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Radiological and chemical toxicity risks of uranium in groundwater based-drinking at Immigration Headquarters Gosa and Federal Housing Lugbe area of Abuja, North Central Nigeria

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Abstract Inadequate public water supply by the Water Board in Abuja has forced the public to source for groundwater as the only alternative for consumption without consideration for radiological risk. The radiological risk for cancer mortality of uranium in Immigration Headquarters Gosa and Federal-Housing Lugbe groundwater water samples were measured and compared with Water Board and hand-dug well water samples from the same area using inductively coupled plasma mass spectrometry. The highest radiological risks for cancer mortality and morbidity were found to be low, with highest values of 1.24×10^{-7} and 1.64×10^{-7} obtained from Federal-Housing Lugbe borehole. The chemical toxicity risk of ^{238}U in drinking water over life time consumption has a mean value of 4.0×10^{-4} μg kg^{-1} day^{-1} with highest value of 6.0×10^{-3} μg kg^{-1} day^{-1} obtained from Federal-Housing Lugbe. Significantly, this study inferred that the ^{238}U concentrations reported in groundwater based-drinking originated from sheared zone of magmatic metamorphosed basaltic dyke intrusion. Due to the low risk values found in the water samples when compared with the International Reference Standard, radiological and chemical toxicity risks values may not pose any health risk to the public that rely on groundwater in the area.

Keywords Abuja · Toxicity risk · Radiological risk · Uranium isotope · Drinking water · Groundwater

Introduction

The toxicity that is introduced to the human body system by the ingestion of uranium through drinking water in the range of 0.004–9 μg L^{-1} per average body weight per day may produce interference with kidney functions. In more recent studies on humans, nephrotoxic effects of uranium in drinking water were found even for low concentrations without clear threshold [1]. Uranium level in groundwater has been reported in Canada to between 2 and 781 μg L^{-1} especially for wells drilled privately [2]. Elevated level of uranium in

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groundwater have also been reported to be above 30 μg L^{-1} in Bangladesh, India, China, Korea, Switzerland, Sweden, Finland, US, Vietnam and Cambodia and Nigeria and its chronically health effect which include toxicity to bones as a result of alpha radiation and damage in kidney [3–12]. It has been established that uranium, the product of radioactive material has contributed significantly to radioactivity of the surroundings which suitably determined the reliablity of groundwater for consumption purposes [13]. Most results of studies on uranium in drinking water suggest that the safe concentration of uranium in drinking water may be within the range guide line values of 2–30 μg L^{-1} [14, 15].

Natural occurring radium has been observed at high activity level in groundwater from two reasonable deep aquifers underlying northern Illinoise used for public water supply and was attributed to the dissolution of aquifer bearing rocks, desorption from the sediment surfaces and ejection of minerals from decay series of radioactive materials in the bedrock [15, 16]. The radiological and chemical toxicity of uranium in groundwater and the associated health risks calls for attention. It is on this basis that the present study was conducted in order to determine the cancer risk associated to the public that rely solely on groundwater. The study was carried out in Gosa and Lugbe area of Abuja, North Central Nigeria. The location of the boreholes drilled for this present study area has the geographical coordinates that lies within the latitudes 8°56′41.4′N and longitudes 7°14.2″22.6′E for Immigration-Headquarters Gosa and latitudes 8°58′2.3″N and longitudes 7°21′5.4′E for Federal-Housing Lugbe borehole.

Material and method

Geology of the study area

The study area is located within the crystalline basement of Nigeria. The dominant rock units in the area comprise mainly of migmatitic and granitic gneisses, granites, granodiorites and amphibolites (Fig. 1). The detailed geology and hydrogeology of the study area was reported elsewhere [17, 18]. The drilling point coordinates at Immigration-Headquarters Gosa lies within the latitudes 8°56′41.4′N and longitudes 7°14.2″22.6′E and latitudes 8°58′2.3″N and

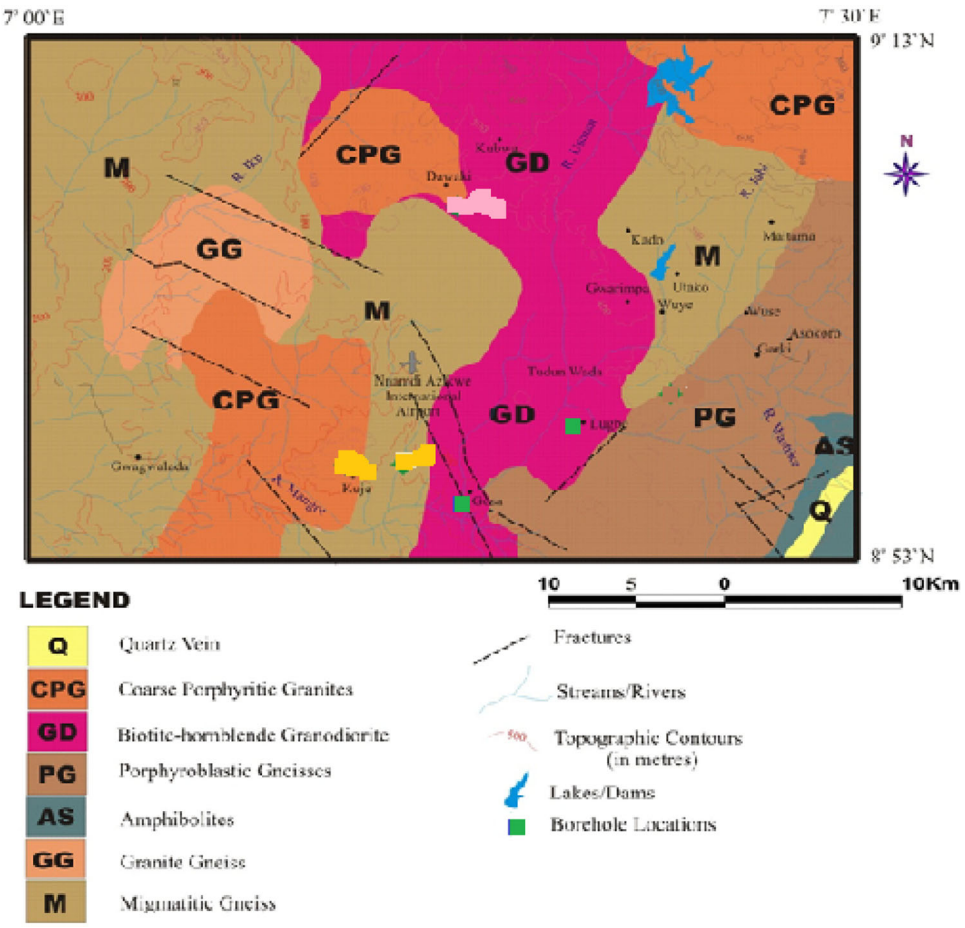

Fig. 1 Geologic map of the study area with *green dots* showing the borehole points. (Color figure online)

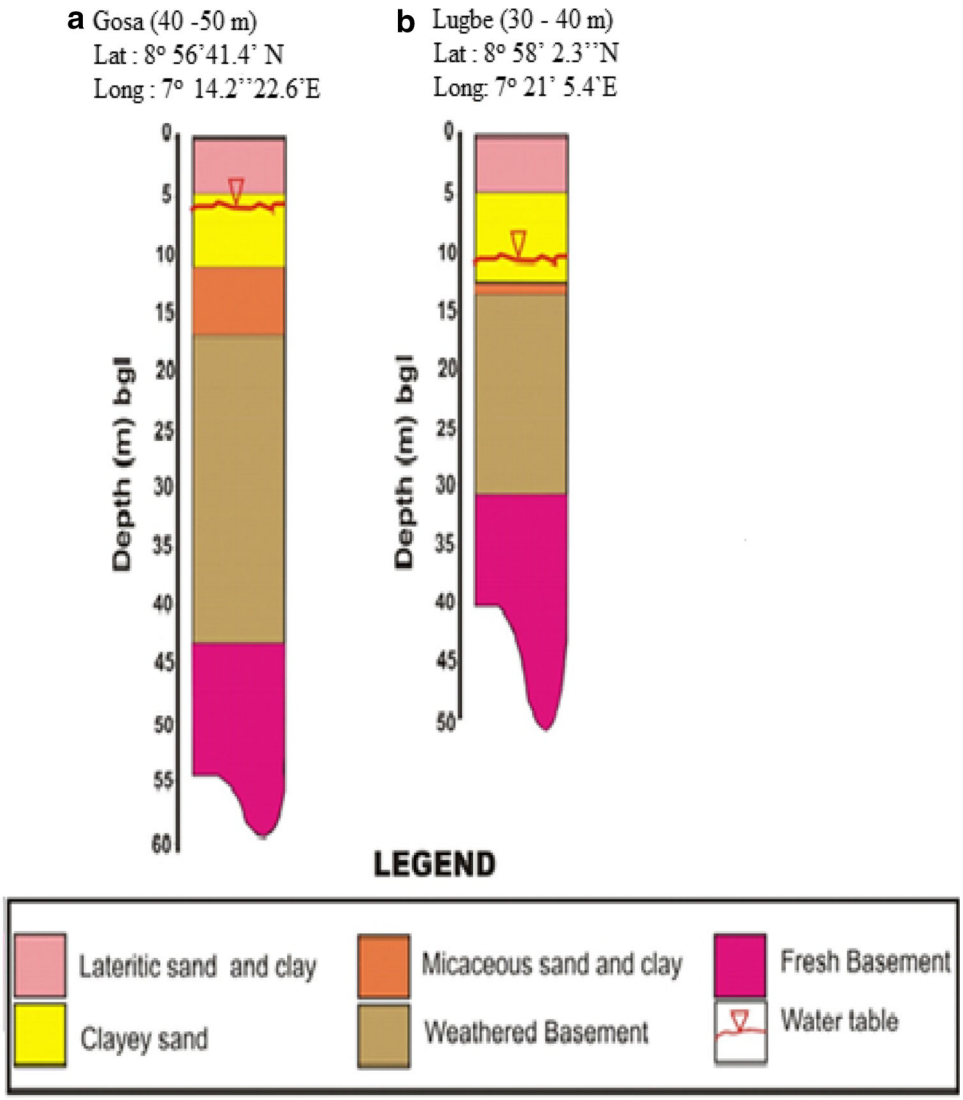

Fig. 2 The lithologs of the borehole points in the study area

longitudes 7°21′5.4′E for Federal-Housing Lugbe borehole respectively. The lithologs of boreholes drilled for this study are presented in Fig. 2a, b respectively.

Determination of elements in groundwater using ICP-MS

For this study, four water samples were collected from two boreholes at Immigration-Headquarters Gosa (two water samples), 40–50 m below ground level and Federal-Housing Lugbe area (two water samples), 30–40 m below ground level for the analysis in order to obtain the signature of radioactive contaminations. Samples were also collected from Water Board and Hand-dug well for comparison. The six water samples were digested according to the previous study in [17, 18]. The experimental analysis was performed at the Universiti Tun Hussein Onn Malaysia Environmental and Soil Science Laboratory. For accurate determination of elemental compositions in each water sample, a solution of analytical method using Elan 9000 instrument (ICP-MS) (PerkinElmer Sciex, Model Elan DRC II, Thornhill, Canada) equipped with a concentric nebulizer (Meinhard Associates, Golden, CO, USA). A baffled cyclonic spray chamber (Glass Expansion, Inc., West Melbourne, Australia), and a quartz torch with a quartz injector tube (2 mm) that performs analysis at parts-per-trillion and lower was used.

The water samples in pellets were placed on a sample holder with a filter paper of small disc size. A 6 mol L^{-1} NH_4NO_3 solution (50 µL) was added to the filter paper followed by the introduction of a sample holder vessel previously charged with 6 mL of absorbing solution (10–100 mmol L^{-1} NH_4OH). After closing and capping the rotor, vessels were pressurized with 20 bar of oxygen thereafter, the rotor was pushed inside the microwave

cavity and the heating period was started using 1400 W for 5 min and the cooling stage using 0 W for 20 min. When this was done for complete digestion, the pressure of each vessel was carefully released and the digests were transferred to a 25 mL volumetric flask and diluted with water for the determination of elements by ICP-MS according to [19]. All vessels were cleaned with 6 mL of concentrated HNO_3 under microwave heating at 1000 W for 10 min and 0 W for 20 min for cooling. Glass and quartz material were soaked in 1.4 mol L^{-1} HNO_3 for 24 h and further washed with water before use. The following operational conditions were used: radiofrequency power of 1300 W and plasma, auxiliary, and nebulizer gas flow rate of 15, 1.2, and 1.08 L min^{-1}, respectively. The isotopes measured were properly monitored. The minimum detectable concentration was 0.01 μg L^{-1}, corresponding to 124 μBq L^{-1} [20]. The two samples from each location show similarities as duplicates from the ICP-MS analysis, as such, one sample was used for result and discussion.

Results and discussion

Activity concentrations of ^{238}U in water samples

The activity concentrations of ^{238}U found in water samples in the study area are presented in Table 1.

The data in Table 1 were converted from ppb to μBq L^{-1} using the conversion factor of 15 μg L^{-1} (0.19 Bq L^{-1}) [8]. The activity concentrations of ^{238}U in groundwater supplies for drinking and domestic purposes were found to be higher at Federal-Housing Lugbe borehole with a value of 2774 μBq L^{-1} whereas lower value of 386 μBq L^{-1} was reported at Immigration-Headquarters Gosa borehole. Comparing with the activity concentration of 1824 μBq L^{-1} which is noted on Water Board sample and 2430 μBq L^{-1} for hand-dug well water sample, they were higher than the Immgration Headquarters Gosa borehole water sample. Comparing the activity level in Lugbe borehole with the Water Board, Lugbe borehole was higher by a factor of 1.14. It was noted that the concentrations of ^{238}U in this present work were distinctly higher than the works reported elsewhere [23–25].

Accumulation of radionuclide (^{238}U) in humans and recommendations for the maximum permissible limit

The annual effective dose was calculated taking into account the activity concentration of the nuclide (Bq L^{-1}), the dose coefficient for ^{238}U (Sv Bq^{-1}) was given as 2.8×10^{-7} [26, 27] and the annual water consumption was given as 731 L $year^{-1}$, [28]. A reference dose of 0.1 mSv $year^{-1}$ corresponds to the activity of 0.5 Bq L^{-1}, from Eq. (1).

$$AED\left(\text{mSv year}^{-1}\right) = AC\left(\text{Bq L}^{-1}\right) \times DC\left(\text{Sv Bq}^{-1}\right) \times AWC\ \text{L year}^{-1} \times 1000, \quad (1)$$

where *AED* is the annual effective dose, *AC* the activity concentration of ^{238}U, *DC* the dose coefficient for ^{238}U, *AWC* the annual water consumption.

Equation (1) was used to determine the annual effective dose of the water samples for ^{238}U radionuclide only in both groundwater based drinking water and Water Board as shown in Table 1. The World Health Organisation (WHO) and Environmental Protection Agency (EPA-USA) used the quantity of 2 L day^{-1} water consumption for adults [29, 30]. Comparing the four water samples in Table 1, the annual effective dose reported higher in Federal-Housing Lugbe borehole with a value of 9.2×10^{-5} mSv $year^{-1}$ and lower value of 1.3×10^{-5} mSv $year^{-1}$ was noted at Immigration Gosa borehole. In Comparing the Water Board and hand-dug well, with values 6.0×10^{-5} and 8.0×10^{-5} mSv $year^{-1}$ respectively which were lower than the values obtained at Federal-Housing Lugbe. In contrast with the previous report of the international standard [21], 0.1 mSv $year^{-1}$, the highest value of the borehole water sample obtained in the study area[1] was far below the recommended value.

Table 1 Results of activity concentrations, annual effective dose of ^{238}U in water samples from the study area and comparing with a study in Brazil and international standards

Location	Activity concentration ^{226}Ra (μBq L^{-1})	Annual effective dose (mSv $year^{-1}$)	Reference
Immigration Headquarters Gosa	386	1.3×10^{-5}	Present study
Federal-Housing Lugbe	2774	9.2×10^{-5}	Present study
Water board	1824	6.0×10^{-5}	Present study
Hand-dug well	2430	8.0×10^{-5}	Present study
Brazil	1013	–	[21]
Council directive 98/83/EY/	19,000	1.0×10^{-1}	[22]

Comparing with the previous study by [26, 27] in the region, it may be that the study area has the same geology that controls the groundwater chemistry. In 2003, the WHO proposed a provisional guideline of 0.1 mSv year^{-1} corresponds to the activity of 0.5 Bq L^{-1}. The result of this present study is below the recommended limit.

Radiological risk assessment of ^{238}U in groundwater from the study area

The lifetime cancer risks *R*, associated with the intake of a given radionuclide were estimated from the product of the applicable risk coefficient, *r,* and the per capita activity intake, *I* expressed in Eq. (2)

$$R = r \times I. \quad (2)$$

According to [16], the average life expectancy at birth in Nigeria is 45.5 year and, an annual consumption of water for an individual is about 731 L. This brings the lifetime intake of water to 33, 215 L. The cancer risk coefficient of ^{238}U is 7.17×10^{-9} Bq^{-1} for mortality and 1.04×10^{-8} Bq^{-1} for morbidity respectively were obtained from the literature [28]. Using Eq. (2) and the coefficients, the cancer mortality and morbidity risks of ^{238}U over lifetime consumption of water were calculated and the results are presented in Table 2.

The cancer mortality risk ranged from 1.48×10^{-8} to 1.24×10^{-7} while for morbidity risk ranges from 2.31×10^{-8} to 1.64×10^{-7} as shown in Table 2. The highest cancer mortality value was found at Federal-Housing Lugbe borehole with a value of 1.24×10^{-7} and lower value reported at Immigration Headquarters Gosa borehole with a value of 1.48×10^{-8}. The highest cancer morbidity of 1.64×10^{-7} was noted at Lugbe whereas lower value of 1.64×10^{-8} reported at Immigration Headquarters Gosa borehole. Comparing Federal-Housing Lugbe cancer mortality risk of 1.24×10^{-7} to 6.85×10^{-8} and 9.12×10^{-8} values of cancer mortality risks for Water Board and hand-dug well respectively, Federal-Housing Lugbe was distinctly higher than the two values. Comparing with the previous study carried out by [26, 27] in the region, it can be observed that they have the same structural control that attributes the groundwater toxic discharge. It can be noted that both cancer mortality and morbidity risks reported is higher at Lugbe borehole which may be due to complexation of uranites in the aquiferous zone. The cancer risk at 10^{-7} is lower compared to the acceptable level of 10^{-3} for the radiological risk [28].

Chemical toxicity risk of ^{238}U in groundwater from the study area

The chemical toxicity risk was evaluated using the lifetime average daily dose of 238U through drinking water intake, and compared it with the reference dose (RFD) of 0.6 μg kg^{-1} day^{-1} [28] used as a standard criteria for ^{226}Ra in several foreign organizations and thereby produce the lifetime average daily dose (*LADD*), Eq. (3)

$$\text{Ingestion } LADD \text{ of drinking water} = \frac{EPC \times IR \times EF \times ED}{AT \times BW}, \quad (3)$$

where, *LADD* is 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 (days year^{-1}), *ED* is the total exposure duration (years), *AT* is the average time (days) and *BW* is the body weight (kg). Using therefore, $IR = 2$ L day^{-1}, $EF = 350$ days, $ED = 45.5$ year, $AT = 16{,}607.5$ (obtained from 45.5×365) and $BW = 70$ kg (for a standard man). The chemical toxicity risk for ^{238}U over lifetime consumption was estimated and presented in Table 3.

The exposure dose ranged from 1×10^{-4} to 7×10^{-3} μg kg^{-1} day^{-1}. The *LADD*s values were observed to be

Table 3 The estimated *LADD* of uranium (^{238}U) in the water samples

Location	*LADD* (μg kg^{-1} day^{-1})	Reference
Immigration Headquarters Gosa borehole	1×10^{-4}	Present
Federal-Housing Lugbe borehole	7×10^{-3}	Present
Water board	4×10^{-3}	Present
Hand-dug well	5×10^{-3}	Present
RFD (reference dose)	6×10^{-1}	[31]

Table 2 The estimated lifetime cancer mortality and morbidity risk of ^{238}U in the water samples

Location	Cancer mortality risk	Cancer morbidity risk	Reference
Immigration Headquarters Gosa	1.48×10^{-8}	2.31×10^{-8}	Present study
Federal-Housing Lugbe	1.24×10^{-7}	1.64×10^{-7}	Present study
Water board	6.85×10^{-8}	1.05×10^{-7}	Present study
Hand-dug well	9.12×10^{-8}	1.40×10^{-7}	Present study
Odeda, Ogun state, Nigeria	2.54×10^{-4}	3.39×10^{-4}	[12]

higher in the Lugbe to Gosa boreholes. This could be due to the altrabasic minerals emanated from the deep seated source caused by magmatic and metamorphic processes of granitic intrusions and its interconnectivity with geochemistry and aquifer bearing formation. Comparing the LADD from Federal-Housing Lugbe to Water Board and hand-dug well, it can be observed that Federal-Housing Lugbe borehole was higher than 4×10^{-3} and 5×10^{-3} μg kg^{-1} day^{-1} values for Water Board and hand-dug well respectively. It is almost in agrrement and range with the values obtained in some parts of Gosa and Lugbe by [26] when compared with the magnitude. By comparing the LADD obtained in this study and the RFD (0.6 μg kg^{-1} day^{-1}) that is an acceptable level, the chemical toxicity risk due to ^{238}U in the water samples were all below the RFD. This shows that there may not be health risks associated with ^{238}U in the water samples which are mainly due to the chemical toxicity risk of ^{226}U.

Conclusions

The highest annual effective dose from radionuclide was noted in Federal-Housing Lugbe borehole water sample with a value of 9.2×10^{-5} mSv $year^{-1}$. The lowest value was reported at Gosa borehole which was geologically attributed to redox condition of ^{238}U due to non-interconnectivity of the fractures that would have served as a pathway for transports of sediments through the groundwater system. Abuja groundwater seems to have the same structural control, toxicity and radiological risk levels when compared with previous studies within Abuja that were published elsewhere. The radiological risks of ^{238}U in the water samples were found to be low and may not pose health risk to the public when compared with the standard international reference.

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