Indian Journal of Pure & Applied Physics
Vol. 61, June 2023, pp. 423-428
DOI: 10.56042/ijpap.v61i6.2412

Estimation of Annual Effective Dose due to Radon Concentration in Water Samples of Moga District of Northern Punjab, India

Supriya Rani[a], Sandeep Kansal[a*], Amit Kumar Singla[a], Salik Nazir[b] & Rohit Mehra[c]

[a]Department of Physics, Maharaja Ranjit Singh Punjab Technical University, Bathinda, Punjab 151 001, India
[b]Department of Physics, Kashmir University, Jammu & Kashmir 190 006, India
[c]Department of Physics, Dr. B.R. Ambedkar National Institute of Technology, Jalandhar, Punjab 144 001, India

Received 20 February 2023; accepted 23 May 2023

The current study evaluated the radon content in drinking water from several sources in the Moga district of Punjab, India, using a scintillation-based detector (groundwater and surface water). The average radon content in water was 3.48 Bq L^{-1}, with a standard deviation of 2 Bq L^{-1}, and a range from 0.88 Bq L^{-1} to 8.82 Bq L^{-1}. The health risk for newborn (1-2 years), children (8-12 years), and adults have also been calculated using the ingestion and inhalation doses (above 17 years). The average annual effective dose that resulted was found to be much lower than the WHO-recommended safe level of 0.1 mSvy-1[1]. Therefore, it can be stated that the population of the examined area is not significantly at danger for radiological health due to radon in water.

Keywords: Radon; Groundwater; Smart RnDuo; Inhalation; Ingestion dose

1 Introduction

Water is a necessity for all living things to survive. In nature, radon is found in all water sources, including lakes, rivers, groundwater, springs, and even rainfall, in addition to the air, soil, and rock[2]. The study region's uranium level and the kind of soil affect how much radon is released from the soil, therefore, outdoor radon quantification can help atmospheric scientists to track air masses. Being a gas, radon quickly escapes to the atmosphere. In hydrologic research that examines the interplay between groundwater and streams, this property of radon gas is employed. A rivulet's high radon content is a reliable indicator of the area's groundwater supplies. Because concentrations are typically higher above the geological faults, Richon has proposed an experimental method to map these faults that are buried near to the surface.[3]Same way, Semprini and Kruger has discovered some limited application in geothermal gradient mining[4]. For the purpose of predicting earthquakes, several researchers have looked into variations in groundwater radon concentrations but any scientific conclusion that suggests a strong relation between radon emanation and earthquakes is yet to be found. The kind of soil, bedrock, faults present, porosity/permeability, physiochemical composition, and geological aquifer characteristics are all connected to the level of radon in the water[5-6].

Temperature changes in the atmosphere cause radon to quickly escape from them into the air because they are exposed and dissolved, Radon is often not present in great amounts in surface water. Despite the fact that groundwater contains substantial amounts, especially when it passes through granite rocks[7]. However, radon serves a dual purpose, benefiting humans while also posing certain risks to their health and the environment[8-10]. According to Fakhri, radon's alpha-particle and its progenies are radioactive and could harm DNA and cause cell concertation in human tissues and organs[11-12]. Even though the amount of radon in drinking water is less than what may be inhaled directly, excessive radon consumption through drinking water can raise certain people's chance of developing stomach cancer and gastric cancer-colon cancer in addition to lung cancer[13-16]. With 168 deaths annually from cancer brought on by radon in drinking water after smoking, it is the second most frequent cancer-causing factor in the United States[8,17-18]. Water is essential for living and is also crucial for maintaining public health. Fresh water resources are becoming increasingly precious due to the rapid rise in world population[19]. According to the National Academy of Science, radon that has

*Corresponding author: (E-mail: skansal2k1@gmail.com)

leaked from contaminated water is responsible for 89% of lung cancer cases and 11% of stomach cancer cases[20-22]. In people who have never smoked, lung cancer is currently the seventh most prevalent cause of cancer-related mortality, and the incidence is increasing.

India has lately published a number of studies evaluating the quantity of radon in drinking water[23-27]. The statistics are still rare, though, given the breadth of the nation and the wide variety of topographical, geological, atmospheric, anthropogenic, and other physical factors. For the district of Moga in the Indian state of Punjab, several groundwater and surface water sources were used to calculate the radon concentrations in the water used for drinking. By using a greater number of places for sample that are dispersed around the district, the current study aims to cover the area thoroughly. This study's approach of measuring radon levels in drinking water is more accurate. Additionally, practically all recent research on radon in water conducted in India strictly followed the guidelines suggested by the Bhabha Atomic Research Centre (BARC), Mumbai[28], enabling precise direct comparisons.

2 Study Area

The research area is the Moga district in the Malwa area of Punjab, India, with latitudes from 75º32’55” E to 75º10’15.71” E and longitudes from 30º22’24” N to 30º48’44.19” N, respectively Fig. 1. It is primarily an alluvial plain, according to Central Government Water Board[29]. In some areas of the district, the soils vary in texture from sand to sandy loam and from loam to heavy loam. For crops like wheat, grains, vegetables, *etc.*, soil is suitable since it is nutrient-rich. The majority of the district's land is sustained in a few isolated areas by loamy sand and sandy loam kaller sand. The Indus basin's Sutlej sub-basin and the Indo-Gangetic plain both include the district area. The two main types of soil discovered are siozerem soil and desert soil. In comparison, desert soils are only present in a small area close to the district's western border, while siozorem soils are present in the majority of the district. Except for the region along the Satluj River, the alluvial deposits are covered in aeolian sands. Aside from being utilised for building construction, soil is also used in agriculture to raise crops.

3 Methodology

3.1 Sample collection

For the current investigation, 50 water samples from diverse locations in the Moga district were gathered. The water was sampled from a variety of drinking water sources, comprising faucets, hand pumps, tube wells, and other devices that were utilised to draw water from the surface or the ground. Each sampling location's GPS coordinates were found using a GPS device (GPSMAP 78S, Garmin Inc.). Additionally, the intensity of the surface contamination caused by the gamma radiation field was determined by (PM1405 Survey Meter, Polimaster Inc.). The depth of underground sources was recorded in the case of groundwater samples.

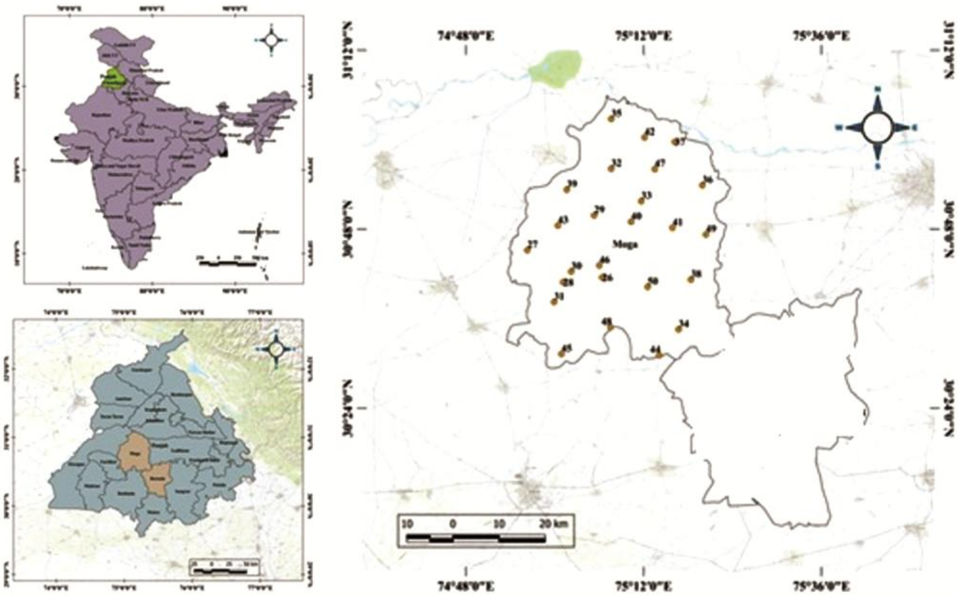

Fig. 1 — Map of study area.

Bhaba Atomic Research Centre's (BARC)"Radon Handbook" recommended the sample collection technique[28]. During sampling and storage, every precaution was taken to prevent the tested water from coming into contact with the atmosphere. The 60 ml glass sampling bottle was held submerged in a container while samples were delicately transferred by inserting the sample tube's open end into the tap's (or other source's) opening and its closed end into the sampling bottle held as indicated in Fig. 2(a). The liquid sample was added to the bottle's capacity roughly 5–7 times before being completely filled, leaving no room for air, and being tightly sealed while submerged in water to prevent leaks.

Radon levels in water samples were measured in-situ to reduce the amount of radon lost due to radioactive decay. Using the SMART RnDuo a scintillation-based radon monitors from (AQTEK Systems, India) and adhering to the measurement technique outlined in the BARC Radon Handbook, radon levels in a water sample were measured. The SMART RnDuo is an autonomous continuous radon metre based on ZnS:Ag scintillation cells. The detector has a better sensitivity compared to other commercial radon monitors thanks to the scintillation cell-based technology, which also renders it immune to the effect of humidity on measurement, a crucial factor in monitoring radon in water.

The measuring setup included a sealed closed loop connection between a SMART RnDuo monitor and a water bubbler affixed to a sample bottle. A diffusion method was used to extract the gas from the water sample into a scintillation cell (150 cc) for radon measurement. During diffusive sampling, the gas is passed through a "progeny filter" and a "thoron discriminator," which eliminate radon/thoron progenies and thoron. based on the continuous PMT counting of the alpha particles generated inside a cell volume by radon and its decay products and accompanying counting electronics, RnDuo's radon measurements. An algorithm was developed to analyse the acquired alpha counts and display the

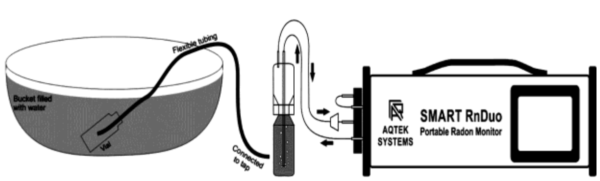

Fig. 2 — (a) Setup diagram for obtaining water samples from several sources, (b) Installation for radon measurement in liquid samples.

radon concentration on a microprocessor device. Fig. 2(b) displays the schematic representation for the same system.

Following setup, the monitor's internal pump, activated for five minutes so that bubbling air through the water sample would remove any dissolved radon and transfer it to the detecting volume. After stopping the pump, a further delay of 5 minutes was added to ensure that any remaining thoron gas ($t_{1/2}$ = 55.6s) totally decayed. Then, radon levels in the air were continually counted over a 15-minute measurement cycle. C_{air} (Bq^{-3}) is the average of three subsequent measurements.

The radon concentration in water (C_{wat}) (Bq/m^3) was then calculated from the value of C_{air} using equation 1 (BARC Radon Handbook).

$$C_{wat} = C_{air}\left(K + \frac{V_{air}}{V_{wat}}\right) \quad \dots (1)$$

where K represents the radon's partition coefficient in water with respect to air (= 0.25),

V_{air} (m^3) is (Bubbler + tubings + detector) volume of air enclosed in the closed loop and V_{wat} is liquid in sampling bottle (m^3) volume.

The radon monitor was routinely calibrated at BARC, Mumbai, using a standard radon source to assure quality assurance in functioning. Using standard radon-thoron sources (Model RN-1025 & TH-1025) purchased from Pylon Electronics Inc., Ottawa, Canada, the device was calibrated in a 0.5 m^3 calibration chamber at the Bhabha Atomic Research Centre (BARC) in Mumbai, India[30]. According to the BARC's handbook, the equipment has a radon effectiveness of 95% after 15 minutes of operation.

Radon levels in water will expose people to radiation doses through ingestion after drinking the water, as well as through inhaling the radon that is released from the water into the interior environment. For newborns, kids, and adults, the radon in water's annual effective dose was calculated to examine how dose differs among them. This was done taking into account the various ages of the population members.

Equation 2 (UNSCEAR), used to get the yearly effective dose, D_{ing} (μSv/y) from ingestion of radon contaminated water is given below:

$$D_{ing} = C_{wat} \times I \times F_{ing} \quad \dots (2)$$

where I (m^3/y) is the subject's annual water intake and C_{wat} (Bq/m^3) is the amount of radon in the water. The dosage conversion factor for radon exposure is F_{ing} (μSv/Bq). The 150 l, 350 l, and 500 l are yearly water intake values. Consequently, with the necessary unit conversions, the ingestion dosage parameter estimates of 23 nSv/Bq, 5.9 nSv/Bq, and 3.5 nSv/Bq were utilised for newborns, children, and adults, respectively[8,31]. The water intake levels utilised are just those that are advised for water consumption by drinking, not through other food sources.

The yearly effective dose due to inhalation of radon, D_{inh} (μSv/y) was evaluated by using equation 3 (UNSCEAR) as:

$$D_{inh} = C_{wat} \times R_{a/w} \times EF \times T \times F_{inh} \qquad \ldots (3)$$

where Rn-222 level in water samples is C_{wat} (Bq/m^3),The ratio of radon in water to radon in the air is $R_{a/w}$ ($=10^{-4}$)[32], Equation of equilibrium between radon and its progeny is EF (= 0.4), T is the typical yearly exposure period for radon produced from water into the atmosphere(350 h), For the individual to breathe in radon (a decay product), F_{inh} (nSv/(Bq/m^3.h)) is the dose conversion factor. Inhaling radon at doses of 33.0 nSv/(Bq/m^3.h) for newborns, 31.4 nSv/(Bq/m^3.h) for children, and 28.3 nSv/(Bq/m^3.h) Brudecki[33] used the phrase for adults with the necessary unit conversions. The ICRP bio-kinetic models and suggested parameters for patients of concern were used to generate these dose conversion factors using the dosimetric method recommended by the ICRP, 137. (ICRP, 66)[34-35].

4 Results and discussion

All 50 water samples from the Moga district are shown in Table 1 with their measured radon concentrations. The concentration ranges from a low of 0.88± 0.09 BqL^{-1} (Moga, surface water) to max value of 8.82 ± 0.51 BqL^{-1} (Gill, underground water) with a mean value of 3.48 ± 0.23 BqL^{-1}. These numbers fall below the 11BqL^{-1}safe limitas suggested by USEPA[36], 100 BqL^{-1} by WHO[37] and 4-40 BqL^{-1} by UNSCEAR[8].

The annual effective dosage of radon from drinking water owing to eating and inhalation for different age groups is also shown in Table 1. The yearly effective dose due to ingestion for newborns (0-2 year) lies in the range of 5.91 ± 0.63 to 59.34 ± 3.41 μSvy^{-1} with average value of 23.43 ± 1.54 μSvy^{-1}, for kids (8-12 year) it lies in the range of 4.73 ± 0.50 to 47.48 ± 2.74 μSvy^{-1} with an average value of 18.75 ± 1.23 μSvy^{-1} and for grownups (above 17 years) it lies in the range of 3.36 ± 0.36 to 33.80 ± 1.95 μSvy^{-1} with an average value of 13.35 ± 0.88 μSvy^{-1}. The yearly inhalation dose varies from 8.11 ± 0.86 to 81.50 ± 4.70 μSvy^{-1} with an average value of 32.19 ± 2.12 μSvy^{-1} for newborns, 7.72 ± 0.82 to 77.55 ± 4.47 μSvy^{-1} with average value of 30.63 ± 2.01 μSvy^{-1} for kids and 6.96 ± 0.74 to 69.89 ± 4.03 μSvy^{-1} with average of 27.60 ± 1.82 μSvy^{-1} for grownups. The computed dosage values are well below the recommended yearly effective dose of 100 μSvy^{-1} by the WHO (2004, 2008)[1,36].

A frequency distribution graph for radon concentrations is shown in Fig. 3. It has been noted that 30% of the specimens have concentrations between 0-2 BqL^{-1}, 34% have concentrations between 2-4 BqL^{-1}, and 36% have concentrations between 4-10 BqL^{-1}. From the calculated values, As demonstrated in Fig. 4, there is only a weak connection (R^2 = 0.002) between the radon concentration in groundwater samples and the depth of the well (24–183 metres). Since the unconfined aquifer is the primary source of the studied underground water, the increase in dissolved radon concentration with complexity can be attributed to the water's higher solubility at higher hydrostatic pressure and the longer contact time it has with the earth as it seeps to greater depths. The greater

Table 1 — Radon concentration, doses due to inhalation and ingestion in the studied area.

Statistics	C_{wat} (BqL^{-1})	S_{wat}	Yearly Effective Dose due to Inhalation (μSvy^{-1}) Newborns		Children/Kids		Grownups		Yearly effective dose due to ingestion (μSvy^{-1}) Newborns		Children/Kids		Grownups	
Minimum	0.88	0.09	8.11	0.86	7.72	0.82	6.96	0.74	5.91	0.63	4.73	0.50	3.36	0.36
Maximum	8.82	0.51	81.50	4.70	77.55	4.47	69.89	4.03	59.34	3.41	47.48	2.74	33.80	1.95
Average	3.48	0.23	32.19	2.12	30.63	2.01	27.60	1.82	23.43	1.54	18.75	1.23	13.35	0.88
Kurtosis	0.21	0.32	0.21	0.32	0.21	0.42	0.21	0.32	0.21	0.32	0.21	0.32	0.21	0.32
Skewness	0.85	0.99	0.85	0.99	0.85	1.03	0.85	0.99	0.85	0.99	0.85	0.99	0.85	0.99
Mode	2.35	0.15	21.71	1.35	20.66	2.00	18.62	1.15	15.81	0.98	12.65	0.78	9.01	0.56
Quartile 1st	1.69	0.14	15.62	1.33	14.86	1.27	13.39	1.14	11.37	0.97	9.10	0.78	6.48	0.55
Quartile 2nd	3.21	0.20	29.66	1.85	28.22	1.76	25.44	1.59	21.60	1.34	17.28	1.08	12.30	0.77
Quartile 3rd	4.77	0.29	44.07	2.68	41.94	2.54	37.80	2.30	32.09	1.95	25.68	1.56	18.28	1.11
Standard deviation	2.00	0.11	18.52	1.02	17.62	0.97	15.88	0.88	13.48	0.74	10.79	0.60	7.68	0.42

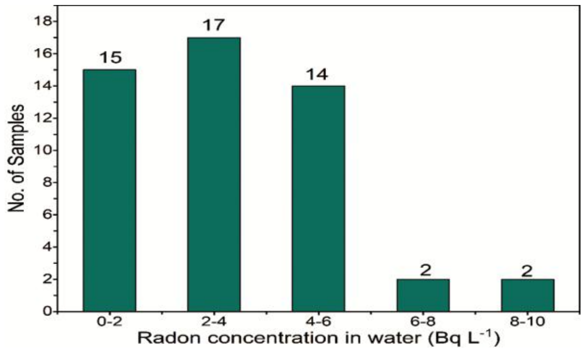

Fig. 3 — Frequency distribution.

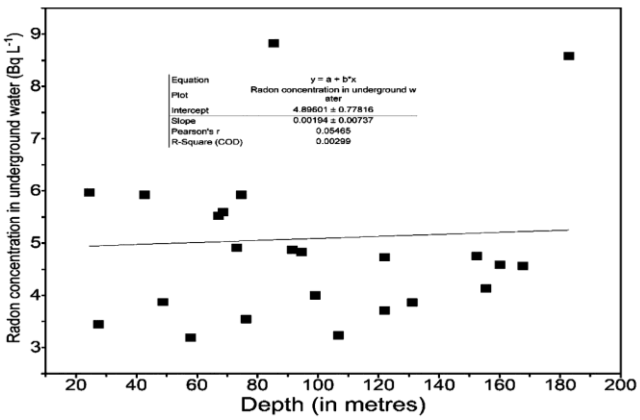

Fig. 4 — Correlation between radon concentration in underground water with depth.

radioactivity in rocks of limited aquifers in the examined area may also be the cause of the higher radon content in specimens of groundwater from depth below 60 m.

The lowest and highest levels of radon in surface water and groundwater ranged from 0.88 – 3.53 BqL^{-1} and 3.19 – 8.82 BqL^{-1}, respectively with a standard deviation of 0.66 BqL^{-1} and 1.55 BqL^{-1}, respectively. The mean radon concentration (± SE) for surface and groundwater were found to be 1.88BqL^{-1} and 5.08 BqL^{-1} respectively. Using SPSS, Table 1 also displays the descriptive statistics, which revealed that the subterranean water sources contain greater radon concentrations than surface water sources and the same has been shown in Fig. 5. This may be because of the reason that underground water directly encounters U-238 rich rocks which release radon in water and cannot escape to atmosphere[38-39]. Also, because the bedrock contains granite, sand, and gravel, radon levels in underground water are typically higher than in surface water[40]. In contrast, aeration and agitation in the water allow radon in surface water samples to quickly escape to the atmosphere. Topography and geological variables

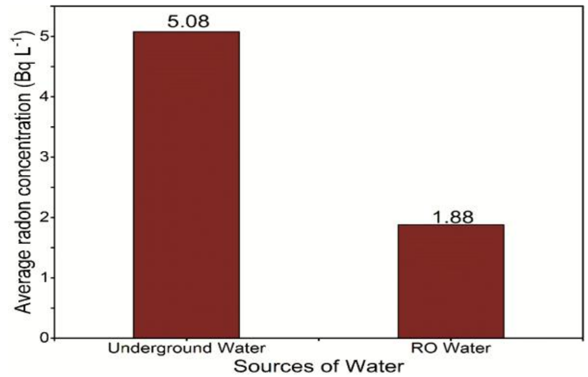

Fig. 5 — Comparison between different sources of water.

affect how much radon is present in surface water and subsurface water[41-42]. As can be seen in Fig. 5, the findings indicate that the average radon concentration in samples of underground water (5.08 BqL^{-1}) is greater than the typical concentration in sources of surface water, which is 1.88 BqL^{-1}.

Radon concentrations in water samples from the examined location have been compared to values from throughout the world, and it was discovered that these values are lower. The average value in the investigated area is slightly higher than the 2.72 BqL^{-1} in Bathinda district, but less than 3.63 BqL^{-1} in Faridkot district, 4.7 BqL^{-1}in Mansa and Muktsar district, Punjab, India[43]. The measured radon concentration (0.17 to 9.84 BqL^{-1}) in the study area are lower than that of Cyprus (0.3 to 20 BqL^{-1}). Greece (0.8 to 20 BqL^{-1})[44], Brazil (0.95 to 36)[45], Turkey (1.46 to 53.64 BqL^{-1})[46], South Korea (300 BqL^{-1})[47], Iran (0.064 to 49.1 BqL^{-1})[48], Sweden (5 to 3470 BqL^{-1})[49].

5 Conclusions

1 The calculated values of radon concentration have been observed to be below the recommended limit of 100 BqL^{-1} by WHO, 11 BqL^{-1} by USEPA, and 4-40 BqL^{-1} by UNSCEAR.

2 It has been determined that newborns receive a larger yearly effective dose via ingestion and inhalation than do children and adults. While the aggregate dose is significantly below the 100 μSvy^{-1} WHO-recommended safe level.

3 Because radon rapidly escapes from surfaces whereas underground water holds, samples of underground water have slightly greater radon concentration values than surface water samples.

4 Radon levels in underground water have been found to have a tenuous positive correlation with depth.

5 It may be concluded that because the detected levels in the studied area are within the advised safe limits, radon in water may not constitute a considerable radiological risk to the general public.

References

1 WHO, In: Incorporating First and Second Addenda, WHO Press, Geneva, 3rd Edn World Health Organisation, Geneva, Switzerland, (2008).
2 Khattak N U, Khan M A, Shah M T & Javed M W, *J Radioanal Nucl Chem*, 290 (2011) 493.
3 Richon P, Klinger Y, Tapponnier P, Li C, Woerd J & Perrier F, *Radiat Meas*, 45 (2010) 211.
4 Smeprini L & Kruger P, *Soc Petrol Eng AIME*, (1980) 8890.
5 Nazir S, Sahoo B K & Rani S, Massod S, Mishra R, Ahmad N, Rashid I, Ahmad S Z & Simnani S, *J Radioanal Nucl Chem*, 329 (2021) 923.
6 Jobbágy V, Altzitzoglou T, Malo P, Tanner V & Hult M, *J Environ Radioact*, 173 (2017) 18.
7 Rangaswamy D R, Srinivasa E, Srilatha M C & Sannappa J, *J Radioanal Nucl Chem*, 307 (2015) 907.
8 UNSCEAR, Report, Annex B: Exposure from Natural Radiations Sources, 1 (2000)
9 Pyngrope A, Khardewsaw A, Sharma Y, Maibam D, Saxana A & Sahoo B K, *Radiat Prot Dosim*, 189 (2020) 1.
10 Jamir S, Sahoo B K, Mishra R & Sinha D, *Groundw Sustain Dev J*, (2022).
11 Fakhri Y, Mahvi A H, Langarizadeh G, Zandsalimi Y & Rasouli L, *Glob J Health Sci*, 8 (2006) 64.
12 Karimdoust S & Ardebili L, *World Appl Sci J*, 10 (2010) 930.
13 Kendall G M & Smith T J, *J Radiol Prot*, 22 (2002) 389.
14 Bonotto D M, *J Environ Radioactiv*, 76 (2004) 319.
15 Singla A K, Kansal S & Mehra R, *J Radioanal Nucl Chem*, 327 (2021) 1073.
16 Singla A K, Kansal S, Rani S & Mehra R, *J Radioanal Nucl Chem*, (2021) doi:10.1007/s10967-021-07930-6.
17 Nazir S, Sahoo B K & Rani S, Massod S, Mishra R, Ahmad N, Rashid I, Ahmad S Z & Simnani S, *J Radioanal Nucl Chem*, 329 (2021) 923.
18 Singh B, Kant K, Garg M, Singh A, Sahoo B K & Sapra B K, *J Radioanal Nucl Chem*, (2020) 1.
19 John G & Rodwan J R, *Bottled Water Rep*, (2012) 12.
20 Rani S, Kansal S, Singla A K, Nazir S & Mehra R, *J Radioanal Nucl Chem*, (2022). doi: 10.1007/s10967-021-08129-5.
21 Rani S, Kansal S, Singla A K, Nazir S & Mehra R, *J Radioanal Nucl Chem*, (2022). doi:10.1007/s10967-022-08674-7.
22 Bajwa B S, Mahajan S, Singh H, Singh J, Singh S, Walia V & Virk H S, *Indoor Inbuilt Environ*, 14 (2005) 481.
23 Kansal S, Mehra R & Singh N P, *J Public Health Epidemiol*, 3 (2011) 352.
24 Singla A K, Kansal S, Rani S & Mehra R, *J Radioanal Nucl Chem*, (2021). doi:10.1007/s10967-021-07930-6.
25 Singla A K, Kansal S, Rani S & Mehra R, *Environ Geochem Health*, (2022). doi: 10.1007/s10653-022-01304-x.
26 Rani S, Kansal S, Singla AK & Mehra R, *Environ Geochem Health*, (2021). doi:10.1007/s10653-021-01012-y.
27 Sapra B K, Sahoo B K & Mishra R, BARC, Mumbai, 51 (2010).
28 Central Ground Water Board, Ministry of Water Resources, (2013).
29 Sahoo B K, Sapra B K, Kanse S D, Gware J J & Mayya Y S, *Radiat Meas*, 58 (2013) 52.
30 NRC, National Academic Press, Washington, USA, (1999).
31 UNSCEAR, Report to the general assembly with scientific report, (1993).
32 Brudecki K, Li W B, Meisenberg O, Tschiersch J, Hoeschen C & Oech U, *Radiat Environ Biophys*, 53 (2014) 535.
33 ICRP, ICRP Publication 137 Ann, 46(3/4), (2014).
34 ICRP, ICRP Publication 66 Ann, ICRP 24 (1-3) (1994).
35 WHO, 3rd Edn, Recommendations, Geneva, 1 (2004).
36 USEPA, U.S. Government Printing Office, (1991).
37 Skeppström K & Olofosson B, *Eur Water*, 17 (2007) 51.
38 Voronov A N, *Environ Geol*, 46 (2004) 630.
39 Stojkovie Z S, Svare- Gajic J V, Dorevic M Z, Grahvac N L, Vasin J R, Duorvic A D & Kravic S Z, *Hem Ind*, 69 (2015) 185.
40 Fonollosa E, Peñalver A, Borrull F & Aguilar C, *J Environ Radioact*, 151 (2016) 275.
41 Prasad M, Kumar G A, Sahoo B K & Ramola R C, *Acta Geophysica*, 66 (2018) 1223.
42 Mehra R, Bhagotra P & Kaur K, *Front Environ Sci*, 3 (2015) 37.
43 Nikolopoulos D & Louizi A, *Radiat Meas*, 43 (2008) 1305.
44 Marques A L, Santos W D & Geraldo L P, *Appl Radiat Isot*, 60 (2004) 801.
45 Tarim U A, Gurler O, Akkaya, Kilic N, Yalein S, Kanyak G & Gundogdu O, *Radiat Prot Dosimetry*, 150 (2012) 207.
46 Cho J S, Ahn J K, Kim H C & Lee D W, *J Environ Radioact*, 75 (2004) 105.
47 Banish A, Arabshahi H & Pourhabib Z, *Int J Phys Sci*, 6 (2011) 7969.
48 Salih I, Backstrom M, Karlsson S, Lund E & Pettersson H, *Appl Radiat Isotopes*, 60 (2004) 99.