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Assessment of Radon-222 in Selected Water Sources in Gwagwalada, Gwagwalada Area Council, FCT, Abuja, Nigeria

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ABSTRACT

The exposure of a population to high concentration of Radon-222 for a long period has significant health effects ranging from respiratory functional changes to cancer of the lungs. Also, a very high level of Radon-222 in drinking water can lead to stomach and gastrointestinal tract cancer. In this work, the activity concentrations of Radon-222 (^{222} Rn) were investigated from thirty (30) water samples which includes twenty (20) borehole water samples and ten (10) well water samples from Gwagwalada town using liquid scintillation counter at the Centre for Energy Research and Training (CERT) Ahmadu Bello University Zaria, Nigeria. Radon-222 concentrations obtained from this analysis ranged within (7.72 to 172.30) *Bq/L*. The highest and the lowest Radon-222 activity concentration were recorded from borehole and well water samples at Abattoir and kasuwan Derey respectively. Borehole water samples recorded the highest mean radon concentration of 45.11*Bq/L* while well water samples recorded the lowest mean Radon-222 concentrations of 27.60*Bq/L*. From computed results, it was observed that 88.89% of the recorded values were found to be above the world average Maximum Contamination Level (MCL) of 10*Bq/L* set by the World Health Organization and the MCL of 11.1*Bq/L* set by the United States Environmental Protection Agency (USEPA, 1991). Similarly, 15% of the recorded values were above the recommended action level of 100*Bq/L* set by the World Health Organization (WHO, 2008). Also, the corresponding Mean Annual Effective Doses estimated for the three (3) categories of people from the two (2) water types were found to be (0.331, 0.662 and 2.318) *mSv/y* in borehole water for adults, children and infant respectively. While due ingestion of Radon-222 in well water samples were found to be (0.201, 0.403 and I.417) *mSv/y* for adults, children and infants respectively. All the Mean Annual Effective Doses were found to be above World Health Organization's (WHO's) recommended reference level of 0.1 *mSv/y* for intake of radionuclides in water (WHO, 2004). These higher values of Radon-222 concentrations in water of the area, pose a threat to the health of the inhabitants of the study area particularly those living in Abattoir and the immediate vicinity of the University of Abuja reaching Hospital where the borehole water sample was taken in Phase 3, indicating that such water is unsafe for human consumption from radiation point of view as such, the inhabitants of such areas are advised to boil the water if they must use it for consumption so as to evaporate the contained radon in them thereby keeping the concentration of Radon-222 in the water as low as reasonably achievable.

Keywords:
Radon-222,
Nuclear Contamination,
Natural Radioactive Sources,
Effective Dose,
Activity Concentration.

INTRODUCTION

Water is the major constituent of the Earth's streams, lakes and oceans and the fluid of most living organisms. It covers about 71% of the Earth surface. It is vital for all known forms of life especially man. Man uses water for various reasons such as transportation, power generation, Agriculture and other domestic activities hence its availability and quality as regards radiological, microbiological, chemical and any other form of contamination are delicate vital issues (Garba et al., 2008). Unfortunately, access to potable drinking water in most developing countries such as Nigeria is a major challenge hence most people rely heavily on untreated surface and groundwater sources for consumption.

The Inhabitants of Gwagwalada Area Council of FCT, inhabitants rely mainly on untreated groundwater sources (well and borehole) as well as surface water sources. This is because there are only few available pipes born water sources and, in most places, where such sources are available. The lower Usuma dam located in the Bwari Area Council of FCT which is intended to remediate this problem needs expansion by the government to reach and serve remote and rural areas of the Federal Capital Territory (FCT) round the clock (Ishaya, 2009) which is why this study investigate the radiological content of ground and surface water sources in Gwagwalada town being one of the satellite towns and mostly residential. Radon-222 is a naturally occurring radioactive inert gas with a half-life of 3.82 days and is a member of the Uranium decay series (Sorntai, 2007). It contributes the largest proportion of the total radiation from natural sources. Most importantly, Radon-222 is soluble in water. The concentration of radon in water is due to the decay of Radium-226 associated with the rock and soil. The Radon-222 gas penetrates through soil and rocks and dissolves in water (Xinwei, 2006). Normally, drinking water from ground water sources has higher concentration of radon than surface water as shown by several studies because of the proximity of the water to the rock sources of the element (Agbaje et al., 2009).

The problem of Radon-222 is a serious issue of concern in the current scientific world. It is well known that Radon-222 and its progenies contribute 50% of the total effective dose from natural sources. In fact, it has been reported that diseases of major concern associated with Radon-222 are stomach cancer from ingestion and lung cancer from inhalation (Mills, 1990). According USEPA (2012), Radon-222 is the second most frequent cause of lung cancer and number one among non-smokers. Research has shown also that these diseases could be as a result of both chronic and acute dose exposure-USEPA has similarly estimated that 15,000-25,000 people died of Radon-222 induced cancer per annum in USA. Virk and Singh (1993) recorded that certain rocks including granites, light colored volcanic rocks, sedimentary rocks containing phosphate and metamorphic rocks have higher average Uranium contents. This research presents the activity concentrations of Radon-222 in water within Gwagwalada town, Gwagwalada Area Council, FCT which served as the baseline study.

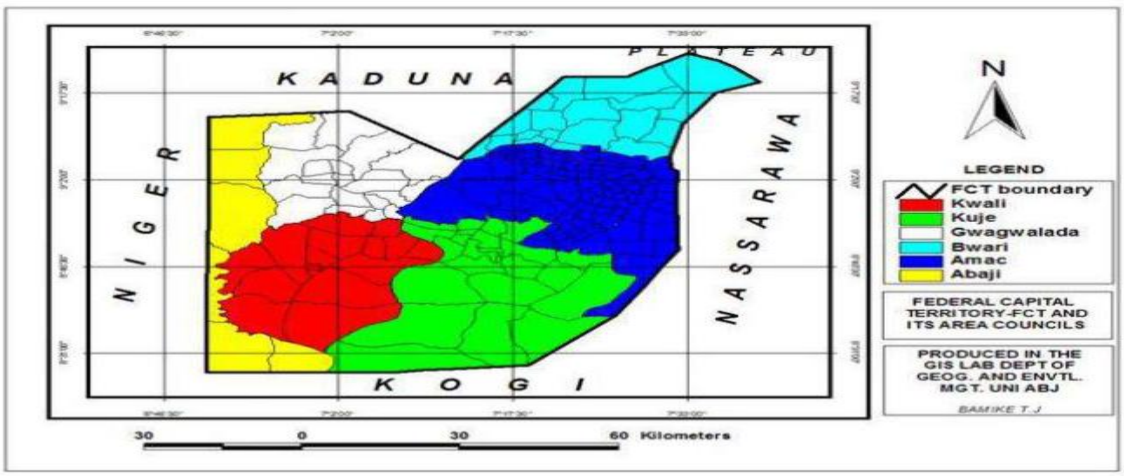

Figure 1: Map of FCT showing the Area Councils with Gwagwalada Area Council in White background. (Bamike, 2014)

MATERIALS AND METHODS

Study Area

Gwagwalada Area Council in FCT lies on the coordinates 8^0 56' 29" North 7^0 5' 31' East (Abaji et-al., 2014). The town is situated along the Abuja-Lokoja express way and bounded by Kaduna state and Abaji Area Council to the north, Abuja Municipal Area Council (AMAC) to the east, Abaji Area Council to the West. Kuje Area Council to the South -east, and Kwali Area Council to the South. Gwagwalada has an estimated land size of about 1069.589km^2 and although the Nigeria Population Commission Census of 2006 officially put the population of Gwagwalada at 157,770, the area council has a 2021 estimated population of about 443,000. The people are predominantly farmers, traders, students and civil servants. According to Mallam et al., (2016), the Gwagwalada is within the savannah tropical vegetation zone and the area is drained by Usman River and its tributaries.

Geology of the Study Area

FCT is predominantly underlain by the Nigerian Basement Complex rock of the Precambrian age (Mamman and Oyebanji, 2000). Figure 2 shows the geologic map of FCT indicating the basic geologic formations. The rocks include different textures of granites, gneiss, migmatites, diorites, metasediments and pegmatites. The geology of the FCT is the same as that of Gwagwalada. Groundwater is found mainly in the variable weathered/transition zone and in fractures, joints and cracks of the crystalline basement while sparse amount of water can be obtained in the freshly unweather bedrock below the weathered layers.

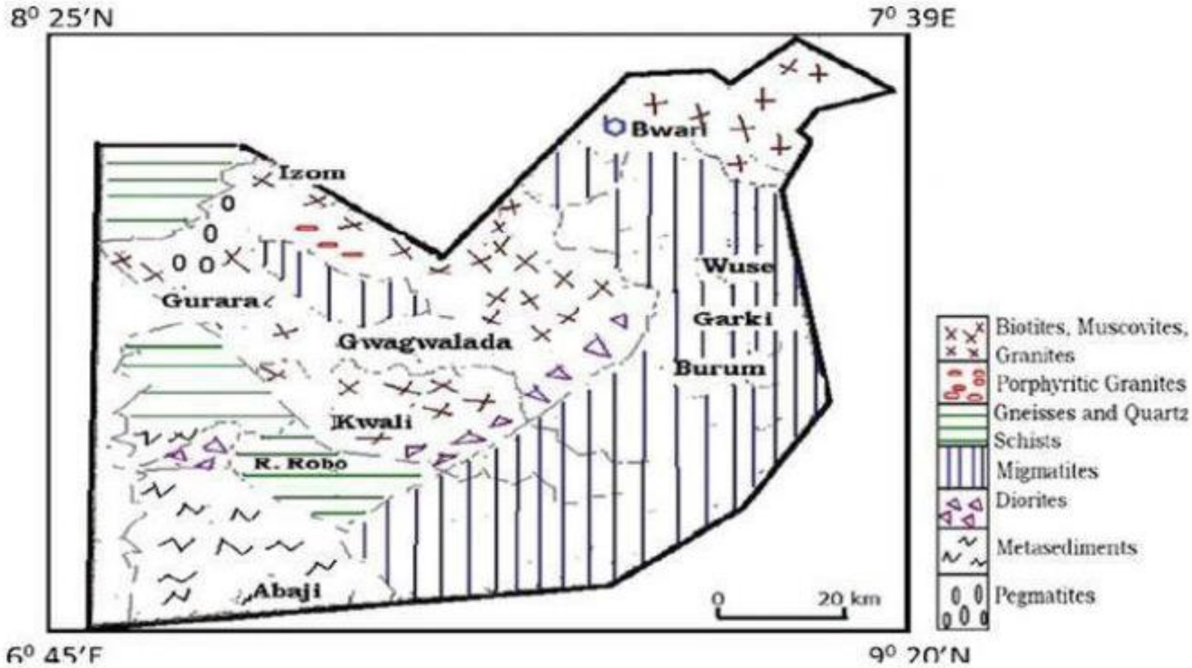

Figure 2: Geologic map of FCT (Adapted from: Dikedi, 2012 in: Mallam et al.)

Materials and Reagents

For the successful completion of this project work, the following materials and reagents were used in line with the description by the American Society for Testing and Materials (ASTM, 1999). They include; Disposable hypodermic syringe (20ml, 10ml capacities), Surgical gloves, Scintillation vials (20ml capacity) with polyethylene inner seal cap liners, Scintillation cocktail, Distilled water, Indelible ink and Masking tape, Liquid Scintillation Counter (Packard Tri-Card LSA 1000TR). Other materials and reagents used in this study include: Global Positioning System (GPS), a piece of clean cloth, Session 1 PH meter and Ethanol.

Sample Collection

From the selected locations in the study area, a total of 30 water samples were randomly collected from various underground (Boreholes and Open wells) water sources at different locations and intervals in Gwagwalada town for analysis as shown in figure 3. To mark and locate the geographical locations of the sample collection points during sampling, a global positioning system (GPS) was used. To collect samples, plastic vials were used and while doing this, the vials were submerged in the water completely until filled and tightly capped before removing them out of the water so as to avoid losing the Radon-222 gas to the atmosphere. Water from wells were first purged before collection of samples. Here, samples were first collected with bailers and then transferred into vials. Boreholes were pumped and allowed to flow each for at least three (3) minutes before samples were collected in order to ensure that fresh samples were obtained. Each collected sample, was properly labelled and the time of sample collection was noted and recorded.

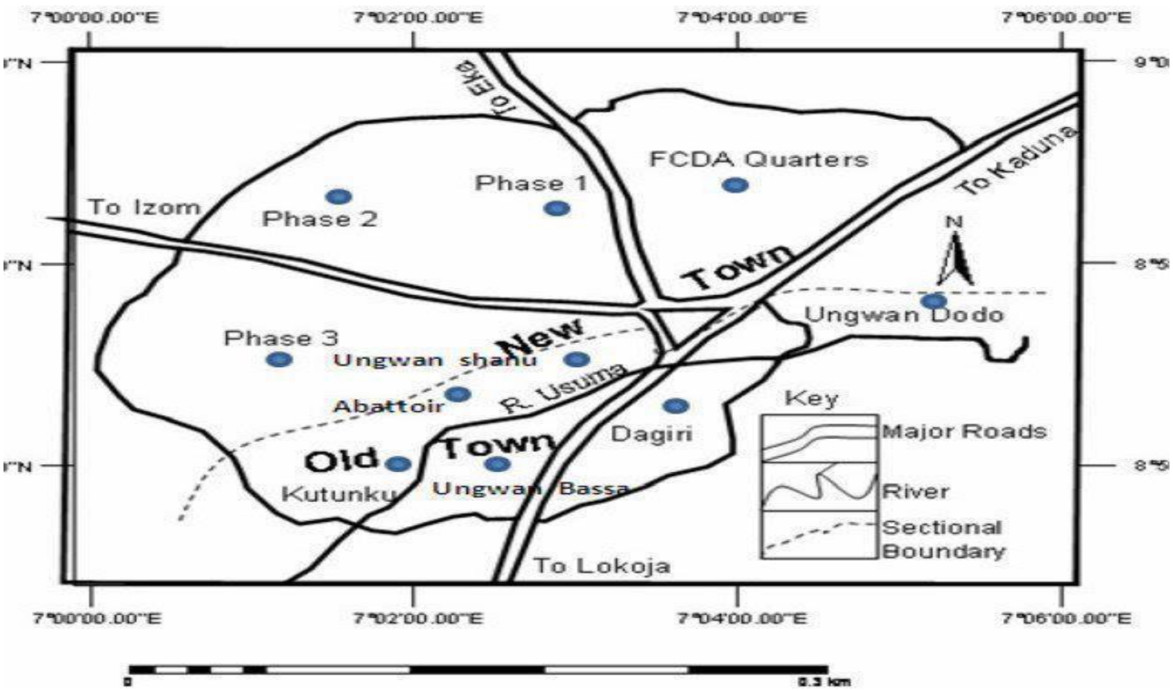

Figure 3: Map of Gwagwalada town showing points of sample collection. (Adapted from Ishaya and Abgaje, 2009)

Sample Preparation

10ml of each sample was added into a vial containing 10ml of toluene-based cocktail (scintillator) using a hypodermic syringe. The vials were tightly capped and shaken vigorously for three (3) minutes to extract Radon-222 in water phase into the organic scintillator. In a similar manner a blank sample for the background was prepared using a distilled water that has been kept in a glass bottle for at least 21 days. The prepared samples were allowed to stand undisturbed for at least three (3) hours each in order for Radon-222 and its alpha decay products attain equilibrium.

Sample Analysis

The prepared samples and the blank were each analyzed using the liquid scintillation counter (Tri-Card LSA 1000) at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Kaduna, Nigeria. Radiation emitted from the samples transferred energy to the organic scintillator which in turn emits light photons. This way each emission result is a pulse of light in form of digit.

To obtain the activity concentration of Radon-222 and background results from the samples, the formula below was employed:

$$CRnw\ (BqL^{-1}) = \frac{100(SC - BC)\ e^{\lambda t}}{60(CF)\ D} \qquad (1)$$

where: CRnw (BqL^{-1}) = Concentration of Radon-222 in Becquerel per liter, SC = Sample Count (Count min^{-1}), BC = Background Count (Count min^{-1}), t = Time difference from sampling to counting (minutes) = Decay Constant (1.26×10^{-4} min^{-1}), 100 = Conversation factor from per 10*ml* to per liter, 60 = Conversation factor from minutes to seconds (*second/minute*), CF = Calibration factor, D = Fraction of Radon-222 in the cocktail in a 22 *ml* total capacity vial form10 *ml* of sample, 10 *ml* of cocktail and 2 *ml* of air.

Similarly, to obtain the corresponding Annual Effective Doses (*mSv/y*) due to ingestion of Radon-222 in water samples from the area under study, the below equation (2) was used taking into consideration the following factors; dose coefficient (*Sv/Bq*), the annual water consumption (*L/Y*) and the activity concentration of Radon-222 obtained from equation (l) (Ryan et al., 2003)

$$E = CRnw\ (D\ L) \qquad (2)$$

From the above equation (2),

CRnW = Concentration of Radon-222

Dose coefficient (10^{-8} *Sv/Bq*, 2×10^{-8} *Sv/Bq*, 7×10^{-8} *Sv/Bq*) for adults, children and infants respectively (UNSCEAR, 2000).

L = Annual water consumption by an adult of 2 litres per day I.e. 730L/Y (UNSCEAR, 1993).

It should be noted from equation (2) also, that doses due to ingestion of radon in water for similar consumption rates could be factor of 2 and 7 higher for children and infants respectively (UNSCEAR, 2000).

RESULTS AND DISCUSSION

The activity concentration of Radon-222 of the obtained thirty (30) water samples collected at different locations of the study area as well as the corresponding Annual Effective Doses due to ingestion of radon in water for the three categories are presented in table 1.

Results

A total of thirty (30) water samples comprising of (10) wells and (20) boreholes were randomly collected from Gwagwalada town and analysed using Liquid Scintillation Counter. It should be noted that the choice of choosing more borehole water as samples during sample collection was because more than 75% of residence in these locations depended on borehole as one of their primary sources of drinking water.

Table 1: The results of the analysis are shown in the table below and their corresponding Annual Effective Doses (AED) in (mSv/y)

S/N	SAMPLE LOCATION	SAMPLE ID	SAMPLE TYPE	Rn (Bq/l)	Adult	Children	Infants
1	Kotongora Estate 1	KT-1	Borehole	11.84	0.086	0.172	0.602
2	Kotongora Estate 2	KT-2	Well	7.81	0.056	0.112	0.392
3	Kotongora Estate 3	KT-3	Borehole	13.33	0.097	0.194	0.679
4	Abattoir 1	AB-1	Well	68.11	0.497	0.994	3.479
5	Abattoir 2	AB-2	Borehole	172.3	1.257	2.514	8.799
6	Abattoir 3	AB-3	Borehole	152.8	1.115	2.23	7.805
7	Phase 1	PH-1A	Borehole	27.78	0.203	0.406	1.421
8.	Phase 1	PH-1B	Borehole	11.67	0.085	0.17	0.595
9	Phase 1	PH-1C	Well	13.39	0.099	0.196	0.681
10	Ungwan Dodo	UGD-1	Borehole	13.33	0.097	1.194	0.679
11	Ungwan Dodo	UGD-2	Well	7.74	0.057	0.113	0.393
12	Ungwan Dodo	UGD-3	Borehole	10.61	0.045	0.91	0.315
13	Kasuwan Derey	KD-1	Well	7.72	0.056	0.112	0.392
14	Kasuwan Derey	KD-2	Borehole	21.98	0.161	1.322	1.127
15	Kasuwan Derey	KD-3	Borehole	21.36	0.156	0.312	1.092
16	Phase 2	PH-2A	Borehole	27.78	0.203	0.406	1.421
17	Phase 2	PH-2B	Well	47.17	0.344	0.688	2.408
18	Phase 2	PH-2C	Borehole	21.38	0.157	0.313	1.093
19	Phase 2	PH-2D	Borehole	21.36	0.156	0.312	1.092
20	Kutunku	KT-1	Borehole	58.11	0.424	0.848	2.968
21	Kutunku	KT-2	Well	47.25	0.346	0.690	2.490
22	Kutunku	KT-3	Borehole	68.11	0.497	0.994	3.479
23	Dagiri	DG-1	Well	27.71	0.200	0.403	1.418
24	Dagiri	DG-2	Borehole	35.28	0.261	0.522	1.827
25	Dagiri	DG-3	Borehole	21.98	0.161	0.322	1.127
26	Ungwan Shanu	UGS-1	Well	27.78	0.203	0.406	1.421
27	Ungwan Shanu	UGS-2	Borehole	21.36	0.156	0.312	1.092
28	Phase 3	PH-3A	Borehole	142.1	1.104	0.208	7.728
29	Phase 3	PH-3B	Well	21.36	0.156	0.312	1.092
30	Phase 3	PH-3C	Borehole	27.78	0.203	0.406	1.421

Discussion of Findings

The mean values of Radon-222 concentrations obtained from table 1 above were calculated and round to be 45.112*Bq/L* and 27.595*Bq/L* respectively for boreholes and well water. Similarly, the corresponding Annual Effective Doses due to ingestion of Radon-222 in Borehole water were found to be (2.318, 0.662 and 0.1331) *mSv/y* for adults, children and infants respectively. While that due to the intake of Radon-222 from well water were found to be (1.417, 0.403, and 0.201) *mSv/y* for adults, children and infants respectively. These results show that both the mean values of Radon-222 concentrations and the Annual Effective Doses (AED) due to ingestion of borehole and well water samples in the study area exceeded the average recommended values of 10*Bq/L* and 0.1*mSv/y* set by the World Health Organization (WHO) for Radon concentration and Annual Effective Dose due to intake of radionuclide in water respectively (WHO, 2004).

Borehole Water

After analyzing the obtained results of radon concentrations for the twenty (20) borehole water samples collected randomly from different locations of the study area as presented in table I above, it showed that Radon-222 concentrations varied from 10.61*Bq/L* to

172.30*Bq/L* with mean value of 45.11*Bq/L*. The maximum concentration (172.30*Bq/L*) was obtained from the Abattoir Area of Gwagwalada while the minimum concentration (10.61*Bq/L*) was found at one of the sampled points at Ungwan Dodo as shown in table 1. All the values obtained from these samples were found to be above maximum contaminant levels of 11.1*Bq/L* set by USEPA and the world average value of 10*Bq/L* set by World Health Organization (WHO 2004). In a related development, the mean concentration of Radon-222 in the study area (45.1 and 12*Bq/L*) was found to be lower than the recommended guideline level of 100*Bq/L* set by the World Health Organization (WHO, 2008). However, 15% of the analyzed borehole water samples which include two samples from Abattoir and one from Phase 3 were found to be above the WHO recommendation. These high concentrations of Radon-222 in Abattoir and Phase 3 water samples which can pose a threat on the health of the inhabitants of these areas could be due to the geology of the area which is basically made up of granites and the concentration of Radium-226 from the parent rock in the aquifer matrix (Mallam et al., 2016). Another reason for the high levels of Radon-222 especially as it concerns the Abattoir samples could be the high population density and low elevation of the areas involved (WHO, 2009) Likewise, the high level of Radon-222 detected in one of the sample locations at Phase 3, which was a borehole situated inside the University of Abuja Teaching Hospital could be as a result of the presence of radionuclides at its various scan and x-ray centers within the hospital (IAEA, 2014).

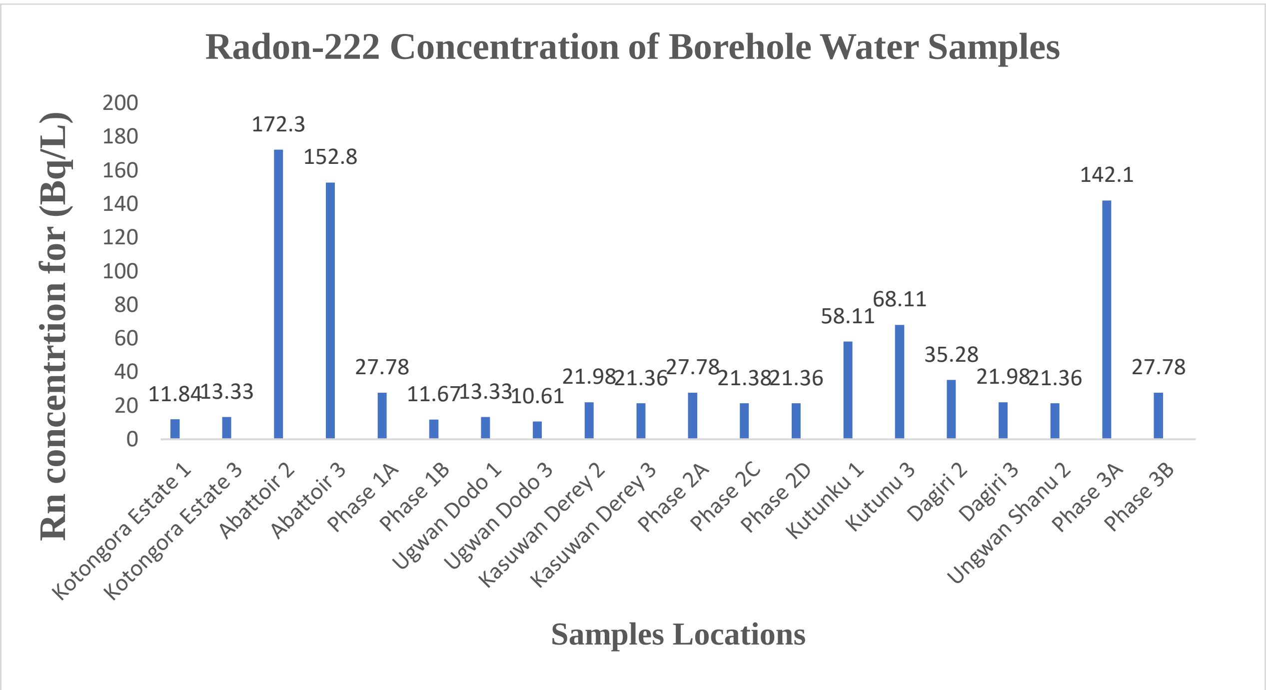

Figure 4: Bar Graph of Radon-222 Concentrations for Borehole Water Samples

Well Water

As presented in table 1, concentration levels of Radon-222 in well water samples collected from ten (10) different wells located across the study area were found to range from (7.72 to 68.11*Bq/L*) with a mean value of 27.60*Bq/L* just as the Borehole samples, Abattoir again recorded the maximum Radon concentration of 45.11Bq/L. Meanwhile, Kasuwan Derey recorded the minimum Radon concentration of 7.72*Bq/L* with the exclusion of Kontongora Estate, Kasuwan Derey and Ungwan Dodo with Radon concentration levels of (7.72, 7.74 and 7.81*Bq/L*) respectively, with a mean value of 27.60*Bq/L*, the remaining locations in the study area have radon concentrations above the maximum contaminant level (MCL) of 11.1*Bq/L* set by United States Environmental Protection Agency (USEPA, 1991) and world average value of 10*Bq/L* set by WHO in 2004. This means that residents in these areas are faced with serious risks of lung cancer and other terminal diseases that come -with ingesting high doses of radiation (WHO, 2021).

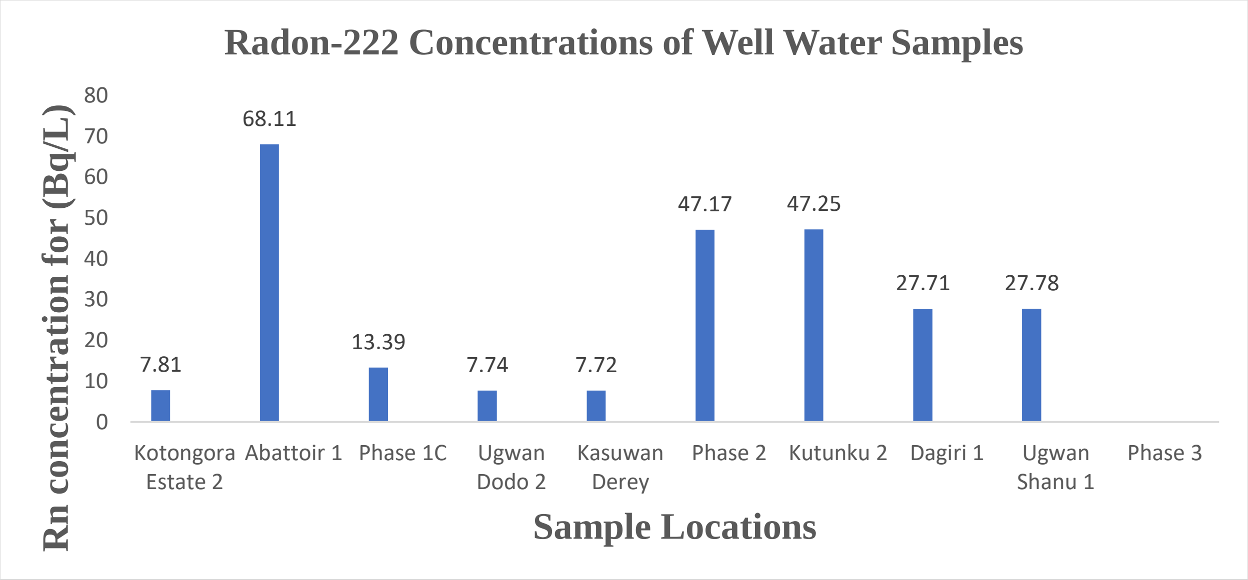

Figure 5: Bar Graph of Radon-222 Concentrations for Well Water Samples

Mean Radon Concentration

For comparison between the radon levels in the two water source types wells and boreholes collected from the study area, the mean concentration of each of the water types were calculated and plotted as shown the pie chart below:

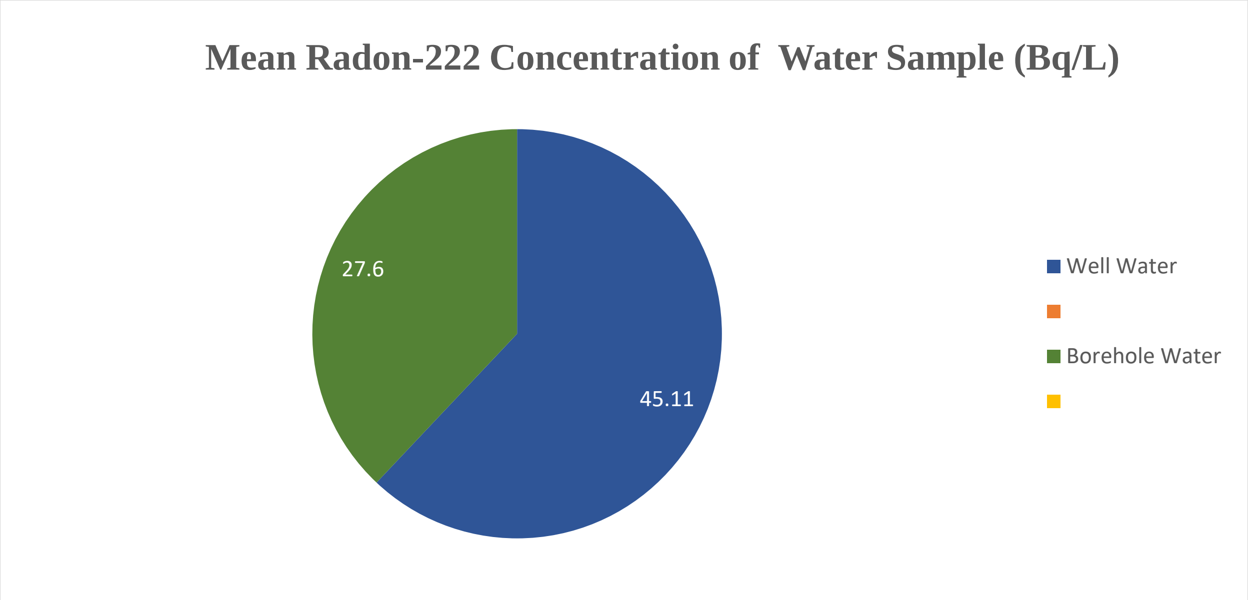

Figure 6: Pie Chart of the Mean Radon-222 Concentrations for the two-water sampled water types

Water Sample

The result showed that samples from borehole have the highest mean concentration of Radon-222 while well water samples have the least mean concentration of Radon-222 between the two water types. It is of importance to note that all the mean Radon-222 concentration values from the water types exceeded the maximum levels set by USEPA (USEPA, 1991) and the world average value of 10*Bq/L* set by the World health organization (WHO, 2004). In suggesting why well water samples generally had lower Radon-222 concentrations as shown by the mean values, it may be said that the lower mean value of Radon-222 concentration for well water as compared to that of borehole water could be due to the fact that well water is closer to the earth surface than borehole water hence, is more aerated and since radon is an evaporative gas, the closer a water source is to the earth surface the more likely it is that it will have a lower radon concentration. Also, a higher recorded mean value for borehole water may be because under pressure radon readily dissolves in water. Hence, the more the depth into the ground of a water source, the more pressure there is. This leads to the radon accumulation in groundwater (Cho et al., 2004). Another reason for this could be the geology of the areas involved.

Annual Effective Doses (AED)
The study area's corresponding Annual Effective Doses due to ingestion of Radon-222 from borehole water samples were estimated for the same water consumption rate and found to range from (0.045 to 8.799) *mSv/y* as shown in table 1. Subsequently, their corresponding mean values were 0.331 0.662 and 2.318*mSv/y* for adults, children and infants respectively. The estimated Annual Effective Doses due to ingestion of Radon-222 from well water samples were found to range from (0.056 to 3.479) *mSv/y* with corresponding mean values of 0.201, 0.403, and 1.417*mSv/y* for adults, children and infants respectively. From the results, 80 Annual Effective Doses representing 88.89% of the estimated Annual Effective Doses for all the human categories (Adults, Children and Infants) were found to be above the World Health Organization's (WHO's) recommended level of 0.1*mSv/y* for intake of radionuclide in water. The higher values of the calculated Annual Effective Doses from the study area showed that most of the water samples could pose a threat to the health and life of residents of these areas should the water be taken directly without proper care and treatment which is mostly the case.

Mean Annual Effective Dose
The Mean Annual Effective Doses due to ingestion of Radon-222 from the sampled water types were calculated for the three (3) categories of humans and found to be (0.331, 0.662 and 2.318) *mSv/y* in borehole water for adults, children and infants respectively. On the other hand, the Mean Annual Effective Doses due to ingestion of Radon-222 in well water samples were found to be (0.201, 0.403, and I.417) *mSv/y* for adults, children and infants respectively. All the Mean Annual Effective Doses were found to be above World Health Organization recommended reference level of 0.1 *mSv/y* for ingestion of radionuclide in water (WHO, 2004). These results revealed that infants with significantly higher doses of Radon-222 for the same water consumption rate have higher risks of contracting lung cancer in the future compared to children and adults as illustrated in figure 7.

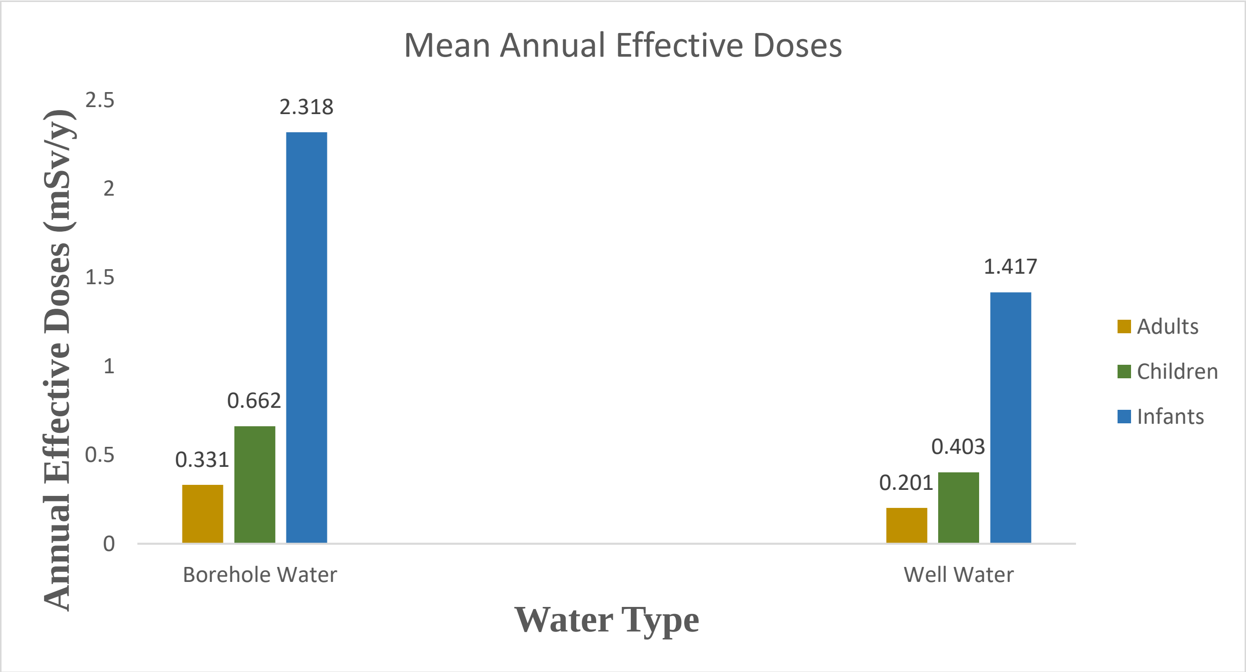

Figure 7: Bar Graph of Mean Annual Effective Doses for the three Water Types

CONCLUSION
Results obtained from the measurement of the activity concentrations of Radon-222 in water samples collected at different locations of Gwagwalada town, Gwagwalada Area Council, FCT revealed that 88.89% of the recorded values of radon concentrations in the present study as well as the mean values obtained for the two (2) water types were above the world average Maximum Contamination Level (MC L) of 10*Bq/L* set by the World Health Organization (WHO) and the

Maximum Contamination Level (MCL) of 1.1*Bq/L* set by the United States Environmental Protection Agency (USEPA, 1991). 15% of the recorded values of radon concentration which includes borehole water samples from Abattoir and Phase 3 also exceeded the recommended action level of 100*Bq/L* set by the World Health Organization (WHO, 2008). These significantly high values of radon concentration can be ascribed to the nature of some factors notably the area's basement rock and soil type. Therefore, these water sources pose a threat to the health of the inhabitants of the area if water from these sources are continually ingested without proper treatment. The likelihood of this threat to health (which could be stomach or lung cancer) is more on infants and children than adults as evident from the estimated Annual Effective Doses of the corresponding radon concentrations in water in which most of the estimated Annual Effective Doses were found to be above the reference level of 0.1*mSv/y* set by World Health Organization (WHO, 2004) for intake of radionuclides in water.

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