also evident that the concentration of these gases varies greatly across different locations, which could be attributed to differences in geology, topography, and building materials.The variation can depend on the air pressure and temperature difference humidity and building material and ventilation facility. All the dosimeters installed in Tirupadi and Mansoorpur were inside the room while at some places they were also installed outside in the verandah.So one reason could also be that due to ventilation facility.

Overall, the results of this study emphasize the need for continuous monitoring of ^{222}Rn, ^{220}Rn, and progeny concentration in different locations and seasons to ensure the safety of individuals. The data presented in Table 1 could be useful in developing strategies to mitigate the concentration of these gases and reduce the associated health risks.

The highest total effective dose is observed in Tirupadi, followed by Charthawal and Muzaffarnagar, while the lowest total effective dose is observed in Kherkee, Rohana, and Barala. This indicates that people living in areas with high radon and thoron progeny concentrations are at a higher risk of exposure to ionizing radiation, which may increase their risk of developing lung cancer. Therefore, it is important to monitor radon and thoron progeny concentration in indoor air and take necessary measures to reduce exposure to ionizing radiation.

The results showed that the concentration varied seasonally, with the lowest concentration in summer in the second quarter and the highest in winter in the fourth quarter. The concentration was found to be influenced by temperature changes, and rising aerosols and dust particles at higher altitudes. Despite the seasonal variation, the average concentration over the year was below the recommended action level set by various organizations, including BARC and WHO. This implies that the concentrations measured do not pose any considerable health risk. However, further studies are necessary to evaluate potential health risks. Ventilation in winter is reduced as rooms and chambers are kept closed for longer periods, which may contribute to the higher concentration observed in winter.

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