

RADON CONCENTRATION IN GROUDWATER AND ASSOCIATED EFFECTIVE DOSE ASSESSMENT IN WESTERN HARYANA, INDIA

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ABSTRACT

Radon levels were measured in 45 groundwater samples collected from Sirsa district of Haryana state, India. The measurements were performed by RAD7 an electronic radon detector manufactured by DurrIDGE Company Inc. The concentrations of radon ranged from 0.60 to 7.81 Bq/l with an average value of 3.90 Bq/l. Radon concentrations from all the villages/towns were well below the reference level of 100 Bq/l prescribed by World Health Organization and European Commission. The total annual effective doses due to ingestion and inhalation of radon in drinking water ranged from 3.03 to 39.48 $\mu\text{Sv/y}$ for adults, 2.67 to 34.73 $\mu\text{Sv/y}$ for children and 4.67 to 60.84 $\mu\text{Sv/y}$ for infants and the average values were found to be 19.69, 17.32 and 30.35 $\mu\text{Sv/y}$ respectively.

Keywords: Annual effective dose; Drinking water; Ingestion; Inhalation; Radon

I. INTRODUCTION

Radon is a naturally occurring, radioactive, noble gas that is odorless, colorless, and tasteless. Radon is formed as part of three radioactive decay chains that begin with uranium or thorium. Uranium and thorium are found in small amounts in most rocks, soil, and water. Radon gas released from rocks and soil can move to air, groundwater and surface water. The International Agency for Research on Cancer [1], World Health Organization [2], Environmental Protection Agency [3], International Commission on Radiological Protection [4] and Agency for Toxic Substances and Disease Registry [5] consider radon to be a human carcinogen.

The occurrence of high levels of radon in drinking water represents a potential health risk due to human exposure through inhalation on account of exhalation of radon and its decay products from water into household air and through direct ingestion of radon in drinking water. The exposure of population to high concentrations of radon and its daughters for a long period lead to pathological effects such as the respiratory functional changes and the occurrence of lung cancer [6]. However, a very high level of radon in drinking water can lead to a significant risk of stomach and gastrointestinal cancer [7]. Based on the report of National Academy of Science, Environmental Protection Agency estimates that radon in drinking water causes about 168 cancer deaths per year, 89% from lung cancer caused by breathing radon released to the indoor air from water and 11% from

stomach cancer caused by consuming water containing radon [8]. High radon concentrations in drinking water around the world [9–13] have been reported but the variation in dose exposure rate among different life stages has been studied only in a few publications such as Yakut et al. [14], Muhammad et al. [15] and Ravikumar et al. [16].

The present investigation aims to study the distribution of radon in groundwater and to compute of annual effective doses for different age groups (infants, children and adults) due to ingestion and inhalation of radon in drinking water from Sirsa district, Haryana.

II. GEOLOGY OF THE STUDY AREA

The Haryana State is located between 27° 39' and 30° 35' North latitudes and 74° 28' and 77° 36' East longitudes in the North India. Fig. 1 shows the geographic location of Sirsa district on the map of Haryana, as well as the location of the sampling sites in Sirsa district. The total human population of the Sirsa district is 1300000 (2011 census), and geographical area of 4277 km².

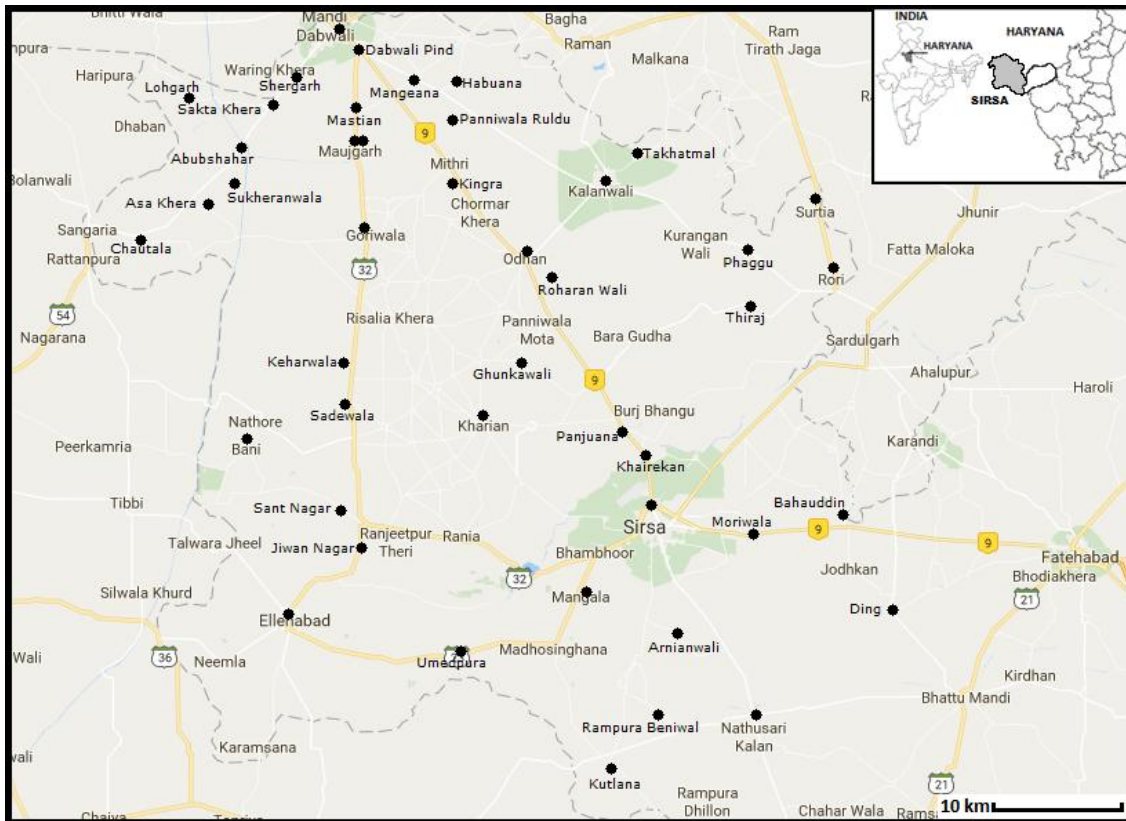


Fig. 1 The map showing the sample locations in Sirsa district, Haryana

The Sirsa district has two types of soils viz. sierozem and desert soils. The district has both confined and unconfined aquifers. The unconfined aquifers occur down to 60 m depth below groundwater in the district and principal aquifer material comprises fine to medium sand and sand mixed with kankar. Tubewells are constructed upto the depth of 40 to 100 m for drinking as well as for irrigation purpose. The major source of recharge to groundwater in the district is rainfall, seepage from canals, return seepage through irrigation and percolation from surface water bodies. The study region is bounded by Mansa, Bathinda and Muktsar districts of

Punjab in the north, Hanumangarh and Sri Ganganagar districts of Rajasthan in south and west, Hisar and Fatehabad districts of Haryana in southeast and northeast respectively [17].

III. MATERIALS AND METHODS

A total of 45 groundwater samples were collected from hand pumps, tube wells and electric motors and analyzed for radon concentration. We chose sampling sites whose waters are continuously used for human consumption as well as in animals and crop production. The RAD7 radon detector manufactured by DurrIDGE Company Inc. has been used for the measurement of radon concentration in the water samples. Fig. 2 is the schematic representations of the RAD7 with RAD H₂O accessory. The device is battery operated, portable and the detection is fast. The Wat 250 protocol and grab mode of the instrument were used for this measurement. The samples were analyzed immediately at the sampling site. Procedure recommended by the Environmental Protection Agency (EPA) was employed to collect water samples. The details of the sample collection and detection technique are given elsewhere [18-19].

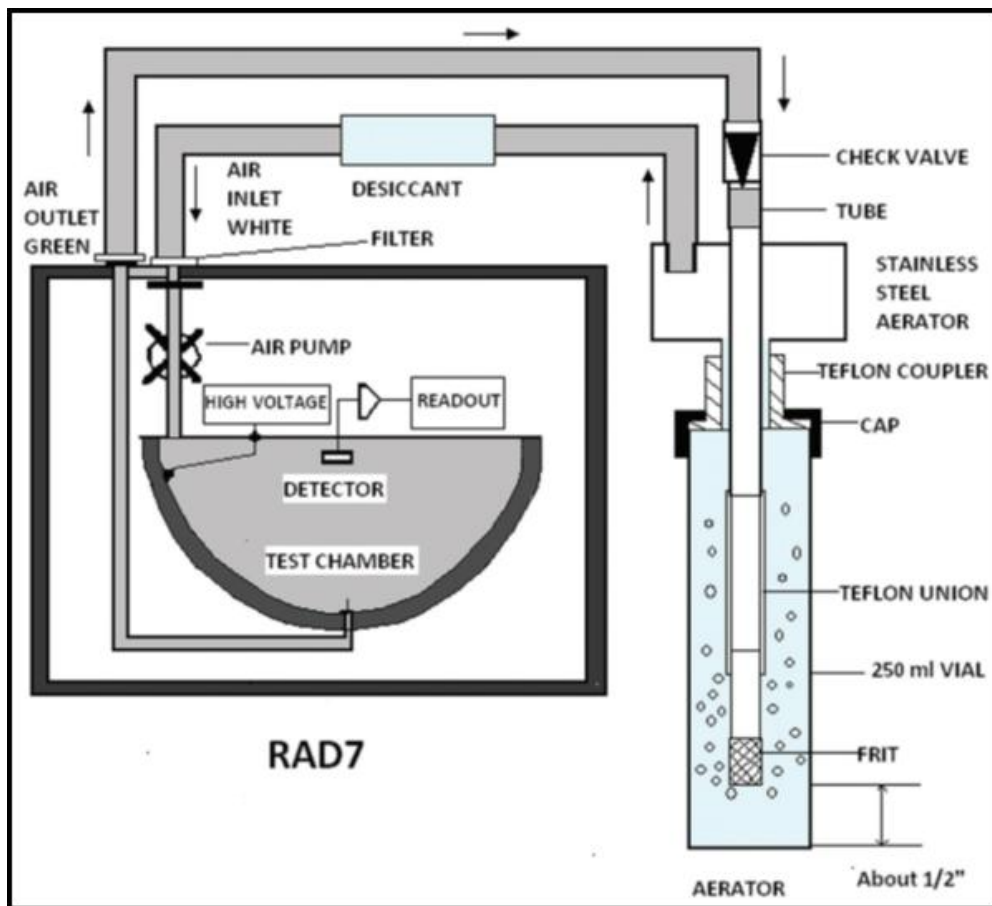


Fig. 2 Schematic diagram of RAD H₂O assembly

IV. RESULTS AND DISCUSSION

4.1 Radon concentration in groundwater

The results of radon measurements in groundwater and the associated radiation doses for infants, children and adults are summarized in Table 1. Table 2 presents the summary statistics. It can be observed from table 2 that the arithmetic mean and median are greater than the standard deviation. The negative value of kurtosis indicates

that the distribution has lighter tails and a flatter peak than the normal distribution. The skewness value is of positive type. The data is slightly skewed with a skewness of 0.10. Radon concentrations ranged from 0.60 Bq/l in village Jiwan Nagar to 7.81 Bq/l in village Abubshahar with an average value of 3.90 Bq/l. The various health and environmental protection agencies have prescribed reference levels of radon in drinking water for human beings. Results show that the radon concentrations from all sampling sites were below the maximum contamination level of 11 Bq/l recommended by United States Environmental Protection Agency [3]. The measured radon concentrations in water samples were well within the United Nations Scientific Committee on the Effects of Atomic Radiations [20] recommended limit (4–40 Bq/l). The radon concentrations in all the water samples were less than 100 Bq/l, which is accepted for drinking purposes as proposed by WHO [2] and European Commission [21].

Table 1 Radon concentration and the estimated total annual effective dose (ingestion and inhalation) for infants, children and adults from groundwater in the Sirsa district, Haryana

Sr. No	Sample Location	Latitude and Longitude	Source	Depth (feet)	²²² Rn Conc. (Bq/l)	pH	TDS (mg/l)	EC (µS/cm)	Total annual effective dose (µSv/y)		
									Infants	Children	Adults
1	Kutlana	29.32 N 75.00 E	TW	80	4.39	8.00	958	1900	34.20	19.52	22.19
2	Nathusari Kalan	29.35 N 75.12 E	HP	100	2.58	7.90	1120	2200	20.10	11.47	13.04
3	Rampura Beniwal	29.37 N 75.03 E	EM	75	2.50	8.10	950	1930	19.48	11.12	12.64
4	Umedpura	29.42 N 74.83 E	TW	250	3.33	7.89	1970	3800	25.94	14.81	16.83
5	Ellenabad	29.44 N 74.67 E	TW	200	4.92	8.38	1490	2930	38.33	21.88	24.87
6	Arnianwali	29.44 N 75.05 E	EM	150	5.36	7.97	915	1800	41.75	23.84	27.09
7	Ding	29.46 N 75.26 E	TW	200	4.13	8.41	370	760	32.17	18.37	20.88
8	Mangala	29.47 N 74.95 E	TW	375	4.28	8.45	950	2120	33.34	19.03	21.64
9	Jiwan Nagar	29.53 N 74.74 E	TW	200	0.60	7.82	940	1860	4.67	2.67	3.03
10	Sirsa City	29.53 N 75.02 E	TW	150	5.21	8.31	960	1920	40.59	23.17	26.34
11	Moriwala	29.53 N 75.15 E	TW	350	4.41	8.36	580	1180	34.35	19.61	22.29
12	Sant nagar	29.55 N 74.72 E	TW	350	3.05	8.62	1920	3810	23.76	13.56	15.42
13	Bahauddin	29.55 N 75.22 E	TW	400	4.80	8.00	970	1870	37.39	21.35	24.26
14	Bani	29.60 N 74.62 E	TW	200	4.49	8.16	520	900	34.98	19.97	22.70
15	Khairkan	29.60 N 75.01 E	TW	80	1.68	8.89	3600	7280	13.09	7.47	8.49
16	Kharian	29.62 N 74.85 E	EM	100	6.25	8.01	1110	2340	48.69	27.79	31.59
17	Panjuana	29.63 N 74.98 E	HP	125	3.65	8.38	226	452	28.43	16.23	18.45
18	Sadewala	29.64 N 74.72 E	TW	100	3.82	8.15	3340	6700	29.76	16.99	19.31
19	Keharwala	29.66 N 74.71 E	TW	75	6.20	7.81	6870	13860	48.30	27.57	31.34
20	Ghunkawali	29.68 N 74.89 E	TW	110	5.66	7.95	5240	10300	44.09	25.17	28.61
21	Thiraj	29.73 N 75.12 E	EM	70	1.52	7.95	1220	2450	11.84	6.76	7.68
22	Roharan Wali	29.74 N 74.93 E	HP	80	3.30	8.06	350	600	25.71	14.68	16.68
23	Rori	29.74 N 75.21 E	HP	45	2.07	8.26	430	840	16.13	9.21	10.46
24	Odhan	29.76 N 74.90 E	TW	65	4.13	7.96	3210	6320	32.17	18.37	20.88
25	Phaggu	29.77 N 75.12 E	HP	50	3.90	7.81	620	999	30.38	17.34	19.71
26	Chautala	29.78 N 74.52 E	EM	80	4.43	7.98	3490	7010	34.51	19.70	22.39

27	Goriwala	29.79 N 74.75 E	TW	50	1.74	8.09	2430	4810	13.55	7.74	8.80
28	Surtia	29.80 N 75.19 E	HP	50	1.93	8.70	2130	4100	15.03	8.58	9.76
29	Asa Khera	29.81 N 74.58 E	EM	60	3.00	7.74	3290	6500	23.37	13.34	15.17
30	Kingra	29.82 N 74.82 E	TW	65	5.51	7.85	1590	3220	42.92	24.50	27.85
31	Sukheranwala	29.83 N 74.62 E	HP	85	2.52	7.98	1250	2480	19.63	11.21	12.74
32	Kalanwali	29.83 N 74.97 E	EM	70	2.25	7.90	7130	14210	17.53	10.01	11.37
33	Takhatmal	29.85 N 75.01 E	HP	100	2.72	8.32	248	490	21.19	12.10	13.75
34	Maujgarh S-1	29.86 N 74.12 E	TW	50	6.46	7.75	760	1540	50.32	28.73	32.66
35	Maujgarh S-2	29.86 N 74.12 E	TW	60	4.76	7.60	870	1700	37.08	21.17	24.06
36	Abubshahar	29.86 N 74.62 E	HP	45	7.81	8.01	3130	6250	60.84	34.73	39.48
37	Panniwala Ruldu	29.88 N 74.83 E	EM	90	4.60	8.18	560	1140	35.83	20.46	23.25
38	Mastian	29.89 N 74.72 E	TW	45	1.57	8.16	910	1830	12.23	6.98	7.94
39	Lohgarh	29.90 N 74.56 E	TW	60	6.15	8.10	4250	8540	47.91	27.35	31.09
40	Sakta Khera	29.90 N 74.64 E	HP	40	5.90	8.29	2510	4960	45.96	26.24	29.82
41	Mangeana	29.92 N 74.79 E	TW	65	1.67	7.67	2520	5070	13.01	7.43	8.44
42	Habuana	29.92 N 74.83 E	EM	60	4.21	7.79	1000	1960	32.80	18.72	21.28
43	Shergarh	29.93 N 74.67 E	HP	70	4.43	7.99	5815	11630	34.51	19.70	22.39
44	Dabwali Pind	29.95 N 74.74 E	EM	80	4.30	7.95	707	1260	33.50	19.12	21.74
45	Mandi Dabwali	29.96 N 74.70 E	EM	70	3.11	8.40	1380	2760	24.23	13.83	15.72

Table 2: Summary statistics of radon in groundwater

Statistics	N	AM	SE	Median	Mode	SD	SV	GM	GSD	SKEW	KURT	Min	Max
Radon	45	3.90	0.24	4.13	4.13	1.60	2.56	3.51	4.95	0.10	-0.42	0.60	7.81

N=number of samples; AM=Arithmetic mean; SE=Standard error; SD=Standard deviation; SV=Sample variance; GM=Geometric mean; GSD=Geometric standard deviation; SKEW=Skewness; KURT=Kurtosis; Min=Minimum; Max=Maximum

4.2 Comparison of radon concentration with world values

Table 3 gives the range of radon concentrations from other parts of the world for comparison. Radon concentrations obtained in the water samples in the present investigation are comparatively lower than those reported for Beijing City, China by Wu et al. [22], Kedah, Malaysia by Ahmad et al. [23], Sakarya, Turkey by Yakut et al. [14], Khyber Pakhtunkhwa, Pakistan by Khattak et al. [24], Hassan district, Karnataka, India by Srinivasa et al. [25], Ramanagara and Tumkur districts, Karnataka, India by Srilatha et al. [26], Balakot and Mansehra cities, Pakistan by Khan et al. [27], Southeastern Brazil by Salim et al. [28], Northern Rajasthan, India by Rani et al. [10] and Fatehabad district, Haryana by Duggal et al. [19] but higher than those reported for Bathinda district of Punjab, India by Duggal et al. [29].

Table 3: Comparison of radon concentration in groundwater with those reported by other investigators

Region	Radon concentration (Bq/l)			References
	Min	Max	Mean	
Beijing City, China	1.45	49.00	11.41	Wu et al. [22]
Kedah, Malaysia	12.4	17.0	14.7	Ahmad et al. [23]
Sakarya, Turkey	1.98	20.80	9.05	Yakut et al. [14]

Khyber Pakhtunkhwa, Pakistan	1.60	18.20	8.80	Khattak et al. [24]
Hassan district, Karnataka, India	0.85	60.74	26.5	Srinivasa et al. [25]
Ramanagara and Tumkur districts, Karnataka, India	2.96	299.06	54.53	Srilatha et al. [26]
Balakot and Mansehra Cities, Pakistan	4.99	24.52	15.52	Khan et al. [27]
Southeastern Brazil	0.06	104	—	Salim et al. [28]
Northern Rajasthan	0.5	85.7	9.03	Rani et al. [10]
Fatehabad, Haryana, India	1.4	22.6	—	Duggal et al. [19]
Bathinda, Punjab, India	0.9	5.1	2.63	Duggal et al. [29]
Sirsa district, Haryana	0.60	7.81	3.90	Present Investigation

4.3 Depth profile of radon in groundwater

In the present investigation, water samples were collected from different depths to study the vertical distribution of radon concentration and to find the possible correlation with radon concentration. It is observed that the maximum mean radon concentration was observed at the depth range of 101-200 ft as presented in Fig. 3. No significant correlation was observed between radon concentration and depth of groundwater.

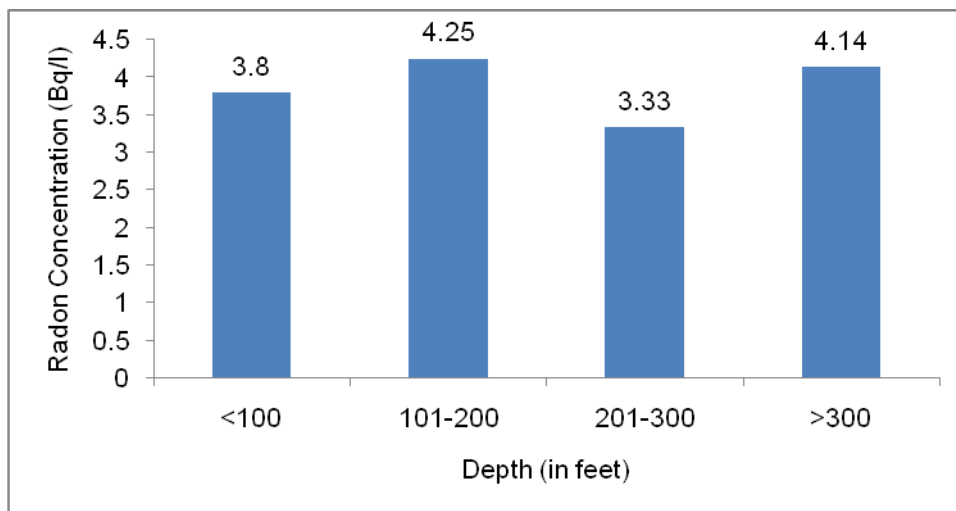


Fig. 3 Variation of radon concentration with depth in groundwater of Sirsa district, Haryana

4.4 Physicochemical analysis

All the water samples had pH values within the permissible limits recommended by USEPA [30], WHO [31], and the Bureau of Indian Standards [32]. EC and TDS ranged from 452 to 14210 $\mu\text{S}/\text{cm}$ and 226 to 7130 mg/l with mean values of 3835 $\mu\text{S}/\text{cm}$ and 1929 mg/l , respectively. For TDS and EC, only 44% and 22% of the groundwater samples had values within the permissible limits of 1000 mg/l [31] and 1500 $\mu\text{S}/\text{cm}$ [33] respectively. Radon concentration was not found to be correlated with pH, TDS and EC (Fig. 4).

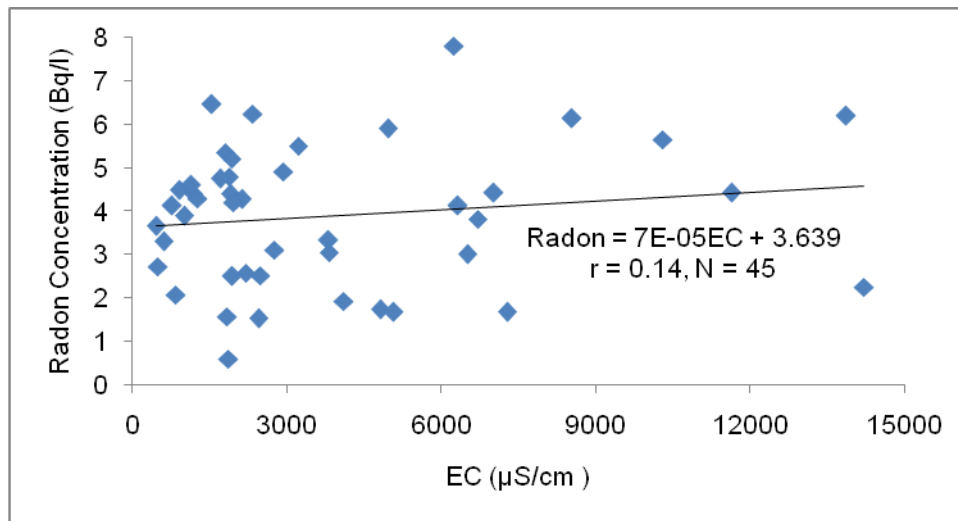


Fig. 4 Dependencies between radon and EC, N denotes the number of correlated pairs and r the correlation coefficient.

4.5 Evaluation of mean annual effective dose

Radon gas enters into human body through ingestion and inhalation as it is released from water into indoor air. The total annual effective doses for adults, children and infants from ingestion and inhalation of radon in water are determined using the documentation of United Nations Scientific Committee on the Effects of Atomic Radiations [34].

Annual effective dose for ingestion was accounted by Eq.1:

$$AED_{Ing} = C_{Rn} \times A_i \times D_f \tag{1}$$

where D_f is the ingesting dose conversion factor for radon (Sv/Bq), A_i is the annual water intake (L/y), and C_{Rn} is the radon activity concentration (Bq/l). For radon, D_f of 23, 5.9 and 3.5 nSv/Bq for infants (≤ 1 y), children (2-17 y) and adults (≥ 17 y), respectively were used [34]. The A_i values of 230, 330 and 730 L/y for infants, children and adults, respectively were used [35].

Annual effective dose for inhalation was calculated by Eq.2:

$$AED_{Inh} = C_{Rn} \times R \times T \times F \times D_f \tag{2}$$

where D_f refers to inhalation dose conversion factor for radon (9 nSv/(Bq h m⁻³)) [34], T is the average indoor occupancy time per individual (7000 h/y), F is the equilibrium factor between radon and its daughters (0.4) and R is the ratio of radon in air to radon in water (10⁻⁴) [36].

The EU Council [37] recommends the determination of the reference level of an effective dose received from drinking water consumption at 0.1 mSv/y. This value excludes the doses received from ³H, ⁴⁰K and ²²²Rn. The data showed significant variations in the dose rate for different age groups. This is due to different dose coefficient and water consumption rate for different age groups (Table 1). Results presented in Table 1 show that the total annual effective doses due to ingestion and inhalation of radon in drinking water ranged from 3.03 to 39.48 µSv/y for adults, 2.67 to 34.73 µSv/y for children and 4.67 to 60.84 µSv/y for infants and the average values were found to be 19.69, 17.32 and 30.35 µSv/y, respectively. Even through infants drinking less water than adults, the total annual effective doses to infants are significantly higher than that to adults, because of the difference in infants' metabolism and smaller organ weights resulting in higher doses for many radionuclides.

The total annual effective dose from all the locations of the studied area is found to be less than 0.1 mSv/y recommended by the EU Council.

V. CONCLUSION

Results of present investigation indicated that the radon concentrations in all water samples were well below the action levels recommended by USEPA, UNSCEAR, EU Council and WHO, so all samples are safe for drinking and other domestic purposes. Radon concentrations obtained in the water samples in the present investigation generally lie below the range reported by all other investigators. The estimated age-dependent annual effective doses were lower than 100 μ Sv/y for all the sampling sites. The total annual effective dose received by infants (≤ 1 y) > adults (≥ 17 y) > children (2-17 y). No correlation was observed between radon concentration and physico-chemical parameters.

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