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

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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}U and ^{232}Th and their decay products as well as non series ^{40}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±0.006 mRh^{-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 ηGyh^{-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 roofing 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 α, β, γ 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 mRh^{-1} or μSvh^{-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 mRh^{-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 1600 because the radiation meter has a maximum response to radiation within these hours as recommended by the

Table 1. BIR exposure levels and related radiological health indices in Emene Industrial Layout.

Sampling point code	Geographical location	Mean exposure reading (mRh^{-1})	Absorbed dose (ηGyh^{-1})	AEDE ($mSvy^{-1}$)	ELCR×10^{-3}
EIL1	N6º28'6.04" E7º36'4.76"	0.012	104.40	0.128	0.448
EIL2	N6º28'10.10" E7º36'10.47"	0.017	147.90	0.181	0.634
EIL3	N6º27'59.07" E7º35'47.69"	0.009	78.30	0.096	0.336
EIL4	N6º27'59.14" E7º35'44.74"	0.011	95.70	0.117	0.409
EIL5	N6º28'1.92" E7º35'58.74"	0.013	113.10	0.139	0.487
EIL6	N6º27'54.90" E7º35'34.54"	0.012	104.40	0.128	0.448
EIL7	N6º27'51.01" E7º35'24.69"	0.014	121.80	0.149	0.522
EIL8	N6º27'52.52" E7º35'25.49"	0.014	121.80	0.149	0.522
EIL9	N6º27'53.87" E7º35'28.95"	0.016	139.20	0.171	0.599
EIL10	N6º27'53.72" E7º35'31.56"	0.014	121.80	0.149	0.522
EIL11	N6º27'55.30" E7º35'40.30"	0.016	139.20	0.171	0.599
EIL12	N6º27'58.14" E7º35'37.61"	0.015	130.50	0.160	0.560
EIL13	N6º27'39.26" E7º34'45.88"	0.011	95.70	0.117	0.409
EIL14	N6º27'33.93" E7º34'42.06"	0.014	121.80	0.149	0.522
EIL15	N6º27'31.84" E7º34'46.82"	0.015	130.50	0.160	0.560
EIL16	N6º27'25.76" E7º34'41.86"	0.013	113.10	0.139	0.487
EIL17	N6º27'21.34" E7º34'52.07"	0.021	182.70	0.224	0.784
EIL18	N6º27'15.96" E7º34'44.01"	0.012	104.40	0.128	0.448
EIL19	N6º27'20.71" E7º34'2.25"	0.012	104.40	0.128	0.448
EIL20	N6º27'14.10" E7º34'4.79"	0.020	174.00	0.213	0.746
EIL21	N6º27'5.78" E7º34'6.41"	0.020	174.00	0.213	0.746
EIL22	N6º26'57.98" E7º34'4.82"	0.013	113.10	0.139	0.487
EIL23	N6º26'51.90" E7º34'6.83"	0.012	104.40	0.128	0.448
EIL24	N6º27'1.46" E7º34'11.45"	0.012	104.40	0.128	0.448
EIL25	N6º27'5.06" E7º34'20.53"	0.013	113.10	0.139	0.487
EIL26	N6º27'4.56" E7º34'27.36"	0.016	139.20	0.171	0.599
EIL27	N6º27'17.60" E7º33'56.14"	0.021	182.70	0.224	0.784
EIL28	N6º27'25.16" E7º34'31.43"	0.011	95.70	0.117	0.409
EIL29	N6º27'33.78" E7º34'36.13"	0.019	165.30	0.203	0.711
EIL30	N6º27'45.19" E7º35'3.08"	0.017	147.90	0.181	0.634
Mean value ±SED		0.015±0.001	126.15±5.10	0.155±0.006	0.541±0.032

National Council on Radiation Protection and Measurements (NCRP, 1993). An *in-situ* approach of measurement with the standard practice of raising the detector tube 1.0 m above ground level with its window facing the point under investigation was adopted to enable sample points maintain their original environmental characteristics (Agbalagba et al., 2016; Ugbede and Echeweozo, 2017). The precise locations of each of the sample point were determined using a geographical positioning system (GPS). The BIR exposure rate obtained were quantitatively used to assess the radiation health impact to the public in the immediate environments and radiation effective doses to different organs of the body by performing a number of radiological health hazard indices calculations using well established mathematical relations.

$$\text{Count rate per minute (CMP)} = 10^{-3}\, Roentgen \times Q.F \quad (1)$$

where Q.F is the quality factor, which is equal to 1 for external environments.

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

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

Sampling point code	D_{organ} ($mSvy^{-1}$)						
	Lungs	Ovaries	Bone marrow	Testes	Kidney	Liver	Whole body
EIL1	0.082	0.074	0.088	0.105	0.079	0.059	0.087
EIL2	0.116	0.105	0.125	0.148	0.112	0.083	0.123
EIL3	0.061	0.056	0.066	0.079	0.060	0.044	0.065
EIL4	0.075	0.068	0.081	0.096	0.073	0.054	0.080
EIL5	0.089	0.081	0.096	0.114	0.086	0.064	0.095
EIL6	0.082	0.074	0.088	0.105	0.079	0.059	0.087
EIL7	0.095	0.086	0.103	0.122	0.092	0.069	0.101
EIL8	0.095	0.086	0.103	0.122	0.092	0.069	0.101
EIL9	0.109	0.099	0.118	0.140	0.106	0.079	0.116
EIL10	0.095	0.086	0.103	0.122	0.092	0.069	0.101
EIL11	0.109	0.099	0.118	0.140	0.106	0.079	0.116
EIL12	0.102	0.093	0.110	0.131	0.099	0.074	0.109
EIL13	0.075	0.068	0.081	0.096	0.073	0.054	0.080
EIL14	0.095	0.086	0.103	0.122	0.092	0.069	0.101
EIL15	0.102	0.093	0.110	0.131	0.099	0.074	0.109
EIL16	0.089	0.081	0.096	0.114	0.086	0.064	0.095
EIL17	0.143	0.130	0.155	0.184	0.139	0.103	0.152
EIL18	0.082	0.074	0.088	0.105	0.079	0.059	0.087
EIL19	0.082	0.074	0.088	0.105	0.079	0.059	0.087
EIL20	0.136	0.124	0.147	0.175	0.132	0.098	0.145
EIL21	0.136	0.124	0.147	0.175	0.132	0.098	0.145
EIL22	0.089	0.081	0.096	0.114	0.086	0.064	0.095
EIL23	0.082	0.074	0.088	0.105	0.079	0.059	0.087
EIL24	0.082	0.074	0.088	0.105	0.079	0.059	0.087
EIL25	0.089	0.081	0.096	0.114	0.086	0.064	0.095
EIL26	0.109	0.099	0.118	0.140	0.106	0.079	0.116
EIL27	0.143	0.130	0.155	0.184	0.139	0.103	0.152
EIL28	0.075	0.068	0.081	0.096	0.073	0.054	0.080
EIL29	0.130	0.118	0.140	0.166	0.126	0.094	0.138
EIL30	0.116	0.105	0.125	0.148	0.112	0.083	0.123
Mean value	0.099	0.090	0.107	0.127	0.096	0.071	0.105

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 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).

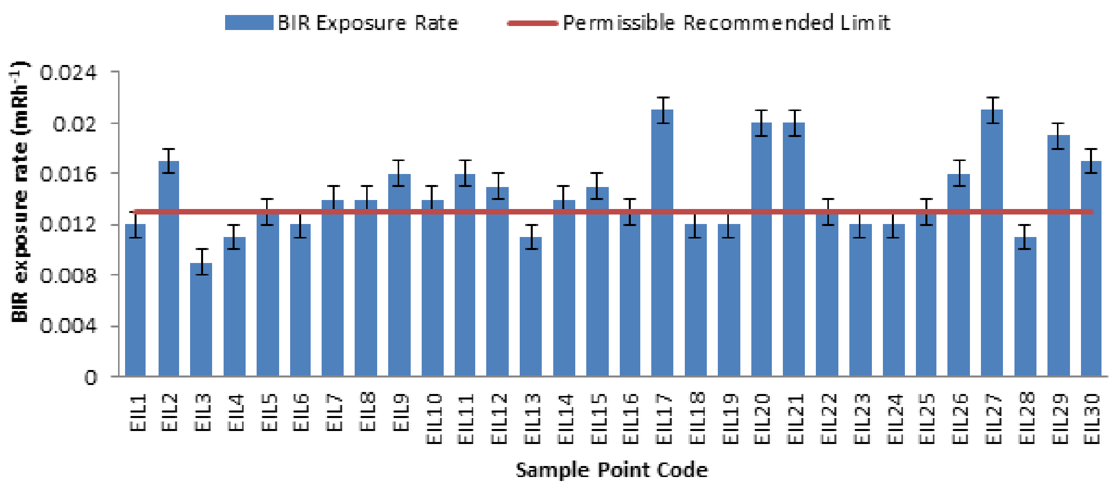

Figure 1. Comparison between BIR exposure rates in Emene Industrial Layout and permissible limit.

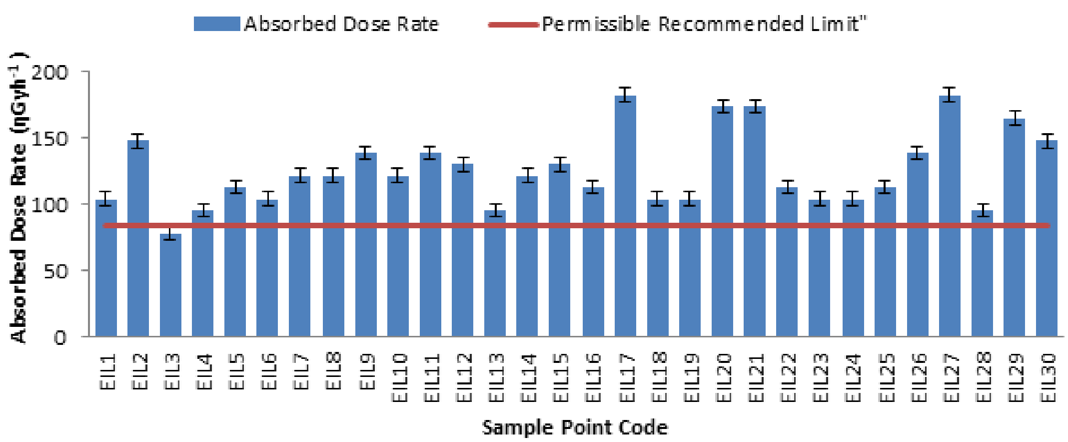

Figure 2. Comparison between the absorbed dose rate in Emene Industrial Layout and permissible safe limit.

$$1\mu Rh^{-1} = 8.7\eta Gyh^{-1} = \frac{8.7\times10^{-3}}{(1/8760y)}\mu Gyy^{-1} \qquad (2)$$

This implies that:

$$1mRh^{-1} = 8.7\eta Gyh^{-1}\times10^{3} = 8700\eta Gyh^{-1} \qquad (3)$$

The calculated absorbed dose rate ranges between 78.30 and 182.70 ηGyh^{-1} with observed mean value of 126.15±5.10 ηGyh^{-1}. These dose rates arising from BIR exposure in the studied locations are far higher than the recorded world weighted average of 59.00 ηGyh^{-1} (Agbalagba, 2017; Monica et al., 2016) and recommended safe limit of 84.0 ηGyh^{-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 ηGyh^{-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 ηGyh^{-1} for Warri city in Delta State, Nigeria reported by Agbalagba (2017) and 132.16±24.36 ηGyh^{-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

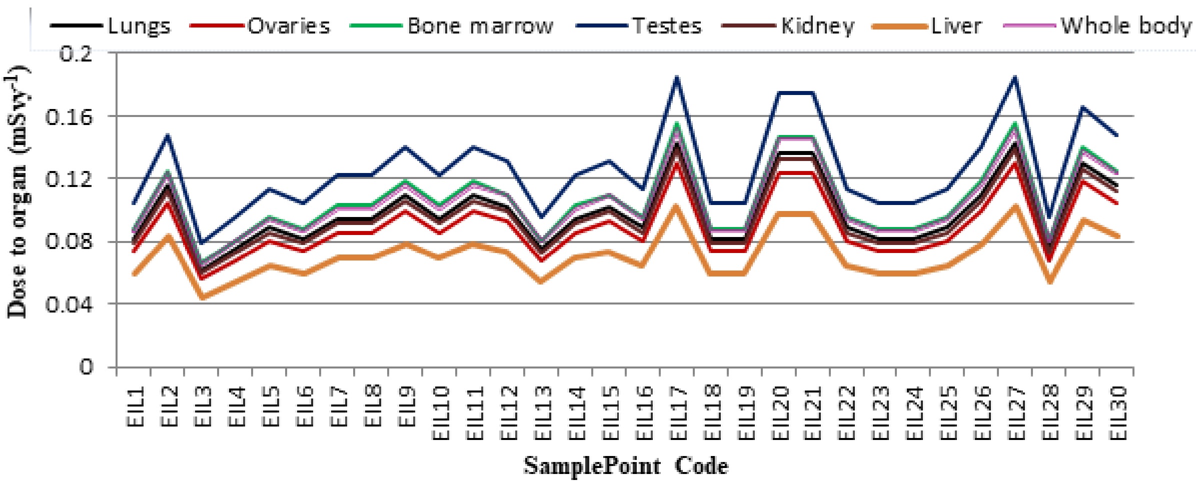

Figure 3. Comparison of the doses to different body organs.

protection to quantify the whole body absorbed dose per year. It is used to assess the potential for long-term effects that might occur in the future. The calculated absorbed dose rates were used to compute the AEDE within the study area using Equation 4 as given by Rafique et al. (2014) and Agbalagba (2017):

$$AEDE(mSvy^{-1}) = ADR(\eta Gyh^{-1}) \times 8760h \times 0.7\,Sv/Gy \times 0.2 \quad (4)$$

where ADR is the absorbed dose rate in ηGyh^{-1}, 8760 is the total hours in a year, 0.7Sv/Gy is the dose conversion factor from absorbed dose in air to the effective dose with an occupancy factor of 0.2 for outdoor exposure as recommended by UNSCEAR (2008).

The calculated values of AEDE range from 0.096 to 0.224 mSvy^{-1} with mean value of 0.155±0.006 mSvy^{-1}. This mean annual effective dose is higher than world average value of 0.07 mSvy^{-1} (ICRP, 2007; UNSCEAR, 2008; Agbalagba, 2017) but within ICRP and UNSCEAR recommended permissible limits of 1.00 mSvy^{-1} for the general public (ICRP, 2007; UNSCEAR, 2008). This implies that the studied location is radiologically contaminated due to the industrial activities taking place in the area. However, the contamination does not constitute any immediate radiological health effect on residents of the area. The annual effective doses evaluated in this study are similar to those reported by Ononugbo and Mgbemere (2016) in fertilizer producing area in Onne River State. The mean value is lower than 0.205±0.017 mean value observed in Idu industrial area of Abuja, Nigeria by James et al. (2013).

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

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

$$D_{organ}(mSvy^{-1}) = AEDE \times F \quad (5)$$

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 as given by ICRP (1996) are 0.64, 0.58, 0.69, 0.82, 0.62, 0.46, and 0.68, respectively

The estimated average D_{organ} values for the 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 mSvy^{-1} respectively. Figure 3 shows the variation of D_{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)

$$ELCR = AEDE(mSvy^{-1}) \times DL \times RF \quad (6)$$

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 $(0.541 \pm 0.032)\times10^{-3}$. 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 Avwiri 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.

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