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Radiological Safety of Water from Hadejia River

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Abstract. Water samples from Hadejia River in the north eastern part of Nigeria were studied in order to ascertain the suitability and radiological safety of water from the river for human consumption. Radioactive measurements, using a lead shielded sodium iodide detector coupled to a multichannel analyzer were used to estimate eight radiological parameters of water samples from Hadejia River. The results show that the values of all the parameters fall within the minimum universal standard, indicating that consuming the water pose no serious radiological hazard, especially for adults. The values of the Absorbed Dose Rate ($50.10511 \text{ nGyh}^{-1}$) and AEDE (12.458 mSvy^{-1}) for the infant however portend that infant consumer could be susceptible to radiation hazard on consuming water from the River. It is however recommended that activities that are capable of enhancing the radiological content of the River be avoided within the area.

Keywords: Radioactivity, Gamma Spectrometry, Specific Activity, Radiological Impact Parameters.

1. Introduction

Water is of prime importance to man [16]. Man uses water for washing, drinking, cooking and for several other purposes which together make water an indispensable commodity to man. There are several sources of water; these include rain, river, stream, water-wells among others. In civilized societies, pipe-borne drinking water is made available hygienically, after being subjected to treatment. However, rural dwellers in developing countries such as Nigeria still depend on rivers and streams as sources of drinking water. Drinking water directly from these sources is, however, not without hazards. Possible health hazards posed by drinking water directly from sources such as streams and rivers include cholera, ring worm, cancer, typhoid etc. Health hazards are due mainly to pollutants in such water bodies. A good example of water pollutant is radionuclide. Radionuclides are elements with unstable nuclides which, as a result of their instability can disintegrate by emitting ionizing radiations such as alpha, gamma and beta radiations. Radionuclides such as isotopes of potassium, K-40; uranium, U-238 and Thorium, Th-232 are present in the human environment (e.g. soil, atmosphere) as a result of both natural and anthropogenic activities. These isotopes can find their ways into water sources through rainfall and weathering activities thereby constituting pollutants thus contaminating the water [15]. When water from such rivers is used for drinking, these elements are ingested into the human systems, leading to health risk since such element will eventually disintegrate,



emitting ionizing radiations into the human system depending on their half life periods. The biological effect of ionizing radiations on human systems can be immediate or delayed, stochastic or non-stochastic. The degree and magnitude of hazard usually depends on the amount absorbed and the rate of absorption by body cells and tissues [25].

Effects of exposure of human cells to radiations from these nuclides can lead to cancer of the lung, pancreas, hepatic, bone, skin and kidney and other diseases such as cataracts, sterility, atrophy of the kidney and leukaemia [1, 2, 4 and 22]. Several authors have studied the level of radiological contamination in rivers within and outside Nigeria with the objective of quantifying the radiological health hazard posed by drinking water from such rivers, using different methods [3, 5, 8, 13, 17 and 18]. Results from such studies showed that radiological values in some rivers are lower while some are higher when compared with recommended standards by the International Commission on Radiological Protection [9]. For instance, the results of [13] and [15] showed higher values of radiological content in the rivers studied. [5] surveyed the radionuclide concentration of soil, sediments and water in Aba River, Abia state and reported higher concentrations compared to previous studies already reported by [12] and [23] for the same River. Thus the level of radiological hazards in a River may change with time. These changes over a period of time could be attributed to the growth of human activities around the river. According to [4], the growth of human population and rapid industrialization can lead to increased pollution of water sources. Since rivers still serve as the major source of water for people in the rural areas especially in Africa, it becomes imperative to know the level of radiation hazards to which humans are exposed by consuming such water hence the objective of this study is to investigate the level of radiological contamination in the Hadejia river in order to ascertain the level of the radiological health hazard posed to human life by consuming water from the river. This is necessary because over 80 percent of the locals living around the river depend on it for drinking, fishing, irrigation and general domestic use. The wetlands support extensive wet-season rice farming, flood-recession agriculture and dry-season irrigation [7, 21]. The river thus supports economy and domestic activities among hundreds of thousands of Nigeria.

2. Materials and methods

2.1. The study area

Fig.1 is the map of the study area. Hadejia River is located in Jigawa state (Latitude 12.64° – 12.65°N and Longitude 10.63° – 10.64°E) bounded by Kano in the south east and Yobe state in the north eastern part of Nigeria. The geology of Jigawa state principally comprises of crystalline and sedimentary rocks, underlain by basement complex rocks. The crystalline rocks are represented by older granites found in pockets part of the study area. The older granite is Precambrian in origin consisting of metamorphic structures of gneiss and amphibolites. The sedimentary rocks that are found in most parts of the area were uncomfortably deposited on the basement crystalline rock [7, 14 and 21].

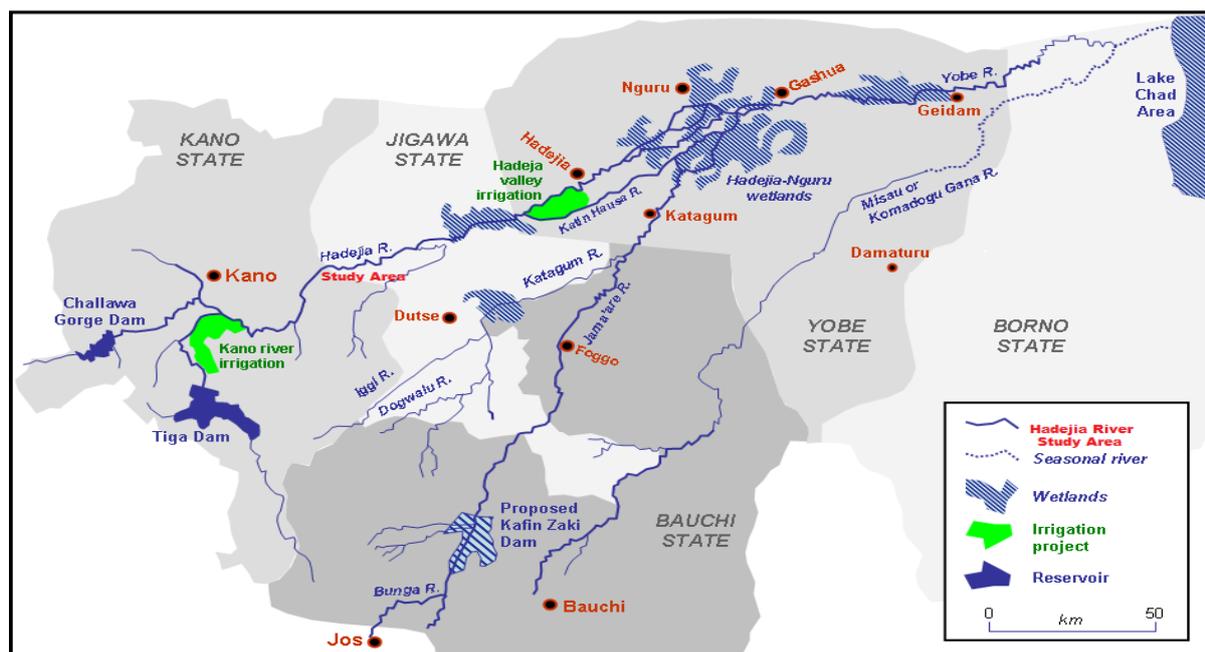


Figure 1: Map of the study area.

2.2. Method of water sampling and preparation

A total of nine water samples were collected using 1 litre polythene bottles and labeled KW1-KW9. Samples were collected randomly in 2 liters polythene bottles with tight covers which were carefully washed in the laboratory and rinsed three times with the sample water to be sure that the samples collected are representative of the bulk. These samples were collected at the bank of the river; an area where there is less dilution of the washout from the surrounding environment. The samples were acidified with 11 M HCl, at a rate of 10 ml per liter to prevent the water from biological growth and chemical action with the surface of the container and transferred to laboratory. The samples were then sealed and stored in the laboratory for 28 days before being analyzed. This was done in order to allow radon and its short-lived progenies to reach secular equilibrium prior to gamma spectroscopy [5]. The gamma spectrometric measurement was carried out using a well calibrated Sodium Iodide NaI (TI) detector enclosed in 5 cm thick lead shield to reduce background radiation. The spectra were analyzed and activity concentration of the detected radionuclide was computed directly and compared with the recommended standards.

2.3. Measurement of Radionuclide Concentration

Radioactivity measurements were done using a lead-shielded 76 mm × 76 mm NaI (TI) detector crystal coupled to a Canberra Series 10 plus Multichannel Analyzer (MCA) through a preamplifier. It has a resolution (FWHM) of about 8% at energy of 0.662 MeV (Cesium, ^{137}Cs) which is considered adequate to distinguish the gamma ray energies of interest. Each sealed sample was placed on the shielded NaI (TI) detector and counted for 18,000 s. This is to ensure that the photons emitted by the samples would only be sufficiently discriminated if their emission probability and their energy were high enough, and the surrounding background continuum low enough. The activity concentration of Bismuth, ^{214}Bi (determined from its 1.120 MeV and 0.609 MeV γ -ray peaks) were chosen to provide an estimate of Radium isotope, ^{226}Ra (Uranium, ^{238}U) in the samples, while that of the daughter radionuclide Actinium, ^{228}Ac (determined from its 0.911 MeV γ -ray peak) was chosen as an indicator of Thorium, ^{232}Th . Potassium, ^{40}K was determined by measuring the 1.460 MeV γ -rays emitted during its decay. The samples were placed symmetrically on top of the detector and measured for a period of 18,000 s. The net area under the corresponding peaks in the energy spectrum was computed by

subtracting counts due to Compton scattering of higher peaks and other background sources from the total area of the peaks. From the net area, the activity concentrations in the samples were obtained using the following equation:

$$C = \frac{A}{\varepsilon V_s P_\gamma t_c} \quad (1)$$

where, A is the net area of the peak, ε is efficiency of the detector for radionuclide n, V_s is the volume of the water sample for measurement in liter, P_γ is gamma emission probability (or branch ratio), and t_c is the counting time [18, 24 and 25].

2.4. Evaluation of Radiological Hazard Parameters

In order to effectively evaluate the radiological impacts on the samples, there are eight parameters that were estimated using the gamma ray spectrometry results for ^{40}K , ^{238}U and ^{232}Th concentrations. These parameters are absorbed dose rate, annual effective dose, radium equivalent index, annual gonadal equivalent dose, external and internal hazard indices, gamma index and excess lifetime cancer risk.

2.4.1. Absorbed Dose Rate. The absorbed dose is a measure of the energy deposited in a medium by ionizing radiation per unit mass. It may be measured as joules per kilogram and represented by the equivalent S.I. unit, gray (Gy) or rad. The health risk due to radiological and clinical effects of radiation is directly related to the absorbed dose rate hence, estimation of this parameter is the first step to evaluating health risk [18, 19]. The unit of absorbed dose rate is nano Gray per hour (nGy/h). The absorbed dose rate D (nGy/h), due to activity concentration of ^{238}U , ^{232}Th and ^{40}K was calculated using;

$$D = C_U A_U + C_{Th} A_{Th} + C_K A_K \quad (2)$$

where A_U , A_{Th} , A_K are the radioactivity concentration in Bq/L and C_U , C_{Th} , and C_K are dose conversion factors which are 0.462, 0.604 and 0.0417 for ^{238}U , ^{232}Th and ^{40}K respectively. Average value is given as 57nGy/h [24, 25].

2.4.2. Annual Effective Dose (AED). Effective Dose is a dose quantity defined by the International Commission on Radiation Protection to monitor and control human exposure to ionizing radiation. It is the tissue-weighted sum of the equivalent doses in all specified tissues and organs of the body and represents the stochastic health risks to the whole body. It takes into account the type of radiation and the nature of each organ or tissue being irradiated, and enables summation of organ doses due to varying levels and types of radiation, both internal and external, to produce an overall calculated effective dose. This combines both internal and external exposures. The Annual Effective Dose (AED) is the sum of the effective dose over a year.

(a) Annual Effective Dose for Ingested Radionuclide ($AED_{\text{Internal Exposure}}$): The annual effective dose rate for all the ingested radionuclides from water was calculated using equation (3) below.

$$AED_{\text{Internal Exposure}} = \sum_i I_i \times 365 \times D_i \quad (3)$$

where I_i is the daily intakes of radionuclide. Intake (Bq/d) = (concentration of radionuclide in food or water in Ci/lb or Bq/kg) \times (consumption rate of water or food in lb/day or kg/day) and the ingestion dose coefficient (dose conversion factor) D_i for adults for ^{40}K , ^{232}Th and ^{238}U is 6.2×10^{-9} , 2.3×10^{-7} and 4.5×10^{-8} Sv/Bq, respectively [10, 24]. The annual effective dose resulting from the ingestion of water was estimated based on the assumption that a daily intake of water per person is 2 l/d for adults and 1 l/d for lower ages and 0.5 l/d for infants [4, 27]. The Dose Conversion Factors for ingestion of radionuclides for members of the public for all ages provided by [10] is giving in Table 1.

Table 1: Dose Conversion Factors for ingestion of radionuclides for members of the public to 70 years of age [10].

Radionuclides	$T_{1/2}$ (years)	DCF (Sv/Bq) Other ages					
		Infants	1year	5years	10years	15years	Adults
^{40}K	1.2×10^9	5.2×10^{-8}	4.2×10^{-8}	2.2×10^{-8}	1.3×10^{-8}	7.6×10^{-9}	6.2×10^{-9}
^{232}Th	1.405×10^1	1.6×10^{-6}	4.5×10^{-7}	3.5×10^{-7}	2.9×10^{-7}	2.5×10^{-7}	2.3×10^{-7}
^{238}U	4.468×10^9	1.4×10^{-7}	1.2×10^{-7}	8.0×10^{-8}	6.8×10^{-8}	6.7×10^{-8}	4.5×10^{-8}

(b) Annual Effective Dose for External Exposures ($\text{AED}_{\text{external Exposure}}$): The annual effective dose received outdoor and indoor by a member of the public is calculated from the absorbed dose rate by applying dose conversion factor of 0.7Sv/Gy and occupancy factor for outdoor and indoor was 0.2 and 0.8 respectively [4]. AED is determined using the following equations [1, 4 and 11].

$$\text{AED}_{\text{outdoor}} (\mu\text{Sv/y}) = D(\text{nGy/h}) \times 8760\text{h} \times 0.7 (\text{Sv/Gy}) \times 0.2 \times 10^{-3} \quad (4)$$

$$\text{AED}_{\text{indoor}} (\mu\text{Sv/y}) = D(\text{nGy/h}) \times 8760\text{h} \times 0.7 (\text{Sv/Gy}) \times 0.8 \times 10^{-3} \quad (5)$$

The $\text{AED}_{\text{indoor}}$ occurs within a house whereby the radiation risks due to use of the soil as building material is taken into consideration. $\text{AED}_{\text{outdoor}}$ involves a consideration of the absorbed dose emitted from radionuclide in the environment such as ^{238}U , ^{232}Th and ^{40}K .

2.4.3. Radium Equivalent Activity Index (Ra_{eq}). The radium equivalent (Ra_{eq}) activity represents a weighted sum of activities of ^{238}U , ^{232}Th and ^{40}K . It is based on the estimation that 1 Bq/kg of ^{238}U , 0.7 Bq/kg of ^{232}Th and 13 Bq/kg of ^{40}K produce the same radiation dose rates. This allows a single index or number to describe the gamma output from different mixtures of ^{238}U , ^{232}Th and ^{40}K in a material. It was calculated using the formula [11, 18]:

$$Ra_{eq} = C_U + 1.43C_{Th} + 0.077C_K \quad (6)$$

Where C_U , C_{Th} , C_K are the radioactivity concentration in Bq/Kg of ^{238}U , ^{232}Th and ^{40}K .

2.4.4. Radiation Hazard Indices. The external radiation hazard (H_{ext}) and the internal radiation hazard (H_{int}) was calculated as follows:

$$H_{\text{ext}} = \left(\frac{C_U}{370}\right) + \left(\frac{C_{Th}}{259}\right) + \left(\frac{C_K}{4810}\right) \quad (7)$$

$$H_{\text{int}} = \left(\frac{C_U}{185}\right) + \left(\frac{C_{Th}}{259}\right) + \left(\frac{C_K}{4810}\right) \quad (8)$$

H_{int} should be less than unity for the radiation hazard to be negligible. Internal exposure to radon is very hazardous which can lead to respiratory diseases like asthma [4]. Natural radionuclide in soil, sediment and rocks produce an external radiation field to which all humans are exposed. H_{ext} must be less than unity for this external radiation hazard to be negligible. H_{ext} equal to unity corresponds to the upper limit of radium equivalent dose (370 Bq/kg) [4, 6, 11, 17, 24, 25 and 27].

2.4.5. *Excess Lifetime Cancer Risk (ELCR)*. The Excess Lifetime cancer risk (ELCR) was calculated using the following equation [4]:

$$\text{ELCR} = \text{AED} \times \text{DL} \times \text{RF} \quad (9)$$

Where, AED is the Annual Equivalent Dose Equivalent, DL is the average duration of life (estimated to 70 years), and RF is the Risk Factor (Sv^{-1}), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP uses RF as 0.05 for public [4]. Average value of ELCR is given as 0.2×10^{-3} [24, 25].

2.4.6. *Annual Gonadal Equivalent Dose (AGED)*. The gonads, the bone marrow and the bone surface cells are considered as organs of interest by [24] because of their sensitivity to radiation. An increase in AGED has been known to affect the bone marrow, causing destruction of the red blood cells that are then replaced by white blood cells. This situation results in a blood cancer called leukemia which is fatal. The AGED for the resident using such material for building was evaluated by the following equation;

$$\text{AGED } (\mu\text{Sv/y}) \text{ C} = 3.09\text{C}_U + 4.18\text{C}_{\text{Th}} + 0.314\text{C}_K \quad (10)$$

Where, C_U , C_{Th} , and C_K are the radioactivity concentration of ^{238}U , ^{232}Th and ^{40}K in soil and water samples.

2.4.7. *Representative Gamma Index (I_γ)*. This is used to estimate the gamma radiation hazard associated with the natural radionuclide in specific investigated samples. The representative gamma index was estimated as follow [4]:

$$I_\gamma = \text{C}_U/150 + \text{C}_{\text{Th}}/100 + \text{C}_K/1500 \leq 1 \quad (11)$$

Where, C_U , C_{Th} , and C_K are the radioactivity concentration of ^{238}U , ^{232}Th and ^{40}K in soil and water samples. The I_γ is correlated with the annual dose rate due to the excess external gamma radiation caused by superficial material. An increase in the representative gamma index greater than the universal standard of unity may result in radiation risk leading to the deformation of human cells thereby causing cancer. Values of $I_\gamma = 1$ corresponds to an annual effective dose of less than or equal to 1 mSv, while $I_\gamma = 0.5$ corresponds to annual effective dose less or equal to 0.3 mSv [4, 11]. Thus, I_γ should be used only as a screening tool for identifying materials that might be of concern to be used as construction materials, though materials with $I_\gamma > 1$ should be avoided [18, 20] since these values correspond to dose rates higher than 1 mSv/y, which is the highest value of the dose rates recommended for humans [24].

3. Results and Discussions

The result of the gamma ray spectrometry of the water samples is presented in Table 2. The radionuclide observed with reliable regularity belonged to the decay series chain headed by Uranium, ^{238}U and Thorium, ^{232}Th as well as the non-series Potassium, ^{40}K . The ^{40}K activity concentration dominated over the ^{238}U and ^{232}Th elemental activities as expected. The activity concentration of ^{40}K ranges between 25.42 ± 9.65 and $93.95 \pm 32.57 \text{ Bq l}^{-1}$ with a mean of $70.13667 \text{ Bq l}^{-1}$ in the water samples. The activity concentration for Uranium, ^{238}U in the water samples ranged between 41.78 ± 12.47 and $66.94 \pm 18.72 \text{ Bq l}^{-1}$ with a mean of $55.41444 \text{ Bq l}^{-1}$. For Thorium, ^{232}Th the activity concentration ranged between 6.64 ± 2.94 and $56.87 \pm 61.94 \text{ Bq l}^{-1}$ with a mean of $35.68778 \text{ Bq l}^{-1}$ (see Table 2 and Fig. 2). The activity concentration of ^{40}K , ^{238}U and ^{232}Th in all the samples exceed the world safe limit of 10.0, 10.0 and 1.0 Bq l^{-1} respectively for water samples by [24] and [26] standards and hence poses a serious health effect.

Table 2: Activity concentration of ⁴⁰K, ²³⁸U and ²³²Th in the water samples.

Code	K-40 (Bq ^l ⁻¹)	Th-232 (Bq ^l ⁻¹)	U-238 (Bq ^l ⁻¹)
kw1	25.42	12.18	63.66
kw2	77.86	51.01	44.92
kw3	37.21	31.63	43.97
kw4	91.86	33.91	64.82
kw5	85.60	50.25	41.78
kw6	47.28	34.54	66.94
kw7	84.49	44.16	46.36
kw8	93.95	6.64	65.61
kw9	87.56	56.87	60.67
Min	25.42	6.64	41.78
Max	93.95	56.87	66.94
Mean	70.14	35.69	55.41
Median	84.49	34.54	60.67
Stdv	26.12	17.26	10.78

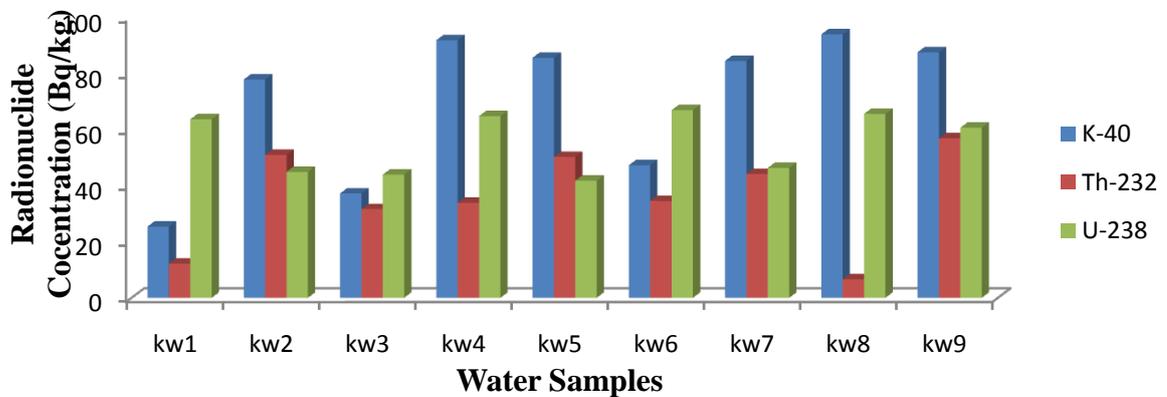


Figure 2: Activity Concentration of ²³⁸U, ²³²Th and ⁴⁰K in the selected water samples from Hadejia River.

The mean Absorbed Dose Rate for the water samples is 50.105nGyh⁻¹ (see Table 3). The mean Absorbed Dose Rate for the water is slightly below the general average value of 57nGyh⁻¹ [24]. The mean AEDE for the ingested radionuclide in drinking water from the area for infants, 1year, 5years, 10years, 15years and adults is 0.012458, 0.009332, 0.006734, 0.005481, 0.0048 and 0.00807mSvy⁻¹ respectively (see Table 3 and Fig. 3). These average values of AEDE for the different age groups are within the acceptable safe limits of 0.1 mSv/year, for the general public. Although it should be noted that daily intake of water per person of 2 ld⁻¹ for adults, 1 ld⁻¹ for lower ages and 0.5 ld⁻¹ for infants was used as the intake of water varies among these age groups. From Fig 3, it is clear that the infants

as expected are more susceptible to radiation hazards in the area followed by 1year then adults, 5years, 10years and then 15years respectively. They are all within the safe limits of 0.1 mSvy^{-1} .

The mean $R_{a_{eq}}$ for the water samples is 109.290 Bql^{-1} . The estimated average value is lower than the recommended maximum value of 370 Bql^{-1} for the safe use of materials in the construction of buildings. This means that the water from this area can safely be used for building and other purposes without much fear of radiological hazards.

Table 3: AEDE for different age categories for the people in the study area.

SAMPLE	AEDE (mSvy^{-1})					
	ADULTS	INFANTS	1YEAR	5YEARS	10YEARS	15YEARS
KW1	0.00425	0.00542	0.00517	0.00361	0.00298	0.00273
KW2	0.01000	0.01670	0.01150	0.00845	0.00688	0.00596
KW3	0.00692	0.01070	0.00769	0.00562	0.00461	0.00406
KW4	0.00824	0.01240	0.00981	0.00696	0.00563	0.00493
KW5	0.01010	0.01650	0.01130	0.00832	0.00676	0.00584
KW6	0.00821	0.01220	0.00932	0.00674	0.00554	0.00491
KW7	0.00932	0.01480	0.01050	0.00767	0.00662	0.00539
KW8	0.00369	0.00450	0.00540	0.00351	0.00277	0.00247
KW9	0.01190	0.01890	0.01330	0.00973	0.00794	0.00691
MEAN	0.00807	0.012458	0.009332	0.006734	0.005481	0.00480

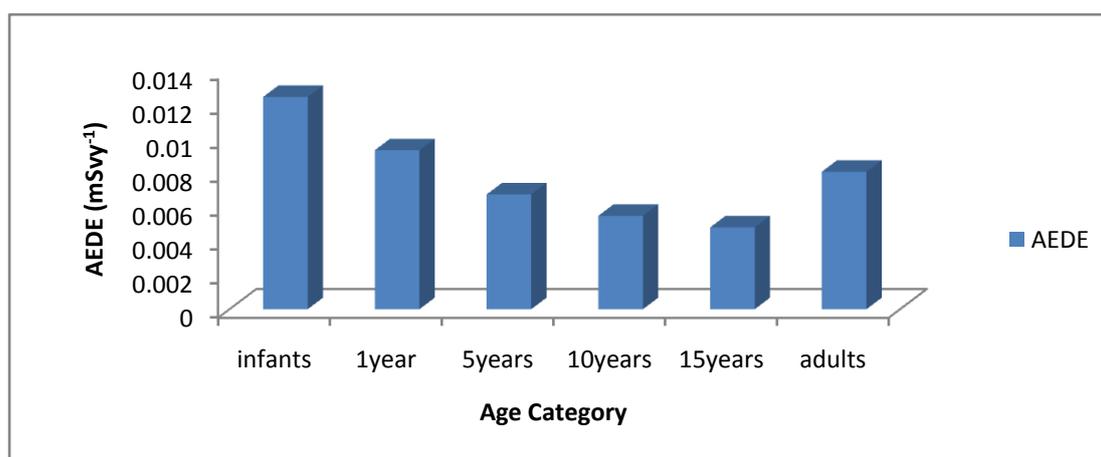


Figure 3: AEDE (mSvy^{-1}) for different age category/group of people in the study area

Table 4: Radiation hazard parameters for the water samples

SAMPLE CODE	D (nGyh ⁻¹)	AED (ADULTS) (μSvy ⁻¹)	RA _{eq} (Bql ⁻¹)	H _{ext}	H _{int}	ELCR	AGED (μvy ⁻¹)	I _γ
KW1	37.835	0.00425	83.034	0.224	0.396	0.0665	255.604	0.563
KW2	54.833	0.01000	123.859	0.334	0.456	0.1225	376.473	0.861
KW3	40.982	0.00692	92.066	0.249	0.368	0.0875	279.764	0.634
KW4	54.287	0.00824	120.384	0.325	0.500	0.1050	370.882	0.832
KW5	53.248	0.01010	120.229	0.325	0.438	0.1155	366.023	0.838
KW6	53.774	0.00821	119.973	0.323	0.505	0.1050	366.072	0.823
KW7	51.661	0.00932	116.015	0.314	0.440	0.1085	354.371	0.807
KW8	38.269	0.00369	82.339	0.223	0.401	0.0560	259.990	0.566
KW9	66.057	0.01190	125.712	0.402	0.566	0.1440	452.681	1.031
MIN	37.835	0.00369	82.339	0.223	0.368	0.0560	255.604	0.563
MAX	66.057	0.01190	125.712	0.402	0.566	0.1440	452.681	1.031
MEAN	50.105	0.00807	109.290	0.302	0.452	0.1012	342.429	0.773

The estimated hazard indices H_{int} and H_{ext} for the water samples are 0.452 and 0.302 respectively. (See Table 4). These values of H_{int} and H_{ext} in water are less than unity which follows that hazardous effects of these radionuclides and their short-lived progenies are negligible. The estimated ELCR for the water samples is 0.1012 (1.012×10⁻³) (See Table 4). The estimated value of ELCR is higher than the average value of 0.2×10⁻³. The high value of the ELCR index for the water samples is due to high AEDE caused by high specific activity of ⁴⁰K radionuclide in the samples. This high value implies that the probability of developing cancer over a lifetime considering seventy years as the average life span of humans is high. The estimated mean value for the AGED in the water samples is 342.429 μSvy⁻¹. The estimated mean I_γ for the water samples is 0.773Svy⁻¹. These values are within the safe limits.

4. Conclusion

A radiological study of the water from Hadejia river have been carried out by the estimation of the eight radiological parameters using data obtained from the gamma ray spectrometry of the samples drawn from the river. The results showed trends that are generally low for most radiation hazard indices calculated except for few indices whose values are above the UNSCEAR recommended thresholds. Therefore, there may be no serious immediate radiological effects to the general populace as a result of consuming water from the river. However, considering the fact that artificial

radionuclides are synthetic radionuclide produced by human activities like high use of fertilizers and agrochemicals, it is hereby recommended that all activities that enhance or introduce radio-nuclides to the environment be discouraged or prohibited within the vicinity of the river in order to avoid any possibilities of radiological hazards.

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