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Radiotoxicity risks of radium-226 (^{226}Ra) on groundwater-based drinking at Dawaki, Kuje, Giri and Sabon-Lugbe area of Abuja, North Central Nigeria

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Abstract In this study, ^{226}Ra and heavy metal concentrations were studied to represent the radiotoxicity risk of groundwater of Abuja, North Central Nigeria. Groundwater samples were collected from five areas in Abuja, and measurements were taken by using inductively coupled plasma mass spectrometer. Radium (^{226}Ra) concentrations were determined from 0.067 to 0.216 µg/L. The mean annual effective dose from the natural radionuclide of ^{226}Ra for the inhabitants was estimated to be 2.2×10^{-5} mSv. In addition, life average daily dose and cancer mortality risk were calculated. As a result, radiological risks of ^{226}Ra in groundwater are quite low, typically in the magnitude of 10^{-7} when compared with the international reference dose level.

Keywords Abuja · Groundwater · Radiological risks · Chemical toxicity risk

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Introduction

Water remains an important natural commodity needed for our day-to-day activities. However, getting water in its pure form has been tough owing to increased industrialization and urbanization that has caused pollution of water (Srilatha et. al. 2014). On the other hand, ground water has been the major sources of drinking water in India and Nigeria, and as such, it may be contaminated with some radioactive compounds (Srilatha et al. 2014; Rangaswamy et al. 2015). In Nigeria, especially in urban and some rural areas, it is exploited as boreholes or hand-dug wells. Possibly, owing to varying subsurface morphology, impurities including radium can be introduced into the water as it flows. However, the colloidal transport of radium has been less studied, but comparing it to barium it can be assumed that colloid formation could also act as a transport form for radium (IAEA 1990). Radium has four natural isotopes: ^{223}Ra, ^{224}Ra, ^{226}Ra and ^{228}Ra. ^{226}Ra and ^{228}Ra are moderately soluble in water. Radium penetrates the subsurface groundwater system by the dissolution of aquifer bearing rocks, desorption from the sediment surfaces and ejection of minerals from decay series of radioactive materials in the bedrock (Lucas and Markun 1992). However, the activity concentration of radium in groundwater depends on the activity concentration of radium in the bedrock as well as mechanisms such as precipitation dissolution, complexation and adsorption–desorption which affects the transport of radium in water. These processes are related to the chemical composition of groundwater (IAEA 1990). In groundwater, the highest activity concentrations of ^{226}Ra have been found from water containing high amounts of sodium, potassium, magnesium and calcium in saline water (Wisconsin Department of Natural Resources 2014; Salonen 1994). Groundwater moves slowly through the pores

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and cracks in underground layers of unconsolidated material and rock called aquifers. As it moves through the aquifer, minerals and other elements, including radium, can dissolve out of the rock into the groundwater. However, some rock more effectively transfers radium into groundwater than others. Eventually, the water can be drawn into nearby drinking water wells as the water is extracted (Wisconsin Department of Natural Resources 2014). The activity concentration of ^{226}Ra is unrelated to that of dissolved uranium (Salonen 1994; Salonen and Huikuri 2002). There has been a closer relation to the groundwater chemistry than to the radium content of the host rock. Correlations between ^{226}Ra and chlorine, bromide, iodide, sulfate, calcium, inactive strontium, sodium and lithium have been found (Tarvainen et al. 2001).

Saline waters are with low movement, as radium occurs as uncomplexed Ra^{2+} cations. Weak complexes which may be caused by sulfate and carbonate anions are likely to be found in water whose salinity is very low and has no influence on the mobility of radium. In saline water, the ratio of ^{226}Ra to ^{228}Ra ranging from 0.44 to 4 was reported in previous work elsewhere which was observed to be lower than the ratio of ^{226}Ra to ^{228}Ra in low saline water (Shapiro 1992). Natural occurring radium has been observed at high activity level in groundwater from two reasonable deep aquifers underlying northern Illinois used for public water supply; however, it 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 (Lucas 1985).

The predominant radium isotopes in groundwater are ^{226}Ra and ^{228}Ra, an alpha and beta emitter with a half-life of 1600 and 5.8 years, respectively (Iyengar 1990; Marovic et al. 1996; Sidhu and Breithart 1998). The toxicity of the human kidney by chronic ingestion of the uranium through drinking water is within the range 0.004–9 μg L^{-1} per body weight per day and may produce interference with kidney functions (Zamora et al. 1998). In more recent studies on humans by Kurttio et al. (2004), nephrotoxic effects of uranium in drinking water were found even for low concentrations without clear threshold. A separate study revealed that ingestion of radium was causally associated with leukemia in man (Lyman et al. 1985). However, the authors stated that further investigations are needed before a causal relationship between ^{226}Ra in drinking water and human leukemia can be established. Other epidemiological studies have found an increased risk of osteosarcoma and radium in drinking water (Finkelstein 1994; Finkelstein and Kreiger 1996). Considering the high radiotoxicity of ^{226}Ra and ^{228}Ra, their presence in water and the associated health risks require particular attention. It is known that even small amounts of a radioactive substance may produce a damaging biological effect, while

ingested and inhaled radiation may pose a serious health risk (Rowland 1993).

Therefore, this study aims to providing the potential radiological risks and chemical toxicity effects of ^{226}Ra exposure to the inhabitants that rely on groundwater in and around Abuja.

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 were reported elsewhere (Omeje et al. 2013). The study location is Dawaki (lat. 9°6′51″N and long. 7°15′39″), Kuje (lat. 8°56′16.7″N and long. 7°11′46.0″E), Giri (lat.: 8°56′45.6″N and long.: 7°13′26.2″E) and Sabon-Lugbe (lat.: 8°59′2.3″N and long.: 7°23′7.8″E). The geological and lithology map of boreholes drilled for this study areas are shown in Figs. 1 and 2, respectively.

Materials and methods

Sampling

In the study area, four (4) boreholes were drilled with the help of Korean rig attached to a compressor of about 30 torn capacity (Maxico Hydrosolution Consult Company Ltd). A total of six (6) water samples were measured, two liters each from Dawaki (DW) with a depth of about 80 m, Kuje (KU) with a depth of about 60 m, Giri (Gi) borehole with a depth of about 50 m and Sabon-Lugbe (SL) borehole with a depth of about 40 m (Fig. 2). Hand-dug well with shallow depth of about 14 m and Water Board (public water supply) in Abuja and suburbs were collected for comparison. The samples were collected in high-density polyethylene containers at the site and washed with a solution of 10 % nitric acid for 15 min, followed by repeated rinsing with distilled water and finally rinsing with ultrapure water (resistivity of about 18 MΩ cm^{-1}). The water samples were stabilized with 5 ml of nitric acid in each liter of water in order to prevent it from adsorbing the wall of the container. Figure 2a, d shows the lithology for boreholes where the water samples were collected for the present study.

Determination of ^{226}Ra in water samples using ICP-MS

Six (6) water samples were digested according to standard procedure (Pereira-Barbosa et al. 2013). The water samples in plastic pellets were acidified to 0.1 M HCL and the
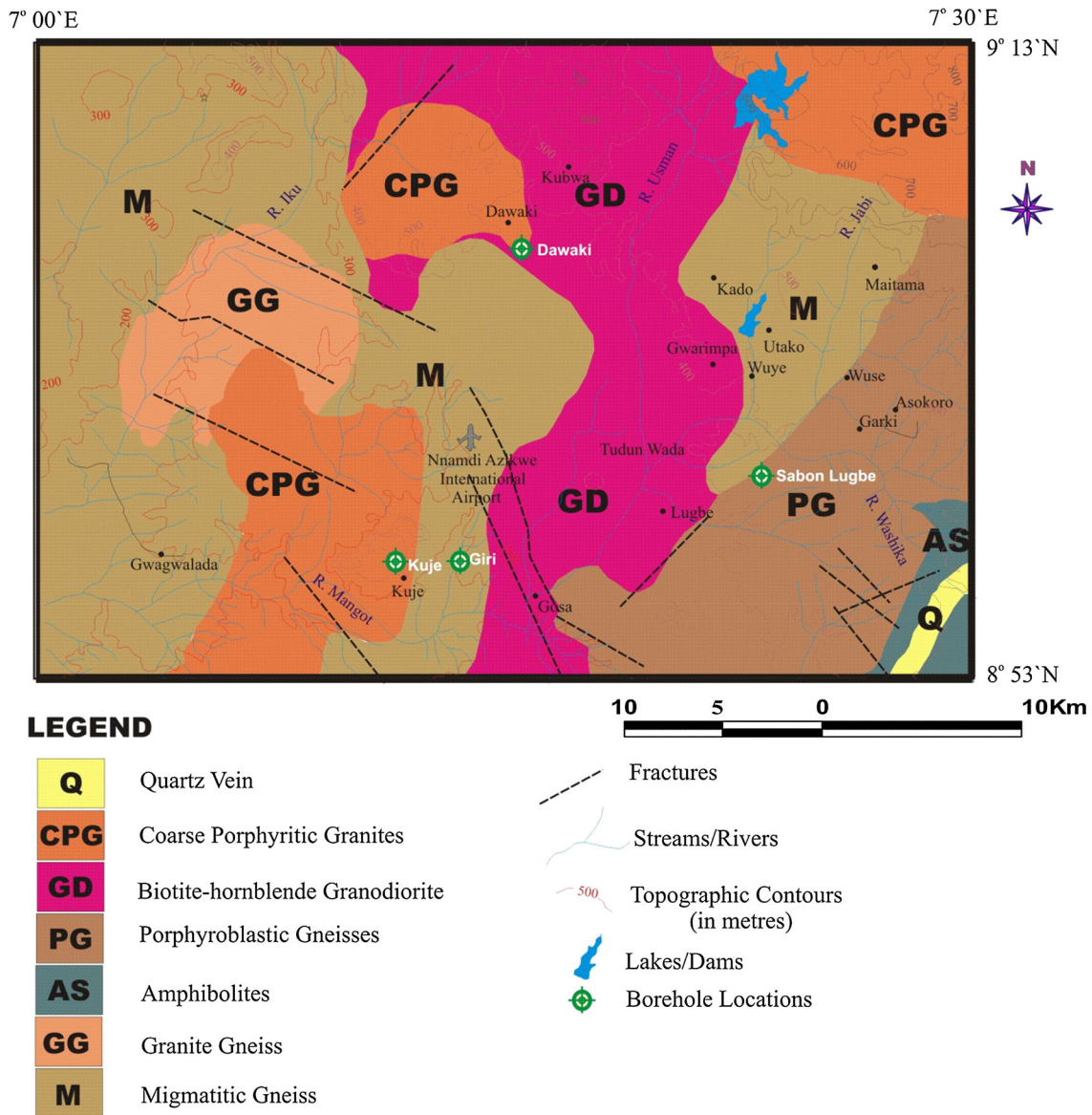
Fig. 1 Geological map of the study area

addition of [228]Th tracer in the presence of ion exchange separator. In a solution of hydrogenated titanium oxide (HTiO), 10 mL 8 M HNO_3 was added. The HTiO was used as a co-precipitation which was diluted with 12 mL 1 M HCL into a microcoprecipitation of $BaSO_4$ (Dai et al. 2012). The determination of [226]Ra was done according to Dai et al. (2012), Mesko et al. (2010) as shown in Fig. 3. The minimum detectable activity (MDA) of the system is approximately 0.22 BqL^{-1} with 4-h counting and 0.09 BqL^{-1} with 20-h counting.

Reagents and standard calibration

Deionized (distilled) water was purified in a Milli-Q system (18.2MX cm, Millipore, Billerica, MA, USA)

before use. One percentage distilled HNO_3 was soaked overnight in volumetric equipment and thoroughly rinsed with Milli-Q water before use. The preparation of all the solutions was obtained by using high-purity 18.2 MX_cm water from a Milli-Q purification system. The preparation of matrix-matched standards was done with high-purity ethanol. Analytical grades were used for all the reagents. Reference analytical solutions were prepared before use by serial dilution of stock solutions (multi-element anion standard solution) and prepared by dissolution in water samples. Argon (99.996 %) was used for the ICP-MS determination of elements. Initial calibration verification of a 100 µg/L in 1.2 % ethanol per 1 % HNO_3 was prepared from 1000 µg L^{-1} multi-element ICP standard containing the elements: Ra, Cr,

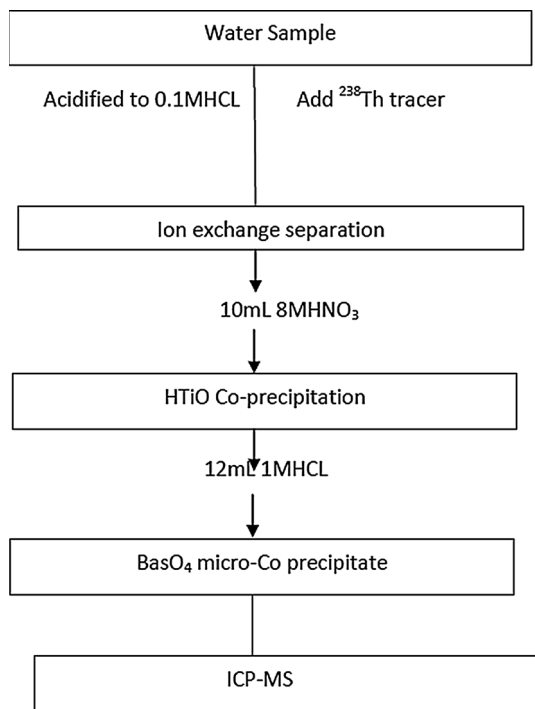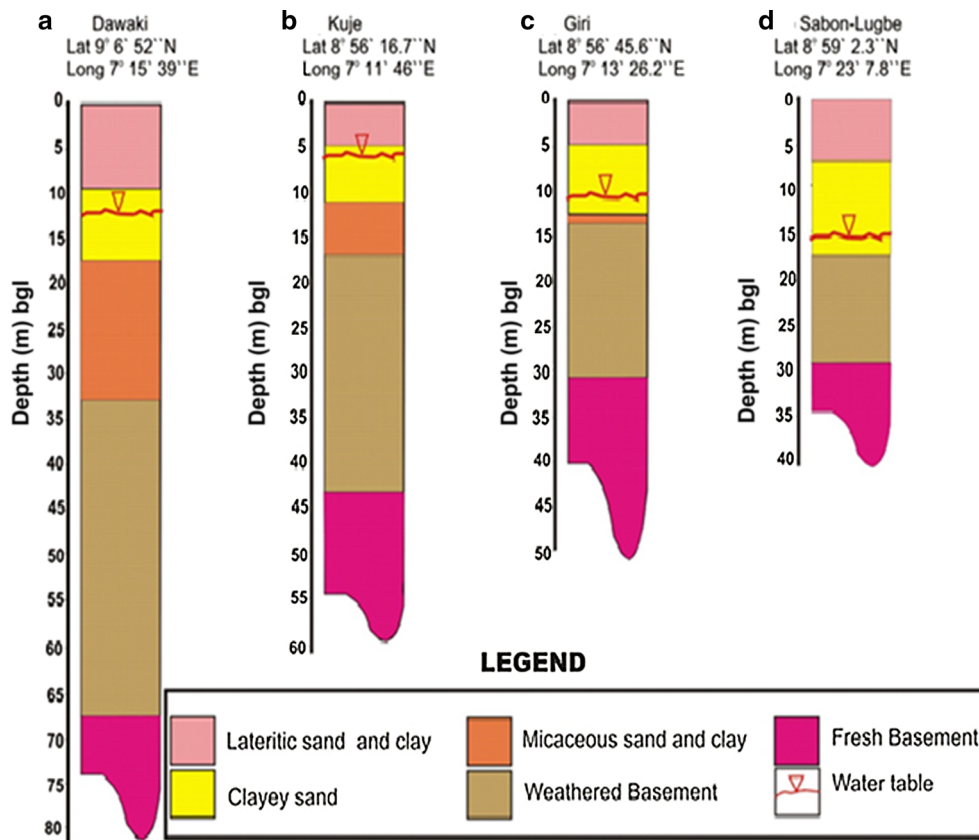Fig. 2 a–d Borehole locations for water sample collections

Cd, As Pb, Zn, Ni, Mg and K. The multi-element standard already contained in the material does not need any additional internal standard. Continuing calibration verification standards were prepared from single-element ICP standards of 20 mg L^{-1} for high- and 250 µg L^{-1} for low-standard series. The continuing calibration verification standards were measured for every 3 samples. However, the duplicates of each water samples were also prepared for possible matrix effects in case of interference. More so, the spike recovery tests were conducted on the water samples at concentration levels of 20 and 100 µg/L and serial dilutions check (1:10 followed by 1:3, finally 1:30 dilution).

Determination of heavy metals by using ICP-MS

For accurate determination of elemental compositions in each water sample, a solution analytical method using ELAN 9000 instrument (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

Fig. 3 Schematic diagram of the ICP-MS analysis

quartz injector tube (2 mm) that performs analysis at parts-per-trillion and lower was used. The measurement using ICP-MS was taken at the Universiti Tun Hussein Onn Malaysia Environmental and Soil Science. 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} (Tarvainen et al. 1999, 2000; Sac et al. 2012).

Results and discussion

Activity concentrations of ^{226}Ra in water samples

The activity concentrations of ^{226}R in groundwater supplies for drinking and domestic purposes range from 443 to 2736 μBq L^{-1} with the highest value of 2736 μBq L^{-1} found at Sabon-Lugbe borehole, whereas lower value of 443 μBq L^{-1} was reported at Giri borehole. This higher activity value found at Sabon-Lugbe may be attributed to basaltic dyke intrusion that outcrop in the region which is used for quarry. Activity concentration of 1824 μBq L^{-1} was noted in Water Board sample, whereas 2430 μBq L^{-1} was reported in hand-dug well water sample. It was observed that the activity concentration of ^{226}Ra radionuclide in groundwater-based drinking water at Sabon-Lugbe borehole was higher than that Water Board sample water and hand-dug well sample by a factor of 1.5 and 1.1, respectively.

Table 1 summarizes the activity concentration of ^{226}Ra in groundwater in the study area and compared to other work published elsewhere (Kobal et al. 1990; Almeida et al. 2004; Gans et al. 1987; Zhuo et al. 2001; Salonen et al. 2002). It was noted that the activity concentrations of ^{226}Ra in this present work at Lugbe were distinctly lower than the works reported in other countries except in Brazil, 1013 μBq L^{-1} (Almeida et al. 2014), which is distinctly lower than the value, 2736 μBq L^{-1} noted in Sabon-Lugbe borehole by a factor of 2.7. The activity concentration of 2736 μBq L^{-1} found in Lugbe borehole may be due to the uranous state (+IV) deposit in the host aquifer bearing rock that may have been oxidized in the form of uranyl condition (+VI). This could be the influence of tectonic activities resulting into dissolution of rock minerals in groundwater system around the basement groundwater channels in some parts of Abuja. Interestingly, the hand-dug well with activity level of 2430 μBq L^{-1} at a depth of about 14 m collected 1.5 km away from Dawaki borehole was closer to the activity level of 2698 μBq L^{-1} found at Dawaki borehole water sample. It may be that they have the same structural control within a geological formation.

Accumulation of radionuclide (^{226}Ra) in humans and recommendations for the maximum permissible limit

The International Commission on Radiological Protection (ICRP) provides recommendations and guidance on all aspects of protection against ionizing radiation, which are published in the commission's own scientific journal, the Annals of the ICRP, also referred to in this work. The process of exposure starts through ingestion of groundwater that contains radionuclides; after entering the human body, radionuclides are typically accumulated in the skeleton, liver, kidney and soft tissues. Ingested radionuclides are not entirely retained in the human body. Dose coefficients help to determine the effective dose associated with radiation exposure in assessing the health risks to people. The dose coefficient is expressed in Sv Bq^{-1}, the effective dose equivalent per unit water activity concentration of the radionuclide. The annual effective dose is calculated taking into account the activity concentration of the nuclide (Bq L^{-1}), the dose coefficient for ^{226}Ra (Sv Bq^{-1}) is given as 2.8×10^{-7} (ICRP 1993, 1995; NRC 1999), and the annual water consumption is given as 731 L year^{-1} (WHO 2004; NRC 1999). A reference dose of 0.1 mSv year^{-1} corresponds to the activity of 0.5 Bq L^{-1}, from Eq. (1).

$$\text{AED}(\text{mSvy}^{-1}) = \text{AC}(\text{Bq L}^{-1}) \times \text{DC}(\text{Sv Bq}^{-1}) \\ \times \text{AWC}(\text{L y}^{-1}) \times 1000 \qquad (1)$$

where AED = annual effective dose, AC = activity concentration of ^{226}Ra, DC = dose coefficient for ^{226}Ra, AWC = annual water consumption.

In the present study, Eq. (1) was used to determine the annual effective dose of the water samples for ^{226}Ra radionuclide in groundwater water and Water Board as shown in Table 1. The World Health Organization (WHO) and Environmental Protection Agency (EPA-USA) used the quantity of 2 L per day water consumption for adults (WHO 2004; ICRP 1993). Comparing the four boreholes in Table 1, the annual effective dose reported higher in Sabon-Lugbe borehole with a value of 9.0×10^{-5} mSv year^{-1} and lower value of 1.5×10^{-5} mSv year^{-1} was noted at Giri borehole. Comparing the Water Board and hand-dug well of values 6.0×10^{-5} and 8.0×10^{-5} mSv year^{-1}, respectively, the highest value was found at Sabon-Lugbe borehole of 9.0×10^{-5} mSv year^{-1} which is distinctly higher. In contrast with the previous report of the international standard (Council Directive 1996) 0.1 mSv year^{-1}, Sabon-Lugbe borehole with a value of

Table 1 Results of activity concentrations, annual effective dose, cancer mortality risk, cancer morbidity risk and life average daily dose of water analysis in Dawaki, Kuje, Giri, Sabon-Lugbe boreholes, Water Board and hand-dug well are compared with international reference standard

Location	Activity concentration ^{226}Ra (μBq L^{-1})	Annual effective dose (mSv year^{-1})	Cancer mortality risk	Cancer morbidity risk	LADD (μg kg^{-1} day^{-1})	References
Dei-Dei	2698	8.9×10^{-5}	1.01×10^{-7}	1.55×10^{-7}	6×10^{-3}	Present study
Kubwa	849	2.8×10^{-5}	3.19×10^{-8}	4.88×10^{-9}	2×10^{-3}	Present study
Gosa	443	1.5×10^{-5}	1.67×10^{-8}	2.55×10^{-8}	1×10^{-3}	Present study
Lugbe	2736	9.0×10^{-5}	1.03×10^{-7}	1.57×10^{-7}	6×10^{-3}	Present study
Water Board	1824	6.0×10^{-5}	6.85×10^{-8}	1.05×10^{-7}	4×10^{-3}	Present study
Hand-dug well	2430	8.0×10^{-5}	9.12×10^{-8}	1.40×10^{-7}	5×10^{-3}	Present study
Slovenia	6333	–	–	–	–	Kobal et al. (1990)
Brazil	1013		–	–	–	Almeida et al. (2014)
Gs Germany	14,567	–	–	–	–	Gans et al. (1978)
CC China	17,733	–	–	–	–	Zhuo et al. (2001)
Fi Finland	20,267	–	–	–	–	Salonen et al. (2002)
USE USEPA, CounCouncil Directive 98/83/EY/	19,000	1.0×10^{-1}		USE		USE USEPA (2000)
Odeda, Ogun state, Nigeria	–	–	2.54×10^{-4}	3.39×10^{-4}	–	Amakom and Jibril (2010)
RFD (reference dose)	–	–	–	–	6×10^{-1}	Ye-shin et al. (2004)

9.0×10^{-5} mSv year^{-1} was far below the recommended value. From the reference work done elsewhere, the radium concentration is limited mainly by chemical toxicity rather than the effective dose (WHO 2006). In 2003, the World Health Organization proposed a provisional guideline of 0.1 mSv year^{-1} corresponds to the activity of 0.5 Bq L^{-1} which is far higher than this present study.

Radiological risk assessment of ^{226}Ra in groundwater from the study area

The radiological risk assessment was to evaluate the life time cancer risk associated with the intake of a given ^{226}Ra radionuclide in groundwater. 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).

$$R = r \times I \qquad (2)$$

According to WHO (WHO 2006), the average life expectancy at birth in Nigeria is 45.5 y and an annual consumption of water for an individual is about 731 L year^{-1}. This brings the lifetime intake of water to 33,216 L. The

cancer risk coefficients of ^{226}Ra are 7.17×10^{-9} Bq^{-1} for mortality and 1.04×10^{-8} Bq^{-1} for morbidity, respectively, obtained from the literature (USEPA 1999; UNSCEAR 2000). Using Eq. (2) and the coefficients, the cancer mortality and morbidity risks of ^{226}Ra over lifetime consumption of water were calculated and the results are presented in Table 1. In Table 1, the cancer mortality risk ranged from 1.67×10^{-8} to 1.03×10^{-7}, while for morbidity risk ranges from 4.88×10^{-9} to 1.57×10^{-7}. The highest cancer mortality value of ^{226}Ra was found at Sabon-Lugbe borehole with a value of 1.03×10^{-7}, and lower value was reported at Giri borehole with a value of 1.67×10^{-8}. The highest cancer morbidity value of ^{226}Ra was 1.57×10^{-7} which was noted at Sabon-Lugbe, whereas lower value of 1.67×10^{-8} was reported at Giri borehole. Comparing Sabon-Lugbe cancer mortality risk of 1.03×10^{-7} to 6.85×10^{-8} and 9.12×10^{-8} values of cancer mortality risks for Water Board and hand-dug well, respectively, Sabon-Lugbe was distinctly higher than the two values. Comparing with a study reported by (Amakom and Jibiri 2010) in Ogun State, Nigeria, four boreholes, Water Board and hand-dug well were lower than 2.5×10^{-4} and 3.4×10^{-4} values obtained for cancer mortality and morbidity risks in Odeda Ogun State,

Nigeria. It can be noted that both cancer mortality and morbidity risks reported are higher at Sabon-Lugbe borehole when compared with other boreholes; it may be that the aquiferous zone may have been affected due to higher deformation of fractures which enabled water to trap at the near surface since the subsurface geology permits the rapid downward movement of water sources from the source and enables the escape of radon gas. The cancer risk at 10^{-7} is lower compared to the acceptable level of 10^{-3} for the radiological risk (USEPA 1999).

Chemical toxicity risk of ^{226}Ra in groundwater from the study area

The chemical toxicity was to determine the effect of the carcinogenic risks associated with chemical toxicity of ^{226}Ra in the water sample selected for this study. The chemical toxicity risk was evaluated using the lifetime average daily dose of ^{226}Ra through drinking water intake and compared it with the reference dose (RFD) of 0.6 µg kg^{-1} day^{-1} (USEPA 1999) used as a standard criteria for ^{226}Ra in several foreign organizations, thereby producing the lifetime average daily dose (LADD), Eq. (3)

Ingestion LADD of drinking water

$$= \frac{\text{EPC} \times \text{IR} \times \text{EF} \times \text{ED}}{\text{AT} \times \text{BW}} \qquad (3)$$

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 years, AT = 16,607.5 (obtained from 45.5 × 365) and BW = 70 kg (for a standard man). The chemical toxicity risk of ^{226}Ra over a lifetime consumption was estimated and is presented in Table 1.

In Table 1, the exposure dose ranged from 1×10^{-3} to 6×10^{-3} µg kg^{-1} day^{-1}. The LADD values were observed to be higher in the Lugbe and Dei-Dei boreholes compared to Kubwa and Gosa boreholes. This could be due to the ultrabasic 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. The lowest value of 1×10^{-3} µg kg^{-1} day^{-1} was found in Giri borehole. Comparing the LADD from Dawaki and Sabon-Lugbe to Water Board and hand-dug well, it can be observed that Dei-Dei and Lugbe boreholes were higher than 4×10^{-3} and 5×10^{-3} values for Water Board and hand-dug well, respectively. 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 ^{226}Ra in the water samples was all below the RFD. This shows that there may not be health risks associated with ^{226}Ra in the water samples which are mainly due to the chemical toxicity risk of ^{226}Ra. This shows that there may not be health risks associated with ^{226}Ra in the water samples which are mainly due to the chemical toxicity risk of ^{226}Ra and its progeny. However, hand-dug well reported higher value of LADD of ^{226}Ra than other water samples; it may be due to the formation of soluble complexes in aqueous phase in weathering and alteration caused by metamorphic process (Gbadebo 2011). In addition, the Water Board of Abuja which is the public water supply in the region noted higher than Kuje and Giri boreholes which may be attributed to solubility and high content of toxic non-carcinogen metals in the source of the surface water of the public water supply.

The toxic elemental concentrations of water samples from the study area

The results of the heavy metals in the sediment samples for As, Cr, Cd, Pb, Ni, Zn, Mg and K varied from 0.0002 to 0.002, 0.0003 to 0.01, 0.00006 to 0.0003, 0.0002 to 0.014, 0.001 to 0.021, 0.02 to 0.277, 0.037 to 2.11 and 0.0006 to 1.41 mg/L, respectively. As presented in Table 2, it has

Table 2 Results of elemental concentrations of water analysis Dawaki, Kuje, Giri, Sabon-Lugbe boreholes, Water Board and hand-dug well and comparing with Pereira-Barbosa et al. (2013) and (Gbadebo 2011)

Sample location	Carcinogenic toxic elements (mg L^{-1})			Non-carcinogenic toxic elements (mg L^{-1})				
	As	Cr	Cd	Pb	Ni	Zn	Mg	K
Dei-Dei borehole	0.002	0.004	0.0001	0.005	0.003	0.02	Nil	Nil
Kubwa borehole	0.0002	0.002	0.00002	0.0002	0.002	0.04	2.11	1.41
Gosa borehole	0.0006	0.0003	0.0003	0.003	0.001	0.032	1.334	1.339
Lugbe	0.002	0.004	0.0001	0.014	0.021	0.277	0.037	0.0006
Water Board	0.001	0.01	0.0002	0.012	0.008	0.04	Nil	Nil
Hand-dug well	0.003	0.001	0.00006	0.002	0.005	0.03	Nil	Nil
Pereira-Barbosa et al. (2013)	0.05	0.1	0.005	0.010	0.07	0.07	0.05	–
Gbadebo (2011)	–	–	–	–	–	–	–	8.0

been observed that the heavy metals in groundwater sample from Sabon-Lugbe, Kuje and Water Board samples constituted slightly higher than those in others for As, Pb Ni, Zn, Mg and K, respectively.

This is because these sample areas are close to the highly effected tectonic region of ultrabasic and mafic igneous. A detailed literature comparison of natural concentration levels of water samples is given in Table 2. It was observed that As, Pb, Ni and Zn concentrations in the waters were higher in Sabon-Lugbe borehole sample than others (Table 2). These heavy metals that accumulate at the Sabon-Lugbe water sample may be the influence of basaltic dyke intrusion at the upper parts of the region. A similar trend is observed with some heavy metals in water samples collected at Kuje borehole for Mg and K with higher concentrations than other water samples. The area may share the same geology with Sabon-Lugbe but varies with different lithological formation of more interbedding of migmatite gneiss complex. Significantly, the public water supply (Water Board) was noted to have higher concentration of Cr as well as higher concentration of Cd at Giri borehole. The higher level of Cr in Water Board may be emanating from the reservoir where the treatment is taken place. The place maybe has a river channel link that may serve as contamination pathway to the public water supply zone. In all cases, all the samples are within the normal range of permissible limit (Job 2008; USEPA 1976, 2005; WHO 2004; IARC 1997). It can be noted that the presence of higher values of Pb, Ni and Zn concentration at Sabon-Lugbe may have contributed to higher activity concentration of ^{226}Ra in the study area which is in agreement with Salonen (1994).

Conclusion

The cause of the radiotoxicity risks of ^{226}Ra in groundwater samples from the study area was investigated and observed that activity concentrations of ^{226}R in groundwater supplies for drinking and domestic purposes were found to be higher at Sabon-Lugbe borehole with a value of 2736 μBq L^{-1}. The mean annual effective dose from the natural radionuclide (^{226}Ra) for the users of borehole was estimated to be 5.55×10^{-5} mSv. The highest annual effective dose from radionuclide was noted in Sabon-Lugbe borehole with a value of 9.0×10^{-5} mSv year^{-1} which was attributed to basaltic dyke intrusion in the area. The radiological risks of ^{226}Ra in the water samples were found to be low, typically in magnitude of 10^{-7} when compared with the Standard International Reference by United State Environmental Protection Agency (USEPA 2000; 1999). The radiological implications may not be the risk; it may be attributed to the chemical toxicity of Pb, Zn

and Mg as a heavy metal which was observed from the water samples collected at Sabon-Lugbe borehole, Giri borehole, Water Board and Kuje borehole, respectively. Significantly, the presence of higher values of Pb, Ni and Zn concentration at Sabon-Lugbe may have contributed to higher activity concentration of ^{226}Ra in the study area. Taking the whole analysis of the groundwater into consideration, it is recommended that the groundwater in Abuja should be treated before consumption to decrease the risk. This study recommends the determination of activity level of ^{210}Po, ^{210}Pb, ^{214}Bi and ^{214}Pb, respectively.

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