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ARTICLE

Natural Radioactivity Levels in Healthy and Groundwater Samples of Al-Manathera Region of Al-Najaf, Iraq

Ali A. Abojassim[a], **Qusay B. Muhamad**[b], **Noor Ali Jafer**[c], and **Hassan A. Mohammed**[b]

[a] *Department of Physics, Faculty of Science, University of Kufa, Al-Najaf, Iraq.*
[b] *Department of Physics, Directorate of Education Najaf, Al- Najaf, Iraq.*
[c] *Radiology Techniques Department, College of Medical Technology, The Islamic University, Najaf, Iraq.*

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Abstract: In this study, the specific activity of the radionuclides 238U, 232Th and 40K was determined in groundwater samples and potable water in Al-Manathera, Al-Najaf governorate, Iraq. The study was carried out using an NaI(TI) scintillation detector of gamma spectroscopy of "3×3" dimensions. The concentrations in Bq/l of 238U, 232Th and 40K have average values of 8.3±1.2, 1.9±0.4 and 57.4±5.7 for the groundwater and 0.6±0.10, 0.07±0.02 and 2.7±0.50 for the potable water. At the same time, another effective dose of ingested water (EDIW) was also calculated in three age groups for the current study. These groups of age include infants (≤ 1 y), children (2 – 17y) and adults (> 17y). As for the comparison with global standards and international limits by WHO2011, ICRP 1991 and WHO 2000, we found that the calculated values for groundwater were over the standardized global limits, but those for potable water were within those limits. This is to say that the EDIW, in addition to the activity concentrations that are within the international limits, were set by the previously mentioned organizations and can be safely consumed. Their consumptions, however, do not pose a threat or a biohazard to their respective cities. On the other hand, consuming groundwater can negatively affect the city's population where the study was conducted.

Keywords: Radionuclide, Effective dose, Drinking water, Al-Manathera.

1. Introduction

Humans can be exposed to any ionizing radiation from all sorts of sources throughout the lifetime, whether they are natural or artificial. Therefore, gaining further knowledge about the general levels and distribution of radionuclides and radiations is essential to measuring the impact of these radiations on living beings. Such radiations can also be of terrestrial or extraterrestrial sources. Of these two mentioned sources of radiation, terrestrial sources constitute the main source of radiation to which the human body is exposed. Such sources of radiation may include cosmic gamma rays, gamma ray emitted from soil particles, building materials, water and even air itself [1]. One of the sources of this radioactivity is the radionuclides, which, with their habit of emitting radiation for thousands of years, represent a daily-life experience for humans. Gamma rays as well as alpha and beta particles are some of the most common radiations that are considered ionizing. Radiations, however, can also be emitted from sources made by mankind. Some of the characteristics of these radiations were applied for different purposes, such as medicine, biology, industry, agriculture, as well as generating electric power. This resulted in the fact that such man-made utilization of radioactivity was the reason for that humans can be exposed to higher rates of radioactivity that is

Corresponding Author: Ali Abid Abojassim **Email**: ali.alhameedawi@uokufa.edu.iq

emitted from different sources in the surrounding environment. However, not all of the human populations around the world are exposed to equal amounts of radioactivity. For instance, patients who are treated with medical irradiation or members of staff who work in nuclear industries may receive higher radiation exposure levels than members of general public [2]. NORM, Naturally Occurring Radioactive Materials, are simply part of our soil on earth. Majorly Radium and Radon, the highest amount of radionuclides in NORM are a result of the decay both Uranium and Thorium naturally have. Exposure to radionuclides from Radon can be higher due to the increasing domesticated and industrial activities in the human life that include the burning of fossil fuel, mineral extraction and the application of fertilizers. Industrial practices involving natural resources often concentrate radionuclides to a degree that may pose a risk to humans and the environment [3]. The most essential and valuable natural source is water, which is supposed to be free of pollutants. It cannot be stressed enough that measuring the naturally emitted radioactivity can be a crucial element in deducing an accurate assessment of the amount of radiation to which people are exposed. The appearance of natural radionuclides in water originates from human activities within the area, such as fertilizers used in agriculture, where water is found [4]. Since the population, especially in Al-Najaf city of Iraq, depend on the Euphrates river in consuming water which originates from Turkey, it's far feasible to have reached radioactive forcing into waterways and eventually to the people. So, it became necessary to accurately ingest the correct amount of water into the machine to be measured by gamma-ray spectroscopy. The related dangers of contaminated drinking water have been expected in steps with their human nature and dwelling standard. As for the ingestion of radionuclides applicable to nuclear emergencies, it is the most important participant to have committed internal doses and consequently long-term health effects. Therefore, it became essential to generate a final analysis of Uranium radionuclide ingestion statistics in consuming water. Many studies have been performed to investigate and measure radioactive elements' concentrations in water samples using different techniques [5-8]. The present study aims to measure natural radioactivity, such as Uranium-238, Thorium-232 and Potassium-40 in healthy and groundwater samples located in Al-Manathera regions in Al-Najaf, Iraq, using gamma-ray spectroscopy with NaI(Tl) detector. In this study, we calculate EDIW due to natural radioactivity in samples under study to warn people of the danger of this pollution in order to use special tools to work during the access to this area to reduce the risk of harmful diseases.

2. Area of Study

About 100 miles to the south of Baghdad, Iraq's capital, lay Al-Najaf province at 19 degrees and 44 minutes longitude, 31 degrees and 59 minutes latitude and 70 meters above sea level [9]. Al-Najaf province has four constituents: Najaf, Kufa, Al-Meshkhab and Al-Manathera, which are the province districts in Al-Najaf. The centre of Al-Najaf consists of a number of residency quarters, such as Al-Zahraa, Al-Askari, Al Shuhadaa, Al-Jamyia, Al-Jumhury, Quirink and others. Two suburbs are officially run by Al Manathera district; these are Al-Hera and Al-Qadissia suburbs. As for the study in hand, the studied water samples were taken from Al-Manathera, as illustrated in Fig. 1.

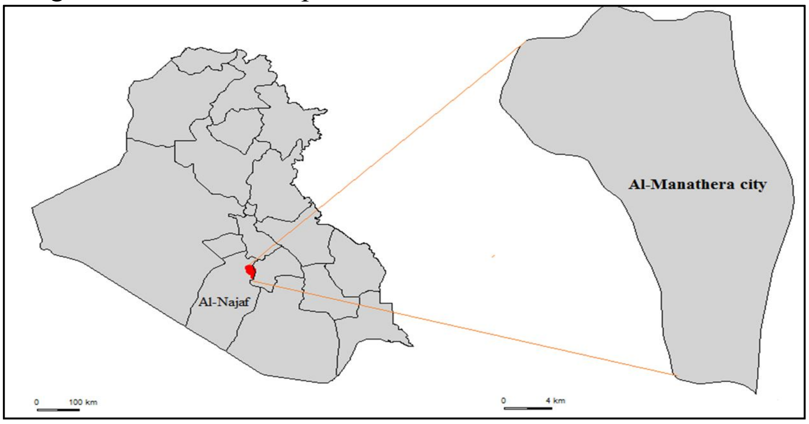

FIG. 1. Area of study.

3. Materials and Methods

3.1 Sampling and Sample Preparation

In the meantime, about ten (10) wells are still used that are over 20 m in depth in Al-Manathera, which are also possible to be utilized to supply the area with drinking water. Ten (10) other locations are also used to produce industrial drinking water. In order to conduct the study, during the summer of 2019, a total of 20 water samples were carefully collected from 20 collection locations in the municipality of Al-Manathera. These locations included groundwater and healthy-water samples, at a rate of 10 samples each, as displayed in Tables 1 and 2.

TABLE 1. Locations and coordinates of groundwater.

Location name	Sample code	Coordinate	
		N	E
Jawad Farm well	G1	31.922391°	44.460966°
Mohammed Farm well	G2	31.928780°	44.460975°
Town Hall Street Farm well	G3	31.930566°	44.461216°
Hameed Farm well	G4	31.921119°	44.458167°
Town Hall Garage Farm well	G5	31.901565°	44.469009°
Fadhil Street Farm well	G6	31.896874°	44.453000°
Mahmoud Street Farm well	G7	31.905357°	44.465250°
Jawad Shiltagh Farm well	G8	31.913906°	44.460501°
Jabour Farm well 1	G9	31.910876°	44.450022°
Jabour Farm well 2	G10	31.903201°	44.450114°

TABLE 2. Locations and coordinates of industry-product healthy drinking water.

Industry name	Sample code	Coordinate	
		N	E
Ahmed Ali Factory	H1	31.910922°	44.469668°
Karar Ibrahim Factory	H2	31.902272°	44.461886°
Said Salim Factory	H3	31.895500°	44.497645°
Hassein Factory	H4	31.899110°	44.485500°
Al-Manathera Factory 1	H5	31.923050°	44.477651°
Al-Manathera Factory 2	H6	31.896070°	44.489810°
Al Jamiya Factory	H7	31.895701°	44.490058°
Al Burkat Factory	H8	31.902812°	44.475007°
Al Askari Factory 1	H9	31.891997°	44.499003°
Al Askari Factory 2	H10	31.894814°	44.490025°

Using polyethelene containers, the collected samples were approximately 5 litres of water. In order to maintain the elements in water from going missing or being deficient, nitric acid was used in the method of sampling that was adopted in this research [10, 11]. Through the process of evaporation, water samples were processed accordingly. Using washed 1 litre of Marinelli beaker that was previously rinsed with dilute sulphuric acid and dried up in order not to contaminate it, they were loaded with a certain amount of random water samples, then sealed firmly. Then, the samples were put on the shelf in order to establish secular equilibrium between ^{226}Ra and ^{238}U with their results and in order to allow the equilibrium of ^{226}Ra-^{222}Rn prior to analyzing them radiometrically [8].

3.2 Gamma Counting

Gamma counting was conducted at the advanced laboratory of the nuclear department of physics, University of Kufa. The measurements of the natural radioactivity experiments of both healthy and groundwater utilized the spectroscopy system of gamma-ray that uses the scintillation detector of Sodium Iodine. Gamma-ray spectrometer consists of a scintillation detector NaI(Tl) system of (3"×3") crystal dimensions (supplier: Alpha Spectra, Inc.-12I12/3) (see Fig. 2) combined with an analyzer of multi-channels (MCA) (ORTEC -Digi Base) that, through its interface, has 4096 channel-connecting units called ADC (Analog to Digital Converters). Using the PC software

(MAESTRO-32) of the lab, the spectroscopic measurements were carried out as the system is connected to parts of the measurement system. Water samples were shielded environmentally using the cylindrical chamber (ORTEC). The components of this shielding process consist of two separate place segments. The upper part consists of lead with (5 cm) thickness and (20cm) length surrounding the crystal with a cover with (5cm) thickness and a diameter of (22 cm). The detector was placed in the center of the chamber to reduce the effect of the scattered radiation from the shield. The detector has an energy resolution of 8.9 at 661.2 keV gamma energy. In this work, the energy calibrations of the gamma-ray spectra were done using standard radioactive sources of ^{137}Cs, ^{60}Co and ^{152}Eu. Counting was done for 24 hours because of the low natural activities of radionuclides in water. The spectrum was measured and the area under the photo-peaks was computed using the algorithm of the MCA. The prominent photo-peaks observed in the spectra of the samples were identified as those of the radionuclides in the natural decay series of ^{238}U, ^{232}Th and the non-series ^{40}K. Subsequently, the transition lines of 1460 keV of ^{40}K, 1764.5 keV of ^{214}Bi, 2614.7 keV of ^{208}Tl were used to determine the ^{238}U and ^{232}Th, as well as the non-series ^{40}K, respectively [12].

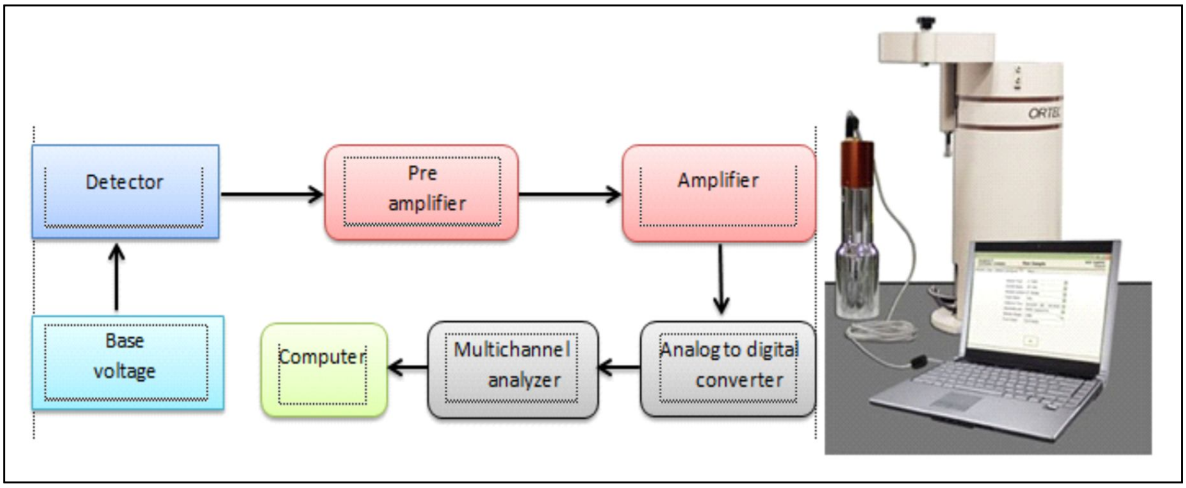

FIG. 2. Diagram of an NaI(Tl) system.

3.3 Concentrations of Activity Effective Dose of Radiation Due to Ingested Water Computation

The concentration C of the radionuclide, in every single sample of water, has been evaluated by the use of the relation [7, 13]:

$$A = \frac{N(E_\gamma)}{\varepsilon(E_\gamma).I_\gamma.V.t_c} \quad (1)$$

where $N(E_\gamma)$ is the net peak area of the radionuclide of interest, $\varepsilon(E_\gamma)$ is the efficiency of the detector for the energy E_γ, I_γ is the intensity per decay for the energy E_γ, V is the volume of the water sample and t_c is the total counting time in seconds (86400 s).

Effective dose of ingested water (EDIW) was calculated (in mSv/y) using the expression in [14-16]:

$$EDIW = \sum_{i=1}^{3} A_i \times C_i \times D_i \quad (2)$$

where A_i refers to the activity concentrations of the identified radionuclides (^{238}U, ^{232}Th and ^{40}K), C_i is the annual intake of sachet drinking water calculated for the age groups ≤ 1y, 2 – 17y and > 17y with an annual average water intake of 230, 330 and 730 litres per year, respectively [17]. D_i is the ingestion dose coefficients for ^{238}U, ^{232}Th and ^{40}K which are 2.8×10^{-7}, 6.9×10^{-7} and 6.2×10^{-9} Sv/Bq, respectively [14].

4. Results and Discussion

Table 3 displays the activity concentrations of ^{238}U, ^{232}Th and ^{40}K of the samples that were taken from the groundwater of Al-Manathera districts. In addition to that, Table 4 presents the same concentrations of activity for the same elements, but in the healthy drinking water samples taken from the same area. Table 3 shows the concentrations of activity in Bq/l for ^{238}U that ranged from 11.26±0.77 to 15.22±0.89 and had an average value of 8.3±1.2. The Table shows the same measurements for ^{232}Th, which also ranged from 0.55±0.10 to 3.85±0.27 and had an average value of 1.9±0.4, while ^{40}K went from 26.90±1.24 to 91.71±2.29 with an average value of 57.4±5.7. On the other hand, Table 4 shows the same measurements, but with potable water and found the following Bq/l values that ranged from 0.11±0.02 to 1.25±0.08 with an average of 0.6±0.1o for ^{238}U, for ^{232}Th from 0.002±0.002 to 0.183±0.019 with an average of 0.07±0.02 and from 0.71±0.06 to 6.27±0.19 with an average of 2.7±0.5 for ^{40}K.

TABLE 3. Results of activity concentrations in groundwater samples in the present study.

Sample code	Activity concentrations (Bq/l)		
	^{238}U	^{232}Th	^{40}K
G1	9.12±0.69	1.08±0.14	52.15±1.72
G2	1.94±0.31	3.06±0.24	26.90±1.24
G3	10.41±0.73	2.24±0.20	50.74±1.70
G4	11.26±0.77	0.55±0.10	62.58±1.89
G5	4.33±0.47	0.59±0.11	69.75±1.99
G6	7.30±0.61	1.49±0.17	34.17±1.39
G7	3.66±0.43	2.18±0.20	48.17±1.65
G8	10.85±0.75	3.85±0.27	73.35±2.04
G9	8.51±0.66	0.66±0.11	91.71±2.29
G10	15.22±0.89	3.38±0.25	64.65±1.91
Average ± S.D.	8.3±1.2	1.9±0.4	57.4±5.7

TABLE 4. Results of activity concentrations in healthy drinking water samples in the present study.

Sample code	Activity concentrations (Bq/l)		
	^{238}U	^{232}Th	^{40}K
H1	0.12±0.02	0.130±0.016	2.21±0.11
H2	0.65±0.06	0.024±0.007	3.70±0.14
H3	0.61±0.06	0.056±0.010	6.27±0.19
H4	0.68±0.06	0.055±0.010	2.68±0.12
H5	1.25±0.08	0.164±0.018	2.87±0.13
H6	0.58±0.05	0.002±0.002	2.85±0.13
H7	0.97±0.07	0.183±0.019	1.11±0.08
H8	0.11±0.02	0.009±0.004	0.71±0.06
H9	0.63±0.06	0.023±0.007	4.15±0.15
H10	0.40±0.01	0.008±0.004	0.79±0.07
Average ± S.D.	0.6±0.10	0.07±0.02	2.7±0.50

WHO, World Health Organization, had previously set the recommended standards for the allowed limits of radionuclides in drinking water in 2008. These levels were updated in 2011. Such standardized limits were set in accordance with the possible effects that such levels of radionuclides may have on the health of human beings and they were confirmed by a number of experiments of mammals. Results obtained from worldwide averages were compared with the standardized limits recommended by WHO in 2011, which are 1, 1 and 10 Bq/l for ^{238}U (^{226}Ra), ^{232}Th (^{228}Ra) and ^{40}K, respectively [17]. Results showed that groundwater levels of ^{238}U has concentrations of activity that are higher than the internationally allowed levels, whereas the same concentrations of activity for the drinking water were within the allowed limits, except for ^{238}U in H5 sample. The activity concentrations of ^{232}Th in most of groundwater samples are higher than the global average limitations (1 Bq/l), while all values of activity concentrations in healthy drinking water were lower than worldwide average limitations [17]. For ^{40}K as in Tables 3 and 4, it is clear that all values of activity concentrations in groundwater samples are found to be higher than the worldwide average, while healthy drinking water samples had lower concentrations than the worldwide average (10 Bq/l) [17]. According to WHO 2011, Fig. 3 compares the current-work average values and the international average values for water samples. According to the measurements conducted for both drinking water and groundwater samples, it can be observed that the concentrations of activity for Potassium are greater than those of Uranium and those of Thorium are lower than those of Uranium for the two types of samples. The concentrations of ^{238}U, ^{232}Th and ^{40}K in the groundwater samples are greater than in healthy drinking water. High levels of ^{40}K were also detected in the groundwater samples, which are a function of the geological formation of the area [18]. ^{40}K is the principal naturally occurring source of internal radiation despite its low isotopic abundance [10]. Also, this probably reflects the abundance of Uranium-bearing minerals associated with granite rocks commonly found in the investigated sectors.

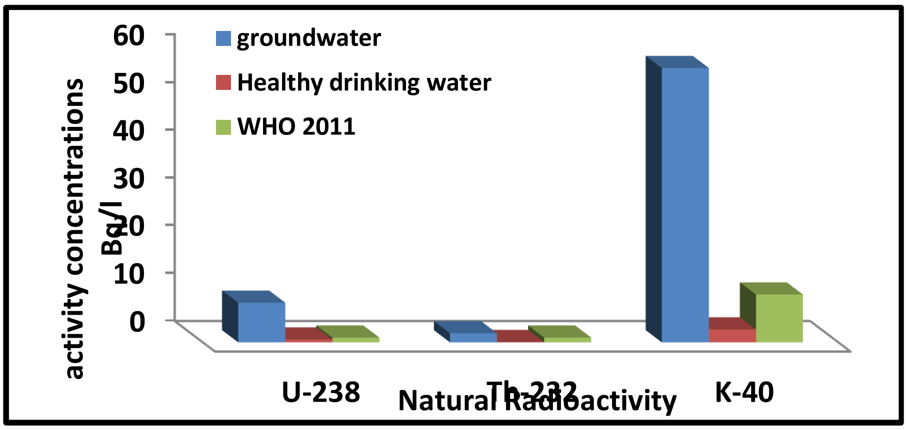

FIG. 3. Comparison of the average of activity concentrations in groundwater, healthy drinking water and WHO 2011.

Tables 5 and 6 present the EDIW consumed by the people, as a result of the absorption of ^{238}U, ^{232}Th and ^{40}K in both the groundwater and healthy drinking water of the three age groups (infants (≤ 1y), children (2 – 17y) and adults (> 17y)), respectively.

TABLE 5. Results of EDIW in groundwater.

Sample code	EDIW (mSv/y)		
	≤ 1 y	2 – 17y	≥ 17y
G1	0.83	1.19	2.64
G2	0.65	0.93	2.06
G3	1.10	1.57	3.49
G4	0.90	1.29	2.86
G5	0.47	0.67	1.50
G6	0.76	1.08	2.40
G7	0.65	0.93	2.06
G8	1.41	2.02	4.49
G9	0.78	1.12	2.49
G10	1.61	2.30	5.11
Average ± S.D.	0.9±0.10	1.3±0.15	2.9±0.3

TABLE 6. Results of EDIW in healthy drinking water.

Sample code	EDIW (mSv/y)		
	≤ 1y	2 – 17y	≥ 17y
H1	0.03	0.05	0.10
H2	0.05	0.07	0.16
H3	0.06	0.08	0.18
H4	0.06	0.08	0.18
H5	0.11	0.16	0.35
H6	0.04	0.06	0.13
H7	0.09	0.13	0.30
H8	0.01	0.01	0.03
H9	0.05	0.07	0.16
H10	0.03	0.04	0.09
Average ± S.D.	0.05±0.008	0.08±0.01	0.17±0.02

The EDIW based on ^{238}U,^{232}Th and^{40}K in groundwater samples for infants (≤ 1y), children (2 – 17y) and adults (> 17y) varied from 0.47 to 1.61 mSv/y with an average of 0.9±0.10 mSv/y, from 0.67 to 2.30 mSv/y with an average of 1.3±0.15 mSv/y and from 1.50 to 5.11 mSv/y with an average of 2.9±0.3 mSv/y, respectively (See Table 5). The EDIW of healthy drinking water samples ranged from 0.01 to 0.11 mSv/y with an average value of 0.05±0.008 mSv/y, from 0.01 to 0.16 mSv/y with an average of 0.08±0.01 mSv/y and from 0.03 to 0.35 mSv/y with an average of 0.17±0.02 mSv/y for infants, children and adults, respectively. In both of Tables 4 and 5, the dosage consumed by adults for groundwater and healthy water EDIW was found to be higher than that of children and infants. The reason behind this difference is that these age groups have variable consumption coefficients as well as different water consumption rates. This leads us to believe that EDIW of samples of groundwater was larger than the acceptable level of 1 mSv/y when comparing the public and general exposure of people and the recommended ICRP 1991 [19] and over 1000% over the recommended level of WHO of 0.1 mSv/y for drinking water. However, the EDIW of all healthy drinking water samples was less than 1 mSv/y [20] although these samples were approved with 0.1 mSv/y drinking water. The current study illustrated that consuming water from groundwater of the study area may be risky due radioactivity that is higher than what is internationally recommended. Studying and measuring radioactivity in drinking water are generally considered means to assess the potentially risky water consumption of groundwater within the study area that may pose further health side-effects to all consumers. The study recommends procedures to be conducted to avoid further health complications to the local population. Healthy drinking water, as shown previously in this study, can be safely consumed and used for daily domestic activities in Al-Manathera district of Al-Najaf city. The study also recommends that similar studies need to be regularly conducted in boreholes, wells and tap water, at least twice a year.

Conclusion

Activity concentrations of (^{283}U, ^{232}Th and ^{40}K) in the taken samples from Al-Manathera show that in the potable water samples were less than those in the groundwater. Furthermore, this study illustrated that the groundwater samples revealed activity concentrations of natural radionuclides (^{238}U, ^{232}Th and ^{40}K) higher than the globally permitted values (1, 1 and 10) Bq/l data from the recommended reference, WHO 2011. However, when the drinking-water samples were tested, it was found that their results were within the internationally allowed limit values. As a result of the combined absorption of each of ^{283}U, ^{232}Th and ^{40}K in groundwater, the average EDIW that people receive within the area of study for the current research is higher than the allowable amount of 1 mSv/y set by ICRP 1991 and 0.1 mSv/y set by WHO, 2000. However, most of the studied samples taken from drinking water contained allowed levels of radioactivity. The study further asserted that, concerning radiological activities, it is risky to consume water from the groundwater sources of the study area, as they exceed the internationally allowed limitations. On the other hand, consuming water from potable-water sources within the same study area poses no health threats to the population according to this study and for the different age groups included in this study.

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