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Determination of Gross Alpha and Gross Beta Activities, and the Corresponding Radiological Risk Parameters in Water Samples from Dzamah Community, Hong, Nigeria

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Abstract: The activities of gross alpha and gross beta particles in groundwater have common environmental concern. In this research, the activities of alpha and beta particles in groundwater along with the associated health risk were determined to know whether they pose a threat to the Dzamah community. Ten (10) water samples were collected from different part of Dzamah area and transported to Center for Energy Research and Training (CERT) ABU Zaria, to analyze gross alpha and gross beta activity using the single channel gas-filled proportional counter. The results found that the mean activity of gross alpha particle is 0.016671 Bql^{-1} while for beta particle the mean activity is 0.026092 Bql^{-1}. When these values were compared with the World Health Organization (WHO) reference dose level of 0.1 and 1.0 Bql^{-1} for gross alpha and gross beta activity respectively, and the reference dose level of annual effective dose of 0.1 $mSv\ y^{-1}$, it is found that the presence of alpha and beta activity in drinking water of Dzamah community does not pose any health problem. These results are of great importance for exploring the health risks due to gross alpha and beta concentrations in Dzamah community potable water and may pave the road to a baseline for future changes in environmental radioactivity due to naturally occurring radioactive materials and human activities.

Keywords: Portable water, radionuclides, Gross Alpha, Gross Beta, concentration, effective dose, Dzamah.

1 Introduction

Radionuclides present the main source of radiation exposure to mankind [1-3]. According to UNSCEAR (1993) about 87% of the radiation dose received by mankind is due to three sources of radionuclides [4], namely: cosmogonic source such as ^{3}H, ^{7}Be, ^{10}B, ^{14}C, ^{36}Cl , ^{32}Si, ^{22}Na, ^{38}S, ^{33}P, primordial source such as ^{40}K, ^{87}Rb, ^{50}V, ^{144}Nd, ^{238}U, ^{235}U, ^{232}Th and anthropogenic source such radionuclides are ^{137}Cs, ^{90}Sr, ^{89}Sr, $^{13}1I$, ^{99}Tc, ^{240}Pu, ^{241}Am, ^{65}Zn, ^{54}Mn and ^{55}Fe are due to fallout from nuclear accident, nuclear weapon testing, research accident, crime, industries, mining and processing of radioactive ore, coal mining, using fertilizers, hydrocarbon exploration and production activities. Several modern industries, particularly in the area of power production and medicines involve nuclear radiation. About 82% of humans have been exposed and absorbed nuclear radiation through ingestion of foodstuff, inhalation of radiation released from water to air and ingestion of drinking water [5-15]. It is reported that despite the ionizing nature of the x-rays, its increasing application involves some potential health risks to human being exposed. Recently, great attention has been paid to monitor and estimate the dose limits of public exposure to x-ray in order to provide an appropriate protection of patients/workers who are frequently undergoing diagnostic x-ray examinations [16-23]. Thus, the knowledge of radionuclides, their activity in the environment and the levels of human exposure to the radiation emitted is of immense important [3,10,24].

Certain types of nucleus, the radionuclides, do disintegrate spontaneously into daughter nuclides and energy in form of particles (alpha or beta) or radiations (gamma) is released [21,25,26]. The energy released (alpha, beta or gamma) by radionuclides poses a number of health problems when deposited in the human body [8,27-29]. Alpha and beta particles are high linear energy transfer radiation, therefore have the ability to deposit high amount of energy at short distances [28,30,31]. Radium and uranium are known to be alpha emitters when ingested into the body, the alpha particle interacts with living cells primarily by ionization or excitation processes, lose their energies to the cells on impact and leads to the formation of chemical species that could alter the chromosomes. This causes serious biological effects to the organs and tissues in the human body [14,32,33]. The environmental radiations have been a topic of concern for many governmental and non-governmental

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organizations worldwide [34,35]. However, there is no history or any assessment of radionuclides concentration in Dzamah area. Therefore, this research is aimed at measuring the activity concentration of naturally occurring radioactive materials in Dzamah portable water through a preliminary procedure of determine the gross alpha and gross beta particle activities.

2 Material and Method

2.1 Sample Selection

Ten (10) water samples were selected from Dzamah portable water source or supply after surveying the most used water source by the community members. Table 1 showed the sample name and their corresponding geographical location from the selected areas of Dzamah, when water is been source.

Table 1: The sample name and their corresponding geographical location in selected areas of Dzamah.

Sample Name	ID	Sample Coordinate	
		Longitude	Latitude
Borehole Sabongari	BGH	10.1738	12.9405
First borehole	FBH	10.1709	12.9432
Dulshishiu	DLS	10.1651	12.9487
Dul Mulagu	DLM	10.1533	12.7530
Dulberikasa	DLK	10.1714	12.9569
Dulgiwasalaku	DKW	10.1832	12.9441
Dulyau	DLY	10.1550	12.9263
Dulhyefafa	DLH	10.1757	12.9425
Dulvami	DLV	10.1724	12.9299
Dul Northan Nigeria	DNN	10.1709	12.9432

2.2 Sample Collection and Preparation

The samples of two (2) litres of water were collected from ten (10) different water sources in Dzamah community. For each of the samples 10 *ml* of nitric acid (HNO_3) was added immediately to retain the radionuclide from escaping. The samples were then transported to center for energy research and training Abu Zaria (CERT ABU ZARIA) for laboratory analysis.

The preparation of the sample for the gross alpha and gross beta counting can be done in the following way: The calculate volume of each samples was measured into a beaker and evaporated on a hot plate to 50 ℃ temperature and then transferred to a clean dry evaporating dish. Few drops of vinyl acetate were added to the sample during evaporation to act as a binder to prevent the precipitation of source of the radionuclides in the sample. The sample was evaporated to dryness on hot plate. The residue was transferred onto to a clean, dry and previously weighed planchet and the difference between the mass of empty planchet and that of the empty planchet plus residue gives the mass of the residue. The residue was uniformly spread on the planchet by dropping a few drops of ethanol. The residue was allowed to dry and then covered with Mylar film ready for counting.

2.3 Proportional Counter

The equipment used for the gross alpha and gross beta counting is a gas flow proportional counter. The counting system incorporates an anti-coincident guard counter used to eliminate interference from high-energy cosmic radiation into the measuring environment. The chamber was covered with 0.1 m lead from within which has stainless steel linings to prevent part of ambient gamma rays from entering the measuring environment. Thus the only contributions to the counting would be from impurities in the chamber constructing materials.

2.4 Energy Calibration

The single channel gas-filled proportional counter was used. For alpha activity counting, the standards are ^{239}Pu alpha sources of diameter 0.038 *m* in an oxidable disc of 0.003 *m* thickness. These sources contain a range of impurities varying from 0.74% to 0.82% of ^{241}Am and ^{240}Pu. The standards for beta activity counting are ^{90}Sr beta sources of diameter 0.038 *m* and an active film of 12 mg/cm^3 thick. The radionuclide impurity in the standard source is less than 0.1%. Due to statistical processes for both nuclear disintegration and measurement itself, subtraction of background is trivial (simple) only when the counting rates are much greater than background. When they are close to each other, a statistical decision must be taken using the "detection limit" formula

$$\text{DL (cpm)} = \frac{3+4.65 \times \sqrt{B_c}}{t(min)}$$

where B_c is the number of counts of background, t is the counting time. The alpha activities were calculated using the formula:

$$\text{Activity } (Bq/l) = \frac{Net\ count(cpm)}{\varepsilon \times 60 \times w}$$

where ε is the detector's efficiency, w is the weight of the sample. The uncertainty (Error) of measurement is calculated with the formula:

$$\text{UN}(Bq/l) = \frac{\sqrt{\text{COUNT}/(\text{CT})^2 + B_c/(\text{CT})^2}}{\text{DE} \times 60 \times \text{Weight of SAMPLE}}$$

The final results were expressed as Activity ($\pm$ uncertainty Bql^{-1}). All the measurements were carried out at CERT ABU ZARIA.

3 Result and Discussion

The values and associated errors in the concentrations of both alpha and beta measured in each water sample were presented in Table 2 and 3. It can be observed from Table 2 that the maximum and minimum gross alpha concentration was 0.1795 Bql^{-1} in First Borehole 0.00221 Bql^{-1} in Dulshishiu alpha respectively with the mean concentration of 0.016671 Bql^{-1}. Table 3 showed the results obtained for gross beta activity were a maximum concentration of 0.10332 Bql^{-1} was detected in Dulvami and gross beta activity below detection limit (BDL) was detected in Dulberikasa and Dul NN. The mean concentration of 0.026092 Bql^{-1} for beta activity was detected.

Table 2: The concentration of gross alpha activity in some selected areas of Dzumah.

Sample ID	Concentration (Bql^{-1})
BGH	0.00500±0.00182
FBH	0.01795±0.00199
DLS	0.00221±0.00081
DLM	0.01072±0.00077
DLK	0.00377±0.00137
DKW	0.00922±0.00123
DLY	0.00854±0.00054
DLH	0.01147±0.00175
DLV	0.04874±0.00170
DNN	0.04909±0.00384
Mean	0.01667±0.00145

Table 3: The concentration of gross beta activity in some selected areas of Dzumah.

Sample ID	Concentration (Bql^{-1})
BGH	0.04763±0.00422
FBH	0.03868±0.00401
DLS	0.00179±0.00164
DLM	0.01521±0.00164
DLK	BDL
DKW	0.00816±0.00233
DLY	0.02110±0.00113
DLH	0.02503±0.00351
DLV	0.10332±0.03500
DNN	BDL
Mean	0.02609±0.00287

The gross alpha and beta activity in the selected area (Table 2 and Table 3) were plotted as a function of the concentrations as shown in Figure 1 and Figure 2 respectively.

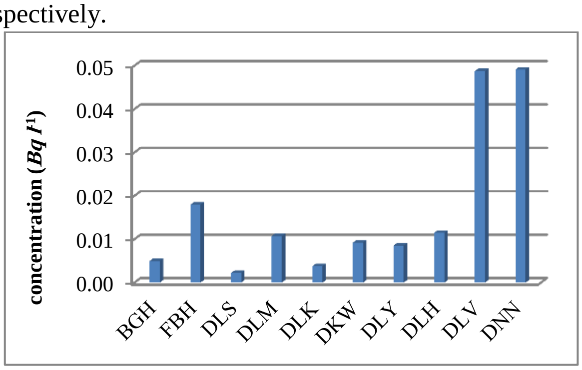

Fig. 1: The concentration of gross alpha particles in some selected areas of Dzumah.

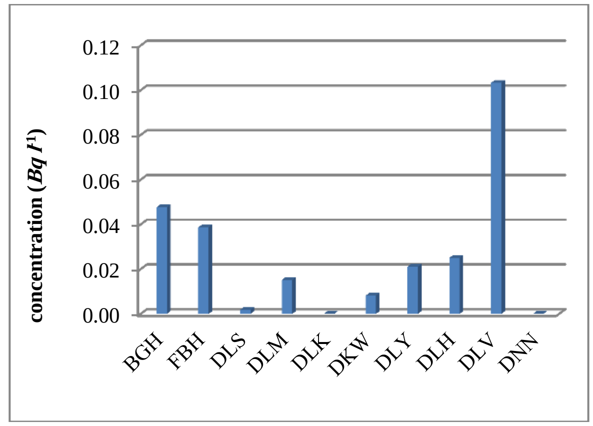

Fig. 2: The concentration of gross beta particles in some selected areas of Dzumah.

The results showed that the maximum and minimum gross alpha particle concentrations were 0.1795 Bql^{-1} in First Borehole and 0.00221 Bql^{-1} in Dulshishiu respectively with the mean value of 0.016671 Bql^{-1} as shown in Figure 1. Figure 2 showed the maximum gross beta concentration of 0.10332 Bql^{-1} in Dulvami and the concentration below detection limit (BDL) were measured in Dulberikasa and NN Well. The mean value of 0.026092 Bql^{-1} was observed for beta particle activity. When these results are compared with the WHO (2004) reference dose level of 0.1 and 1.0 Bql^{-1} for gross alpha and gross beta particles respectively, it is found that the presence of alpha and beta particles in drinking water of Dzamah community does not pose any health problem [27].

3.1 Estimation of Radiological Risk Parameters

The study continue to further calculate some radiological risk parameters to quantify the health impacts associated with human exposure to gross alpha and gross beta particles emitted by radionuclides present in Dzamah portable water.

3.1.1 The Annual Effective Equivalent Dose (D_{eff})

The maximum permissible contaminant level of radioactivity in water is 0.5 Bql^{-1} for gross alpha concentration, excluding ^{222}Rn, 1 Bql^{-1} for gross beta concentration, excluding ^{40}K and 100 Bql^{-1} for ^{222}Rn concentration [8,31]. According to WHO, (2017), the ***gross beta activity*** of ^{228}Ra measured in a sample, includes a contribution from the presence of ^{40}K. Unlike other radionuclides, ^{40}K is an essential element for the good functioning of the human body [36]. Therefore, the ^{40}K contribution should be subtracted from the gross beta activity and thus the annual effective dose calculations (1) and (2) have to represent the ***residual beta activity*** in order to avoid dose overestimation [37]. For this reason, the assessment has to be due to contribution of each radionuclide [28,31,37-39].

Therefore, the concentration for eleven (11) radionuclides can be determined from the relations:

$$D_{eff}(\alpha) = \sum_{i=1}^{11} \left[R'_\alpha \times \xi_\alpha\left({}^{A}X_i\right) \times d' \times T\right] \qquad (1)$$

and

$$D_{eff}(\beta) = \sum_{i=1}^{11} \left[R'_\beta \times \xi_\beta\left({}^{A}X_i\right) \times d' \times T\right] \qquad (2)$$

where i indicates the 11 radionuclides to be evaluated in this study, R'_α and R'_β are the gross alpha and beta particle activity per litre respectively, $\xi_\alpha\left({}^{A}X\right)$ and $\xi_\beta\left({}^{A}X\right)$ are the dose conversion factor for ingested radionuclide X with nucleon number A, d' is the daily consumption rate and T is the exposure period. The parameters R'_α and R'_β are measured in $Bq\ l^{-1}$, $\xi_\alpha\left({}^{A}X\right)$ and $\xi_\beta\left({}^{A}X\right)$ measured in $Sv\ Bq^{-1}$, d' is measured in litre per day ($l\ d^{-1}$) and T is measured in year. For the purpose of this study, d' is taken to be 2.0 $l\ d^{-1}$ for adult, 1 $l\ d^{-1}$ for child and 0.5 $l\ d^{-1}$ for infant. While the values of $\xi_\alpha\left({}^{A}X\right)$ and $\xi_\beta\left({}^{A}X\right)$ used are shown in Table 4 [28,31,37,40-44].

Table 4: The dose conversion factors (ξ) used in this study.

Radionuclide (^{A}X)	**ξ ($mSv\ Bq^{-1}$)**
^{230}Th	2.1×10^{-4}
^{228}Th	7.2×10^{-5}
^{228}Ra	6.9×10^{-4}
^{210}Po	1.2×10^{-3}
^{210}Pb	6.9×10^{-4}
^{226}Ra	2.8×10^{-4}
^{232}Th	2.3×10^{-4}
^{234}U	4.9×10^{-5}
^{235}U	4.7×10^{-5}
^{238}U	4.5×10^{-5}
^{40}K	6.2×10^{-6}

However, when applying the relations (1) and (2), radionuclides such as ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{90}Sr, and ^{241}Am the activity of alpha and beta particles are very low when compared with other radionuclides natural alpha and beta emitting radionuclides. Therefore their annual effective dose can be neglected [45].
The activities of natural radionuclides in drinking water are due to the specific activities of their decay products and the activity of some important radionuclides present in water decreases in the following order:

$$^{210}Po > {}^{228}Ra > {}^{210}Pb > {}^{226}Ra > {}^{224}Ra > {}^{232}Th > {}^{234}U > {}^{235}U > {}^{238}U$$

This indicates that ^{210}Po and ^{228}Ra have the highest activity and thus the highest effective dose coefficients [27-29,33,47].

Using the measured concentrations of gross alpha and gross beta activity in water samples, the annual effective dose due to their ingestion through water consumption over a year is calculated using (1) and (2) and the results are presented in Table 5. The annual effective dose for gross alpha activity in drinking water consumed by infant, child and adult are respectively 0.0428, 0.0214 and 0.0107 $mSv\ Bq^{-1}$. The annual effective dose for gross beta activity in drinking water consumed by infant, child and adult are respectively 0.0670, 0.0335 and 0.0168 $mSv\ Bq^{-1}$. WHO recommended that the reference dose level does not exceeded 0.1 $mSv\ y^{-1}$. The reference dose level of 0.1 mSv is equal to 10% of the dose limit for members of the public [31,33,46,48,49]. It can be seen from Table 5 that the percentage (%) of alpha and beta activities in radionuclide ^{230}Th, ^{228}Th, ^{228}Ra, ^{210}Po, ^{210}Pb, ^{226}Ra, ^{232}Th, ^{234}U, ^{235}U, ^{238}U and ^{40}K are 5.97, 2.05, 19.61, 34.10, 19.61, 7.96, 6.54, 1.39, 1.34, 1.28 and 0.18% respectively.

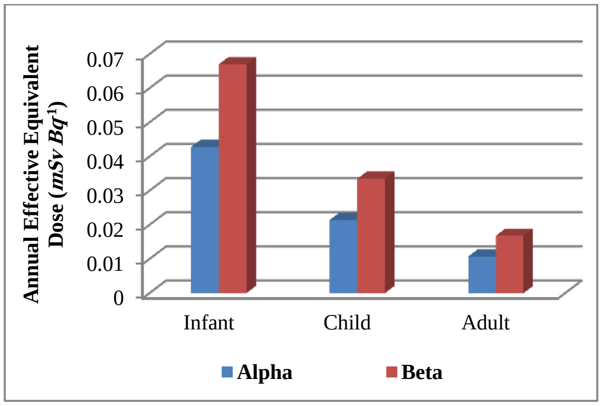

Fig. 3: The Annual Effective Equivalent Dose for adult, child and infant.

It can be observed from Figure 3 that an infant absorbed higher (0.0670 $mSv\ Bq^{-1}$) gross beta concentration present in Dzamah portable water. An adult absorbed lowest (0.0107 $mSv\ Bq^{-1}$) concentration for gross alpha activity when compared with child and infant.

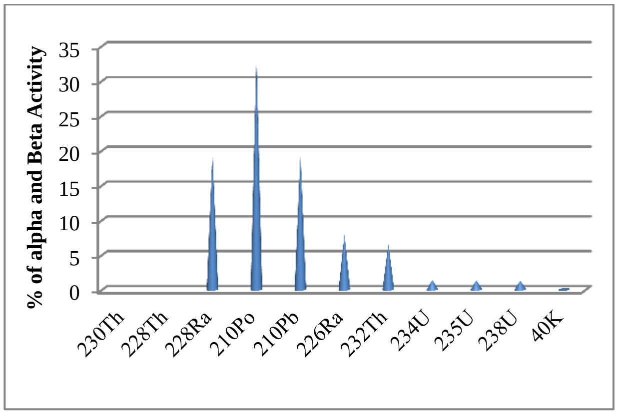

Fig. 4: Percentage (%) of alpha and beta concentration in each radionuclide.

Table 5: The computed The Annual Effective Equivalent Dose for adult, child and infant due to alpha and beta activity from certain radionuclides present in drinking water of Dzamah community during the year 2021.

Nuclide ($^A_Z X$)	Annual Effective Equivalent Dose ($mSv\ Bq^{-1}$)						Percentage (%) of Alpha and Beta Concentration in Each Radionuclide
	Infant		Child		Adult		
	$D_{eff}(\alpha)$	$D_{eff}(\beta)$	$D_{eff}(\alpha)$	$D_{eff}(\beta)$	$D_{eff}(\alpha)$	$D_{eff}(\beta)$	
^{230}Th	0.0026	0.0040	0.0013	0.0020	0.0006	0.0010	5.97
^{228}Th	0.0009	0.0014	0.0004	0.0007	0.0002	0.0003	2.05
^{228}Ra	0.0084	0.0131	0.0042	0.0066	0.0021	0.0033	19.61
^{210}Po	0.0146	0.0229	0.0073	0.0114	0.0037	0.0057	34.10
^{210}Pb	0.0084	0.0131	0.0042	0.0066	0.0021	0.0033	19.61
^{226}Ra	0.0034	0.0053	0.0017	0.0027	0.0009	0.0013	7.96
^{232}Th	0.0028	0.0044	0.0014	0.0022	0.0007	0.0011	6.54
^{234}U	0.0006	0.0009	0.0003	0.0005	0.0001	0.0002	1.39
^{235}U	0.0006	0.0009	0.0003	0.0004	0.0001	0.0002	1.34
^{238}U	0.0005	0.0009	0.0003	0.0004	0.0001	0.0002	1.28
^{40}K	0.0001	0.0001	0.0000	0.0001	0.0000	0.0000	0.18
Total	**0.0428**	**0.0670**	**0.0214**	**0.0335**	**0.0107**	**0.0168**	**100**

Figure 4 showed a higher percentage of 34.10 for ^{210}Po, nuclide and lowest percentage of 0.18 for ^{40}K nuclide. It is reported by Van *at. al.*, (2020) that the percentages of ^{238}U, ^{235}U, ^{234}U, ^{226}Ra, and ^{210}Po calculated for deep sea fish and other organisms were 1.7, 0.1, 1.7, 17.9, and 78.6% in terms of gross alpha activity, respectively, and for ^{210}Pb and ^{40}K, 0.1 and 99.9% in terms of gross beta activity, respectively [45].

3.1.2 The Annual Gonadal Equivalent Dose (G_{eq})

The Annual Gonadal Dose Equivalent (G_{eq}) measures the health risk to human gonads resulting from exposure to gross alpha and gross beta particles and can be computed using the relation:

$$G_{eq}(\alpha,\beta) = \frac{D_{eff}(\alpha,\beta)}{w_r \times w_t} \quad (3)$$

where w_r is the radiation weighting factor and w_t is the tissue weighting factor, w_r for alpha activity is 20, and for beta activity it is given as 1. For gonads, w_t is 0.20 for alpha activity and beta activity [29,46]. Table 6 showed the G_{eq} associated with gross alpha and gross beta activities concentrations measures for infant, child and adult.

3.1.3 The Excess Lifetime Cancer Risk ($\mathcal{E}_{cr}$)

Excess Lifetime Cancer Risk ($\mathcal{E}_{cr}$) is the probability of developing cancer over a lifetime at a given exposure level in 70 years (the average duration of life for humans). For gross alpha or gross beta activity concentration, $\mathcal{E}_{cr}$ is calculated using the relation:

$$\mathcal{E}_{cr}(\alpha,\beta) = D_{eff}(\alpha,\beta) \times T_a \times f_r \quad (4)$$

where T_a is the average life span of man (estimated to be 70 years), and f_r is cancer risk factor ($5.0 \times 10^{-5}\ mSv^{-1}$) for the public [29,42,46].

Table 6 showed the $\mathcal{E}_{cr}$ associated with gross alpha and gross beta activities concentrations measures for infant, child and adult.

3.1.4 The Life Time Hereditary Effects (H_{cr})

Lifetime hereditary effect is calculated from the relation:

$$H_{cr} = D_{eff}(\alpha,\beta) \times h_{cr} \times T_a \quad (5)$$

where $D_{eff}(\alpha,\beta)$ represents the total mean annual effective dose measured in $mSv\ yr^{-1}$ and h_{cr} represents the hereditary effect factor or coefficient, 0.2×10^{-2} [32].

Table 6 showed the H_{cr} associated with gross alpha and gross beta activities concentrations measures for infant, child and adult.

Table 6: The G_{eq}, $\mathcal{E}_{cr}$, and H_{cr} for adults, children and infants calculated using (3), (4) and (5) respectively.

	G_{eq}		$\mathcal{E}_{cr} \times 10^{-5}$		$H_{cr} \times 10^{-2}$	
	Alpha	***Beta***	**Alpha**	**Beta**	**Alpha**	**Beta**
Adult	0.02	0.03	14.99	23.46	6.00	9.38
Child	0.01	0.02	7.49	11.73	3.00	4.69
Infant	0.005	0.008	3.75	5.86	1.49	2.35

4 Conclusions

The research has found that the presence of alpha and beta activity in drinking water of Dzamah community does not pose any health problem. This suggested that there is no any radiological threat to the health of Dzamah community consuming water from the ten (10) sample areas. This simple preliminary analysis of gross alpha and beta activities due to some radionuclides present in Dzamah water source could offers useful parameters for preliminary screening of water quality. It is recommended that more sophisticated and time consuming procedures is needed to determine the concentration of the radionuclides present in water, and that other water quality issues—such as hardness, iron, manganese and pH level are to be treated.

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