Systematic Characterization of Soil along River Kaduna, Nigeria

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Abstract

Soil samples from flooded parts of river Kaduna, (latitude 10°27’00”N and 10°30’00”N and longitude 7°24’00”E and 7°24’00”E) in Angwan Muazu, Kaduna State, Nigeria were analyzed for Naturally Occurring Radioactive Materials (NORMS) using gamma spectrometry. Samples were taken systematically in the area at depths of (0-5, 5-25, 25-50, 50-100)cm. The Sodium Iodide (NaI(Tl)) detector in a low background configuration was used for the activity concentrations for $^{40}$K, $^{226}$Ra and $^{232}$Th. A similar study, the control (where no flooding occurred) was also carried out (using same profile depths as above). Results showed that the maximum activity concentrations at the control site (802.1±7.1, 49.80±4.3 and 146.40±3.7Bqkg$^{-1}$) were lower than those where the flood occurred (885.46±12.4, 50.93±4.3 and 168.72±5.3Bqkg$^{-1}$, respectively for $^{40}$K, $^{226}$Ra and $^{232}$Th). The lowest activity concentrations respectively for $^{40}$K, $^{226}$Ra and $^{232}$Th were : (649.0±8.3, 11.5±3.5 and 68.0±2.6Bqkg$^{-1}$ and 840.7±12.9, 7.51±3.5 and 43.42±4.1Bqkg$^{-1}$) for the control and flooded areas respectively. Further radioactivity measurements (for the flooded area) were also calculated from the acquired samples respectively for each profile depth to obtain: The absorbed dose rate (D) in air at 1 metre above the ground surface (104.72±3.66, 103.82±4.33, 115.73±4.55and 142.70±5.05 (nGr/hr)); The external and Internal hazard index ($H_{Ext}$and $H_{Int}$); ($H_{Ext}$: 154.12±5.39, 152.80±6.37, 170.31±6.69 and 210.01±7.44; $H_{Int}$ : 616.48±21.55, 611.18±25.46, 681.25±26.77 and 840.05±29.74 (Bq/Kg)). The radium equivalent activity ($Ra_{eq}$) (217.47±8.00, 215.42±9.45, 241.07±9.94 and 299.19±11.04 (Bq/Kg)); and the Activity Concentration Index (I ) (0.80±0.03, 0.79±0.03, 0.89±0.03 and 1.09±0.04). Comparing the flooded area obtained values of the $Ra_{eq}$ with the world accepted safety limit value of 370 Bq.kg$^{-1}$ further reveals from the current work that there is no posed radiological hazard in the usage of the soil at the area.

KEYWORDS: Absorbed Dose Rate (D), Annual Effective Dose Equivalent (AEDE), Radium Equivalent Activity (Raeq), External Hazard Index (Hex), Gamma Spectrometry

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INTRODUCTION
Soil is a mixture of organic matter, minerals, gases, liquids, and organisms that together support life (Voroney, 2007). Soil is a product of the influence of climate, relief (elevation, orientation, and slope of terrain), organisms, and its parent materials (original minerals) interacting over time (Mbah, 2018). It continually undergoes development by way of numerous physical, chemical and biological processes, which include weathering with associated erosion. Given its complexity and strong internal connectedness, it is considered an ecosystem by soil ecologists. (Komarov et al, 2017).Flooding on the other hand is a common transitory circumstance of partial or whole inundation of normally dry areas from overflow of inland or tidal waters or from unusual and rapid buildup or runoff. Flooding occurrence is considered the world’s worst global peril in terms of enormousness, occurrence, and geographical spread, loss of life and property, and displacement of people and socio-economic activities (Varrani et al, 2017). As human beings, we are constantly bare to natural radiation from within and outside earth. The initial arises from the natural radioactivity in soil (from $^{238}$U and $^{234}$Th series and $^{40}$K) while the latter from cosmic and other sources outside the earth. The assessment of gamma radiation dose from natural sources is of particular significance as natural radiation is the largest contributor to the external dose of world population (Yu et al, 1994). External gamma dose estimation due to the terrestrial sources is essential as these doses vary depending upon to concentrations of natural radionuclides, $^{238}$U, $^{234}$Th their daughter and $^{40}$K, present in the soils and rocks which further depends upon the local geology of each region in the world (Becket al, 1972). Many studies have been carried out worldwide in order to determine the risks and effects of long term, low level and natural radiation exposure (Sohrabi, 1998).This study therefore serves a base line for assessing the radiological risks associated with the flooded soil along river Kaduna, Nigeria.

MATERIALS AND METHODS
Study Area
Kaduna is the state capital of Kaduna State in north-western Nigeria. The Kaduna River is a tributary of the Niger River which flows for 550 kilometers through Nigeria. The study area along the river Kaduna specifically in Angwan Muazu, Kaduna State had coordinates latitude $10^\circ27'00"N$ and $10^\circ30'00"N$ and longitude $7^\circ24'.00"E$ and $7^\circ24'.00"E$.

Sample Site Selection
A simple systematic random sampling technique was used to select the locations sampled along the river in the study area. Samples were collected according to the specified distances as show Znin Figure 1 and at depths of (0-5, 5-25, 25-50, 50-100).

Table 1: Location grid of selected points

<table>
<thead>
<tr>
<th>S</th>
<th>N</th>
<th>GRID POINTS</th>
<th>LATITUDE</th>
<th>LONGITUDE</th>
<th>SAMPLING REQUIREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>P</td>
<td>$10^\circ27'00&quot;N$</td>
<td>$7^\circ24'00&quot;E$</td>
<td>Soil samples</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Q</td>
<td>$10^\circ30'00&quot;N$</td>
<td>$7^\circ24'03&quot;E$</td>
<td>Soil Samples</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>R</td>
<td>$10^\circ27'22&quot;N$</td>
<td>$7^\circ25'10&quot;E$</td>
<td>Soil samples</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>S</td>
<td>$10^\circ30'22&quot;N$</td>
<td>$7^\circ25'13&quot;E$</td>
<td>Soil Samples</td>
<td></td>
</tr>
</tbody>
</table>
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Collection and preparation of samples
Thirty seven (37) soil samples were collected, dried under ambient room temperature and analyzed for gamma spectrometry using a 7.62 cm x 7.62 cm NaI(Tl) detector with an energy resolution of 7.2 at 661.6 keV γ-ray energy from $^{137}$Cs located inside the low background counting laboratory, an IAEA certified laboratory, at the Centre for Energy Research and Training (CERT), Ahmadu Bello University (ABU), Zaria. The spectral and live times of the NORMs were acquired using MAESTRO software.

Theoretical Considerations

Assessment of Radiation Hazard Associated with NORM
In this study, radiological parameters such as the radium equivalent indices, the external and internal hazard indices, the indoor absorbed dose rate and the annual effective dose will be used to determine the potential radiation hazard associated with the soil samples associated with the flooded river bank.

1  Radium Equivalent Activity.
The Radium equivalent activity is used to assess the hazards associated with materials that contain $^{226}$Ra, $^{232}$Th and $^{40}$K in Bq/Kg, and it is mathematically defined in Equation 1. It represents the activity levels of $^{226}$Ra, $^{232}$Th and $^{40}$K by a single quantity which takes into account the radiation hazards associated with Equation (1).

\[
Ra_{eq} \text{ (Bq.Kg}^{-1}) = A_{Ra} + 1.43A_{Th} + 0.077A_{K} \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots
\]

2  Absorbed Dose (D)
From equation 2. It has been assumed that 10Bq.Kg$^{-1}$ of $^{226}$Ra, 7Bq.Kg$^{-1}$ of $^{232}$Th and 130 Bq.Kg$^{-1}$ of $^{40}$K produce equal gamma dose.
The uniform distribution of the naturally occurring radionuclides ($^{226}$Ra, $^{232}$Th and $^{40}$K) will be calculated based on guidelines provided by UNSCEAR (2000). We assumed that the contributions from other naturally occurring radionuclides were insignificant. Therefore, the Dose, D, can be calculated to by UNSCEAR (2000) as:

$$D \text{ (nGy.h}^{-1}) = 0.462A_{Ra} + 0.621A_{Th} + 0.0417A_{K}$$

To estimate the annual effective dose rates, the conversion coefficients from absorbed dose in air to effective dose (0.75Sv.Gy$^{-1}$) and outdoor occupancy factor (0.2) proposed by UNSCEAR, (2000) will be used. Therefore, the annual effective dose rate (mSv.Yr$^{-1}$) will be calculated.

Effective Dose rate (mSv.Yr$^{-1}$) = $D \text{ (nGy.Yr}^{-1}) \times 8760h.yr^{-1} \times 0.7 \times (10^3\text{mSv}/10^9\text{nGy}) \times 0.2$

$$= D \times 1.21 \times 10^{-3} \text{ (mSv.Yr}^{-1})$$

3 External ($H_{ex}$) and Internal ($H_{in}$) Radiation hazard Indices.

A widely used hazard index (reflecting the external exposure) called the external Hazard Index, $H_{ex}$, defined by (Beretka and Matthew, 1985)

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810}$$

In addition to External Hazard Index, radon and its short-lived products are also hazardous to the respiratory organs. The internal exposure to radon and its daughter products is quantified by Internal Hazard Index, $H_{in}$, which is given by:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810}$$

The values of the indices ($H_{ex}$, $H_{in}$) must be less than unity for the radiation hazard to be negligible.

RESULTS AND DISCUSSION

The activity concentration (Bq/Kg) at each depth profile level of the flooded area for $^{40}$K, $^{226}$Ra and $^{232}$Th are shown in Fig. 2, 3 and 4 respectively for each of the sampled grid points A-K with depths, and further a similar plot using values from the control area (where no flooding occurred) i.e. Fig. 5, 6 and 7 respectively for each of the sampled grid points C-K with depths. From (0.00 -5.00, 5.00-25.00, 25.00-50.00, 50.00 -100.00) cm, it is obvious that the highest activity concentrations of $^{40}$K, $^{226}$Ra and $^{232}$Th are 885.46±12.4 (grid point D), 50.93±4.3 (grid point D) and 168.72±5.3Bqkg$^{-1}$ (grid point J), respectively, at depth 50-100cm. The same is also glaring for the control area which has its highest activity concentrations of $^{40}$K, $^{226}$Ra and $^{232}$Th to be 802.1±7.1 (grid point C), 49.80±4.3 (grid point C) and 146.40±3.7Bqkg$^{-1}$ (grid point C), respectively, at depth 50-100cm. Similarly, the lowest activity concentrations were at respectively at depth 0-<5cm. From Fig 2-9, it is obvious again that the lowest activity concentrations of $^{40}$K, $^{226}$Ra and $^{232}$Th are 840.7±12.9 (grid point K), 7.51±3.5 (grid point E) and 43.42±4.1Bqkg$^{-1}$ (grid point E), respectively, at depth 50-100cm. The same is also glaring for the control area Fig. 5 - 8, which has its lowest activity concentrations of $^{40}$K, $^{226}$Ra and $^{232}$Th to be
649.0±8.3 (grid point C), 11.5±3.5 (grid point C), and 68.0±2.6 Bq kg\(^{-1}\) (grid point C). Generally, it can also be observed from Fig. 2 – 7, that the activity concentrations increased with a gradual increase in depth (0.00-100.00 cm).

Comparing this current study with accepted world mean activity concentrations in soil (Table 3 and 4) respectively for the flooded area and the control area. According to the UNSCEAR,2000 report, the worldwide activity concentrations of \(^{40}\)K, \(^{226}\)Ra and \(^{232}\)Th were reported to be 17-60, 11-64 and 140-850 Bq/kg having mean concentrations of 35, 30 and 400 Bq kg\(^{-1}\), respectively. From the computations of this work, the obtained results show that the activity concentrations of \(^{40}\)K, \(^{226}\)Ra and \(^{232}\)Th in all the soil samples of the control area were slightly lower than the flooded region, this indicating that the flooded river must have contributed to the increased activity concentration of the region. Further only the values of \(^{226}\)Ra for both the control and flooded region (31.0±3.9 and 28.9±4.3) respectively fell within the world range. Both the mean activities of \(^{40}\)K and \(^{232}\)Th (Flooded area and control) were slightly higher value than the worldwide mean concentration.

Further radioactivity measurements were also calculated from the acquired samples which are:

- The absorbed dose rate (\(D\)) in air at 1 metre above the ground surface;
- The annual effective dose equivalent (\(AEDE\)) from outdoor terrestrial gamma radiation;
- The external and Internal hazard index (\(H_{Eext}\) and \(H_{Eintr}\));
- The radium equivalent activity (\(Ra_{eq}\));
- and the Activity Concentration Index (\(I\)).

The mean absorbed dose rate (of the calculated value) are 0.13±0.00; 0.12±0.01; 0.14±0.01 and 0.17±0.01 mSv/yr. (Flooded area) and also 0.11±0.00; 0.12±0.00; 0.12±0.00 and 0.15±0.01 mSv/yr. (Control area) all respectively for each of the profile depths which ranged from: 0-<5; 5-<25; 25-<50 and 50-<100 cm. Since the absorbed dose rate in air at 1 metre above the ground surface does not directly provide the radiological risk to which an individual is exposed (Santawamaitre et al., 2010). The annual effective dose equivalent from outdoor terrestrial gamma radiation would have to be estimated by taking into account the conversion coefficients from absorbed dose in air to effective dose and the outdoor and indoor occupancy factor. The acceptable annual effective dose for members of the public without constraint should be 1.0 mSv/yr. for safety purposes (ICRP, 1990; Schauer et al., 2009). However under radiological constraints for an adequate protection of potential users of 0.5 mSv/y as recommended by EC report (1999) in which all the values obtained in the current work were comparable to that.

To assess whether these soils would not constitute hazard when used as building materials by the people of the area also necessitated the calculation of the radium equivalent activity (\(Ra_{eq}\)). The values of \(Ra_{eq}\) ranged from 217.47±8.00 to 299.19±11.04 Bq kg\(^{-1}\) for the flooded area (Table 5) which was slightly higher, though not significantly larger than the control area values which ranged from: 189.73±7.01 to 267.47±9.23 Bq kg\(^{-1}\) for the (control area) (Table 5). This indicated that there is no posed radiological hazard in the usage of the soil. Further, comparing the flooded area obtained values of the \(Ra_{eq}\) with the world accepted safety limit value of 370 Bq kg\(^{-1}\) (UNSCEAR, 1988; Belivermis et al., 2010) clarifies the assertion as to whether the soil materials when used for building will constitute a health hazard of radiation.
Fig. 2: Plot of Activity Concentration of K-40 at Sampled Locations with Depth.

Fig. 3: Plot of Activity Concentration of Ra-226 at Sampled Locations with Depth.
Fig. 4: Plot of Activity Concentration of Th-232 at Sampled Locations with Depth.

Fig. 5: Concentration of K at Sampled Locations with Depth. (Control Area)
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Fig. 6: Concentration of Ra at Sampled Locations with Depth. (Control Area)

Fig. 7: Concentration of Th at Sampled Locations with Depth. (Control Area)

Table 3: Comparison of the Mean Activity Concentrations of K-40, Ra-226 and Th-232 at each Profile Depth With Corresponding World Mean Values.

<table>
<thead>
<tr>
<th>Sampled Depths (cm)</th>
<th>K-40</th>
<th>Activity Concentration (Bq/Kg)</th>
<th>Ra-226</th>
<th>Th-232</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 - &lt; 5.00</td>
<td>656.8 ± 12.3</td>
<td>18.7 ± 3.9</td>
<td>103.8 ± 2.2</td>
<td></td>
</tr>
<tr>
<td>5.00 - 25.00</td>
<td>696.2 ± 12.4</td>
<td>23.6 ± 4.2</td>
<td>96.8 ± 3.0</td>
<td></td>
</tr>
<tr>
<td>25.00 - 50.00</td>
<td>734.6 ± 12.5</td>
<td>31.5 ± 4.4</td>
<td>107.2 ± 3.2</td>
<td></td>
</tr>
<tr>
<td>50.00 - 100.00</td>
<td>775.7 ± 13.8</td>
<td>41.7 ± 4.8</td>
<td>138.5 ± 3.7</td>
<td></td>
</tr>
<tr>
<td>MEAN</td>
<td>715.8 ± 12.7</td>
<td>28.9 ± 4.3</td>
<td>111.6 ± 3.0</td>
<td></td>
</tr>
<tr>
<td>World Wide Range</td>
<td>140 - 850</td>
<td>17 – 60</td>
<td>11 – 64</td>
<td></td>
</tr>
<tr>
<td>World Wide Mean</td>
<td>400</td>
<td>35</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>
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Table 4: Comparism of the Mean Activity Concentrations of K-40, Ra-226 and Th-232 at each Profile Depth With Corresponding World Mean Values [Control Area]

<table>
<thead>
<tr>
<th>Sampled Depths (cm)</th>
<th>K-40</th>
<th>Activity Concentration (Bq/Kg)</th>
<th>Ra-226</th>
<th>Th-232</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00 – 5.00</td>
<td>657.9±7.7</td>
<td>24.0± 3.5</td>
<td>80.6± 2.0</td>
<td></td>
</tr>
<tr>
<td>5.00 – 25.00</td>
<td>664.8±7.9</td>
<td>28.2± 3.7</td>
<td>88.5± 2.0</td>
<td></td>
</tr>
<tr>
<td>25.00 – 50.00</td>
<td>706.4±7.4</td>
<td>32.9± 4.1</td>
<td>87.2± 2.5</td>
<td></td>
</tr>
<tr>
<td>50.00 – 100.00</td>
<td>739.1±8.0</td>
<td>39.0± 4.2</td>
<td>120.2± 3.1</td>
<td></td>
</tr>
<tr>
<td>MEAN</td>
<td>692.1± 7.8</td>
<td>31.0± 3.9</td>
<td>94.1± 2.4</td>
<td></td>
</tr>
<tr>
<td>World Wide Range</td>
<td>140 - 850</td>
<td>17 - 60</td>
<td>11 - 64</td>
<td></td>
</tr>
<tr>
<td>World Wide Mean</td>
<td>400</td>
<td>35</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

Table 5: The Calculated Dose rate (D), Annual Effective Dose Equivalent, Hazard Index (H\(_e\)) (External and Internal), Radium Equivalent Activity (\(Ra_{eq}\)) and the Activity Concentration Index (\(I\))

<table>
<thead>
<tr>
<th>Profile depth (cm)</th>
<th>D (nG(_\Gamma)/hr)</th>
<th>D (mSv/y)</th>
<th>(H_e) (Outdoor) (Bq/Kg)</th>
<th>(H_e) (Indoor) (Bq/Kg)</th>
<th>(Ra_{eq}) (Bq/Kg)</th>
<th>I (Bq/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5</td>
<td>104.72±3.66</td>
<td>0.13±0.00</td>
<td>154.12±5.39</td>
<td>616.48±21.55</td>
<td>217.47±8.00</td>
<td>0.80±0.03</td>
</tr>
<tr>
<td>5–25</td>
<td>103.82±4.33</td>
<td>0.12±0.01</td>
<td>152.80±6.37</td>
<td>611.18±25.46</td>
<td>215.42±9.45</td>
<td>0.79±0.03</td>
</tr>
<tr>
<td>25–50</td>
<td>115.73±4.55</td>
<td>0.14±0.01</td>
<td>170.31±6.69</td>
<td>681.25±26.77</td>
<td>241.07±9.94</td>
<td>0.89±0.03</td>
</tr>
<tr>
<td>50–100</td>
<td>142.70±5.05</td>
<td>0.17±0.01</td>
<td>210.01±7.44</td>
<td>840.05±29.74</td>
<td>299.19±11.04</td>
<td>1.09±0.04</td>
</tr>
</tbody>
</table>

Table 6: The Calculated Dose rate (D), Annual Effective Dose Equivalent, Hazard Index (H\(_e\)) (External and Internal), Radium Equivalent Activity (\(Ra_{eq}\)) and the Activity Concentration Index (\(I\)) [Control Area]

<table>
<thead>
<tr>
<th>Profile depth (cm)</th>
<th>D (nG(_\Gamma)/hr)</th>
<th>D (mSv/y)</th>
<th>(H_e) (Outdoor) (Bq/Kg)</th>
<th>(H_e) (Indoor) (Bq/Kg)</th>
<th>(Ra_{eq}) (Bq/Kg)</th>
<th>I (Bq/Kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–5</td>
<td>91.60±3.18</td>
<td>0.11±0.00</td>
<td>134.80±4.69</td>
<td>539.20±18.74</td>
<td>189.73±7.01</td>
<td>0.70±0.02</td>
</tr>
<tr>
<td>5–25</td>
<td>98.93±3.26</td>
<td>0.12±0.00</td>
<td>145.60±4.80</td>
<td>582.40±19.20</td>
<td>205.71±7.19</td>
<td>0.76±0.03</td>
</tr>
<tr>
<td>25–50</td>
<td>101.84±4.69</td>
<td>0.12±0.00</td>
<td>149.88±5.43</td>
<td>599.52±21.71</td>
<td>211.78±8.14</td>
<td>0.78±0.03</td>
</tr>
<tr>
<td>50–100</td>
<td>127.79±4.19</td>
<td>0.15±0.01</td>
<td>188.06±6.17</td>
<td>752.24±24.69</td>
<td>267.47±9.23</td>
<td>0.98±0.03</td>
</tr>
</tbody>
</table>

CONCLUSION

The soil samples along the flooded bank of river Kaduna which were analyzed for naturally occurring radionuclides using gamma spectrometry technique, making use of the Sodium Iodide (NaI(Tl)) detector in a low background configuration for the activity concentrations for \(^{40}\)K, \(^{226}\)Ra and \(^{232}\)Thshowed that the maximum activity concentrations in the area were within the tolerable limit of \((885.46±12.4, 50.93±4.3 \text{ and } 168.72±5.3 \text{Bqkg}^{-1})\), respectively for, \(^{40}\)K, \(^{226}\)Ra and \(^{232}\)Th. Comparing the flooded area obtained values of the \(Ra_{eq}\) with the world accepted safety limit value of 370 Bq.kg\(^{-1}\) further reveals from the current work that there is no posed radiological hazard in the usage of the soil.
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