Available: DOI: https://doi.org/10.54117/gjpas.v3i1.130 Research article

Gadau Journal of Pure and Allied Sciences
Gadau J Pure Alli Sci, 3(1): 1-14 (2024)
ISSN: 2955-1722
DOI: https://doi.org/10.54117/gjpas.v3i1.130

Assessment of Natural Radioactivity in Drinking Water from some Selected Districts of Michika, Adamawa State, Nigeria

Suleiman Saidu Zarma[1], Nuraddeen Nasiru Garba[1], Nasiru Rabiu[1], Umar Muhammad Dankawu[2], Suleiman Bello[3], Adamu David Gaima Kafadi[2] and Chifu E. Ndikilar[2]

[1]Department of Physics, Ahmadu Bello University Zaria, Kaduna State, Nigeria.
[2]Department of Physics, Federal University Dutse, Dutse, Jigawa State, Nigeria.
[3]Department of Physics, Umaru Musa Yar'adua University, Katsina State, Nigeria.

*Correspondence: saiduzarma@gmail.com; +2347036033334

Abstract

Radionuclides are source of radiation that were recorded to have damaging health effects for people living in a community with high back-ground radiation. This study was carryout to assess natural radioactivity in drinking water sources at some districts of Michika, Adamawa State, Nigeria. Twenty-four (24) water Samples from three different sources (surface, borehole and well), were collected and analyzed using a thallium activated 3″ x 3″ sodium iodide [NaI (TI)] detector connected to ORTEC 456 amplifier available at Center of Energy Research and Training (CERT), Zaria. The results show that the mean activity concentration for ^{226}Ra, ^{232}Th and ^{40}K are 57.05, 40.31 and 193.6 Bql^{-1} for borehole samples, 82.09, 23.0 and 199.4 for surface samples and 87.65, 38.82 and 215.7 for well samples. These values are higher than the control value of activity concentration set by UNSCEAR 200). The mean absorbed dose rate (D) for borehole, surface and well water samples were found to be 58.78, 60.1 and 72.94 nGy/h respectively. The mean values surface and well samples were higher than the maximum accepted value of 59nGy/h as recommended by (UNSCEAR, 2000) however, borehole is within the MCL. The mean values of total annual effective dose for borehole, surface and well water samples were 0.08, 0.08 and 0.09 respectively. These values are below 0.12, 0.1 and 1.0 mSvy^{-1} as recommended by UNSCEAR, WHO and ICRP. Also, the mean values of Radium Equivalent Activity were 129.6, 130.4 and 159.8 Bql^{-1} for borehole, surface and well water samples respectively. All the value of R_{aeq} were below the maximum recommended value of 370 Bql^{-1}. The mean value of total cancer risk is 3.18E-06, 3.25E-06 and 3.91E-06 for borehole, surface and well water samples respectively. All the mean values were above the acceptable range of 1E-06 to 1E-04. Based on our findings, the water sources in this area are not safe for domestic use. However continuous radiological monitoring of the water is recommended to safeguard the health of the populace.

Article History
Received: 27/07/2023
Accepted: 27/01/2024
Published: 07/03/2024

Keywords
Radioactivity; Norms; Hazard indices; Annual Effective Dose; and Cancer risk.

How to cite this paper: Zarma S. S, Garba N. N., Rabiu N., Dankawu U. M., Bello S., Adamu G. D., and Chifu E. N. (2024). Assessment of Natural Radioactivity in Drinking Water from some Selected Districts of Michika, Adamawa State, Nigeria. *Gadau J Pure Alli Sci, 3(1): 1-14.* https://doi.org/10.54117/gjpas.v3i1.130.

1.0 Introduction

Water is a crucial resource for the survival and existence of humankind and the importance of ensuring good quality drinking water cannot be over emphasized. Most of the inhibitas depend on surface, groundwater, boreholes, and wells for their survival (Dankawu *et al.*, 2021). Most of the water used for drinking and other domestic purposes usually contain number of natural radionuclides such as radon, uranium, radium, isotopes, tritium, etc. Their concentrations vary widely as they rely on the aquifer of the prevailing lithology and absence or the presence

Journal of the Faculty of Science, Bauchi State University Gadau, Nigeria
Phytochemistry and Natural Product

of air in it (Aguko *et al*., 2020). Water pollution is a serious issue in rural and urban communities. The quality of water sources of any area defined the quality of goods produced, its economy, public health and industrial development (Chifu *et al*., 2016). Radiation in the environment originates from a number of humans made and naturally occurring sources while the exposure from it occurs through inhalation, ingestion, injection, or absorption of radioactive materials (Abba *et al*., 2020). Radiation in the environment originates from a number of humans-made and naturally occurring sources while the exposure from it can occur through inhalation, ingestion, injection, or absorption of radioactive materials (Abba *et al*., 2020). Natural sources contribute significant quantities of radiation toward the total radiation exposure to humans (Garba *et al.*, 2013). Radioactivity in water is playing a crucial role in transferring radionuclides from the environment to human. Tritium, potassium, and radium are the most important natural radionuclides in drinking water and their decay products are in essence gamma and beta emitters (Shittu *et al*., 2016). The human body has some amounts of radionuclides, which either originate from man-made sources of radiation and continuous exposure to natural radiation (i.e., terrestrial sources, cosmic ray, and radon) or they exist naturally from birth inside the human body such as carbon (14C), potassium (40K) and lead (210Pb) (Hassan et al., 2018). Radioactivity in water comes mainly from radionuclide of 232Th, and238 Udecay series and 40K in soil as well as industrial effluents, wastes and other maritime activities. Most rural and urban communities depend on water such as taps, borehole, river, surface, creeks etc. for their daily needs. Consequently, radionuclides can also be transported to food chain through irrigation (Ononugbo and Anyalebechi1, 2017). Radiation health effects from uranium in the northern part of Adamawa state, Nigeria has attracted a lot of attention. It has been reported and confirmed from hospitals (whose names were not disclosed for ethical reasons) in the host communities that, several mysterious deaths, still born babies, deformed babies (like single leg, smooth featureless face) have been witnessed in the area (Zarma *et al*., 2023). This was corroborated by a Daily Trust Newspaper report of 3rd August 2016 and Oak TV report of October 19, 2016), that uranium ore mineral radiation exists in communities of Michika Local Government Area (LGA) following activities of the defunct uranium mining company jointly owned by Nigeria and French Companies between 1980-1983 (Zarma *et al*., 2023). Thus, it is necessary to assess the safety and quality of different water sources used in the area, especially domestic purpose. This study attempts to assess the radiological status of different water sources used for domestic purposes in Michika LGA, Adamawa State, Nigeria.

2.0 MATERIALS AND METHODS

2.1 Study Area

The study was carried out in Michika Local Government Areas, Adamawa State, Nigeria (Figure 1). It consists of 8 districts and 16 wards. The districts include Garta, Sina, Futu, Himike, Nbororo, Ghunchi, Nkala, Baza and Minchika town. The area has a population of 179,460 (2011 NPC projection) with an area of 967km^2 and a population density of 186km^2. The area lies within latitudes 10°32'N to 10°41'N and longitudes 13°19'E to 13°25'E, and it is bounded to the West by Borno State, to the East by Republic of Cameroon, to the North by Madagali Local Government Area and to the South by Mubi Local Government Area respectively. The area is relatively flat in the west and hilly in the eastern part, and despite the hilly nature of some parts of the area, there are good footpaths, road networks and tracks (Nur and Ayuni, 2011).

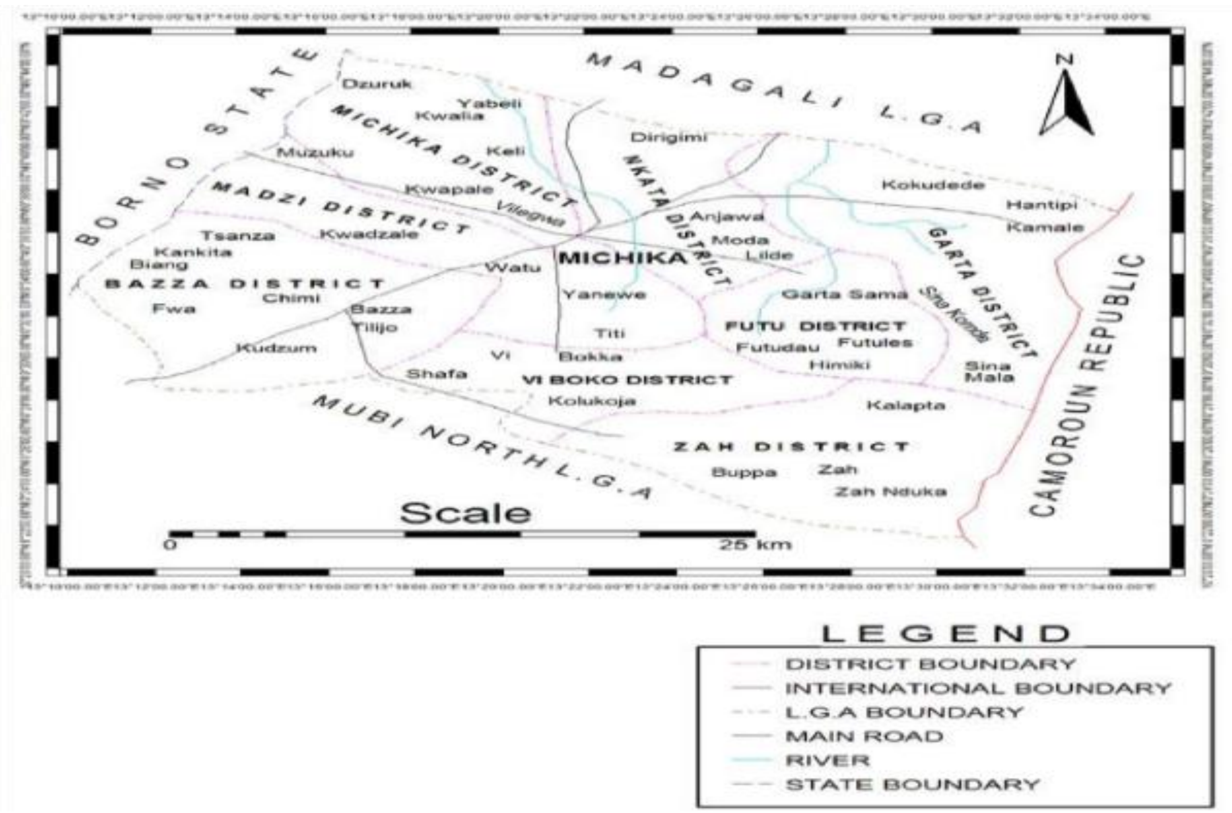

Figure 1. Districts Map of Michika Local government Area (Williams *et al.*, 2015).

2.2 Geology of the Study Area

The study area is a flat land with patches of outcrops of granitic rock except in the southeastern part where the elevations of the mountains attain over 2500 feet (Figure 2), with many rivers originated from the mountains and generally flow towards west and northwest of the study area. The rivers include Rafin Wantse, Yedseram, and Rafin Nanda. The rocks aid in the formation of dendritic pattern of drainage network. The valleys that drained the rivers have alluvial flood plains comprising mainly of coarse quarzitic materials. However, granites ranging from fine course, grained, pegmatite, granodiorites, and biotite granite predominantly occupy the southern part of the area.

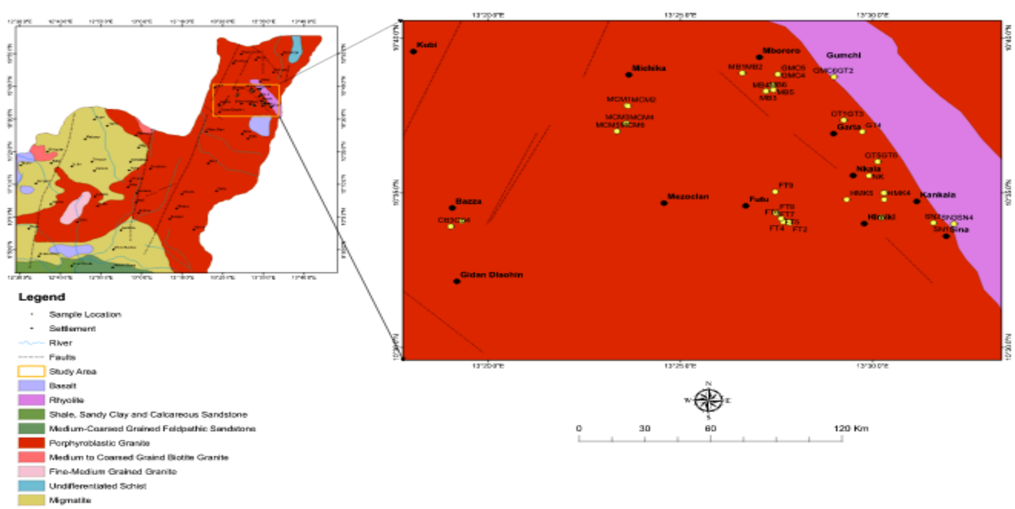

Figure 2: Geological map of the study area (Nur and Ayuni 2011)

2.3 Sample Collection

Twenty-four (24) water sample were collected randomly in a clean 1L bottles with tight covers from within the study area from three different domestic sources of water namely: surface, borehole and wells water sources respectively. The surface water samples were collected with the aid of a bailer, to ensure fresh samples were obtained. The hand dug shallow well water samples were collected directly, by dipping a clean container attached to a long rope to reach the water level in the well. The water samples from borehole were collected after evacuating the existing water in the pipe (Tchokossa *et al.,* 1999), 10mL of 65% HNO3 was added to all samples to avoid changes in the state of the ions that are present in the samples. In addition, to prevent or avoid CO_2 trapping, the bottles were filled to the brim without any headspace, after which, the samples were transferred to the laboratory immediately after collection and analyzed within few days so that the sample composition could not change.

2.4 Sample Preparation and Analysis

The collected samples were evaporated (without boiling) in a furnace at temperature of 60^0C to reduce their volume from approximately 1.5L to 0.2L and was poured into 0.2L cylindrical polyethylene vials that is of detector geometry. The samples were sealed and stored for about four weeks to reach radioactive equilibrium.

The samples were analyzed using a thallium activated 3″ x 3″ sodium iodide [NaI (TI)] detector connected to ORTEC 456 amplifier. Background measurement and efficiency calibration of the system were made possible using ^{137}Cs and ^{60}Co standard sources from IAEA, Vienna. Spectrum were accumulated for background for 29,000s at 900 V to produce strong peaks at gamma emitting energies of 1460 keV for ^{40}K; 609 keV of ^{214}Bi and 911 keV of ^{228}Ac, which was used to estimate the concentration of ^{226}Ra and ^{228}Ra respectively. The activity of the standards at the time of calibration is 25.37 kBq for ^{137}Cs and 4.84 kBq for ^{60}Co. The background spectra measured under the same conditions for both the sample and standard measurements, were used to correct the estimated activity concentration of the sample in accordance with Arogunjo *et al.,* (2005). The activity concentration (C) in Bql^{-1} of the radionuclide in a sample was determined after subtracting decay correction using the expression:

$$Cs\ (BqL^{-1}) = \frac{Ca}{\mathcal{E} * V * t * \text{ɣ}} \quad (1)$$

Where Cs is the sample concentration, Ɛ is the efficiency of the detector for ɣ-energy of interest, Ca is the net peak area of a peak at energy, V is the sample volume (L), ɣ is the emission probability of radionuclide of interest and t is the total counting time.

2.5 Radium Equivalent Activity (Ra_{eq}) and Absorbed Dose Rate (D)

The Radium Equivalent Activity (Ra_{eq}) and Absorbed Dose Rate (D) were calculated from radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K, using Equation 2 and 3 respectively as proposed by UNSCEAR, 2000 (Jibiri *et al*., 2007; Belivermis *et al*, 2009).

$$Ra_{eq}\ (Bq / kg) = A_{Ra} + 1.43A_{Th} + 0.077\ A_K \quad (2)$$

$$D\ (nGyh^{-1}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \quad (3)$$

where Ra_{eq} is the radium equivalent activity, D is the absorbed dose rate and A_{Ra}, A_{Th} and A_k are the specific activities concentration of ^{226}Ra, ^{232}Th and ^{40}K, respectively. In defining Ra_{eq} activity, it is assumed that 10 Bq\kg of ^{226}Ra, 7 Bq\kg of ^{232}Th and 130 Bq\kg of ^{40}K produced equal gamma ray dose. The maximum value of Ra_{eq} must be less than the acceptable safe limit of 370 Bq\kg (Lydie and Nemba, 2009).

2.6 Annual Effective Dose

The annual effective dose due to external gamma radiation, annual effective dose due to ingestion and total annual effective dose were obtained from the mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K as defined by equations 4, 5 and 6 respectively. (UNSCEAR, 2000; ICRP, 2012).

$$AED\gamma = D \times 8760h \times 0.2 \times 0.7Sv\ Gy \times 10^{-3} \quad (4)$$

$$AED_{ing}\ (mSvy^{-1}) = AR \times IR \times DCF \quad (5)$$

$$TAED = AED\gamma + ED_{ing} \quad (6)$$

where AEDγ is the annual effective dose due to external gamma radiation, AED_{ing} is the annual effective dose due to ingestion, TAED is the total annual effective dose, D is the absorbed dose rate in air, 0.7 $SvGy^{-1}$ is the dose conversion coefficients, 0.2 is the outdoor occupancy factor, AR is the mean activity concentration of radionuclides in a sample (Bq/kg), IR is the water consumption rate per year ($730Ly^{-1}$) (DEA, 2010). DCF is the effective dose coefficient in $SvBq^{-1}$ for the ingestion of natural radionuclides of ^{226}Ra, ^{232}Th and ^{40}K with values of 4.50E-08, 2.30E-07 and 6.20E-09 respectively (ICRP, 2012).

2.7 Radiation Hazard Indices

The external and internal hazard indices were used to estimate the external and internal hazards that could arise from the use of water samples. These indices were computed using equation 7 and 8 respectively as proposed by UNSCEAR (2000). Furthermore, gamma and alpha indices ($\boldsymbol{I\gamma}$ *and* $I\alpha$) were used to estimate the excess γ and α radiation. They were estimated using equation 9 and 10 respectively (Asaduzzaman *et al*., 2016; Xinwei *et al*., 2006).

$$Hex = A_{Ra}/370 + A_{Th}/259 + A_K/4810 \quad (7)$$

$Hin = A_{Ra}/185 + A_{Th}/259 + A_K/4810$ (8)

$I\gamma r = A_{Ra}/300 + A_{Th}/2100 + A_K/3000$ (9)

$I\alpha = A_{Ra}/200\ (Bq/kg)$ (10)

2.8 Cancer Risks

The fatality cancer risk, hereditary cancer risk and total cancer risk due to low doses without threshold dose known as stochastic effects was estimated using equations 11, 12 and 13 respectively based on ICRP (2007) cancer risk assessment methodology.

$FCR = total\ AED\ (Sv) * cancer\ nominal\ risk\ fact$ (11)

$Hereditary\ risk = totalAED\ (Sv) * hereditary\ nominal\ riskfactor$ (12)

TCR = FCR+ HCR (13)

where TCR is the total cancer risk, FCR is the *Fatality cancer risk* and HCR is the *Hereditary risk*.

3.0 Result and Discussion

TABLE 1: Sample ID and coordinate of the Borehole Water Sample Location

Sample ID	Longitude	Latitude
HM1	11º 42’11”	33º 38’40”
MC1	11º 45’ 20”	32º 25’32”
MC4	11º 44’ 25”	32º 22’43”
MC5	11º 41’ 21”	31º 35’16”
FL1	11º 41’ 28”	33º 27’54”
B1	11º 41’ 24”	31º 38’27”
GA1	11º 44’ 47”	33º 27’16”
N1	11º 42’ 48”	33º 34’21”
MB1	11º 45’ 50”	33º 25’13”

TABLE 2: Sample ID and coordinate of the Surface Water Sample Location

Sample	**Longitude**	**Latitude**
HM3	11º 41’56”	33º 38’33”
MC3	11º 45’19”	32º 25’55”
FL3	11º 41’29”	33º 29’50”
B3	11º 45’49”	33º 25’11”
GA3	11º 43’17”	33º 36’51”

TABLE 3: Sample ID and coordinate of the Well Water Sample Location

Sample	**Longitude**	**Latitude**
HM2	11º 42’11”	33º 38’37”
MC2	11º 44’42”	32º 23’25”
FL2	11º 41’26”	33º 11’38”
B2	11º 41’22”	31º 35’14”
GA2	11º 41’22”	33º 32’31”
S1	11º 44’26”	33º 40’38”
GH1	11º 46’20”	33º 24’33”
Z1	11º 45’52”	33º 27’19”
N2	13º 22’44”	10º 38’42”
MB2	11º 46’29”	32º 58’32”

Table: 4. Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in (Bqkg^{-1}), Absorb Dose Rate, Annual Effective Dose Due to External Gamma Radiation, Annual Effective Dose due to Ingestion and Total Annual Effective Dose for Borehole Water Samples Respectively.

SAMPLE ID	^{226}Ra	^{232}Th	^{40}K	D	AEDγ	AEDing	TAED
HM1	69.95	18.48	27.03	44.61	0.05	0	0.058
MC1	49.34	29.49	234.5	50.38	0.06	0	0.07
MC4	64.96	77.07	184.9	84.27	0.1	0	0.11
MC5	82.33	10.11	141.6	50.05	0.06	0	0.06
FL1	74.34	24.18	271.1	60.26	0.07	0	0.08
B1	45.82	18.76	174.8	39.79	0.05	0	0.05
GA1	51.77	37.08	83.01	49.78	0.06	0	0.06
N1	33.48	106.2	141.7	85.5	0.1	0	0.11
MB1	41.48	41.44	483.8	64.37	0.08	0	0.08
MEAN	**57.05**	**40.31**	**193.6**	**58.78**	**0.07**	**0**	**0.08**
MIN	**33.48**	**10.11**	**27.03**	**39.79**	**0.05**	**0**	**0.05**
MAX	**82.33**	**106.2**	**483.8**	**85.5**	**0.1**	**0**	**0.11**

From Table 4. and Figure. 3&4 the Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in Bql^{-1} for borehole water sample were range between 33.48 to 82.33, 10.11 to 106.2 and 27.03 to 483.8 with the mean value of 57.05, 40.31 and 193.6. The minimum value of the absorb dose rate is 39.79 obtained from B1 sample location while the maximum value is 85.5 obtained from NI sample location, with average value of 58.78. O.05 and 0.11 are the lowest and highest value of total annual effective dose obtained from B1 and NI samples location, with mean value of 0.08. Below is the chart of activity concentration of Uranium, Thorium and Potassium for Borehole water samples.

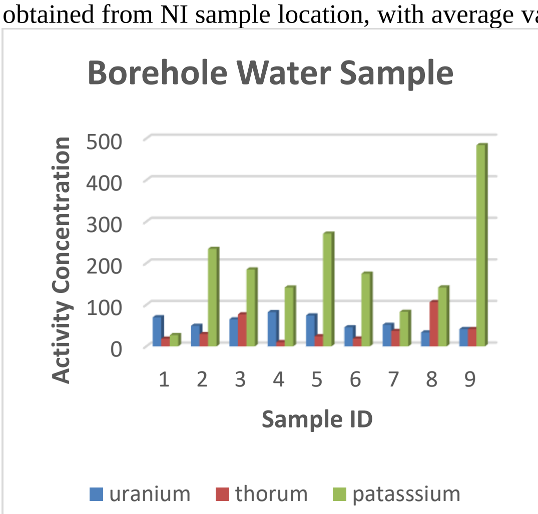

Figure 3. Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K for Borehole Water Sample

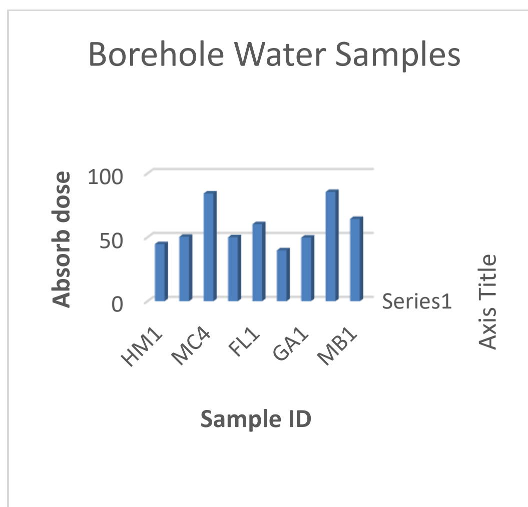

Figure. 4. Absorb Dose for Borehole Water Sample

TABLE: 5. Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in (Bql^{-1}), Absorb Dose Rate, Annual Effective Dose Due to External Gamma Radiation, Annual Effective Dose due to Ingestion and Total Annual Effective Dose for Surface Water Samples Respectively.

SAMPLE ID	^{226}Ra (Bql^{-1})	^{232}Th	^{40}K	D	AEDγ ($mSvy^{-1}$)	AEDing ($mSvy^{-1}$)	TAED ($mSvy^{-1}$)
HM3	105.6	31.3	233.0	77.4	0.09	0	0.1
MC3	84.73	29.4	148.3	63.1	0.08	0	0.08
FL3	29.96	33.3	267.2	45.1	0.06	0	0.06
B3	70.75	6.84	209.5	45.6	0.06	0	0.06
GA3	119.5	14.2	138.9	69.6	0.09	0	0.09
MEAN	**82.09**	**23.0**	**199.4**	**60.1**	**0.08**	**0**	**0.08**
MIN	**29.96**	**6.84**	**138.9**	**45.1**	**0.06**	**0**	**0.06**
MAX	**119.5**	**33.3**	**267.2**	**77.4**	**0.09**	**0**	**0.1**

From Table 5. and Figure. 3&4 The activity concentration of ^{226}Ra, ^{232}Th and ^{4fi0}K for Surface Water Samples were ranges from 29.96 to 119.5, 6.84 to 33.3 and 138.9 to 267 Bql^{-1} respectively, with mean value of 82.09, 23.0 and 199.4 Bql^{-1}. The minimum value was obtained from FL3, B3 and GA3 respectively, while the maximum values were obtained in GA3 and FL3 samples locations. The lowest and highest value of the absorb dose rate were found to be 45.1. and 77.4 with mean value of 60.1. FL3 is the sample location with lowest value while HM3 is the sample location with highest value. 0.1 and 0.06 $mSvy^{-1}$ are maximum and minimum value of total annual effective dose obtained from HM3 and FL3. Figure. 5&5 is the chart of activity concentration of Uranium, Thorium and Potassium for Surface water samples.

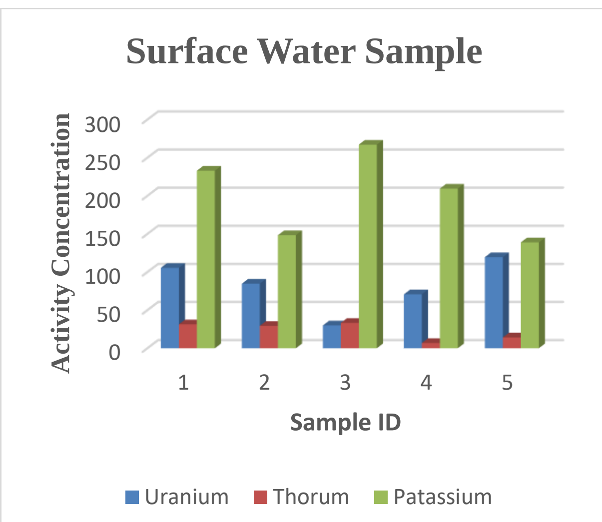

Figure. 5. Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K Surface Water Sample

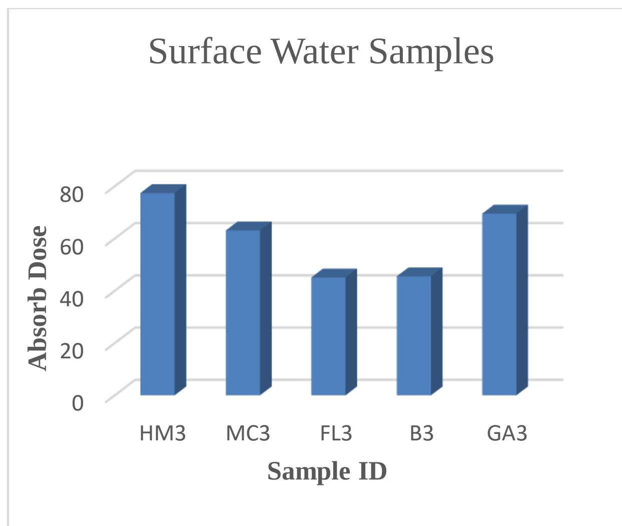

Figure. 6. Absorb Dose for Surface Water Sample

TABLE: 6. Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in (Bql^{-1}), Absorb Dose Rate, Annual Effective Dose Due to External Gamma Radiation, Annual Effective Dose due to Ingestion and Total Annual Effective Dose in (mSvy^{-1}) for Well Water Samples Respectively.

SAMPLE ID	^{226}Ra	^{232}Th	^{40}K	D	AEDγ	AEDing	TAED
HM2	143.6	17.3	187.9	84.64	0.1	0	0.11
MC2	145.9	19.27	194.7	87.18	0.11	0	0.11
FL2	112.9	22.65	263.5	76.83	0.09	0	0.1
B2	60.56	18.68	239.5	49.25	0.06	0	0.06
GA2	113.9	31.46	142.8	77.59	0.1	0	0.1
S1	118.4	31.38	221.1	82.86	0.1	0	0.11
GH1	74.34	26.7	206.2	59.07	0.07	0	0.08
Z1	23.65	103.5	355.3	88.27	0.11	0	0.11
N2	22.82	77.18	231.0	66.79	0.08	0	0.09
MB2	60.4	40.07	115.2	56.91	0.07	0	0.07
MEAN	**87.65**	**38.82**	**215.7**	**72.94**	**0.089**	**0**	**0.09**
MIN	**22.82**	**17.3**	**115.2**	**49.25**	**0.06**	**0**	**0.06**
MAX	**145.9**	**103.5**	**355.3**	**88.27**	**0.11**	**0**	**0.11**

Figure 7&8 is the Chart of activity concentration of Uranium, Thorium and Potassium for well water samples.

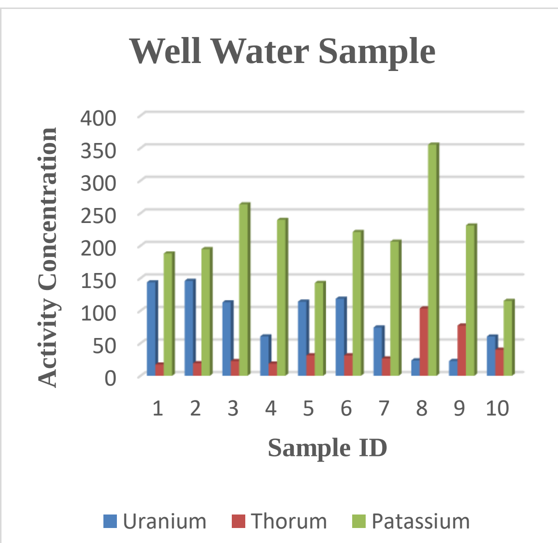

Figure. 7. Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K Well Water Sample.

Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K in (Bql^{-1}) for Well water sample were found to be from 22.82 to 145.9, 17.3 to 103.5, 49.25 to 88.27. with mean value of 87.65, 38.82 and 215.7 Bql^{-1} · The highest values were found in MC2 and Z1 sample location, while the lowest value was found in N2, HM2 and

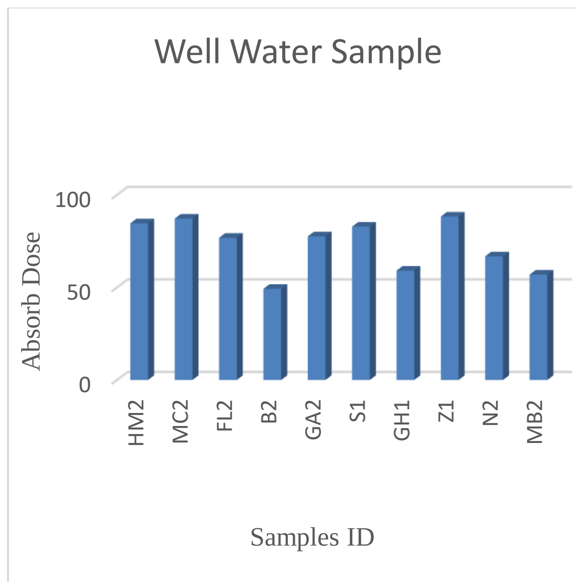

Figure. 8. Absorb Dose for Well Water Sample

MB2 samples location respectively. 88.27 and 49.25 are the highest and lowest value of absorb dose for well water sample, with mean value of 72.94. The total annual effective dose was to be between 0.06 mSvy^{-1} as the lowest value obtained from B2 sample location to 0.11 mSvy^{-1} as the highest value obtained from HM2 sample location, with mean value of 0.09. The mean values of Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K for all water sources (borehole, surface and well) were found to be higher than the maximum contaminated level (MCL) set by UNSCEAR (2000). The mean value of the absorbed dose are 58.78, 60.1 and 72.94 Bql^{-1} for borehole, surface and well respectively. The mean values of surface and well were found to be higher than the maximum accepted value of 59nGy/h as recommended by (UNSCEAR, 2000). However, the mean value of borehole samples was found to be almost equal to the accepted value of 59nGy/h. The values of total annual effective dose for all water sources were found to be within the UNSCEAR reported world average value of 0.12 mSv/y, the WHO "World Health Organization" limit of 0.1 mSv/y and also lower than the ICRP "International Commission on Radiological Protection" preference limit of 1.0 mSv/y.

Table 7. Hazard Indices for Borehole Water Samples

Sample Id	Ra_{eq}	H_{ex}	H_{in}	$I\gamma$	$I\alpha$	**FCR**	**HCR**	**TCR**
HM1	98.46	0.266	0.455	0.543	0.350	2.39E-06	5.83E-08	2.45E-06
MC1	109.6	0.296	0.429	0.492	0.24	2.68E-06	6.54E-08	2.75E-06
MC4	189.4	0.512	0.687	0.769	0.325	4.38E-06	1.07E-07	4.49E-06
MC5	107.7	0.291	0.514	0.617	0.412	2.66E-06	6.50E-08	2.73E-06
FL1	129.8	0.351	0.552	0.645	0.372	3.18E-06	7.75E-08	3.26E-06
B1	86.10	0.233	0.356	0.414	0.229	2.15E-06	5.24E-08	2.20E-06
GA1	111.2	0.300	0.440	0.506	0.259	2.65E-06	6.47E-08	2.72E-06
N1	196.2	0.523	0.620	0.663	0.167	4.45E-06	1.08E-07	4.56E-06
MB1	137.1	0.373	0.485	0.537	0.207	3.38E-06	8.25E-08	3.47E-06
MEAN	**129.6**	**0.350**	**0.504**	**0.576**	**0.285**	**3.10E-06**	**7.56E-08**	**3.18E-06**
MIN	**86.10**	**0.233**	**0.356**	**0.414**	**0.167**	**2.15E-06**	**5.24E-08**	**2.20E-06**
MAX	**196.2**	**0.523**	**0.687**	**0.769**	**0.412**	**4.45E-06**	**1.08E-07**	**4.56E-06**

The hazard indices (R_{aeq}, H_{ex}, H_{in}, $I\gamma$ and $I\alpha$,) for borehole water sample vary respectively from 86.10 to 196.2, 0.233 to 0.523, 0.356 to 0.687, 0.414 to 0.769 and 0.167 to 0.412 with mean value of 129.6, 0.350, 0.504, 0.576 and 0.285. The lowest value of (R_{aeq}, H_{ex}, H_{in}, $I\gamma$ and $I\alpha$,) were found in B1 and N1 sample location, while the highest values was obtained from N1, MC4 and MC5 sample location. The Fatality Cancer Risk were found to be in the ranges of 2.15E-06 to 4.45E-06, with mean value of 3.10E-06 while the hereditary cancer risk varies from 5.24E-08 to 1.08E-07 with mean value of 7.56E-08 and the total cancer risk varies from 2.20E-06 to 4.56E-06 with mean value of 3.18E-06. Figure 9 present the radium equivalent of borehole water sample.

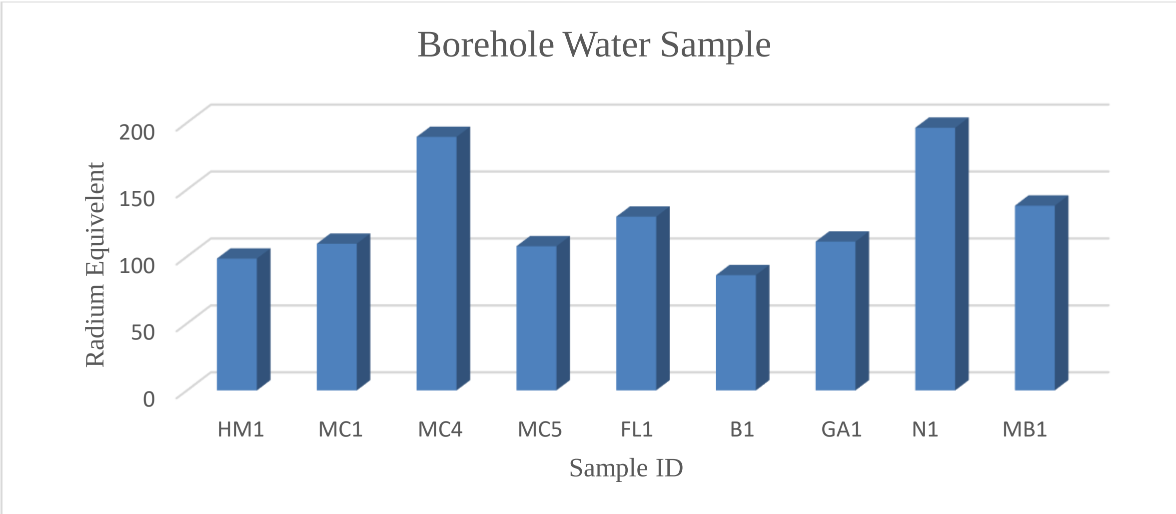

Figure 9: Radium Equivalent for Borehole Water Samples

Table 8. Hazard Indices for Surface Water Samples

Sample Id	**Ra_{eq}**	**H_{ex}**	**H_{in}**	**$I\gamma$**	**$I\alpha$**	**FCR**	**HCR**	**TCR**
HM3	168.3	0.455	0.740	0.873	0.528	4.04E-06	9.86E-08	4.14E-06
MC3	138.2	0.373	0.602	0.709	0.424	3.32E-06	8.10E-08	3.40E-06
FL3	98.16	0.265	0.346	0.383	0.150	2.42E-06	5.89E-08	2.47E-06
B3	96.66	0.261	0.452	0.542	0.3534	2.44E-06	5.95E-08	2.50E-06
GA3	150.4	0.407	0.729	0.880	0.597	3.65E-06	8.89E-08	3.73E-06
MEAN	**130.4**	**0.352**	**0.574**	**0.678**	**0.410**	**3.17E-06**	**7.74E-08**	**3.25E-06**
MIN	**96.66**	**0.261**	**0.346**	**0.383**	**0.150**	**2.42E-06**	**5.89E-08**	**2.47E-06**
MAX	**168.3**	**0.455**	**0.740**	**0.88**	**0.597**	**4.04E-06**	**9.86E-08**	**4.14E-06**

The values of R_{aeq}, H_{ex}, H_{in}, $\boldsymbol{I\gamma}$ and $I\alpha$ for surface water sample were range from 96.66 to 168.3, 0.261 to 0.455, 0.346 to 0.740, 0.383 to 0.880 and 0.150 to 0.597. FL3 is the sample location with lowest value of R_{aeq}, H_{ex}, H_{in}, $\boldsymbol{I\gamma}$ and $I\alpha$, while HM3 is the sample location with highest value R_{aeq}, H_{ex} and H_{in}. the highest values $\boldsymbol{I\gamma}$ and $I\alpha$ was found in GA3 sample location. 2.42E-6 and 4.04E-06 were the lowest and highest value of Fatality Cancer Risk, with mean value of 3.17E-06. The maximum and minimum values of hereditary cancer risk are 9.86E-8 and 5.89E-8, with mean value of 7.74E-8**.** Also, the total cancer risk range between 2.47E-06 to 4.14E-06 with mean value of 3.25E-06. The lowest value of fatality, heredity and total cancer risk were found in FL3 sample location while the highest value was found in HM3 sample location Figure 10 present radium Equivalent for Surface Water Samples

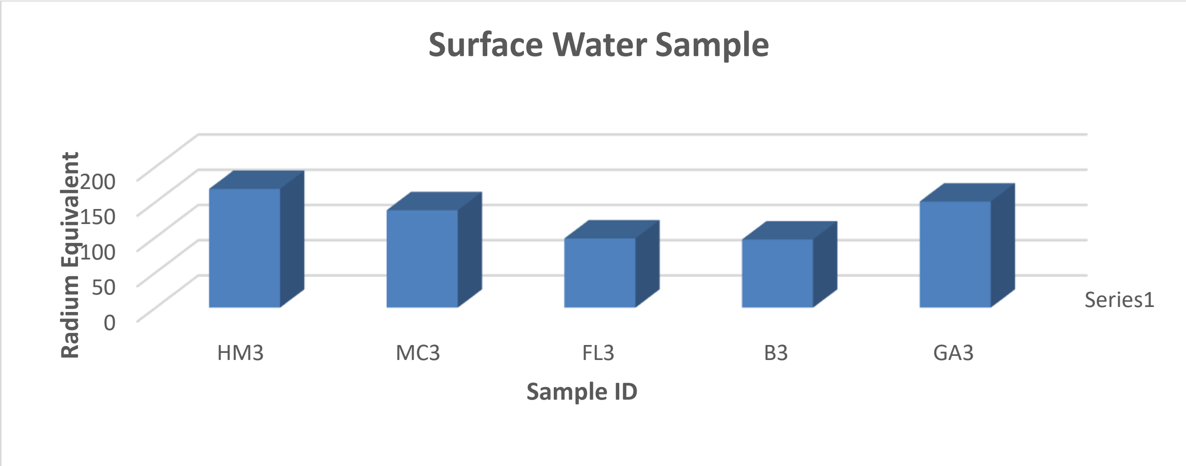

Figure 10: Radium Equivalent for Surface Water Samples

Table 9. Hazard Indices for Well Water Samples

Sample Id	Ra_{eq}	H_{ex}	H_{in}	$I\gamma$	$I\alpha$	FCR	HCR	TCR
HM2	182.8	0.494	0.882	**1.063**	0.718	4.40E-06	1.07E-07	4.51E-06
MC2	188.5	0.509	0.904	**1.088**	0.730	4.53E-06	1.11E-07	4.64E-06
FL2	165.6	0.447	0.752	0.895	0.564	4.01E-06	9.78E-08	4.11E-06
B2	105.7	0.289	0.449	0.526	0.303	2.62E-06	6.40E-08	2.69E-06
GA2	169.9	0.459	0.767	0.911	0.570	4.05E-06	9.88E-08	4.15E-06
S1	180.2	0.487	0.807	0.956	0.592	4.31E-06	1.05E-07	4.42E-06
GH1	128.5	0.347	0.548	0.642	0.372	3.12E-06	7.61E-08	3.19E-06
Z1	199.1	0.538	0.601	0.631	0.118	4.59E-06	1.12E-07	4.70E-06
N2	151.0	0.408	0.469	0.498	0.114	3.51E-06	8.55E-08	3.59E-06
MB2	126.6	0.342	0.505	0.581	0.302	3.01E-06	7.34E-08	3.08E-06
MEAN	**159.8**	**0.432**	**0.669**	**0.779**	**0.438**	**3.82E-06**	**9.31E-08**	**3.91E-06**
MIN	**105.7**	**0.289**	**0.449**	**0.498**	**0.114**	**2.62E-06**	**6.40E-08**	**2.69E-06**
MAX	**199.1**	**0.538**	**0.904**	**1.088**	**0.730**	**4.59E-06**	**1.12E-07**	**4.70E-06**

The minimum and maximum values of R_{aeq}, H_{ex}, H_{in}, $\boldsymbol{I\gamma}$ and $I\alpha$ for well water samples were found to be 105.7 and 199.1, 0.289 and 0.538, 0.449 and 0.904, 0.498 and 1.088, 0.114 and 0.730 respectively. The minimum value of R_{aeq}, H_{ex} and H_{in} was obtained from B2 sample location, and N2 is the sample location with maximum values of $\boldsymbol{I\gamma}$ and $I\alpha$. The maximum value of R_{aeq} and H_{ex} was found in Z1 sample location, the values of fatality cancer risk were range between 2.62E-06 to 4.59E-06 as the lowest and highest values obtained in B2 and ZI, with mean value of 3.82E-06. The highest and lowest value of heredity cancer risk varies from 1.12E-07 to 6.40E-08 with mean value of 9.31E-08. The total cancer risk ranges from 2.69E-06 and 4.70E-06 with mean value of 3.91E-06. The minimum and maximum value heredity and total cancer risk was found in B2 and Z1 respectively.

The radium equivalents (R_{aeq}) of all three sources of water (Borehole, Surface and Well) were far lower than the maximum recommended levels of radium equivalents of 370 Bql^{-1}. The values of H_{ex}, H_{in}, $\boldsymbol{I\gamma}$ and $I\alpha$ of all samples are far less than unity. These mean values were above the acceptable regulatory value set by USEPA (1989). Figure 11 present radium Equivalent for Surface Water Samples

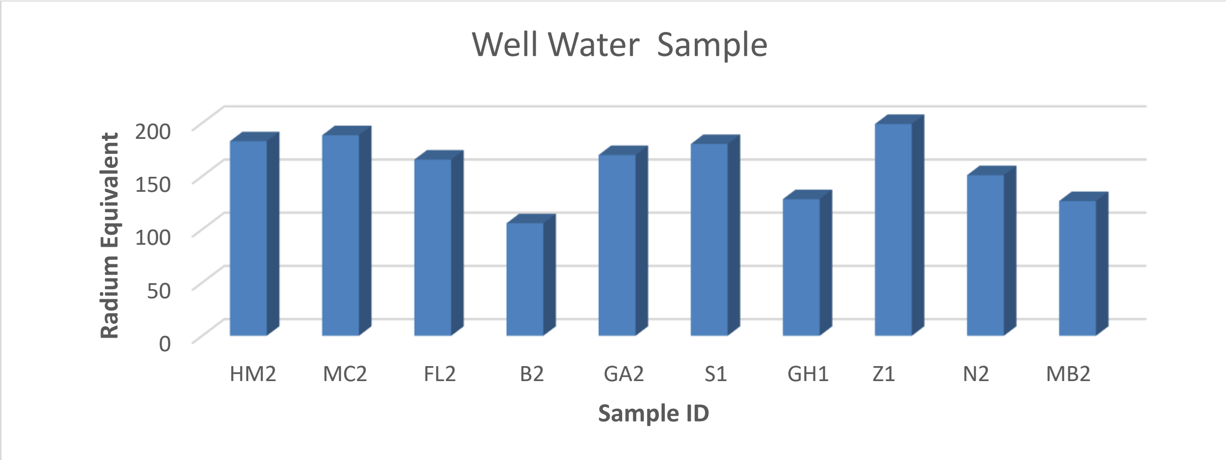

Figure 11. Radium Equivalent for Well Water Samples

The finding of this study revealed that the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K of this current study was not in accordance with research carried out by Alaboodi *et al*. (2019), who found the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K to be lower than the maximum permissible limit as recommended by United Nation Scientific Committee on Effects of Atomic Radiation. The Annual Effective Dose was not in line with the current study as he obtained values higher than the maximum control value set by UNSCEAR and WHO. However, the results are in line with all other radiological parameters such as H_{ex}, H_{in}, $\boldsymbol{I\gamma}$ and $I\alpha$as both values were found to be within the ranges of the global limit. Also, this study was not in accordance with research carried out by Fatima *et al* (2006); Ibrahim *et al* (2014); Nwanko ,(2012); Ahmed, (2004) and Aguko *et al* (2020) whose found the activity concentration levels of ^{226}Ra, ^{232}Th and ^{40}K to be within the maximum accepted level as recommended by the World Health Organization. However, all the results of annul effective dose are in line with current results of this study as all the value of annual effective dose were found to be within the public exposure control set by the World Health Organization (WHO, 2002 and ICRP, 2012).

The findings also revealed that the highest value of hazard indices (R_{aeq}, H_{ex}, H_{in}, $\boldsymbol{I\gamma}$ and $I\alpha$,) was obtain from well water sample. This may be due to air pollution and radiation coming directly from sun. In addition, the study revealed that most of the estimated radiological parameters from boreholes were within the acceptable range. This may be due to absorption from the wall of some part of the pipes. It may also be due to old age water supply infrastructure.

4.0 Conclusion

This study was carryout to assess natural radioactivity for drinking water sources in Michika Local Government Areas, Adamawa State, Nigeria. The mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K of all the three water sources were higher than the control value of activity concentration as set by UNSCEAR (2000). And almost four times higher than the study carried out by Fatima *et al.*, 2006; Ibrahim *et al*., 2014; Nwanko LI, 2012; Ahmed, 2004 and Aguko *et al.*, 2020. Also, the mean values of absorbed dose rate D (nGy/h) for surface and well water sources were found to be higher than the maximum accepted value of 59nGy/h as recommended by (UNSCEAR, 2000) while borehole water source are within the accepted valu Therefore, the area under this study can be classified as area with high background radiation. Thus, people living in the study area need to take good precaution before using the water. The values of estimated annual effective doses and radium equivalent activity Raeq were far lower than the maximum permissible limit of 0.12, 0.1 and 1.0 $mSvy^{-1}$ for annual effective doses and 370 Bql^{-1} for Raeq as recommended by UNSCEAR, WHO and ICRP. Hence based on these estimated parameters it can be concluded that waters in this study area need special treatment for life consumption.

Acknowledgement

The authors wish to appreciate the understanding of Minchika local government chairman for permitting us to carried out this research work.

Declarations

Ethics approval and consent to participate.

Not Applicable

Consent for publication

All authors have read and consented to the submission of the manuscript.

Availability of data and material

Not Applicable.

Competing interests

All authors declare no competing interests.

Funding

There was no funding for the current report.

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