https://dx.doi.org/10.4314/dujopas.v10i2b.16
ISSN (Print): 2476-8316
ISSN (Online): 2635-3490
Dutse Journal of Pure and Applied Sciences (DUJOPAS), *Vol. 10 No. 2b June 2024*

Assessment of Radiological Hazard Risks Due to Gross Alpha and Beta Radioactivity in Groundwater from Damaturu, North-Eastern Nigeria

M. Ahmadu[1,*], Mustapha Suleiman Gimba[2], Habu Tela Abba[2], Yakubu Mohammed[2,3], U. M. Dankawu[3], F.M. Lariski[2], M. Uzair[4]

[1] Department of Chemistry,
Federal University Dutse,
P.M.B 7156,
Jigawa State,
Nigeria.

[2] Department of Physics,
Yobe State University,
P.M.B 1144,
Damaturu,
Yobe State,
Nigeria.

[3] Department of Physics,
Federal University Dutse,
P.M.B 7156,
Jigawa State,
Nigeria.

[4] Department of Physics,
Sule Lamido University Kafin Hausa,
Jigawa State,
Nigeria.

E-mail: ahmadumusa681@gmail.com

Abstract

Groundwater remains the largest source of potable water in Damaturu town. The study of gross radioactivity and its associated hazard risks in potable water is crucial to the health and well-being of the populace of the study area. Thus, radiological hazard indices such as annual effective dose, excess lifetime cancer risk, lifetime hereditary effect, and lifetime fatality cancer risk due to gross alpha and beta radiation from fifteen samples of borehole water have been evaluated. The mean values obtained from the analyses are 2531.48E–5 mSvy^{-1} & 5637.92E–5 for AED, 12.18E–5 & 23.26E–5 for ELCR, 443.01E–5 & 845.69E–5 for LHE and 12.18E–5 & 23.26E–5 for LFCR, respectively. By comparison, all the mean values obtained from this study are below the recommended limits set by UNSCEAR. Thus, the study indicates that the groundwater in the study area is radiologically safe for drinking purposes as the radiation dose level is very low. However, it is recommended that the study be further expanded to include all sources of potable water in the study area. This study aimed to provide baseline radiological survey of potable water for the study area.

Author for Correspondence

Keywords: Radiation Hazard Risk, Gross Alpha and Beta, Groundwater, Damaturu.

INTRODUCTION

Water is an essential and fundamental substance for sustaining life that exhibits the characteristics of being inexpensive yet invaluable. In fact, the quantity and quality of water profoundly impact the well-being of humans and their longevity, as any insufficiency in hydration or deterioration in quality can lead to detrimental imbalances and severe afflictions (Moran, 2023). The significance of water to human beings and other forms of life is manifold, to the extent that its abundance and quality are pivotal for human existence (Dankawu *et al*., 2021; Mititelu *et al*., 2023). Water is procured from two primary natural sources; surface water, which includes freshwater lakes, rivers, and streams; and groundwater, which encompasses borehole water and well water (Dankawu *et al*., 2022; Okunola *et al*., 2020). As a result of the universality of water as a solvent, the predicament of water pollution has emerged with impact on the quality of water available for human consumption. Some of the pollutants consist of heavy metals, radionuclides, and toxic chemicals, among others (Madzunya *et al*., 2020).

Human activities and certain natural phenomena have the potential to contaminate this water, thereby impacting its quality. Among these human activities are the disposal of sewage, the leaching of fertilizers and other agrochemicals from the soil, and the disposal of medical and industrial wastes, all of which frequently contain radioactive substances that can significantly contribute to the underlying activity of the water bodies (Sati *et al*., 2022). Contamination of water by radioactivity as a result of natural processes occurs when water flows over and dissolves specific types of rocks that contain primitive radioactive isotopes known as naturally occurring radioactive materials (NORMs) (Mohammed *et al*., 2022). These materials disintegrate, emitting all sorts of radiation; alpha particles, beta particles, or gamma radiation. It is common for drinking water sourced from deep wells and boreholes to have a high concentration of these radioisotopes (Ogundare & Adekoya, 2015). It has been estimated that approximately 82% of the human population has been exposed to and assimilated radioactive substances by means of the consumption of edibles, inhalation of radionuclides in the air, and ingestion of water (Adamu *et al*., 2022). The human body consists of roughly 60-70% water; therefore, a radiological survey of potable water is necessary in line with the World Health Organisation (WHO) guidelines (Lu *et al*., 2023; WHO, 2017). Therefore, for the initial screening and subsequent assessment of radiological danger from drinking waters, gross alpha and beta activity are highly helpful metrics. Due to their high linear energy transfer and potential to expose tissues to continuous radiation doses when ingested, these radiation particles pose a range of health risks when present in drinking water (Ogundare & Adekoya, 2015).

Until recently, research attention on radioactivity in potable water is mostly limited to alpha and beta detection and quantification with little emphasis on risk parameters, especially in a developing country such as Nigeria. While it is true that alpha and beta detection is useful as preliminary screening, further analysis of hazard indices serves to establish and provide a baseline data of effects that may arise from the ingestion of radionuclides in potable water. However, not many researchers have devoted time and effort in assessing these parameters. For instance, Görür *et al*. determined the annual effect dose and gross alpha and beta concentration from various water samples in Samsun province of Turkey (Görür *et al*., 2011). The study's findings show that, for all water samples, the annual effective doses are less than the 0.1 $mSvy^{-1}$ WHO-recommended reference limit. Such low levels of the effective dose are expected as the average alpha and beta activity concentrations in river, drinking and spring water samples did not exceed WHO recommendations. Abdulkarim *et al*. determined the annual effective dose and excess lifetime cancer risk due to gross alpha beta activity in water samples of a mining site in Jayfi, Pago Tungan Goro of Minna, Niger State, Nigeria (Abdulkarim *et al*., 2023). The water samples were analysed using the MPC 2000DP detector and the result obtained showed that the annual effective dose and excess lifetime cancer risk, due to alpha and beta activity, are 0.013237 $mSvy^{-1}$ & 0.645534 $mSvy^{-1}$ and 0.280742E–3 and 1.77E–3, respectively. Similarly, Söğüt *et al*. evaluated the annual effective dose and excess lifetime cancer risk from the concentration of gross alpha and beta in drinking waters of Reyhanlı District, Hatay (Söğüt *et al*., 2022). Finding from this study showed that the annual effective dose from gross beta radioactivity is greater than the limiting value recommended by WHO even though the gross beta activity itself is below the recommended limit. Sang *et al*. measured the cancer risk associated with gross alpha and beta activity in potable water from the major geographical regions of China (Sang *et al*., 2021). They found that the annual cancer risk due to radioactive pollution in Chinese drinking water is 7.75E–7 per year, lower than the threshold of 5. 5E–6 per year. Furthermore, Ndikilar *et al*. estimated the annual effective dose from gross alpha and beta radioactivity in potable water for all age groups in Dutse town, Nigeria (Ndikilar *et al*., 2016). The result showed that the annual effective dose from alpha and beta radioactivity was above the recommended level of 0.1 $mSvy^{-1}$ for all age groups except for infants where the dose from alpha is below the limit. This result is not surprising given that the alpha and beta concentrations (0.23 *Bq/l* and 283 *Bq/l*) were above the reference level of WHO. Adamu *et al*. calculated the radiological risk parameters associated with gross alpha and beta activity concentrations in samples of water from Dzamah in Hong, Nigeria (Adamu *et al*., 2022). The result showed that the lifetime hereditary effect for alpha and beta is 6.0E–2 $mSvy^{-1}$ & 9.38E–2 $mSvy^{-1}$, 3.0E–2 $mSvy^{-1}$ & 4.69E–2 $mSvy^{-1}$ and 1.49E–2 $mSvy^{-1}$ & 2.35E–2 $mSvy^{-1}$ for adults, children and infants respectively. Nwaka *et al*. also evaluated the radiological risk parameters due to gross radioactivity concentrations (Nwaka *et al*., 2018). They found that the maximum lifetime fatality cancer risk of 0.173E–3 $mSvy^{-1}$ and 2.237E–3 $mSvy^{-1}$ for alpha and beta radiations respectively, far below the 0.1 $mSvy^{-1}$, limit was recorded for Atta stream samples.

As indicated by literature survey, the assessment of the radiological impact related to the groundwater use in the study area, thought to be a significant factor in the natural radiation exposure of humans, is facilitated by the determination of the gross alpha and beta radioactivity. This kind of research has been done throughout Nigeria and other countries, but it is important to remember that variations in the geology and atmosphere cause the concentrations of these radionuclides to vary. Herein, we assessed radiological hazard indices resulting from the gross alpha and beta radioactivity concentrations in groundwater from Damaturu. Compared to previous studies on radiological hazards indices carried out in the study area, this study evaluated for the first time the annual effective dose, excess lifetime cancer risk, lifetime hereditary effect, and lifetime fatality cancer risk associated with the ingestion of alpha and beta radiation present in the groundwater of the study area. The gross alpha and beta concentrations used in this study are adopted from our previous work (Mohammed *et al*., 2022) carried out in 2021. We believe the findings of this study will be a valuable source of information and set the groundwork for further radiological evaluation of drinking water in the study area.

MATERIALS AND METHOD

Study Area

The water samples were sourced from fifteen boreholes around Damaturu town, the state capital of Yobe State, with a total landmass of 2366 km^2 and an estimated population of 125,000 per the 2017 estimate of the National Population Commission and National Bureau of Statistics. The study area does not have a centralised source of water, and most of the population relies on groundwater accessible via wells and boreholes. It is located in a semi-arid part of northeastern Nigeria between latitudes 11.6583^{0}N and 11.7833^{0}N and longitudes 11.9000^{0}E and 12.0300^{0}E. The coordinates of the sampling points were recorded (and presented in Table 1), as shown in Figure 1. It is important to mention that the relief pattern of Damaturu is plain with an average depression between 45 to 75 m and the town has no river or any surface water flowing through it.

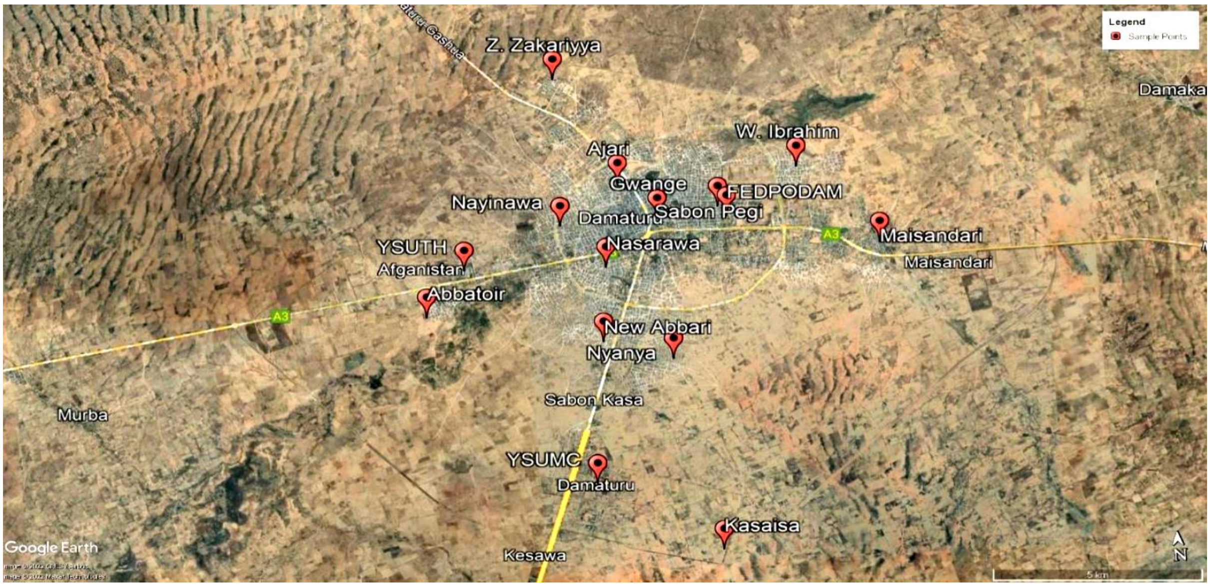

Figure 1: Sampling points in the study area. Adapted from (Mohammed *et al*., 2022)

Materials

The materials and equipment used in the collection, preparation, and analysis of gross radioactivity in the water samples were listed and specified in our previous work (Mohammed *et al*., 2022). Some of the materials include plastic container (2L), nitric acid, Germin etrex GPS device, electric hot plate, analytical weighing balance, vinyl acetate, acetone and MPC2000B-DP proportional counter.

Method

Sample collection and preparation

Fifteen (15) groundwater samples were gathered in 2L plastic containers, and a GPS device was used to capture the geographic coordinates of the sampling locations, as illustrated in Figure 1. These samples underwent a preparation process involving slow evaporation to achieve dryness, followed by an assessment for gross alpha and beta activities utilizing the MPC2000B-DP (PIC) gas-free proportional counter at the Health Physics and Radiation Biophysics Section (HPRBS) of the Centre for Energy Research and Training (CERT) in Zaria. The determination of alpha and beta activities can be conducted either separately or concurrently. The method comprises inputting preset counting time and the selection of the counting mode, with results being exhibited as raw counts or counts per minute (*cpm*). In this particular investigation, the counting method was adjusted to individually count alpha and beta activity over a time span of 30 minutes. Prior to the sample counting, the background activity ($B_{\alpha,\beta}$) was assessed, and the counting process was performed twice due to the stochastic nature of radioactivity. Subsequently, the alpha and beta activity concentration of the samples was computed in *Bq/l* using the formula:

$$A_{a,\beta} = (Net\ cpm)/(E_{a,\beta}\ x\ S_{eff}\ x\ S_{vol}\ x\ 60) \quad (1)$$

where $Net\ cpm = raw\ cpm - B_{a,\beta}$; $E_{a,\beta}$ is the efficiency of the detector for alpha an beta counting; S_{eff} is the sample efficiency; S_{vol} is the actual volume of sample water that produced the optimum residue weight; and 60 is a time conversion factor.

Annual effective dose (AED)

AED gives the cumulative equivalent dosage in particular human tissues and organs resulting from consumption of water containing alpha and beta emitters over a year and is calculated from the formula (Samson *et al.*, 2018):

$$AED_{a,\beta} = A_{a,\beta}\ x\ D_{cf}\ x\ I_{avg} \quad (2)$$

where $AED_{a,\beta}$ is the annual effective dose due to alpha or beta radiation in $mSvy^{-1}$; $A_{a,\beta}$ is the alpha or beta activity concentration in *Bq/l*, D_{cf} (*2.2E–3 mSv/Bq* for alpha radiation and beta radiation) is a dose conversion factor; and I_{avg} *(730 l)* is the average annual water intake of an adult person based on the WHO estimation of 2*l* per day.

Excess lifetime cancer risk (ELCR)

ELCR measures the lifetime probability of cancer development at a specific exposure level. The average human lifespan was assumed to be 70 years in this study, and ELCR for gross alpha and beta was computed using the following formula (Söğüt *et al.*, 2022):

$$ELCR_{a,\beta} = AED_{a,\beta}\ x\ C_R\ x\ L_T \quad (3)$$

where $ELCR_{a,\beta}$ is the excess lifetime cancer risk from ingestion of alpha and beta radiation; $AED_{a,\beta}$ is the annual effective dose (in $mSvy^{-1}$) due to alpha and beta radiation; C_R is the cancer risk factor (5.5E–5 mSv^{-1}) (Enyinna & Uzochukwu, 2016); and L_T is the average life expectancy (70 years).

Lifetime hereditary effect (LHE)

The hereditary effects of radiation, particularly alpha and beta radiation, are of concern due to their potential to damage the genetic material in reproductive cells, leading to mutations that can be passed down to subsequent generations. Therefore, the LHE is evaluated using the formula (Adamu *et al.*, 2022):

$$LHE_{a,\beta} = AED_{a,\beta}\ x\ H_F\ x\ L_T \quad (4)$$

where $LHE_{a,\beta}$ is the lifetime hereditary effect (in $mSvy^{-1}$); $AED_{a,\beta}$ is the annual effective dose (in $mSvy^{-1}$) due to alpha and beta radiation; H_F is the hereditary effect coefficient (taken as 0.2E–2) (Nwaka *et al.*, 2018); and L_T is the average human lifetime.

Lifetime fatality cancer risk (LFCR)

LFCR refers to the probability of developing or dying from cancer over the course of a lifetime. Herein, the LFCR is estimated using the formula (Nwaka *et al.*, 2018):

$$LFCR_{a,\beta} = AED_{a,\beta}\ x\ C_R\ x\ L_T \quad (5)$$

where $LFCR_{a,\beta}$ is the lifetime fatality cancer risk due ingestion of alpha and beta radiation; $AED_{a,\beta}$ is the mean annual effective dose (in $mSvy^{-1}$); C_R is the cancer risk factor (5.5E–5 $mSvy^{-1}$); and L_T is the average human lifetime.

RESULT AND DISCUSSION

The AED, ELCR, LHE and LFCR were calculated using equations 2-5 respectively and the results are presented in Tables 1-2 along with their respective mean averages for the study area. It is worth mentioning that although the values of the ELCR and the LFCR are exactly the same as presented in Tables 1 and 2 above, the two parameters are slightly different. While the ELCR refers to the risk of developing cancer due to exposure to alpha and beta radioactivity and is used to measure or quantify the potential long-term health impact of exposure to a carcinogenic substance, the LFCR relates to the probability of dying from cancer over a person's lifetime as a result of exposure to a specific carcinogen, in this case, gross alpha and beta radioactivity (Freni, 1987; National Research Council (US) Committee on the Biological Effects of Ionizing Radiation (BEIR V), 1990). It takes into account not only the risk of developing cancer but also the likelihood of the cancer being fatal. It is also worth taking note that the gross radioactivity of some samples was below the detection limit of the equipment used, and hence their values are represented by BDL, which stands for 'below detection limit'.

Annual effective dose and excess lifetime cancer risk

Table 1: AED and ELCR due to gross alpha and beta radioactivity

Sample ID	Geocoordinates		AED ($x10^{-5}$ $mSvy^{-1}$)		ELCR ($x10^{-5}$)	
	Latitude	**Longitude**	**Alpha**	**Beta**	**Alpha**	**Beta**
Abbatoir	11.72569	11.91302	2028.38	2474.85	7.81	9.53
Ajari	11.75643	11.95682	2850.65	5722.18	10.98	22.03
FEDPODAM	11.74682	11.98000	3709.86	4899.91	14.28	18.87
Gwangwe	11.74713	11.96486	8071.76	12827.12	31.08	49.38
Kasaisa	11.66368	11.97375	3252.15	8799.27	12.52	33.88
Maisandari	11.73823	12.01291	BDL	4522.50	BDL	17.41
Nasarawa	11.7357	11.95289	4606. 01	10866.20	17.73	41.84
Nayinawa	11.74654	11.94359	BDL	5338.34	BDL	20.55
New Abbari	11.71713	11.95108	126. 87	BDL	0.49	BDL
Nyanya	11.71193	11.96602	3146.15	3618.32	12.11	13.93
Sabon Pegi	11.74928	11.97822	2070. 13	7856.55	7.97	30.25
Waziri Ibrahim	11.75817	11.99601	BDL	1644. 54	BDL	6.33
YSUMC	11.68187	11.94736	2241. 98	3942.73	8.63	15.18
YSUTH	11.73640	11.92200	4541. 77	10092.10	17.49	38.86
Zanna Zakariya	11.78324	11.94446	1326. 56	1964.14	5.11	7.56
Mean			**2531.48**	**5637.92**	**12.18**	**23.26**

The AED ranges from 8071.76E–5 $mSvy^{-1}$ to 126.87E–5 $mSvy^{-1}$ and 12827.12E–5 $mSvy^{-1}$ to 1644.54E–5 $mSvy^{-1}$ for alpha and beta radiation, respectively. As expected, the water sample from Gwange possessed the highest AED value, while New Abbari (for alpha) and Waziri Ibrahim (for beta) have the lowest AED value, and the mean value for the study area is 2531.48E–5 $mSvy^{-1}$ and 5637.92E–5 $mSvy^{-1}$ for alpha and beta, respectively, lower than the 0.1 $mSvy^{-1}$ limit. Furthermore, the result shows that ELCR ranges from 0.49E–5 to 31.08E–5 and from 6.33E–5 to 49.38E–5 for alpha and beta radiation, respectively, with a mean average of 12.18E–5 and 23.26E–5. Water sample Gwange exhibited the highest ELCR for both alpha and beta radiation, whereas the lowest ELCR value was recorded for samples from New Abbari and Waziri Ibrahim for alpha and beta radiation, respectively. Figure 2 shows the comparison of the AED and ELCR of the various samples with the mean average of the study area.

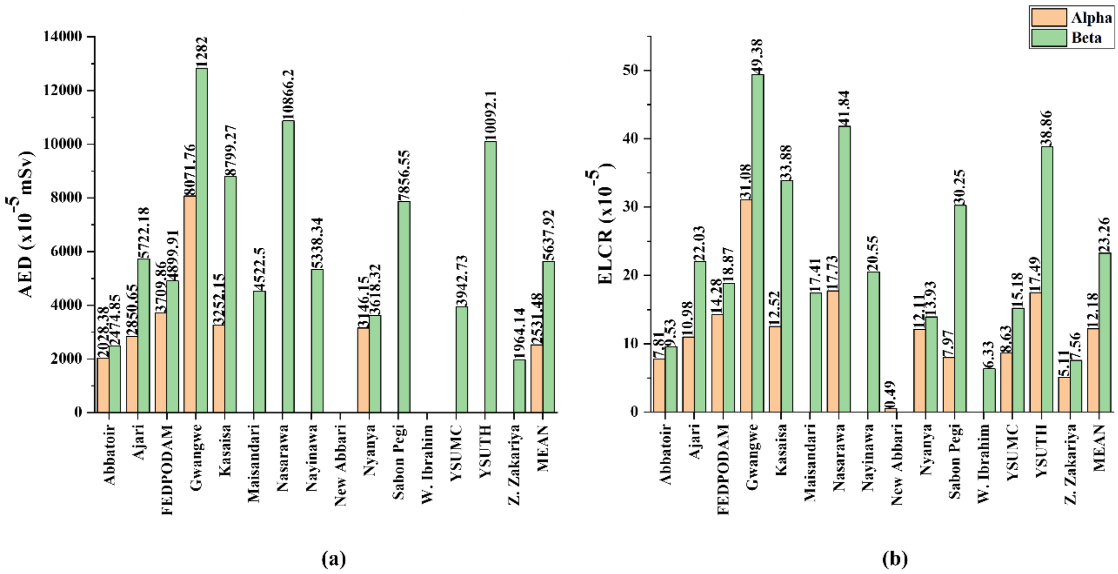

Figure 2: Comparison with mean average in the study (a) annual effective dose and (b) excess lifetime cancer risk

Lifetime hereditary effect and lifetime fatality cancer risk

Table 2: LHE and LFCR due to gross alpha and beta radioactivity

Sample ID	Geocoordinates		LHE ($x10^{-5}$ $mSvy^{-1}$)		LFCR ($x10^{-5}$)	
	Latitude	Longitude	Alpha	Beta	Alpha	Beta
Abbatoir	11.72569	11.91302	283.97	346.48	7.81	9.53
Ajari	11.75643	11.95682	399.09	801.11	10.98	22.03
FEDPODAM	11.74682	11.98000	519.38	685.99	14.28	18.87
Gwangwe	11.74713	11.96486	1130.05	1795.80	31.08	49.38
Kasaisa	11.66368	11.97375	455.30	1231.90	12.52	33.88
Maisandari	11.73823	12.01291	BDL	633.15	BDL	17.41
Nasarawa	11.7357	11.95289	644.84	1521.27	17.73	41.84
Nayinawa	11.74654	11.94359	BDL	747.37	BDL	20.55
New Abbari	11.71713	11.95108	17.76	BDL	0.49	BDL
Nyanya	11.71193	11.96602	440.46	506.57	12.11	13.93
Sabon Pegi	11.74928	11.97822	289.82	1099.92	7.97	30.25
Waziri Ibrahim	11.75817	11.99601	BDL	230.24	BDL	6.33
YSUMC	11.68187	11.94736	313.88	551.98	8.63	15.18
YSUTH	11.73640	11.92200	635.85	1412.90	17.49	38.86
Zanna Zakariya	11.78324	11.94446	185.72	274.98	5.11	7.56
Mean			**443.01**	**845.69**	**12.18**	**23.26**

As for the LHE, the values range from 17.76E–5 mSvy^{-1} to 1130.05E–5 mSvy^{-1} for alpha radiation and from 230.24E–5 mSvy^{-1} to 1795.80E–5 mSvy^{-1} for beta radiation, with a mean value of 443.01E–5 mSvy^{-1} and 845.69E–5 mSvy^{-1} respectively. While samples from Waziri Ibrahim (for beta) and New Abbari (for alpha) had the lowest LHE values, Gwange water sample had the highest LHE value for both alpha and beta radiation. In addition, the results reveal that the LFCR ranges, for alpha and beta radiation respectively, from 0.49E–5 to 31.08E–5 and from 6.33E–5 to 49.38E–5 for alpha and beta radiation respectively, with mean values of 12.18E–5 and 23.26E–5. The water sample from Gwange had the highest LFCR for both beta and alpha radiation, whereas the New Abbari and Waziri Ibrahim samples had the lowest LFCR values for beta and alpha radiation, respectively. The LHE and LFCR of the different samples are compared with the mean value of the study region in Figure 3.

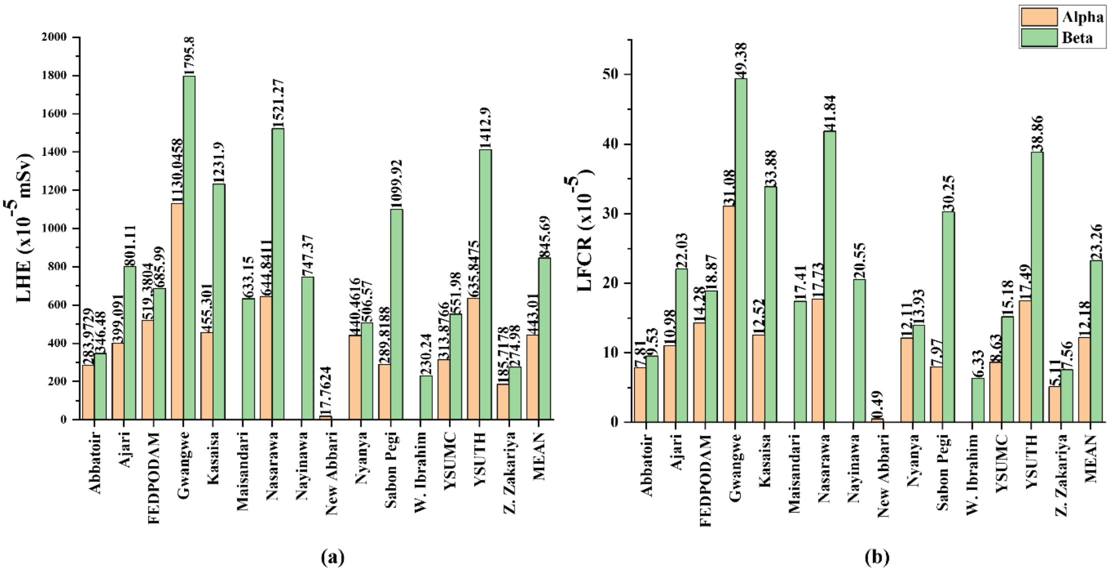

Figure 3: Comparison with mean average in the study (a) lifetime hereditary effect (b) lifetime cancer risk

The present study has been compared to similar studies from within and outside Nigeria. For instance, in the work of Bello *et al*., the annual effective dose due to gross alpha and beta radiation in water samples from the gold mining areas of Shanono and Bagwai in Kano, Nigeria, is 0.228 mSvy^{-1} and 0.457 mSvy^{-1} respectively, which is about 9 and 8 times more than the mean averages in the present study (Bello *et al*., 2020). This can be attributed to the mining activities in the areas of Shanono and Bagwai. Furthermore, Fleifil and Sudani evaluated the annual effective dose arising from the consumption of water in Misan Province, Iraq (Fleifil & Al-Sudani, 2021). They found that the annual effective dose due to alpha radiation in the samples did not exceed the WHO recommended limit of 0.1 mSvy^{-1}. Söğüt *et al*. estimated the excess lifetime cancer risk parameter from the gross radioactivity in the waters of Reyhanlı district, Hatay (Söğüt *et al*., 2022). Results of the analyses indicated mean values of 28.66E–7 (alpha) and 0.418E–3 (beta) for the study area, less than the ELCR value due to alpha but greater than the ELCR due to beta radiation in the current study. Additionally, Seydou and Abdullahi determined the excess lifetime cancer risk from the gross alpha and beta activity concentrations in drinking water from Gombe, Nigeria (Seydou & Abdullahi, 2016). The mean values of ELCR realised from the study are 0.00094 and 0.0171 due to alpha and beta emitters, about 8 and 73 times greater than the mean values of this study. Table 3 gives a summary of the comparison of AED and ELCR in this study with other studies across the world.

Table 3: Comparison of AED and ELCR with studies from literature

Study area	AED ($mSvy^{-1}$)		ELCR		Reference
	α	β	α	β	
Kano, Nigeria	0.228	0.457	-	-	(Bello *et al.*, 2020)
Misan, Iraq	0.033	-	-	-	(Fleifil & Al-Sudani, 2021)
Reyhanlı, Hatay	-	-	28.66E–7	0.418E–5	(Söğüt *et al.*, 2022)
Gombe, Nigeria	-	-	0.00094	0.0171	(Seydou & Abdullahi, 2016)
Damaturu, Nigeria	2531.48E–5	5637.92E–5	12.18E–5	23.26E–5	This work

Similarly, when Adamu *et al*. analysed the lifetime hereditary effect due to gross radioactivity in water samples from Dzamah locality of Hong, Nigeria, the result showed that the LHE values due to alpha for infants, children and adults in the study are 1.49E–2 $mSvy^{-1}$, 3.0E–2 $mSvy^{-1}$ and 6.0E–2 $mSvy^{-1}$ respectively and the LHE values due to beta for infants, children and adults in the study are 2.35E–2 $mSvy^{-1}$, 4.69E–2 $mSvy^{-1}$ and 9.38E–2 $mSvy^{-1}$ respectively (Adamu *et al*., 2022). Just like in the present study, the hazards indices due to beta radiation are higher than those due to alpha radiation, but none are up to the recommended limit of 0.1 $mSvy^{-1}$. In another study, Nwaka *et al*. measured the lifetime hereditary effect and lifetime fatality cancer risk associated with gross radioactivity in saltwater lakes in Ebonyi State, Nigeria (Nwaka *et al*., 2018). Their analyses showed that the LHE values range from 0.014E–5 $mSvy^{-1}$ to 0.63E–5 $mSvy^{-1}$ for alpha radiation and from 0.70E–3 $mSvy^{-1}$ to 8.134E–3 $mSvy^{-1}$ for beta radiation. The LFCR values range from 0.173E–3 to 0.004E–3 and from 2.237E–3 to 0.058E–3 for alpha and beta radiation, respectively. With the exception of Ugwulangwu borehole water and Uburu sachet water, none of the samples exceeded the limit of 0.1 $mSvy^{-1}$ for LHE, in contrast with the present work, in which none of the samples were up to the reference limit. Table 4 presents a summary of the comparison made with other studies from literature.

Table 4: Comparison of LHE and LFCR with studies from literature

Study area	LHE ($mSvy^{-1}$)		LFCR		Reference
	α	β	α	β	
Dzamah, Nigeria	6.00E–2	9.38E–2	-	-	(Adamu *et al*., 2022)
Ebonyi, Nigeria		3.934E–5		1.082E–3	(Nwaka *et al*., 2018)
Damaturu, Nigeria	443.01E–5	845.69E–5	12.18E–5	23.26E–5	This work

CONCLUSION

The findings from this study unequivocally demonstrated that borehole water, which serves as the main source of potable water in Damaturu, is safe to drink and does not provide a health concern to the residents of the town as the hazard indices evaluated were below the standard limit set by UNSCEAR (UNSCEAR, 2022). This is due to the fact that the annual effective dose, excess lifetime cancer risk and lifetime hereditary effect values of all samples were found to be below the acceptable limit for drinking water. However, it is recommended that the radiological analyses in the study be extended to other sources of drinking water and a more robust method of determining the gross radioactivity be employed. Lastly, the information gathered for this study will hopefully serve as a baseline for future assessments of the drinking water quality in the study area.

REFERENCES

Abdulkarim, M. S., Nurudeen, A. A., & Abdullateef, O. O. (2023). Determination of annual effective dose equivalent and the excess lifetime cancers risk in water samples from a mining site in Jayfi, Pago Tungan Goro of Minna, Niger State, Nigeria. *Dutse Journal of Pure and Applied Sciences*, *9*(3b), 232–239. https://doi.org/10.4314/dujopas.v9i3b.24

Adamu, A., Ephraim, S. A., & Ibrahim, G. (2022). Determination of Gross Alpha and Gross Beta Activities, and the Corresponding Radiological Risk Parameters in Water Samples from Dzamah Community, Hong, Nigeria. *Journal of Radiation and Nuclear Applications*, *7*(2), 7–13. https://doi.org/10.18576/jrna/070202

Bello, S., Nasiru, R., Garba, N. N., & Adeyemo, D. J. (2020). Annual effective dose associated with radon, gross alpha and gross beta radioactivity in drinking water from gold mining areas of Shanono and Bagwai, Kano state, Nigeria. *Microchemical Journal*, *154*(October 2019), 104551. https://doi.org/10.1016/j.microc.2019.104551

Dankawu, U. M., Adamu, G. D., Kafadi, D., Maharaz, N. M., Usman, F. M., Shuaibu, H. Y., Zangina, T., Lariski, F. M., Ahmadu, M., Uzair, M., Yakubu, A., & Zarma, S. S. (2021). Determination of Radon Concentration and the Annual Effective Dose Due to Inhalation for Some and Wellwater Supply in Dutse, Jigwa State Nigeria. *Journal of Science, Technology, Mathematics and Education (JOSTMED)*, *17*(3), 8–19. https://www.researchgate.net/publication/360270980

Dankawu, U. M., Shuaibu, H. Y., Maharaz, M. N., Zangina, T., Lariski, F. M., Ahmadu, M., Zarma, S. S., Benedict, J. N., Uzair, M., Adamu, G. D., & Yakubu, A. (2022). Estimation of excess life cancer risk and annual effective dose for boreholes and well water in Dutse, Jigawa State Nigeria. *Dutse Journal of Pure and Applied Sciences*, *7*(4a), 209–218. https://doi.org/10.4314/dujopas.v7i4a.22

Enyinna, P., & Uzochukwu, F. (2016). Assessment of radiological risk parameters associated with some selected rivers around oil mineral producing sites in Abia state, Nigeria due to gross alpha and beta radiations. *Journal of Radiation and Cancer Research*, *7*(2), 50. https://doi.org/10.4103/0973-0168.191712

Fleifil, S. S., & Al-Sudani, Z. A. I. (2021). Evaluation of gross alpha and beta activity concentrations and annual effective dose in drinking waters of misan province-iraq using low background gas flow proportional counter (Lb-4110). *NeuroQuantology*, *19*(11), 22–31. https://doi.org/10.14704/nq.2021.19.11.NQ21172

Freni, S. C. (1987). Application of Estimated Excess Lifetime Cancer Risk in Field Situations. In *Uncertainty in Risk Assessment, Risk Management, and Decision Making* (pp. 339–347). Springer US. https://doi.org/10.1007/978-1-4684-5317-1_27

Görür, F. K., Keser, R., Dizman, S., & Okumuşoğlu, N. T. (2011). Annual effective dose and concentration levels of gross α and β in various waters from Samsun, Turkey. *Desalination*, *279*(1–3), 135–139. https://doi.org/10.1016/j.desal.2011.05.071

Lu, H., Ayers, E., Patel, P., & Mattoo, T. K. (2023). Body water percentage from childhood to old age. *Kidney Research and Clinical Practice*, *42*(3), 340–348. https://doi.org/10.23876/j.krcp.22.062

Madzunya, D., Dudu, V. P., Mathuthu, M., & Manjoro, M. (2020). Radiological health risk assessment of drinking water and soil dust from Gauteng and North West Provinces, in South Africa. *Heliyon*, *6*(2), e03392. https://doi.org/10.1016/j.heliyon.2020.e03392

Mititelu, M., Neacşu, M. S., Ioniță-Mîndrican, C.-B., Coza, M., Şeşureac, M., Cartojan, M., Holingher, D., & Olteanu, G. (2023). Water, the indispensable component for the health and functioning of the human body. *Farmacist.Ro*, *1*(210), 30. https://doi.org/10.26416/Farm.210.1.2023.7760

Mohammed, Y., Abba, H. T., & Gimba, M. S. (2022). Determination of the Gross Alpha and Beta Activity Concentration in Groundwater from Damaturu. *Communication in Physical*

Sciences, *8*(2), 179–186.

Moran, S. (2023). Water. In *Kirk-Othmer Encyclopedia of Chemical Technology* (pp. 1–34). Wiley. https://doi.org/10.1002/0471238961.1618151613151807.a01.pub3

National Research Council (US) Committee on the Biological Effects of Ionizing Radiation (BEIR V). (1990). *Health Effects of Exposure to Low Levels of Ionizing Radiation: Beir V*. https://www.ncbi.nlm.nih.gov/books/NBK218705/

Ndikilar, C. E., Abdullahi, S., & Ayuba, D. K. (2016). Determination of Radioactivity Concentration and Estimation of Annual Effective Dose for All Age Categories of Drinking Water. *IOSR Journal of Applied Physics*, *8*(3), 13–22. https://doi.org/10.9790/4861-0803031322

Nwaka, B., Avwiri, G., & Ononugbo, C. (2018). Radiological Risks Associated with Gross Alpha and Beta Activity Concentrations of Water Resources within Salt Water Lakes, Ebonyi State, Nigeria. *International Journal of TROPICAL DISEASE & Health*, *30*(1), 1–10. https://doi.org/10.9734/ijtdh/2018/39066

Ogundare, F. O., & Adekoya, O. I. (2015). Gross alpha and beta radioactivity in surface soil and drinkable water around a steel processing facility. *Journal of Radiation Research and Applied Sciences*, *8*(3), 411–417. https://doi.org/10.1016/j.jrras.2015.02.009

Okunola, O. J., Oladipo, M. O. A., Aker, T., & Popoola, O. B. (2020). Risk assessment of drinkable water sources using gross alpha and beta radioactivity levels and heavy metals. *Heliyon*, *6*(8), e04668. https://doi.org/10.1016/j.heliyon.2020.e04668

Samson, D. O., Ajala, E. O., & Adeyemi, O. F. (2018). Determination of Gross Alpha Activity Concentrations and Annual Effective Dose in Portable Drinking Water in Abuja Metropolis, Nigeria. *Www.Arcjournals.Org International Journal of Advanced Research in Physical Science*, *5*(2), 2349–7882. www.arcjournals.org

Sang, C., An, W., Sørensen, P. B., Han, M., Hong, Y., & Yang, M. (2021). Gross alpha and beta measurements in drinkable water from seven major geographical regions of China and the associated cancer risks. *Ecotoxicology and Environmental Safety*, *208*. https://doi.org/10.1016/j.ecoenv.2020.111728

Sati, L., Otokpa, O. B., Selman, N. J., & John, I. S. (2022). Determination of Gross Alpha and Beta Concentration and Annual Committed Dose In Drinking Water Sources of Ampang West and Kerang in Mangu LGA., Plateau State, Nigeria. *International Journal of Research and Innovation in Applied Science (IJRIAS)*, *VI*(II), 173–175. https://www.researchgate.net/profile/Sati-Lubis/publication/365704801_Determination_of_Gross_Alpha_and_Beta_Concentration_and_Annual_Committed_Dose_In_Drinking_Water_Sources_of_Ampang_West_and_Kerang_in_Mangu_LGA_Plateau_State_Nigeria/links/637f4c267b0e35

Seydou, H., & Abdullahi, S. (2016). Radiation Hazard Indices due to Intake of Radionuclides in Drinking Water in Gombe, Nigeria. *IOSR Journal of Applied Physics*, *08*(04), 67–73. https://doi.org/10.9790/4861-0804016773

Söğüt, Ö., Alnashar, M. S., Eyicil, M., & Selçuk Zorer, Ö. (2022). Pollution and Health Risk Evaluations from Gross Radioactivity in Drinking Waters in Reyhanlı District, Hatay. *Water, Air, and Soil Pollution*, *233*(8). https://doi.org/10.1007/s11270-022-05795-3

UNSCEAR. (2022). *Sources, Effects and Risks of Ionizing Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2020/2021 Report, Volume IV* (162nd ed.). United Nations Scientific Committee on the Effects of Atomic Radiation. https://doi.org/10.18356/9789210010061

WHO. (2017). *Guidelines for Drinking Water Quality* (World Health Organization (WHO) (Ed.); 4th ed., Vol. 55). http://apps.who.int/iris/bitstream/10665/44584/1/9789241548151_eng.pdf