

## **Study on Estimation of Inhalation and Ingestion Dose due to $^{222}\text{Rn}$ Concentration in Different Types of Ground Water of Some Taluks of Uttara Kannada District, Karnataka, India**

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### **Abstract**

The primary goal of this study was to determine the risk due to radon concentration in drinking water. Water is essential for most of the life on the Earth, and the quality of drinking water is a key criterion for one's health. Radon ( $^{222}\text{Rn}$ ) and radium ( $^{226}\text{Ra}$ ) are the radioactive elements that can be found in water. Thirty samples of drinking water were collected in Haliyal, Joida, and Mundgod taluks of Uttara Kannada district. Emanometry technique was used to determine the concentration of  $^{222}\text{Rn}$  activity. The activity concentration of  $^{222}\text{Rn}$  in water varies between  $3.78 \pm 0.38 \text{ Bq l}^{-1}$  and  $135.96 \pm 1.72 \text{ Bq l}^{-1}$  with a mean value of  $26.23 \pm 0.65 \text{ Bq l}^{-1}$ . The cumulative average annual effective doses for all of the samples under investigation are well below the safe limit of  $100 \mu\text{Sv y}^{-1}$  suggested by WHO.

*Keywords:* Radon; Radon bubbler; Annual effective dose; Haliyal; Joida; Mundgod

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### **1. Introduction**

Water is necessary for life on this planet. The requirement for high-quality drinking water is essential for human health. Demand for pure and fresh water has risen in recent decades as a result of fast population growth, erratic rainfall, increased environmental degradation, urbanization, and industry. Water becomes contaminated as a result of increased industrial and human activities. Ground water is substantially more radioactive than surface water due to its passage through rocks and soil formations, as well as the dissolution of various chemicals, minerals, and radioactive pollutants. The concentration of  $^{222}\text{Rn}$  in ground water varies depending on the hydrogeology of the location or aquifer, whereas it is very low in surface water, with concentration below  $4 \text{ Bq l}^{-1}$  [1-7].

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$^{222}\text{Rn}$  is a naturally occurring alpha emitting radioactive gas that is chemically inert. This colourless, tasteless, and odourless gas is produced by the natural radioactive decay series of uranium, which is found in trace amount throughout the Earth's crust in rocks and soils. The three naturally occurring isotopes of radon are radon ( $^{222}\text{Rn}$ ), thoron ( $^{220}\text{Rn}$ ), and actinon ( $^{219}\text{Rn}$ ). Among these, radon ( $^{222}\text{Rn}$ ) is the most stable isotope produced by the disintegration of  $^{238}\text{U}$ , accounting for approximately 99.3 % of total uranium in the Earth's crust. Thoron ( $^{220}\text{Rn}$ ) is a  $^{232}\text{Th}$  decay product, whereas actinon ( $^{219}\text{Rn}$ ) is generated via  $^{235}\text{U}$  decay [5-8]. Because of its 3.825-day half-life, the  $^{222}\text{Rn}$  isotope has adequate time to persist in water and air, posing health risks such as lung cancer, stomach-colon cancer, and leukaemia [9,10]. The transmission of radon from water to indoor air and its inhalation, as well as ingestion, are the two potential health risks provided by radon-enriched drinking water. While radon is emitted from water, such as when showering or bathing, it increases the overall risk of inhalation associated with indoor radon. Although radon in drinking water is not a direct health risk, it is harmful to the environment [11]. Long-term exposure of the population to high levels of radon and its daughters causes pathological outcomes such as respiratory functioning abnormalities and lung cancer [12].

However, drinking water with a high  $^{222}\text{Rn}$  level can increase the risk of stomach cancer and gastrointestinal cancer [13]. According to the Environmental Protection Agency (EPA), radon is the second most common cause of lung cancer in the United States, after smoking [14]. In the United States,  $^{222}\text{Rn}$  gas in drinking water is responsible for approximately 168 cancer deaths each year, with 89 % of these deaths are due to lung cancer caused by water-borne radon and 11 % are due to stomach cancer caused by consuming radon-contaminated water [15]. The permissible maximum contamination level (MCL) for  $^{222}\text{Rn}$  in water has been suggested by the USEPA as  $11.1 \text{ Bq l}^{-1}$  [16]. From public health perspective, understanding the activity concentration of  $^{222}\text{Rn}$  in drinking water is very significant. Hence, an attempt has been made for the first time in the current study to estimate  $^{222}\text{Rn}$  concentration in drinking water.

## **2. Experimental**

### **2.1. Study area**

The study area Haliyal, Joida, and Mundgod taluks are located in Uttara Kannada district in Karnataka state of India, between north latitudes  $13^{\circ} 55' 0''$  to  $15^{\circ} 31' 01''$  and east longitudes  $74^{\circ} 0' 35''$  to  $75^{\circ} 10' 23''$ . The geology of the study area consists of different types of rocks like metabasalt, laterite, granitic gneiss and chloriteschist as well as minerals such as iron ore, bauxite ore, magnetite and silicate. Soil types include red soil, red loamy soil and black cotton soil. The geological map of the study area is as shown in Fig. 1.

## 2.2. Samples collection and preparation

Total 30 drinking water samples were taken from various locations in Haliyal, Joida, and Mundgod taluks of Uttara Kannada district. From each location four samples were taken for measuring radon concentration. The water was permitted to run fully for at least 10-15 min before the sample was taken in order to obtain fresh water from the bore wells and hand pumps. Approximately 250 mL of water was collected in special plastic bottles for the calculation of radon in-water activity, ensuring minimal radon loss by degassing and without air contact [17]. The plastic bottles were completely filled in a gentle way, so that there was zero head space. It was taken care to ensure that there is no air bubble left within the container and also prevented aeration during the sampling processes, which could lead to degassing [18]. All the collected samples were analyzed within 24 h.

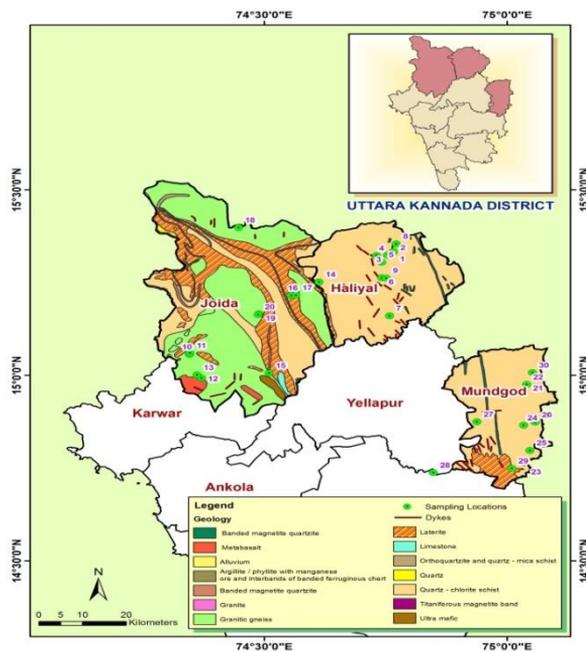


Fig. 1. Geological map of the study area.

## 2.3. Determination of $^{222}\text{Rn}$ by bubbler method

The  $^{222}\text{Rn}$  concentration in drinking water was determined using the emanometry technique [19,20]. The complete setup of radon bubbler is shown in Fig. 2. After collecting water samples using the aforesaid standard process, the samples were brought to the laboratory and were immediately analyzed. 70 mL of water sample was transferred into the bubbler using the vacuum transfer technique. The dissolved  $^{222}\text{Rn}$

in the water was transferred to a scintillation cell that had been pre-evacuated and background counted. To allow radon to achieve equilibrium with its daughters, the scintillation cell was undisturbed for 180 min (3 h) and then it was coupled to a photomultiplier and alpha counting assembly. The concentration of radon in groundwater samples was determined using equation (1) [20].

$$^{222}\text{Rn} (\text{Bq l}^{-1}) = \frac{6.97 \times 10^{-2} \times D}{E \times V \times (1 - e^{-\lambda t}) \times e^{-\lambda T}} \quad (1)$$

where,  $D$  is counts above the background,  $V$  is volume of water (L),  $E$  is efficiency of the scintillation cell (74 %),  $\lambda$  is decay constant for radon ( $2.098 \times 10^{-6} \text{ s}^{-1}$ ),  $T$  is counting delay after sampling (s), and  $t$  is counting duration (s).

#### 2.4. Estimation of dose due to inhalation and ingestion of $^{222}\text{Rn}$ in drinking water

The public is exposed to a higher dosage of radiation from waterborne radon than from any other water pollutants [21]. The annual effective doses of radon in water for inhalation and ingestion were calculated using the parameter set out in the UNSCEAR 2000 report as

$$(D_{\text{In}} \mu\text{Sv y}^{-1}) = A_{\text{RnW}} \times C_{\text{aW}} \times F \times I \times \text{DCF} \quad (2)$$

where  $D_{\text{In}}$  is the effective dose for inhalation,  $A_{\text{RnW}}$  is the radon concentration in water ( $\text{Bq l}^{-1}$  or  $\text{kBq m}^{-3}$ ),  $C_{\text{aW}}$  is the ratio of radon in air to the radon in water ( $10^{-4}$ ),  $F$  is the equilibrium factor between radon and its progenies (0.4),  $I$  is the average indoor occupancy time per individual ( $7000 \text{ ha}^{-1}$ ) and DCF is the dose conversion factor for radon exposure [ $9 \text{ nSv (Bq h m}^{-3}\text{)}^{-1}$ ].

The ingestion dose is calculated using the following formula,

$$(D_{\text{Ig}} \mu\text{Sv y}^{-1}) = A_{\text{RnW}} \times C_{\text{w}} \times \text{EDC} \quad (3)$$

Where  $D_{\text{Ig}}$  is the effective dose for ingestion,  $C_{\text{w}}$  is the weighted estimate of water consumption ( $60 \text{ l y}^{-1}$ ) and EDC is the effective dose coefficient for ingestion ( $3.5 \text{ nSvBq}^{-1}$ ) respectively. The dose contribution to the lungs and stomach from this source is estimated by multiplying the inhalation and ingestion doses by the appropriate tissue weighting factor for the lungs and stomach respectively.



Fig. 2. Complete set up of Radon bubbler method.

### 3. Results and Discussion

The mean activity concentrations of  $^{222}\text{Rn}$  in drinking water and annual effective dose due to inhalation and ingestion of the study area are summarized in Table 1.

Table 1. Estimated value of Radon concentration and annual effective dose in various drinking water samples of the study area.

Sl.No	Locations	Water source	$^{222}\text{Rn}$ ( $\text{Bq l}^{-1}$ )	Annual effective dose ( $\mu\text{Sv y}^{-1}$ )				
				Inhalation	Lung	Ingestion	Stomach	Total
<b>HALIYAL TALUK</b>								
1	Halyal	BW	$46.71 \pm 1.02$	117.71	14.13	9.81	1.18	127.52
2	Halyal College	BW	$61.53 \pm 1.21$	155.06	18.61	12.92	1.55	167.98
3	Haliyal	TW	$6.76 \pm 0.53$	23.54	2.82	1.96	0.24	25.50
4	Kesarolli	BW	$39.79 \pm 0.92$	100.27	12.03	8.36	1.00	108.63
5	Kesarolli	RW	$3.78 \pm 0.38$	9.52	1.14	0.79	0.10	10.32
6	Karlkatta	BW	$39.35 \pm 0.56$	99.16	11.90	8.26	0.99	107.43
7	Bhagavathi	BW	$52.74 \pm 0.95$	132.90	15.95	11.08	1.33	143.98
8	Kerwada	BW	$31.38 \pm 0.71$	79.07	9.49	6.59	0.79	85.66
9	Sambarani	OW	$16.01 \pm 0.48$	40.35	4.84	3.36	0.40	43.71
<b>JOIDA TALUK</b>								
10	Nujji	BW	$39.96 \pm 0.87$	100.70	12.08	8.39	1.01	109.09
11	Nujji	OW	$10.58 \pm 0.39$	26.66	3.20	2.22	0.27	28.88
12	Ansi	OW	$5.49 \pm 0.34$	13.83	1.66	1.15	0.14	14.99
13	AnsiGhat	Spring	$4.80 \pm 0.39$	12.10	1.45	1.01	0.12	13.10
14	Dandeli	OW	$13.59 \pm 0.71$	34.25	4.11	2.85	0.34	37.10
15	Ullavi	OW	$9.01 \pm 0.47$	22.72	2.73	1.89	0.23	24.61
16	Pradani	OW	$15.16 \pm 0.58$	38.21	4.59	3.18	0.38	41.40
17	Pradani	CDW	$5.11 \pm 0.35$	12.87	1.54	1.07	0.13	13.94
18	Chapali	OW	$18.79 \pm 0.68$	47.35	5.68	3.95	0.47	51.30
19	Joida Town	OW	$12.66 \pm 0.52$	31.90	3.83	2.66	0.32	34.56
20	Joida	Pond	$4.72 \pm 0.41$	11.89	1.43	0.99	0.12	12.89
<b>MUNDAGOD TALUK</b>								
21	Mundgod	BW	$135.96 \pm 1.72$	342.62	41.11	28.55	3.43	371.17
22	Mundgod	TW	$9.34 \pm 0.28$	17.04	2.04	1.42	0.17	18.46
23	Gotagudi	HP	$24.93 \pm 0.69$	62.83	7.54	5.24	0.63	68.06
24	Katoor	HP	$26.76 \pm 0.46$	67.44	8.09	5.62	0.67	73.05
25	Pala	HP	$46.47 \pm 0.81$	117.10	14.05	9.76	1.17	126.86
26	Alalli	HP	$24.94 \pm 0.63$	62.86	7.54	5.24	0.63	68.10
27	Ganadahalli	HP	$53.24 \pm 1.03$	134.16	16.10	11.18	1.34	145.35
28	Kudragi	OW	$14.96 \pm 0.61$	37.70	4.52	3.14	0.38	40.84
29	Malgi	OW	$8.03 \pm 0.42$	20.23	2.43	1.69	0.20	21.92
30	Bachaniki	DW	$4.38 \pm 0.49$	11.03	1.32	0.92	0.11	11.95
	<b>Minimum</b>		$3.78 \pm 0.38$	9.52	1.14	0.79	0.1	10.32
	<b>Maximum</b>		$135.96 \pm 1.72$	342.62	41.11	28.55	3.43	371.17
	<b>Average</b>		$26.23 \pm 0.65$	66.10	7.93	5.51	0.66	71.61

BW-Bore Well, TW- Tap Water, RW- River Water, OW-Open Well, CDW-Check Dam Water  
HP- Hand Pump and DW-Dam water

The radon concentration in drinking water in Haliyal, Joida and Mundgod taluks are varied from  $3.78 \pm 0.38 \text{ Bq l}^{-1}$  and  $135.96 \pm 1.72 \text{ Bq l}^{-1}$ . With a mean value of  $26.23 \pm 0.65 \text{ Bq l}^{-1}$ . The maximum activity concentration of radon was observed in bore well water taken at Mundgod, this is because of the depth of the bore well as well as granites at the underground bed rock. Higher activity concentration of  $^{222}\text{Rn}$  was

observed in water taken from bore well and hand pumps at Haliyal, Bhagavati, Kerosalli, Karlakatta, Nujji, Ganadahalli, and Pala. This is due to the fact that this region is attributed with granitic gneiss at various depths and the presence of thrusts, faults and shears which provides the way for the upward movement of radon gas with higher radioactivity [22,23].

The intermediate concentration of  $^{222}\text{Rn}$  in drinking water was observed in water samples collected from open wells, this may be due to the underlying bedrock system attributed by laterite and chlorite schist which contains lower activity concentration of radionuclide [22,23] and the least (minimum) activity of radon is observed in the water samples collected from ponds, rivers, spring and dams. This may be due to lesser depth and also they are well exposed and radon gas is escaped easily into the atmosphere due to atmospheric temperature variation, hence radon concentration in water is the least at some locations.

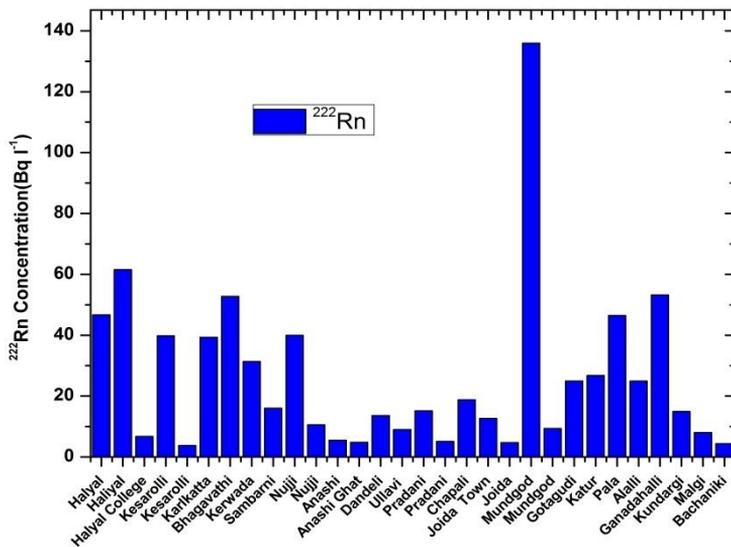


Fig. 3. Variation of radon concentration in water with the locations.

The variation of  $^{222}\text{Rn}$  concentration in water with the locations is shown in Fig. 3. Figure shows that, there is a wide variation of radon concentration. The geological region with high uranium/radium containing granite rock (local geology) and geo-hydrological conditions of the aquifer are the dependent factors for variation of  $^{222}\text{Rn}$  activity in drinking water [24].  $^{226}\text{Ra}$  rich minerals present along the cracked surface putrefy and discharge  $^{222}\text{Rn}$  into the groundwater. The diverse depths of water resources, as well as a different process influencing the climate and geo-hydrological nature of the locations, are further causes for the differences in  $^{222}\text{Rn}$  concentration [25,26].

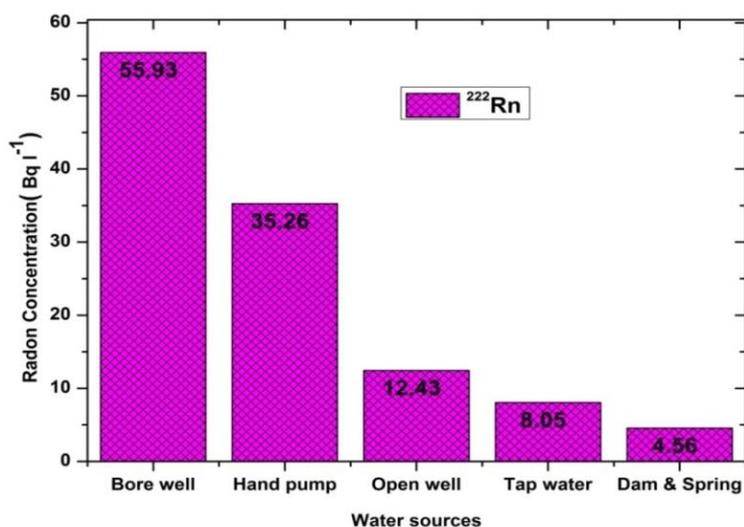


Fig. 4. Variation of radon concentration with different types of water sources.

Fig. 4 depicts the variation in  $^{222}\text{Rn}$  concentrations as a function of diverse water resources. The concentration of  $^{222}\text{Rn}$  in ground water (from bore wells and hand pumps) is higher than in surface water. This could be because, radionuclides like  $^{238}\text{U}$  and  $^{226}\text{Ra}$  can be found in varying amounts in rocks and soil. The greater depth of the bore wells and hand pumps is another factor for the higher  $^{222}\text{Rn}$  concentration. Deeper bore wells and hand pumps allow more water to interact with an aquifer of significant thickness [27,28]. In comparison to tube well and hand pump water, tap water has lower  $^{222}\text{Rn}$  content. This is due to dissolved  $^{222}\text{Rn}$  being disrobed and released along the path between the water source and the water sample collection point. Surface water had the lowest  $^{222}\text{Rn}$  activity concentration. Because of the atmospheric temperature variations, the surface water (river, pond, and spring) is well exposed, and the dissolved radon is easily discharged into the atmosphere.

Among 30 samples 63.3 % (19 samples) showed radon concentration exceeding the maximum contaminant level of  $11.1 \text{ Bq l}^{-1}$  proposed by USEPA [29]. From this study, it is observed that 6 out of 30 drinking water samples (about 20 %) have  $^{222}\text{Rn}$  activity concentration levels much higher than the UNSCEAR maximum recommended level of  $40 \text{ Bq l}^{-1}$  [30]. The measured radon concentrations were compared to the European Commission's recommendations for public protection against radon exposure in drinking water supplies, which recommends  $100 \text{ Bq l}^{-1}$  as action threshold for public water supplies [31]. Only one sample was observed to exceed the action threshold of  $100 \text{ Bq l}^{-1}$  [32].

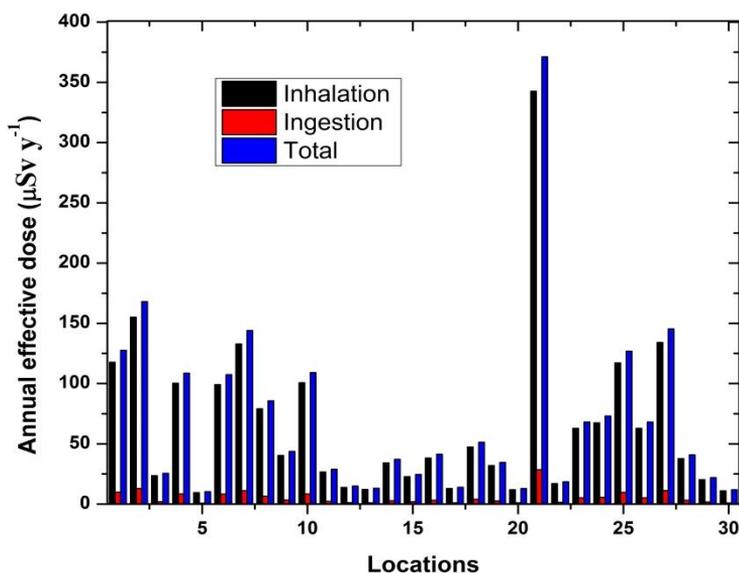


Fig. 5. Variation of inhalation, ingestion and total dose with the location.

The variation of inhalation, ingestion and total dose with the location is shown in Fig. 5. The measured inhalation dose varied from  $9.52 \mu\text{Sv y}^{-1}$  to  $342.62 \mu\text{Sv y}^{-1}$  with a mean of  $66.10 \mu\text{Sv y}^{-1}$ . Ingestion dose received varies from  $0.79 \mu\text{Sv y}^{-1}$  to  $28.55 \mu\text{Sv y}^{-1}$  with an average value of  $5.51 \mu\text{Sv y}^{-1}$ . The quantity of radon reaching the lungs from these sources ranges from  $1.14 \mu\text{Sv y}^{-1}$  to  $41.11 \mu\text{Sv y}^{-1}$  with a geometric mean of  $7.93 \mu\text{Sv y}^{-1}$ . The quantity of radon reaching the stomach from these sources ranges from  $0.10 \mu\text{Sv y}^{-1}$  to  $3.43 \mu\text{Sv y}^{-1}$  with a geometric mean of  $0.66 \mu\text{Sv y}^{-1}$ . The total annual dose due to inhalation and ingestion of  $^{222}\text{Rn}$  ranges from  $10.32 \mu\text{Sv y}^{-1}$  to  $371.17 \mu\text{Sv y}^{-1}$  with a geometric mean of  $71.61 \mu\text{Sv y}^{-1}$ . The World Health Organization (WHO) and the EU Council recommend the determination of reference level of the annual effective dose received from drinking water consumption at  $100 \mu\text{Sv y}^{-1}$  [31-33].

#### 4. Conclusion

Wide variations in radon concentrations in drinking water samples were found in this analysis. This is due to the heterogeneous distribution of radionuclides resulting from granite, granitic gneiss and chlorite schist of the nearby aquifers. About 36.7 % of the samples actually used by the inhabitants of the study area have radon concentrations less than the EPA recommended level of  $11.1 \text{ Bq l}^{-1}$ . In this study, the mean total annual effective dose due to  $^{222}\text{Rn}$  in drinking water is less than  $100 \mu\text{Sv y}^{-1}$  and hence the water is appropriate for drinking and no further intervention is required.

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## References

1. A. A. Jamal, Poll Res. **17**, 111 (1998). <https://doi.org/10.17077/2168-569X.1269>
2. C. R. Ramakrishnaiah, C. Sadashivaiah, and G. Ranganna, Indian J. Chem. **6**, 523 (2009). <https://doi.org/10.1155/2009/757424>
3. V. Singh, Res. J. Chem. Environ. **10**, 62 (2006). [https://doi.org/10.1016/S0377-1237\(06\)80142-5](https://doi.org/10.1016/S0377-1237(06)80142-5)
4. G. H. Murhekar, Int. J. Res. Chem. Environ. **1**, 183 (2011).
5. N. U. Khattak, M. A. Khan, M. T. Shah, and M. W. Javed, Pakistan J. Radioanal Nucl. Chem. **290**, 493 (2011). <https://doi.org/10.1007/s10967-011-1297-2>
6. United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR), Sources and Effects of Ionizing Radiation (United Nation, New York, 2000).
7. D. R. Rangaswamy, E. Srinivasa, M. C. Srilatha, and J. Sannappa, Indian J. Radioanal Nucl. Chem. (2015).
8. E. Srinivasa, D. R. Rangaswamy, and J. Sannappa, Indian J. Radioanal Nucl. Chem. **305**, 665 (2015). <https://doi.org/10.1007/s10967-015-4034-4>
9. L. S. Finn, Phys. Rev. **46**, 5236 (1992). <https://doi.org/10.1103/PhysRevD.46.5236>
10. A. N. Voronov, Environ. Geol. **46**, 630 (2004). <https://doi.org/10.1007/s00254-003-0857-3>
11. F. T. Cross, N. H. Hartley, and W. Hoffmann, Health Phys. **48**, 649 (1985). <https://doi.org/10.1097/00004032-198505000-00006>
12. V. I. Beir, Report of the Committee on the Biological Effects of Ionizing Radiation, Health Effects of Exposure to Radon (National Research Council, The National Academies Press, Washington, 1999).
13. G. M. Kendal and T. J. Smith, J. Radiol. Prot. **22**, 389 (2002). <https://doi.org/10.1088/0952-4746/22/4/304>
14. Environmental Protection Agency (EPA), A Citizen's Guide to Radon (United States Environmental Protection Agency, 2009).
15. National Academy of Sciences Report, Risk Assessment of Radon in Drinking Water (National Academy Press, Washington, 1999) pp. 18.
16. USEPA, National Primary Drinking Water Regulations for Radionuclides (US, Governmental Printing Office, Washington EPA/570/9-91/700, 1991).
17. C. Stringer and W. C. Burnett, Health Phys. **87**, 642 (2004).
18. Y. S. Mayya, K. P. Eappen, and K. S. V. Nambi, Radiat. Prot. Dosimetry **77**, 177 (1998). <https://doi.org/10.1093/oxfordjournals.rpd.a032308>
19. C. D. Strain, J. E. Watson, and S. W. Fong, Health Phys. **37**, 779 (1979).
20. M. Raghavayya, M. A. R. Iyengar, and P. M. Markose, Bull. Radiat. Prot. **3**, 11 (1980).
21. E. Vitz, Health Phys. **60**, 817 (1991). <https://doi.org/10.1097/00004032-199106000-00007>
22. E. Srinivasa, D. R. Rangaswamy, S. Suresh, S. R. Nagabhushana, J. Sannappa, and K. Umehsareddy, India Radiat. Prot. Environ. **41**, 132 (2018). [https://doi.org/10.4103/rpe.RPE\\_46\\_18](https://doi.org/10.4103/rpe.RPE_46_18)
23. J. Sannappa, S. Suresh, D. R. Rangaswamy, and E. Srinivasa, J. Radioanal. Chem. **323**, 1459 (2019). <https://doi.org/10.1007/s10967-019-06812-2>
24. V. M. Choubey, and R. C. Ramola, Indian Environ. Geol. **32**, 258 (1997). <https://doi.org/10.1007/s002540050215>
25. G. Kuntsson and B. Olofsson, NGU Bull. **439**, 79 (2002).

26. S. Suresh, D. R. Rangaswamy, E. Srinivas, and J. Sannappa, *J. Radiat. Res. Appl. Sci.* **13**, 12 (2020). <https://doi.org/10.1080/16878507.2019.1693175>
27. N. U. Khattak, M. A. Khan, M. T. Shah, and M. W. Javed, *Pakistan J. Radioanal. Nucl. Chem.* **290**, 493(2011). <https://doi.org/10.1007/s10967-011-1297-2>
28. L. Xinwei, *Radiat. Prot. Dosim.* **121**, 452 (2006). <https://doi.org/10.1093/rpd/ncl048>
29. US Environmental Protection Agency, US EPA, *Radon in Drinking Water Health Risk Reduction and Cost Analysis* (1999).
30. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), *Sources and Effects of Ionizing Radiation (UNSCEAR 2008 report to the general assembly with Scientific annexes, 2008)*.
31. Commission, *Commission Recommendation, Official J. Eur. Communities* (2001).
32. WHO, *Guidelines for Third Edition Recommendations Drinking-Water Quality (World Health Organization, Geneva, 2008) Vol. 1*.
33. World Health Organization (WHO), *Guidelines for Drinking Water Quality: Radiological Aspects* (2004).