CHEMICAL AND RADIOLOGICAL HEALTH RISKS ASSESSMENT OF RADIONUCLIDES IN WATER SOURCES IN AKWA IBOM STATE, NIGERIA

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ABSTRACT

The activity concentrations of $^{40}$K, $^{238}$U, and $^{232}$Th in drinking water sources in oil and gas producing communities of Akwa Ibom State were measured using gamma ray spectroscopic system. The results obtained were used to calculate human health chemical and radiological risk over lifetime consumption by the population. The overall average activity concentrations of $^{40}$K, $^{238}$U, and $^{232}$Th were found to be 112.2; 8.5; and 9.7 Bq.L⁻¹, respectively. The results for the following communities Eket, Esit Eket and Eastern Obolo revealed concentrations higher than acceptable safe limits, while those of Ibeno, Ikot Abasi and Uyo were lower or within safe limits. The radiological risks for cancer mortality and morbidity for the three nuclides were in the range of $10^{-3}$ to $10^{-4}$, respectively. Chemical toxicity ranged from 36 to 216 μg.kg⁻¹.day⁻¹ for $^{40}$K, 3 to 216 μg.kg⁻¹.day⁻¹ for $^{238}$U and 4 to 18 μg.kg⁻¹.day⁻¹ for $^{232}$Th. Similarly, values for Eket, Esit Eket and Eastern Obolo were found to be higher than the recommended acceptable safe level by various international organizations, while those of Ibeno, Ikot Abasi and Uyo were below. The overall results reveal that there are health risks associated with the presence of $^{40}$K, $^{238}$U, and $^{232}$Th in water used for drinking and domestic purposes by these communities mainly attributable to chemical toxicity. There is urgent need for actions to protect public health in the affected communities.

KEY WORDS

Water quality, human health protection, cancer mortality and morbidity risk.

1. Introduction

Nigeria like many countries in sub-saharan Africa still face challenges in availability of clean and portable water to its ever increasing population. Most of the rural and semi-urban populations depend on raw surface and ground water for domestic and drinking purposes. It is estimated that only 48% of inhabitants of the urban and semi-urban areas and 39% of inhabitants of the rural areas have access to potable water supply [1]. The situation with the residents in the oil and gas producing communities in the Niger Delta Region of Nigeria is particularly severe as available natural water resources are threatened by pollution. Several reports in the literature have elaborated on the severity of the water crisis in this region [2-7]. Radionuclides are ubiquitous in the environment and elevated levels of uranium, thorium and their daughter products might be present in water in areas that are rich in natural radioactivity or through human activities including oil and gas operations. Recently, considerable attention has been given to low-level exposure arising from naturally occurring radionuclides, particularly $^{238}$U, $^{232}$Th, their decay products and $^{40}$K.

When ingested or inhaled, naturally occurring radionuclides are distributed among body organs according to the metabolism of the element involved, which normally exhibits varying sensitivities to radiation [8]. High concentrations of uranium greater than 15 μg.l⁻¹ in domestic water may present harmful biological effects in humans [9]. Most results from uranium studies in drinking water suggest that the safe concentration of uranium in drinking water may be within the range of proposed guideline values of 2 - 30 μg.l⁻¹ [9,10], which is equivalent to 0.11 - 1.66 Bq.l⁻¹. Uranium is a predominantly alpha-emitting radionuclide, with the potential of DNA damage if the emitted alpha particles reach the cell nuclei of the body for instance, through water ingestion [11].

Akwa Ibom state is one of the nine states in the Niger Delta Region of Nigeria, located between latitudes 4°30'N and 5°30'N and longitudes 7°30'E and 8°20'E. It has a total land area of 8,412 km², and falls within the sedimentary area of Nigeria. Approximately 75% of the state is located on coastal plain sands and alluvium which covers the whole of the southern, central and partially the northern parts while the sandstone of the Ameke formation and the underlying Imo shale cover the remaining 25% [12]. Akwa Ibom state is divided into 3 hydro geological areas based on the regional water table. They include (i) South (Ikot Abasi, Eket and Oron local government areas with water level accessible at less than
40 m). The south happens to be an area dominated by onshore/offshore petroleum oil and gas exploration with such major oil multinationals (Shell, Exxon Mobil, Agip, Elf and Total) whose activities may pose pollution challenges to available sources of drinking water.

The area is also constantly washed by the southern Atlantic ocean; (ii) the middle (Uyo, Etinan, Abak, Essien Udin, Oruk Anam, among others) with a water level value ranging between 40 and 55 m. As coastal plain sand, the lithology of the area is very favourable for the storage and extraction of groundwater. Consequently, private and commercial borehole engagement are very common in this region, especially taking advantage of high urban and consequent demographic growth and (iii) the North (Itu, Ini, Ikono, northern part of Ikot Ekpene local government areas with the water level values greater than 55 m).

There are no data on the radiological and chemical health effects of $^{238}$U, $^{232}$Th, and $^{40}$K in drinking water and domestic supplies in communities hosting oil and gas exploration activities in Akwa Ibom State. This study aims to provide data and information on the concentrations of $^{238}$U, $^{232}$Th, and $^{40}$K in the surface and underground waters and the associated radiological and chemical risks they may pose to the population. The selected communities in Akwa Ibom State include Eastern Obolo, Eket, Esit Eket, Ibene, and Ikot Abasi known as the oil and gas producing areas while Uyo a non-oil producing is used as control.

2. Materials and Methods

2.1 Study Area

Eastern Obolo is located between latitude $4^\circ56'26''N$ and longitude $7^\circ44'49''E$; Eket, latitude $4^\circ38'45''N$ and longitude $7^\circ56'26''E$; Esit Eket, latitude $4^\circ39'52''N$ and longitude $8^\circ1'40''E$; Ibeno, latitude $4^\circ34'19''N$ and longitude $7^\circ58'31''E$; Ikot Abasi, latitude $4^\circ37'33''N$ and longitude $7^\circ40'56''E$; and Uyo, latitude $5^\circ1'15''N$ and longitude $7^\circ56'3''E$, all in Akwa Ibom State. Akwa Ibom State is a state in the Niger Delta region of Nigeria. The location of sampling points within the study area is shown in Figure 1.

![Figure 1: Sampling locations within selected communities in Akwa Ibom State, Nigeria](image-url)
2.2 Sampling
A total of eighty two (82) samples; forty four (44) ground water samples and thirty eight (38) surface water samples were collected across the six local government areas under study. In all, seventy seven (77) water samples were collected from community water supply in the major oil communities of Eastern Obolo, Eket and Esit Eket, Ibeno, and Ikot Abasi; and five (5) from Uyo as a control site. A Geographical Positioning System (GPS) was used for coordinate measurement. Sampling protocols described by [13] and [14] were followed.

2.3 Radioactivity Measurement
The analysis of the radioactivity in the water samples was done using gamma-ray spectroscopy at Centre for Energy Research and development, Obafemi Awolowo University Ile-Ife and the standard procedure followed has been described elsewhere [15,16]. The detector used was a lead shielded 7.6 x 7.6cm (3x3 inches) NaI(Tl) detector crystal coupled to ORTEC 456 amplifier. The detector was connected to a computer program MAESTRO window that matched gamma energies to a library of possible isotopes. The net area under the corresponding peaks in the energy spectrum was computed by subtracting counts due to Compton scattering of higher peaks and other background sources from the total area of the peaks. From the net area, the activity concentrations in the samples were obtained using;

\[ C (\text{Bq.l}^{-1}) = K C_n \]  

Where \( C \) is the activation concentration of the radionuclide in the sample given in Bq.l\(^{-1}\), \( C_n \) is the count rate under the corresponding peak, \( K = \frac{1}{\epsilon P_{\gamma}} \). \( \epsilon \) is the detector efficiency at the specific \( \gamma \)-ray energy, \( P_{\gamma} \) is the absolute transition probability of the specific \( \gamma \)-ray energy, and \( V_s \) is the volume of the sample. Using equation 1, the activity concentrations of \(^{40}\)K, \(^{238}\)U, and \(^{232}\)Th in each of the water samples was determined [7,11,15].

3. Results and Discussion

3.1 Activity Concentrations of Radionuclides in Water
The summary of location, sample size and concentrations of radionuclides (Bq.l\(^{-1}\)) in the study area are presented in Table 1. The activity concentration of potassium ranged from 14.2 to 289.5 Bq.l\(^{-1}\); uranium ranged from 0.6 to 17.6 Bq.l\(^{-1}\) and thorium ranged from 0.1 to 20.3 Bq.l\(^{-1}\).

\[ 1 \text{Bq.l}^{-1} = 27.0 \text{pCi.l}^{-1}; 1 \mu\text{g.l}^{-1} = \frac{1 \text{pCi.l}^{-1}}{0.87} \]  

Computed mass concentration, cancer mortality and morbidity risk values, lifetime average daily dose and chronic daily intake based on average concentration values for \(^{40}\)K, \(^{238}\)U, \(^{232}\)Th, and some international standards are presented in Tables 2, 3, and 4, respectively.

<table>
<thead>
<tr>
<th>Location</th>
<th>Sample Size</th>
<th>(^{40})K Average</th>
<th>(^{40})K Range</th>
<th>(^{238})U Average</th>
<th>(^{238})U Range</th>
<th>(^{232})Th Average</th>
<th>(^{232})Th Range</th>
</tr>
</thead>
</table>
The mass concentration of uranium ranged from 102.4 ± 45.94 to 550.4 ± 190.83 µg.l⁻¹ (Table 2). Various health and environmental protection agencies have recommended a safe limit of uranium in drinking water for human beings. The World Health Organization sets the limit for uranium at 15 µg.l⁻¹ [2]; the United States Environmental Protection Agency recommends 30 µg.L⁻¹ [17, 18]; and Health Canada [19] sets the standard as 20 µg.l⁻¹. These levels were set to represent the concentration that would not result in any significant risk to health over a lifetime consumption of drinking water. All the samples exceeded the recommended limits, with Eket having the highest concentration of 550.4 µg.l⁻¹. The trend in Table 2 indicates that areas with high oil activities like Eket, Esit Eket and Eastern Obolo have high concentrations of uranium as compared to areas with little or no oil activities like Ikot Abasi and Uyo. This result is in agreement with the findings of [7] and [11].

Information on the concentration of potassium-40 in the study area is presented in Table 3. The mass concentration of potassium ranged from 1347.18 ± 429.18 to 7886.85 ± 1419.69 µg.l⁻¹.

Thorium shows similar overall trend as uranium (Table 4). The mass concentration of thorium ranged from 141.85 ± 50.78 to 668.21 ± 202.00 µg.l⁻¹. Safe limit for thorium is set at 1 Bq.l⁻¹ [2], which is equivalent to 40.3 µg.l⁻¹. Similarly, all the samples exceeded the recommended limits, with Eket having the highest concentration.

<table>
<thead>
<tr>
<th>Location</th>
<th>Concentration (µg.l⁻¹)</th>
<th>Cancer Mortality Risk</th>
<th>Cancer Morbidity Risk</th>
<th>LADD (µg.kg⁻¹.day⁻¹)</th>
<th>CDI (mg/kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esit Eket</td>
<td>7322.3 ± 1391.33</td>
<td>2.97 x 10⁻³</td>
<td>4.61 x 10⁻⁴</td>
<td>200.61</td>
<td>0.209</td>
</tr>
<tr>
<td>Eket</td>
<td>7649.8 ± 1460.80</td>
<td>3.10 x 10⁻³</td>
<td>4.81 x 10⁻⁴</td>
<td>209.58</td>
<td>0.219</td>
</tr>
<tr>
<td>Eastern Obolo</td>
<td>7886.8 ± 1419.69</td>
<td>3.19 x 10⁻³</td>
<td>4.96 x 10⁻⁴</td>
<td>216.08</td>
<td>0.225</td>
</tr>
<tr>
<td>Ibene</td>
<td>1347.2 ± 429.18</td>
<td>5.46 x 10⁻⁴</td>
<td>8.48 x 10⁻⁴</td>
<td>36.91</td>
<td>0.038</td>
</tr>
<tr>
<td>Ikot Abasi</td>
<td>1543.4 ± 464.64</td>
<td>6.25 x 10⁻⁴</td>
<td>9.71 x 10⁻⁴</td>
<td>42.29</td>
<td>0.044</td>
</tr>
<tr>
<td>Uyo</td>
<td>1374.6 ± 422.73</td>
<td>5.57 x 10⁻⁴</td>
<td>8.63 x 10⁻⁴</td>
<td>37.66</td>
<td>0.039</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location</th>
<th>Concentration (µg.l⁻¹)</th>
<th>Cancer Mortality Risk</th>
<th>Cancer Morbidity Risk</th>
<th>LADD (µg.kg⁻¹.day⁻¹)</th>
<th>CDI (mg/kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esit Eket</td>
<td>594.9 ± 179.77</td>
<td>1.05 x 10⁻⁷</td>
<td>1.53 x 10⁻⁷</td>
<td>16.30</td>
<td>4.43</td>
</tr>
<tr>
<td>Eket</td>
<td>668.2 ± 202.00</td>
<td>1.18 x 10⁻⁷</td>
<td>1.72 x 10⁻⁷</td>
<td>18.31</td>
<td>4.97</td>
</tr>
<tr>
<td>Eastern Obolo</td>
<td>519.8 ± 142.80</td>
<td>9.15 x 10⁻⁷</td>
<td>1.33 x 10⁻⁷</td>
<td>14.24</td>
<td>3.87</td>
</tr>
<tr>
<td>Ibene</td>
<td>246.2 ± 85.84</td>
<td>4.34 x 10⁻⁷</td>
<td>6.33 x 10⁻⁴</td>
<td>6.75</td>
<td>1.83</td>
</tr>
<tr>
<td>Ikot Abasi</td>
<td>141.9 ± 50.78</td>
<td>2.50 x 10⁻⁷</td>
<td>3.65 x 10⁻⁴</td>
<td>3.89</td>
<td>1.06</td>
</tr>
<tr>
<td>Uyo</td>
<td>162.8 ± 54.81</td>
<td>2.87 x 10⁻⁷</td>
<td>4.19 x 10⁻⁴</td>
<td>4.46</td>
<td>1.21</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Risk Assessment</th>
<th>Concentration (µg.l⁻¹)</th>
<th>Cancer Mortality Risk</th>
<th>Cancer Morbidity Risk</th>
<th>LADD (µg.kg⁻¹.day⁻¹)</th>
<th>Concentration (mrem/yr)</th>
<th>CDI (mg/kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Esit Eket</td>
<td>594.9 ± 179.77</td>
<td>1.05 x 10⁻⁷</td>
<td>1.53 x 10⁻⁷</td>
<td>16.30</td>
<td>4.43</td>
<td>0.017</td>
</tr>
<tr>
<td>Eket</td>
<td>668.2 ± 202.00</td>
<td>1.18 x 10⁻⁷</td>
<td>1.72 x 10⁻⁷</td>
<td>18.31</td>
<td>4.97</td>
<td>0.019</td>
</tr>
<tr>
<td>Eastern Obolo</td>
<td>519.8 ± 142.80</td>
<td>9.15 x 10⁻⁷</td>
<td>1.33 x 10⁻⁷</td>
<td>14.24</td>
<td>3.87</td>
<td>0.015</td>
</tr>
<tr>
<td>Ibene</td>
<td>246.2 ± 85.84</td>
<td>4.34 x 10⁻⁷</td>
<td>6.33 x 10⁻⁴</td>
<td>6.75</td>
<td>1.83</td>
<td>0.007</td>
</tr>
<tr>
<td>Ikot Abasi</td>
<td>141.9 ± 50.78</td>
<td>2.50 x 10⁻⁷</td>
<td>3.65 x 10⁻⁴</td>
<td>3.89</td>
<td>1.06</td>
<td>0.004</td>
</tr>
<tr>
<td>Uyo</td>
<td>162.8 ± 54.81</td>
<td>2.87 x 10⁻⁷</td>
<td>4.19 x 10⁻⁴</td>
<td>4.46</td>
<td>1.21</td>
<td>0.005</td>
</tr>
</tbody>
</table>

WHO MCL (2003)  
USEPA MCL (2003)  

Table 2: Computed mass concentration, cancer mortality and morbidity risk values, lifetime average daily dose and chronic daily intake based on average concentration values for U-238

Table 3: Computed mass concentration, cancer mortality and morbidity risk values, lifetime average daily dose and chronic daily intake based on average concentration values for K-40, and some international standards

Table 4: Computed mass concentration, cancer mortality and morbidity risk values, lifetime average daily dose and chronic daily intake based on average concentration values for Th-232, and some international standards
3.2 Radiological Risk Assessment
The lifetime cancer risks, R, associated with intake of a given radionuclide was estimated from the product of the applicable risk coefficient, r, and the per capita activity intake, I, expressed in equation (3).

\[ R = r \times I \]  

(3)

According to World Bank [20], the average life expectancy at birth in Nigeria for an adult man is 52 years, and an annual consumption of water for an individual is about 730 L (2 litres per day for 365 days). This brings the lifetime intake of water to 37,960 litres. The cancer risk coefficients for uranium-238 are 1.13 × 10⁻⁶ Bq⁻¹ and 1.73 × 10⁻⁹ Bq⁻¹; thorium-232: 1.87 × 10⁻⁹ Bq⁻¹ and 2.73 × 10⁻⁹ Bq⁻¹; and potassium-40: 4.30 × 10⁻¹⁰ Bq⁻¹ and 6.68 × 10⁻¹⁰ Bq⁻¹, for mortality and morbidity, respectively, were obtained from literature [17, 21]. Using equation 3, and these coefficients the cancer mortality and morbidity risks of ⁴⁰K, ²³⁸U, and ²³²Th over lifetime consumption of water in the study area were calculated. The results obtained are presented in Table 2. The cancer mortality risk for uranium ranged from 1.09 × 10⁻⁴ to 5.86 × 10⁻⁵, while the cancer morbidity risk ranged from 1.67 × 10⁻⁴ to 8.97 × 10⁻⁵. The cancer risk level with an average of ~10⁻⁴ is lower compared to the acceptable level of 10⁻³ for the radiological cancer risk [7, 11, 22].

For Thorium, the cancer mortality risk ranged from 2.50 × 10⁻⁴ to 1.18 × 10⁻⁵. The cancer morbidity risk ranged from 3.65 × 10⁻⁴ to 1.72 × 10⁻⁵ (Table 3). The cancer risk levels obtained were either lower or equal to acceptable level of 10⁻³ for the radiological cancer risk [7, 11, 22].

The potassium cancer mortality risk ranged from 5.46 × 10⁻⁴ to 3.19 × 10⁻³. The cancer morbidity risk ranged from 8.48 × 10⁻⁴ to 4.96 × 10⁻³. The lowest and highest values were in Ibeno and Eastern Obolo, respectively. Although there is no standard reference limit or maximum contaminant level for potassium, what is ingested is readily absorbed into the bloodstream and distributed throughout the body, with homeostatic controls regulating how much is retained or cleared. However it is reported that the health hazard of potassium-40 is associated with cell damage caused by the ionizing radiation that results from radioactive decay, with the general potential for subsequent cancer induction [23]. Therefore, Eastern Obolo, Eket and Esit Eket with high concentrations of potassium may be prone to cancer induction.

3.3 Chemical Toxicity Assessment
The chemical toxicity risk was evaluated using the lifetime average daily dose (LADD) of ⁴⁰K, ²³⁸U, and ²³²Th through water intake, and compared with the reference dose (RFD) of 0.6 μg.kg⁻¹.day⁻¹ (Uranium) and 4 mrem/yr (Thorium), respectively [22, 24, 25]. These are used as standard criteria for ⁴⁰K, ²³⁸U, and ²³²Th and a hazard quotient is calculated from equation 4 below.

\[ \text{Hazard quotient} = \frac{\text{LADD}}{\text{RFD}} \]  

(4)

And

\[ \text{Ingestion LADD of drinking water} = \frac{\text{EPC} \times \text{IR} \times \text{EF} \times \text{ED}}{\text{AT} \times \text{BW}} \]  

(5)

Where: LADD, 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, IR = 2 litres.day⁻¹; EF = 350 days, ED = 52 years, AT = 18, 980 (obtained from 52 × 365) days, and BW = 70 kg (for a standard man) the chemical toxicity risk of ⁴⁰K, ²³⁸U, and ²³²Th over a lifetime consumption was estimated.

The estimated lifetime average daily dose (LADD) results for uranium-238 are presented in Table 2. The LADD values obtained ranged from 2.80 to 15.08μg.kg⁻¹.day⁻¹. The LADD values were observed to be higher in Eket, Esit Eket, and Eastern Obolo where oil exploration and production activities occur, unlike Ikot Abasi and Uyo where there are little or no such activities. The results agree with other findings [7]. A comparison of the lifetime average daily dose (LADD) obtained in this study and the reference dose (RFD) of 0.6 μgkg⁻¹.day⁻¹ which is the acceptable level, reveal that the chemical toxicity risk due to uranium in the water samples were all above the reference dose. Signifying that there may be health risks associated with uranium in the water samples which are mainly due to chemical toxicity.
The LADD values obtained for thorium ranged from 3.89 to 18.31 μg kg\(^{-1}\) day\(^{-1}\). According to Florida Department of Environmental Protection, the average annual concentration of beta particle and photon radioactivity from man-made radionuclides in drinking water, like thorium, should not produce a total annual exposure greater than 4 millirem/year [26]; a maximum contaminant level (MCL) corroborated by many international organizations [2, 18, 19]. The Department recommends that the concentration of thorium be calculated on the basis of a 2 liter per day water intake for group G; \(P_g\) = Exposed population group (number of people exposed); \(R_{ig}\) = Excess lifetime cancer risk for the \(i_g\) chemical for the most exposed subject in group, G. (maximum individual risk). The chronic daily intake of radionuclides is summarized in Tables 2, 3 and 4. Results for the lifetime risk (R) and excess cancer burden (B) based on the population of the study area are presented in Table 5.

**3.4 Cancer Burden on the Population**

In order to evaluate the excess cancer burden within a population in the study area, the lifetime risk, R, can also be expressed in terms of the product of the chronic daily intake (CDI) which is also called the average daily dose, and the potency factor (PF) of the radionuclide [29], expressed in the following equations:

\[
R = CDI \times PF \tag{6}
\]

And

\[
CDI = \frac{EPC \times IR}{BW} \tag{7}
\]

Where EPC is the exposure point concentration of radionuclide (mg/l); IR is the water ingestion rate (l.day\(^{-1}\)) and BW is the body weight (kg). Using, IR = 2 l.day\(^{-1}\) and BW = 70 kg, the CDI was estimated. PF is 2.47 \times 10^{-13} risk/pCi (9.55 \times 10^{-14} risk/mg) for \(^{238}\)U; and 1.01 \times 10^{-10} risk/pCi (1.51 \times 10^{-14} risk/mg) for \(^{234}\)Th [30]. The excess cancer burden (B) is a product of the population [31] and the lifetime risk (R) [29], given by the expression:

\[
B = R \times P \tag{8}
\]

That is,

\[
B_{ig} = R_{ig} \times P_g \tag{9}
\]

**Table 5: Computed lifetime risk (R) and excess cancer burden (B) based on the population of the study area**

<table>
<thead>
<tr>
<th></th>
<th>(^{40})K</th>
<th>(^{238})U</th>
<th>(^{234})Th</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population (^*)</td>
<td>Lifetime Risk</td>
<td>Cancer Burden</td>
<td>Lifetime Risk</td>
</tr>
<tr>
<td>Esit Eket</td>
<td>(63701)</td>
<td>(7.72 \times 10^{13})</td>
<td>(4.92 \times 10^{-10})</td>
</tr>
<tr>
<td>Eket</td>
<td>(172557)</td>
<td>(8.06 \times 10^{14})</td>
<td>(1.39 \times 10^{-09})</td>
</tr>
<tr>
<td>Eastern Obolo</td>
<td>(60543)</td>
<td>(8.31 \times 10^{13})</td>
<td>(5.03 \times 10^{-10})</td>
</tr>
<tr>
<td>Ikpo Abasi</td>
<td>(75380)</td>
<td>(1.42 \times 10^{15})</td>
<td>(1.07 \times 10^{-10})</td>
</tr>
<tr>
<td>Uyo</td>
<td>(309573)</td>
<td>(1.63 \times 10^{14})</td>
<td>(2.15 \times 10^{-10})</td>
</tr>
<tr>
<td>Total</td>
<td>(813777)</td>
<td>(2.86 \times 10^{14})</td>
<td>(2.33 \times 10^{-08})</td>
</tr>
</tbody>
</table>

\(^*\)[31]
is the case with Uyo. Therefore, the excess cancer burden increases with population.

4. Conclusion

The activity concentration of uranium-238, thorium-232 and potassium-40 in surface and underground water samples in Eket, Esit Eket, Eastern Obolo, Ibeno, Ikot Abasi and Uyo local government areas of Akwa Ibom State, Nigeria have been measured using gamma spectroscopy. The average mass concentration of uranium in the area exceeded the recommended limits by various international organizations, with Eket having the highest concentration. Cancer mortality and morbidity risk values for uranium were found to be in agreement with other reported values within the country and are well below acceptable level. The chemical toxicity risk of uranium were found to be higher in Eket, Esit Eket and Eastern Obolo, and lower in Uyo, Ikot Abasi and Ibeno, but all above the acceptable level of 0.6 µgkg⁻¹day⁻¹. It could therefore be concluded that health risk due to uranium content in water supplies from ingestion in the study area may be attributed to chemical toxicity of uranium as a heavy metal rather than radiological risk. The mass concentration of thorium also exceeded the acceptable safe limit. The cancer risk levels obtained for thorium were either lower or equal to acceptable level. However, for chemical toxicity, Eket and Esit Eket exceeded the maximum 4 mrem/yr exposure limit, making the area prone to chemical toxicity resulting from presence of thorium in drinking water. The concentrations of potassium were found to be high, with the possibility of cancer induction. Cancer burden is seen to increase with population. The study showed that the radioactivity concentration in water sources used for drinking and domestic purposes by the populace of the studied area is in the following order of magnitude; Ikot Abasi < Uyo < Ibeno < Eastern Obolo < Esit Eket < Eket. There is need for further investigation to protect public health.

References


[29] H. I. Inyang, Beyond contaminant concentration measurements: use of data in contaminant migration analyses and environmental risk assessment. An invited lecture by a Duke Energy Distinguished Professor of Environmental Engineering and Science, and Professor of Earth Science, University of North Carolina, Charlotte, USA at the University of Uyo, Uyo, on 3rd January, 2013.
