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Assessment of Natural Radioactivity in Spring, Borehole and Well Water in Hong Local Government Area, Adamawa State, Nigeria

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ABSTRACT

Radionuclides are source of radiation known to have adverse health effects in individuals living in areas with high background radiation. This study investigated naturally occurring radionuclide levels of ^{238}U, ^{232}Th, and ^{40}K respectively, were assessed in drinking water sources at some districts of Hong, Adamawa State, Nigeria. Nineteen (19) water Samples from three different sources (spring, borehole, and well), were collected and analyzed using a thallium-doped sodium iodide [NaI (TI)] detector at LAUTECH, Obgomosho. The results show that the mean activity concentration for, ^{238}U, ^{232}Th, and ^{40}K are 2.91, 1.63, and 55.31 BqL^{-1} for spring samples, 2.70, 1.63, and 69.12 for borehole samples and 2.82, 1.48 and 66.25 for well samples. These values are higher than the control value of activity concentration set by (UNSCEAR 2000). The mean absorbed dose rate (D) for spring, borehole, and well water samples were found to be 4.21, 5.11, and 4.81 nGyh^{-1} respectively. All the water samples were lower than the maximum accepted value of 59 nGyh^{-1} as recommended by (UNSCEAR, 2000). The mean values of the total annual effective dose for spring, borehole, and well water samples were 0.00574, 0.00694, and 0.0065 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 8.72, 10.35, and 9.76 BqL^{-1} for spring, borehole, and well water samples respectively. All the values of Ra_{eq} were below the maximum recommended value of 370 BqL^{-1}. The mean value of total cancer risk is 3.22 x 10^{-9}, 3.90 x 10^{-9}, and 3.66 x 10^{-9} for spring, borehole, and well water samples respectively. All the mean values were below the acceptable range of 1 x 10^{-6} to 1 x 10^{-4}. Based on our findings, the water sources in this area are safe for domestic use. However continuous radiological monitoring of the water is recommended to safeguard the health of the populace.

Keywords:
Radioactivity,
Radiation,
Radionuclide,
Spring,
Borehole,
Well water.

INTRODUCTION

Water is a transparent, odorless, and tasteless liquid compound consisting of hydrogen and oxygen atoms (H_2O), crucial for the survival and existence of all forms of life support systems (Dankawu *et al.*, 2021). Dankawu *et al*, (2021) further opined that ensuring good quality drinking water is important in improving the quality of human life and preventing diseases. Water is used in many communities for different purposes such as agriculture, power generation, and also for domestic purposes (Chifu *et al.*, 2016). Potable quality water is crucial for health and a basic human need that requires suitable management, treatment techniques, and monitoring or control (Fatemah *et al.*, 2020). The quality of groundwater sources, including springs, boreholes, and well water, is a concern due to natural radionuclides that can pose significant risks to human health and the environment (WHO, 2011). Despite the fundamental human right to access safe and clean drinking water, many communities worldwide, particularly in rural and disadvantaged areas, rely on these water sources, which may be contaminated with harmful parameters (UN, 2010). The provision and access to water supply is one of the fundamental needs for human survival. Access to water supply implies having sufficient water for personal and domestic uses of at least 50–100 L of water per person per day from a safe, acceptable, affordable, and physically accessible (UN 2012). In reality, the water required for domestic consumption should possess a high degree of purity and should be free from suspended and dissolved impurities. Spring, dug wells and boreholes water are expected to be less contaminated. However, there are possibilities of introducing contaminants, depending on management and the temperature gradient of the water environment (Alexander, 2018).

Most of the water used for drinking and other domestic purposes usually contains some natural radionuclides such as radon, uranium, radium, isotopes, and tritium. In most case, ground water is used without prior treatment. Since soils and rocks contain both naturally occurring and artificially introduced radionuclides, ground water is likely to contain varying concentrations of these radionuclides, depending on their solubility in water (Akinloye, 2008). Their concentrations vary widely as they rely on the aquifer of the prevailing lithology and the absence or the presence of air in it (Aguko *et al.*, 2020). Radiation in the environment originates from some human-made and naturally occurring sources while exposure to 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 plays a crucial role in transferring radionuclides from the environment to humans. 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 rays, and radon) or exist naturally from birth inside the human body such as carbon (^{14}C), potassium (^{40}K) and lead ($^{21}0Pb$) (Hassan *et al.*, 2018). Radioactivity in water comes mainly from radionuclides of ^{232}Th, and ^{238}U decay series and ^{40}K in soil as well as industrial effluents, wastes, and other maritime activities. Most rural and urban communities depend on water such as springs, boreholes, and well water for their daily needs. Consequently, radionuclides can also be transported to the food chain through irrigation (Ononugbo & Anyalebechi, 2017).

Water is required by all living things for cell metabolism. The continuous existence of man on this planet will depend on the availability of good-quality water. Radiation health effects from uranium in the northern part of Adamawa state, Nigeria have attracted a lot of attention, it has been reported and confirmed in Michika Local Government Area of Adamawa state, that both soil and water samples in this area contain radionuclides (Zarma *et al.*, 2023). Therefore, radionuclides can potentially be found in Hong Local Government due to its proximity (approximately 50km) to Michika and sharing similar geological formations within the Upper Benue Trough, the granite rocks characteristic of this region increase the likelihood of radionuclides deposits (Amadi *et al*, 2019). Therefore there is a need to regularly examine the quality of water to make it safe for consumption and domestic use.

The research was aimed to assess the activity concentrations of natural radionuclides and radiological parameters; such as radium equivalent activity, absorbed dose rate, annual effective dose, radiation hazard indices, and cancer risks in springs, boreholes, and well water in the Hong Local Government Area of Adamawa State. The study would help to identify communities and populations most vulnerable to low-quality water that can lead to potential waterborne health risks and reduce water-related diseases and mortality rates. This work was limited to the activity concentrations of natural radionuclides and radiological parameters; such as radium equivalent activity, absorbed dose rate, annual effective dose, radiation hazard indices, and cancer risks in springs, boreholes, and well water in the Hong.

Concept of Water: Water is a vital, clear, colorless, odorless, and tasteless liquid substance essential for human survival, economic development, and environmental sustainability (Ibrahim *et al.*, 2018). It is composed of hydrogen and oxygen atoms (H_2O), water possesses unique physical properties, including a density of 1 gram per cubic centimeter (g/cm³), boiling point of 100°C (212°F), and freezing point of 0°C (32°F) (Abubakar & Mohammed, 2019). Water exists in various forms, including freshwater (rivers, lakes, groundwater), saltwater (oceans, seas), alkaline water (pH > 7), acidic water (pH < 7), mineral water, and distilled water (Yusuf & Ahmed, 2020).

The energy produced as electromagnetic waves or particles that travel across space and have the ability to interact or penetrate various materials is known as radiation. Depending on the radiation's source, kind, and energy deposited, radiation can alter materials (Was, 2017). Terrestrial radiation is energy in transit that comes from the Earth. Primordial radionuclides are those that existed when the earth was formed. They can be found in both igneous and sedimentary rocks all over the world. These radionuclides can move into the air, water, and soil. Some of these radionuclides have also been dispersed by human activities like uranium mining (IAEA, 2016).

Man and all other forms of life on Earth have always been exposed to radiation from the natural environment and have evolved in its presence. Cosmic radiation, terrestrial radiation, inhalation, and ingestion are the four main ways that the general public is exposed to natural radiation, according to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2020). The constant barrage of cosmic radiation is caused by fast-moving particles that are present in space and come from many sources, such as the sun and other celestial events in the universe that manifest as rays. Although protons make up the majority of cosmic rays, they can also be particles or wave energy.

MATERIALS AND METHODS

The materials used in the assessment of activity concentrations of natural radionuclides and radiological parameters; such as radium equivalent activity, absorbed dose rate, annual effective dose, radiation hazard indices, and cancer risks were; Polyethylene bottles, Disposal Hand Glove, Handheld GPS, Distilled Water and Gamma-ray spectrometer of type; Sodium Iodide doped with Thallium [NaI(TI)] detector.

Study Area

Hong Local Government Area is situated in the North-Eastern part of Adamawa State, Nigeria. It lies between latitude 10.38ºN and longitude 12.35ºE (Priscilla *et al* 2018). It shares a boundary with Gombi in the south, Mubi North and Mubi South in the west, and Michika to the North. Hong Local Government area has a land mass of about 2419 square kilometers and a total population of 195,580 people (National Population Census, 2011). The topography of Hong local government is a picture of mountain land transverse by the river, and valley of Hawul and Kuliyi. It has its headquarters in Hong Town is the largest settlement and is classified by Ilesanmi (1999) as a third-order core urban settlement in Adamawa state. Hong LGA consists of seven (7) districts namely; Hong, Dugwaba, Pella, Kulinyi, Hildi, Gaya, and Uba districts.

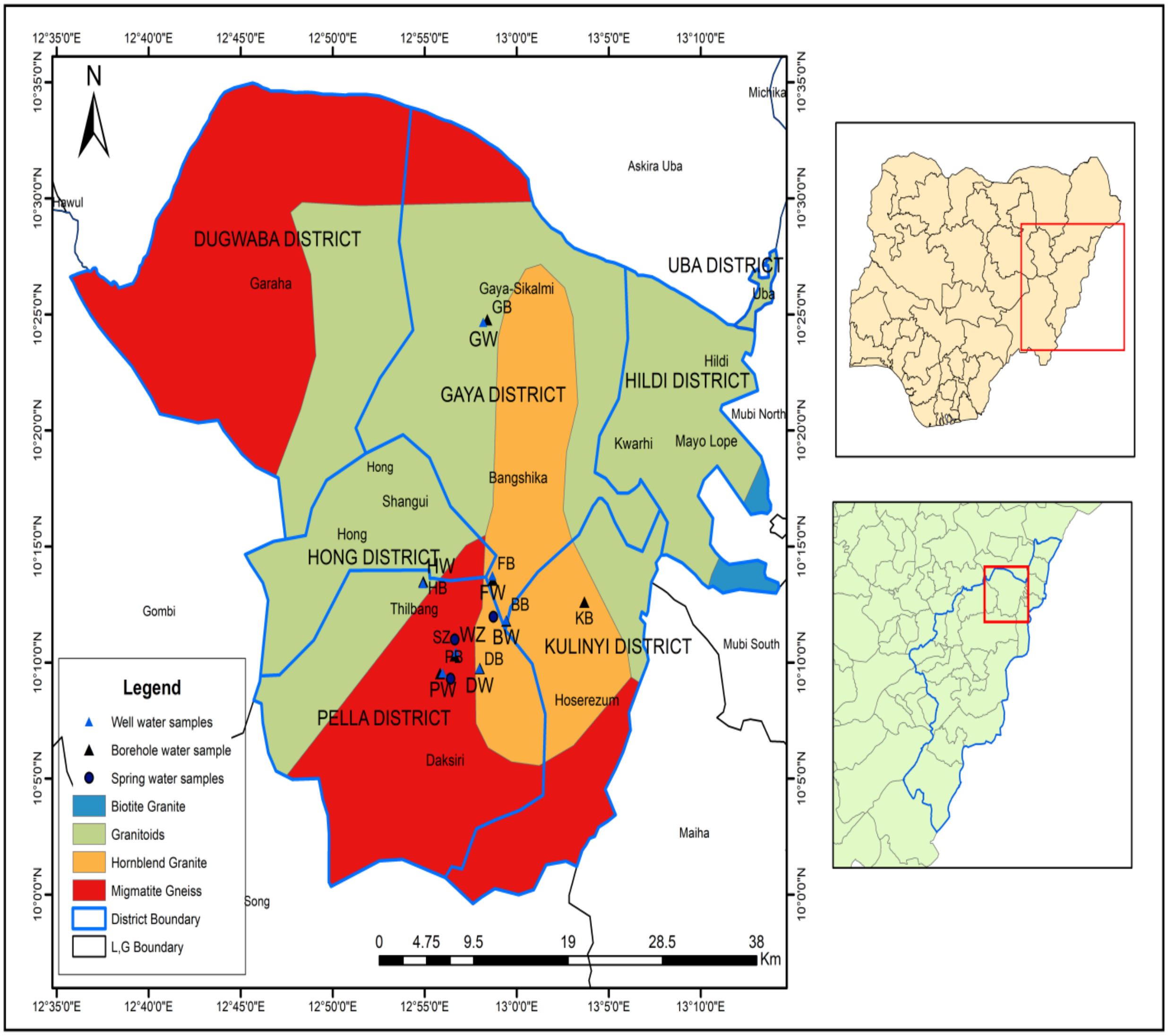

Figure 1: A map of the study area of Hong Local Government

Method of Water Sample Collection for Natural Radioactivity

A total of nineteen (19) water samples, three (3) spring water samples from, Pella, Dzuma, and Banshika, eight (8) borehole and well water samples from Hong, Pella, Fadama Reke, Banshika, Dzuma, Dilchidama, Kwakwa, and Gaya Garsanu were collected within Hong Local Government of Adamawa State, utilizing GPS coordinate for location tracking and labeling. The water samples were collected using clean 75CL polyethylene bottles. The bottles were washed with detergent and rinsed with distilled water and then rinsed with the water to be sampled and filled to the brim with it to avoid contaminations with external sources and it was taken to the laboratory within two days for analysis.

Determination of Natural Radionuclide

The natural radionuclide was determined using gamma ray spectrometry analyses [NaI(TI)] for the water samples at the Department of Pure and Applied Physics Ladoke Akintola University of Technology, Ogbomoso, Ibadan, Nigeria.

Method of Data Analysis

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 ^{238}U, ^{232}Th and ^{40}K. This assumption is commonly used in natural environmental samples where uranium and radium are expected to be in equilibrium, using Equation (1) and (2) respectively as proposed by UNSCEAR, 2000 (Jibiri *et al.*, 2007; Belivermis *et al*, 2009).

Ra_{eq} (Bq / kg) = AU + 1.43ATh + 0.077 AK (1)

D (nGyh-1) = 0.462AU + 0.604ATh + 0.0417AK (2)

where Ra_{eq} is the radium equivalent activity, D is the absorbed dose rate and ARa, ATh and AK 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).

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}U, ^{232}Th and ^{40}K as defined by equations (3.3), (3.4) and (3.5) respectively. (UNSCEAR, 2000; ICRP, 2012).

AEDγ = D x 8760h x 0.2 x 0.7Sv Gy x 10^{-} (3)

AED(mSvy-1) = AR x IR x DCF (4)

TAED = AEDγ + A$EDing$ (5)

where AED_{γ} 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 (730 Ly^{-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 4.50x10^{-8}, 2.30 x 10^{-7} and 6.20 x 10^{-9} respectively (ICRP, 2012).

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 (3.6) and (3.7) respectively as proposed by UNSCEAR (2000). Furthermore, gamma and alpha indices ($\boldsymbol{I_{\gamma}}$ *and* I_{α}) were used to estimate the excess γ and α radiation. They were estimated using equation (3.8) and (3.9) respectively (Asaduzzaman *et al.*, 2016; Xinwei *et al.*, 2006).

Hex = ARa/370 + ATh/259 + AK /4810 (6)

Hin = ARa/185 + ATh/259 + AK /4810 (7)

$I_{\gamma r}$ = ARa⁄300 + ATh/2100 + AK /3000 (8)

I_{α} = ARa /200 (Bq/kg) (9)

Cancer Risks

The fatality cancer risk, hereditary cancer risk and total cancer risk due to low doses without threshold dose known as stochastic effects were estimated using equations (10), (11) and (12) respectively based on ICRP (2007) cancer risk assessment methodology.

$FCR = total\ AED\ (Sv)$ x $cancer\ nominal\ risk\ factor$ (10)

$Hereditary\ risk = totalAED\ (Sv)$ x $hereditary\ nominal\ risk factor$ (11)

TCR = FCR+ HCR (12)

Where TCR is the total cancer risk, FCR is the $Fatality\ cancer\ risk$ and HCR is the $Hereditary\ risk$.

RESULTS AND DISCUSSION

Table 1: Sample ID and coordinate of the Spring Water Sample Location

Sample ID	Longitude	Latitude
SZ	012^0 56.640	10^0 10.995
PS	012^0 56.406	10^0 09.303
BS	012^0 58.734	10^0 11.969

SZ = Dzuma Sprig water, PS = Pella Spring water, BS = Banshika Spring water.

Table 2: Sample ID and coordinate of the Borehole Water Sample Location

Sample ID	Longitude	Latitude
BZ	$012^{0}56.639$	$10^{0}10.305$
PB	$012^{0}55.837$	$10^{0}09.538$
BB	$012^{0}59.437$	$10^{0}11.796$
KB	$013^{0}02.751$	$10^{0}11.206$
FB	$012^{0}58.706$	$10^{0}13.565$
HB	$012^{0}54.931$	$10^{0}13.487$
DB	$012^{0}57.996$	$10^{0}09.759$
GB	$012^{0}58.407$	$10^{0}24.778$

BZ = Dzuma borehole water, PB = Pella borehole water, BB = Banshika borehole water, KB = Kwakwah borehole water, FB = Fadama Reke borehole water, HB = Hong borehole water, DB = Dilchidama borehole water, GB = Gaya borehole water.

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

Sample ID	Longitude	Latitude
WZ	$012^{0}56.699$	$10^{0}10.462$
PW	$012^{0}55.986$	$10^{0}09.559$
BW	$012^{0}59.423$	$10^{0}11.828$
KW	$013^{0}02.758$	$10^{0}11.174$
FW	$012^{0}58.689$	$10^{0}13.745$
HW	$012^{0}54.914$	$10^{0}13.411$
DW	$012^{0}57.987$	$10^{0}09.750$
GW	$012^{0}58.186$	$10^{0}24.669$

WZ = Dzuma well water, PW = Pella well water, BW = Banshika well water, KW = Kwakwah well water, FW = Fadama Reke well water, HW = Hong well water, DW = Dilchidama well water, GW = Gaya well water.

Table 4: Activity Concentration of ^{226}U, ^{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 Spring Water Samples Respectively

Sample ID	^{236}U (BqL^{-1})	^{232}Th (BqL^{-1})	^{40}K (BqL^{-1})	D nGyh^{-1}	AEDγ (mSvy^{-1})	AEDing (mSvy^{-1})	TAED (mSvy^{-1})
SZ	2.61	1.72	55.31	4.55	0.0056	0.00062	0.00621
PS	2.55	1.44	34.66	3.49	0.0043	0.00048	0.00477
BS	3.56	1.73	45.52	4.59	0.0056	0.00061	0.00624
MEAN	**2.91**	**1.63**	**55.31**	**4.21**	**0.0052**	**0.00057**	**0.00574**
MIN	**2.55**	**1.44**	**34.66**	**3.49**	**0.0043**	**0.00048**	**0.00477**
MAX	**3.56**	**1.73**	**45.52**	**4.59**	**0.0056**	**0.00066**	**0.00624**

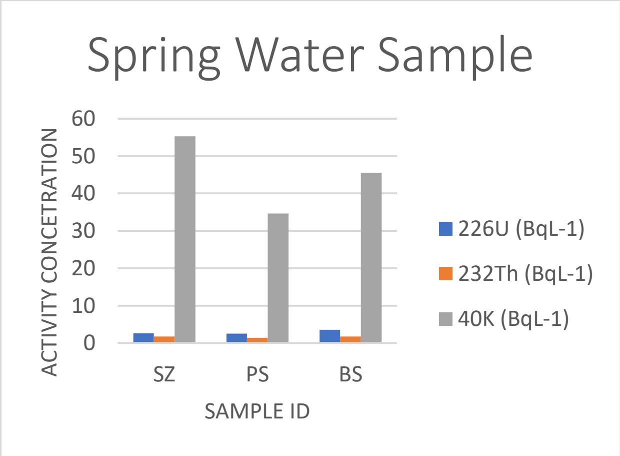

Figure 2: Activity Concentration of ^{238}U, ^{232}Th and ^{40}K for Spring Water Sample

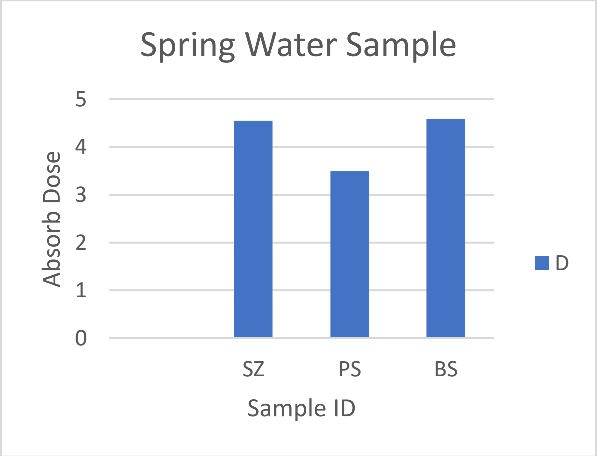

Figure 3: Absorb Dose for Spring Water Sample

From Table 4, the Activity Concentration of ^{238}U, ^{232}Th, and ^{40}K in BqL^{-1} for the spring water sample ranged between 2.55 to 3.56 BqL^{-1}, 1.44 to 1.73BqL^{-1} and 34.66 to 45.52BqL^{-1} with the mean value of 2.91, 1.63 and 55.31BqL^{-1}. The minimum value of the absorbed dose rate is 3.49nGyh-1 obtained from the PS sample location while the maximum value is 4.59 nGyh-1 obtained from the BS sample location, with an average value of 4.21. 0.00477 and 0.00624 nGyh^{-1} and the lowest and highest value of total annual effective dose obtained from PS and BS samples location, with a mean value of 0.00574mSvy^{-1}. Figure 2 and 3 is the chart of activity concentration of ^{238}U, ^{232}Th, and ^{40}K for spring water samples.

Table 5: Activity Concentration of ^{238}U, ^{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 Borehole Water Samples Respectively

Sample ID	^{236}U (BqL^{-1})	^{232}Th (BqL^{-1})	^{40}K (BqL^{-1})	D nGyh^{-1}	AEDγ (mSvy^{-1})	AEDing (mSvy^{-1})	TAED (mSvy^{-1})
BZ	3.16	1.72	61.28	5.05	0.0062	0.00067	0.00687
PB	1.58	1.68	69.01	4.62	0.0057	0.00065	0.00632
BB	2.93	1.89	74.06	5.58	0.0068	0.00075	0.00760
KB	2.41	1.35	72.45	4.95	0.0061	0.00063	0.00670
FB	2.85	1.73	62.29	4.96	0.0061	0.00067	0.00675
HB	3.12	1.61	74.93	5.54	0.0068	0.00071	0.00750
DB	1.83	1.42	61.34	4.26	0.0052	0.00058	0.00580
GB	3.70	1.61	77.59	5.92	0.0073	0.00074	0.00800
MEAN	**2. 70**	**1.63**	**69.12**	**5.11**	**0.0063**	**0.00067**	**0.00694**
MIN	**1.58**	**1.35**	**61.28**	**4.26**	**0.0052**	**0.00058**	**0.00580**
MAX	**3.70**	**1.89**	**77.59**	**5.92**	**0.0073**	**0.00075**	**0.00800**

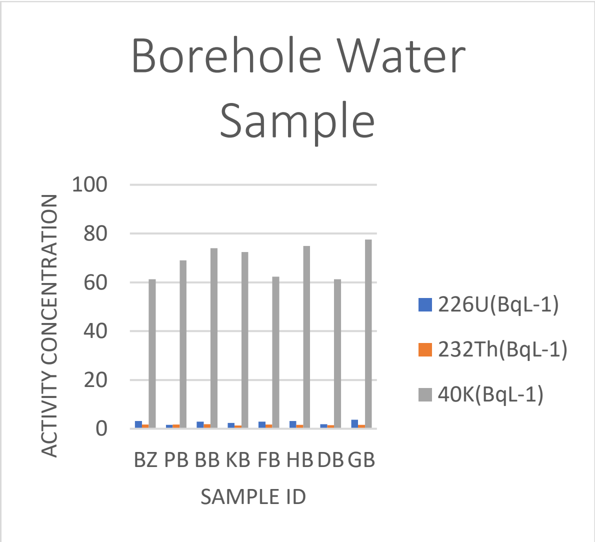

Figure 4: Activity Concentration of ^{238}U, ^{232}Th and ^{40}K for Borehole Water Sample

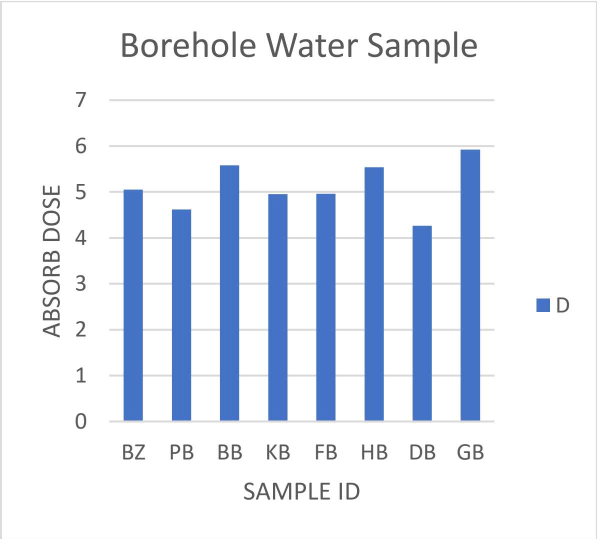

Figure 5: Absorb Dose for Borehole Water Sample

From Table 5, the activity concentration of ^{238}U, ^{232}Th, and ^{40}K for Borehole Water Samples ranged from 1.58 to 3.70BqL^{-1}, 1.35 to 1.89BqL^{-1} and 61.28 to 77.59 BqL^{-1} respectively, with mean value of 2.70, 1.63 and 69.12 BqL^{-1}. The minimum value was obtained from PB, KB, and BZ respectively, while the maximum values were obtained in GB, BB, and GB sample locations. The lowest and highest value of the absorbed dose rate was found to be 4.26 and 5.92nGyh^{-1} with a mean value of 5.11nGyh^{-1}. DB is the sample location with the lowest value while GB is the sample location with the highest value. 0.00800 and 0.00580 mSvy^{-1} are the maximum and minimum values of the total annual effective dose obtained from GB and DB. Figures 4 and 5 are the chart of activity concentration of Uranium, Thorium, and Potassium for Borehole water samples.

Table 6: Activity Concentration of ^{238}U, ^{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 Well Water Samples Respectively

Sample ID	^{236}U (BqL^{-1})	^{232}Th (BqL^{-1})	^{40}K (BqL^{-1})	D nGyh^{-1}	AEDγ (mSvy-1)	AEDing (mSvy-1)	TAED (mSvy-1)
WZ	2.82	1.62	75.63	5.44	0.0067	0.00071	0.0074
PW	3.55	1.54	71.56	5.55	0.0068	0.00070	0.0075
BW	2.35	1.66	55.48	4.40	0.0054	0.00061	0.0060
KW	2.16	1.53	62.84	4.54	0.0056	0.00061	0.0062
FW	3.68	1.22	51.83	4.60	0.0056	0.00056	0.0062
HW	2.51	1.51	61.43	4.63	0.0057	0.00061	0.0063
DW	2.64	1.23	55.40	4.27	0.0052	0.00054	0.0058
GW	2.86	1.55	66.25	5.02	0.0062	0.00065	0.0068
MEAN	**2.82**	**1.48**	**62.55**	**4.81**	**0.0059**	**0.00062**	**0.0065**
MIN	**2.16**	**1.22**	**51.83**	**4.27**	**0.0052**	**0.00054**	**0.0058**
MAX	**3.68**	**1.66**	**75.63**	**5.55**	**0.0068**	**0.00007**	**0.0075**

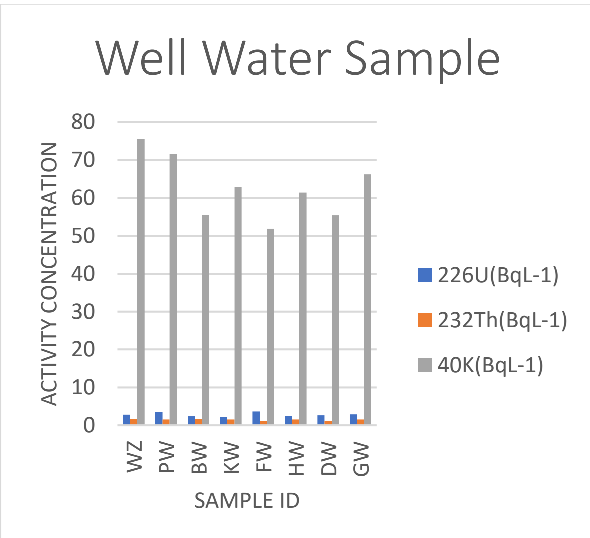

Figure 6: Activity Concentration of ^{238}U, ^{232}Th and ^{40}K For Well Water Sample

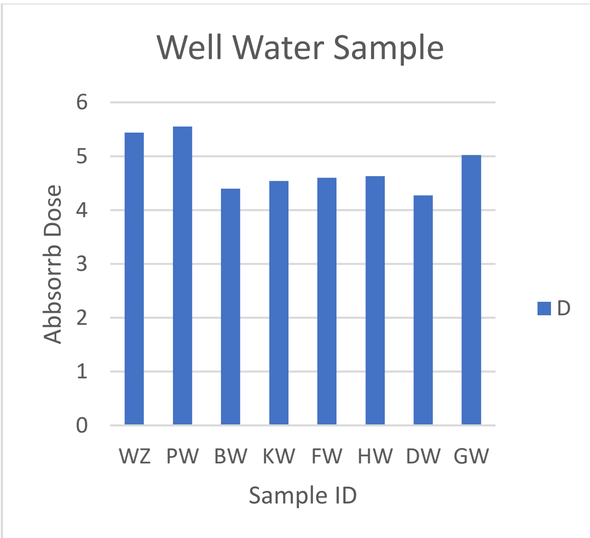

Figure 7: Absorb Dose for Well Water Sample

Figures 6 and 7 shows the activity concentration of 238U, 232Th, and 40K for well water samples. Activity Concentrations of ^{238}U, ^{232}Th, and ^{40}K in (BqL^{-1}) for the Well water sample were found to be from 2.16 to 3.68, 1.22 to 1.66, 51.83 to 75.63BqL^{-1}, with mean values of 2.82, 1.48 and 62.55BqL^{-1}. The highest values were found in FW, BW, and WZ sample locations, while the lowest value was found in KW, FW, and FW sample locations respectively. 5.55 and 4.27nGyh^{-1} are the highest and lowest values of absorbed dose for the well water sample, with a mean value of 4.81nGyh^{-1}. The total annual effective dose was to be between 0.0058mSvy^{-1} as the lowest value obtained from the DW sample location to 0.0075mSvy^{-1} as the highest value obtained from the PW sample location, with a mean value of 0.0065mSvy^{-1}.

The mean values of activity concentration of ^{238}U, ^{232}Th, and ^{40}K for all water sources (spring, borehole, and well) were found to be higher than the maximum contaminated level (MCL) of <1 BqL^{-1} for ^{238}U, ^{232}Th, and 10BqL^{-1} for ^{40}K set by UNSCEAR (2000). The mean value of the absorbed dose for spring, borehole, and well water was found to be lower than the maximum accepted value of 59nGyh^{-1} as recommended by (UNSCEAR, 2000). The values of total annual effective dose for all water sources were found to be far below the UNSCEAR reported world average value of 0.12 mSvy^{-1}, the WHO "World Health Organization" limit of 0.1 mSvy^{-1}and also lower than the ICRP "International Commission on Radiological Protection" preference limit of 1.0 mSvy^{-1}.

Table 7: Hazard Indices for Spring Water Samples

Sample ID	Ra_{eq}	H_{ex}	H_{in}	I_{γ}	I_{α}	FCR	HCR	TCR
SZ	9.33	0.025	0.032	0.028	0.013	3.41×10^{-9}	7.45×10^{-11}	3.49×10^{-9}
PS	7.28	0.020	0.027	0.021	0.013	2.62×10^{-9}	5.72×10^{-11}	2.68×10^{-9}
BS	9.54	0.026	0.035	0.028	0.018	3.43×10^{-9}	7.49×10^{-11}	3.51×10^{-9}
MEAN	**8.72**	**0.024**	**0.031**	**0.026**	**0.015**	$\mathbf{3.16\times10^{-9}}$	$\mathbf{6.89\times10^{-11}}$	$\mathbf{3.22\times10^{-9}}$
MIN	**7.28**	**0.020**	**0.027**	**0.021**	**0.013**	$\mathbf{2.62\times10^{-9}}$	$\mathbf{5.72\times10^{-11}}$	$\mathbf{2.68\times10^{-9}}$
MAX	**9.54**	**0.026**	**0.035**	**0.028**	**0.018**	$\mathbf{3.43\times10^{-9}}$	$\mathbf{7.49\times10^{-11}}$	$\mathbf{3.51\times10^{-9}}$

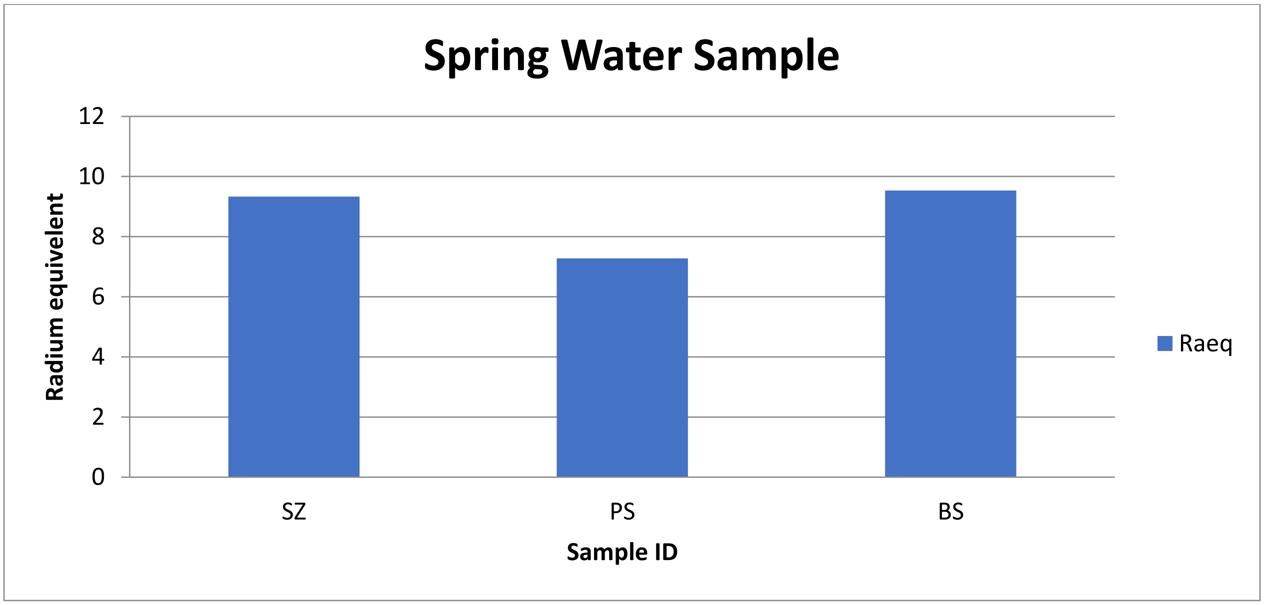

Figure 8: Radium Equivalent for Spring Water Samples

The hazard indices (Ra_{eq}, H_{ex}, H_{in}, I_{γ} and I_{α},) for spring water sample vary respectively from 7.28 to 9.54, 0.020 to 0.026, 0.027 to 0.035, 0.021 to 0.028 and 0.013 to 0.018 with mean value of 8.72, 0.024, 0.031, 0.026 and 0.015. The lowest value of (Ra_{eq}, H_{ex}, H_{in}, I_{γ} and I_{α}) were all found in PS and SZ sample location, while the highest values was obtained from SZ and BS sample location. The Fatality Cancer Risk were found to be in the ranges of 2.62×10^{-9} to 3.43×10^{-9}, with mean value of 3.16×10^{-9} while the hereditary cancer risk varies from 5.72×10^{-11} to 7.49×10^{-11} with mean value of 6.89×10^{-11} and the total cancer risk varies from 2.68×10^{-9} to 3.51×10^{-9} with mean value of $3.22\times10^{-9.}$ Figure 8 present the radium equivalent of spring water sample.

Table 8: Hazard Indices for Borehole Water Samples

Sample ID	Ra_{eq}	H_{ex}	H_{in}	I_{γ}	I_{α}	FCR	HCR	TCR
BZ	10.34	0.028	0.036	0.032	0.016	3.78×10^{-9}	8.24×10^{-11}	3.86×10^{-9}
PB	9.30	0.025	0.029	0.029	0.008	3.47×10^{-9}	7.5810^{-11}	3.55×10^{-9}
BB	11.34	0.031	0.039	0.035	0.015	4.18×10^{-9}	9.12×10^{-11}	4.27×10^{-9}
KB	9.92	0.027	0.033	0.033	0.012	3.69×10^{-9}	8.05×10^{-11}	3.78×10^{-9}
FB	10.12	0.027	0.035	0.031	0.014	3.71×10^{-9}	8.10×10^{-11}	3.79×10^{-9}
HB	11.19	0.030	0.039	0.036	0.016	4.13×10^{-9}	9.01×10^{-11}	4.22×10^{-9}
DB	8.58	0.023	0.028	0.027	0.009	3.19×10^{-9}	6.96×10^{-11}	3.26×10^{-9}
GB	11.98	0.032	0.042	0.039	0.019	4.40×10^{-9}	9.60×10^{-11}	4.50×10^{-9}
MEAN	**10.35**	**0.028**	**0.035**	**0.033**	**0.013**	$\mathbf{3.82\times10^{-9}}$	$\mathbf{8.33\times10^{-11}}$	$\mathbf{3.90\times10^{-9}}$
MIN	**8.58**	**0.023**	**0.028**	**0.027**	**0.008**	$\mathbf{3.19\times10^{-9}}$	$\mathbf{6.96\times10^{-11}}$	$\mathbf{3.26\times10^{-9}}$
MAX	**11.98**	**0.032**	**0.042**	**0.039**	**0.019**	$\mathbf{4.40\times10^{-9}}$	$\mathbf{9.60\times10^{-11}}$	$\mathbf{4.50\times10^{-9}}$

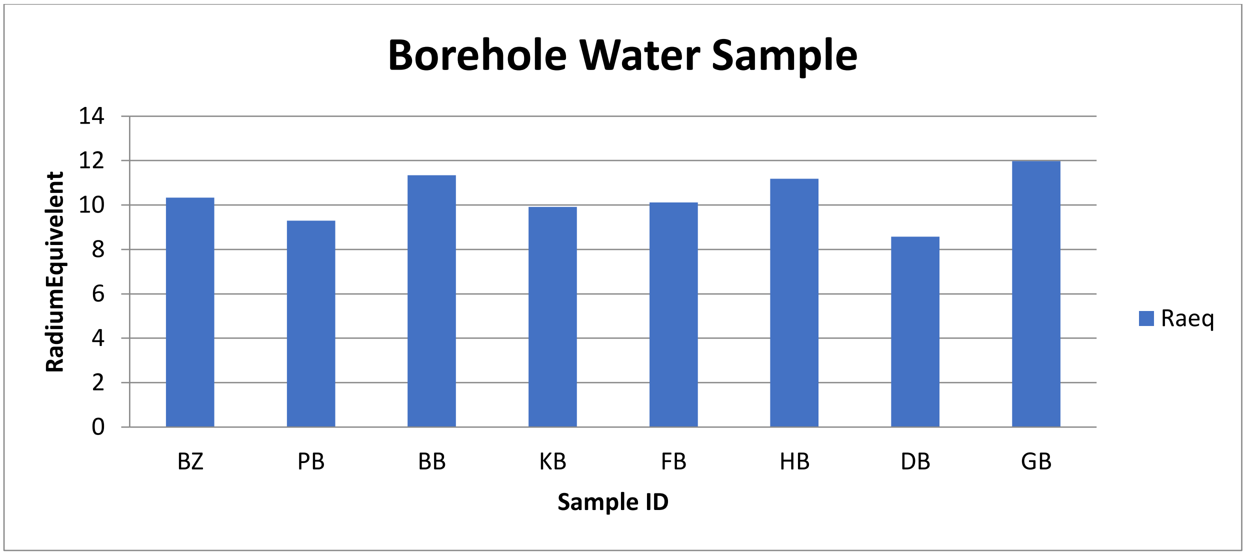

Figure 9: Radium Equivalent for Borehole Water Samples

The values of Ra_{eq}, H_{ex}, H_{in}, $\boldsymbol{I_\gamma}$ and I_α for borehole water sample were range from 8.58 to 11.98, 0.023 to 0.032, 0.028 to 0.042, 0.027 to 0.039 and 0.008 to 0.019. DB, and PB were the sample location with lowest value of Ra_{eq}, H_{ex}, H_{in}, $\boldsymbol{I_\gamma}$ and I_α, while BB and GB were the sample location with highest value Ra_{eq}, H_{ex} and H_{in}, $\boldsymbol{I_\gamma}$ and I_α. 3.19E-09 and 4.40E-09 were the lowest and highest value of Fatality Cancer Risk, with mean value of $3.82x10^{-9.}$ The maximum and minimum values of hereditary cancer risk are $9.60x10^{-11}$ and $6.96x10^{-11}$, with mean value of $8.33x10^{-11}$. Also, the total cancer risk range between $3.26x10^{-9}$ to $4.50x10^{-9}$ with mean value of $3.90x10^{-9.}$ The lowest value of fatality, heredity and total cancer risk were found in DB sample location while the highest value was found in GB sample location. Figure 9 present radium equivalent for Borehole Water Samples.

Table 9: Hazard Indices for Well Water Samples

Sample ID	**Ra_{eq}**	**H_{ex}**	**H_{in}**	**I_γ**	**I_α**	**FCR**	**HCR**	**TCR**
WZ	10.96	0.030	0.037	0.035	0.014	$4.05x10^{-9}$	$8.85x10^{-11}$	$4.14x10^{-9}$
PW	11.26	0.030	0.040	0.036	0.018	$4.13x10^{-9}$	$9.01x10^{-11}$	$4.22x10^{-9}$
BW	9.00	0.024	0.031	0.027	0.012	$3.30x10^{-9}$	$7.21x10^{-11}$	$3.38x10^{-9}$
KW	9.19	0.025	0.031	0.029	0.011	$3.41x10^{-9}$	$7.42x10^{-11}$	$3.47x10^{-9}$
FW	9.42	0.025	0.035	0.030	0.018	$3.41x10^{-9}$	$7.44x10^{-11}$	$3.48x10^{-9}$
HW	9.40	0.025	0.032	0.030	0.013	$3.46x10^{-9}$	$7.56x10^{-11}$	$3.54x10^{-9}$
DW	8.66	0.023	0.031	0.028	0.013	$3.18x10^{-9}$	$6.94x10^{-11}$	$3.25x10^{-9}$
GW	10.18	0.027	0.035	0.032	0.014	$3.75x10^{-9}$	$8.17x10^{-11}$	$3.83x10^{-9}$
MEAN	**9.76**	**0.026**	**0.034**	**0.031**	**0.014**	**$3.59x10^{-9}$**	**$7.82x10^{-11}$**	**$3.66x10^{-9}$**
MIN	**8.66**	**0.023**	**0.031**	**0.027**	**0.011**	**$3.18x10^{-9}$**	**$6.94x10^{-11}$**	**$3.25x10^{-9}$**
MAX	**10.96**	**0.030**	**0.037**	**0.036**	**0.018**	**$4.13x10^{-9}$**	**$9.01x10^{-11}$**	**$4.22x10^{-9}$**

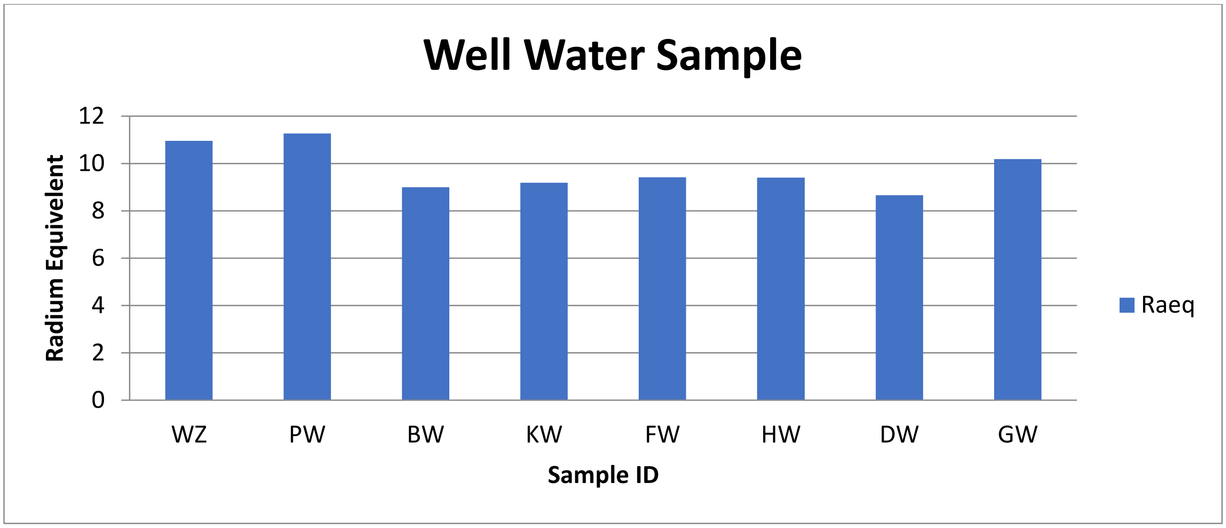

Figure 10: Radium Equivalent for Well Water Samples

The minimum and maximum values of Ra_{eq}, H_{ex}, H_{in}, $\boldsymbol{I_\gamma}$ and I_α for well water samples were found to be 8.66 and 10.96, 0.023 and 0.030, 0.031 and 0.037, 0.027 and 0.036, 0.011 and 0.018 respectively. The minimum value of Ra_{eq}, H_{ex} and H_{in} was obtained from DW sample location, and BW and KW were the sample location with minimum values of $\boldsymbol{I_\gamma}$ and I_α. The maximum values of Ra_{eq}, H_{in}, were found in WZ, sample location, H_{ex}, $\boldsymbol{I_\gamma}$ and I_α were found in WZ and PW, PW and PW and FW sample location, the values of fatality cancer risk were range between 3.18×10^{-9} to 4.13×10^{-9} as the lowest and highest values obtained in DW and PW, with mean value of 3.59×10^{-9}. The highest and lowest value of heredity cancer risk varies from 9.01×10^{-11} to 6.94×10^{-11} with mean value of 7.82×10^{-11}. The total cancer risk ranges from 3.25×10^{-9} to 4.22×10^{-9} with mean value of 3.66×10^{-9}. The minimum and maximum value heredity and total cancer risk was found in DW and PW respectively. Figure 10 present the radium equivalent of well water sample.

The radium equivalents (Ra_{eq}) of all three sources of water (Spring, Borehole 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_α of all samples are far less than unity. These mean values were below the acceptable regulatory value set by WHO, (2017).

The finding of this study revealed that the activity concentration of ^{238}U, ^{232}Th and ^{40}K of this current study was not in accordance with research carried out by Alaboodi *et al*. (2020) and Aguko *et al.*, (2020) whose found the activity concentration of ^{238}U, ^{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_α as both values were found to be within the ranges of the global limit.

The findings also revealed that the highest value of hazard indices, Ra_{eq}, H_{ex}, H_{in}, $\boldsymbol{I_\gamma}$ except for I_α, was obtained from borehole water sample. This may be due to the depth of the borehole water often in contact with granite, phosphate rocks, or uranium rich formations (IAEA, 2014). In addition, the study revealed that most of the estimated radiological parameters from spring were the borehole and well water. This may be due to shallow aquifers with a faster recharge rate of spring water which give less time for radionuclide to dissolve in the water (Edet & Nganje, 2015).

CONCLUSION

This study was carried out to assess natural radioactivity in spring, borehole, and well water in Hong Local Government Areas, Adamawa State, Nigeria. The mean activity concentration of ^{238}U, ^{232}Th, and ^{40}K of all three water sources was higher than the control value of activity concentration as set by regulatory body for radiation. Also, the mean values of absorbed dose rate D (nGy/h) for spring, borehole, and well water sources were found to be lower than the maximum accepted value of 59 $nGyh^{-1}$ as recommended by health guidelines. Therefore, the area under this study can be classified as an area with low background radiation. The values of estimated annual effective doses and radium equivalent activity Ra_{eq} 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 Ra_{eq} as recommended by international guidelines. Hence based on these estimated parameters it can be concluded that waters in this study area need no special treatment for life consumption. Based on the findings of this study, the following recommendations are proposed to improve water quality and reduce health risks associated with natural radioactivity contaminants in spring, boreholes, and well water. Households should use cost-effective treatment methods such as filtration, boiling, and chemical purification to minimize exposure to harmful contaminants before consumption. Water should be stored in clean, covered containers to prevent contamination and deterioration of water quality, and hygiene practices should be maintained to reduce waterborne diseases.

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