Discover Applied Sciences

RESEARCH Open Access

Investigation of radionuclide concentration in Ildabey water source Eyl Somalia

Afam Uzorka[1*], Musa Bawa[1], Sharmarke Abdullahi Mohamed[1], Ademola Olatide Olaniyan[1] and Living Ounyesiga[1]

*Correspondence:
Afam Uzorka
afamuzorka@gmail.com
[1]Department of Physical Sciences, School of Natural and Applied Sciences, Kampala International University, Kampala, Uganda

Abstract

The presence of naturally occurring radionuclides in drinking water can lead to long-term health risks from internal radiation exposure. Therefore, conducting a radiological assessment of water sources is essential to evaluate potential hazards, ensure public safety, and verify compliance with international health guidelines. This study investigates the concentrations of radionuclides and associated radiological hazards in the Ildabey water source, located in Eyl, Somalia. Water samples were collected from three zones (Zone A—initial flow, Zone B—rocky downstream, Zone C—stagnant storage) to represent varying geological and hydrological conditions. High-Purity Germanium (HPGe) gamma-ray spectroscopy was used to quantify activity concentrations of Uranium-238 (^{238}U), Thorium-232 (^{232}Th), Radium-226 (^{226}Ra), Radon-222 (^{222}Rn), and Potassium-40 (^{40}K), while a Liquid Scintillation Counter measured gross alpha and beta radiation. The results showed ^{238}U concentrations ranging from 3.50 ± 0.97 to 9.30 ± 1.17 Bq/l, and ^{226}Ra from 0.60 ± 0.07 to 2.70 ± 0.93 Bq/l, with some values exceeding World Health Organization (WHO) recommended limits. The committed effective dose (CED) due to ingestion ranged from 0.4301 to 1.1344 mSv/year, with an average of 0.7005 mSv/year, significantly surpassing the WHO guideline of 0.1 mSv/year. Radiological hazard indices such as radium equivalent activity, external and internal hazard indices were also computed, confirming the presence of moderate radiological risk. These findings underscore the need for regular radiological monitoring and public health interventions to ensure the safety of water used for human consumption in the region.

Article Highlights

- Radionuclide levels in water samples from Eyl, Somalia water stayed within WHO safety limits.
- External radiation risk is low, but long-term intake may pose health concerns.
- Regular testing and safety measures are needed to protect public health in the region.

Keywords Radionuclides, Water contamination, Radiological risk, Somalia

1 Introduction

Water is a fundamental resource for human survival, yet its quality can be affected by various environmental and geological factors, including the presence of naturally occurring radioactive materials (NORMs). Radionuclides such as uranium-238 (^{238}U), thorium-232 (^{232}Th), radium-226 (^{226}Ra), radon-222 (^{222}Rn), and potassium-40 (^{40}K) can dissolve into groundwater from surrounding rock formations, posing potential health risks when consumed over extended periods [11, 13, 33]. Chronic exposure to these radionuclides has been linked to increased risks of cancer, kidney disease, and other radiological health effects [9, 24, 30].

Radionuclides in groundwater originate from igneous, metamorphic, and sedimentary rocks containing uranium and thorium deposits. According to Vengosh et al. [34], the concentration of radionuclides in water depends on factors such as rock type, water-rock interaction, and hydrogeological conditions. Similarly, Akortia et al. [1] reported that ^{232}Th concentrations in groundwater varied depending on mineralogical composition, with higher levels in areas with phosphate-rich rocks. Studies in coastal regions have also shown variations in radionuclide concentrations due to sediment deposition and seawater intrusion. Research by Salama et al. [26] in Egypt found that groundwater near coastal zones contained higher radon (^{222}Rn) levels, possibly due to radioactive decay in aquifer sediments. This is relevant to Eyl, Somalia, as its proximity to the Indian Ocean may influence radionuclide concentrations in its groundwater sources.

Exposure to ^{238}U and ^{226}Ra through drinking water has been linked to nephrotoxicity and increased risks of bone cancer, as these radionuclides tend to accumulate in the kidneys and bones [20, 23]. Radon (^{222}Rn) exposure is of particular concern because it is a gaseous radionuclide that can be inhaled or ingested, increasing lung cancer risk [2, 27]. The World Health Organization (WHO) has established guideline limits for these radionuclides in drinking water to minimize health risks, recommending a maximum of 10 Bq/L for ^{238}U and 1.0 Bq/L for ^{226}Ra [6].

Several studies have assessed radionuclide concentrations in African groundwater. In Kenya, Kilavi et al. [17] reported ^{238}U concentrations ranging from 0.2 to 16.7 Bq/L, while in Sudan, Othman & Asaad [22], found that radon levels in some water sources exceeded WHO safety limits. A study by Godwin et al. [12] in Nigeria found ^{238}U and ^{224}Ra concentrations ranging from 5.41 ± 1.37 Bq/l to 1.36 ± 0.51 Bq/l Bq/L and 5.75 ± 1.30 Bq/l to 1.95 ± 0.58 Bq/l, respectively, in drinking water, highlighting the need for continuous monitoring. Comparatively, limited studies have been conducted in Somalia, highlighting the need for research in this region. Given Somalia's complex geology, including uranium-rich rock formations, understanding radionuclide distribution in its water sources is critical.

Despite extensive studies on radionuclides in water globally, there is a lack of data on radionuclide contamination in Somali water sources, particularly in Eyl. The Ildabey water source in Eyl, Somalia, is a primary drinking water supply for the local community. However, the geological characteristics of the region, which may contain uranium-rich rock formations, raise concerns about potential radioactive contamination. Without proper assessment, long-term exposure to radioactive contaminants could pose serious health threats to the population. This study aims to address this gap by investigating the concentration of radionuclides and the levels of alpha and beta radioactivity in the Ildabey water source. This study aims to determine the concentration of the radionuclides

^{238}U, ^{232}Th, ^{226}Ra, ^{222}Rn, and ^{40}K in water samples from the Ildabey water source and to identify the rate of alpha and beta radioactivity in this water source.

By evaluating radionuclide concentrations and alpha and beta radioactivity levels, this research will contribute to the scientific understanding of radiological water safety in Somalia, aligning with global efforts to monitor and mitigate environmental radioactivity. In addition, this study will provide baseline data for policymakers and health officials, ensuring safe drinking water for the local population.

2 Methodology

2.1 Study area

This study is conducted in Eyl, Somalia, specifically focusing on the Ildabey water source, which is used by the local population for drinking and other domestic purposes. Eyl, Somalia, located at approximately latitude 7.9833° N and longitude 49.8167° E, is a coastal town in the northeastern Nugal region of Puntland [25]. Figure 1 shows the geographical location of Eyl, Somalia. Positioned along the Indian Ocean, Eyl has historically been known for its fishing and trade activities and has also gained attention for archaeological sites, drawing interest from researchers and tourists alike. The town is further noted for its natural water sources, including the Ildabey water source, which is essential for the local community's domestic and agricultural needs.

Fig. 1 Geographical location of Eyl Somalia

Fig. 2 Representative sample locations (**A**, **B**, and **C**)

Table 1 Study zones overview—Ildabey water source, Eyl, Somalia

Zone	GPS coordinates	Description	Physical observations
Zone A	7.9833° N, 49.8167° E	Initial water flow source	Clear, undisturbed water Minimal contact with rocks or sediments Low turbidity
Zone B	7.9833° N, 49.81761° E	Rocky downstream flow	Moderate turbulence Contact with mineral-rich rocks Increased potential for radionuclide leaching
Zone C	7.9833° N, 49.81761° E	Water collection and storage area	Stagnant water Presence of sand and sediment Potential for ^{222}Rn accumulation and sediment-bound radionuclides

2.2 Sampling procedure

To investigate radioactive radiation levels, water samples were collected from predetermined locations across the Ildabey water source in Eyl, Somalia. Three distinct water source locations, designated as Zone A, Zone B, and Zone C (Fig. 2), were selected for this study. From each zone, four samples (S1, S2, S3, and S4) were collected at various points to ensure comprehensive coverage. The collected water samples were filtered to remove any suspended solids using a filtration system. The samples were carefully labeled to maintain representation and traceability. The sampling procedure was repeated three times for each location to enhance the reliability and accuracy of the findings.

Table 1 describes the study zones. Zone A serves as a baseline to assess natural background radionuclide levels. Zone B highlights the impact of geological interaction on radionuclide enrichment. Zone C allows evaluation of accumulation and sedimentation effects over time.

2.3 Measurement of radionuclides concentrations and alpha and beta activity concentrations

A coaxial p-type High-Purity Germanium (HPGe) detector, CANBERRA GC4020 model, with Relative Efficiency of 40%, Energy Resolution ~ 1.8 keV at 1332 keV, Energy Range of 50 keV to 3 MeV and Electrically powered cryocSooler (X-Cooler II) (Fig. 3), was used to measure the concentrations of radionuclides (^{238}U, ^{232}Th, ^{222}Rn and ^{40}K) in the water samples.

Water samples were collected in 1-liter Marinelli beakers and sealed for 30 days to ensure secular equilibrium between parent and progeny radionuclides. Each sample was

Fig. 3 Gamma-ray spectrometry

placed on the HPGe detector inside a low-background lead shielding chamber (≥ 10 cm thickness) to minimize cosmic and environmental interference. Data acquisition system (MCA – multichannel analyzer) interfaced with GENIE-2000 software was used for spectrum collection and radionuclide identification.

Samples were counted for at least 80,000–100,000 s (22–28 h) to ensure statistical significance [15], especially for low-activity radionuclides. The net peak areas of gamma lines were calculated and corrected for background radiation. The specific activity A (Bq/L) for each radionuclide was calculated using [7]:

$$A = \frac{N}{\epsilon \,.\, I_\gamma \,.\, t.\, V} \tag{1}$$

where: N = net peak count rate (counts/s); ε = detector efficiency at that energy; Iγ = gamma emission probability; t = counting time (s); V = volume of the water sample (L).

Energy calibration was performed using a standard mixed gamma source (e.g., Eu-152, Co-60, Cs-137) to relate known gamma energies to channel numbers in the spectrum [32]. Efficiency vs. energy curve was established using calibrated aqueous standard solutions in Marinelli geometry, provided by International Atomic Energy Agency (IAEA). Efficiency calibration was validated using certified reference materials (CRMs), International Atomic Energy Agency – Reference Geological Uranium Standard 1 (IAEA-RGU-1), for natural radionuclides in environmental matrices.

As shown in Table 2, each radionuclide is characterized by specific energy values.

Radon-222 was calculated using [8, 19]:

$$C_{R_n} = C_{R_a}[1 - \exp(-\lambda_{R_n} \times T_d)] \tag{2}$$

.

Table 2 Energies used to identify specific radionuclides

Radionuclide	Gamma energy (keV)	Emission probability (%)	Comments
U-238 (via ^{234}Pa and ^{214}Bi)	351.9 (^{214}Pb), 609.3 (^{214}Bi), 1120.3 (^{214}Bi)	35.8%, 46.1%, 14.9%	Used after secular equilibrium (30 days)
Th-232 (via ^{228}Ac and ^{212}Pb)	338.4 (^{228}Ac), 911.2 (^{228}Ac), 583.2 (^{208}Tl)	12.5%, 29.0%, 85.0%	Used after equilibrium
Ra-226	186.2 keV	3.5%	Note: overlaps with ^{235}U, needs deconvolution
Rn-222	Not directly measured (see below)	–	Discussed separately
K-40	1460.8 keV	10.7%	Used directly

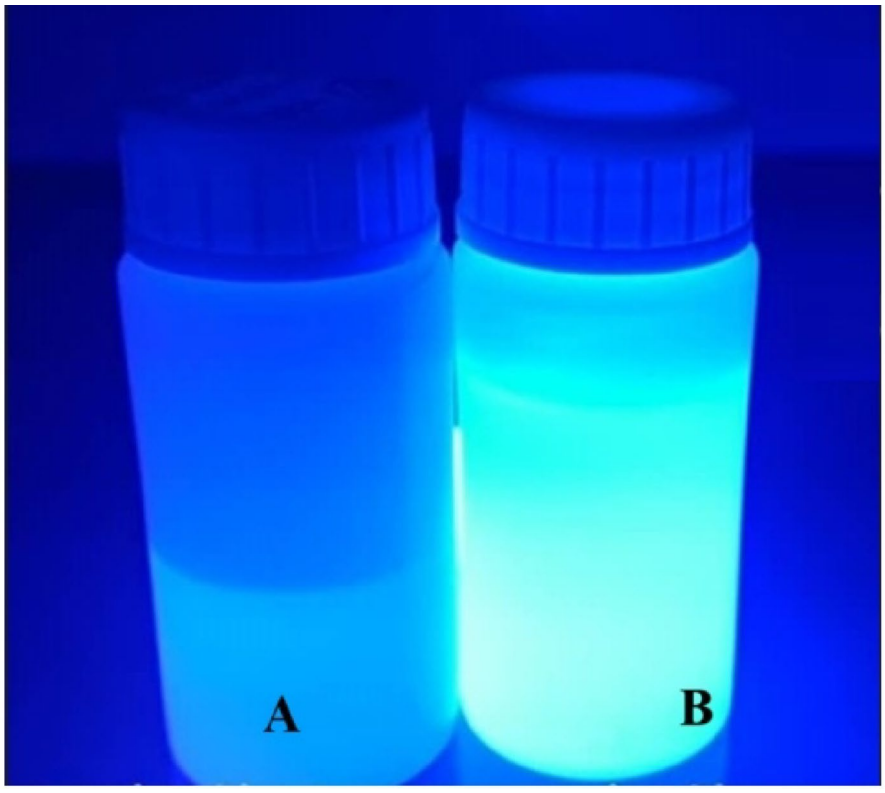

Fig. 4 **A** shows liquid without scintillation cocktail and **B** show liquid with scintillation cocktail

C_{R_n} and C_{R_a} are the activity concentrations of ^{222}Rn and ^{226}Ra in Bq/l respectively, λ_{R_n} is the decay constant of ^{222}Rn and T_d is the delay time between sampling and counting.

Liquid Scintillation Counter, PerkinElmer Tri-Carb 4910 TR model, Triple-to-double coincidence ratio (TDCR) for low-background counting, 20 mL low-potassium glass vials, (Fig. 4) was used to measure the alpha and beta radioactivity in a water samples. Ultima Gold AB (alpha-beta discrimination) scintillation cocktail was used.

Samples were prepared by mixing 10 ml of water sample with 10 ml scintillation cocktail [5, 14], Vials sealed to prevent radon escape, and samples dark-adapted for 2 h before counting. Each sample counted for 1,000–2,000 s. Background readings taken with blank samples. Alpha/beta separation is achieved through pulse shape analysis and TDCR logic.

Calibration standards used was Am-241 for alpha, Sr-90/Y-90 for beta [28]. Quench correction curves established using internal quench standards. System calibrated using automatic quench correction and external standard (Ba-133).

pH Meter was used to measure the pH of the water samples.

2.3.1 Quality control and low-level detection measures

Background control: dedicated low-background chamber; daily background checks; blanks and procedural blanks included with each batch.

Recovery and efficiency testing: Known activity spikes added to random samples; Percent recovery calculated (acceptable range 85–115%).

Detection limit assessment: Assessed monthly and after maintenance.

Replicate counting: 10% of samples were duplicated; Standard deviation monitored (< 5% variability).

2.4 Evaluation of radiological hazards effect

To determine the amount of radioactive hazard in the selected water samples, several risk indicators were computed, including:

Radium equivalents (Ra_{eq}): It is described as the sum of the ratios of the radioactive concentration of the radionuclides ^{238}U, ^{232}Th, ^{222}Rn and ^{40}K which are calculated using the following formula [3, 21].

$$\mathrm{Ra._{eq}\ (Bq/l)} \;=\; \mathrm{C_u} + \;1.43\ \mathrm{C_{Th}} + \;0.077\mathrm{C_k} \tag{3}$$

C_U: Activity concentration of ^{238}U in Bq/l; C_{Th}: Activity concentration of ^{232}Th in Bq/l; C_k: Activity concentration of ^{40}K in Bq/l.

The coefficients in the formula (1, 1.43, and 0.077) are derived from the approximate hazard equivalencies of these radionuclides, with ^{238}U taken as the baseline (coefficient = 1).

Internal (H_{in}) and Externals (H_{ex}): The external and internal risk levels (H_{ex}. & H_{in}.) Are calculated using the following equations [10, 30, 31]:

$$\mathrm{H_{ex}} = \sum \frac{C_i}{A_i} \tag{4}$$

C_i: Activity concentration of radionuclide i in Bq/l, A_i: Reference activity concentration that represents the maximum allowable activity of radionuclide *i* for external exposure (370 for ^{238}U, 259 ^{232}Th, and 4810 for ^{40}K).

$$\mathrm{H_{in}} = \sum \frac{C_i}{B_i} \tag{5}$$

C_i: Activity concentration of radionuclide *i* in Bq/l; B_i: Reference activity concentration for internal exposure for radionuclide *i* (185 for ^{238}U, 259 ^{232}Th, and 4810 for ^{40}K).

Committed Effective Dose (CED): Committed Effective Dose (CED) is the effective dose over a period of 50 years (for adults) after intake of a radionuclide, measured in millisieverts (mSv). Committed Effective Dose (CED) is calculated according to the following formula [16]:

$$CED\ (Sv) = A \times IR \times DC \tag{6}$$

Table 3 Physiochemical parameters of Ildabey water source

Samples code	Parameters		
	PH of the sample	Conductivity (μ/Cm)	TDS (mg/l)
S1ZA	6.73	463	310.21
S2ZA	6.75	467	312.89
S3ZA	6.78	488	326.96
S4ZA	7.2	497	332.99
S1ZB	7.2	497	332.99
S2ZB	8.0	542	363.14
S3ZB	7.7	523	350.41
S4ZB	7.4	508	340.36
S1ZC	6.82	494	330.98
S2ZC	6.84	496	332.32
S3ZC	6.87	499	334.33
S4ZC	6.89	505	338.35

Table 4 Activity concentrations of radionuclides in water samples (Bq/l)

Sample code	^{238}U	^{226}Ra	^{222}Rn	^{232}Th	^{40}K
S1ZA	7.83 ± 1.30	2.70 ± 0.93	1.70 ± 0.91	0.46 ± 0.23	10.95 ± 0.34
S2ZA	4.63 ± 1.31	0.90 ± 0.13	3.50 ± 0.31	0.56 ± 0.36	29.60 ± 0.41
S3ZA	3.50 ± 0.97	1.20 ± 0.15	3.07 ± 0.73	0.67 ± 0.17	8.70 ± 0.72
S4ZA	5.80 ± 0.37	0.78 ± 0.07	2.50 ± 0.78	0.95 ± 0.19	13.14 ± 0.20
S1ZB	7.11 ± 0.41	1.05 ± 0.21	3.00 ± 0.11	1.17 ± 0.98	15.60 ± 0.37
S2ZB	4.20 ± 1.12	0.60 ± 0.07	3.60 ± 0.83	1.80 ± 0.89	17.90 ± 0.21
S3ZB	8.03 ± 1.33	2.40 ± 0.95	1.25 ± 0.39	1.63 ± 0.75	21.65 ± 0.45
S4ZB	6.90 ± 1.19	2.10 ± 0.71	1.96 ± 0.42	2.85 ± 1.03	16.30 ± 0.89
S1ZC	3.80 ± 1.39	1.70 ± 0.17	4.05 ± 0.51	1.19 ± 0.91	10.05 ± 0.93
S2ZC	7.35 ± 0.79	1.11 ± 0.09	2.88 ± 0.79	1.53 ± 0.77	12.34 ± 0.42
S3ZC	9.30 ± 1.17	1.93 ± 0.61	2.73 ± 0.66	0.78 ± 0.32	13.80 ± 0.37
S4ZC	6.85 ± 1.78	0.80 ± 0.18	1.56 ± 0.37	2.25 ± 0.99	16.50 ± 0.29
Max	9.30 ± 1.17	2.70 ± 0.93	4.05 ± 0.51	2.85 ± 1.03	29.60 ± 0.41
Min	3.50 ± 0.97	0.60 ± 0.07	1.25 ± 0.39	0.46 ± 0.23	8.70 ± 0.72
WHO guide line	10.00	1.00	100.00	1.00	Not limited

Where: A = Activity concentration of the radionuclide in water (Bq/L); IR = Ingestion rate (L/year). Typically: 730 L/year (2 L/day × 365 days); DC = Dose coefficient (Sv/Bq) from ingestion, ICRP Publication 119 [29].

3 Results

Table 3 shows the physiochemical parameters of the water samples. The TDS range from 310.21 to 363.14 mg/L. The pH values range from 6.73 to 8.00.

Table 4 presents the activity concentrations of radionuclides in water samples (Bq/l) and the WHO guideline [6]. Uranium-238 (^{238}U) concentrations vary from 3.50 ± 0.97 Bq/l (S3ZA) to 9.30 ± 1.17 Bq/l (S3ZC), with the maximum value being 9.30 Bq/l and the minimum value being 3.50 Bq/l. Generally, the levels seem to be moderately spread across the samples. Radium-226 (^{226}Ra) concentrations range from 0.60 ± 0.07 Bq/l (S2ZB) to 2.70 ± 0.93 Bq/l (S1ZA). The variation is noticeable, but this radionuclide is generally present at lower levels compared to ^{238}U. Radon-222 (^{222}Rn) shows some fluctuation, with concentrations ranging from 1.25 ± 0.39 Bq/l (S3ZB) to 4.05 ± 0.51 Bq/l (S1ZC). The concentration of Thorium-232 (^{232}Th) ranges from 0.46 ± 0.23 Bq/l (S1ZA) to 2.85 ± 1.03 Bq/l (S4ZB). Potassium-40(^{40}K) is the

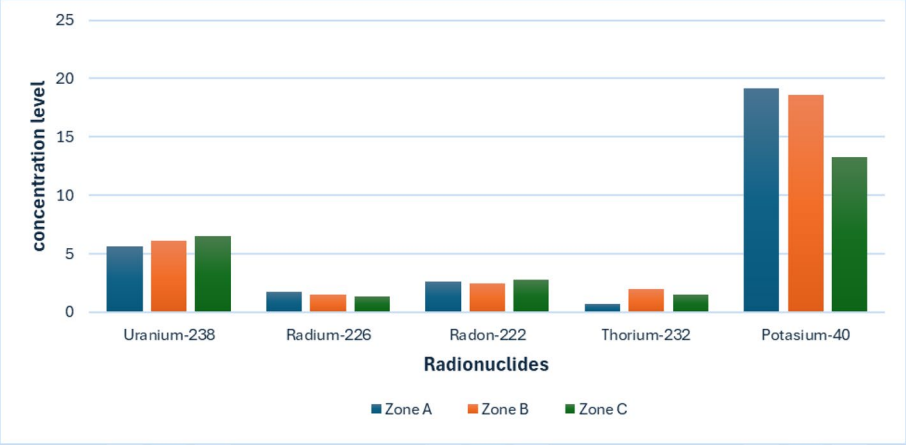

Fig. 5 Radionuclide concentration trends

Table 5 ANOVA results for radionuclide concentrations in water samples

Radionuclide	*F*-statistic	*p*-value
^{238}U	0.573	0.583
^{226}Ra	0.049	0.953
^{222}Rn	0.142	0.870
^{232}Th	4.765	0.039
^{40}K	0.629	0.555

Table 6 Tukey's HSD test results for ^{232}Th concentration across zones

Group 1	Group 2	Mean difference	*p*-value	95% CI	Significant difference?
Zone A	Zone B	1.2025	0.0338	0.0995–2.3055	Yes ($p < 0.05$)
Zone A	Zone C	0.7775	0.1758	0.1758–1.8805	No
Zone B	Zone C	-0.4250	0.5514	0.5514–0.6780	No

most abundant radionuclide in the dataset, ranging from 8.70 ± 0.72 Bq/l (S3ZA) to 29.60 ± 0.41 Bq/l (S2ZA). Potassium-40 concentrations are generally high across the samples.

Figure 5 shows the radionuclide concentration trends. Zone A has low Thorium-232 (0.46–0.95 Bq/l) and a high Potassium-40 peak (29.60 Bq/l), suggesting mixed geological substrates with less granitic influence and potential feldspar or clay minerals. Zone B shows the highest Thorium-232 (up to 2.85 Bq/l), indicating granitic/metamorphic rocks with balanced igneous-sedimentary influences. Zone C has the highest Uranium-238 (9.30 Bq/l), pointing to uranium-rich formations, porous rocks, and moderate granite influence.

The ANOVA test was conducted to determine if there are statistically significant differences in radionuclide concentrations among the three zones (A, B, and C). Table 5 presents the ANOVA result.

There is no significant difference in the concentrations of ^{238}U, ^{226}Ra, ^{222}Rn, and ^{40}K among the three zones. ^{232}Th shows a statistically significant difference ($p = 0.039$), suggesting that its concentration varies notably between at least two zones.

Tukey's HSD test was conducted to identify which specific zones differ for ^{232}Th. Table 6 presents the Tukey's HSD test results for ^{232}Th concentration across zones. There is a statistically significant difference in ^{232}Th concentration between Zone A and Zone

Table 7 Alpha and beta concentration in the samples

Sample code	Alpha values	Beta values
S1ZA	0.016 ± 0.007	0.037 ± 0.009
S2ZA	0.015 ± 0.006	0.051 ± 0.007
S3ZA	0.011 ± 0.005	0.003 ± 0.002
S4ZA	0.012 ± 0.005	0.034 ± 0.006
S1ZB	0.035 ± 0.011	0.025 ± 0.010
S2ZB	0.045 ± 0.015	0.045 ± 0.010
S3ZB	0.030 ± 0.010	0.037 ± 0.009
S4ZB	0.017 ± 0.006	0.034 ± 0.008
S1ZC	0.034 ± 0.005	0.055 ± 0.007
S2ZC	0.025 ± 0.009	0.024 ± 0.010
S3ZC	0.019 ± 0.008	0.044 ± 0.010
S4ZC	0.015 ± 0.006	0.036 ± 0.009
Maximum	0.045 ± 0.015	0.055 ± 0.007
Minimum	0.011 ± 0.005	0.003 ± 0.002
Average	0.0228 ± 0.003	0.0354 ± 0.0024
WHO guide line [4]	0.50	1.00

Table 8 ANOVA results for alpha and beta radioactivity in water samples

Parameter	*F*-statistic	*p*-value	Interpretation
Alpha activity	4.777	0.0386	Significant difference ($p < 0.05$)
Beta activity	0.334	0.7242	No significant difference across zones

Table 9 Tukey's HSD test results for alpha radiation across zones

Group 1	Group 2	Mean difference	*p*-value	95% CI	Significant difference?
Zone A	Zone B	0.0183	0.0315	0.0018–0.0347	Yes (**$p < 0.05$p**)
Zone A	Zone C	0.0098	0.2754	−0.0067–0.0262	No
Zone B	Zone C	-0.0085	0.3631	−0.0250–0.0080	No

B, meaning Zone B has significantly higher thorium levels compared to Zone A. No significant differences were found between Zone A & Zone C or Zone B & Zone C. This suggests that thorium-232 concentration is notably affected in Zone B, possibly due to geological factors.

Table 7 shows the alpha and beta concentration in the samples. There were no collected water samples that exceeded the WHO screening levels for gross alpha and beta activity of 0.5 Bq/L and 1.0 Bq/L respectively.

Table 8 shows the ANOVA results for Alpha and Beta radioactivity in water samples. Alpha radiation levels differ significantly among the zones ($p = 0.0386$). Beta radiation levels do not show significant variation ($p = 0.7242$), indicating uniform beta activity across the zones.

Tukey's HSD test was carried out to pinpoint which zones have significantly different alpha radiation levels. Table 9 shows the Tukey's HSD test for alpha radiation across all zones. Zone A and Zone B have a significant difference in alpha radiation levels, with Zone B having higher alpha activity. No significant differences were found between Zone A & Zone C or Zone B & Zone C. This suggests that Zone B has significantly higher alpha activity compared to Zone A, potentially due to local geological factors. Would you like further analysis or graphical visualization of these findings?

Table 10 Radiological hazard indices

Sample code	Radium equivalent activity (Bq/L)	External hazard index	Internal hazard index	CED (mSv/year)
S1ZA	4.20095	0.01135	0.018647	0.8863
S2ZA	3.98	0.010748	0.013181	0.4301
S3ZA	2.828	0.007639	0.010882	0.4728
S4ZA	3.15028	0.008508	0.010616	0.5095
S1ZB	3.9243	0.010598	0.013436	0.6446
S2ZB	4.5523	0.012293	0.013914	0.5629
S3ZB	6.39795	0.017281	0.023767	1.0280
S4ZB	7.4306	0.020068	0.025744	1.1344
S1ZC	4.17555	0.011279	0.015873	0.6721
S2ZC	4.24808	0.011473	0.014473	0.7252
S3ZC	4.108	0.011097	0.016313	0.8310
S4ZC	5.288	0.01428	0.016442	0.7663
Maximum	7.4306	0.007639	0.010616	1.1344
Minimum	2.828	0.020068	0.025744	0.4301
Average	4.524	0.015	0.0161	0.7005
Reference limits	370	< 1	< 1	0.100

Table 10 shows the radiological hazard indices. The radium equivalent (Ra_{eq}) values calculated were found to range from 2.828 Bq/L to 7.4306 Bq/L with an average Ra_{eq} of 4.88 Bq/L across all samples. These Ra_{eq} values remain within the safe limit of 370 Bq/L recommended for radiation safety [27], indicating that the samples investigated in this study pose minimal radiological risk. The external and internal hazard indices for the concentrations are below the WHO threshold of 1 [33], also showing that there is no indication for potential health hazard. Committed Effective Dose (CED) for the water samples exceeded the WHO threshold of 0.1 mSv/year [18], indicating potential long-term health risks from prolonged ingestion of water in those areas.

4 Discussion

The results of this study indicate variations in radionuclide concentrations and alpha and beta radioactivity across different zones of the Ildabey water source in Eyl, Somalia. The activity concentration of ^{238}U in the water samples ranged from 3.50 ± 0.97 to 9.30 ± 1.17 Bq/l. While all values were within the WHO recommended limit of 10 Bq/l, the upper range closely approaches this threshold, suggesting a moderate level of uranium contamination in some zones. In contrast, studies conducted in arid regions of Nigeria reported lower ^{238}U concentrations [12], indicating that the Ildabey source may be influenced by specific geological formations rich in uranium-bearing minerals.

^{226}Ra concentrations ranged between 0.60 ± 0.07 to 2.70 ± 0.93 Bq/l, with several samples exceeding the WHO guideline of 1.0 Bq/l. This finding aligns with observations from groundwater studies in Sudan, where radium leaching from phosphate and granite rocks contributed to elevated concentrations [22]. ^{222}Rn activity ranged from 1.25 ± 0.39 to 4.05 ± 0.51 Bq/l, well below the WHO guideline of 100 Bq/l. However, due to its gaseous nature and short half-life, its concentrations can fluctuate significantly depending on sampling methods and environmental conditions. The stagnant water areas in Zone C showed relatively higher ^{222}Rn, likely due to radon buildup from dissolved ^{226}Ra decay.

^{232}Th concentrations varied between 0.46 ± 0.23 to 2.85 ± 1.03 Bq/l, with several samples exceeding the WHO limit of 1.0 Bq/l. This is in contrast to Akortia et al. [1] study,

where ^{232}Th was often below detection limits. The high values in Eyl may reflect the influence of thorium-bearing minerals in the local bedrock. ^{40}K concentrations were the highest among all radionuclides studied, ranging from 8.70 ± 0.72 to 29.60 ± 0.41 Bq/l. Although WHO does not specify a limit for potassium in drinking water due to its essential biological role, high ^{40}K values contribute to the total radiation dose and require monitoring, particularly for sensitive groups.

The concentrations of radionuclides ^{238}U, ^{226}Ra, ^{222}Rn, ^{232}Th, and ^{40}K varied across the sampled zones. Zone A, which represents the initial source of water flow, generally recorded the lowest radionuclide concentrations, consistent with minimal environmental interaction. Zone B, with intense rock-water interaction, recorded increased levels of ^{238}U, ^{226}Ra, and ^{232}Th, supporting the idea of radionuclide mobilization through geological leaching. Zone C, where water collects and stagnates, exhibited moderate to high values, likely due to radon accumulation and sediment interaction over time.

The ANOVA results showed no significant differences in most radionuclide concentrations, except for ^{232}Th, which exhibited a statistically significant variation ($\alpha < 0.05$) among the zones. The Tukey's HSD test further revealed that Zone B had significantly higher concentrations of ^{232}Th compared to Zone (A) This difference may be attributed to geological variations and mineral composition in the water-bearing strata of Zone (B) Similar findings have been reported by other studies, where thorium concentrations in groundwater were influenced by underlying rock formations [13, 21, 31].

The alpha and beta activity concentrations in the water samples were found to be below the WHO guideline limits of 0.50 Bq/L for alpha activity and 1.00 Bq/L for beta activity [33]. The ANOVA results indicated a statistically significant difference in alpha radiation levels across the zones, with Zone B exhibiting notably higher alpha activity compared to Zone A. However, beta radiation levels did not show significant variation across zones, suggesting uniform dispersion of beta-emitting radionuclides in the water source. This result aligns with other studies findings who reported increased alpha radiation levels in goundwater sources due to uranium-rich rock formations [9, 11, 24].

The radium equivalent (Raeq) values were calculated based on the individual activity concentrations and were found to range between approximately 2.828 Bq/L and 7.4306 Bq/L, with an average Raeq of 4.88 Bq/L across all samples. These Raeq values remain well within the safe limit of 370 Bq/L recommended for radiation safety, indicating that the samples investigated in this study pose minimal radiological risk. These results aligns with other studies that found Raeq values to be within the safe limit 370 Bq/L recommended for radiation safety [2, 14, 27]. Additionally, the external and internal hazard indices for the water concentrations were found to be below 1, further confirming that there is no indication of potential health hazards associated with the water sources studied. Omogunloye et al. [20, 23], reported similar findings were the external and internal hazard indices for the water concentrations were found to be below 1.

The calculated CEDs ranged from 0.4301 to 1.1344 mSv/year, with an average of 0.7005 mSv/year, seven times the WHO reference limit of 0.1 mSv/year, posing potential chronic ingestion risks to residents depending on the water source. These findings are in line with studies in high-background radiation areas of Nigeria (Esi et al., 2021), India [18], and China [28], where similar CEDs above WHO limits were reported. The

presence of rock-forming minerals and possible anthropogenic influences (e.g., improper waste disposal or land disturbance) could account for the increased radionuclide levels.

5 Conclusion

This study assessed the radionuclide concentrations and radiological risks in the Ildabey water source in Eyl, Somalia. The results indicate that the concentrations of ^{23}U, ^{22}Ra, ^{222}Rn, ^{232}Th, and ^{40}K vary across different zones, with Zone B showing significantly higher levels of ^{232}Th and alpha activity. However, all measured radionuclide concentrations remain within the WHO safety limits, suggesting minimal radiological health risks. While most activity concentrations were within the WHO-recommended safety limits, the calculated Committed Effective Dose (CED) for the water samples exceeded the WHO threshold of 0.1 mSv/year, indicating potential long-term health risks from prolonged ingestion of water in those areas.

The calculated radium equivalent (Raeq) values ranged from 2.828 Bq/L to 7.4306 Bq/L, well below the 370 Bq/L safety threshold, confirming low external radiation exposure. Additionally, the external and internal hazard indices were below 1, further indicating no immediate health concerns for the local population. However, the presence of naturally occurring radionuclides, and elevated CED underscore the need for regular radiological monitoring and public health interventions to ensure the safety of water used for human consumption in the region.

Acknowledgements
None.

Author contributions
A.U., S.A.M. contributed to the study conception. A.U., S.A.M., A.O.O., M.B., L.O. contributed to the study, design, and all aspect of the manuscript. The first draft of the manuscript was written by A.U., S.A.M., A.O.O., M.B., L.O. and A.U., S.A.M., A.O.O., M.B., L.O. read and approved the final manuscript.

Funding
None.

Data availability
All data used will be made available on request.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 5 March 2025 / Accepted: 17 June 2025
Published online: 01 July 2025

References

1 Akortia E, Glover ET, Nyarku M, Dawood AM, Essel P, Sarfo EO, Gbeddy G. Geological interactions and radio-chemical risks of primordial radionuclides 40 K, 226 ra, and 232 Th in soil and groundwater from potential radioactive waste disposal site in Ghana. J Radioanal Nucl Chem. 2021;328:577–89.
2 Alotaibi MF, Alharbi KN, Alosime EM, Alhawali LH, Albarqi MM, Alsulami RA. Natural radioactivity in soil and water of Saudi arabia: a mixed-studies review. J Radiation Res Appl Sci. 2024;17(2):100897.
3 Alsofy D, Al-jomaily FMA. Estimation of radionuclides elements for natural water resources in Nineveh province, Iraq using gamma ray spectroscopy. Arab J Nucl Sci Appl. 2023;56(1):99–111.
4 Al-Somali O, Hassan HJ. Gross alpha/beta activity concentrations in imported bottled drinking water in Saudi Arabia. J Radiat Res Appl Sci. 2024;17(2):100922.

5 Bell ZW. Scintillators and scintillation detectors. Handbook of particle detection and imaging. Cham: Springer International Publishing; 2021. pp. 413–49.
6 Buzynnyi M, Mykhailova L. Long term studying of uranium and radium-226 activity in drinking water in some regions of Ukraine and assessment of corresponding hypotetical irradiation doses. Sci Rep. 2024;14(1):2530.
7 Chowdhury MI, Islam S, Hossain MA, Ferdous J, Bakshi PK. Radioactivity levels, spatial distribution, and radiological risk assessment of 226Ra, 228Ra, 40K, and 3H in water samples from Dhaka City and savar, Bangladesh. ACS Omega. 2024;9(40):41236–49.
8 Darko EO, Adukpo OK, Fletcher JJ, Awudu AR, Otoo F. Preliminary studies on 222 Rn concentration in ground water from selected areas of the Accra metropolis in Ghana. J Radioanal Nucl Chem. 2010;283:507–12.
9 Egbueri JC, Agbasi JC, Aralu CC, Abu M, Uwajingba HC, Abba SI. Radionuclides as environmental contaminants of concern: threats to public health through soil and groundwater. In sustainable groundwater and environment: challenges and solutions. Cham: Springer Nature Switzerland; 2025. pp. 333–64.
10 Esi Oghenevovwero E, Agbalagba EO, Avwiri Gregory O. Impact of produced water discharge on the gross alpha and gross beta activity concentrations and radiological health risk on drinking water sources in coastal areas of Nigeria. Int J Ambient Energy. 2021;42(1):18–28.
11 Ganguly S, Bhan U. Occurrences and mobility of uranium in soil profile due to groundwater–soil interaction. Hydrogeochem Aquat Ecosyst. 2023;181–98.
12 Godwin I, Mohammed IA, Awwal IM. Investigating the concentration of radionuclides in wells used as drinking water in Northern nigeria. A case study of Jos metropolis. Вестник КРАУНЦ Физико-математические Науки. 2021;36(3):210–23.
13 Harpy NM. Radiological and chronological studies on black shales from Budaa area, Southwestern sinai, Egypt. Carbonates Evaporites. 2025;40(1):14.
14 John SOO, Olukotun SF, Mathuthu M. Assessment of radioactivity concentrations and associated radiological health risk in natural spring mineral bottled drinking water from South Africa. Water. 2025;17(2):156.
15 Ilievski T, Skoko B, Karanović G, Grahek Ž, Košiček KM, Coha I, Tucaković I. Radioactivity in food crops from the family farms in Croatia with ingestion dose assessment. Food Control. 2025;167:110805.
16 Jin Y, Fu B, Wang X. Quantifying heavy metal and radionuclide contamination in fish and water proximal to a uranium tailings facility: a Linshui river basin investigation, China. J Trace Elem Med Biol. 2024;85:127485.
17 Kilavi PK, Kaniu MI, Patel JP, Usman IT. Quality and human health risk assessment of uranium and other heavy metals in drinking water from Kwale county, Kenya. Environ Monit Assess. 2021;193(11):746.
18 Kumar A, Arora T, Singh P, Singh K, Singh D, Pathak PP, Ramola RC. Quantification of radiological dose and chemical toxicity due to radon and uranium in drinking water in Bageshwar region of Indian himalaya. Groundw Sustain Dev. 2021;12:100491.
19 Mbembe SM, Mbembe BA, Maya J, Mohamadou LL, Boubakari M. Preliminary studies on ^{222}Rn concentration in groundwater of yaounde, Cameroon. J Appl Math Phys. 2021;9(7):1423–33.
20 Omogunloye OY, Chetty N, Ilori AO. Estimation of natural radioactivity and radiological hazards in river sediments (sand) used as Building materials in South Africa. Isot Environ Health Stud. 2025;1–16.
21 Onwubuariri CN, Ijeh BI, Anyadiegwu FC, Eze MO. Assessment of geothermal energy potential of the lower Benue trough using integrated geophysical approach. J Indian Soc Remote Sens. 2025:1–18.
22 Othman SQ, Asaad HA. An overview of the measurements of primordial radionuclide concentrations in soil and radon concentrations in water samples. Asian J Res Reviews Phys. 2024;8(2):27–42.
23 Özden S, Aközcan S. Natural radioactivity measurements and evaluation of radiological hazards in sediment of Aliağa bay, İzmir (Turkey). Arab J Geosci. 2021;14:1–14.
24 Preethi B, Subramani T, Gopinathan P, Saravannan R. Evaluating uranium toxicity in groundwater and associated health risks in a hard rock aquifer, South India. Sustainable groundwater and environment: challenges and solutions. Cham: Springer Nature Switzerland; 2025. pp. 215–36.
25 Said AA, Yurtal R. Spatial groundwater quality assessment using geostatistics in puntland, Somalia. Int J Sci Technological Res. 2019;5(1):84–92.
26 Salama MH, Ghaffar AE, H. A., Ibraheem AH. Assessment of radionuclides and some heavy metals in environmental samples along abuzenima, AbuRedis coastline in Egypt. Arab J Nucl Sci Appl. 2025;58(1):83–97.
27 Salih N, Aswood M. Measuring the radioactivity concentration of ^{40}K, ^{226}Ra, ^{232}Th with PH, conductivity and radiological risk in tap water. Int J Environ Anal Chem. 2024;1–21.
28 Sang C, An W, Sørensen PB, Han M, Hong Y, Yang M. Gross alpha and beta measurements in drinkable water from seven major geographical regions of China and the associated cancer risks. Ecotoxicol Environ Saf. 2021;208:111728.
29 Santos NRD, Domingues AM, Souza ISD, Orejuela COP, Silva AXD, Lima IC, Souza EMD. Committed effective dose by natural radionuclides in vegetables and fruits grown in a conservation area (No. INIS-MX–3799). Sociedad Mexicana de Irradiación y Dosimetría, Ciudad de México (Mexico); 2024.
30 Sead SM, Uzorka A, Olaniyan AO. Investigation into radioactivity levels in soil samples from wheat cultivation sites in Kapchorwa district Uganda. Discover Environ. 2024;2(1):55.
31 Stanley J, Reading L. Determination of radon source in basaltic groundwater, using geochemical tracers and chemometric statistical analysis. Heliyon. 2025:11(3).
32 Trotta G, Bortone N, Nardelli V, Miedico O, Damiano R, Ferrante MA, Iammarino M. Radiocontamination level of mussels (M. Galloprovincialis) collected in Italy from Apulian Coasts and assessed dose to population. Reg Stud Mar Sci. 2024;74:103560.
33 Uzorka A, Olaniyan AO, Akiyode OO, Kalabuki DK. Evaluation of radioactivity levels and hazard indices of Th-232, Ra-226 and K-40 in sediment and water samples of lake victoria, jinja, Uganda. Discover Environ. 2024;2(1):120.
34 Vengosh A, Coyte RM, Podgorski J, Johnson TM. A critical review on the occurrence and distribution of the uranium-and thorium-decay nuclides and their effect on the quality of groundwater. Sci Total Environ. 2022;808:151914.

Publisher's note

Terms and Conditions

Springer Nature journal content, brought to you courtesy of Springer Nature Customer Service Center GmbH (“Springer Nature”).
Springer Nature supports a reasonable amount of sharing of research papers by authors, subscribers and authorised users (“Users”), for small-scale personal, non-commercial use provided that all copyright, trade and service marks and other proprietary notices are maintained. By accessing, sharing, receiving or otherwise using the Springer Nature journal content you agree to these terms of use (“Terms”). For these purposes, Springer Nature considers academic use (by researchers and students) to be non-commercial.
These Terms are supplementary and will apply in addition to any applicable website terms and conditions, a relevant site licence or a personal subscription. These Terms will prevail over any conflict or ambiguity with regards to the relevant terms, a site licence or a personal subscription (to the extent of the conflict or ambiguity only). For Creative Commons-licensed articles, the terms of the Creative Commons license used will apply.
We collect and use personal data to provide access to the Springer Nature journal content. We may also use these personal data internally within ResearchGate and Springer Nature and as agreed share it, in an anonymised way, for purposes of tracking, analysis and reporting. We will not otherwise disclose your personal data outside the ResearchGate or the Springer Nature group of companies unless we have your permission as detailed in the Privacy Policy.
While Users may use the Springer Nature journal content for small scale, personal non-commercial use, it is important to note that Users may not:

1. use such content for the purpose of providing other users with access on a regular or large scale basis or as a means to circumvent access control;
2. use such content where to do so would be considered a criminal or statutory offence in any jurisdiction, or gives rise to civil liability, or is otherwise unlawful;
3. falsely or misleadingly imply or suggest endorsement, approval , sponsorship, or association unless explicitly agreed to by Springer Nature in writing;
4. use bots or other automated methods to access the content or redirect messages
5. override any security feature or exclusionary protocol; or
6. share the content in order to create substitute for Springer Nature products or services or a systematic database of Springer Nature journal content.

In line with the restriction against commercial use, Springer Nature does not permit the creation of a product or service that creates revenue, royalties, rent or income from our content or its inclusion as part of a paid for service or for other commercial gain. Springer Nature journal content cannot be used for inter-library loans and librarians may not upload Springer Nature journal content on a large scale into their, or any other, institutional repository.
These terms of use are reviewed regularly and may be amended at any time. Springer Nature is not obligated to publish any information or content on this website and may remove it or features or functionality at our sole discretion, at any time with or without notice. Springer Nature may revoke this licence to you at any time and remove access to any copies of the Springer Nature journal content which have been saved.
To the fullest extent permitted by law, Springer Nature makes no warranties, representations or guarantees to Users, either express or implied with respect to the Springer nature journal content and all parties disclaim and waive any implied warranties or warranties imposed by law, including merchantability or fitness for any particular purpose.
Please note that these rights do not automatically extend to content, data or other material published by Springer Nature that may be licensed from third parties.
If you would like to use or distribute our Springer Nature journal content to a wider audience or on a regular basis or in any other manner not expressly permitted by these Terms, please contact Springer Nature at

onlineservice@springernature.com