Radiological and Toxicity Impact of Uranium $^{238}\text{U}$ in Ground Water to Different Age Groups at Wurno, Sokoto State, Nigeria

Ibrahim Isah$^1$, Aminu Saidu$^2$, Sabi B. Muhammad$^2$, Murtala M. Hamza$^2$, Aliyu Bala$^2$, and Usman Abubakar$^3$

One of the primary goals of the World Health Organization (WHO) is for every society to have an adequate supply of safe drinking water. This work aimed to assess the radiological and toxicity impact of ground water of Wurno Local Government Area. Uranium activity concentration from 45 water samples collected from different locations in the study area were determined using HpGe detector, the result from the analysis was used to evaluate the annual effective dose due to ingestion of groundwater from the study area by the inhabitants. Radiological and chemical toxicity risks were also calculated. High level activity was reported in Diggim while low activity level was reported in Nassarawa-Dage. The annual effective doses for adult, children and infants were estimated to be from 0.008 mSv$^1$ to 0.32 mSv$^1$. The highest risk cancer mortality value was found at Diggim with a value of $4.34 \times 10^{-4}$ while the lowest value was observed at Nassarawa Daje with a value of $1.17 \times 10^{-5}$. Chemical toxicity value ranged from 0.59 – 21.79 µg.kg$^{-1}$.day$^{-1}$ with an average dose value of 5.12 µg.kg$^{-1}$.day$^{-1}$. The lifetime average daily dose (LADD) values were reported to be higher at Diggim and lower at Nassarawa-Dage with the values 21.79 µg.kg$^{-1}$.day$^{-1}$ and 0.59 µg.kg$^{-1}$.day$^{-1}$ respectively compared with 0.6 µg.kg$^{-1}$.day$^{-1}$ WHO limit standard. Significantly, the high activity level, and chemical toxicity risk reported from this study is an indication that the area may have developed some fractures of granitic strata in the subsurface geology that contributed to the wide distribution of radiation dose.

Keywords: Boreholes; Uranium; Inhabitants; Risk; Toxicity.

1. Introduction

Naturally occurring radionuclides materials (NORMs) found in the groundwater system varied from one location to another and exist mainly from rocks and minerals from which the water is in contact with (Maxwell and Wagiran, 2015). With emphasis on the use of groundwater, natural radioactivity has been examined widely in different parts of the world to assess the radiological risks to inhabitants (Benedik, et al., 2012). Naturally occurring radioactive materials explicitly accumulate in human body primarily through the intake of food and water or as part of advanced lifestyles (El-Gamal, et al., 2019), they are also in the air breathed by man (Tchokossa, et al., 2011). The danger of radioactivity to human can be due to prolonged exposure of the inhabitants from natural radionuclides like $^{238}\text{U}$ (Adekunle, et al., 2013). The contribution of drinking water as source of exposure to human is important to consider especially when the drinking-water supplies is drawn from ground water.

In Nigeria, groundwater is regarded as the most favored source of quality drinking water. Groundwater is cleaner and easy to treat when compared to the surface water. Consequently, lots of boreholes and wells have been dug everywhere especially in rural areas in order to get access to potable drinking water (Maxwell and Wagiran, 2015). Groundwater refers to collection of water in pores and fractures of soil and rocks below the water table. Water table is the level at which the water pressure equals the atmospheric pressure. (Ndontchung, et al., 2014). However, anthropogenic activities can contaminate groundwater in addition to its natural chemical components which can results to several health issues.

Uranium occur greatly in nature as part of the composite of granites and other mineral deposits (Boekhout, et al., 2015). One of the long-lived radionuclides, Uranium salt is the most soluble, and forms ions with oxidation states of +4 ($\text{UO}_2^{2+}$) and +6 ($\text{UO}_4^{2-}$)
Radiological and Toxicity Impact of Uranium \(^{238}\)U in Ground Water to Different Age Groups… Full paper

and \(U^{4+}\) and \(+6\) (\(UO_3\) and \(UO_2^{2+}\)). Approximately 99.3% of natural Uranium exist as \(^{238}\)U radionuclide with a half-life of about 4.5 billion years, its decay chain end with a stable nuclide referred to as lead-206. While the remaining isotopes consist of \(^{234}\)U 0.72%, \(^{235}\)U 0.0054%. (Missimer, et al., 2019). All isotopes of uranium decay by alpha and gamma emissions (Khattab, et al., 2017). Activity concentrations and chemical toxicity of Uranium in groundwater virtually depends on the subsurface geology, lithology, geomorphology, environmental conditions and several geological factors of the region (Jibiri, et al., 2021). Uranium exist in groundwater in dissolved form due to the existence of certain minerals such as uraninite, pitchblende, and cornalite as minor mineral in form of complexed oxide of silicate phosphate, lignite, validate, and monazite sands (Singh, et al., 2014).

Uranium in human body has effect to kidney, liver and other soft tissues. Many researchers (Abbasi and Mirekhtiar, 2019; Kurttio, et al., 2005, and Maxwell and Wagiran, 2015) have extensively studied these effects. Chemical concentration of uranium in groundwater based drinking water above recommended limit has been the genesis of pathological and radiological health effects in human body such as genetic damage reported in mammals (WHO, 2004). Uranium was known to be nephrotoxin as identified by WHO, (Kurttio, et al., 2005), which implies that Uranium is a naturally produced chemical which can result to kidney problem. Several investigations to assess the uranium concentration and different health impact has been carried out in groundwater. (Achuka, 2017) carried out radionuclide concentration in groundwater of Ogun state. (Missimer, et al., 2019). Assess the natural radiation in the rocks, soils, and groundwater of Southern Florida. Sufficient exposure to Uranium and it daughter product \(^{222}\)Rn can results to lung cancer. Uranium concentration in groundwater system is mostly less than 50 ppb. Although, aquifers found to contain uranium mineralization bearing formation at times display uranium concentration greater than 50 ppb (Missimer, et al., 2019). Many uncertainties as a result of particles recoil and chemical processes exist regarding the concentration of \(^{238}\)U.

Considering the risk of the presence of natural radionuclides in groundwater system due to internal exposure, there is need to assess the natural radioactivity levels in groundwater of all environent in order to protect members of the public against high radiation dose due to intake (Nguelem, et al., 2013). Assessment of Uranium in ground water is not known to have been carried out in this study area. The present work is to study the radiological concentration and chemical toxicity risks of \(^{238}\)U for three aged groups of the inhabitants that permanently depends on the groundwater for drinking in Wurno Local Government Area, Sokoto State.

1.1 Geography and Geology of the Study Area

The study area falls within the geographical location of Latitude 13° 17” 03” and Longitude 5° 25’ 39”. The study area is bounded to the north by Gwadabawa local government area, to the east by Goronyo local government area, to the south by Rabah local government area, and to the west by Kwame local government area. The climate of the study area is not different from the general climate of Sokoto State, which is hot and dry for most periods, of the year. The mean temperature for most parts in the state is about 37°C. The map of the study area is shown in Figure 1. Soil in the study area are mainly sandy soil, clayed subsoil, with alluvial soils predominating along the flood plains of the river valleys (Ayaji, 2016). The study area is located within the lullumened basin, which is surrounded by the Precambrian basement complex. The lulumemden basin of West Africa is a sedimentary basin, which extended from Mali and western boundary of Niger republic through northern Benin Republic and northwestern Nigeria. Its southwestern sector covers northwestern Nigeria where it is called the Sokoto Basin, a multi-layered semi confined to confined groundwater basin (Adelana and Olasehinde, 2006). Minerals found around the basement complex include limestone, gold, marble, clay, kaolin, feldspar, gypsum and lignite.

Figure 1: Map of the Sokoto State showing some geological feature

2. Methodology

2.1 Sampling Technique

The sampling technique used for this research work is the stratified random sampling. In this
research work, the study area was divided into 45 grids of 5.3km x 5.3km. Each grid according to the scale has an area of about 28.09 square kilometers. From each grid, one settlement was selected by simple random process. One sample was collected per grid, giving a total number of 45 samples.

Figure. 2: Stratified map of Wurno Local Government Area.

2.2 Sample Collection
Forty-five (45) groundwater samples from boreholes and dug wells were collected from the study area using the stratified random sampling techniques. The water samples were collected in the month of April to May 2019 towards end of dry season and the beginning of raining season. At each point of sample collection, several measures were observed to avoid contamination of the water samples. In the case of borehole water, the water was allowed to flow for at least 5min before taking the sample, to avoid collection of stagnant water from the borehole. A filter was used in collecting water sample from the hand dug wells to avoid passage of unnecessary particles into the water sample. One litre polyethylene gallon was used to collect the water sample from both boreholes and hand dug wells, about 1\% of the polyethylene gallon was left unfilled to allow for expansion, and 15 ml of dilute Nitric acid was immediately added to the water samples, this was made possible to prevent adsorption of the radionuclides on the walls of the container. The water samples were thoroughly sealed and labelled accordingly. A Global Positioning System (Model) GPS was used to take the reading for the coordinate and the elevation at each sample location and were recorded immediately. Thereafter, the samples were transported to National Institute for Radiation Research and Protection (NIRRP) University of Ibadan for preparation and analysis.

2.3 Sample Preparation
Water analysis was prepared in the laboratory at the National Institute of Radiation Protection and Research (NIRPR), University of Ibadan, Nigeria. The whole samples (forty-five samples) were left for twenty-eight days (28 days) at the sample preparation lab. to enable them attain secular equilibrium before counting.

2.4 Energy Calibration
The energy calibration of standard radionuclides of known activities and well-defined energies was carried out within the energy range from 60 KeV to 2000 KeV. The standard calibration was long enough counte to produce well defined photo peaks.

2.5 Efficiency Calibration
The efficiency of the detector is the ratio of the actual events registered by the detector to the total number of events emitted the source of radiation.

In this research work, the efficiency calibrations were performed by counting radionuclides of known activities with well-defined energies in the energy range of 60 KeV to 2000 KeV. The equation below was used to determine the efficiencies.

\[
\eta(\text{Eff}) = \frac{N_T - N_B}{P_E A_S t_s} \tag{2.1}
\]

Where, \(\eta(\text{Eff})\) is the efficiency of the detector, \(N_T\) is the net total under a photo peak, \(N_B\) is the background count of the detector, \(P_E\) is the probability of gamma emission for energy \(E\), \(A_S\) is the activity of the radionuclide in the calibration standard during calibration and \(t_A\) stands for the counting time.

2.6 Minimum Detectable Activity
This is an important concept in the determination of activity of a particular sample. Minimum detectable activity referred to the smallest amount of radioactivity that could be determined under certain conditions. The minimum detectable activities for the radionuclides of interest were computed using average peak areas at the gamma ray lines according to equation (3.2).

\[
M \text{DA} = \frac{\sigma B}{\eta P T W} \tag{2.2}
\]

Where, \(\sigma\) is the statistical coverage factor with value equal 1.645 (confidence level of 95 percent), \(B\) is the background for the region of interest of each radionuclide, \(P\) is the gamma emission probability (gamma yield) of each radionuclide, \(T\) is the counting time in second, \(W\) is the weight of the sample container and \(\eta\) is the detector efficiency for the measured gamma ray energy.
2.7 Activity Concentration of Radionuclides

$^{238}$U activity concentration was determined from 1001 keV gamma lines using equation (3.3).

$$A_C = \frac{C_n}{P_{\gamma} M \varepsilon} \quad (2.3)$$

where $A_C$ is the activity concentration of the radionuclide in the sample in Bq/L, $C_n$ is the net count under the corresponding peak, $P_{\gamma}$ is the absolute transition probability of the specific gamma ray, $M$ is the mass of the water sample (L) and $\varepsilon$ is the detector efficiency at the specific gamma ray energy.

2.8 Sample Analysis

The measurement of the radionuclides concentration of all the samples were done using a Camberre P-type High purity Germanium (HpGe) detector of length 69.8 mm and diameter of 78 mm with a relative efficiency of 80 %. The detector was enclosed in a lead shield of thickness 10 cm in order to reduce the interference due to background radiation from the surrounding with liquid nitrogen to serve as a cooling system. Complete electronics instrument was connected to a PC-based multichannel analyzer for gamma spectrum evaluation. The energy and efficiency calibration of the HpGe detector was performed using the 1.33 MeV gamma line of $^{60}$Co resulting to energy resolution of 2.3 KeV (FWHM) with a relative yield of 1.73%. Liquid nitrogen was used to enhance the detector operation at a very low temperature. Multi-channel analyser was installed to a personal computer that acquired the data. 500 ml Marinelli beaker was used to maintained fixed geometry for both the standard source and the samples. An amplifier which was utilized by the HpGe detector signal processing was incorporated in addition to an analogue-to-digital converter (ADC). The HpGe detector was automatically connected to a multi-channel analyser that was installed in a personal computer for acquiring data. $^{238}$U activity concentration was determined from 1001 keV gamma lines.

3 Result and Discussion

3.1 Activity Concentration

| N/So | Samples location | Elevation | Latitude | Longitude | $^{238}$ U |
|------|----------------|-----------|----------|-----------|------------|
| 1    | Ruga           | 284       | 5.35358  | 13.26011  | 5.15±0.84  |
| 2    | Kagar Rafi     | 253       | 5.37113  | 13.13139  | 0.53±0.15  |
| 3    | Gidan Modi     | 264       | 5.48925  | 13.30173  | 1.94±0.30  |
| 4    | Sisawa         | 301       | 5.34513  | 13.16647  | 2.42±0.32  |
| 5    | Gyal-Gyal      | 276       | 5.3573   | 13.12188  | 0.92±0.24  |
| 6    | Gidan Salihu   | 281       | 5.3533   | 13.24817  | 0.46±0.14  |
| 7    | Guntun Gida    | 310       | 5.39781  | 13.21568  | 3.19±0.36  |
| 8    | Achida         | 319       | 5.39636  | 13.16679  | 0.84±0.24  |
| 9    | Alkammu        | 307       | 5.37324  | 13.13633  | 2.25±0.33  |
| 10   | Kaurare        | 313       | 5.36822  | 13.12525  | 1.13±0.33  |
| 11   | Yar Wurno      | 251       | 5.66921  | 13.46919  | 0.33±0.12  |
| 12   | Dabagin Adakata| 314       | 5.36822  | 13.45219  | 2.66±0.46  |
| 13   | Sidingo        | 258       | 5.66875  | 13.42347  | 2.53±0.35  |
| 14   | Saketa         | 286       | 5.40655  | 13.20305  | 2.40±0.30  |
| 15   | Tudun Malami   | 307       | 5.40905  | 13.16269  | 3.01±0.42  |
| 16   | Suntubawa      | 301       | 5.52336  | 13.21386  | 0.58±0.11  |
| 17   | Gidan Kamba    | 298       | 5.57547  | 13.22852  | 3.41±0.51  |
| 18   | Danbiso        | 287       | 5.45836  | 13.32836  | 2.72±0.44  |
| 19   | Dabagin Yari   | 316       | 5.77552  | 13.44002  | 1.55±0.28  |
| 20   | Gidan Koro     | 325       | 5.75184  | 13.37283  | 1.43±0.23  |
| 21   | Munki          | 334       | 5.76002  | 13.33511  | 0.88±0.19  |
| 22   | Dabagin Bum    | 327       | 5.80176  | 13.39616  | 7.37±0.84  |
| 23   | Duhuwar        | 287       | 5.68975  | 13.36113  | 5.76±0.98  |
| 24   | Nasarawar Daje | 298       | 5.70891  | 13.39505  | 0.26±0.07  |
| 25   | Lugu           | 256       | 5.72475  | 13.45447  | 1.91±0.35  |
CaJoST 2022, 2, 190-202 © 2022 Faculty of Science, Sokoto State University, Sokoto. | 194

26  Dabagin Busau  328  5.76901  13.43811  2.56±0.39
27  Marnona  336  5.81882  13.35191  0.71±0.18
28  Sabon Birnin Daji  260  5.51252  13.27733  1.00±0.23
29  Sabon Garin Daji  298  5.49005  13.3278  0.69±0.16
30  Kawadata  289  5.50744  13.24263  2.59±0.36
31  Gidan Ardo  276  5.49294  13.29286  0.91±0.21
32  Chacho  286  5.45558  13.16683  1.02±0.18
33  Arba  260  5.55447  13.28641  5.75±1.19
34  Barayar Zaki  261  5.55611  13.29455  1.48±0.21
35  Gwarsu  262  5.58391  13.26697  0.93±0.18
36  Ragar Gizo  284  5.59013  13.31175  1.55±0.41
37  Kwardaba  279  5.5118  13.26705  3.03±0.35
38  Doron Sule  287  5.50955  13.25933  2.79±0.52
39  Sabon Galin Liman  268  5.61477  13.28766  0.58±0.11
40  Dinawa  336  5.42594  13.23433  1.05±0.26
41  Jodo  287  5.66094  13.29472  0.63±0.16
42  Jantsara  276  5.36927  13.12877  3.01±0.31
43  Laka  260  5.80083  13.28425  2.27±0.78
44  Digim  287  5.75638  13.28694  9.66±0.97
45  Kadagiwa  269  5.77005  13.27908  4.09±0.21

Table 1 displayed the activity concentration from the study area in Bq.L⁻¹. The activity concentration ranged from 0.26 ± 0.07 to 9.66 ± 0.97 Bq.L⁻¹, with an average value of 2.27±0.36. The activity concentration of ²³⁸U was found to be higher at Diggim with the value of 9.66 ± 0.97 Bq.L⁻¹, whereas, lowest value was reported at Nassarawar-Daje with 0.26 ± 0.07 Bq.L⁻¹. It can be observed from Table 1, and with reference to the adopted guidance level (GL) of 10.00 Bq.L⁻¹ for Uranium in drinking water (WHO, 2006) that activity concentration of ²³⁸U in some settlements are higher than other settlements, probably due to the variations in their depth and differences in the subsurface rocks geology. Difference in the geological formation is another factor responsible for the variations in the activity concentrations.

The study area exists within three geological formations, namely, Kalambaina formation, Dange formation and Rima group. Dange formation consist mainly shales separated by the calcareous. The Kalambaina formation consist of limestones and very rich in carbonate. Rima group consist of mudstones and friable sandstones separated by the fissilferous, calcareous and shaley (Obaje, 2013). The subsurface rock containing different elements can also be responsible for the variations in the activity concentration. The reason for higher activity concentration of ²³⁸U from Diggim is due to the geological features of the existing formation within the settlement (Rima group) which may contain elements responsible for the elevated radiation. Uranous state (+IV) deposit in the host aquifer-bearing rock that may also be responsible for high activity concentration. The lower activity concentration was found at Nassarawa-Daje which falls within Kalambaina formation. The activity concentration of ²³⁸U found in all the locations are below the recommended set limit by WHO.

The data in Table 1 was converted to µg.L⁻¹. According to WHO proposed provisional guideline, there is 15 µg L⁻¹ for every 0.19 Bq L⁻¹ (WHO, 2006, Maxwell, and Wagira, 2015). The result is shown in Table 2.

Table 2: Mass concentration of ²³⁸U in (µg.L⁻¹)

| S/N | Samples location | Activity Conc. (Bq L⁻¹) | ²³⁸U µgL⁻¹ |
|-----|-----------------|------------------------|------------|
| 1   | Ruga            | 5.15±0.84              | 406.579    |
| 2   | Kagar Rafi      | 0.53±0.15              | 41.842     |
| 3   | Gidan Modi      | 1.94±0.30              | 153.158    |
| 4   | Gidansawa       | 2.42±0.32              | 191.053    |
| 5   | Gyal-Gyal       | 0.92±0.24              | 72.632     |
| 6   | Gidan Salihu    | 0.46±0.14              | 36.316     |
| 7   | Gunun Gida      | 3.19±0.36              | 251.842    |
| 8   | Achida          | 0.84±0.24              | 66.316     |
| 9   | Alkamnu         | 2.25±0.33              | 177.632    |
| 10  | Kaurare         | 1.13±0.33              | 89.211     |
| 11  | Yar Wurno       | 0.33±0.12              | 26.053     |
| 12  | Dabagin Adakata | 2.66±0.46              | 210.00     |
Radiological and Toxicity Impact of Uranium ($^{238}\text{U}$) in Ground Water to Different Age Groups...

| Location         | Activity Concentration ($^{238}\text{U}$) Bq L$^{-1}$ | Annual Effective Dose (mSv y$^{-1}$) |
|------------------|--------------------------------------------------|-----------------------------------|
| Sidingo          | 2.53±0.35                                       | 199.736                           |
| Saketa           | 2.40±0.30                                       | 189.474                           |
| Malami           | 3.01±0.42                                       | 237.632                           |
| Suntubawa        | 0.58±0.11                                       | 45.789                            |
| Gidan Kamba      | 3.41±0.51                                       | 269.211                           |
| Danbiso          | 2.72±0.44                                       | 214.737                           |
| Dabagin Yari     | 1.55±0.28                                       | 122.369                           |
| Gidan Koro       | 1.43±0.23                                       | 112.895                           |
| Munki            | 0.88±0.19                                       | 69.474                            |
| Gidan Bum        | 7.37±0.84                                       | 581.842                           |
| Duhuwur Maranawa | 5.76±0.98                                       | 454.737                           |
| Nasarawar Daje   | 0.26±0.07                                       | 20.526                            |
| Lugu             | 1.91±0.35                                       | 150.789                           |
| Dabagin Busau    | 2.56±0.39                                       | 202.105                           |
| Marnona Sabon    | 0.71±0.18                                       | 56.053                            |
| Birnin Daji      | 1.00±0.23                                       | 89.211                            |
| Garin Daji       | 0.69±0.16                                       | 54.474                            |
| Kawadata         | 2.59±0.36                                       | 204.474                           |
| Gidan Ardo       | 0.91±0.21                                       | 71.842                            |
| Chacho           | 1.02±0.18                                       | 80.526                            |
| Arba             | 5.75±1.19                                       | 454.974                           |
| Barayar Zaki     | 1.48±0.21                                       | 116.842                           |
| Gawanunu Daje    | 0.93±0.18                                       | 73.421                            |
| Rgar Gizo        | 1.55±0.41                                       | 122.368                           |
| Kwardaba         | 3.03±0.35                                       | 239.211                           |
| Doron Sule       | 2.79±0.52                                       | 220.263                           |
| Sabon            | 0.58±0.11                                       | 45.789                            |
| Galin Liman      | 1.05±0.26                                       | 82.895                            |
| Dinawa           | 0.63±0.16                                       | 49.737                            |
| Jantsara         | 3.01±0.31                                       | 237.631                           |
| Laka             | 2.27±0.78                                       | 179.211                           |
| Digim            | 9.66±0.97                                       | 762.632                           |
| Kadagiwa         | 4.09±0.21                                       | 322.894                           |

**Minimum** 20.526  
**Maximum** 581.842  
**Mean** 179.053

[Figure 3. Activity concentration of $^{238}\text{U}$ in different location of Wurno Local Government Area.]

### 3.2 Annual Effective Dose from Daily Intake of $^{238}\text{U}$, from Water Samples.

The annual effective dose due to intake of $^{238}\text{U}$, was calculated taking into account the activity concentration (AC) of $^{238}\text{U}$ in Bq L$^{-1}$, the dose conversion factor (DC) of the radionuclides in question given in Sv.Bq$^{-1}$ and annual water consumption (AWC) rate for an average adult in L. The activity concentration of the radionuclides was earlier displayed in Table 1, the ingested dose conversion factors was taken to be $4.5 \times 10^{-8}$ for $^{238}\text{U}$ (ICRP, 2012).

$$\text{AED (mSv y}^{-1}) = \text{AC (Bq.L}^{-1}) \times \text{DC (Sv.Bq}^{-1}) \times \text{AWC (L y}^{-1})$$

Where AED is the annual effective dose (mSv y$^{-1}$), AC the activity concentration of the radionuclide (Bq.L$^{-1}$) in this study, DC the dose coefficient for $^{238}\text{U}$ in (Sv.Bq$^{-1}$) and AWC is the annual water consumption in litres per year.

Equation 4.0, was used to calculate the annual effective dose to an individual due to intake of natural radionuclide $^{238}\text{U}$ from all the Sampled water of the study area and was presented in Table 3. It can be observed from this table that $^{238}\text{U}$ shows lower values of AED. This may be due fact that $^{238}\text{U}$ has decayed to it daughter radionuclides and as such, little or no trace of it can be dictated. In addition, most of the areas that displayed higher value of $^{238}\text{U}$ are boreholes related samples with a depth much higher than the hand-dug wells probably, the $^{222}\text{Rn}$ content in the water may not have way to escape to the surrounding as compared to hand-dug where the $^{222}\text{Rn}$ content finds it easier to escape to the surrounding and consequently lower amount of $^{238}\text{U}$ was observed. The derived annual effective dose received by the inhabitants as a result of ingestion of $^{238}\text{U}$ in water is estimated to have a range of 0.008 mSv.y$^{-1}$ to 0.32 mSv.y$^{-1}$. Diggim displayed the highest value of the annual effective dose to an individual due to Uranium
(\(^{238}\)U) contribution to the tone of 0.32 mSv.y\(^{-1}\) which is higher than the recommended set limit of 0.1 mSv.y\(^{-1}\) and lowest value was reported in Nassarawar-Daje with a value of 0.008 mSv.y\(^{-1}\). Annual effective dose due to intake of \(^{238}\)U and \(^{226}\)Ra in ground water of Deidei, Kubwa, Gosa and Lugbe area of Abuja was found to be 8.9 \times 10^{-5} mSv.y\(^{-1}\), 2.8 \times 10^{-5} mSv.y\(^{-1}\), 1.5 \times 10^{-5} mSv.y\(^{-1}\) and 9.0 \times 10^{-5} mSv.y\(^{-1}\) (Maxwell and Wagiran, 2016). The values obtained by Maxwell and Wagiran (2016) were below the recommended value. According to ICPR 69 (Duggal, et al. 2019), Uranium and its daughter product Radium gets to the blood through the soft tissues and excretes in urine. It can be excreted in few months but the parents could be retained for years. The variation in the annual effective dose between this present study and the study carried out by Maxwell and Wagiran, (2016) could be due to the differences in the geological formations of the two different study areas.

Table 3: Annual effective dose due to \(^{238}\)U

| N/So | Samples location       | Adult (Sv.Bq\(^{-1}\) for \(^{238}\)U) | Children (Sv.Bq\(^{-1}\) for \(^{238}\)U) | Infants (Sv.Bq\(^{-1}\) for \(^{238}\)U) |
|------|------------------------|----------------------------------------|------------------------------------------|---------------------------------------|
| 1    | Ruga                   | 1.69E-04                               | 2.33E-04                                 | 1.60E-04                             |
| 2    | Kagar Rafi             | 1.74E-05                               | 2.39E-05                                 | 1.64E-05                             |
| 3    | Gidan Modi             | 6.37E-05                               | 8.76E-05                                 | 6.01E-05                             |
| 4    | Sisawa                 | 7.95E-05                               | 1.09E-04                                 | 7.50E-05                             |
| 5    | Gyal-Gyal              | 3.02E-05                               | 4.15E-05                                 | 2.85E-05                             |
| 6    | Gidan Salihu           | 1.51E-05                               | 2.08E-05                                 | 1.43E-05                             |
| 7    | Guntun Gida            | 1.05E-04                               | 1.44E-04                                 | 9.89E-05                             |
| 8    | Achida                 | 2.76E-05                               | 3.79E-05                                 | 2.60E-05                             |
| 9    | Alkammu                | 7.39E-05                               | 1.02E-04                                 | 6.98E-05                             |
| 10   | Kaurare                | 3.71E-05                               | 5.10E-05                                 | 3.50E-05                             |
| 11   | Yar Wurno Dangida      | 1.08E-05                               | 1.49E-05                                 | 1.02E-05                             |
| 12   | Dabagin Adakata        | 8.74E-05                               | 1.20E-04                                 | 8.25E-05                             |
| 13   | Sidingo                | 8.31E-05                               | 1.14E-04                                 | 7.84E-05                             |
| 14   | Saketa                 | 7.88E-05                               | 1.08E-04                                 | 7.44E-05                             |
| 15   | Tudun Malami           | 9.89E-05                               | 1.36E-04                                 | 9.33E-05                             |
| 16   | Suntubawa              | 1.91E-05                               | 2.62E-05                                 | 1.80E-05                             |
| 17   | Gidan Kamba            | 1.12E-04                               | 1.54E-04                                 | 1.06E-04                             |
| 18   | Danbiso                | 8.94E-05                               | 1.23E-04                                 | 8.43E-05                             |
| 19   | Dabagin Yari           | 5.09E-05                               | 7.00E-05                                 | 4.81E-05                             |
| 20   | Gidan Koro             | 4.70E-05                               | 6.46E-05                                 | 4.43E-05                             |
| 21   | Munki                  | 2.89E-05                               | 3.97E-05                                 | 2.73E-05                             |
| 22   | Dabagin Bum            | 2.42E-04                               | 3.33E-04                                 | 2.28E-04                             |
| 23   | Duhuwar Maranawa       | 1.89E-04                               | 2.60E-04                                 | 1.79E-04                             |
| 24   | Nasarawar Daje         | 8.54E-06                               | 1.17E-05                                 | 8.06E-06                             |
| 25   | Lugu                   | 6.27E-05                               | 8.62E-05                                 | 5.92E-05                             |
| 26   | Dabagin Busau          | 8.41E-05                               | 1.16E-04                                 | 7.94E-05                             |
| 27   | Marnona                | 2.33E-05                               | 3.21E-05                                 | 2.20E-05                             |
| 28   | Sabon Birnin Daji      | 3.71E-05                               | 5.10E-05                                 | 3.50E-05                             |
| 29   | Sabon Garin Daji       | 2.27E-05                               | 3.12E-05                                 | 2.14E-05                             |
| 30   | Kawadata               | 8.51E-05                               | 1.17E-04                                 | 8.03E-05                             |
| 31   | Gidan Ardo             | 2.99E-05                               | 4.11E-05                                 | 2.82E-05                             |
| 32   | Chacho                 | 3.35E-05                               | 4.61E-05                                 | 3.16E-05                             |
| 33   | Arba                   | 1.89E-04                               | 2.60E-04                                 | 1.78E-04                             |
Also the annual effective dose according to three different age groups (> 17 (adults), 2 – 17 (Children) and 0 – 2 (Infants) years) was calculated. The annual effective dose for Adult members (> 17 years) ranges from 0.008 mSv\(^{-1}\) – 0.32 mSv\(^{-1}\) with an average value of 0.074 mSv\(^{-1}\). Annual effective dose for children (2-17 years) ranged from 0.012 mSv\(^{-1}\) – 0.44 mSv\(^{-1}\) with an average value of 0.1 mSv\(^{-1}\). The annual effective dose for Infants (0-2 years) ranged from 0.0081 mSv\(^{-1}\) – 0.29 mSv\(^{-1}\) with an average value of 0.07 mSv\(^{-1}\). It can be observed from the Table 3 that children are at highest risk followed by Adult, then Infants. The highest annual effective was found in children, could be attributed to the metabolic activity and the amount of water intake for the children. The result of the annual effective dose from this study was compared with results from other studies done elsewhere. Achuka, 2017, estimated the annual effective dose for six age groups. Her result reveal high annual effective from age group 12-17 yrs. Patra, et al., 2013, estimated an annual effective dose for Adult, Children, and Infants. His result displayed high annual effective dose to have emanate from children.

### 3.3 Radiological Assessment of \(^{238}\text{U}\) from Groundwater of the Study Area.

The aim of the radiological risk assessment in this present study is to estimate the life time cancer risk due to ingestion of \(^{238}\text{U}\) in drinking water of the study area. The lifetime cancer risks (R), associated with the intake of a given radionuclide, was estimated from the product of the applicable risk coefficient \(r\) and the per capita activity intake \(I\) expressed as follows (Maxwell and Wagiran 2015).

\[
R = r \times I
\]

\[3.2\]

Where, \(R\) is the lifetime cancer risks associated with intake of uranium and radium in ground water; \(r\) is cancer risk coefficient; and \(I\) is the per capital activity intake. The per capital activity intake (I) is the product of activity concentration in Bq.L\(^{-1}\) and lifetime intake of water and was calculated for \(^{238}\text{U}\). The cancer mortality and morbidity risks for only the age group > 17 was considered. The average life expectancy in Nigeria was estimated to be 54.5 years according to the world health organisation (WHO), and annual consumption of water for an average adult is about 730 L year\(^{-1}\), which result to a total of 39,785 L for an estimated lifetime water intake. The cancer risk coefficients (\(r\)) of \(^{238}\text{U}\) is 1.13 \(\times\) 10\(^{-5}\) Bq\(^{-1}\) for mortality and 1.73 \(\times\) 10\(^{-8}\) Bq\(^{-1}\) for morbidity (USEPA 1999, UNSCEAR 2000). Equation 4.2 was used to calculate cancer mortality and morbidity risks and the results were presented in Table 4.

From Table 4, it can be observed that \(^{238}\text{U}\) cancer mortality risk spanned from 1.17 \(\times\) 10\(^{-5}\) – 4.34 \(\times\) 10\(^{-4}\), while cancer morbidity risk spanned from 1.79 \(\times\) 10\(^{-5}\) – 6.65 \(\times\) 10\(^{-4}\). Their mean values were found to be 1.02 \(\times\) 10\(^{-4}\) and 1.56 \(\times\) 10\(^{-4}\) for mortality and morbidity respectively. The highest mortality value was found at Digigim with a value of 4.34 \(\times\) 10\(^{-4}\) while lowest value was observed at Nassarawa Daje with a value of 1.17 \(\times\) 10\(^{-5}\). The highest cancer morbidity value was reported at the same Digigim town with a value of 6.65 \(\times\) 10\(^{-4}\) and lowest cancer morbidity value was reported at Nassarawa Daje with a value 1.79 \(\times\) 10\(^{-5}\). In contrast with a study reported by Achuka, (Achuka, 2017) in Ogun state, Nigeria, the mean cancer mortality value of 1.02 \(\times\) 10\(^{-4}\) which is from this study, is lower than 10.70 \(\times\) 10\(^{-5}\) value obtained by Achuka with a factor of 5 \(\times\) 10\(^{-6}\). For cancer morbidity value, the value, 1.56 \(\times\) 10\(^{-4}\) from this study was lower than 16.40 \(\times\) 10\(^{-5}\) value obtained with a factor of 8 \(\times\) 10\(^{-6}\). When
the near surface since the subsurface geology allows the fast downward transfer of water sources from the source can be the major factors responsible for the high radiation dose which results to elevated cancer mortality and morbidity values.

Table 4: Lifetime cancer risks mortality and morbidity for 238U

| S/N | Samples location | 238U (Mortality) | 238U (Morbidity) |
|-----|------------------|-----------------|-----------------|
| 1   | Ruga             | 2.32E-04        | 3.54E-04        |
| 2   | Kagar Rafi       | 2.38E-05        | 3.65E-05        |
| 3   | Gidan Modu       | 8.72E-05        | 1.34E-04        |
| 4   | Sisawa           | 1.09E-04        | 1.67E-04        |
| 5   | Gyal-Gyal        | 4.14E-05        | 6.33E-05        |
| 6   | Gidan Salihu     | 2.07E-05        | 3.17E-05        |
| 7   | Gunton Gida      | 1.43E-04        | 2.20E-04        |
| 8   | Achida           | 3.78E-05        | 5.78E-05        |
| 9   | Alkammu          | 1.01E-04        | 1.55E-04        |
| 10  | Kaurare          | 5.08E-05        | 7.78E-05        |
| 11  | Yar Wurro        | 1.48E-05        | 2.27E-05        |
| 12  | Dabagin          | 1.20E-04        | 1.83E-04        |
| 13  | Adakata          | 1.14E-04        | 1.74E-04        |
| 14  | Sidingo          | 1.08E-04        | 1.65E-04        |
| 15  | Tudun Malami     | 1.35E-04        | 2.07E-04        |
| 16  | Suntubawa        | 2.61E-05        | 3.99E-05        |
| 17  | Gidan Kamba      | 1.53E-04        | 2.35E-04        |
| 18  | Danbiso          | 1.22E-04        | 1.87E-04        |
| 19  | Dabagin Yari     | 6.97E-05        | 1.07E-04        |
| 20  | Gidan Koro       | 6.43E-05        | 9.84E-05        |
| 21  | Munki            | 3.96E-05        | 6.06E-05        |
| 22  | Dabagin Bum      | 3.31E-04        | 5.07E-04        |
| 23  | Duhuwara         | 2.59E-04        | 3.96E-04        |

24 Nasarawar Daje 1.17E-05 1.79E-05
25 Lugu 8.59E-05 1.31E-04
26 Dabagin Busau 1.15E-04 1.76E-04
27 Marnona 3.19E-05 4.89E-05
28 Sabon Birnin Daji 5.08E-05 7.78E-05
29 Sabon Garin Daji 3.10E-05 4.75E-05
30 Kawadata 1.16E-04 1.78E-04
31 Gidan Ardo 4.09E-05 6.26E-05
32 Chacho 4.59E-05 7.02E-05
33 Arba 2.59E-04 3.96E-04
34 Barayar Zaki 6.65E-05 1.02E-04
35 Gawasu 4.18E-05 6.40E-05
36 Ragas Gizo 6.97E-05 1.07E-04
37 Kwardaba 1.36E-04 2.09E-04
38 Doron Sule 1.25E-04 1.92E-04
39 Sabon Gamin Liman 2.61E-05 3.99E-05
40 Dinawa 4.72E-05 7.23E-05
41 Jodo 2.83E-05 4.34E-05
42 Jantsara 1.35E-04 2.07E-04
43 Laka 1.02E-04 1.56E-04
44 Digim 4.34E-04 6.65E-04
45 Kadagiwa 1.84E-04 2.82E-04
Minimum 1.17E-05 1.79E-05
Maximum 4.34E-04 6.65E-04
Mean value 1.02E-04 1.56E-04

3.4 Chemical toxicity risk assessment of 238U in groundwater samples of the study area

In order to determine the effects of the non-carcinogenic risks the chemical toxicity risk associated with groundwater (borehole and well) containing levels of Uranium was evaluated. The analysis was done using Hyper Pure Germanium (HPGe) detector to obtained the activity concentration of individual radionuclides and the result from gamma-ray spectrometer given in Bq L⁻¹ was converted to µg L⁻¹ to obtained the concentration (Maxwell and Wagiran, 2015).

The chemical toxicity risk was evaluated using the lifetime average daily dose (LADD) of Uranium (238U). Equation 3.3 was used.

Ingestion LADD of drinking water = \( \frac{EPC \times IR \times EF \times ED}{AT \times BW} \)

3.3

Where LADD is the lifetime average daily dose (µg kg⁻¹ day⁻¹), EPC is the exposure point concentration (µg L⁻¹), IR is the water ingestion rate (L day⁻¹), EF is the exposure frequency.
Radiological and Toxicity Impact of Uranium (\(^{238}\text{U}\)) in Ground Water to Different Age Groups…

Therefore, using IR = 2L day\(^{-1}\), for an average adult, EF = 365 days, and ED = 54.5 years (WHO, 2006), AT = 19,892.5 \((\text{days})\) and BW = 70 kg according to USEPA, weight of a standard value for man. The chemical toxicity risk for uranium over lifetime consumption of groundwater (borehole and well) from the study area was estimated and presented in Table 5.

The chemical toxicity dose ranged from 0.59 – 21.79 µg.kg\(^{-1}\).day\(^{-1}\) with an average dose value of 5.12 µg.kg\(^{-1}\).day\(^{-1}\). The LADD values was reported to be higher at Diggim and lower at Nassarawa-Daje with the values 21.79 µg.kg\(^{-1}\).day\(^{-1}\) and 0.59 µg.kg\(^{-1}\).day\(^{-1}\) respectively. The higher LADD dose value reported at Diggim could be due to the subsurface geochemistry which contains rocks of high density cracks and fractures that serves as source rocks to the water bearing formation caused by tectonic event of Pan-African Orogeny. Later on magmatic and metamorphic processes of granitic intrusions and it interconnectivity with geochemistry and aquifer bearing formation yield in the existence of uranium bearing rocks from the deep-seated source (Maxwell and Wagiran, 2015). The lower LADD reported from Nassarawa-Daje could be due to absence of the uranium bearing rocks. Comparing the LADD obtained in this study and the RFD (0.6 µg.kg\(^{-1}\).day\(^{-1}\)) (WHO, 2006) the chemical toxicity risk due to \(^{238}\text{U}\) in the water samples were all above the RFD. This shows that there may be health risks associated with chemical toxicity rather than radiological factor.

**Table 5:** Lifetime average daily dose due to \(^{238}\text{U}\) in groundwater of the study area.

| S/N | Sample location      | \(^{238}\text{U}\) (LADD) |
|-----|----------------------|--------------------------|
| 1   | Ruga                 | 11.617                   |
| 2   | Kagar Rafi           | 1.195                    |
| 3   | Gidan Modii          | 4.376                    |
| 4   | Sisawa               | 5.459                    |
| 5   | Gyal-Gyal            | 2.075                    |
| 6   | Gidan Salihu         | 1.038                    |
| 7   | Gun tun Gida         | 7.195                    |
| 8   | Achida               | 1.895                    |
| 9   | Alkammu              | 5.075                    |
| 10  | Kaurare              | 2.549                    |
| 11  | Yar Wurno Dan gida   | 0.744                    |
| 12  | Dabagin Adakata      | 6                        |
| 13  | Sidingo              | 5.707                    |
| 14  | Saketa               | 5.414                    |
| 15  | Tudun Malami         | 6.789                    |
| 16  | Suntubawa            | 1.308                    |
| 17  | Gidan Kamba          | 7.692                    |
| 18  | Danbiso              | 6.135                    |
| 19  | Dabagin Yari         | 3.496                    |
| 20  | Gidan Koro           | 3.226                    |
| 21  | Munki                | 1.984                    |
| 22  | Dabagin Burn         | 16.624                   |
| 23  | Duhuwar Maranawa     | 12.992                   |
| 24  | Nassarawar Daje      | 0.586                    |
| 25  | Lugu                 | 4.308                    |
| 26  | Dabagin Busau        | 5.774                    |
| 27  | Marnona              | 1.602                    |
| 28  | Sabon Birnin Daji    | 2.549                    |
| 29  | Sabon Garin Daji     | 1.556                    |
| 30  | Kawadada             | 5.842                    |
| 31  | Gidan Ardo           | 2.053                    |
| 32  | Chacho               | 2.301                    |
| 33  | Arba                 | 12.969                   |
| 34  | Barayar Zaki         | 3.338                    |
| 35  | Gawasu               | 2.097                    |
| 36  | Ragur Gizo           | 3.496                    |
| 37  | Kwardaba             | 6.834                    |
| 38  | Doron Sule           | 6.293                    |
| 39  | Sabon Garin Liman    | 1.308                    |
| 40  | Dinawa               | 2.368                    |
| 41  | Jodo                 | 1.421                    |
| 42  | Jantsara             | 6.789                    |
| 43  | Laka                 | 5.120                    |
| 44  | Diggim               | 21.789                   |
| 45  | Kadagiwa             | 9.225                    |

Minimum 0.586  
Maximum 21.789  
Average 5.116

**Figure 4.** Lifetime average daily dose due to \(^{238}\text{U}\) in groundwater

### 3.4 Estimation of hazard quotient of \(^{238}\text{U}\) in groundwater samples of the study area

The hazard quotient due to ingestion of the radionuclides of interest from the study area was
estimated in order to ascertain the adverse health effects expected from exposure. The hazard quotient is the ratio of the lifetime average daily dose (LADD) and the set limit through which no adverse effects are expected. According to United State Environmental Protection Agency EPA, 2000, if the hazard quotient from ingestion of water containing radionuclides concentration is not above 1, then no adverse health effects is expected. The hazard quotient cannot be translated to be a probability that adverse health effects will occur, and is unlikely to be proportional to risk. Most importantly, it is wise to note that a hazard quotient more than unity does not guaranty adverse health effects. equation 4 was utilized for the calculation. (Maxwell and Wagiran, 2015) and result was presented in Table 5. From Table 5, the hazard quotient was reported to be high in almost all the 45 water samples. Only two settlements were reported to have value within the international organization standard value of <1 (UNSCEAR, 2000).

Hazard quotient = \( \frac{\text{LADD}}{\text{RFD}} \)

Table 6: Hazard quotient due to \(^{238}\text{U}\)

| S/N | Sample Location | \(^{238}\text{U}\) Hazard Quotient |
|-----|-----------------|----------------------------------|
| 1   | Ruga            | 19.3609                          |
| 2   | Kagar Rafi      | 1.9924                           |
| 3   | Gidan Moda      | 7.2932                           |
| 4   | Sisawa          | 9.0977                           |
| 5   | Gyal-Gyal       | 3.4586                           |
| 6   | Gidan Salihu    | 1.7293                           |
| 7   | Gunten Gida     | 11.9924                          |
| 8   | Achida          | 3.1578                           |
| 9   | Alkammu         | 8.4586                           |
| 10  | Kaurare         | 4.2481                           |
| 11  | Yar Wurra       | 1.2406                           |
| 12  | Dabagin         | 10.0000                          |
| 13  | Adakata         | 9.5112                           |
| 14  | Sidingo         | 9.0225                           |
| 15  | Tudun Malami    | 11.3157                          |
| 16  | Suntubawa       | 2.1804                           |
| 17  | Gidan Kamba     | 12.8195                          |
| 18  | Danbiso         | 10.2255                          |
| 19  | Dabagin Yari    | 5.8270                           |
| 20  | Gidan Koro      | 5.3759                           |
| 21  | Munku           | 3.3082                           |
| 22  | Dabagin Bum     | 27.7066                          |
| 23  | Duhuwar         | 21.6541                          |
| 24  | Maranawa        |                                  |
| 25  | Dage            | 0.9774                           |
| 26  | Lugu            | 7.1805                           |
| 27  | Dabagin Busau   | 9.6241                           |
| 28  | Marmona         | 2.6692                           |
| 29  | Sabon Garin Daji| 2.5940                           |
| 30  | Kawadata        | 9.7368                           |
| 31  | Gidan Ardo      | 3.4211                           |
| 32  | Chacho          | 3.8346                           |
| 33  | Arba            | 21.6165                          |
| 34  | Barayar Zaki    | 5.5639                           |
| 35  | Gawasu          | 3.4962                           |
| 36  | Ragar Gizo      | 5.8270                           |
| 37  | Kwardaba        | 11.3909                          |
| 38  | Doron Sule      | 10.4887                          |
| 39  | Sabon Garin     | 2.1804                           |
| 40  | Liman           | 3.9473                           |
| 41  | Jodo            | 2.3684                           |
| 42  | Jantsara        | 11.3158                          |
| 43  | Laka            | 8.5338                           |
| 44  | Diggin          | 36.3157                          |
| 45  | Kadagiwa        | 15.3759                          |

Minimum 0.977

Maximum 36.315

Average 8.526

Figure 5. Showing \(^{238}\text{U}\) hazard quotient in different location of the study area

4. Conclusion

In this present study, the variation of radioactivity content was observed from the study area. This may probably due to the variations in the depth of the boreholes and wells which allows the \(^{222}\text{Rn}\) concentration to easily escape from wells than in boreholes. The estimated annual effective doses for the groups Adult, children and infants ranged from 0.008 mSv.y\(^{-1}\) – 0.32 mSv.y\(^{-1}\) with an average value of 0.074 mSv.y\(^{-1}\), 0.012 – 0.44 mSv.y\(^{-1}\) with an average value of 0.1 mSv.y\(^{-1}\) and 0.0081 – 0.29 mSv.y\(^{-1}\) with an average value of 0.07 mSv.y\(^{-1}\) respectively. The highest annual effective was found in children could be attributed to the metabolic activity and the amount of water intake for the children. Radiological risks found within the study area for \(^{238}\text{U}\) ranged 1.17 \(\times\) \(10^{-5}\) – 4.34 \(\times\) \(10^{-4}\) with an average value of 1.02 \(\times\) \(10^{-4}\) for mortality and 1.79 \(\times\) \(10^{-5}\) – 6.65 \(\times\) \(10^{-4}\) with an average value of

**CaJoST, 2022, 2, 190-202** © 2022 Faculty of Science, Sokoto State University, Sokoto.
1.56 \times 10^{-4}. The value exceeded the set limit of 10^{-3} (USEPA, 1999) in almost all the locations. Mining and tectonic activity that were taking place in the study that enable water to trap at the near surface from the source can be the major factors responsible for the high radiation dose. The chemical toxicity risk due to $^{238}\text{U}$ exceeded the set limit of (0.6 μg·kg^{-1}·day^{-1}). This shows that there may be health risks associated with $^{238}\text{U}$ in the water samples. The hazard quotient in 43 settlements exceeded the international standard of < 1. The only two locations Yar-Wurno Dangida and Nassarawar-Daje have value within the set limit. However, this study has been created a fingerprint of the groundwater and the results can be used in determining the source of high radiation dose in Wurno Local Government. It is therefore, recommended that chemical toxicity risk (non-carcinogenic) pollution may be the major source of health risk and the groundwater in Wurno Local Government should be treated before consumption to minimized the possible health risk. Concurrently, quality protection and monitoring should be adopted.

Acknowledgements

The authors would like to thank the Department of Physics, Usmanu Danfodiyo University, Sokoto. The authors unmeasurably acknowledge the National Institute for Radiation Protection and Research (NIRPR) University of Ibadan, Nigeria.

Conflict of Interest

The authors declare that there is no conflict of interest.

References

Abbasi, A., & Mirekhtiary, F. (2019). Lifetime risk assessment of Radium-226 in drinking water samples. *International Journal of Radiation Research*, 17(1), 163-170. DOI: 10.18869/acadpub.ijrr.17.1.163

Achuka, J. A., Rachael, U. M., & David, O. K. (2017). Radiological risks assessment of Ogun state drinking water. *American Journal of Applied Sciences*, 14(5), 540-550. DOI: 10.3844/ajassp.2017.540.550.

Adekunle, A. A., Badejo, A. O., & Oyerinde, A. O. (2013). Pollution studies on groundwater contamination: Water quality of Abeokuta, Ogun State, South West Nigeria. *J. Environ. Earth Sci.*, 3, 161-166. ISSN: 2224-3216 (Paper) ISSN: 2225-0948 (Online)

Adelana, S. M. A., Olasehinde, P. I., & Vrakka, P. (2006). A quantitative estimation of groundwater recharge in parts of Sokoto Basin, Nigeria. *Journal of Environmental Hydrology*, 14, 1-17. DOI: cloudfront.net/35174238/JEH.

Ajayi, O. (2016). Flood Inundation mapping using remote sensing and GIS techniques: A case study of sokoto plain, Nigeria. A thesis submitted to the School of Environment, Flinders University of South Australia. Pp.22. DOI: flinders.edu.au/file/25729d2-e62c-48f0-b55f-d07f86e673e1/1.

Benedik, L., & Jeran, Z. (2012). Radiological of natural and mineral drinking waters in Slovenia. *Radiation Protection Dosimetry*, 151, 306–313. DOI: 10.1093/rdp/ncs009.

Boekhout, F., Gerard, M., Kanzari, A., Michel, A., Dejeant, A., Galoisy, L., Galas, G., & Descostes, M. (2015). Uranium migration and retention during weathering of a granitic waste rock pile. *Applied Geochemistry*, 58, 123-135. DOI.org/10.1016/j.apgeochem.2015.02.012

Duggal, V., Sharma, S., & Mehra, R. (2019). Risk assessment of radon in drinking water in Khetro copper belt of Rajasthan, India. *Chemosphere*. 239. https://doi.org/10.1016/j.chemosphere.2019.124782.

El-Gamal, H., Safelnasr, A., & Salaheldin, G. (2019). Determination of natural radionuclides for water resources on the west bank of the Nile River, Assiut Governorate, Egypt. *MDPI*, 11(2), 311. https://doi.org/10.3390/w11020311

ICRP. (2012). Age dependent doses to members of the public from intake of radionuclides. Part 4: ingestion dose coefficients. Oxford: Pergampm Press; (Annals of the ICRP, ICRP publication 69). https://doi.org/10.1016/S0146-6453(00)80008-1

ICRP. (2012). Annals of the ICRP: ICRP publication 119: Compendium of dose coefficient based on ICRP publication. ICRP, 42, 71-86. https://doi.org/10.1016/j.icrp.2012.06.038.

Jibiri, N. N., & Eke, B. C. (2021). Radionuclide contents in yam samples and health risks assessment in Osogbo oil producing locality, Imo state, Nigeria. *International Journal Phys. Res. Appl.* (4), 006-014. https://doi.org/10.29328/journal.ipra.100103

Khattab, R. M., Tuovinen, H., Lehto, E. I., & El-Assay, E. I., & El-Feky, G. M. (2017). Determination of uranium in Egyptian granitie ore by gamma, alpha, and mass spectrometry. *Instrumentation Science & Technology*, 45(3), 338-348. https://doi.org/10.1080/10739149.2016.1242078

Kurtto, P., Komulainen, H., Leino, A., Salonen, L., Auvinen, A., Saha, H. (2005). Bone as a possible target of chemical toxicity of natural uranium in drinking water. *Environ Health Perspectives*...
Maxwell, O., Wagiran, H., Lee, S. K., Embong, Z, & Ugwooke, P. E. (2015). Radioactivity level and toxic elemental concentration in groundwater at Dei-Dei and Kubwa areas of Abuja, North Central Nigeria. *Journal of Radiation Physics and Chemistry*. 107, 23-30. https://doi.org/10.1016/j.radphyschem.2014.09.003.

Missimer, T. M., Teaf, C., Maliva, G. R., Thomson, A. D., & Covert, D. (2019). Natural radiation in the rocks, soils, and groundwater of Southern Florida with a discussion on potential health impacts. *International Journal of Environmental Research and Public Health*. 16 (1793), 1-22. https://doi.org/10.3390/ijerph16101793.

Ndontchueng, M. M., Simo, A., Nguelem, E. J. M., Beyala, J. F., & Kryeziu, D. (2014). Preliminary study of natural radioactivity and radiological risk assessment in some mineral bottled water produced in Cameroon. *International Journal of Science*, 2 (3), 271-276. DOI: 10.4236/jamp.2021.97095.

Nguelem, E., Ndongchueng, M., Darko, E, & Schandof, C. (2013). Assessment of naturally radioactive level in groundwater from selected areas in Accra Metropolis 1. *Research Journal of Environmental and Earth Sciences*, 5(2), 85-93. ISSN: 2041-0484; e-ISSN: 2041-0492.

Obaje, O., Aduku, M., & Yusuf, I. (2013). The Sokoto basin of Northwestern Nigeria: A preliminary assessment of the hydrocarbon prospectivity. *Petroleum Technology Development Journal*. 3 (2), 66-80. DOI: www.researchgate.net/profile/Yusuf-Ishaq/publication/322978396.

Patra, A. C., Mohapatra, S., Sahoo, S. K., Lenka, P., Dubey, J. S., Tripathi, R. M., & Puranik, V. D. (2013). Age dependent dose and health risk due to intake of uranium in drinking water from Jaduguda, India. *Radiation Protection Dosimetry*, 155 (2): 210-216. https://doi.org/10.1093/rpd/ncs328.

Singh, B., Kataria, N., Garg, V. K., Yadav, P., & Kishore, N. (2014). Uranium quantification in groundwater and health risk from its ingestion in Haryana, India. *Toxicological & Environmental Chemistry*, 96(10), 1571-1580.