

Assessment of Radon Concentration and Radiation Dose from Drinking Water in Vasanthanarasapura Industrial Area Phase-II, Tumkur, Karnataka, India

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Abstract

Radon (^{222}Rn) is a naturally occurring radioactive gas generated in the uranium-238 decay series and can accumulate in groundwater through water-rock interaction. The present study assessed ^{222}Rn activity concentrations in 20 drinking-water samples collected from Vasanthanarasapura Industrial Area Phase-II, Tumkur, Karnataka, using Lucas scintillation-cell emanometry with a PSI-RBS-1 radon bubbler. The corrected ^{222}Rn concentrations ranged from 10.36 to 39.62 Bq L⁻¹, with an arithmetic mean of 22.37 Bq L⁻¹, geometric mean of 20.99 Bq L⁻¹, and standard deviation of 8.15 Bq L⁻¹. The estimated total dose component reported in the supplied calculation dataset ranged from 28.36 to 108.25, with a mean of 61.20; the dose values should be reported with their verified unit and dose-coefficient basis in the final submission. The spatial variability is consistent with differences in lithology, weathering, fracturing, groundwater residence time, and water-rock interaction. The study provides baseline information for environmental radiation monitoring and identifies locations requiring periodic follow-up measurements.

Keywords: ^{222}Rn ; drinking water; groundwater; Lucas scintillation cell; emanometry; inhalation dose; ingestion dose.

1. Introduction

Radon (^{222}Rn) is a radioactive noble gas produced in the decay chain of ^{238}U through ^{226}Ra and is an important component of natural radiation exposure. Radon can migrate from mineral grains into pore spaces and groundwater, particularly where uranium- and radium-bearing minerals, fractures, permeability, and groundwater circulation favour its transport. Groundwater used for drinking can therefore contain dissolved radon. Exposure may occur by direct ingestion and, importantly, by inhalation after radon is released from water into indoor air

during activities such as bathing, washing, and cooking. The World Health Organization notes that radon released from drinking water can contribute to indoor-air exposure and that the inhalation pathway is normally more important than ingestion. [1,2,15,16]

Radon concentrations in groundwater are highly site-specific. Studies from Karnataka have reported substantial spatial variability in groundwater and drinking-water radon concentrations, reflecting differences in geological setting and hydrogeological conditions. The present investigation focuses on Vasanthanarasapura Industrial Area Phase-II, where groundwater is used for drinking and domestic purposes. The objectives were to determine ^{222}Rn activity concentration in drinking-water samples, estimate the associated dose components using the study's adopted calculation model, examine spatial variability, and provide baseline information for environmental radiation monitoring. [3–7,10–12]

2. Study area

The present investigation was carried out in **Vasanthanarasapura Industrial Area Phase-II**, located in Tumkur (Tumakuru) District, Karnataka, India. The study area lies approximately between **13°24'–13°27' N latitude and 77°08'–77°12' E longitude** and is situated about 15 km north of Tumkur city along the National Highway NH-48. Vasanthanarasapura Industrial Area Phase-II is an important industrial development region administered under the Karnataka Industrial Areas Development Board (KIADB). The industrial estate accommodates diverse manufacturing activities, including engineering, automobile, textile, food-processing, pharmaceutical and chemical industries. The progressive expansion of industrial activities has increased the demand for groundwater for industrial, domestic and drinking-water requirements. Groundwater extracted through borewells constitutes an important source of water for industrial workers, nearby residential settlements and commercial establishments.

The region experiences a semi-arid tropical climate, with relatively warm summers and comparatively cooler winter conditions. Seasonal variations in rainfall and temperature can influence groundwater recharge, groundwater movement and the transport of dissolved radionuclides. From a geological perspective, the study area forms part of the Eastern Dharwar Craton and is predominantly underlain by Precambrian crystalline rocks associated with the Peninsular Gneissic Complex. The principal lithological units reported in the region include migmatitic gneisses, granodiorite–tonalite gneisses, granitic rocks and ultramafic schists. These crystalline formations may contain accessory minerals bearing uranium and radium, which are important source materials for the generation of ^{222}Rn .

The radioactive decay of ^{226}Ra present within these geological formations produces ^{222}Rn , which can migrate through pores, fractures and interconnected pathways in the rock and soil. Weathering of crystalline rocks increases the interaction between groundwater and mineral surfaces and may facilitate the transfer of radon and

its parent radionuclides into groundwater. Fractured and weathered zones may therefore act as preferential pathways for groundwater movement and radon transport. The soils of the region are reported to include red loamy soil, red sandy loam and clay loam, which can influence infiltration, groundwater recharge and radionuclide migration. The combined influence of lithology, weathering, fracturing, groundwater circulation and water–rock interaction can result in considerable spatial variability in dissolved ^{222}Rn concentrations. The hydrogeological characteristics of the region are therefore particularly relevant when interpreting differences in radon concentration among individual groundwater sources. Since groundwater is extensively used for drinking and domestic purposes in and around the industrial estate, assessment of its radiological quality is important from an environmental-health perspective. Industrial development and increasing groundwater abstraction further emphasize the need for systematic monitoring of naturally occurring radionuclides in local water resources.

For the present investigation, 20 groundwater samples were collected from representative drinking-water sources distributed throughout Vasanthanasapura Industrial Area Phase-II. The sampling locations included borewells, public water-supply points, industrial water sources and residential drinking-water facilities, thereby providing spatial coverage of the principal groundwater-use areas. The geographical coordinates of the sampling locations were recorded using a handheld GPS receiver to facilitate spatial identification and interpretation of the measured ^{222}Rn concentrations. The geological and hydrogeological characteristics of Vasanthanasapura Industrial Area Phase-II therefore provide an appropriate natural setting for investigating the occurrence and spatial distribution of ^{222}Rn in groundwater. The study-area characteristics are particularly relevant because radon concentration in groundwater is controlled by the availability of uranium- and radium-bearing minerals, groundwater residence time, permeability, fractures and the extent of water–rock interaction. Accordingly, characterization of the study area provides an essential geological and environmental framework for interpreting the measured ^{222}Rn activity concentrations and the associated inhalation and ingestion dose estimates.^[7]

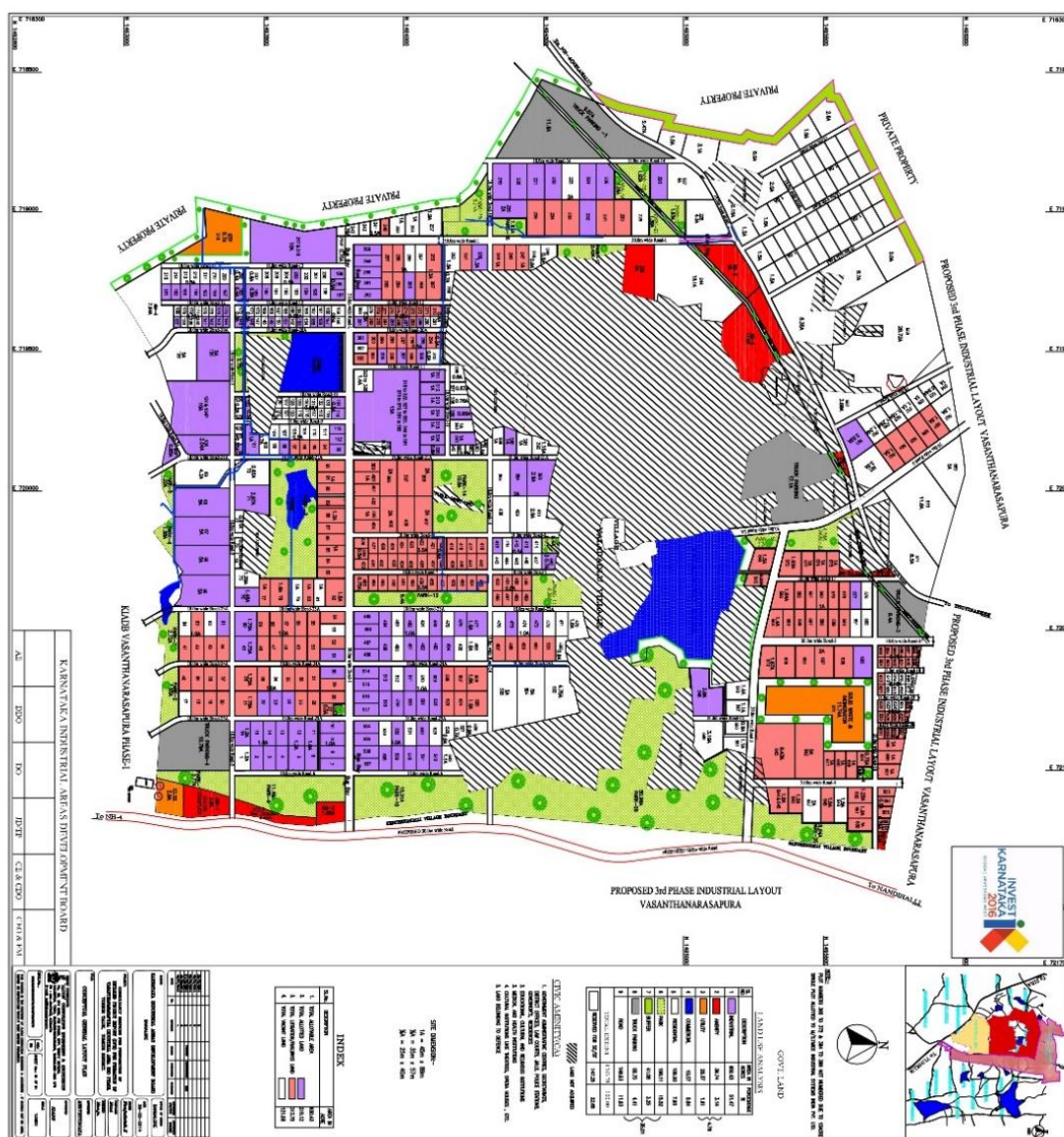


Fig. 1. Layout map of Vasanthanarasapura Industrial Area Phase-II

3. Materials and methods

3.1 Sampling and radon measurement

A total of 20 drinking-water samples were collected from representative locations in Vasanthanarasapura Industrial Area Phase-II. Approximately 500 mL of water was collected in airtight polyethylene bottles, avoiding headspace and air bubbles as far as practicable. Samples were sealed, labelled, transported to the laboratory, and analysed within 24 h to minimize radon loss through radioactive decay. Four replicate samples were collected at each location and the mean concentration was used for the subsequent analysis. ^[4,8]

Radon was extracted by an emanometry procedure using a PSI-RBS-1 radon bubbler coupled to a Lucas scintillation cell and a photomultiplier-tube alpha-counting system. Approximately 70 mL of water was introduced into the bubbler, and air was circulated through the sample to transfer dissolved radon into the evacuated Lucas cell. The cell was then sealed and allowed to approach equilibrium with short-lived radon progeny for approximately 3 h before counting. Alpha counts were recorded for 17 min and corrected for background. The activity concentration was obtained using the calibrated Lucas-cell/emanometry calculation.^[4,8]

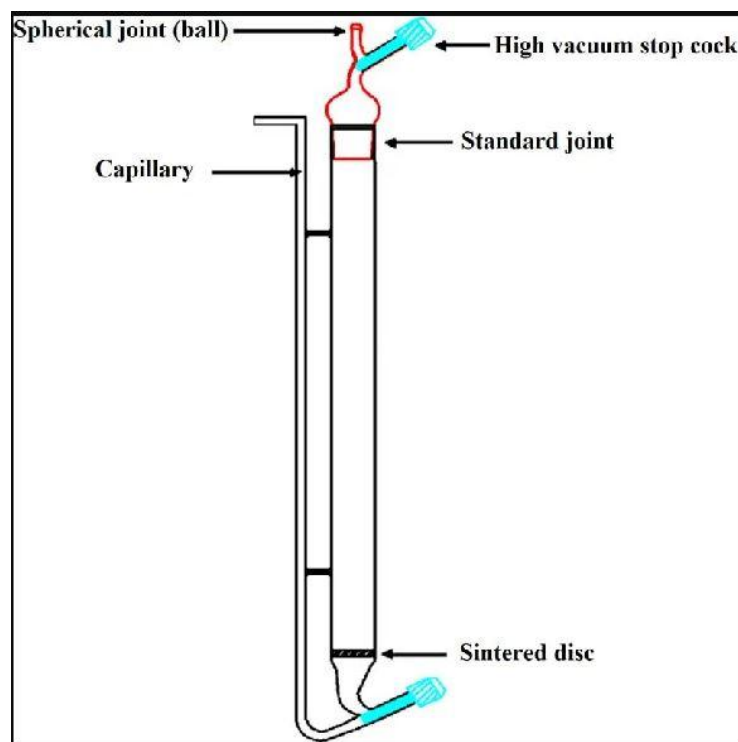


Fig. 2. Schematic representation of the PSI-RBS-1 radon bubbler used for radon extraction.

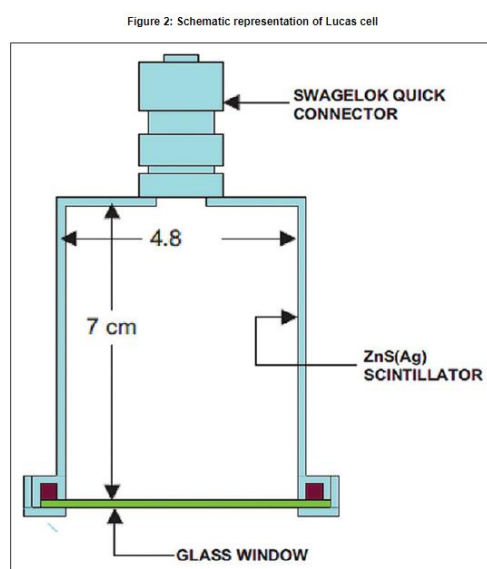


Fig. 3. Schematic representation of the Lucas scintillation cell used for alpha counting.

3.2 Dose assessment

The manuscript estimates inhalation and ingestion dose components from the measured ^{222}Rn concentration using the exposure assumptions adopted in the original calculation, including the water-to-air transfer parameter, equilibrium factor, occupancy time, water-consumption rate, and dose coefficients.

$$^{222}\text{Rn}(\text{Bql}^{-1}) = \frac{6.97 \times 10^{-2} \times C_B}{E \times V \times (1 - e^{-\lambda\theta_t})e^{-\lambda\theta_t}} - - - - 1$$

Where: C_B is the total Counts above background, V is the volume of water (in L), E represents the Efficiency of the Scintillation/Lucas cell (74%), λ represents decay constant for radon ($2.098 \times 10^{-6} \text{ s}^{-1}$), θ_t is the delay time after sampling.

2.1 Estimation of Inhalation dose and Ingestion dose due to ^{222}Rn in drinking water

The annual effective doses of radon in water for inhalation and ingestion were determined using an UNSCEAR-based approach, as given by^[1]

$$E_{\text{in}}(\mu\text{Svy}^{-1}) = R_{\text{CW}} \times R_{\text{aw}} \times E_{\text{q}} \times A_{\text{int}} \times \text{DCF} - - - - - 2$$

Where: E_i represents the effective dose for inhalation, C_w represents the radon concentration in water, R represents the radon-in-air to water transfer ratio (10^{-4}), F represents the equilibrium factor of radon and its progeny (0.4), t represents the average indoor occupancy time per individual (7000 h a^{-1}), and DCF represents the dose conversion factor for radon exposure [$9 \text{ nSv (Bq h m}^{-3})^{-1}$]. $E_{\text{in}} R_{\text{CW}} \text{Bql}^{-1}$ or kBqm^{-3}), $R_{\text{aw}} E_{\text{q}} A_{\text{int}}$ ^[1]

The following formula is used to calculate the ingestion dose:

$$D_{\text{ing}} = R_{\text{CW}} \times W_{\text{C}} \times E_{\text{D}} - - - - - 3$$

Where: E_{ing} represents the effective dose for ingestion, C_w represents the radon concentration in drinking water, DWC represents the estimated water consumption (60 L a^{-1}), and DCF represents the effective ingestion dose coefficient. $D_{\text{ing}} R_{\text{CW}} \text{Bql}^{-1}) W_{\text{C}} E_{\text{D}} \text{Bq}^{-1}$)^[10]

$$TD_{\text{ing}}(\mu\text{Svy}^{-1}) = R_{\text{CW}} \times \text{DWC} \times C_{\text{F}} \times E_{\text{T}} - - - - - 4$$

$TD_{\text{ing}} E_{\text{t}}$ represents total effective dose, C_w represents the radon concentration levels in drinking water, and DWC represents daily water consumption and exposure time. Age-dependent water-consumption assumptions may be applied when estimating doses for different population groups. $R_{\text{CW}} \text{Bql}^{-1}) E_{\text{T}}$ ^[1,10,13]

$$\text{Effective Dose}(\mu\text{Svy}^{-1}) = T_{\text{WF}} \times D_{\text{In}}, D_{\text{Ing}} - - - - - 5$$

Where: wT represents the tissue weighting factor; for the lungs and stomach, the value used in the adopted calculation is 0.12. $T_{\text{WF}} T_{\text{WF}}$ ^[15,16]

4. Results and discussion

4.1 Radon concentration in drinking water

The corrected ^{222}Rn concentrations ranged from 10.36 to 39.62 Bq L⁻¹, with an arithmetic mean of 22.59 Bq L⁻¹, geometric mean of 21.36 Bq L⁻¹, and standard deviation of 7.63 Bq L⁻¹. The maximum value occurred at L19 and the minimum at L17. The maximum-to-minimum ratio is approximately 3.83, demonstrating appreciable spatial variability among the sampled water sources.

The measured range is comparable with several reported values from Karnataka. Karthik Kumar et al. reported geometric means of 39.13 and 3.78 Bq L⁻¹ for Sira and Tiptur, respectively; Srinivasa et al. reported concentrations from 0.51 to 151.98 Bq L⁻¹ in Chikmagalur; Yashaswini et al. reported 1.1–38.9 Bq L⁻¹ around the Kabini River basin; and Crasta et al. reported 2.05–28.02 Bq L⁻¹ in coastal Karnataka. Additional studies from Davanagere, Tumkur industrial areas, and the Varahi–Markandeya and Magadi regions further demonstrate the geographical variability of groundwater radon in Karnataka. [3–7,10–12]

Table 1. Corrected ^{222}Rn concentrations and associated dose components

Location	^{222}Rn (Bq l ⁻¹)	Annual Effective Dose Equivalent Dose(μSvy^{-1})				
		Inhalation	Lung	Ingestion	Stomach	Total
L1	12.19	30.29	3.76	2.52	0.38	32.81
L2	26.89	67.55	8.11	5.64	0.75	73.18
L3	11.36	28.66	3.44	2.40	0.47	31.06
L4	37.16	93.53	11.20	7.77	0.92	102.09
L5	34.05	85.74	10.31	7.19	0.80	92.93
L6	18.32	46.49	5.57	3.87	0.47	50.37
L7	21.17	53.34	6.39	4.45	0.54	57.78
L8	23.03	58.23	6.98	4.86	0.59	63.09
L9	19.01	48.02	5.76	4.01	0.47	52.00
L10	20.24	50.93	6.11	4.25	0.54	55.18
L11	19.19	48.33	5.81	4.03	0.56	52.36
L12	21.39	53.73	6.45	4.47	0.53	58.20
L13	23.62	59.65	7.16	4.98	0.64	64.61
L14	25.81	65.08	7.81	5.42	0.66	70.50
L15	20.62	51.97	6.24	4.33	0.53	56.29

L16	22.24	56.28	6.76	4.69	0.50	60.96
L17	10.36	26.23	3.16	2.20	0.29	28.36
L18	21.24	53.75	6.45	4.48	0.54	58.22
L19	39.62	99.86	12.01	8.27	1.03	108.25
L20	24.19	60.62	7.27	5.05	0.60	65.67
Maximum	39.62	99.86	12.01	8.27	1.03	108.25
Minimum	10.36	26.23	3.16	2.20	0.29	28.36
Average	22.59	56.91	6.84	4.74	0.59	61.70
GM	21.36	53.83	6.47	4.49	0.57	58.34
SD	7.63	19.23	2.30	1.60	0.17	20.92

4.2 Dose assessment

The dose components increase systematically with ^{222}Rn concentration because the adopted dose model is concentration-dependent. The reported inhalation component ranged from 26.23 to 99.86, while the ingestion component ranged from 2.20 to 8.27; the corresponding total values ranged from 28.36 to 108.25. The highest total value occurs at L19, consistent with its maximum radon concentration, whereas L17 gives the minimum total value. This monotonic relationship provides an internal consistency check on the spreadsheet calculations. Radon released from water during domestic use can contribute to indoor-air exposure. WHO guidance emphasizes that the inhalation pathway from radon released into indoor air is generally more important than direct ingestion for drinking-water radon exposure. Therefore, the present findings should be interpreted as an environmental exposure assessment rather than evidence of a direct health effect in the sampled population. [2]

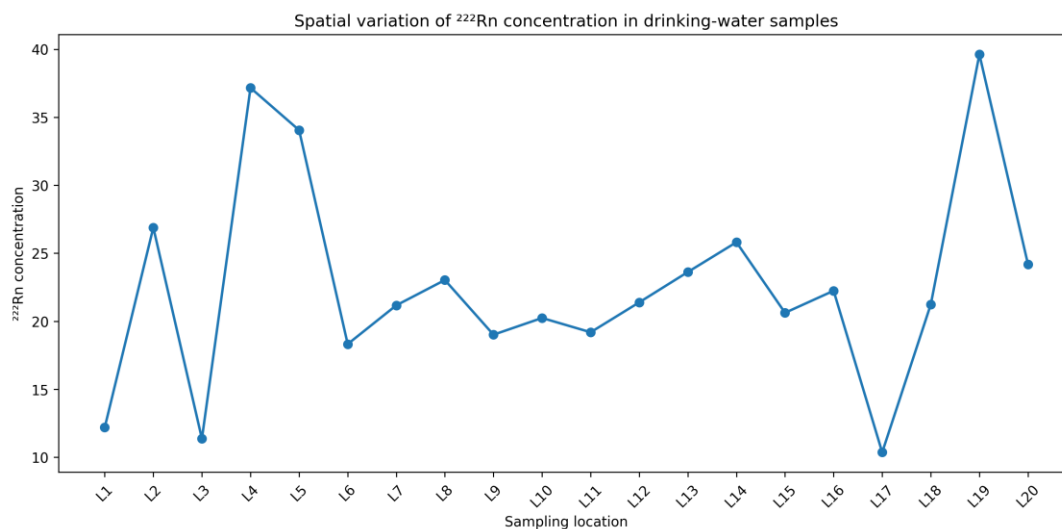


Fig. 4. Spatial variation of corrected ^{222}Rn activity concentration in Drinking-water samples from L1–L20.

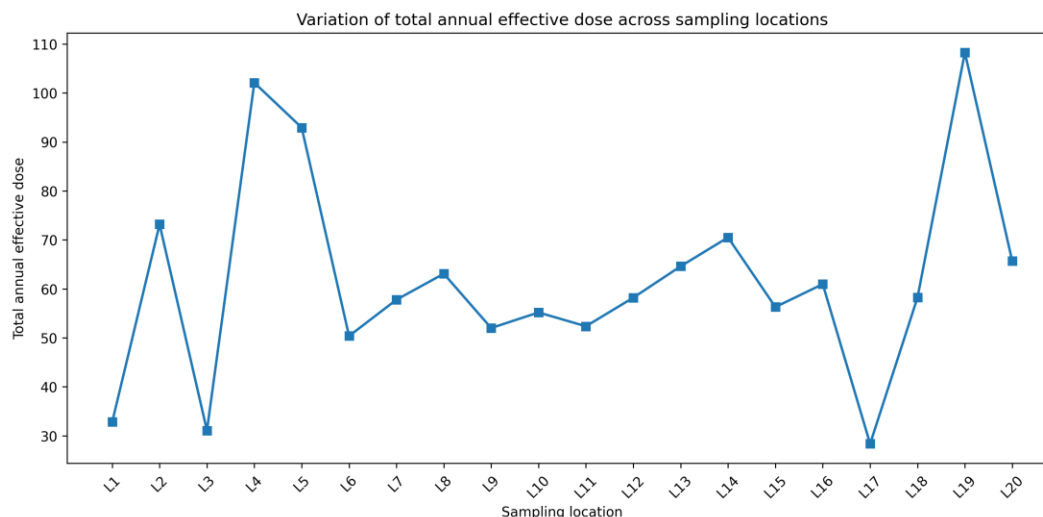


Fig. 5. Spatial variation of the corrected total dose component reported for the sampled locations.

4.3 Comparison with guidance values

The measured concentrations should not be compared with a single value as though it were a universal international limit. The United States Environmental Protection Agency proposed a maximum contaminant level (MCL) of 300 pCi L⁻¹ (approximately 11.1 Bq L⁻¹) for radon in public drinking water in its 1999 proposed rule. WHO guidance recommends that national screening levels be established in relation to the national reference level for radon in air; therefore, drinking-water screening values should not be presented as universal health-based limits. ^[9,13]

5. Conclusion

The ²²²Rn activity concentrations in the 20 investigated drinking-water samples ranged from 10.36 to 39.62 Bq L⁻¹, with an arithmetic mean of 22.59 Bq L⁻¹, indicating appreciable spatial variability. The observed variation is plausibly associated with differences in lithology, mineral composition, weathering, fracturing, groundwater residence time, and water–rock interaction, although these controls were not independently quantified in the present study. The corrected dose dataset shows a consistent increase in inhalation, ingestion, organ-related, and total dose components with increasing ²²²Rn concentration, with the highest values occurring at L19. The results provide a useful baseline for environmental radiation surveillance, but the dose coefficients and units should be explicitly verified against the original calculation sheet before journal submission. ^[1,2]

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