

Radon-222 in Groundwater from Dodoma City: Concentrations and Dose Assessment

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1. Introduction

Radon-222 (^{222}Rn) is produced in the uranium-238 decay series and may migrate from radium-bearing rocks into groundwater. Exposure occurs through ingestion and inhalation after release from water during household use [1,2]. Previous Tanzanian studies focused mainly on soil-gas or occupational mine-air radon, whereas dissolved radon in domestic groundwater remains insufficiently investigated. Dodoma City is semi-arid, depends extensively on groundwater and is underlain by a weathered and fractured crystalline basement aquifer [3]. These conditions can produce source-to-source variation, yet baseline information on dissolved ^{222}Rn and related doses in domestic groundwater remains limited. This study assessed groundwater ^{222}Rn , estimated doses, and compared results with relevant reference criteria.

2. Materials and Methods

2.1 Sampling and Measurement

Sampling was conducted in July 2025 during the dry season. One sample was collected directly from a tap at each of 21 boreholes and 12 shallow wells used for domestic supply. The ten wards and sources were purposively selected for spatial coverage, source availability, community use and accessibility. Airtight glass bottles were filled to overflow, sealed without headspace and analysed within 12 h. A 100 mL aliquot was measured using an AlphaGUARD PQ2000 PRO coupled to AquaKIT and AlphaPUMP [4]. The closed loop was operated at 0.5 L min^{-1} . Background was recorded for 10 min, followed by 1 min readings for approximately 20 min. Calculations used a system volume of 1102 mL, a sample volume of 100 mL and a water-to-air partition coefficient of 0.26. Results were background corrected, converted to water concentration and decay corrected to sampling time. The loop was flushed between samples to minimise carry-over.

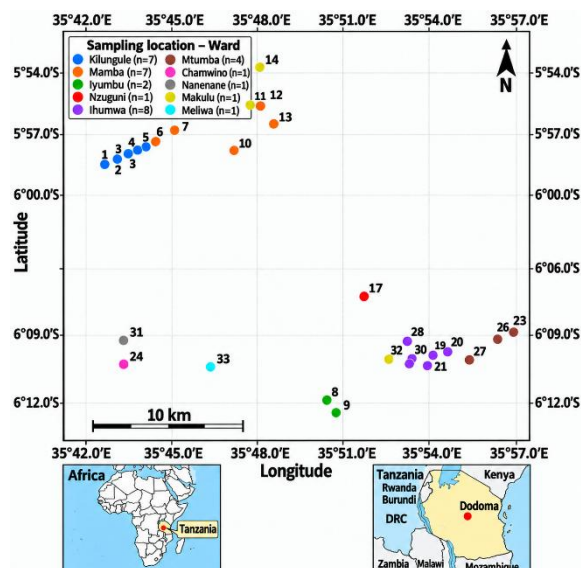


Fig. 1. Locations of the 33 sampled groundwater sources across ten wards of Dodoma City.

2.2 Dose and Data Analysis

Annual ingestion dose used an intake of 730 L y^{-1} and a coefficient of 3.5 nSv Bq^{-1} . Inhalation dose used a water-to-air transfer factor of 0.1 Bq m^{-3} per Bq L^{-1} , an equilibrium factor of 0.4, indoor occupancy of 7000 h y^{-1} and a dose conversion factor of 12 nSv h^{-1} per Bq m^{-3} [1,2]. Total dose was the sum of both pathways. Minimum, maximum, mean, standard deviation (SD) and ward-level ranges were calculated. Ward means were used only for $n > 1$; $n = 1$ denotes one source. Ward comparisons were descriptive because sample sizes were small and unequal. Concentrations were compared with the USEPA proposed Maximum Contaminant Level (MCL) of 11.1 Bq L^{-1} as a comparative reference [5]. Total annual effective doses were compared with the WHO individual dose criterion (IDC) of 0.1 mSv y^{-1} . For additional radiological context, doses were also compared with approximately 1 mSv y^{-1} , which WHO discusses for drinking-water in existing exposure situations [2].

3. Results and Discussion

3.1 Radon Concentration Results

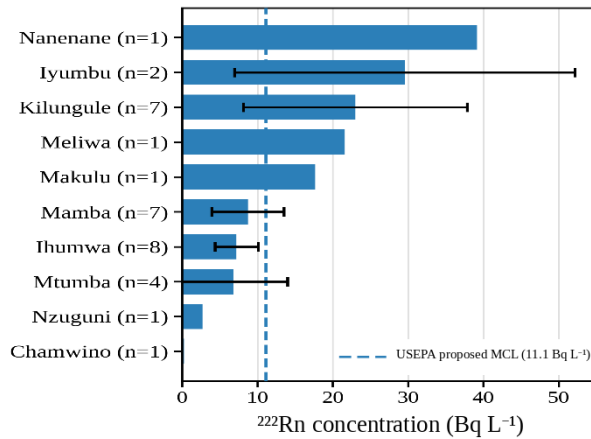


Fig. 2. Ward values; means for $n > 1$, single-source values for $n = 1$; error bars: SD ($n > 1$); dashed: USEPA proposed MCL (11.1 Bq L⁻¹).

^{222}Rn concentrations ranged from 0.2 to 49.4 Bq L⁻¹ (13.6 ± 12.5 Bq L⁻¹), with the maximum individual concentration measured in Kilungule and the minimum in Chamwino. 14 of 33 samples (42.4%) were above the USEPA proposed MCL of 11.1 Bq L⁻¹. Values for $n = 1$ represent individual sampled sources rather than ward means, while summaries for $n = 1-2$ should be interpreted descriptively.

By source type, boreholes ($n = 21$) had higher ^{222}Rn concentrations (19.5 ± 12.2 Bq L⁻¹) than shallow wells ($n = 12$; 3.3 ± 2.1 Bq L⁻¹). All 14 samples above the USEPA proposed MCL were from boreholes. The higher concentrations observed in boreholes may be associated with longer water-rock contact and reduced radon loss, although the roles of source depth, residence time, and aquifer geochemistry could not be evaluated in this study.

Table I. Ward-level ^{222}Rn concentration and total annual effective dose (mean $\pm$ SD for $n > 1$; $n = 1$: single-source result)

Ward	n	^{222}Rn (Bq L ⁻¹)	Range (Bq L ⁻¹)	Total dose ($\mu\text{Sv y}^{-1}$)
Chamwino	1	0.20	0.20 - 0.20	1.2
Ihumwa	8	7.22 ± 2.87	2.61 - 10.59	42.7
Iyumbu	2	29.56 ± 22.61	13.57 - 45.54	174.8
Kilungule	7	23.00 ± 14.87	2.70 - 49.40	136.1
Makulu	1	17.68	17.68 - 17.68	104.7
Mamba	7	8.73 ± 4.80	2.31 - 14.60	51.6
Meliwa	1	21.59	21.59 - 21.59	127.8
Mtumba	4	6.81 ± 7.19	0.70 - 16.24	40.2
Nanenane	1	39.20	39.20 - 39.20	231.9
Nzuguni	1	2.71	2.71 - 2.71	16.0
Overall	33	13.60 ± 12.53	0.20 - 49.40	80.4

3.2 Dose Assessment and Radiological Significance

Measured ^{222}Rn concentrations were converted to ingestion and inhalation doses using the exposure factors in Section 2.2, and total annual effective dose was calculated as their sum. Nine samples (27.3%) had total annual effective doses above the WHO individual dose criterion (IDC) of 0.1 mSv y⁻¹ [2]. All estimated doses remained below approximately 1 mSv y⁻¹ [2]. At the overall mean concentration, ingestion, inhalation and total annual effective doses were 34.7, 45.7 and 80.4 $\mu\text{Sv y}^{-1}$, respectively.

The maximum concentration of 49.4 Bq L⁻¹ was about 4.5 times the USEPA proposed MCL. Under the assumed exposure parameters, inhalation contributed about 57% of the mean estimated total dose [1,2]. The nine samples with total annual effective doses above 0.1 mSv y⁻¹ warrant confirmatory assessment.

3.3 Limitations and Groundwater Management

The concentration pattern indicates substantial local variability. Previous hydrogeological studies support a regional interpretation involving groundwater movement through weathered and fractured crystalline aquifers in Dodoma [3]. Differences in lithology, fracture density,

groundwater residence time and circulation may influence radon accumulation. However, borehole depth, aquifer uranium content, fracture characteristics and groundwater residence time were not directly measured at the sampled sources. These factors therefore cannot be confirmed as the causes of the observed radon variation. Household ventilation was also not measured, limiting source-specific assessment of inhalation exposure. Nanenane, Makulu, Meliwa, Nzuguni and Chamwino each had only one sampled source; these are single-source results and should not be considered representative of the entire ward. The study covered only the July 2025 dry season, and dose estimates used standard exposure factors rather than locally measured water-use, occupancy and ventilation conditions. Because Dodoma is semi-arid, actual drinking-water consumption may differ from the assumed intake, while household occupancy and ventilation can vary with dwelling design, season and daily practices. Consequently, the standardized exposure factors may under- or overestimate individual ingestion and inhalation doses. These limitations support cautious interpretation and repeated seasonal assessment.

Measured ^{222}Rn concentrations ranged from 0.2 to 49.4 Bq L⁻¹, with associated uncertainties of 0.13 to 3.52 Bq L⁻¹. Follow-up should prioritise Nanenane, Iyumbu and Kilungule, repeat wards represented by one source, cover wet and dry seasons, and consider aeration, storage before use, or lower-radon sources where elevated values persist.

4. Conclusions

Groundwater used for domestic supply in Dodoma City contained 0.2 to 49.4 Bq L⁻¹ of ^{222}Rn and showed marked variation among the sampled groundwater sources. Overall, 42.4% of samples exceeded the USEPA proposed MCL of 11.1 Bq L⁻¹ [5], while 27.3% had total annual effective doses above the WHO individual dose criterion (IDC) of 0.1 mSv y⁻¹ [2]. All estimated doses remained below approximately 1 mSv y⁻¹ [2]. The study provides baseline data for groundwater sources in Dodoma City and identifies locations warranting confirmatory and seasonal monitoring. Repeated wet and dry season monitoring, confirmation of wards represented by one source, and practical mitigation for persistently elevated sources would strengthen groundwater safety management.

ACKNOWLEDGEMENT

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