Radionuclide Concentration and Lifetime Cancer Risk Due to Gamma Radioactivity from Quarry Stone Aggregates in Jos and Its Environs, North Central Nigeria

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Abstract

Naturally occurring radionuclides 238U, 232Th and 40K present in crushed stone aggregates from seven (7) quarries in Jos and its environs were measured using Gamma Ray Spectrometer. This is mainly for the purpose of evaluating the radiation health hazard indices and excess lifetime cancer risk (ELCR) that may arise due to the use of such crushed stones for building construction. Mean concentration of 238U, 232Th and 40K from the quarries were found to be 4.0-15.1 ppm, 25.7-51.7 ppm, and 3.9%-4.4%, while their activity concentration range from 49.5-186.5 Bq kg\(^{-1}\) for 238U, 104.3-209.9 Bq kg\(^{-1}\) for 232Th, and 1158.1-1471.1 Bq kg\(^{-1}\) for 40K respectively. Absorbed dose in air (149.85–264.35 mGy h\(^{-1}\)), annual effective dose equivalents for internal and external (0.69-1.22 mSv y\(^{-1}\) and 0.23-0.41 mSv y\(^{-1}\)), hazard indices (1.00-2.05 indoor, and 0.87-1.53 outdoor), and radium equivalent activity (317.51-573.11 Bq kg\(^{-1}\)) were calculated. These values are higher than the world's averages. Total excess lifetime cancer risk (ELCR) from the quarries was found to be 3.21×10\(^{-3}\) - 5.68×10\(^{-3}\) with an average of 4.45x10\(^{-3}\). This is 15.34 times higher than the world average of 0.29x10\(^{-3}\) below which negligible risk of developing cancer has been stated. Crushed stones from quarries in Jos and its environs therefore may have contributed significantly to cancer risks in this area.

Keywords: Quarry; Crushed Stones; Uranium; Thorium; Potassium; Activity Concentration; Hazard Indices; Excess Lifetime Cancer Risk; Jos Environs.

1. Introduction

Quarry stones are construction aggregate produced by breaking removed rocks into desired sizes using a crusher or hammer. Due to their angular surface which makes it easy to roll and key into cement mix, crushed stone are used mainly for construction projects. In a study by Ilangovana et al. (2008), the strength of quarry rock dust concrete was reported to be 10-12% more than that of similar mix of conventional concrete. Hameed & Sekar (2009) also reported that the flexural strength increases in concrete with crushed stone dust compared with the concrete with natural sand. Quarry stone aggregates are used extensively for building construction in Jos and in many cities in Nigeria. The rocks being quarried here are mainly biotite granite and biotite hornblende granite, all belonging to the Younger Granite Complex. They are known to contain significant amount of radioactive mineral such as thorite (ThSiO\(_4\)), zircon (ZrSiO\(_4\)) and monazite (Ce,La,Yt)PO\(_4\)) on the Jos Plateau are believed to have been derived from these Complexes.
2.2 Determination of concentration of naturally radioactive elements
Measurement of gamma radiation emanating from the naturally radioactive constituents of the crushed rocks was carried out using RS-230 Gamma Spectrometer (Figure 2). The spectrometer is a handheld auto-stabilized 1024 channel piece of equipment which uses a large (103 cm$^3$) BGO (Bismuth Germanate Oxide) detector for improved level of system sensitivity and accuracy. The use of a BGO gives very significant increase in performance over the normal NaI detector. For a better accuracy, a preset time of 120 seconds was used for the measurement per point while the assay mode provided the concentrations of Potassium (K %), equivalent Thorium (eTh) in ppm, and equivalent Uranium (eU) in ppm for each point of measurement. The energy response of the equipment is 30–3000 kev. Between fifty (50) and one hundred and twenty (120) measurements were recorded from different sizes of crushed stone aggregates for each of the quarry, and the average calculated. The values were then converted into activity concentrations in Bqkg$^{-1}$ with which the lifetime cancer risk values were determined.

3. Results and Discussion
Radionuclide concentration, activity concentration, absorbed dose rate in air, annual effective dose equivalent (AEDE), radium equivalent activity (Ra$_{eq}$), hazard indices, and excess lifetime cancer risk (ELCR) were determined in this study.
3.1 Radioelement concentration and Specific Activity.

Concentration of radionuclides (Table 1) varies from one quarry to another owing to differences in the mineral composition of the rocks. Average concentration of $^{238}\text{U}$, $^{232}\text{Th}$ and $^{40}\text{K}$ in the crushed stones and their activity concentrations are 15.1 ppm, 47.9 ppm, 4.4%, and 186.5, 194.5, 1377.2 Bq kg$^{-1}$ respectively for Getegere Stone Crushing Company Zaramaganda, 14.1 ppm, 51.7 ppm, 4.1%, and 174.1, 209.9, 1283.3 Bq kg$^{-1}$ for RicRock Quarry Fobur, 5.5 ppm, 26.8 ppm, 3.7%, and 67.9, 86.9, 1043.2 Bq kg$^{-1}$ for Doi-Du Quarry near Jos, and 10.8, 15.8, 4.1% for Satzen Company Quarry Buji. They also include 9.0 ppm, 31.7 ppm, 4.3%, and 111.5, 128.7, 1333.4 Bq kg$^{-1}$ for Bauchi Ring Road Quarry, as well as 4.0 ppm, 30.7 ppm, 3.9% and 67.9, 108.8, 1158.1 Bq kg$^{-1}$ for Bauchi Ring Road Quarry, as well as 4.0 ppm, 30.7 ppm, 3.9% and 67.9, 108.8, 1158.1 Bq kg$^{-1}$ for Bauchi Ring Road Quarry, as well as 4.0 ppm, 30.7 ppm, 3.9% and 67.9, 108.8, 1158.1 Bq kg$^{-1}$ for Bauchi Ring Road Quarry.

The absorbed dose rate in the air due to gamma rays 1 metre above the ground from the quarries was calculated according to UNSCEAR (2000), using Equation 1.

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

Where 0.462, 0.621 and 0.0417 are the conversion factors for $^{238}\text{U}$, $^{232}\text{Th}$ and $^{40}\text{K}$ respectively. The assumption here is that other natural radionuclides contributes negligible amount to the absorbed dose rate. The absorbed dose rate in air from the quarries investigated (Table 2) varies from 149.85–264.35 nGy h$^{-1}$. The Gintegere Stone Crushing Company Bukuru, Jos (Q1), and the Mararaba Jamaa Quarry Bukuru, Jos (Q2) recorded the highest values. The two quarries source rock fragments for crushing from the Jos-Bukuru Complex.

Table 1. Radiation parameters for quarries in Jos and environs.

<table>
<thead>
<tr>
<th>S/No</th>
<th>QUARRY NAME</th>
<th>COORDINATE</th>
<th>DATA SUMMARY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>(°N)</td>
<td>(°E)</td>
</tr>
<tr>
<td>1</td>
<td>Getegere Stone Crushing Company Bukuru, Jos</td>
<td>15.1</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Mararaba Jamaa Quarry Bukuru, Jos</td>
<td>14.1</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Doi-Du Nafang Quarry Rayfield, Jos</td>
<td>12.2</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Satzen Company Quarry Buij Near Jos</td>
<td>7.0</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>RicRock Quarry Fobur Near Jos</td>
<td>9.0</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>Bauchi Ring Road Quarry, Jos</td>
<td>5.5</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>DTV Quarry, DTV-Jebu</td>
<td>4.0</td>
<td>1.4</td>
</tr>
</tbody>
</table>

These quarries feed from rocks of the Jos-Bukuru Complex known to contain significantly high amount of potassium, thorium, and uranium. Generally, granitic rocks are known to be enriched in Thorium (Th) and Uranium (U), with an average of 15 µg g$^{-1}$ of Th and 5 µg g$^{-1}$ of U (Faure 1986; Mènager et al. 1993).

3.2 Absorbed Dose Rate in Air (D)

The absorbed dose rate in the air due to gamma rays 1 metre above the ground from the quarries was calculated according to UNSCEAR (2000), using Equation 1.

Annual effective dose equivalents (indoor and outdoor) were calculated for the seven (7) quarries under study.
using Equation 2 and 3.

\[ AEDE_{\text{Indoor}} (\text{mSv y}^{-1}) = D (\text{nGy h}^{-1}) \times 8760 \text{ hy}^{-1} \times 0.75 \times 0.75 \text{ Sv Gy}^{-1} \times 10^{-6} \]  
(2)

\[ AEDE_{\text{Outdoor}} (\text{mSv y}^{-1}) = D (\text{nGy h}^{-1}) \times 8760 \text{ hy}^{-1} \times 0.75 \times 0.75 \text{ Sv Gy}^{-1} \times 10^{-6} \]  
(3)

Where D is the absorbed dose in air, 8760 (24x365) is the number of hours in a year, 0.75 is the indoor occupancy factor, which represents the fraction of time spent indoor, and 0.75 Sv Gy\(^{-1}\) is the conversion coefficient from absorbed dose in air to effective dose received by adults. The values of AEDE ranges from 0.69-1.22 mSv y\(^{-1}\) for internal and 0.23-0.41 mSv y\(^{-1}\) for external (Table 2).

### 3.4 Hazard Indices (HI)

Hazard Indices (internal and external) are reflections of exposure to radiation. The hazard indices were calculated using Equation 5 and 6 according to Shoeib & Thabayneh (2014).

\[ H_{\text{in}} = A_{u}/185 + A_{\text{Th}}/259 + A_{k}/4810 \]  
(4)

\[ H_{\text{ex}} = A_{u}/370 + A_{\text{Th}}/259 + A_{k}/4810 \]  
(5)

Where \(A_u\), \(A_{\text{Th}}\) and \(A_k\) are the specific activity concentrations of \(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\) respectively. The mean internal and external hazard index should be less than 1 to provide acceptable level of personal safety. The values of radiation hazard indices in the studied quarries are 1.00-2.05 for indoor, and 0.86-1.55 for outdoor. The mean internal and external hazard index are less than 1 in some of the quarries but higher in others.

<table>
<thead>
<tr>
<th>S/N</th>
<th>QUARR Y ID</th>
<th>D (nGy h(^{-1}))</th>
<th>AEDE Int. (mSv y(^{-1}))</th>
<th>AEDE Ext. (mSv y(^{-1}))</th>
<th>RaEq (Bq kg(^{-1}))</th>
<th>HI indoo r</th>
<th>HI outdoo r</th>
<th>ELC R (In)</th>
<th>ELC R Out</th>
<th>ELCR (Total)</th>
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<tbody>
<tr>
<td>1</td>
<td>Q1</td>
<td>264.35</td>
<td>1.22</td>
<td>0.41</td>
<td>570.63</td>
<td>2.02</td>
<td>1.54</td>
<td>4.26</td>
<td>1.42</td>
<td>5.68</td>
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<tr>
<td>2</td>
<td>Q2</td>
<td>264.31</td>
<td>1.22</td>
<td>0.41</td>
<td>573.11</td>
<td>1.74</td>
<td>1.33</td>
<td>3.71</td>
<td>1.24</td>
<td>4.95</td>
</tr>
<tr>
<td>3</td>
<td>Q3</td>
<td>230.29</td>
<td>1.06</td>
<td>0.35</td>
<td>492.69</td>
<td>1.14</td>
<td>0.90</td>
<td>2.55</td>
<td>0.85</td>
<td>3.40</td>
</tr>
<tr>
<td>4</td>
<td>Q4</td>
<td>158.25</td>
<td>0.73</td>
<td>0.24</td>
<td>334.47</td>
<td>1.38</td>
<td>1.08</td>
<td>3.02</td>
<td>1.01</td>
<td>4.03</td>
</tr>
<tr>
<td>5</td>
<td>Q5</td>
<td>187.40</td>
<td>0.86</td>
<td>0.29</td>
<td>398.83</td>
<td>1.04</td>
<td>0.86</td>
<td>2.41</td>
<td>0.80</td>
<td>3.21</td>
</tr>
<tr>
<td>6</td>
<td>Q6</td>
<td>149.85</td>
<td>0.69</td>
<td>0.23</td>
<td>317.51</td>
<td>1.00</td>
<td>0.87</td>
<td>2.43</td>
<td>0.81</td>
<td>3.24</td>
</tr>
<tr>
<td>7</td>
<td>Q7</td>
<td>151.13</td>
<td>0.70</td>
<td>0.23</td>
<td>321.63</td>
<td>1.00</td>
<td>0.87</td>
<td>2.43</td>
<td>0.81</td>
<td>3.24</td>
</tr>
</tbody>
</table>

**Quarry Index**

Q1- Getegere Stone Crushing Company Bukuru, Jos
Q2- Mararaba Jamma Quarry Bukuru, Jos
Q3- Doi-Du Naflang Quarry Rayfield, Jos
Q4- Satzen Company Quarry Buji Near Jos
Q- Ricrock Quarry Fobur Near Jos
Q6- Bauchi Ring Road Quarry, Jos

### 3.5 Radium Equivalent Activity (Ra\(_\text{eq}\))

Radium equivalent activity (Ra\(_\text{eq}\)) is a single index which sums up the gamma output from different mixture of \(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\) emanating from a rock. For safety, radium equivalent activity (Ra\(_\text{eq}\)) is set at 370 Bq kg\(^{-1}\). This is equivalent to a maximum permissible dose of 1.5 mSv y\(^{-1}\) to human from exposures to natural radiation. Radium equivalent activity was calculated according to Beretka & Matthew (1985); UNSCEAR (2000) as follows:

\[ \text{Ra}_{\text{eq}} \text{ (Bq kg}^{-1}\text{)} = A_{\text{Ra}} + 1.43 A_{\text{Th}} + 0.077 A_{\text{K}} \]  
(6)

Where \(A_{\text{Ra}}\), \(A_{\text{Th}}\) and \(A_{\text{K}}\) are the specific activity concentrations of \(^{238}\text{U}\), \(^{232}\text{Th}\) and \(^{40}\text{K}\) respectively. The value of Ra\(_\text{eq}\) ranges from 317.51-573.11 Bq kg\(^{-1}\) (Table 2). With a tolerable Ra\(_\text{eq}\) value of 370 Bq kg\(^{-1}\), radiation safety may become a concern if crushed stones from quarries with higher values as identified in this study are used in buildings construction.

### 3.6 Excess Lifetime Cancer Risk (ELCR)

Exposure to radiation on a long-term basis is believed to have some risks of causing cancer. It means, therefore that all human to a large extent are at a risk of getting cancer because we are all exposed to many sources of radiation within our living environment. According to the National Cancer Institute (2009), American men have a 44% lifetime risk of cancer, while women have a 38% lifetime risk. It implies therefore that there is chance of about 33% (or 0.33) that a person will get some type of cancer at some stage of life. Excess lifetime cancer risk’ (ELCR) refers to the additional risk of getting cancer that a person might have if that person is exposed to cancer-causing materials over a long period of time. The allowable value is additional or excess of 1 in 100,000 chances (1 \times 10^{-5}). In line with the position of Ramasamy et al. (2009), Emelue et al. (2014), the excess lifetime cancer risk (ELCR) was calculated based on the calculated values of annual effective dose equivalents using the following equation:
ELCR_{indoors} = AEDE_{indoors} \times DL \times RF \quad (7)
ELCR_{outdoors} = AEDE_{outdoors} \times DL \times RF \quad (8)

Where AEDE is the annual effective dose equivalent, DL is the average duration of life (70 years), and RF is the risk factor or fatal cancer risk per Sievert. The International Committee on Radiation Protection ICRP (1991) peg RF at 0.05 for the public.

The excess lifetime cancer risk (ELCR) of the study area ranges from $2.43 \times 10^{-3}$ to $4.26 \times 10^{-3}$, (indoor) while for outdoor, it ranges from $0.80 \times 10^{-3}$ to $1.42 \times 10^{-3}$ (Table 2). These values are higher than the reference value of $0.29 \times 10^{-2}$ below which negligible risk of developing cancer has been fixed (Aziz et al. 2014). The total (ELCR) ranges from $3.21 \times 10^{-3}$ to $5.68 \times 10^{-3}$ with an average value of $4.45 \times 10^{-3}$. This is 15.34 times higher than the reference value of $0.29 \times 10^{-3}$. The quarries with the highest (ELCR) are Getegere Stone Crushing Company Bukuru, Jos and Mararaba Jamaa Quarry Bukuru, Jos.

Similar studies carried out by Solomon et al. (2018) on hollow aggregate filled stone-dust blocks and sandcrete blocks produced in Jos Plateau State, Nigeria, gave a range of $1.26 \times 10^{-3}$ to $1.74 \times 10^{-3}$ for indoor, and a range of $0.43 \times 10^{-3}$ to $0.58 \times 10^{-3}$ for outdoor. For aggregate-filled stone-dust blocks, ELCR (indoor) varies from $2.46 \times 10^{-3}$ to $2.99 \times 10^{-3}$ while for the outdoor, it ranges from $0.82 \times 10^{-3}$ to $1.00 \times 10^{-3}$. The report concluded that the risk of developing cancer (ELCR) is much higher for dwellers of buildings constructed with aggregate filled stone-dust blocks compared to ‘ordinary’ sandcrete blocks. A study on the determination of (ELCR) in and around Warri Refining and Petrochemical Company in Niger Delta, Nigeria was carried out by Emelue et al. (2014). The result revealed that the risk of developing cancer is below the standard.

In a similar study carried out in high background radiation area (Kerala, India) by Ramasamy et al. (2013), an average (ELCR) value of $1.7 \times 10^{-3}$ was recorded, amounting to six times the world average ($0.29 \times 10^{-2}$). According to Taskin et al. (2009), excess lifetime cancer risk (ELCR) in Kirkkareli Turkey is $0.50 \times 10^{-3}$. Ramasamy et al. (2009) equally carried out the evaluation of (ELCR) in river sediments of Karnataka and Tamilnadu, India, and reported an average ELCR value of $0.20 \times 10^{-3}$. This is low, and less than the world average. ELCR in natural environment therefore is a function of the local geology.

4. Conclusion

The concentration and specific activity of $^{238}U$, $^{232}Th$ and $^{40}K$ from crushed stones have been determined across major quarries in Jos, north central Nigeria using the RS-230 Gamma Spectrometer. Radiological parameters from the various quarries which include absorbed dose rate in air, annual effective dose equivalent, radium equivalent activity, internal hazard index and excess lifetime cancer risk were found to be generally higher within the Getegere Stone Crushing Company Bukuru, Jos and the Mararaba Jamaa Quarry Bukuru, Jos. Both quarries source their aggregate product from biotite granite belonging to the Jos-Bukuru Complex. The average of total Excess Lifetime Cancer Risk from the quarries ($4.45 \times 10^{-3}$) is 15.34 times higher than the world average of $0.29 \times 10^{-3}$ below which negligible risk of developing cancer has been stated. Crushed stones from quarries in Jos and its environs therefore may have contributed significantly to cancer risks in this area.

5. References


National Cancer Institute, USA. (2009). Surveillance, Epidemiology, and End Results (SEER) Program. The Surveillance, Epidemiology, and End Results (SEER) Program of the National Cancer Institute works to provide information on cancer statistics in an effort to reduce the burden of cancer among the U.S. population.


