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Investigating the Radiological Burden of Working and Residing Around Coal Mine Site in Nigeria

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ABSTRACT: The evaluation of the radiological burden of working and living in coal mine area has been carried out, using a digilert 100 nuclear radiation monitor and geographical positioning system (GPS). The monitoring of the background ionizing radiation (BIR) levels was carried out in one year on monthly bases. Measured mean exposure rate for the three mining sites are 0.017 ± 0.006 mR h⁻¹(1.43 ± 0.67 mSv y-1), 0.014 ± 0.004 mR h⁻¹(1.21 ± 0.34 mSv y-1) and 0.016 ± 0.003 mRh⁻¹(1.41 ± 0.25 mSv y-1) for Onyeama, Udi and Ogbete mining sites respectively. The estimated mean absorbed dose rate are 147.90 ± 48.62 qGy h-1, 123.54 ± 34.80 qGy h-1and 149.34 ± 26.10 qGy h-1respectively. The mean annual effective dose equivalent (AEDE) calculated for the study coal mining sites are 0.21 ± 0.06 mSv y-1, 0.15 ± 0.04 mSv y-1 and 0.20 ± 0.03 mSv y-1, while the mean excess lifetime cancer risk (ELCR) are (0.74 ± 0.14) x10³, (0.53 ± 0.21) x10³ and (0.69 ± 0.11) x10³ respectively. The calculated Excess Lifetime Cancer Risk values obtained may not cause immediate cancer risk to residents and workers in the coal mine. The dose to organs received shows that testes have the highest dose of 0.14mSvy⁻¹, while liver has the lowest dose values of 0.06mSvy⁻¹. The study revealed that of the 3 sites, 30 sampling locations and 360 exposure measurements made, 74.6% exceeded the World ambient levels of 0.013 mRh⁻¹(1.0mSvy-1) recommended by UNSCEAR, and the values obtained in this work are higher than most values reported in literature. The exposure levels obtained in this study may constitute a long term radiation related health risk to the residents and coal miners in the study area.

KEYWORDS: Exposure levels, Cancer risk, Coal mine, Nigeria

I. INTRODUCTION

The knowledge of radionuclide and radiation levels in the environment is an important tool for the assessment of the effects of radiation exposure due to terrestrial sources. Man is exposed continually to ionizing radiation from natural sources with or without his consent and this phenomenon is unending and unpredictable, with some of the exposure to natural radiation sources being modified by human activities [1]. Hence, exposure to ionizing radiation emitted by these radionuclides is an inescapable feature of life on the earth. But continuous exposure to ionizing radiation can lead to damage of vital cells in the body causing diseases like cancer, cataract and leukemia [2].

Humans are exposed to ionizing radiations from radioactive nuclides by direct exposure, inhalation of contaminated dust particles, other examples include; natural radionuclides released into the environment in mineral processing and usage, phosphate fertilizer processing, fossil fuel combustion and quarry and coal mining activity[3]. Some persons are exposed to enhanced levels of natural radiation at their places of work, such workers include; underground (uranium, tin, silver, coal etc.) miners, oil field workers and some workers involved in mineral processing [4,5]. Presently, the major fossil fuels in Nigeria are coal, crude oil and bitumen of which coal is among the most exploited. Coal is known to be largely associated with naturally Occurring Radioactive Materials (NORM), as it contains ²³⁸U/ ²²⁶Ra, ³²⁷Th and ⁴⁰K [6]. The radioactive (radon) contamination of this geological mineral material has become of concern in radiation



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protection [7,8, 9]. They have been found to be capable of resulting in high radiological exposure of the public relative to that caused by the nuclear industry for instance [10]. Thus, there may be health implications of exposure to these radioactive laden minerals to both the exploiters and those living in the immediate environments where exploitation is being carried out [11]. Moreso, the natural radionuclides in coals release to the atmosphere gives rise to one of the components of technological enhanced natural radiation [9]. Burning of the coal produces coal fly ash which on released into the environment may also cause some radiological impact on the populace and all these have heighten growing concern of people living and working around coal exploration environment [12]. Coal was first found in commercial quantity in Enugu and it was a major source of energy and power supply in the 50's to 70's and still very relevant today in Nigeria because of its diverse applications and usage. Coal mining and its activities have adverse effects on the lives of miners and individuals living around the mining sites, because its mining activities generate hundreds of millions of tons of waste products and liberating particles dust, including desulphurization sludge that contains mercury, uranium (radon), thorium, arsenic and other heavy metals [13]. In recent time, researchers have found a strong correlation between radiation exposure and health hazard on people living within and workers in these environment eco- system, which are attributed to the ionizing radiation release from fossil fuel and some solid minerals during mining [14,15,16]. Considering the complaints by host communities in recent time in Enugu of strange health problem due to the coal mining activities and the reality of living within the environment of coal mine, working in mining sites environment and working in coal thermal power, led credence to this research work. Therefore, the need to assess the background ionizing radiation (BIR) levels of the Enugu mining sites and appropriately estimating the exposure dose rate and other hazard indices arose.

Moreso, in 1999, the National Research Council of the National Academy of Sciences published the Biological Effects of Ionizing Radiations VI report, Health Effects of Exposure to Radon, which concludes that indoor radon is "the second leading cause of lung cancer after cigarette smoking", UNSCEAR, ICRP and WHO also have the same position. Mining for uranium, tin, silver, coal, and other types of underground mines may have increased radon exposure. Many epidemiologic studies of those who mine uranium and other ores have established exposure to radon daughters as a lung cancer cause [4,17]. Other recognized or suspected carcinogens in mine air include silica dust, cigarette smoke, arsenic, diesel exhaust particles, etc. Consequent upon these, this study sought to investigate the radiological implications associated with the exploitation of this major Nigerian fossil fuel (coal). Specifically, as it affect the miners working at the sites and those living within the active and closed mining sites environment. The data obtained in this study will add to Enugu radiation survey data-base and will increase the world data base on radionuclide level monitored around coal mining site worldwide.

II. STUDY AREA

The three study mine sites Onyeama, Udi and Ogbete, are all in Enugu state, Nigeria. The area lies within latitude N06^o 26 and N06^o 29 and longitude E007^o 26 and E007^o 28. Onyeama mine site has companion shale formation which consists of soft grey to dark grey shale, mudstone and sandy shale. The shale weather rapidly to red clay soil which forms lateral capping of considerable thickness (Egboka). Onyeama site started mining operation in 1952 and shut down during the Nigeria civil war and close finally in 2002, but recently re-open for mining operation. Udi mine site has Manu formation which consists of fine to medium grained sand stones, sandy shales, shales and mudstones. This site which mining operation started 1962 has been abandoned since mid-1998. Ogbete coal mine site is characterized by Ajali sandstone which overlies the Manu formation; mining operation started in the site in 1915 and was closed during the Nigerian civil war but re- opened in 1989 **[18]**.

III. EXPERIMENTAL PROCEDURE

An *insitu* approach of the background radiation levels measurement was preferred to enable samples maintain their original environmental characteristics. The assessment was achieved using a factory calibrated Inspector Digilert 100 Nuclear radiation meter [19]. The meter's sensitivity is 3500 CPM/ (mRh⁻¹) referenced to Cs-137 and its maximum



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alpha and beta efficiencies are 18% and 33% respectively. It has a halogen-quenched Geiger-Muller detector tube of effective diameter of 45 mm and a mica window density of 1.5-2.0 mgcm². During field measurements, the tube of the radiation meter was held at a standard distance of 1.0 m above the ground and placed at about 1.5 m away from the suspected source(s) **[20, 21]**. Measurement were taken at selected positions within the mining sites, mining pits (boreholes), the mining administrative yards, residential areas around the mining sites and host communities. The geographical positioning system (GPS) readings for the particular sampling locations were recorded. However no GPS readings were recorded inside the pits/boreholes because at those depths the GPS was cut off from communicating with the mother satellite for information decoding.

For optimum results, measurements were carried out between 1300 to 1600 hours, since the radiation meters have maximum response to environmental radiation within these hours [22]. At each sampling site, three readings were obtained at the accumulation of gamma radiation for about 300 seconds at each sampling point. This was carried out twice a month for one year and the average values computed for each of the sampling point. In a mine site, ten different sampling spots were delineated for the radiation levels measurement to ensure adequate coverage of the mining site environment. The count rate per minute recorded in the nuclear radiation monitoring meter was automatically converted to milli-roentgen per hour (mRh⁻¹) with an inbuilt converter using the relation.

Count rate per minute (CMP) = 10^3 roentgen x Q.F

Where Q.F is the quality factor, which is unity for external environment.

IV. RESULTS

(1)

Table 1: Background Ionizing Radiation (BIR) Levels and Equivalent Dose rate of Onyeama Coal Mine Site

S/N	Location	Geographical Location (GPS)	Measured BIR Readings (mRh ^{-'})			Equivalent Dose	Absorbed Dose Rate	Annual Effective Dos	Excess Lifetime
			Min.	Max.	Average	(mSvy)	(ηGyh *)	$(mSvv^{-1})$	(uSvy ⁻¹)
1	Entrance of Borehole 1544, 1.067m	N06° 28.19.7' E007° 26.47.1'	0.014	0.018	0.016±0.00 5	1.35±0.42	139.20±43.50	0.16±0.06	0.56±0.21
2	Inside Borehole 1544, 1.067m		0.024	0.040	0.032±0.01 1	2.69±0.93	278.40±95.70	0.34±0.10	1.20±0.35
3	Shop near Borehole 1544, 1.067m	N06° 28.21.4' E007°' 26'45.2'	0.012	0.015	0.013±0.00 2	1.09±0.17	113.10±17.40	0.14±0.05	0.49±0.18
4	Entrance of Borehole 1378, 0.78	N06° 28'42.4' E007° 26'42.3'	0.016	0.018	0.017±0.00 7	1.43±0.59	147.90±60.90	0.18±0.04	0.63±0.14
5	Inside Borehole 1378, 0.787m	No reading	0.022	0.037	0.029±0.00 7	2.44±0.59	252.30±60.90	0.31±0.07	1.09±0.26
6	River Ekulu	N06° 28' 52.3' E007° 26' 56.2'	0.009	0.013	0.011±0.00 3	0.93±0.25	95.70±26.10	0.12±0.03	0.42±0.11



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7	Express Road (9 th Mile Road)	N06° 28'30.8' E007° 26'54.1'	0.009	0.011	0.010±0.00 3	0.84±0.25	87.00±26.10	0.11±0.03	0.39±0.11
8	Entrance of Borehole 1325, 1.321m	N06° 28'27.5' E007° 26'51.3'	0.017	0.019	0.018±0.00 4	1.51±0.34	156.60±34.80	0.19±0.04	0.67±0.15
9	Inside Borehole 1325, 1.321m		0.040	0.043	0.042±0.01 0	3.53±0.84	365.40±87.00	0.45±0.11	1.58±0.39
10	Sand Mining Site Borehole 1325 1 321m	N06° 28'26.3' E007° 26'50.2'	0.011	0.013	0.012±0.00 4	1.01±0.34	104.40±34.80	0.13±0.04	0.45±0.14
MEAN	VALUE		0.009	0.043	0.017±0.00	1.43±0.67	147.90±48.62	0.21 ± 0.06	0.74±0.02
World	average				0.013	1.00	59.00	0.07	0.29mSvy ⁻¹

Table 2: Background Ionizing Radiation (BIR) Levels and Equivalent Dose rate of Udi Coal Mine Site

S/ N	Location	Geographical Location (GPS)	Measured BIR Readings (mRh ^{-'})			Equivalent Dose	Absorbed Dose Rate	Annual Effective Dos	Excess Lifetime
			Min.	Max.	Average	(mSvy*)	(ηGyh^{-1})	e Equivalent (mSvy ⁻¹)	(µSvy ⁻¹)
1	Entrance of Borehole 003	N06° 29.20.3' E007° 27.47.4'	0.014	0.017	0.016±0.00 4	1.35±0.17	139.20±34.80	0.17±0.04	0.60±0.15
2	Inside Borehole 003		0.024	0.040	0.029±0.00 8	2.44±0.42	217.50±78.30	0.27±0.10	0.95±0.35
3	Farm near Borehole 003	N06° 29.21.0' E007°' 27'50.5'	0.012	0.015	0.010±0.00 2	0.84±0.17	130.50±17.40	0.16±0.05	0.56±0.18
4	Entrance of Borehole 007	N06° 29'21.4' E007° 27'51.4'	0.016	0.018	0.014±0.00 3	1.18±0.17	113.10±34.80	0.14±0.04	0.49±0.14
5	Inside Borehole 007		0.022	0.037	0.024±0.00 6	2.02±0.34	208.80±52.20	0.26±0.06	0.91±0.22
6	Peasant Road Near Borehole 007	N06° 29'22.4' E007° 27'51.2'	0.008	0.011	0.010±0.00 2	0.84±0.17	87.00±17.40	0.11±0.02	0.39±0.07
7	Residential Area Borehole 007	N06° 29'24.0' E007° 27'55.1'	0.006	0.010	0.008±0.00 1	0.67±0.08	69.60±8.70	0.09±0.01	0.32±0.04



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8	Entrance of Borehole 013 (abandoned	N06° 29'22.5' E007° 27'51.5'	0.007	0.009	0.008±0.00 1	0.67±0.08	69.60±8.70	0.09±0.01	0.32±0.04
9	for <u>30years</u>) Inside Borehole 013		0.010	0.020	0.015±0.00 3	1.26±0.25	130.50±26.10	0.16±0.03	0.56±0.11
10	Residential Area near Borehole 013	N06° 29'2253' E007° 27'51.6'	0.007	0.009	0.008±0.00 1	0.67±0.08	69.60±8.70	0.09±0.01	0.32±0.04
MEAN	VALUE		0.006	0.040	0.014±0.00	1.21 ± 0.34	123.54±34.80	0.15 ± 0.04	0.53 ± 0.14
World average				0.013	1.00	59.00	0.07	0.29mSvy ⁻¹	

Table 3: Background Ionizing Radiation (BIR) Levels and Equivalent Dose rate of Ogbete Coal Mine Site

S/N	S/N Location Geographica l		Mea	sured BI (mR	R Readings h-')	Equivalent Dose (mSvy ⁴)	Absorbed Dose Rate	Annual Effective Dos e Equivalent (mSvy ⁻¹)	Excess Lifetime
	(GPS)	Min.	Max.	Average	(nGyn)		(µSvy ⁻¹)		
1	Farm near first Borehole	N06º 26.17.1' E007º 28.45.1'	0.009	0.017	0.012±0.002	1.01±0.17	104.40±17.40	0.13±0.02	0.45±0.07
2	Entrance of first Borehole	N06° 26.19.7' E007° 28.47.3'	0.009	0.012	0.011±0.002	0.93±0.17	217.50±78.30	0.27±0.10	0.96±0.35
3	Inside first Borehole		0.020	0.035	0.029±0.005	2.44±0.42	252.30 ±43.50	0.31±0.05	1.09±0.18
4	Residential area near first Borehole	N06° 26'22.4' E007° 28'50.0'	0.006	0.011	0.009±0.002	0.76±0.08	78.30±17.40	0.10±0.04	0.35±0.14
5	Entrance of second Borehole	N06° 26'25.4' E007° 28'53.3'	0.011	0.018	0.015±0.003	1.26±0.25	130.50±26.10	0.16±0.03	0.56±0.11
6	Inside second Borehole		0.020	0.042	0.032± 0.008	2.69±0.67	278.40±69.60	0.34±0.09	1.20±0.32
7	Entrance of third Borehole	N06° 26'27.8' E007° 28'51.1'	0.011	0.020	0.016±0.004	1.35±0.34	139.20±34.80	0.17±0.04	0.60±0.15
8	Inside third Borehole		0.021	0.035	0.027±0.005	2.27±0.34	234.90±43.50	0.29±0.05	1.02±0.19
9	Residential area near third	N06° 28'31.0' E007° 28'55.7'	0.006	0.011	0.009±0.001	0.76±0.08	78.30±8.70	0.10±0.01	0.35±0.04
10	Borehole Ogbete express	N06° 26' 33.8' E007° 28' 57.2'	0.005	0.010	0.008±0.001	0.67±0.08	69.60±8.70	0.09±0.01	0.32±0.04
MEAN	VALUE		0.00 6	0.042	0.016±0.003	1.41±0.25	149.34±26.10	0.20±0.03	0.69±0.11
World average				0.013	1.00	59.00	0.07	0.29mSvy ⁴	



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Fig 1: Comparison of measure BIR levels in Onyeama coal mine site with world BIR levels



Fig 2: Comparison of measure BIR levels in Udi coal mine site with world BIR levels



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Fig 3: Comparison of measure BIR levels in Ogbete coal mine site with world BIR levels



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VI. DISCUSSION OF RESULTS

The results of the measured BIR exposure levels and the calculated hazard indices for the three (Onyeama, Udi and Ogbete) coal mining sites environment in Enugu state are presented in Tables 1-3. In this study, different known radiation health hazard indices analysis were used to arrive at a better and reliable conclusion on the radiation status of the coal mine environment and the health implications on residents and coal mine workers in the study area and in line with radioprotection and as reported in previous studies [23-29]. This goal was achieved by assessing and estimating the following radiation hazard indices; equivalent dose, absorbed dose rate, the annual equivalent dose rate, the excess life cancer risk and dose to different organs.

Background Ionizing Radiation (BIR) Exposure Levels

Three coal mine sites environment were considered in this study with different mining boreholes (pits) where mining operations are taking place or have been mined and abandoned. The result of the measured BIR levels in Onyeama coal mining area ranged from 0.009 mR h⁻¹ in River Ekulu and 9th Mile express road sampling point to 0.040 mR h⁻¹ in the inside borehole of Onyeama active mining site with a mean value of 0.017±0.006 mR h⁻¹. In Udi coal mine area, the BIR levels ranges from 0.006 mR h⁻¹ in Udi residential area to 0.040 mR h⁻¹ in the inside of the active coal mining borehole with a mean value of 0.014±0.004 mR h⁻¹. While in Ogbete coal mine site environment, the BIR value ranges from 0.006 mR h⁺ in the residential area near one of the abandoned borehole to 0.042 mR h⁺ in the inside of the second active coal mine borehole with a mean value of 0.016 ± 0.006 mR h⁻¹. The mean values obtained in the three coal mining environment showed that they are above the world normal BIR level of 0.013 mR h⁻¹, which is an indication of the elevation of the BIR level of the study area. The highest BIR levels of 0.043 mR h⁻¹, 0.040 mR h⁻¹ and 0.042 mR h⁻¹ measured consistently inside the borehole of Onyeama, Udi and Ogbete mine sites respectively can be attributed to the trace quantities of naturally occurring primordial radionuclides (NORM) arising from the U and Th series and "K. These naturally occurring radionuclides contribute most of the environmental radiation (radon) and they are higher than the reported values in the South Western states [30]. A comparison of the radiation exposure levels in the three coal mine sites environment shown in figures 1-3, reveals that the two active mine sites (Onyeama and Ogbete) exposure levels are higher than the Udi abandoned mine site environment, which is an indication of the enhance level of the BIR due to activities of the coal mine. The lowest BIR level of 0.006 mR h⁻¹ obtained in the residential area can be attributed to the proximity of the houses to the mining sites and the direction of dispersion of the coal fly ash and the transportation phenomenon in the mining sites.

Equivalent Dose Rate

This research adopted the method of estimating the whole body equivalent dose rate over a period of one year, using the NCRP National recommendation [31].

1mRh-1 = 0.96 x 24 x 365100 mSvy-1

(2)

The results of the calculated whole body equivalent dose rate in the study area are presented in column 5 of Tables 1-3. In Onyeama mining site as presented in Table 1, the results obtained indicate value range of 0.93 ± 0.25 mSv y⁻¹ to 3.53 ± 0.84 mSv y⁻¹ with a mean value of 1.43 ± 0.67 mSv y⁻¹. In Udi mine site environment the equivalent dose rate ranged from 0.67 ± 0.08 mSv y⁻¹ to 2.44 ± 0.42 mSv y⁻¹ with a mean value of 1.21 ± 0.34 mSv y⁻¹, while in Ogbete coal mine environment, the equivalent dose rate average values ranged from 0.76 ± 0.08 mSv y⁻¹ to 2.69 ± 0.67 mSv y⁻¹ with a mean value of 1.41 ± 0.25 mSv y⁻¹. These computed equivalent dose rates obtained for the three mine sites in this study revealed that the calculated results are well above the standard permissible limit of 1.0 mSv y⁻¹ for the public, but they are within the recommended occupational permissible limit of 1.5 mSv y⁻¹ for people working in a technically enhanced radioactive environments [**32**]. These values obtained are in agreement with previous study in solid mineral mining environments in Nigeria [**6,10, 12, 33**] and in the Niger Delta oil and gas exploration and exploitation environment of Nigeria, which indicates that the study environment is radiologically contaminated [**1,15,16, 21, 22, 1,.34, 35**].



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Absorbed Dose Rate

The data obtained for the external background ionizing radiation exposure rate in $\mu R h^{-1}$ was converted into absorbed dose rate μ Gy y-1 using the conversion factor [28].

 $1\mu Rh^{-1} = 8.7Gyh-1 = 8.7 x 10-3(18760y) \mu Gyy-1 = 76.212\mu Gyy-1$ (3)

The results of the gamma absorbed dose rates for the three coal mineral mining sites environment in the study area are presented in column 6 of Tables 1, 2 and 3. The results obtained in Onyeama mining site environment indicate absorbed dose rate range of $87.00\pm26.10 \, \text{nGy h-1}$ to $365.40\pm87.00 \, \text{Gy h-1}$ with a mean value of $147.90\pm48.62 \, \text{Gy h-1}$, while in Udi mine site environment, the values obtained ranged from 69.60±8.70 Gy h-1 to 217.50±78.30 Gy h-1 with a mean value of 123.54±34.80 Gy h-1. In Ogbete coal mine site environment, the average values obtained ranged from 69.60±8.70 Gy h-1 to 217.50±78.30 Gy h-1 with a mean value of 149.34±26.10 Gy h-1. The obtained mean gamma absorbed dose rates in the study area are higher than the values previously reported in literatures, of 81.61 gy h-1 for Muzaffarabad and 102.70 ηGy h-1, for Poonch in Turkey, and the Greek population value of 32 ηGy h-1 [27, 28,36]. They are also higher than values reported in some part of the world as documented in the UNSCEAR report [17]. These countries includes New Zealand (20 Gy h-1)), United States (38 Gy h-1)), United Kingdom (60 Gy h-1), Poland (67 ηGy h-1), Norway (80 ηGy h-1), China (100 ηGy h-1), Portugal (102 ηGy h-1), Italy (105 ηGyh-1) etc [17]. However, the obtained gamma dose rates in this study are similar to the range of values report in Turkey, 78.30-135.70 nGy h-1, Japan, 13.8 to 187.0 ηGy h-1and 75.0 ηGy h-1 to 509.38 ηGy h-1[37, 38, 26]. The overall mean value obtained in this study area is twice the world population weighted average gamma dose rates value of $59 \, \eta \text{Gy h-1}$ [17].

The Annual Effective Dose Equivalent (AEDE)

In calculating the annual effective dose equivalent (AEDE) outdoor received by residents living in the study area, we used the dose conversion factor of 0.7S v/Gy recommended by the UNSEAR for the conversion coefficient from absorbed dose in air to effective dose received by adults and occupancy factor of 0.2 for outdoor [17].

The annual effective dose equivalent outdoor was determined using the equation

AEDE (Outdoor) (mSvy⁻¹) = Absorbed dose (η Gyh⁻¹) x 8760 h x 0.7Sv/Gy x 0.2 (4)

= Absorbed dose (η Gyh⁻¹) x 1.2264x 10⁻³

The results of the computed annual effective dose equivalent are presented in Tables 1 to 3. The values obtained in Onyeama coal mining site environment indicate value range of 0.11 ± 0.03 mSv y⁺ to 0.45 ± 0.11 mSv y⁺ with mean value 0.21 ± 0.06 mSv y⁻¹. In Udi coal mine site area, the annual effective dose equivalent ranges from 0.09 ± 0.01 mSv y⁺¹ to 0.27 ± 0.10 mSv y⁻¹ with a mean value 0.15 ± 0.04 mSv y⁻¹, while in Ogbete coal mine area, the obtained average values ranged from 0.09 ± 0.01 mSv y⁻¹ to 0.34 ± 0.09 mSv y⁻¹ with a mean value 0.20 ± 0.03 mSv y⁻¹. These annual effective dose equivalent values obtained are similar to the values reported in Al-Rakkah in Saudi Arabia [39], and the outdoor values range of 0.106 mSv y⁻¹ to 0.240 mSv y⁻¹ with mean value of 0.164 mSv y⁻¹reported in Jhelum valley [28]. These values obtained are still within the values reported in the fly ash produced at Orji River Thermal Plant [12]. The worldwide average of the annual effective dose is 0.48 mSv of which 0.07 mSv y-1 is from outdoor and 0.34 mSv y-1 from indoor exposure [17,26, 39]. The values obtained in this study are above the world average normal annual effective dose level for outdoor environment which is an indication of radiological contamination that may lead to environmental pollution of the study area from accumulative effect.

Excess Life Cancer Risk (ELCR)

The Excess Life Cancer Risk (ELCR) was computed from the values of AEDE, using the expression:

ELCR $(mSvy^{-1}) = AEDE x$ Average Duration of Life (DL) x Risk Factor (RF)(5)

Where, AEDE is the annual effective dose equivalent, DL is duration of life (70 years) and RF is the risk factor (Sv-1) for fatal cancer risk per Sievert. For low dose background radiations which are consider to produce stochastic effects, ICRP 60 uses value of 0.05 for the public exposure [28,40].

The calculated excess lifetime cancer risks (ELCR) indicated average value range of $0.39\pm0.11 \times 10^{-3}$ to 1.58 ± 0.39 $x10^{3}$ with a mean value of $0.74\pm0.21 x10^{3}$ in Onyeama coal mine site environment. In Udi coal mine study area, the excess life cancer risks (ELCR) average values ranged from 0.32±0.04 x10³ to 0.95±0.35 x10³ with a mean value of $0.53\pm0.14 \times 10^3$, while in Ogbete mine site the average value ranges from $0.32\pm0.04 \times 10^3$ to $1.20\pm0.32 \times 10^3$ with a



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mean value of $0.69\pm0.11 \times 10^3$ The range of values obtained in Udi abandoned coal mine site are similar with the value range of 0.352×10^3 to 0.792×10^3 with a mean value of 0.543×10^3 obtained in Jhelum valley in Pakistan, but Onyeama and Ogbete values are higher compared to the Jhelum value reported. However, the average ELCR value obtained in this present study area is less than the world average value of 0.29×10^3 [28,40]. This result obtained for ELCR indicates no immediate chances of contacting cancer of any kind by the coal miners and those residing close to the coal mining sites.

The Effective Dose Rate (D_{wgan}) in mSv y-1 to different Body Organs or Tissues

The effective dose rate delivered to a particular organ can be calculated using the relation [41];

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

Where AEDE is annual effective dose, O is the occupancy factor 0.8 and F is the conversion factor of organ dose from ingestion.

(6)

The result of the effective dose rate delivered to the different organs in the three coal mine sites environment are presented in figure 4, with the F values for Lungs, Ovaries, Bone marrow, Testes, Kidneys, Liver and Whole body as 0.64, 0.58, 0.69, 0.82, 0.62, 0.46 and 0.68 respectively, obtained from ICRP [42]. The annual effective dose to organs model estimate the amount of the radiation intake by man that goes to and accumulate in the various body organs and tissues. Seven organs/ tissues were examined and the obtained result show that the testes organ will receive the highest dose with estimated average values of 0.14 mSv y⁻¹, 0.10 mSv y⁻¹ and 0.13 mSv y⁻¹ in Onyeama, Udi and Ogbete coal mine sites respectively. While the estimated average dose received was found to be lowest in liver with average values of 0.08 mSv y⁻¹, 0.06 mSv y⁻¹ and 0.07 mSv y⁻¹ in Onyeama, Udi and Ogbete coal mine sites respectively. These results indicate that the estimated doses to the different organs examined are all below the international tolerable limit dose intake to the body organ of 1.0 mSv annually for the public. The relatively higher dose to the testes and low dose intake to the liver is in agreement with food nutrient absorption [41, 43]. This indicates that the impact of exposure to BIR levels in coal mining environment will contributes just little to the radiation dose to these examined organs of the adult Nigerian living and working around these coal mine sites in Enugu. However, this may call for a concern in some organs due to long term accumulative effects.

VII. CONCLUSION

The evaluation of the radiological impact of working and living around a coal mine sites environment in Nigeria has been carried out. The overall results obtained in the study revealed an elevation of the background ionizing radiation level, equivalent dose rate, absorbed dose rate and annual effective dose equivalent rate especially in the active coal mining sites of Onyeama and Ogbete, which shows a non-complaint ratio of 4:2 of the parameter of assessing health hazard indices. These results obtained in this research work when compared with reported BIR values in other parts of the world reveal a relative elevation over them. Hence, there may be a likelihood of future (long-term) accumulating health side-effects on the part of the coal miners, who may work above eight hours a day and over a long retirement period of thirty years.

Since radiation exposure in these environments may constitute health hazard on the long term, especially to miners and other workers in the active mining sites. Reduction in exposure time through excessive mining is therefore recommended. Good and adequate medical facilities and care should be provided for miners through regular medical check-ups and examination, while resident and commercial activity should be situated in about 700 meters proximity to active mining site. There should be a regular monitoring of radiation levels in these environments and all government agencies responsible for the safety of the environment should enforce all the existing legislation on environment protection. The values obtained inside the boreholes of the active mine sites call for further studies to identify the specific activity contribution of the radionuclides in the study area.



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