RADIOLGICAL RISKS OF RADU-226 ON GROUNDWATER BASED-DRINKING IN KUBWA AND GOSA AREA OF ABUJA, NORTH CENTRAL NIGERIA

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ABSTRACT: The radiological risks associated with radium-226 in groundwater samples were analyzed using Inductively Coupled Plasma Mass Spectrometer (ICP-MS). The mean annual effective dose from the natural radionuclide of radium-226 ($^{226}$Ra) was estimated to be $2.2 \times 10^{-8}$ mSv. In the groundwater samples, Lifetime average daily dose (LADD) ranged from $1 \times 10^{-9}$ to $2 \times 10^{-9}$ µg kg$^{-1}$ day$^{-1}$. The LADDS and the highest cancer mortality risk was found at Kubwa borehole with a value of $3.1 \times 10^{-9}$ and lower value reported at Gosa borehole with a value of $1.8 \times 10^{-9}$. The highest cancer morbidity of $9.7 \times 10^{-9}$ was noted at Kubwa whereas lower value of $5.2 \times 10^{-9}$ reported at Gosa borehole. The radiological risks of $^{226}$Ra in the water samples were found to be low, typically in magnitude of $10^{-7}$. With this low level of radiological implications, it may be the chemical toxicity associated with $^{226}$Ra as a heavy metal. The values obtained in the study area may not pose radiological hazards to the residents that rely on groundwater. At the same time, measures of groundwater quality protection and monitoring should be enhanced and new supply source which has lower risk must found.

Keywords: Abuja, Groundwater, Radiological Risks, Chemical Toxicity

1.0 INTRODUCTION

The activity concentrations of $^{238}$U, $^{232}$Th and $^{40}$K in groundwater are connected to the activity concentrations of $^{226}$Ra and $^{232}$Th of aquifer bearing formation, and their decay products in subsurface rock formation. This occurs as a result of reactions between groundwater, soil and bedrock which release quantities of dissolved mineral components depending on the mineralogical and geochemical composition of the rock formation [1-2]. It also depends on the chemical composition of the water, degree of weathering of the subsurface rock formation, redox conditions and the residence time of groundwater in subsurface water bearing formation. [3]. $^{238}$U and $^{232}$Th decay series in soils, bedrocks and groundwater system is controlled by the chemical substances, radioactive decay and surrounding physical factors. As a result of these controlled processes, the radioactive elements emit alpha into the groundwater or to the surrounding, resulting into decay series of disequilibrium of nuclides [3].

The predominant radium isotopes in groundwater are $^{226}$Ra, an alpha emitter with a half-life of 1600 years, and $^{228}$Ra, a beta emitter with a half-life of 5.8 years [4-6]. Considering the high radioactivity 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 and that ingested and inhaled radiation can be a serious health risk [7].

In this study, the main emphasis is to determine the activity concentration and human radiological risk over life time consumption of $^{226}$Ra in groundwater-based drinking at Kubwa and Gosa boreholes recommended by [8]. The study area is located within the crystalline basement complex of Nigeria. The rocks of this area are mainly migmatite, Leucocratic granite, quartzmonite and granodiorite. The detailed geology and hydrogeology of the study area was reported elsewhere [8]. The drilling point coordinates at Kubwa lies within lat. $9^\circ 6’16.7”$ N and long. $7^\circ 16’26.0”$E whereas that of Gosa area lies within the coordinate of lat. $8^\circ 56’45.6”$ N and Long: $7^\circ 13’26.2”$ E.

3.0 Materials and Methods:

Four (4) water samples measured two litres each from Kubwa, with a depth of about 60 m. Gosa area with depth of about 50 m, Hand-dug well of shallow depth of 14 m and Water Board (public water supply) in Abuja and suburbs were collected. Water samples were collected in high density polyethylene containers at the site in Nigeria previously washed in a solution of 10 % nitric acid for 15 minutes, followed by repeated rinsing with distilled water and finally rinsing with ultrapure water (resitivity of about 18 MΩ cm$^{-1}$). The collection containers were kept in sealed polyethylene bags before the collection of samples. The water samples were stabilized with 5 ml of nitric acid in each litre of water in order to prevent it from attacking to the wall of the container. For accurate determination of elemental compositions in each water sample, a solution analytical method was used; a multi-standard calibration method was applied using Elan 9000 instrument that performs analysis at parts-per-trillion and lower. The minimum detectable concentration was 0.01 µg L$^{-1}$, corresponding to 124 µBq L$^{-1}$ [9].

3.1 Sample Analysis using ELAN 9000 Instrument and Technique

Measurement using ICP-MS was performed at the Universiti Tun Hussein Onn Malaysia Environmental and Soil Science Laboratory. ICP-MS is a relatively new method for determining multi-element analysis and ideal for groundwater, since the vast majority of target compounds can be detected below 0.1 mg L$^{-1}$. Water Samples were digested according to the previous study [10]. The water samples in Pellets were placed on a sample holder with a small disc of filter paper. A 6 mol L$^{-1}$ NH$_4$NO$_3$ 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\textsuperscript{L\textsuperscript{-1}} NH\textsubscript{4}OH). All raw data, including methods and parameters used, are stored in an encrypted, checksum-protected data set, in order to guard against data tampering. Audit trails that capture file, system and security-related events provide traceability for most software applications. The powerful quality-control system allows one to set limits, parameters and standards based on U.S. EPA, [11]. Determination methods used in this study for analysing radionuclides and other heavy metals have been accredited according to ISO standard 17025 (European Standard EN ISO/IEC 17025:2000).

4.0 RESULTS AND DISCUSSION

4.1 Accumulation of Radionuclide (\textsuperscript{226}Ra) in Humans and Recommendations for the Maximum Permissible Limit

The activity concentrations of \textsuperscript{226}Ra that were determined in groundwater samples were used to interpret the human radiological risks of annual effective dose as presented in Table 1 using Equation (1) below.

\[
AED = \frac{AC \times DC \times AWC \times L \times y^{-1}}{1000}
\]

where,

\[AED = \text{Annual effective dose}\]
\[AC = \text{Activity concentration of } \textsuperscript{226}Ra\]
\[DC = \text{Dose coefficient for } \textsuperscript{226}Ra\]
\[AWC = \text{Annual water consumption}\]

In the present study, Equation (1) was used to determine the annual effective dose of the water samples for \textsuperscript{226}Ra 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 litres per day water consumption for adults [18 - 17]. Comparing the two boreholes in Table 1, the annual effective dose reported was far below the recommended value of 1.5 x 10\textsuperscript{-5} mSv y\textsuperscript{-1}.

**Table 1: Results of activity concentrations, Annual Effective Dose of \textsuperscript{226}Ra in Water Samples from the Study area and comparing with various countries and International Standard**

<table>
<thead>
<tr>
<th>Location</th>
<th>Activity Concentration \textsuperscript{226}Ra (µBq L\textsuperscript{-1})</th>
<th>Annual Effective Dose (mSv y\textsuperscript{-1})</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dei-Dei</td>
<td>2698</td>
<td>8.9 x 10\textsuperscript{-7}</td>
<td>Present Study</td>
</tr>
<tr>
<td>Kubwa</td>
<td>849</td>
<td>2.8 x 10\textsuperscript{-5}</td>
<td>Present Study</td>
</tr>
<tr>
<td>Gosa</td>
<td>443</td>
<td>1.5 x 10\textsuperscript{-5}</td>
<td>Present Study</td>
</tr>
<tr>
<td>Lugbe</td>
<td>2736</td>
<td>9.0 x 10\textsuperscript{-5}</td>
<td>Present Study</td>
</tr>
<tr>
<td>Water Board</td>
<td>1824</td>
<td>6.0 x 10\textsuperscript{-5}</td>
<td>Present Study</td>
</tr>
<tr>
<td>Hand-dug well</td>
<td>2430</td>
<td>8.0 x 10\textsuperscript{-5}</td>
<td>Present Study</td>
</tr>
<tr>
<td>USE USEPA, County Council</td>
<td>19,000</td>
<td>1.0 x 10\textsuperscript{-1}</td>
<td>[12,13]</td>
</tr>
</tbody>
</table>

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 International Commission on Radiological Protection, Volume 79, Number 5, 1997. Determination methods used in this study for analysing radionuclides and other heavy metals have been accredited according to ISO standard 17025 (European Standard EN ISO/IEC 17025:2000).
The radiological risk assessment was to evaluate the lifetime cancer risk associated with the intake of a given $^{226}\text{Ra}$ in groundwater. The lifetime cancer risks were calculated and the results are presented in Table 2.

### Table 2: The estimated lifetime cancer mortality and morbidity risk of $^{226}\text{Ra}$ in the water Samples.

<table>
<thead>
<tr>
<th>Location</th>
<th>Cancer Mortality Risk</th>
<th>Cancer Morbidity Risk</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dei-Dei borehole</td>
<td>$1.01 \times 10^{-7}$</td>
<td>$1.55 \times 10^{-7}$</td>
<td>Present Study</td>
</tr>
<tr>
<td>Kubwa borehole</td>
<td>$3.19 \times 10^{-8}$</td>
<td>$4.88 \times 10^{-9}$</td>
<td>Present Study</td>
</tr>
<tr>
<td>Gosa borehole</td>
<td>$1.67 \times 10^{-8}$</td>
<td>$2.55 \times 10^{-8}$</td>
<td>Present Study</td>
</tr>
<tr>
<td>Lugbe borehole</td>
<td>$1.03 \times 10^{-7}$</td>
<td>$1.57 \times 10^{-7}$</td>
<td>Present Study</td>
</tr>
<tr>
<td>Water Board</td>
<td>$6.85 \times 10^{-8}$</td>
<td>$1.05 \times 10^{-7}$</td>
<td>Present Study</td>
</tr>
<tr>
<td>Hand-dug well</td>
<td>$9.12 \times 10^{-8}$</td>
<td>$1.40 \times 10^{-7}$</td>
<td>Present Study</td>
</tr>
<tr>
<td>Odeda, Ogun state</td>
<td>$2.54 \times 10^{-4}$</td>
<td>$3.39 \times 10^{-4}$</td>
<td>[23]</td>
</tr>
</tbody>
</table>

In Table 2, the cancer mortality risks ranged from $1.8 \times 10^{-8}$ to $9.5 \times 10^{-8}$ while for morbidity risks, it ranges from $9.7 \times 10^{-8}$ to $2.8 \times 10^{-7}$. From the two boreholes in Table 3, the highest cancer mortality risk was found at Kubwa borehole with a value of $3.1 \times 10^{-8}$ and lower value reported at Gosa borehole with a value of $1.8 \times 10^{-8}$. The highest cancer morbidity of $9.7 \times 10^{-9}$ was noted at Kubwa whereas lower value of $5.2 \times 10^{-9}$ reported at Gosa borehole. In contrast with the cancer mortality and morbidity risks from Water Board, 7.2 $\times 10^{-8}$ and 2.1 $\times 10^{-7}$, Hand-dug well, 9.5 $\times 10^{-8}$ and 2.8 $\times 10^{-7}$ respectively were higher than the values obtained from Kubwa and Gosa boreholes. Comparing with a study reported by [23] in Ogun State, Nigeria, both Kubwa borehole, Water Board and Hand-dug well were lower than 2.5 $\times 10^{-8}$ and 3.4 $\times 10^{-4}$ 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 is higher at Kubwa borehole when compared with Gosa borehole; 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 enable the escape of radon gas. The cancer risk at $10^{-3}$ is lower compared to the acceptable level of $10^{-3}$ for the radiological risk [23].

### 4.2 Chemical Toxicity Risk of $^{238}\text{U}$ in Groundwater from the Study Area

The chemical toxicity was to determine the effect of the carcinogenic risks associated with chemical toxicity of $^{238}\text{U}$ in the water sample selected for this study. The chemical toxicity risk was evaluated using the lifetime average daily dose of $^{238}\text{U}$ through drinking water intake, and compared it with the reference dose (RFD) of 0.6 $\mu$g kg$^{-1}$ day$^{-1}$ [24] used as a standard criteria for $^{238}\text{U}$ in several foreign organizations and thereby produce the lifetime average daily dose (LADD), Equation (3)

$\text{LADD of drinking water} = \frac{E_P \times R \times E_F \times E_D}{AT \times BW}$

where, $LADD$ is lifetime average daily dose ($\mu$g kg$^{-1}$ day$^{-1}$), $E_P$ is the exposure point concentration ($\mu$g L$^{-1}$), $R$ is the water ingestion rate (L day$^{-1}$), $E_F$ 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, $R = 2$ L day$^{-1}$, $EF = 350$ days, $ED = 45.5$ y, $AT = 16,607.5$ (obtained from 45.5 x 365) and $BW = 70$ kg (for a standard man). The chemical toxicity risk for $^{238}\text{U}$ over a lifetime consumption was estimated and presented in Table 3.

### Table 3: The estimated lifetime average daily dose (LADD) of uranium in the water samples.

<table>
<thead>
<tr>
<th>Location</th>
<th>LADD (µg kg$^{-1}$ day$^{-1}$)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dei-Dei borehole</td>
<td>$6 \times 10^{-3}$</td>
<td>present</td>
</tr>
<tr>
<td>Kubwa borehole</td>
<td>$2 \times 10^{-3}$</td>
<td>present</td>
</tr>
<tr>
<td>Gosa borehole</td>
<td>$1 \times 10^{-3}$</td>
<td>present</td>
</tr>
<tr>
<td>Lugbe borehole</td>
<td>$6 \times 10^{-3}$</td>
<td>present</td>
</tr>
<tr>
<td>Water Board</td>
<td>$4 \times 10^{-3}$</td>
<td>Present</td>
</tr>
<tr>
<td>Hand-dug well</td>
<td>$5 \times 10^{-3}$</td>
<td>Present</td>
</tr>
<tr>
<td>RDF (Reference Dose)</td>
<td>$6 \times 10^{-1}$</td>
<td>[24]</td>
</tr>
</tbody>
</table>

In Table 3, the lifetime average daily dose (LADD) ranged from $1 \times 10^{-3}$ to $5 \times 10^{-3}$ $\mu$g kg$^{-1}$ day$^{-1}$. The LADDs values were observed to be higher in Kubwa borehole with a value of $2 \times 10^{-3}$ $\mu$g kg$^{-1}$ day$^{-1}$ compared to Gosa borehole with a value of $1 \times 10^{-3}$ $\mu$g kg$^{-1}$ day$^{-1}$. This could be due to the interbedding of 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. The lowest value of $1 \times 10^{-3}$ $\mu$g kg$^{-1}$ day$^{-1}$ was found in Gosa borehole. Comparing the LADDs from Kubwa and Gosa Boreholes to Water Board and hand-dug well, it can be noted that both boreholes were lower than $4 \times 10^{-3}$ and $5 \times 10^{-3}$ values for Water Board and hand-dug well respectively. Comparing the LADD obtained in this study with the Reference Dose (RFD) (0.6 $\mu$g kg$^{-1}$ day$^{-1}$) that is an acceptable level; the chemical toxicity risk due to $^{226}\text{Ra}$ in the water samples were all below the RFD. This shows that there may not be health risks...
associated with $^{226}\text{Ra}$ in the water samples which are mainly due to the chemical toxicity risk of $^{226}\text{Ra}$ and its progeny. However, Hand-dug well reported higher value of LADD of $^{226}\text{Ra}$ 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. In addition, the Water Board of Abuja which is the public water supply in the region noted higher than Kubwa and Gosa 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.

5.0 CONCLUSION

The mean annual effective dose from the natural radionuclide ($^{226}\text{Ra}$) for the inhabitants that rely on groundwater was estimated to be $2.2 \times 10^{-2}$ mSv of the annual collective dose. The highest annual effective dose from radionuclide was noted in Kubwa Borehole with a value of $2.8 \times 10^{-3}$ mSv y$^{-1}$. The lowest value was reported at Gosa borehole which may be due to ultrabasic intrusion of schist belt formation. The magnitude of $10^{-7}$ obtained for the radiological risks of $^{226}\text{Ra}$ in the water samples may not pose health risk to the consumers within the study area. Adequate measures for groundwater quality is needed for no amount of dose exposure is safe for long accumulation.

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