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ASSESSMENT OF IONIZING RADIATION EXPOSURE LEVELS AND ASSOCIATED HEALTH RISK IN SOME SELECTED SOLID MINERAL MINING SITES EDO-NORTH, NIGERIA

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ABSTRACT

Ionizing radiation exposure rate and its associated health risks were assessed using Digilert 200 and Rados Radiation Monitoring Meter, integrated with Geographical Positioning System (Garmin GPSMAP 76S) of some selected solid mineral mining sites across Edo-North Nigeria. The mean exposure rates show some characteristic range of 0.010±0.005 $mRhr^{-1}$ *to 0.027* $mRhr^{-1}$ *across the entire study. The obtained mean exposures rates at all the mining pits were higher than the ICRP standard limit of 0.013* $mRhr^{-1}$*, except at freedom limestones mining pit where we recorded 0.010* mRh^{-1}*. It was also observed that limestones mining sites exhibited low exposure rate while granite mining sites exhibited high exposure rate. The computed equivalent dose rate ranges from 1.049* $mSvy^{-1}$ *to 2.287* $mSvy^{-1}$*, which is well above the recommended permissible limit of 1.0* $mSvy^{-1}$ *for the general public. 91.7% of the mining sites recorded higher absorbed dose rate but the mean AEDE recorded across the entire study area are below the ICRP standard. The average excess lifetime cancer risk shows variation from 0.472 x* 10^{-3} *to 1.27 x* 10^{-3}*. . By this result, the probability of contacting cancer due to radiation exposure is higher in places like Cinoma pit, Cetraco pit, Niger-Cat pit, Jigom pit, Oaries pit and Petra-Quarries pit.*

Keywords: Assessment, Mining pits, Background, Exposure, lifetime cancer risk

INTRODUCTION

The full scale legacy of radiological implication posed by the exploration, exploitation, mining, processing of solid mineral resources across Communities in Edo-North has become quite apparent in recent years (Olanrewaju & Avwiri, 2017). Solid mineral mining activities in parts of Edo State have being of great economic appeal, with capacity to compliment local and foreign exchange earnings, as well as attracting foreign direct investment to the Nigeria economy. Therefore, the human activities involved in the transition of these mineral through the various natural stages induce a great radiological impact on the earth biosphere (Ononugbo & Nte, 2019). Natural radioactivity is widespread in the earth environment and it exists in various geological formations such as earth crust, rocks, soils, plants, water and air (Ononugbo & Nte, 2019). When rocks are disintegrated through natural process (Weathering), radionuclides are transported to soil by infiltration (Agbalagba *et al*., 2016; Onwuka *et al*., 2019). According to Olanrewaju & Avwiri, (2017), the ways minerals incorporate the radionuclide depend on several geological conditions that is dependent on the mineral species and geological formation from which they originate. Primordial radioactive elements (Uranium-235, Uranium-238, Thorium-232 and Potassium-40) are originally associated with the earth during its formation in 4.6b years ago (Jibril, 2001; Lee *et al.*, 2009). Yau Idris (2008), averred that Mine Tailings in the form of Technologically Enhanced Naturally occurring Radioactive Material (TENORM), with long life radionuclides and relatively high radio-toxicities also exists in some of the solid mineral mining sites. If these natural radionuclides are not managed properly, large contaminated areas associated with different pathways can take place (Anekwe *et al.*, 2013; Avwiri *et al.*, 2014). Consequently, members of the public and workers around these Communities may suffer radiation hazard (Onwuka *et al.*, 2019). Jibiri (2001) stated that an increase in background ionizing radiation from numerous sources has various health consequences for the populace. Excessive exposure of workers and residents to ionizing radiation from the exploration and exploitation of solid minerals could results to Deterministic or Stochastic health effect such as Cancer, eye cataracts, mental imbalances and so on (Agbalagba *et al.*, 2016; Aliyu & Ramli, 2015; Almayahi *et al.*, 2013 and Lu *et al.*, 2012). There have been growing appeals to the presidency through the Regulatory Authority (NNRA) of the need for radiological assessment of solid minerals mining sites across Nigeria (Clouvas *et al.*, 2004).

Hence the radiological status of the mining sites in the six Local Government Areas of Edo-North calls for an urgent establishment which will serve as a working document and baseline resource for the various governmental agencies. The Legislative arm of Government shall also find this work piece appealing in their periodic quest for nuclear safety and Radiological Protection Act Review. This result of this research work shall however compliment the Presidential Intervention initiatives on the management of NORM in Nigeria and also form a basis for the establishment of National Radioactive Waste Management Facility in Nigeria.

MATERIALS AND METHODS

Study Area

The study area is located at the northern part of Edo State, which falls within the north – east of Benin City, the State's Capital and it is the North Senatorial District of Edo State, Nigeria. Structurally, the study area, Edo-North is made up of Six (6) Local Government Areas with administrative headquaters, viz: Akoko-Edo (Igara), Etsako-East (Agenegbode), Etsako-Central (Fugar), Etsako-West (Auchi), Owan-East(Afuze) and Owan-West(Sabongida-Ora). Out all the six LGAs five are involved in solid mineral mining business in commercial scale. These are Akoko-Edo, Etsako-East, Owan-West, Owan-East and Etsako-West LGAs are involved in quarry business in Edo-North (Figure 1).

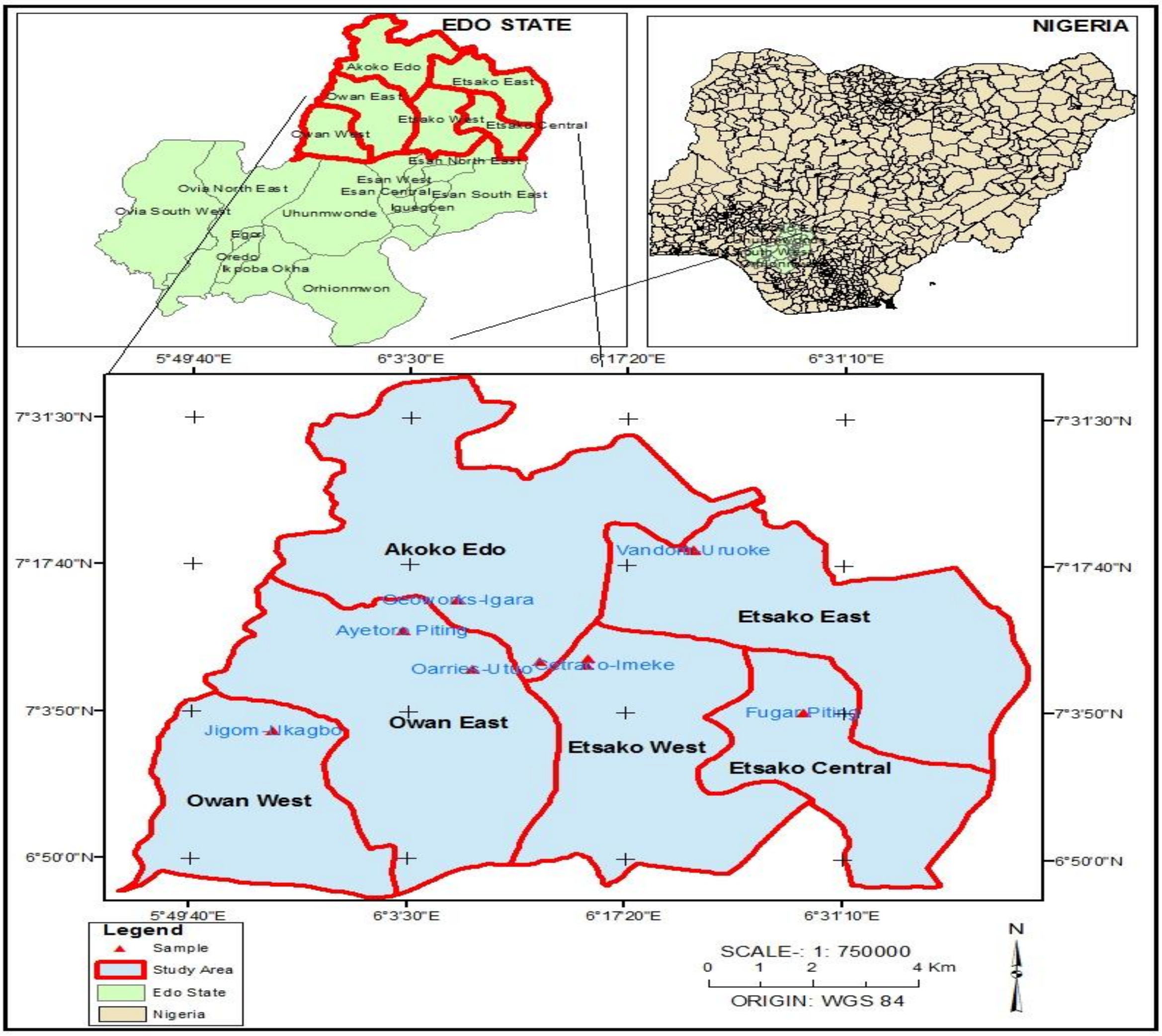

Fig.1: Map showing the six Local government Areas in Edo-North.

METHODS

In-situ measurement of radiation exposure rate of the mining sites was measured using two well calibrated state-of-the-art nuclear monitors (Digilert 200 (S.E. International Incorporation, Summer Town, USA) and Rados). The Rados is a gamma radiation detector while Digilert 200 radiation monitoring meter (S.E. International Incorporation, Summer Town, USA), containing a Geiger-Muller tube capable of detecting alpha, beta, gamma and X-rays within the temperature range of 10°C and 50°C. These two survey meters were integrated with geographical positioning system (Garmin GPSMAP 76S) for location mapping. The Geiger-Muller tube generates a pulse current each time radiation passes through the tube and causes ionization. Each pulse is electronically detected and registered as a count. The radiation monitors were calibrated with a 137Cs source of specific energy at National Institute of Radiation Protection and Research, University of Ibadan and set to measure exposures rate in milli Roentgen per hour ($mRhr^{-1}$) and micro Sievert per hour($\mu Svhr^{-1}$). The GPS was used for georeference the sampling points in terms of longitude and latitude. Readings were obtained in line with best environmental requirements, within the hours of 1300 and 1600 since the exposure rate meter has a maximum response to environmental radiation within these hours (Agbalagba *et al*., 2016). The radiation exposure reading in the entire study area were used to compute the secondary radio-parameters such as absorbed dose rate, annual effective dose equivalent(AEDE), excess lifetime cancer risk(ELCR) and equivalent dose.

Radiological Risk Parameters

Absorbed Dose

It is defined as is the measure of the amount of energy (radionuclides) deposited by ionization radiation in the human body for a given period (Lu *et al*., 2012). The exposure rates were converted to absorbed dose rate using the conversion factor (Jibril, 2001).

$$1\mu\mathrm{Rh}^{-1} = 8.7\ \mathrm{nGyh}^{-1} = 8.7 \times 10^{-3} / \left(\frac{1}{8760\mathrm{y}}\right) \qquad (1)$$

Annual Effective Dose Equivalent (AEDE)

The calculated absorbed dose rates were used to estimate the annual effective dose equivalent (AEDE) received by residents living in the study areas. Dose conversion factor of 0.7 Sv/Gy recommended by UNSCEAR for the conversion coefficient from the absorbed dose in air to the effective dose received by adults (Agbalagba, *et al.*, 2016) and an occupancy factor of 0.25 for outdoor exposure was used. The annual effective dose equivalent was estimated using Equation 2 (Amanjeet *et al*., 2017; Lu *et al*., 2012).

$$\mathrm{AEDE\ (outdoor)}\ (\mathrm{m}Sv\mathrm{y}^{-1}) = \mathrm{Absorbed\ dose}(\mathrm{nGyh}^{-1}) \times 8760 \times \frac{0.7\mathrm{Sv}}{\mathrm{Gy}} \times 0.25 \qquad (2)$$

Excess Life time Cancer Risk (ELCR)

This is the probability of residents and workers living within the solid mineral mining communities developing cancer. It was determined using Equation 3 (Agbalagba *et al*., 2016; Aliyu and Ramli 2015).

$$\mathrm{ELCR} = \mathrm{AEDE} \times \mathrm{Average\ duration\ of\ life\ (DL)} \times \mathrm{Risk\ factor\ (RF)} \qquad (3)$$

Where AEDE, DL and RF is the annual effective dose equivalent, duration of life (70 years) and the risk factor (Sv^{-1}), fatal cancer risk per Sievert. For low dose background radiations which are considered to produce stochastic effects, ICRP 60 uses 0.05 for the public (Agbalagba, 2017).

RESULTS AND DISCUSSIONS

Results

A total of 121 measurements of radiation dose rates were measured throughout the entire solid mineral mining province of Edo-North. The result of the measured exposure rate and the calculated hazard risks for the twelve (12) selected mining sites from the six (6) local government areas that make up Edo-North and its surroundings are presented in Tables 1. Analysis using different radiation models to arrive at a more reliable health risks to an irradiated person was performed. To do the analytical assessment of the radiation hazards associated with gamma radiation levels in entire study area, the following radiation hazard indices were used: annual effective dose equivalent, absorbed dose rate, equivalent dose and excess lifetime cancer risk. The various radiological health hazard findings were analyzed with the aid of a statistical tool (SPSS) and environmental contouring software (Surfer-

8) which are presented in Figures 2 to 6. Figure 2b shows the radio-map of the area.

Table 1. Mean Radiation Exposure Rate and Radiological risk parameters of 12 mining sites in Six LGA of Edo-North.

S/N	**Sites/Community /LGA**	**Geographical Position**	**Average exposure Rate (mRh^{-1})**	**Absorbed Dose rate (nGyh^{-1})**	**AEDE (mSvy^{-1})**	**ELCR (x10^{-3})**	**Equivalent Dose (mSvy^{-1})**
1.	Cinoma-Okpilla (CO) Etsako-East LGA	07°19.173’N 006°21.620’E	0.026 ±0.009	211.2	0.324	1.010	2.179
2.	Vandom-Uruoke (VU) Etsako-West LGA	07°10.999’N 006°19.842’E	0.015 ±0.004	129.6	0.199	0.70	1.253
3.	Geoworks-Igara (GI) Akoko-Edo LGA	07°14.416’N 006°06.541’E	0.014 ±0.005	124.4	0.191	0.667	1.202
4.	Ayetoro Piting (AP) Owan-East LGA	07°11.524’N 006°03.161’E	0.015 ± 0.008	127.7	0.205	0.719	1.195
5.	Freedom-Ikpeshi (FI) Akoko-Edo LGA	07°08.038’N 006°11.902’E	0.010 ± 0.005	87.9	0.135	0.472	1.049
6.	Cetraco-Imeke (CI) Etsako-West LGA	07°08.295’N 006°14.816E	0.023 ± 0.005	195.8	0.300	1.050	1.892
7.	Fugar Piting (FP) Etsako-Central LGA	07°03.923’N 006°28.681’E	0.015 ± 0.005	127.0	0.195	0.682	1.228
8.	Niger-Cat, Iyiku (NCI) Etsako-West LGA	**07**°08.913’N 006°14.984’E	0.027 ± 0.005	236.6	0.363	1.270	2.287
9.	Jigom-Ukagbo (JU) Owan-West LGA	07°02.069’N 005°54.901’E	0.025 ±0.009	217.5	0.333	1.167	2.102
10.	BUA-Ogbo-Okpilla (BOO) Etsako-East LGA	**07**°19.580’N 006°20.671E	0.021 ± 0.01	180.1	0.276	0.966	1.741
11.	Oarries-Utuo (OU) Owan-East LGA	**07**°08.836’N 006°02.294’E	0.024 ± 0.006	202.7	0.311	1.088	1.960
12	**Petra-Ihieube-Ogben (PIO) Owan-East LGA**	**07°07.949’N, 006°07.609’E**	**0.023 ± 0.011**	**205.3**	**0.315**	**1.100**	**1.985**

Table 2: Comparison of Location Averages for each Factor

Location	Average Exposure Rate (mRh $^{-1}$)	Absorbed Dose Rate (nGyh^{-1})	AEDE (mSvy^{-1})	ELCR (x10 $^{-3}$)	Equivalent Dose (mSvy^{-1})
	Mean± Std	**Mean± Std**	**Mean± Std**	**Mean± Std**	**Mean± Std**
CO	0.026± 0.013^{ab}	211.17± 126.62^{d}	0.324± 0.194^{d}	1.134± 0.678^{d}	2.179± 1.067^{c}
VU	0.015± 0.007^{a}	129.63± 59.92^{ab}	0.199± 0.092^{ab}	0.696± 0.321^{ab}	1.253± 0.579^{ab}
GI	0.014± 0.01^{a}	124.41± 84.55^{ab}	0.191± 0.13^{ab}	0.667± 0.453^{ab}	1.202± 0.817^{ab}
AP	0.015± 0.004^{a}	133.98± 33.62^{abc}	0.205± 0.051^{abc}	0.719± 0.18^{abc}	1.195± 0.441^{ab}
FI	0.01± 0.005^{a}	87.87± 40.28^{a}	0.135± 0.062^{a}	0.472± 0.216^{a}	1.049± 0.501^{a}
CI	0.023± 0.008^{ab}	195.75± 66.16^{cd}	0.3± 0.101^{cd}	1.05± 0.355^{cd}	1.892± 0.639^{c}
FP	0.026± 0.037^{ab}	127.02± 42.26^{ab}	0.195± 0.065^{ab}	0.682± 0.227^{ab}	1.228± 0.409^{ab}
NCI	0.027± 0.01^{ab}	236.64± 88.51^{d}	0.363± 0.136^{d}	1.27± 0.475^{d}	2.287± 0.856^{c}
JU	0.025± 0.005^{ab}	217.5± 40.18^{d}	0.333± 0.062^{d}	1.167± 0.215^{d}	2.102± 0.389^{c}
BOO	0.021± 0.006^{ab}	180.09± 53.79^{bcd}	0.276± 0.082^{bcd}	0.966± 0.288^{bcd}	1.741± 0.52^{bc}
OU	0.043± 0.061^{b}	202.73± 59.5^{d}	0.311± 0.091^{d}	1.088± 0.319^{d}	1.959± 0.575^{c}
PIO	0.023± 0.007^{ab}	205.32± 59.6^{d}	0.315± 0.091^{d}	1.101± 0.32^{d}	1.985± 0.576^{c}
ANOVA (p-value)	1.536 (0.129)	4.88 (0.000)	4.885 (0.000)	4.892 (0.000)	4.934 (0.000)
Decision	**Not Significant**	**Significant**	**Significant**	**Significant**	**Significant**

NB: Row Mean± Std with same superscript alphabet is not significantly different.

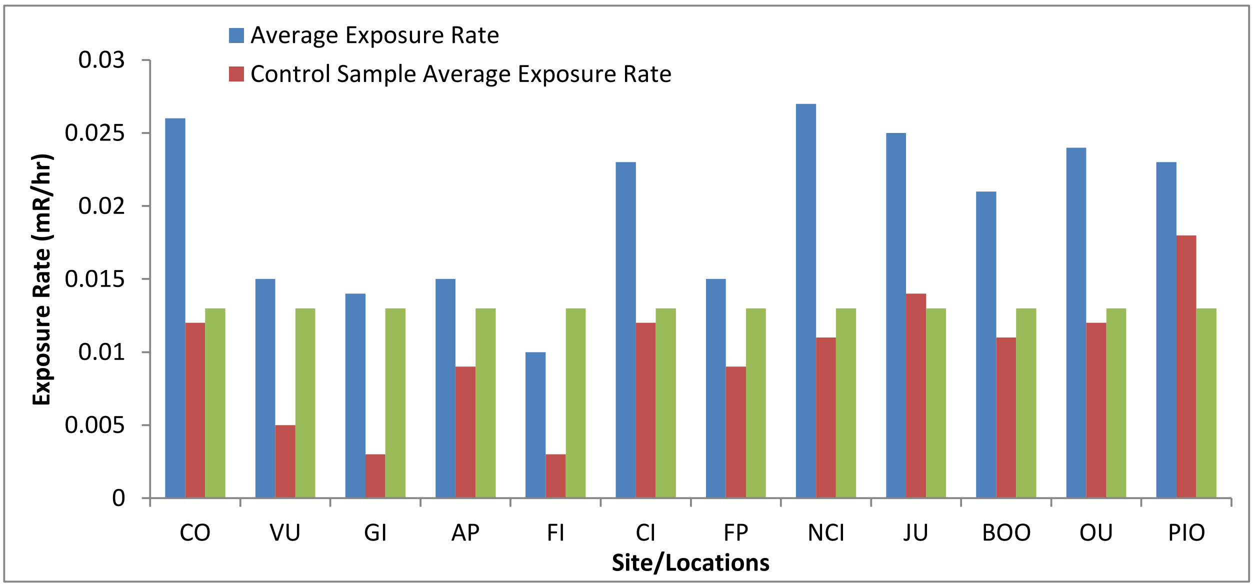

Fig. 2a: Comparison of Mean Exposure Rate with control and world standard across the entire Edo-North study areas.

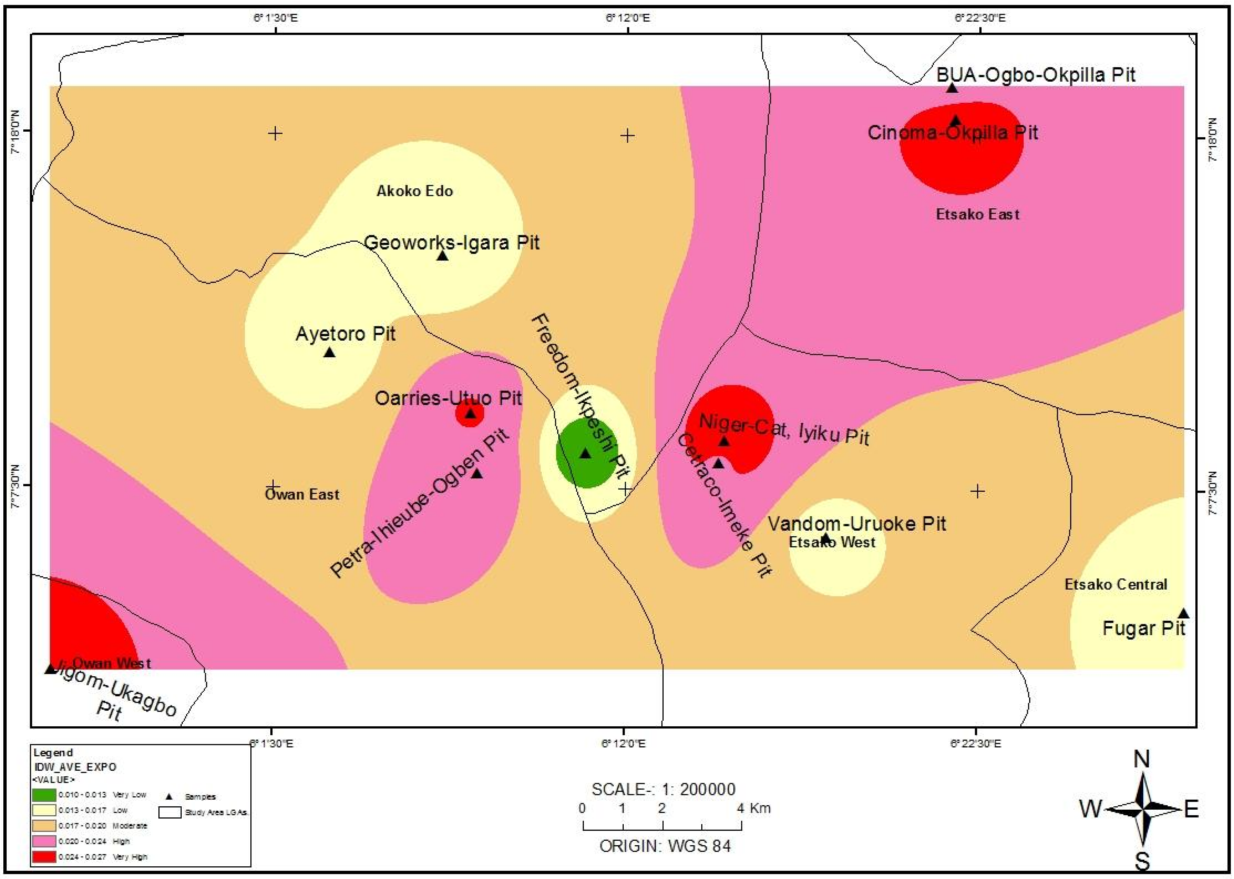

Fig. 2b. Radio - Map showing the variation of mean average exposure rate across the entire Edo-North study area.

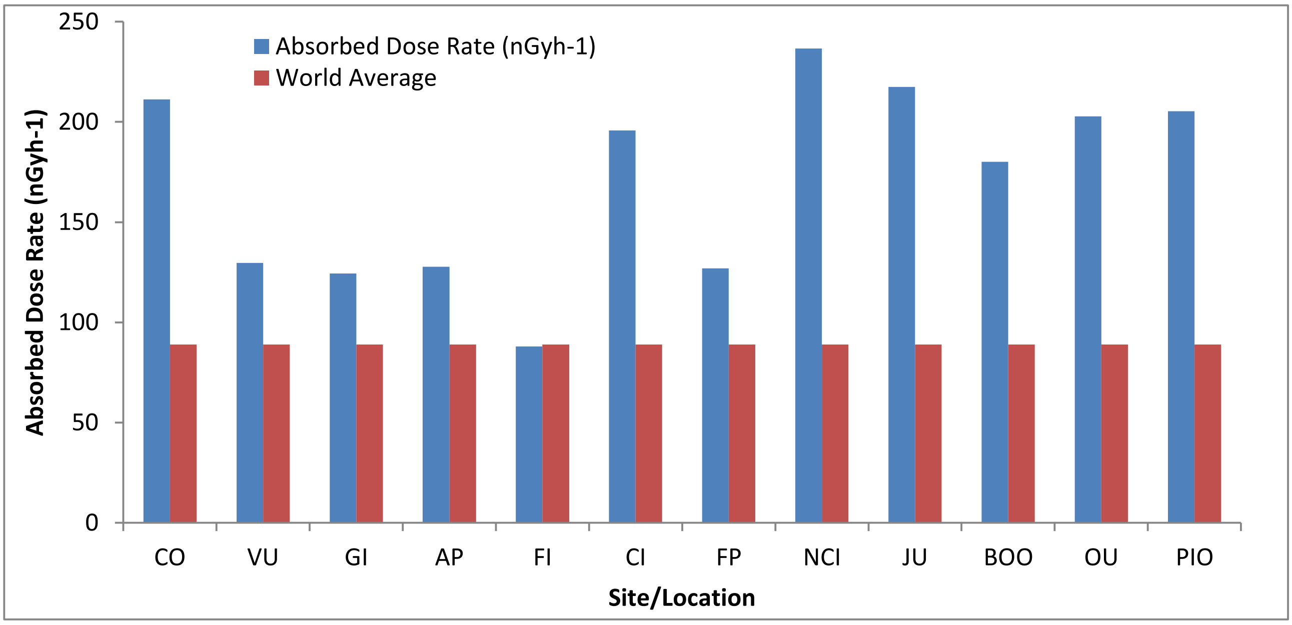

Fig.3. Comparison of mean absorbed dose rate with world standard across the entire Edo-North study areas.

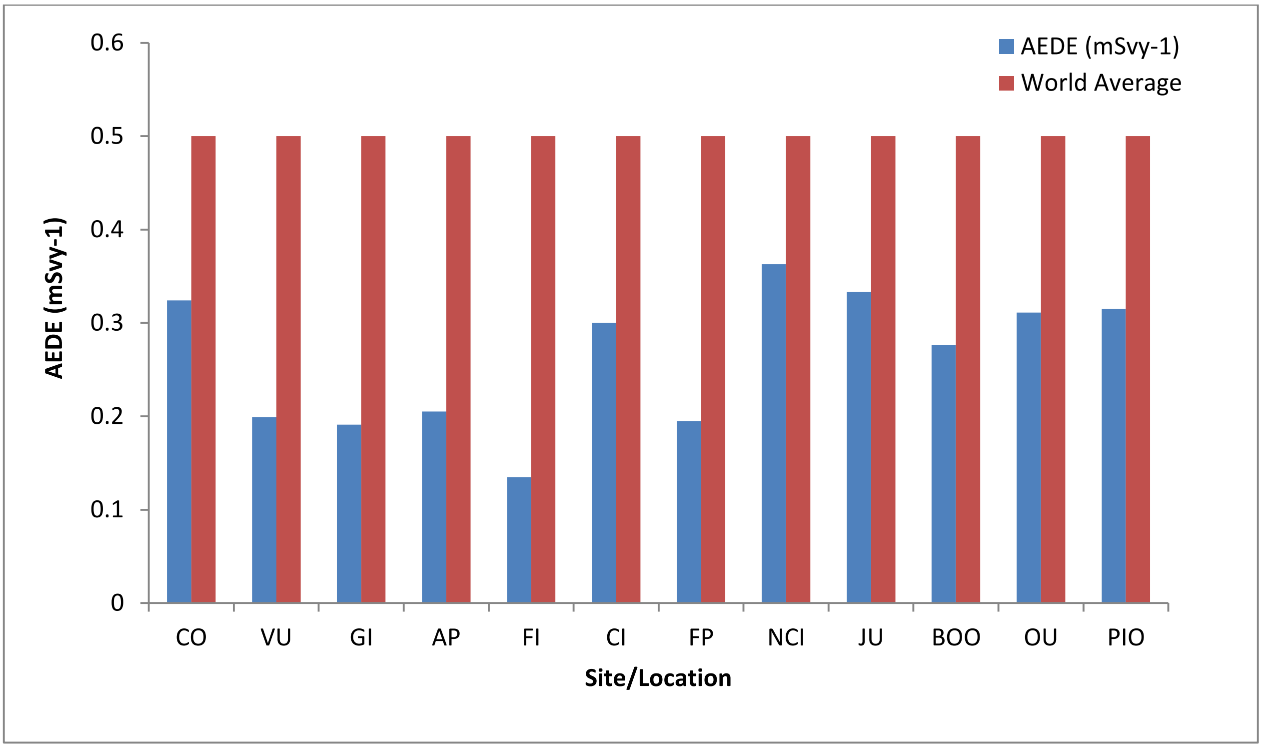

Fig.4. Comparison of mean annual effective dose equivalent (AEDE) with world standard across the entire Edo-North study areas.

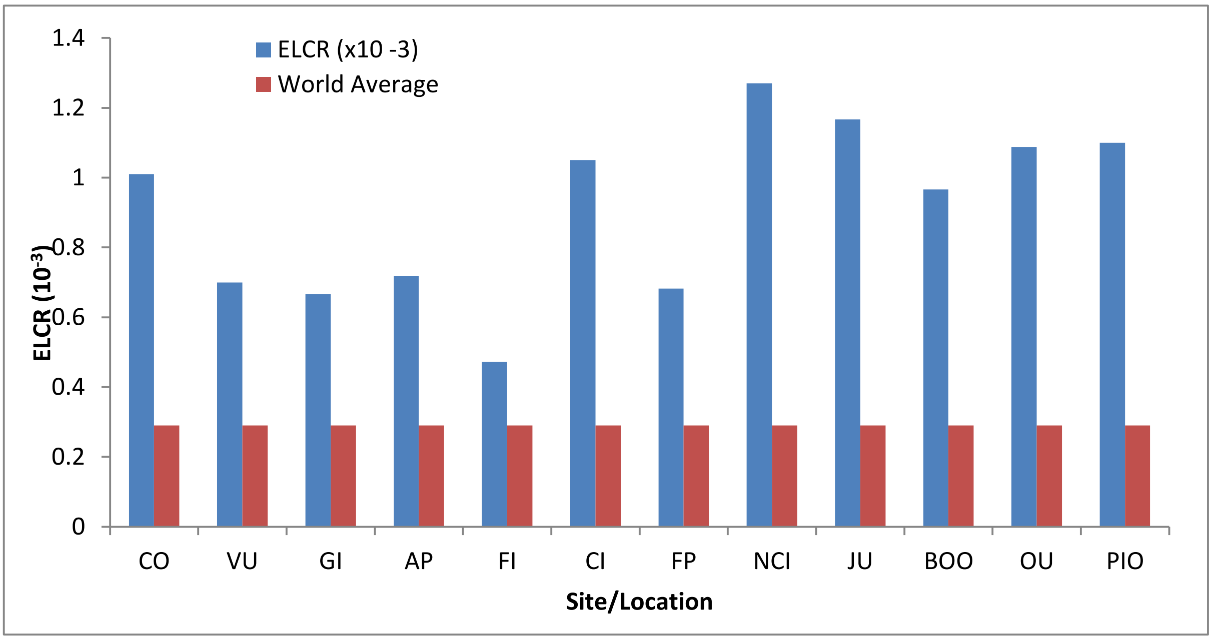

Fig.5. Comparison of mean excess lifetime cancer risk (ELCR) with world standard across the entire Edo-North study areas.

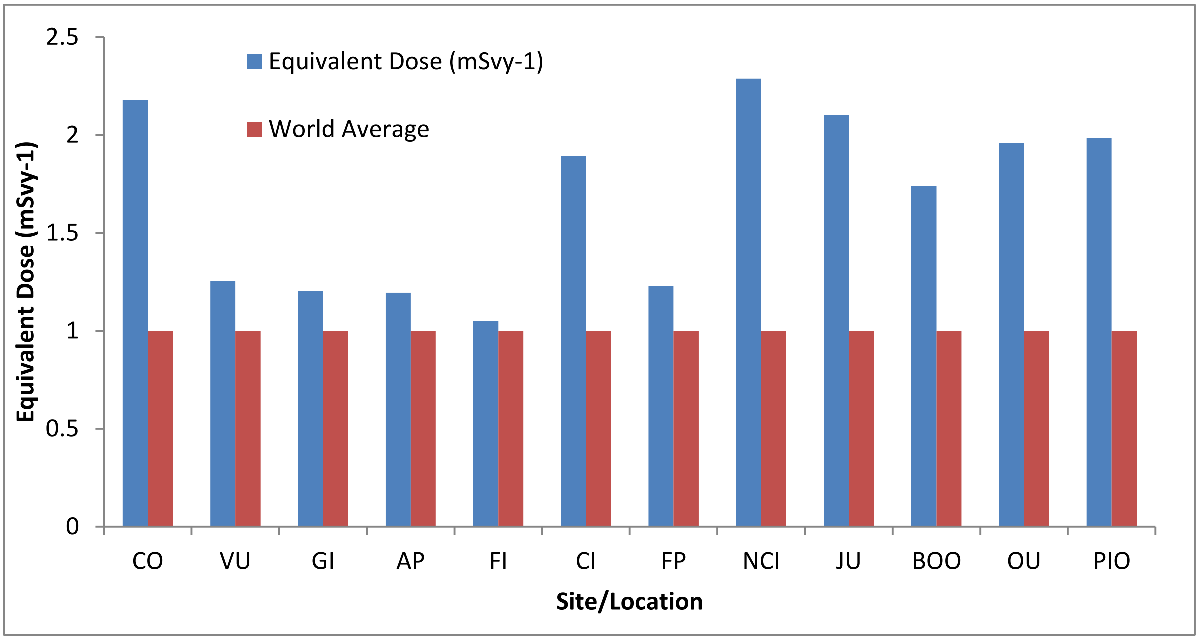

Fig.6. Comparison of mean Equivalent dose with world standard across the entire Edo-North study areas.

DISCUSSION

The mean exposure rate measured in all the mining sites studied is presented in Table 1. The mean exposure rates show some characteristic range of $0.010 \pm 0.005\ \mathrm{mRhr}^{-1}$ to $0.027\ \mathrm{mRhr}^{-1}$ across the entire study. The obtained mean exposures rates at all the mining pits were higher than the ICRP standard limit of $0.013\ \mathrm{mRhr}^{-1}$ (Babatunde *et al.*, 2019), except at freedom limestones mining pit where we recorded $0.010\ \mathrm{mRh}^{-1}$ (Table 1). The anomalous high values of the radiological parameters across the entire solid mineral mining sites in Edo-North may be attributed to the prevailing anthropogenic and mining activities taking place in the area. Technologically enhanced Radioactive Materials are known to be associated with solid mineral mining sites, and this may be responsible for the anomalous high BIR level delineated across the study area. The low values of exposure rate obtained at the Freedom limestone mining pit may be as a result of the homogeneous and radiological-low-value nature of limestone deposits across the world. Similarly, mining sites that are under-layed with granitic rocks appears to exhibit elevated background ionizing radiation level (Cetraco granitic mining pit(Imeke), Niger-Cat granitic mining pit(Iyiku), Petra-Quarries granitic mining pit (Ihieube Ogben), Jigom granitic mining pit(Ukagbo) and Oarries granitic mining pit at Utuo, Owan-East LGA). Also the mean exposure rate observed at Bua limestone/granitic mining pit ($0.021 \pm 0.001\ \mathrm{mRhr}^{-1}$ correlates well with that obtained by Onwuka *et al.* (2019) in Bua cement factory Okpilla, Olanrewaju and Avwiri (2017) in Benue state, Aliyu & Ramli (2015) in Nasarawa state and Sanusi (2017) in Kuala Lumpur-Malaysia. Many previous studies have revealed the influences of geological setting on background radiation (Onwuka *et al.*, 2019; Ovuomarie – Kelvin *et al.*, 2018; Olarewaju & Avwiri, 2017; Perez *et al*. 2018). Sanusi

(2017) has statistically verified that granitic rock is the main factor to high contribution of background radiation (>250 nGy h^{-1}) in state of Selangor, whereas, low background radiation (<190 nGy h^{-1}) are mostly associated with metamorphic and sedimentary based rocks (Quindos *et al*. 1991) from Silurian to Carboniferous age for instance, limestone, shale, sandstones, schist, quartzite and phyllite (Clouvas et *al*. 2004). Similar findings were also reported by Lee *et al.,* (2009) and Almayahi *et al*., 2013) for Kinta district (Perak state) and the Northern States, respectively.

The computed equivalent dose rate across the entire study areas sampled are well above the recommended permissible limit of 1.0 $mSvy^{-1}$ for the general public and some of them (2.179 $mSvy^{-1}$at Cinoma, 2.102 $mSvy^{-1}$ at Jigom, 2.287 $mSvy^{-1}$ at Niger-cat, 1.892 $mSvy^{-1}$ at Cetraco, 1.741 $mSvy^{-1}$ at Bua, 1.960 $mSvy^{-1}$ at quarries and 1.985 $mSvy^{-1}$ at Petra-Quarries), were quite above the recommended occupational permissible limit of 1.5 $mSvy^{-1}$ (Ononugbo and Nte, 2019). These results agree quite well with previous findings of a typical solid mineral mining environment.

The gamma radiation absorbed dose rate obtained from the study area is presented in Table 1. Results show that absorbed dose rate was higher than world standard average (89 nGy/h) in all locations except in Freedom mining pit Ikpeshi (FI), which recorded lower absorbed dose rate (87.9 nGy/h). The gamma absorbed dose rate generated from Cinoma pit, Niger-Cat pit, Jigom pit, Oaries pit and petra-Quarries pit are similar with range values (104.4 – 330.6 $nGyh^{-1}$ and mean value 234.9 $nGyh^{-1}$) reported in Bua Cement factory, Okpilla by Onwuka *et al*. (2019).The mean values obtained from Vandom pit, Geo works pit, Fugar pit, Ayetoro pit and Freedom pit are lower than the values (141.30±31.31 $nGyh^{-1}$) previously obtained in Warri city by Agbalagba (2017) but higher than Rafique *et al*., (2013) in Jhelum Valley (81.61 $nGyh^{-1}$) for Muzaffarabad, and 102.70 $nGyh^{-1}$ for Poonch in Turkey and the Greek population value of 32 $nGyh^{-1}$ by Clouvas and Anonopoulos (2004) excepting the mean value(87.9 $nGyh^{-1}$) reported at Freedom limestone mining pit. It is important to note that 91.7% of the studied area had their absorbed dose rate higher than the world average of 89 $nGyh^{-1}$(Avwiri, *et al.*, 2014).

The average annual effective dose equivalent (AEDE) deduced from Cinoma pit, Cetraco pit, Niger-Cat pit, Jigom pit, Bua pit, Oarries and Petra-Quarries pit appears to be higher than the reported values of 0.19, 0.15, and 0.20 $mSvy^{-1}$ by Agbalagba, (2017). However, AEDE mean values obtained from Vandom pit, Geoworks pit, Ayetoro pit, Freedom pit and Fugar pit falls within the range reported by Agbalagba, in Warri city. In comparison to global measured values, these values were all below the assigned worldwide values of 0.50 $mSvy^{-1}$ (Taskin *et al*., 2009) for outdoor environments. In the system of radiological protection, ICRP stated that the reference level used in conjunction with the optimisation of protection to restrict individual dose due to “existing exposure” is between 1$mSvy^{-1}$ and 20 $mSvy^{-1.}$ The mean AED received by members of public across the entire study area is below ICRP reference range and too low to cause an acute radiation effects. Nevertheless, in terms of lifetime exposure risk, such exposures would potentially give rise to stochastic effects to members of the public (Idris 2008). The calculated excess lifetime

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cancer risk (ELCR) is presented Table 1. ELCR estimated from the study areas ranges from 0.427 x 10^{-3} to 1.27 x 10^{-3}, with mean value of 0.91 x 10^{-3}. The average excess lifetime cancer risks obtained in these study areas are higher than the world average of 0.29 x 10^{-3} (Taskin *et al.*, 2009). By this result, the probability of contacting cancer due to ionization of tissues/organ is higher in places like Cinoma pit, Cetraco pit, Niger-Cat pit, Jigom pit, Oaries pit and Petra-Quarries pit.

Table 2 represents the comparison of the various radio-parameters using analysis of variance (ANOVA-SPSS). The Results shows that the various locations average exposure rates are not significantly different ($p>0.05$) at 5% level of significance. However, the locations absorbed dose rates, AEDEs, ELCR and equivalent doses are significantly different ($p<0.05$) at 5% level of significance. The Post-Hoc test show that mean ± standard deviation with same alphabet superscript is not significantly different ($p>0.05$), which implies that mean ± standard deviation with different alphabet superscript is significantly different ($p<0.05$).

CONCLUSION

The effectiveness of using Digilert 200 and Rados Radiation Monitoring Meter, integrated with Geographical Positioning System (Garmin GPSMAP 76S) for studying Ionizing Radiation Exposure levels and Associated Health Risk in some selected Solid Mineral Mining Sites across Edo-North, Nigeria have been demonstrated by this study. The following conclusions may be deduced from this study:

1) The radiation exposure rates shows that 91.7% of the sample locations indicate high radiation levels with mean values higher than 0.013 mRh^{-1} ICRP permissible limit for normal background radiation level.
2) The computed absorbed dose rate in the entire solid mineral mining sites were higher than the world standard value of 89 nGy/h, except at Freedom mining pit, which recorded lower absorbed dose rate of 87.9 nGy/h.
3) The calculated mean annual effective dose equivalent (AEDE) across the study area was lower than the 1.0 mSvy^{-1} world permissible value and similar to recorded values from other mining environments.
4) The estimated excess lifetime cancer risk (ELCR) values are higher than the world acceptable value of 0.29 x 10^{-3} for exposure and there could be probability of developing cancer over time for residents of the study areas.

Based on the findings of this research, the following recommendations were made:

a) Miners in the mining sites should be protected from radiation, by putting on appropriate PPEs (Leaded Apron, Gonad Shields, Leaded goggles and gloves).
b) Workers spend less time in the mining pits in order to keep absorbed dose As-Low-As-Reasonably Achievable (ALARA).
c) Adjacent communities should be relocated at least 2km away from mining sites, especially that of Ikpeshi and Uruoke.

d) We recommend that Government brings Solid Mineral Mining Activities under Regulatory control.

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