**Full Length Research Paper**

**Assessment of outdoor radiation levels and radiological health hazards in Emene Industrial Layout of Enugu State, Nigeria**

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Received 3 September, 2018; Accepted 3 December, 2018

A study to assess the outdoor Background Ionizing Radiation (BIR) levels in Emene Industrial Layout of Enugu State, Nigeria has been conducted. An *in-situ* measurement of BIR exposure rate in mRh⁻¹ for 30 locations was done using a well calibrated portable GQ GMC-320 PLUS nuclear radiation detector at an elevation of 1.0 m above ground level with a geographical positioning system (GPS) for geographical location. The measured BIR exposure rates were used to evaluate the radiological health hazards and radiation effective doses to different body organs using well established radiological relations. The obtained values were compared with recommended permissible limits to ascertain the radiological health status of the environment. The mean values of BIR exposure levels (0.015±0.001 mRh⁻¹), absorbed dose rates (126.15±5.10 ηGyh⁻¹) and excess lifetime cancer risk (0.541±0.032×10⁻³) are higher than their recommended safe limits of 0.013 mRh⁻¹, 84.0 ηGyh⁻¹, 0.29×10⁻³ respectively as recommended by ICRP and UNSCEAR. The mean annual effective dose equivalent (0.155±0.006 mSvy⁻¹) is within recommended permissible limits of 1.00 mSvy⁻¹ for general public exposure. Also, the effective doses to different body organs are all below the recommended limits of 1.0 mSvy⁻¹. Generally, the study shows that Emene Industrial Layout is radiologically contaminated due to industrial activities taking place. However, the contamination does not constitute any immediate radiological health effect on resident of the area but there is the potential for long-term health hazards in the future such as cancer due to accumulated doses.

**Key words:** BIR exposure level, effective dose, industrial activities, Emene Industrial Layout.

**INTRODUCTION**

The advent of industrialization coupled with poor environmental management systems have resulted to the release of various forms of toxic, corrosive and radioactive contaminants or pollutants into the environment. The negative health impact of industrial activities in the environment has been an issue of discussion in contemporary times. Environmental contamination and degradation is a global concern.

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because of its negative health impact. Background ionization radiation (BIR) could be considered as environmental contamination especially when it exceeds safe occupational and public limits (Agbalagba et al., 2016). BIR in the environment which was originally due to natural sources of terrestrial primordial radionuclides and extraterrestrial cosmic rays has over the years increased due to human activities and especially in the industrial environments. This is because raw materials used in industries contain naturally occurring radioactive materials (NORM) (Ademola and Olatunji, 2013) which are later released into the environment as waste after undergoing some industrial processes. Enhanced levels of naturally occurring radionuclides may be associated with certain natural materials, minerals and other resources used as raw materials in industries due to their region and origin (Lu and Zhang, 2006; Ademola and Olatunji, 2013). The most important are the series $^{238}\text{U}$ and $^{232}\text{Th}$ and their decay products as well as non series $^{40}\text{K}$. Exploitation of these resources for the production of consumer items may lead to further enhancement of the radioactivity at concentrations above normal which are redistributed and released into the environment. The end result of this is increased BIR levels. This, in effect exposes the populace to high radiation doses and hazards.

Research data available on BIR levels assessment in some cities and towns worldwide show regions of low and high BIR levels. In Nigeria for example, Agbalagba et al. (2016) reported high radiation levels within Ughelli metropolis and its environs due to the industrial nature of the area. Agbalagba (2017) documented mean BIR exposure value of $0.022\pm0.006 \text{ mR} \text{h}^{-1}$ in industrial zone of Warri city. James et al. (2013) studied the radiation levels of Idu industrial area of Abuja and recorded low radiation doses in the area. Akpabio et al. (2005) also studied the environmental radioactive levels in Ikot–Ekpene and reported that the radioactivity levels in the area is generally low ranging. Within Keffi and Akwanga towns of central Nigeria, Termizi-Ramli et al. (2014) also reported low radiation levels that are within recommended safe limits for the areas. Outside the country, Zarghani and Jafari (2017) recorded low range radiation doses in Birjand, Iran. In Chihuahua City, Mexico, Luevano-Gurrola et al. (2015) observed high outdoor gamma dose rates ranging from 113 to 310 $\text{ngy} \text{h}^{-1}$.

High radiation levels and doses are detrimental to human health. Ionizing radiation are highly energetic particles with high penetrating power. When such radiation passes through a biological cell, it causes both excitation and ionization thereby altering the cells structure (Emelue et al., 2014). Exposure to high levels of gamma radiation causes a number of harmful effects in man such as mutation and cancer of various types (Aziz et al., 2014) and different kinds of diseases (Taskin et al., 2009). The practice of radiation protection has ensured that human exposure to radiation be kept to as low as reasonably achievable, called the ALARA principle (ICRP, 1973). One of the roles of radiation protection bodies is to ensure that the exposure of the public does not exceed certain safe limits as set up from time to time by regulatory agencies (Mokobia and Oyibo, 2017). Baseline data about BIR levels in Emene Industrial Layout (EIL) has not been established. Firstly, this study is aimed to report BIR exposure levels for the area and to assessing the impact of the industrial activities on BIR levels in the environment. The related radiological health indices are evaluated to know the health status of the environment.

MATERIALS AND METHODS

Study area

The study area, Emene Industrial Layout is located in Enugu East Local Government Area of Enugu State, South Eastern Nigerian. Thirty sampling points were carefully marked out for BIR exposure measurement which evenly covers the locations of the various industries/factories in the study area. Each of the sampling point was assigned a code (EIL1 to EIL30) for easy referencing. The nature of activities in the study area includes but not limited to the following; petroleum storage facilities, aluminum roof sheet manufacturing, palm kernel oil extraction and processing, gas cylinders fabrication, gas storage and dispensing facilities, asphalt processing, saw mill, floor mill, plastic processing and production, metal fabrication/welding, automobile workshops and assembly plant, blocks/brick production, construction equipment yard, cement warehouses, asbestos production, oxygen and acetylene gases production, paint factory, etc.

Sampling and measurement

Measurement of terrestrial outdoor BIR exposure levels was done using a portable factory calibrated GQ GMC-320 PLUS nuclear radiation detector (from GQ Electronics LLC, USA). The radiation meter contains a Geiger-Muller detector tube capable of detecting $\alpha$, $\beta$, $\gamma$ and x-rays which was pre-set to detect background gamma radiation. The detector has a gamma energy range of 0.1 to 1.25 MeV and sensitivity of 0.1 ~ 1 MeV. When radiation passes through the Geiger tube, it triggers an electrical pulse for the CPU to register as a count in the basic count rate unit of Count per Minute (CPM). The CPM count rate indicates the radiation level and it can be converted to other traditional radiation units, such as $\text{mR} \text{h}^{-1}$ or $\mu\text{Sv} \text{h}^{-1}$. The working voltage of the detector is 3.6 to 3.7 V with power consumption rate of 25 to 125 mW dependent on the count rate.

The radiation level assessment was conducted for five months; from January to May 2018, with three BIR exposure readings taken for each sampling points at an interval of four minutes per month. This was done to account for any variation in the environmental parameters due to seasonal conditions (dry and wet seasons) and also to account for the fluctuating nature of radiation. The count rate per minute recorded in the detector was converted to radiation exposure in $\text{mR} \text{h}^{-1}$ with an inbuilt converter according to Equation 1. A total of 15 measurements for each sample point were taken for the five months and the average recorded in this report as mean exposure readings. Readings were taken between the hours of 1300 and 1800 because the radiation meter has a maximum response to radiation within these hours as recommended by the
The different organs of the body are given different radiological health indices calculati". 

The BIR exposure level measurements and the related radiological health parameters are given in Table 1. Table 2 shows the results for the effective dose to some body organs. The different radiological health indices used in evaluating the radiation health status of the studied environment are absorbed dose, AEDE and the excess lifetime cancer risk (ELCR).

### Results and Discussion

The results for the BIR exposure level measurements and the related radiological health parameters are given in Table 1. Table 2 shows the results for the effective dose to some body organs. The different radiological health indices used in evaluating the radiation health status of the studied environment are absorbed dose, AEDE and the excess lifetime cancer risk (ELCR).

#### BIR Exposure Rate Levels

The BIR exposure rate measured ranges from 0.009 to 0.021 mRh^{-1} with mean value of 0.015±0.001 mRh^{-1}. The mean exposure rate for the studied environment...
The measured BIR reported here is lower than 0.018±0.004 mRh\(^{-1}\) value observed by Osimobi et al. (2015) in solid mineral mining sites of Enugu State, Nigeria. The mean value is higher than that measured by Ononugbo and Mgbemere (2016) in a fertilizer company in Onne, Rivers State, Nigeria which ranges between 11.73 and 14.95 ηRh\(^{-1}\).

### Absorbed dose rate (ADR) in air

The absorbed dose is used to assess the potential for any biochemical changes in specific tissues. It quantifies the radiation energy that might be absorbed by a potentially exposed individual. The measured BIR exposure levels were converted to radiation absorbed dose rate in air using Equation 2 according to Rafique et al. (2014) and Agbalagba (2017).

### Table 2. Dose to different organs of the body in Emene Industrial Layout.

<table>
<thead>
<tr>
<th>Sampling point code</th>
<th>Lungs</th>
<th>Ovaries</th>
<th>Bone marrow</th>
<th>Testes</th>
<th>Kidney</th>
<th>Liver</th>
<th>Whole body</th>
</tr>
</thead>
<tbody>
<tr>
<td>EIL1</td>
<td>0.082</td>
<td>0.074</td>
<td>0.088</td>
<td>0.105</td>
<td>0.079</td>
<td>0.059</td>
<td>0.087</td>
</tr>
<tr>
<td>EIL2</td>
<td>0.116</td>
<td>0.105</td>
<td>0.125</td>
<td>0.148</td>
<td>0.112</td>
<td>0.083</td>
<td>0.123</td>
</tr>
<tr>
<td>EIL3</td>
<td>0.061</td>
<td>0.056</td>
<td>0.066</td>
<td>0.079</td>
<td>0.060</td>
<td>0.044</td>
<td>0.065</td>
</tr>
<tr>
<td>EIL4</td>
<td>0.075</td>
<td>0.068</td>
<td>0.081</td>
<td>0.096</td>
<td>0.073</td>
<td>0.054</td>
<td>0.080</td>
</tr>
<tr>
<td>EIL5</td>
<td>0.089</td>
<td>0.081</td>
<td>0.096</td>
<td>0.114</td>
<td>0.086</td>
<td>0.064</td>
<td>0.095</td>
</tr>
<tr>
<td>EIL6</td>
<td>0.082</td>
<td>0.074</td>
<td>0.088</td>
<td>0.105</td>
<td>0.079</td>
<td>0.059</td>
<td>0.087</td>
</tr>
<tr>
<td>EIL7</td>
<td>0.095</td>
<td>0.086</td>
<td>0.103</td>
<td>0.122</td>
<td>0.092</td>
<td>0.069</td>
<td>0.101</td>
</tr>
<tr>
<td>EIL8</td>
<td>0.095</td>
<td>0.086</td>
<td>0.103</td>
<td>0.122</td>
<td>0.092</td>
<td>0.069</td>
<td>0.101</td>
</tr>
<tr>
<td>EIL9</td>
<td>0.109</td>
<td>0.099</td>
<td>0.118</td>
<td>0.140</td>
<td>0.106</td>
<td>0.079</td>
<td>0.116</td>
</tr>
<tr>
<td>EIL10</td>
<td>0.095</td>
<td>0.086</td>
<td>0.103</td>
<td>0.122</td>
<td>0.092</td>
<td>0.069</td>
<td>0.101</td>
</tr>
<tr>
<td>EIL11</td>
<td>0.109</td>
<td>0.099</td>
<td>0.118</td>
<td>0.140</td>
<td>0.106</td>
<td>0.079</td>
<td>0.116</td>
</tr>
<tr>
<td>EIL12</td>
<td>0.102</td>
<td>0.093</td>
<td>0.110</td>
<td>0.131</td>
<td>0.099</td>
<td>0.074</td>
<td>0.109</td>
</tr>
<tr>
<td>EIL13</td>
<td>0.075</td>
<td>0.068</td>
<td>0.081</td>
<td>0.096</td>
<td>0.073</td>
<td>0.054</td>
<td>0.080</td>
</tr>
<tr>
<td>EIL14</td>
<td>0.095</td>
<td>0.086</td>
<td>0.103</td>
<td>0.122</td>
<td>0.092</td>
<td>0.069</td>
<td>0.101</td>
</tr>
<tr>
<td>EIL15</td>
<td>0.102</td>
<td>0.093</td>
<td>0.110</td>
<td>0.131</td>
<td>0.099</td>
<td>0.074</td>
<td>0.109</td>
</tr>
<tr>
<td>EIL16</td>
<td>0.089</td>
<td>0.081</td>
<td>0.096</td>
<td>0.114</td>
<td>0.086</td>
<td>0.064</td>
<td>0.095</td>
</tr>
<tr>
<td>EIL17</td>
<td>0.143</td>
<td>0.130</td>
<td>0.155</td>
<td>0.184</td>
<td>0.139</td>
<td>0.103</td>
<td>0.152</td>
</tr>
<tr>
<td>EIL18</td>
<td>0.082</td>
<td>0.074</td>
<td>0.088</td>
<td>0.105</td>
<td>0.079</td>
<td>0.059</td>
<td>0.087</td>
</tr>
<tr>
<td>EIL19</td>
<td>0.082</td>
<td>0.074</td>
<td>0.088</td>
<td>0.105</td>
<td>0.079</td>
<td>0.059</td>
<td>0.087</td>
</tr>
<tr>
<td>EIL20</td>
<td>0.136</td>
<td>0.124</td>
<td>0.147</td>
<td>0.175</td>
<td>0.132</td>
<td>0.098</td>
<td>0.145</td>
</tr>
<tr>
<td>EIL21</td>
<td>0.136</td>
<td>0.124</td>
<td>0.147</td>
<td>0.175</td>
<td>0.132</td>
<td>0.098</td>
<td>0.145</td>
</tr>
<tr>
<td>EIL22</td>
<td>0.089</td>
<td>0.081</td>
<td>0.096</td>
<td>0.114</td>
<td>0.086</td>
<td>0.064</td>
<td>0.095</td>
</tr>
<tr>
<td>EIL23</td>
<td>0.082</td>
<td>0.074</td>
<td>0.088</td>
<td>0.105</td>
<td>0.079</td>
<td>0.059</td>
<td>0.087</td>
</tr>
<tr>
<td>EIL24</td>
<td>0.082</td>
<td>0.074</td>
<td>0.088</td>
<td>0.105</td>
<td>0.079</td>
<td>0.059</td>
<td>0.087</td>
</tr>
<tr>
<td>EIL25</td>
<td>0.089</td>
<td>0.081</td>
<td>0.096</td>
<td>0.114</td>
<td>0.086</td>
<td>0.064</td>
<td>0.095</td>
</tr>
<tr>
<td>EIL26</td>
<td>0.109</td>
<td>0.099</td>
<td>0.118</td>
<td>0.140</td>
<td>0.106</td>
<td>0.079</td>
<td>0.116</td>
</tr>
<tr>
<td>EIL27</td>
<td>0.143</td>
<td>0.130</td>
<td>0.155</td>
<td>0.184</td>
<td>0.139</td>
<td>0.103</td>
<td>0.152</td>
</tr>
<tr>
<td>EIL28</td>
<td>0.075</td>
<td>0.068</td>
<td>0.081</td>
<td>0.096</td>
<td>0.073</td>
<td>0.054</td>
<td>0.080</td>
</tr>
<tr>
<td>EIL29</td>
<td>0.130</td>
<td>0.118</td>
<td>0.140</td>
<td>0.166</td>
<td>0.126</td>
<td>0.094</td>
<td>0.138</td>
</tr>
<tr>
<td>EIL30</td>
<td>0.116</td>
<td>0.105</td>
<td>0.125</td>
<td>0.148</td>
<td>0.112</td>
<td>0.083</td>
<td>0.123</td>
</tr>
<tr>
<td>Mean value</td>
<td>0.099</td>
<td>0.090</td>
<td>0.107</td>
<td>0.127</td>
<td>0.096</td>
<td>0.071</td>
<td>0.105</td>
</tr>
</tbody>
</table>

exceeded the recommended permissible limit of 0.013 mRh\(^{-1}\) (ICRP, 2007; Osimobi et al., 2015; Agbalagba et al., 2016). The result indicates that 53.3% of the sample points exceeded the permissible BIR level for the general public. The variation and high exposure rate level is attributed to the different industrial activities carried out in the different sampling locations and their geophysical characterization. Petroleum products, chemicals and construction materials like asphalt, granites, cement, etc. have been recognized to contain some radioactive elements (Agbalagba et al., 2016) which enhance BIR level and are well available at the sample locations. The high BIR levels are suggestive indication that the environment is radiologically contaminated and unhealthy for the general public. The fluctuating pattern of the exposure level in comparison with recommended safe limit is shown in Figure 1. The mean exposure level
Comparison between BIR exposure rates in Emene Industrial Layout and permissible limit

Comparison between the absorbed dose rate in Emene Industrial Layout and permissible safe limit

\[
1 \mu R h^{-1} = 8.7 \gamma G y h^{-1} = \frac{8.7 \times 10^{-3}}{1/8760 y} \mu G y y^{-1}
\]

This implies that:

\[
1 m R h^{-1} = 8.7 \gamma G y h^{-1} \times 10^3 = 8700 \gamma G y h^{-1}
\]

The calculated absorbed dose rate ranges between 78.30 and 182.70 $\gamma G y h^{-1}$ with observed mean value of 126.15±5.10 $\gamma G y h^{-1}$. These dose rates arising from BIR exposure in the studied locations are far higher than the recorded world weighted average of 59.00 $\gamma G y h^{-1}$ (Agbalagba, 2017; Monica et al., 2016) and recommended safe limit of 84.0 $\gamma G y h^{-1}$ (UNSCEAR, 2008; Ononugbo and Mgbemere, 2016) for outdoor exposure as shown in Figure 2. These dose rates show a radiation contaminated environment. Though the dose rate at these levels may not constitute any immediate health hazards to the residents of the locality, there is the potential for long-term health hazards in the future due to accumulated doses. The mean dose rate is higher than 97.44±20.42, 124.41±33.21, 97.44±12.17, 99.18±21.78 and 119.19±17.90 $\gamma G y h^{-1}$ dose rates earlier reported by Benson and Ugbede (2018) in populated motor packs environment of Enugu city but lower than 141.30±31.31 $\gamma G y h^{-1}$ for Warri city in Delta State, Nigeria reported by Agbalagba (2017) and 132.16±24.36 $\gamma G y h^{-1}$ for Ughelli metropolis in Delta State Nigeria by Agbalagba et al. (2016).

**Annual effective dose equivalent AEDE**

The AEDE is used in radiation assessment and
Figure 3. Comparison of the doses to different body organs.

Effective dose to different body organs ($D_{\text{organ}}$)

The effective dose to organs ($D_{\text{organ}}$) estimates the amount of radiation dose intake to various body organs and tissues. The $D_{\text{organ}}$ of the body due to inhalation was calculated using Equation 5 as given by Darwish et al. (2015).

$$D_{\text{organ}}(\text{mSv}^{-1}) = AEDE \times F$$  \hfill (5)

where $F$ is the conversion factor of organ dose from air dose. The $F$ value for lungs, ovaries, bone marrow, testes, kidney, liver and whole body due to radiation exposure and inhalation in the Emene industrial environment are 0.099, 0.090, 0.107, 0.127, 0.096, 0.071 and 0.105 mSv$^{-1}$ respectively. Figure 3 shows the variation of $D_{\text{organ}}$ to the different organs. These results are all below the international tolerable limits of 1.0 mSv annually (Agbalagba, 2017) which further stress that the radiation levels do not constitute any immediate health effect on residents of the area. From the results, it is concluded that the testes and ovaries have highest and lowest sensitivity to radiation respectively. Similar conclusion has also been made by Darwish et al. (2015) and Agbalagba (2017).

Excess lifetime cancer risk ELCR

The ELCR was evaluated using the annual effective dose values using Equation 6 according to Rafique et al. (2014) and Agbalagba (2017)

$$ELCR = AEDE(\text{mSv}^{-1}) \times DL \times RF$$  \hfill (6)

where DL is average duration of life (70 years) and RF is
the fatal cancer risk factor per sievert (Sv⁻¹). For low-dose background radiation, which is considered to produce stochastic effects, ICRP 103 uses a fatal cancer risk factor value of 0.05 for public exposure (ICRP, 2007). The excess lifetime cancer risk is used in radiation protection assessment to predict the probability of an individual developing cancer over his lifetime due to low radiation dose exposure, if it will occur at all. The calculated values for the ELCR ranges from 0.336×10⁻³ to 0.784×10⁻³. The mean ELCR value obtained is (0.541 ± 0.032)×10⁻³. This mean value is approximately 86.6% higher than the world average value of 0.29×10⁻³. This high value for excess lifetime cancer risk indicates that there exist the possibilities of cancer development by residents who wish to spend all their life time in the area. The ELCR values report here are lower than those reported by Agbalagba (2017) in industrial areas of Warri Nigeria and also lower than those for Okposi Okwu Salt Lake and Uburu Salt Lake environments of Ebonyi State, Nigeria reported by Awwiri et al. (2016).

Conclusion

This study so far has examined the radiological impact of industrial activities in Emene Industrial Layout by the assessment of the background radiation exposure levels in the area. From the study, the following conclusions are made:

1) The background radiation exposure rates shows that 53.3% of the sample locations indicate high radiation levels with mean value of 0.015±0.001 mRh⁻¹ which is above 0.013 mRh⁻¹ recommended limit for normal background radiation level.
2) The absorbed dose rates arising from BIR exposure are well above world average value which indicates a radiation contaminated environment.
3) The mean excess lifetime cancer risk value is 86.6% higher than the world average value. This suggests the possibility of cancer development in residents living in the area who wish to spend all their life time in the study area.
4) Generally, the study shows that Emene Industrial Layout is radiologically contaminated as a result of industrial activities taking place. The contamination and the radiation levels at these rates do not constitute any immediate health effect on residents of the area as shown by the effective dose to some organs of the body. However, there is the potential for long-term health hazards in future such as cancer due to accumulated doses.

RECOMMENDATIONS

1) The operators of the industries and concerned government agencies such as ministries of health and environment should devise means of reducing radioactive contaminants discharged into the environment to prevent further increase in the radiation level of the area.
2) High radioactive materials should be properly shielded and industries involved in the use of such materials be cited in isolated areas.
3) Residential buildings should be cited far away at places where the impact of the industries on BIR levels is less significant.
4) Regular monitoring of radiation levels in the area should be carried out by management of the various companies operating in the area, concerned government agencies and radiation protection scientists and agencies.
5) Further studies on radionuclides concentration in soil, water and crops planted in the area should be carried out.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors thank Prof. C.E. Mokobia of Delta State University for releasing the radiation meter at subsidized rate as well as the managements of companies and residences of Emene Industrial Layout for giving free access to their compound.

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