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Estimation of Exhalation Rates of Radon and Thoron in the Soil Samples Collected from Gurugram, Haryana, India

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Natural radioactivity is the term used to describe radioactivity that persists in the soil, rocks, and water due to fundamental radionuclides such as uranium, thorium, potassium, etc. As a result, radiation affects everyone on the planet. Researchers worldwide find this topic particularly interesting due to the hazardous effects of radionuclides on human health. A systematic survey employing trustworthy methodological approaches is necessary to objectively assess these radionuclides in the environment. In the present paper, ZnS:Ag scintillator-based SMART RnDuo (AQTEK System, India) is used to measure exhalation rates of isotopes ^{222}Rn and ^{220}Rn (radon and thoron) of soil samples. Forty soil samples were studied. For the study of ^{222}Rn, monitoring of the mass exhalation (R_m) was conducted. In the case of ^{220}Rn, monitoring of surface exhalation (R_s) was studied. The radon mass exhalation rate is found in the range of 14±1 to 55±5 mBqkg^{-1}h^{-1} with an average of 34±10 mBqkg^{-1}h^{-1} and thoron surface exhalation rate in the range of 2200±215 to 7560±420 Bqm^{-2}h^{-1} with an average of 4280±960 Bqm^{-2}h^{-1}. Thus, elevated thoron level is observed in most of the samples. Results are compared with the world's average values.

Keywords: Alpha scintillometry; Exhalation rate; Soil samples; Radon; Thoron

1 Introduction

Due to the decay of ^{226}Ra/^{224}Ra, which is present in rocks and soil due to primordial radionuclides, radon, and thoron are continually created in soil grains and rocks[1]. By two primary mechanisms, emanation and exhalation, thoron and radonare released and reached the atmosphere. The process of releasing radon and thoron from dense mineral grains into the spaces between the soil and rock grains is known as emanation. Radon and thoron gas are moved from air-filled pores to the atmosphere during exhalation[2,3]. The radon emanation coefficient, also referred to as the emanation strength, is the proportion of radon atoms emitted to those produced. The movement of emitted radon toward the soil surface is caused by molecular diffusion and advection mechanisms. Through various pathways, radon/thoron enters the enclosed area and the air. The primary components of radon gas in the enclosed area are the soil underneath or close to dwellings and building materials. In contrast, the primary sources of thoron gas in the enclosed area are only construction materials. Radon and thoron are introduced into the enclosed area through pores in construction materials, and openings in surface soil. Water is another way that radon enters indoor spaces[4]. Showering, doing laundry, washing dishes, and other home chores are ways to introduce radon into an enclosed area. The higher levels of radon and thoron in an enclosed area can cause continuous inhalation for residents for an extended period of time. Diurnal and seasonal measurements of radon activities in groundwater and soil through online monitoring devices are essential in predicting earthquakes. Countries like China, India, Japan, Russia, Turkey, and the United States are located on the plate boundaries of the earth, and therefore, several projects are ongoing in these countries. The present study region and the region nearby it falls under seismic zone 4 in respect of earthquake possibilities in India. Also, data generated from this investigation can be useful for future possible studies associated with this field. The results of this investigation will help to choose the soil as raw material for construction purposes.

Various investigations were performed in different parts of India and abroad to measure the radionuclides level and determine their associated radiological

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hazards. Different research groups in India have worked for more than five decades in this field on measuring radionuclide concentration in air, water & soil, and also in different construction building materials, cereals, vegetation samples, *etc*. Both the techniques viz., active and passive were adopted by researchers for these experimental studies. Chauhan and Chakravarti[5], measured the radon level in stones and soil samples collected from Haryana and Nearby regions. LR-115 type II detectors were used for the investigation. Radon concentration in soil samples were found in the range of 246±29 to 453±35 Bqm^{-3} and 482±91 to 689±84 Bqm^{-3} collected from Haryana/Delhi area and nearby thermal power plant respectively whereas the radon level. Radon in stone samples was found in the range of 472±39 to 905±69 Bqm^{-3}. Kumari *et al*.[6], determined the radon exhalation rate in 25 building materials samples collected from the market of district Gurugram, Haryana, India. SSNTDs-based CAN method was adopted for radon study in various building materials. The range of measured mass exhalation was 0.9±0.1 to 8±0.5 $mBqkg^{-1}h^{-1}$and for surface exhalation was 77±15 to 794±46 $mBqm^{-2}h^{-1}$. Thus, after the literature review, it is concluded that there seems to be a research gap in this field in monitoring radionuclides in the study region's soil. The present work is part of a major research project of BARC, Mumbai, Government of India, in which radionuclides monitoring have been done in indoor regions, water, and soil samples. The present paper indicates the outcomes of soil samples of district Gurugram, Haryana, India. The results of this paper will help in radon mapping of nation.

2 Study Area

The present study region shares its boundaries withthe Alwar district of Rajasthan State onthe west side, the district Faridabad in the east direction, and Jhajjar and Rewari onthe northwest side. Total 286 villages are situated in Gurugram and it covers 1254 sq km of land within its boundaries. The northeastern and upper northwest portions of the study area have tropical and brown soil, whereas the southern portions have soggy and salty soils. The region appears to have a flat surface and also Aravalli hills cross through the study region. The major part of the Gurugram district is underlain by Quaternary alluvium consisting of sand, clay, and silt. The alluvium comprises thick beds of fine to coarse-grained sand with alternating layers of thin clay. The alluvial plain is formed by the Sahibi River which is a tributary of River Yamuna. The soil of this region is medium-textured loamy sand. In Pataudi and Sohna blocks the organic content of soils is lowest, just up to 0.20 % (very low category). In the rest of the district, organic content is 0.2 to 0.40 % and falls in the low category. The thickness of the sandy layer is very limited. Tube wells in the depth range of 45 to 90 m below ground level have been installed by different agencies in the block. The yield of these tube wells varies in different areas ranging from 129 to 606 liters per minute. The normal annual rainfall in the Gurugram district is about 596 mm spread over 28 days. Groundwater in the Gurugram block occurs in unconfined and semi confined conditions. The shallow groundwater of the district is alkaline in nature (pH 7.25 to 8.13) and is moderate to highly saline (EC 805 to 3410µS/cm). Among cations, sodium is the dominant cation in 63% of samples, and in the remaining mixed cationic character is observed whereas, among anions, mostly mixed anionic character dominates. However, bicarbonate is found to be the dominant anion in 25% of samples[7,8].

3 Materials and Methods

The study region is shown in Fig. 1. Forty soil samples were tested in the present paper and sampling villages are mentioned as shown in Fig. 2. Samples were collected in heavy polythene bags after 5 to 10 cm of surface soil was removed. To reduce the moisture content, soil samples were dried in an oven for 36 hours at 110 °C. To achieve uniformity and enable inter comparison, samples were sieved. Alpha scintillometry was utilized on the samples after that. For monitoring of mentioned radionuclides, a cylindrical accumulation container was filled with soil samples and attached to the apparatus, as shown in Fig. 3. A progeny filter allowed radon and thoron gases to the detector volume and blocks the solid decay products of these gases. Using an algorithm built into the monitor's microcontroller, the scintillation cell counts the scintillation photons produced by the alpha particles which are produced by radon and its decay products, and converts them to the concentration of radon and thoron. Radon concentration accumulation over time was tracked for up to 12 hours. The monitor's build-up data were recovered and utilized afterward to estimate fitting parameters and the sample's radon mass exhalation rate by the growth curve model.

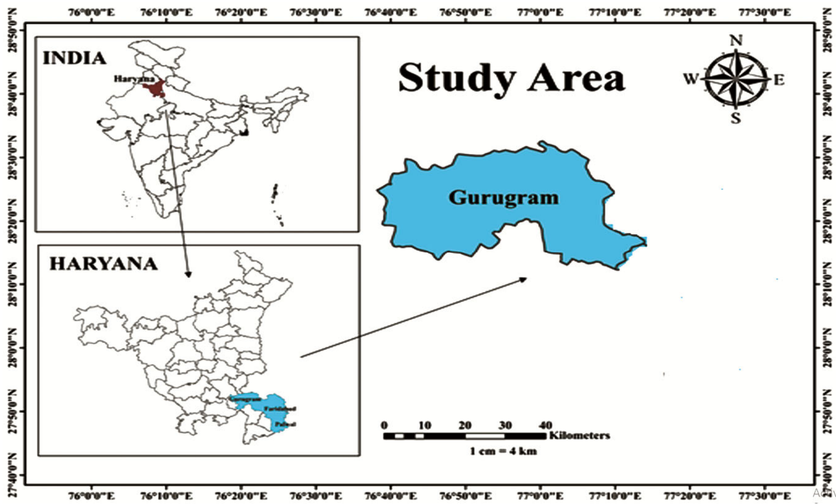

Fig. 1 — Geographical map of investigated area of Gurugram region of State Haryana, India. (*The map is only intended to be used as a visual aid and do not indicate any view on the legal positionof any country or territory or the delimitation frontiers or boundaries.)

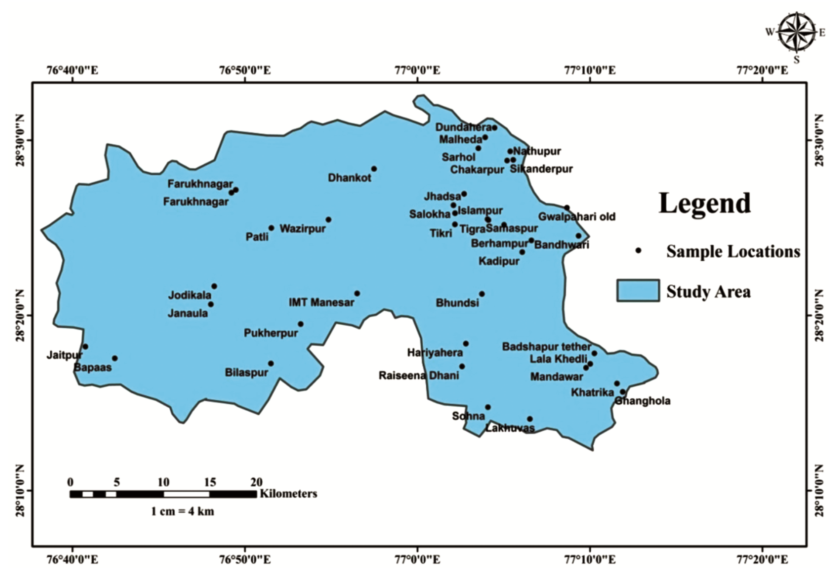

Fig. 2 — Representation of sampling locations in the district Gurugram of State Haryana, India. (*The map is only intended to be used as a visual aid and do not indicate any view on the legal positionof any country or territory or the delimitation frontiers or boundaries.)

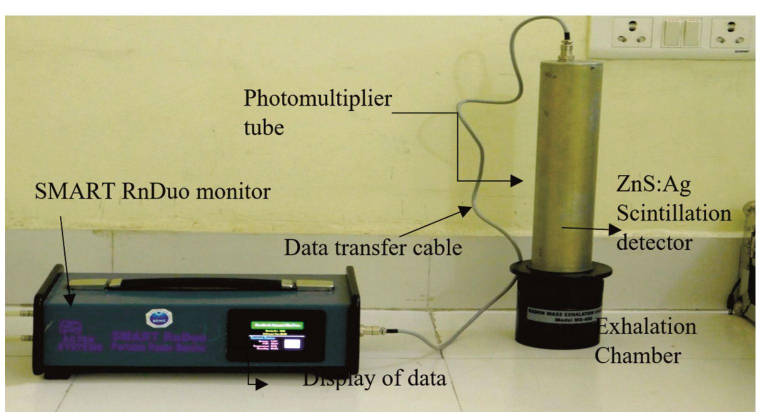

Fig. 3 — Experimental arrangement for radon measurements in diffusion mode sampling.

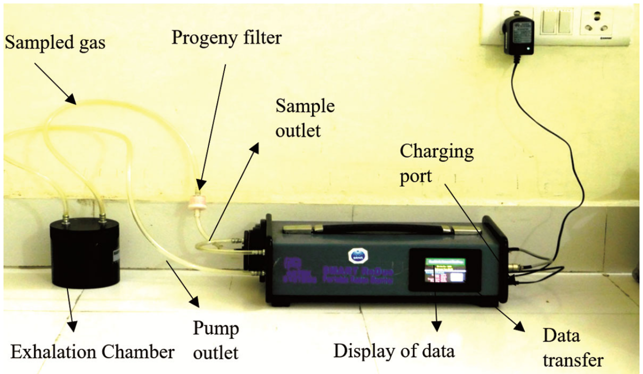

Fig. 4 — Experimental arrangement for thoron measurements in flow mode sampling.

Thoron measurements were taken in the flow mode as depicted in Fig. 4. The monitor's scintillation cell and the accumulation chamber's air were recirculated using the equipment's built-in micropump, which has a flow rate of 0.7 liters per minute. The monitor ran on a 15-minute cycle. The pump is turned on for the first five minutes of this 15-minute cycle by the monitor's microcontroller, and it is left off for the next ten. During the running of the pump, thoron as well as radon in the chamber pass through the progeny filter and into the scintillation cell. Thus, the counts within the first five minutes indicate the levels of radon and thoron as well as the persistent background. To ensure that the thoron decays almost entirely, a delay of five minutes is applied later (half-life 55.6 s). Results of radon monitoring are provided in the final five minutes. The microcontroller uses the proper calibration factor and the difference between counts obtained during the first five minutes and the last five minutes to estimate the thoron concentration. Measurements were made for one hour with a 15-minute duration monitoring to determine the equilibrium thoron concentration in the accumulation chamber[9].The methodology was different for both measurements. In the case of radon diffusion mode sampling was used and in the case of thoron flow mode sampling was used. For thoron measurement, the sample arrangement was the exactly same however we know that the top surface contributes in the case of thoron exhalation as it is a surface phenomenon instead of the bulk phenomenon.

The radon level (C_R) (Bqm^{-3}) is calculated using Eq. 1[10]

$$C_R(t) = \frac{R_m\, S}{V\lambda}\left(1 - e^{-\lambda t}\right) c_o e^{-\lambda t} \qquad \ldots(1)$$

where, R_m (mBqkg^{-1}h^{-1}) represents radon mass exhalation, V (m^3) is effective volume, S (kg) is sample weight, λ is radon decay constant, C_0 is initial radon concentration in the chamber.

Error with R_m that is E_m is calculated using Eq. 2.

$$E_R(t) = \frac{E_m\, S}{V\lambda}\left(1 - e^{-\lambda t}\right) + c_o e^{-\lambda t} \qquad \ldots(2)$$

Where, E_R is the measurement error associated with radon mass exhalation rate as given by SMART RnDuo.

The R_s (Bqm^{-2}h^{-1}) is calculated using Eq. 3[11]

$$R_s = \frac{C_{Ave} \times V \times \lambda}{A} \qquad \ldots(3)$$

Where, C_{Ave} (Bqm^{-3}) is the mean value of measured thoron level, V (m^3) is effective volume, A is the surface area of thoron exhalation, λ is thoron decay constant.

Error with R_s that is E_s is given by Eq. 4

$$E_s = \frac{E_{eq} \times V \times \lambda}{A} \qquad \ldots(4)$$

Where, E_{eq} is the average error valueof thoron as given by SMART RnDuo.

4 Results and Discussion

The present paper reported the results of radon and thoron exhalation from soil and the concentration values are used to calculate exhalation rates as mentioned in Table 1. The R_m (mBqkg^{-1}h^{-1}) is found as {variation (average)} {14±1–55±5 (34±10)} and R_s (Bqm^{-2}h^{-1}) as {2200±215–7560±420 (4280±960)}. The greater mass exhalation rate of radon may be caused by the region's soil's noticeably elevated radium concentration. The significantly increased thorium levels in these soil samples may cause a high thoron concentration and surface exhalation rate[12,13].

^{220}Rn has a short half-life of about 55 seconds therefore, its mobility in soil may not be as detrimental to people from outside exposure but may be problematic insided wellings because its short-lived progenies contribute approximately ninety-eight percent to the annual effective dose from inhaling thoron, and its progeny. The greater soil thoron level suggests that there may be a high indoor thoron concentration; thus, indoor investigation of the thoron and its progeny is required in the present study area. Outcomes of the study reveal that the tested samples have radon levels below the world average values of 57 mBqkg^{-1}h^{-1} and thoron levels in30% samples were

Table 1 — The measured R_m and R_s of soil samples of district Gurugram.

Sample Code	Village/ Town name	GPS coordinates Latitude N	Longitude E	R_m ($mBqkg^{-1}h^{-1}$)	R_s ($Bqm^{-2}h^{-1}$) × 10^3
GS01	Bandhwari	28º24'32.6"	77º09'20.2"	20 ± 3	2.6 ± 0.3
GS02	Gwalpahari old	28º26'08.9"	77º08'39.7"	22 ± 3	3.1 ± 0.3
GS03	Lakhuvas	28º14'05.3"	77º06'31.1"	14 ± 2	2.2 ± 0.3
GS04	Sohna	28º14'45.8"	77º04'04.9"	26 ± 3	3.8 ± 0.4
GS05	Jodikala	28º21'40.0"	76º48'13.1"	28 ± 3	3.2 ± 0.3
GS06	Janaula	28º20'38.0"	76º48'01.2"	23 ± 3	2.4 ± 0.3
GS07	Ghanghola	28º15'38.5"	77º11'53.6"	35 ± 4	4.6 ± 0.5
GS08	Khatrika	28º16'07.1"	77º11'33.9"	30 ± 4	4.2 ± 0.5
GS09	Mandawar	28º17'00.8"	77º09'46.1"	25 ± 3	3.6 ± 0.4
GS10	Badshapur tether	28º17'50.0"	77º10'15.3"	40 ± 4	4.8 ± 0.5
GS11	Lala Khedli	28º17'14.2"	77º10'01.0"	37 ± 3	5.8 ± 0.5
GS12	Raiseena Dhani	28º17'05.1"	77º02'34.9"	48 ± 5	5.4 ± 0.5
GS13	Hariyahera	28º18'23.5"	77º02'48.2"	35 ± 4	4.5 ± 0.5
GS14	Pukherpur	28º19'30.5"	76º53'13.9"	24 ± 3	3.5 ± 0.4
GS15	Bapaas	28º17'33.0"	76º42'27.2"	34 ± 4	4.6 ± 0.5
GS16	Jaitpur	28º18'13.0"	76º40'45.2"	26 ± 3	2.5 ± 0.3
GS17	Tikri	28º25'11.9"	77º02'10.3"	32 ± 4	4.2 ± 0.5
GS18	Farukhnagar	28º27'00.5"	76º49'12.8"	29 ± 3	3.4 ± 0.4
GS19	Farukhnagar	28º27'10.0"	76º49'28.2"	30 ± 4	4.2 ± 0.5
GS20	Patli	28º24'59.5"	76º51'31.8"	44 ± 5	6.6 ± 0.6
GS21	Bhundsi	28º21'13.6"	77º03'44.0"	35 ± 4	5.2 ± 0.5
GS22	Dhankot	28º28'22.0"	76º57'28.8"	41 ± 5	5.8 ± 0.5
GS23	Bilaspur	28º17'15.3"	76º51'30.2"	28 ± 3	3.3 ± 0.4
GS24	IMT Manesar	28º21'15.4"	76º56'30.1"	34 ± 4	4.4 ± 0.5
GS25	Wazirpur	28º25'28.2"	76º54'50.5"	55 ± 5	7.6 ± 0.6
GS26	Kadipur	28º23'36.8"	77º06'04.3"	35 ± 4	3.8 ± 0.4
GS27	Berhampur	28º24'17.0"	77º06'36.1"	38 ± 4	4.4 ± 0.5
GS28	Sushant Lok	28º25'10.4"	77º05'00.9"	44 ± 5	5.7 ± 0.5
GS29	Tigra	28º25'26.7"	77º04'06.7"	28 ± 3	3.2 ± 0.4
GS30	Samaspur	28º25'29.6"	77º04'03.6"	42 ± 5	5.2 ± 0.5
GS31	Islampur	28º25'50.2"	77º02'10.6"	50 ± 5	6.5 ± 0.6
GS32	Jhadsa	28º26'56.3"	77º02'42.0"	35 ± 4	3.5 ± 0.4
GS33	Katerpuri	28º30'10.0"	77º03'55.3"	36 ± 4	4.2 ± 0.5
GS34	Malheda	28º30'10.1"	77º03'55.4"	18 ± 3	2.4 ± 0.3
GS35	Dundahera	28º30'42.6"	77º04'28.2"	25 ± 3	3.8 ± 0.4
GS36	Sarhol	28º29'32.6"	77º03'31.6"	42 ± 5	3.2 ± 0.4
GS37	Chakarpur	28º28'50.3"	77º05'11.6"	52 ± 5	5.5 ± 0.5
GS38	Sikanderpur	28º28'52.8"	77º05'33.0"	24 ± 3	3.6 ± 0.4
GS39	Nathupur	28º29'21.9"	77º05'22.4"	36 ± 4	4.3 ± 0.5
GS40	Salokha	28º26'17.5"	77º02'05.1"	38 ± 5	5.0 ± 0.5

found higher than 3600 $Bqm^{-2}h^{-1}$ respectively[13,14]. Thus, sampling locations that have lower levels of radio nuclides can be used for the selection of soil to use for bricks and other building material construction.

Our previous finding of surrounding regions of State Haryana indicates that R_m varies from 12 to 62 $mBqkg^{-1}h^{-1}$ with a mean value of 31 $mBqkg^{-1}h^{-1}$ in district Faridabad of State Haryana and from 16 to 48 $mBqkg^{-1}h^{-1}$ with a mean value of 28 $mBqkg^{-1}h^{-1}$ in district Palwal of State Haryana as shown in Fig. 5 and R_s varies from 3319 to 10167 $Bqm^{-2}h^{-1}$ with a mean value of 5846 $Bqm^{-2}h^{-1}$ in the district Faridabad of State Haryana and from 1800 to 6331$Bqm^{-2}h^{-1}$ with a mean value of 3850 $Bqm^{-2}h^{-1}$ in the district Palwal of State Haryana[4,12] as shown in Fig. 6. Also, outcomes of measurements conducted in other nearby states in India are compared with present study as shown in Table 2. Thus, results of the present investigation are comparable to surrounding regions. Some locations from this study region can be select for online diurnal and seasonal monitoring of soil

Table 2 — The measured R_m and R_s of soil samples of district Gurugram.

Study Region	Radon mass exhalation rate (mBq kg^{-1} h^{-1}) {range (mean)}	Thoron surface exhalation rate (Bq m^{-2} h^{-1}) {range (mean)}	Reference
Jammu & Kashmir, India	15–38	90–4880	[16]
Bengaluru, India	–	4737–10886	[17]
Kalpakkam, India	–	942–7720	[18]
Shiwalik Himalayas, India	7–48	123–2606	[19]
Jammu & Kashmir, India	8–62	295–3628	[20]
Himachal Pradesh, India	10–54 (22)	–	[21]
Tan Taran, Punjab, India	(23)	(1531)	[22]
Amritsar, Punjab, India.	(20)	(664)	[22]
Hanumangarh district, Rajasthan, India	11–62 (35)	3090–9560 (6440)	[23]
Barnala&Moga, Punjab, India	5–41 (25)	1500–23770 (15620)	[13]
Faridabad, Haryana, India	12–62 (31)	3319–10167 (5846)	[4]
Palwal, Haryana, India	16–48 (28)	1800–6331 (3850)	[12]
Gurugram Haryana, India	14–55 (34)	2200– 7560 (4280)	Present Study

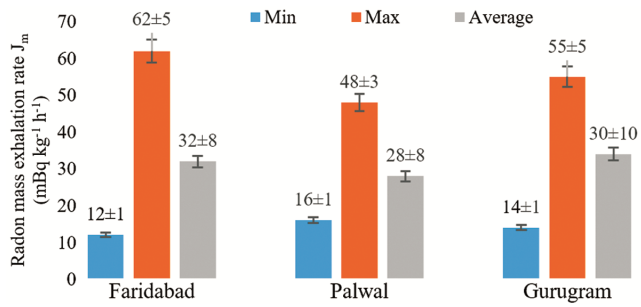

Fig. 5 — ofradon mass exhalation rate of soil samples of district Faridabad, Palwal and Gurugram of Southern Haryana, India.

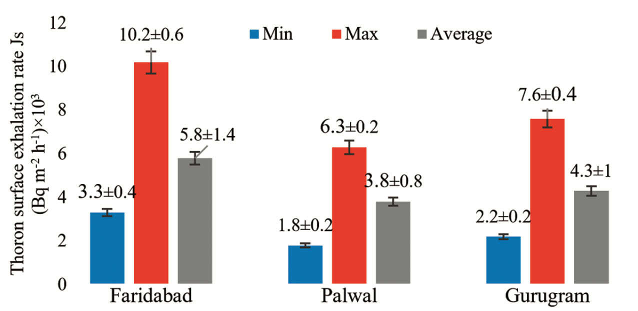

Fig. 6 — Comparison ofthoron surface exhalation rate of soil samples of district Faridabad, Palwal and Gurugram of Southern Haryana, India.

radon gas which can be useful for seismic and other related monitoring.

5 Conclusion

In soil samples taken from villages in the Gurugram district, there is a significant variance in the R_m and R_s levels. It could be ascribed to geography, different soil samples' geological locations, the makeup of the bedrock beneath, etc. High thoron surface exhalation results in high indoor thoron concentration, but thoron itself is not a severe concern for dwellings in the study region its progeny can be therefore, an indoor investigation of decay products levels is required.

Acknowledgment

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