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Radiochemical Risk Assessment of Uranium in Groundwater of Jos Plateau, Nigeria

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ABSTRACT: One of the goals ofthe World Health organisation (WHO) and UNICEF is provision of adequate, clean and safe drinking water, thus, measurement of uranium content in drinking water is of great importance considering its effects on human health. Inductive Coupled Plasma (ICP) Mass Spectrometer was used to determine the chemical concentrations of ^{238}U in groundwater samples collected from various aquifers hosted by different geological formations in Jos Plateau. The concentration of ^{238}U in water samples was found to vary from $1.4 - 35\ \mu g\ L^{-1}$ which were subsequently converted to activity concentrations of ^{238}U in the samples. The results obtained were used to calculate annual effective dose and human radiological risks over lifetime consumption by the inhabitants in the area. Mortality and morbidity risks range from 1.287×10^{-6} to 3.218×10^{-6} and 3.218×10^{-6} to 4.927×10^{-5}, respectively. The risk indices are compared with the safe limits recommended for drinking water by health agencies such as WHO and USEPA. Few samples were found to have concentration of ^{238}U exceeding standard value. The data of this work could be useful for prognosis of uranium persuaded diseases in the local inhabitants of the study area.

KEY WORDS: Radiochemical, Uranium, Groundwater, Geological formation, ICP-MS, Mortality and Morbidity Risk.

I. INTRODUCTION

Chemical and activity concentrations of uranium in groundwater mainly depend on the environmental conditions, lithology, geomorphology and other geological factors of the region. Uranium exist in groundwater in dissolved form due to the presence of certain minerals such pitchblende, uranitie, and cornalite or as minor mineral in form of complex oxide of silicate, phosphate, validates, lignite and monazite sands (Mahesh et al., 2001; Maxwell et al., 2015). To achieve the goal of the united nation for providing safe and clean water for the citizens of its member nations, uranium concentrations in groundwater sources has to be determined. Our ecosystem is also severely disturb by potential anthropogenic radiotoxic elements from the environment (Abdallah and Morsy, 2013). The health effects of uranium in human kidney have been extensively studied (Kundt et al., 2009; Kurttio et al., 2002) and in bone of laboratory animals (Larivière, 2007). Kidney functions has been reported to be inferred by chemical toxicity effects due to chronic ingestion of drinking water containing uranium in the range of 0.004 to 9 $\mu g\ L^{-1}$ per body weight (Zamora, 1998). Most results from uranium studies in drinking water suggest that the safe concentration of uranium in drinking water may be within the range guideline values of $2–30 mgL^{-1}$(Kurttio et al., 2002; WHO, 2006b).

Chemical concentration of uranium in drinking water above permissible limit has being the cause of pathological and radiochemical health effects in the body (WHO, 2004) such as genetic damage observed in mammals, plants, insects and microorganisms. According to World Health organisation (WHO, 2008) and United State Environmental Protection Agency (USEPA, 2011), uranium concentration greater than 15 µg $L^{-1}$and 30 $\mu g\ L^{-1}$ in drinking water may lead to harmful biological effects in humans. Therefore, intake of natural radionuclides in drinking water is of great concern compared to other sources as groundwater is the major source of domestic water supply. Therefore, this study is proposed to investigate the quality of groundwater (boreholes and hand dug wells), in terms of uranium concentration, that are used for human consumption without treatment for Jos Plateau.

II. MATERIALS AND METHOD

A) THE STUDY AREA

The study area is geographically located on Jos Plateau in the north central region of Nigeria between the latitudes of $8^0 30' - 10^0 24'$ north of the equator and longitudes of $9^0 20' - 9^0 30'$ of Greenwich meridian and covers nine local government areas (LGAs) of Plateau state. The area has a total land size of 15,038 km^2 and a population of 1,933, 505 (NPC, 2006).

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B) THE GEOLOGY OF THE AREA

Jos plateau is mainly made of eight geological types classified under three geological groups namely; the basement complex, younger granites and volcanic rocks as extensively studied by Falconer (1921). About 50% of Jos Plateau is underlain by basement complexes such as migmatite-gneiss-quartzite, in some places, the basement complex is intruded by Precambrian to the late Paleozoic Pan-African granite (Older Granite), diorite, charnockite. The geological formations and their coding is given in Table1. Digital map of the geological formations is shown in Figure 1.

Table 1: Geological formations of Jos Plateau.

S/N	Code	Name
1	G1	Basement Complex
2	G2	Biotite
3	G3	Older granites
4	G4	Rhyolite
5	G5	Older Basalt
6	G6	Newer Basalt
7	G7	Clay and Shale
8	G8	Younger granites

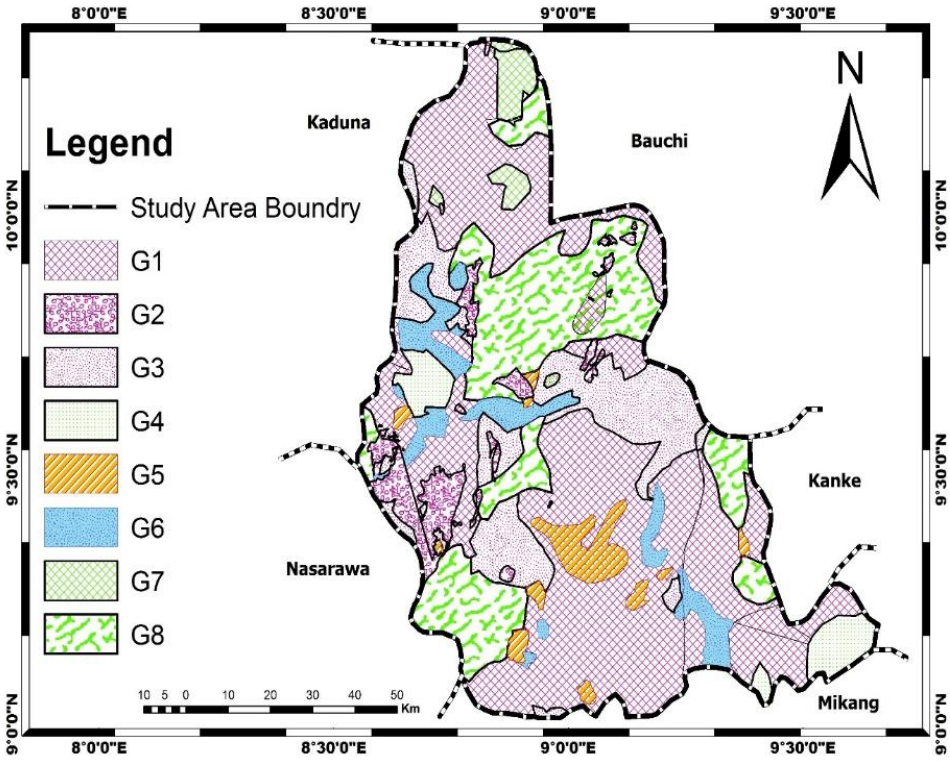

Fig. 1 Geological formations of the study area

C) SAMPLE COLLECTION AND PREPARATION

Water samples from boreholes and hand dug wells were collected in a plastic containers across the entire geological formations of the study area. Each sample was stabilized by 5 mL of nitric acid for each litre of the sample. All sample containers were labelled and transported to laboratory for analysis.

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D) ANALYTICAL METHOD

Measurement of uranium concentration in the groundwater samples were carried out using inductively coupled plasma mass spectrometry (ICP-MS). Each sample was measured three (3) times for 60 min. The repetition is to check reproducibility and stability with analytes and internal standards. Standard for calibration were run at the beginning and end of sequence of counting the samples.

III. RESULTS AND DISCUSSION

A) CHEMICAL AND ACTIVITY CONCENTRATIONS OF ^{238}U.

The results for chemical concentrations of ^{238}U in groundwater for different geological formation bearing aquifers are presented in figure1. The concentrations of ^{238}U was found to varied from 1.4 μg L^{-1} measured in borehole water and 35 μg L^{-1}measured in hand-dug well with the highest value noted in G5 (Older basalt) and the lowest value was measured in G2 (Biotite). The mass to activity concentration conversion factor of 0.0245 Bq μg^{-1} for natural uranium was used to convert the data to activity concentrations. The corresponding activity concentrations of ^{238}U varied between 3.43×10^{-2} Bq L^{-1} and 8.58×10^{-1} Bq L^{-1} (Fig. 2).This is in consistent with a similar work conducted by Abdurabu et al. (2016). Higher activities for ^{238}U observed in older basalt could be related to the uranium content in the host aquifers and its chemical compositions, uranium solubility, presence of oxygen and its complexion agents, and nature of contact between granitic intrusions, uraniferrous minerals and groundwater (Hess et al., 1985). Lower values observed in water sample from boreholes compared to hand-dug well could be attributed to the tectonic impact that resulted in subsurface deformation and large scale fractures that could serve as pathway for ^{222}Rn to escape to the surface, thus, decreasing the activity concentration of ^{238}U in groundwater samples from boreholes.

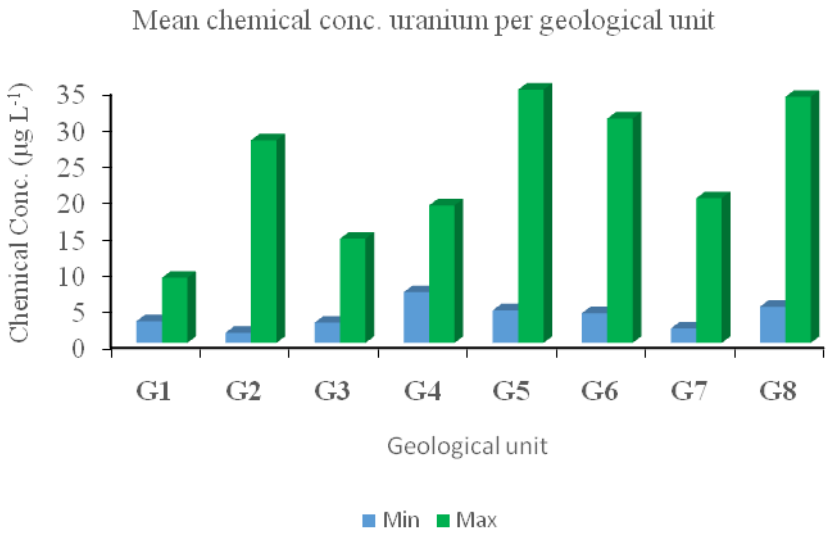

Figure 1: Chemical Concentration of ^{238}U for each geological formation.

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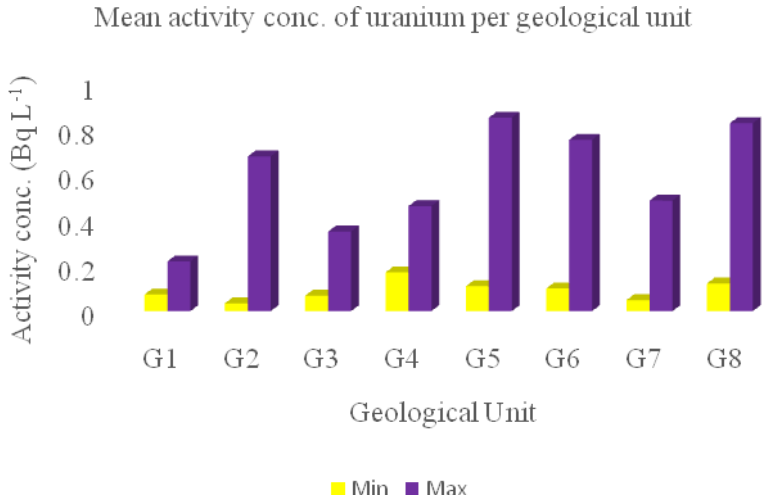

Figure 2: Activity Concentration of ^{238}U for each geological formation.

World Health Organisation (WHO, 2008) and United State Environmental Protection Agency (USEPA, 2003) have recommend 15 µg L^{-1} and 30 μg L^{-1} , respectively, as safe limits for uranium in drinking water for human beings. It could be observe from the figure 1, some samples were found to have concentrations exceeding the safe limits. Higher concentrations may be attributed to higher background radiation reported in the area for which the major contribution was from uranium and thorium decay series (Jibiri et al., 2009).Uranium activity concentration in some of the water samples are found to exceed the radiological limit of 0.19 Bq L^{-1} recommended by WHO (2006a) in drinking water as can be seen in figure 2.

B) ANNUAL EFFECTIVE DOSE DUE TO INGESTION

Recommendations and guidelines on all aspects of protection against exposure to ionising radiation have been provided by International Commission on Radiological Protection (ICRP, 1996) in the commission's annual journal. Radionuclides, after ingestion, uranium are typically accumulated in the skeleton, liver, kidney and soft tissues. Thus, annual effective dose due water consumption is given by

Annual effective dose (mSv y^{-1}) = Activity concentration (Bq L^{-1}) × dose coefficient (Sv Bq^{-1})× annual water consumption (Ly^{-1})×1000

where dose coefficient and annual water consumption are given as 3.5×10^{-6} mSv Bq^{-1} and 730 litres per annum (Kandari et al., 2016). The annual dose for ingestion varies from 2.128×10^{-6} mSv y^{-1} to 5.370×10^{-5} mSv y^{-1}. None of the values exceed the accepted limit of 0.1 mSv y^{-1} as provided by UNSCEAR (2000).

C) MORTALITY AND MORBIDITY CANCER RISK OF ^{238}U IN GROUNDWATER

Mortality and morbidity cancer risks (R) associated with the ingestion of a radiochemical is defined by the equation below:

$$R = rxI$$

where r represent the risk coefficient of the ingested radionuclide and I is the per capita activity intake of the radionuclide. The mortality and morbidity risk coefficients for uranium are given by 1.13 x 10^{-9} Bq^{-1} and 1.73 x 10^{-9} Bq^{-1}, respectively (UNSCEAR, 2000; USEPA, 1999). According to WHO (2006), the average life expectancy at birth in Nigeria is 45.5 years and, an annual consumption of water for an individual is about seven hundred and thirty (730) litres. This brings the lifetime intake of water to 33,215 litres.

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The values were calculated to range from 1.287×10^{-6} to 3.218×10^{-6} for mortality risk, while 3.218×10^{-6} to 4.927×10^{-5} for morbidity risk. All values were found to be low compared to the acceptable level of 10^{-3} for the radiological risk (USEPA, 1999). The risk at 4.927×10^{-5}, is distinctly higher than 2.55×10^{-8} reported by Omeje and Wagiran (2016) in Gossa, North-central Nigeria and lower than 2.54×10^{-4} reported by Amakom and Jibiri (2010) in Ogun state of Nigeria.

D) CHEMICAL TOXICITY RISK

Chemical toxicity of a radionuclide is defined as the lifetime average daily dose (LADD in the unit of μg kg^{-1} day^{-1}) of the element through the ingestion of drinking water. Mathematically given by (WHO, 2011).

$$LADD = \frac{EPC \times IR \times EF \times LE}{BW \times AT}$$

where *EPC* represent the exposure point of concentration (μg L^{-1}), IR means water ingestion rate (2 litres of water per day) (WHO, 2003). EF is the exposure frequency (350 days year^{-1}), LE is the life expectancy which is given as 45.5 years for an average Nigerian according to WHO (2008) report. AT is the average time (i.e average life time expectancy in days given by 365 $\times$45.5 = 16607.5 days) and BW is the body weight (70 kg for an average Nigerian). The LADD values ranges from 3.82×10^{-3} µg kg^{-1}day^{-1} to 9.56×10^{-2} µg kg^{-1}day^{-1} with the highest value measured in G5 (older basalt) and lowest observed in G2 (Biotite) for water samples from hand dug well and borehole, respectively. Chemical toxicity risk values due groundwater consumption in the area were found to be lower than the reference dose (*RFD*) of 0.6 µg kg^{-1}day^{-1} (Kim et al., 2004). The extent of harms from toxic risk is indicated by hazard quotient (*HQ*):

$$HQ = \frac{LADD}{R_f D}$$

where R_fD is reference dose and is recommended to be 0.6 μg kg^{-1} day^{-1} by WHO (2011). Hazard quotient were calculated to range between 6.37×10^{-3} and 1.59×10^{-1}. The values are found to be below the recommended reference dose (*RFD*).

IV. CONCLUSION

In this study, chemical and activity concentrations of uranium (^{238}U) in groundwater samples from Jos Plateau were determined using Inductive Coupled Plasma Mass Spectroscopy (ICP-MS) analytical technique. Higher chemical concentrations of ^{238}U were observed in both boreholes and hand dug wells. The highest value, 35 µg L^{-1} was noted in the geological unit G5 (older basalt) and lowest 1.4 µg L^{-1} was found in G2 (Biotite). It was concluded that annual effective dose values due water consumption are within the safe limit for this area. Radiological cancer risks of mortality and morbidity values were distinctly found to be lower than the acceptable value of 10^{-3} for radiological risk as provided by USEPA. The chemical toxicity risk of ^{238}U in drinking water over a lifetime consumption has values that are within standard limit. The results obtained for the hazard quotient were found to be below recommended reference dose (*RFD*). Study on radionuclides distribution pattern for the area is hereby recommended.

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