Field Measurement of Radionuclide Concentrations in Host Rocks within Some Mines in Abakaliki-Ishiagu Areas, Southeastern Nigeria

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Abstract: The study points include six (6) selected mines scattered around Abakaliki-Ishiagu areas in Ebonyi State, Southern Benue Trough, Nigeria. They are enclosed within latitudes 5° 45[1] N-6° 35[1]N and longitudes 7° 25[1]E-8° 15[1] E respectively. The mines are quite accessible through network of roads including the Abakaliki-Afikpo-Okigwe and Abakaliki-Enugu roads. A correlation of radiological parameters across the mines indicates that they did not follow the same trend as the activity concentration. Result of the mean values of the radium equivalent dose (Ra_{eq}) across the mines showed that the highest values occurred within the limestones, followed by the shales, dolomite and finally, Pyroclastic. Field measurement of activity concentration of ^{40}K, ^{238}U and ^{232}Th indicate that their concentration varies from one mine to another depending on the rock type. This variation is largely dependent on the geology of the area which has influenced the mineralogy of the rocks. Highest concentration of radioactive elements occurred in the baked shales, followed by the limestones, dolerites and lastly, the pyroclastic.

Key words: Radioactivity · Mine · Abakaliki · Ishiagu · Southeast · Nigeria

INTRODUCTION

The Abakaliki and Ishiagu areas in southeastern Nigeria are popular for their large deposit of solid minerals and construction materials in the form of Lead-Zinc (Pb-Zn) [1, 2] volcanic rocks [3-5] and limestones [6, 7]. These have necessitated the rampant occurrence of multiple mines scattered around the area. Mining of the solid minerals has contributed immensely to the economic development of Ebonyi State through taxes and generation of employment opportunities to the teeming youths of the area. This has made the communities and clusters around the mines commercial hubs hosting crowd all day.

A study of radiation level in an environment can give insight into the rate of risk associated with human existence in such places [8, 9]. Exposure to radiations can lead to damage of molecules through loss of electrons thereby destroying some enzymes in the body and can degenerate to ailments such as cancer [10, 11]. Its impact on aquatic lives includes sudden changes in pollination patterns, reduction in the activities of planktons and

increase in the quantity of ozone produced at the lower atmosphere. Human exposure to radioactive radiations may lead to such symptoms as nausea, vomiting, general body weakness, headache, hair loss and skin burns, cancer, kidney dysfunction, bone fraction, hypertension, brain damage [12].

Study has shown that background levels of natural radiation in a given environment can be influenced by emissions from geologic materials [13]. Mine sites have proven to be a possible means of increasing radioactive radiations in the environment [14] hence the need to check emissions from such environments and possibly inhibit the risk factors associated with it [15]. Radioactive emissions from rocks are dependent upon the percentage of radioactive elements originally in its mineralogical composition, as well as those from diagenetic alterations [16]. Potassium rich Feldspars and Micas are known for their high radioactive isotopes [17]. Zircon, monazite, sphene and apatite all contain isotopes of uranium and thorium, which when they occur in rocks can influence their ability to release radiations into the environment. High levels of radiations are usually associated with

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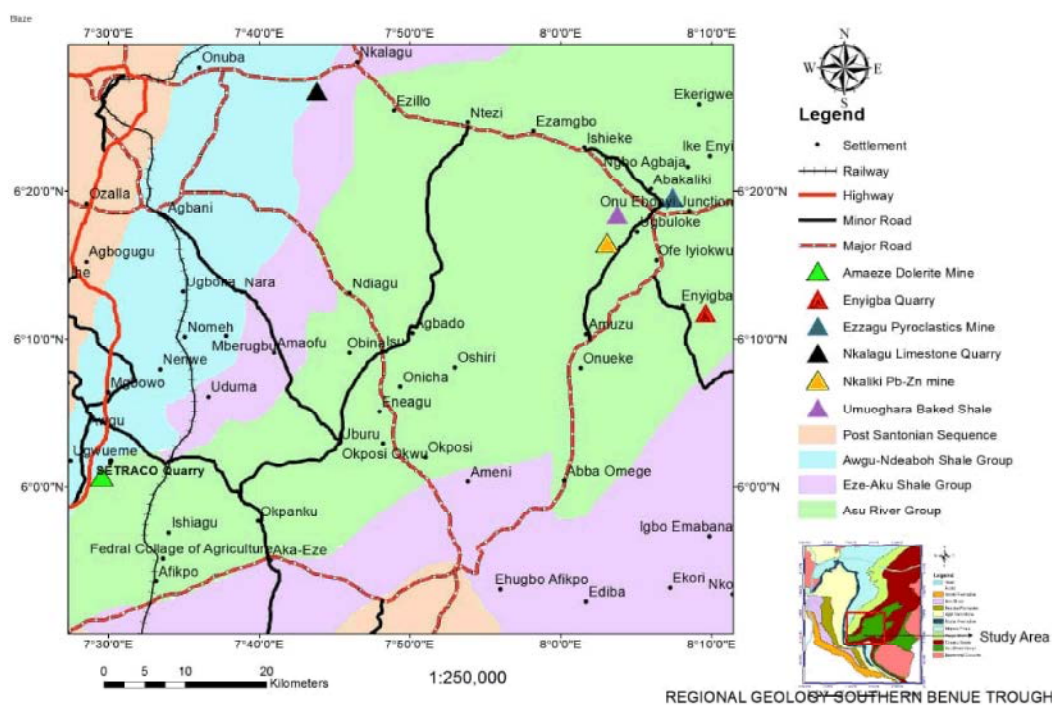
Fig. 1: Location map of the study area indicating geology and the research mines.

granitic and pegmatitic rocks due to large amount of potassium feldspar and mica in them, coupled with presence of accessory minerals such as zircon, apatite and sphene [18]. Low concentration of potassium, uranium and thorium is common in mafic igneous rocks such basalts, resulting in their low radioactivity. Generally, igneous rocks without mica and feldspar usually have very low concentrations of potassium. Radionuclide occurrences in sedimentary rocks are more in detrital particles, with arkosic sandstones and black carbonaceous shales having highest percentage of radioactive elements when compared with other forms of sedimentary rocks.

Previous works on direct measurement of radioactive radiations in the field and mine sites include that of [19], Farrington [20], Grant [21], Hashim [22], Hoque [23], Igbal *et al*. [24] and Ikhane *et al*. [25]. No in situ measurement of radiations from the mining sites in the study area has been carried out before now. The required baseline survey for determination of radioactivity level within these sites was not done, hence the need for the present work. Laboratory measurement of possible radiations from Asu River Group shales alone was studied by Johnson [26]. Geochemical studies on the rocks encountered within the research mines were independently carried out by Khater *et al*. [27], Murat [28], Nwachukwu [29] and Okogbue and Nweke [30]. Similar studies have also been carried out on

soils and water systems around some of the mines [31]. The results of these geochemical studies, although not directly related to study of radiations in the area, suggest that the rocks contain radioactive elements which can induce radiations in the environment. The present study was aimed at measuring the radiological hazard indices associated with the mining of the minerals and rocks, as well as correlation of radionuclide concentration in different rock lithologies in the study area. To achieve this, in situ measurement of the activity concentration of the radioactive elements within the mines were carried out using gamma ray spectrometry, after which radiological parameters such as hazard indices, absorbed dose rate, annual effective dose rate among others were calculated from the field data.

Geologic Setting: The study area is within the southern portion of the Benue Trough with a sedimentary succession of pre-Santonian periods belonging to Albian and Turonian times (Fig. 1). The Albian age is represented by the Asu River Group [32] with formations under it as Abakaliki and Ebonyi Formations [33]. The Asu River Group consists of alternating shales and siltstones with occurrences of fine-grained micaceous and feldsparthiod sandstones, mudstones and limestones [34]. The Turonian age is represented by the Eze-Aku Group. It unconformably

overlies the Asu River Group in the study area. It includes all the lithostratigraphic units deposited in the late Cenomanian to Turonian in the southern Benue Trough [35] which includes the Eze-Aku Shales, the Nkalagu Limestone and Amasiri Sandstone. It consists of hard, flaggy, calcareous grey or black shales with siltstones [3] sandstones and limestones [7].

Tectonism which affected the study area in the Santonian times [5] deformed these rocks and other pre-Santonian deposits thereby turning the Abakaliki area into fold belts [7] which is today popularly called "Abakaliki Fold Belts" or "Abakaliki Anticlinorium" and further led to the formation of two depocentres namely the "Anambra and Afikpo Basins" in the western and southeastern portions of the fold belt [3]. These tightly folded Cretaceous sediments of Asu River and Eze-Aku Groups in the study area are underlying the Abakaliki Anticlinorium. They have been intruded by numerous magmatic rocks ranging from basic / intermediate igneous rocks in Ishiagu area [9] to pyroclstics in Abakaliki area [11, 12]. An integration of tectonism with magmatism and diagenesis has enhanced major alterations of these rocks [13, 14] thereby baking them and leading to their common use as construction materials [2-4].

Different views exist on the origin of the Pb-Zn mineralization within the study area. Considering the magmatic activities in the area, some earlier scholars attributed its origin to magmatic hydrothermal solutions [3]. On the contrary, Akande *et al*. [5] and Amakom and Aghamelu [6] attributed the mineralization to circulating connate brine that leached metals from sedimentary pile. These minerals occur in veins as open space-filling within en echelon, tensional, steeply dipping fracture systems commonly astride anticlinal axes [23, 24] in the dark-grey to black shales of Asu River Group.

The aforementioned geologic events have led to the proliferation of mines in the study area, ranging from exploitation of Pb-Zn deposits to blasting and quarrying of igneous rocks, consolidated sandstones, limestones and baked shales for construction purposes.

MATERIALS AND METHODS

Description of the Mines: The six mines used in this research, with indication of survey points have been represented in Fig. 1 and briefly discussed below.

The Nkaliki Pb-Zn mine is located in Nkaliki Echara Unuhu, Abakaliki L.G.A., along Nkaliki-Orieuzor road. The Pb-Zn minerals in this location are hosted by the Asu River Shales.

The Ameka Pb-Zn mine is located in Ameka community, Ezza south L. G. A., in the same axis with the Enyigba-Ameri Pb-Zn fields [7]. In this location, the Pb - Zn is as well hosted by the Asu River Shales.

Evidence of igneous activity in the Asu River Group shales in Abakaliki area is represented partly by the large deposits of the pyroclstics [14, 15] which outcropped at about 10 km north of Abakaliki, in Sharon Village, Ezzagu community in the present day Izzi L.G. A. Hundreds of tones of the pyroclastics are exploited per day for construction purposes. The environment as well is always densely populated.

Umuoghara, a community in Ezza North L. G. A. of Ebonyi state, plays host to the popular Ebonyi State quarry industrial cluster with hundreds of machines quarrying at the same time. It is underlain by shales of the Asu River Group which has been baked due to igneous activity in the area. The high level of induration of these shales associated with baking gave it the name baked shale [12] and has led to their being mined /quarried as construction material. A beehive of activity in the area makes it densely populated for close to 12 hours per day.

The Nkalagu Limestone mine is located along the Abakaliki-Enugu expressway, directly opposite the Nkwo Nkalagu market, at about 200 m before the popular Nkalagu Junction. The Limestone deposit here belongs to the Turonian age [14]. It is basically mined for construction purposes.

Amaeze Dolerite mine is located at Amaeze village of Ishiagu community in the present-day Ivo L. G. A. of Ebonyi State. It is popularly known as Setraco quarry. The rock that is mined and quarried here are dolerites which intruded the folded shales of the Albian Asu River Group in Ishiagu area [27]. The rocks are used as construction materials.

Radiometric Surveying: In situ measurement of radiations from the mines was carried out using portable BGO-RS 230 gamma ray spectrometer. Profiles were taken from inside the mines, where active exploitation is ongoing with readings taken at 10 m intervals, to outside the mines which served as control data. Field measurement was carried out in both static and dynamic mode. Static mode was applied in taking readings at each discrete measurement point along the profile, while dynamic mode was applied in moving the instrument from one discrete point to another along the profile. Measurement time for each point ranged from 2 mins. in areas with high concentration of radiations, to 5 mins. in areas of low concentration. Coordinates of each measurement point

were recorded using Garmin Csx 76 Global Positioning System (GPS). The acquired data were saved in the spectrometer with Potassium [40]K recorded in part per percentage (ppp), Uranium [238]U and Thorium [232]Th in part per million (ppm). These values were later converted to Becquerel per kilogramme (Bg/kg) in line with the guidelines of the International Atomic Energy Agency.

Determination of Radiological Parameters

Radium Equivalent Dose: A single index which describes the gamma output from different mixture of [238]U, [232]Th and [40]K in the mining environments were calculated using equation 1 [35].

$$Ra_{eq}\left(BqKg^{-1}\right) = A_{Ra} + 1.43 A_{Th} + 0.077 A_K \tag{1}$$

External Hazard Index: This was calculated using equation 2 [28, 29].

$$H_{ex} = \left(\frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}\right) \le 1 \tag{2}$$

Internal Hazard Index: The impact of Radium on the respiratory organs when exposed to it was calculated using equation 3 [20].

$$H_{in} = \left(\frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810}\right) \le 1 \tag{3}$$

Representative Gamma Index: To establish whether a dose standard was met, the gamma activity concentration index (I_{yr}) was estimated using equation 4 [17, 18].

$$I_{yr} = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \tag{4}$$

Annual Gonadal Equivalent Dose (AGED): The impact of the activity concentrations of the three measured radioactive parameters on the gonads, active bone marrow and the bone was calculated using equation 5 [19].

$$AGED\left(\mu Svy^{-1}\right) = 3.09 A_{Ra} + 4.18 A_{Th} + 0.314 A_K \tag{5}$$

Absorbed Dose Rate in Air: The absorbed dose rate, AD in air, at 1 m above ground due to [238]U, [238]Th and [40]K around the mines was calculated using equation 6 [4, 5].

$$AD \text{ in air } \left(nGyh^{-1}\right) = \left(0.462 A_{Ra} + 0.604 A_{Th} + 0.042 A_K\right) \tag{6}$$

Annual Effective Dose Equivalent (AEDE) Outdoor: This is a product of the absorbed dose D, time T (8760), occupancy factor f (0.2), quotient of effective and absorbed dose rate ($0.7 SvGy^{-1}$), as well as conversion formula ε (10^{-6}) as given in equation 7 [13, 14].

$$AEDE \text{ outdoor}\left(\mu Svy^{-1}\right) = DTfQ \times 10^{-6} \tag{7}$$

Excess Lifetime Cancer Risk (ELCR): Using life span of 70 years of continuous exposure to radiations from the mines, the excess life cancer risk was calculated using equation 8 [15].

$$ELCR = D \times DL \times RF \tag{8}$$

Where:

D = Annual effective dose; DL = Life time duration; and RF = Risk Factor or Fatal cancer per sievert = 0.05

RESULTS

Nkaliki Pb-Zn Mine: Results of both the field measurement and calculated hazard indices for the Nkaliki Pb-Zn mine are shown in Table 1. The total count ranges from 340-885 Bq/Kg, with a mean value of 550.87 Bq/Kg. Out of the radioactive elements evaluated, potassium [40]K made highest contribution to the total count, having values ranging from 250-742.80 Bq/Kg and a mean of 454.09 Bq/Kg. This was followed by thorium [232]Th which has values ranging from 38-107.90 Bq/Kg, with a mean of 60.37 Bq/Kg. Uranium [238]U has the least value range in this site with values ranging from 13.57-57.90 Bq/Kg and mean of 32.04 Bq/Kg. The radium equivalent dose (Ra_{eq}) for the Nkaliki mine ranges from 97.41-241.21 Bq/Kg, with a mean of 153.34 Bq/Kg. The external hazard index (H_{ex}) ranges from 0.26-0.67 Bq/Kg with a mean of 0.414 Bq/Kg. Value range for internal hazard index (H_{in}) is from 0.32-0.74 Bq/Kg and mean of 0.50 Bq/Kg. The representative gamma index (Rgi) has values ranging from 0.71-1.77 and a mean of 1.12. The annual gonadal equivalent dose (AGED) has values ranging from 313.05-773.72 µsvy^{-1} and mean of 492.45 µsvy^{-1}. Result of the absorbed dose rate in air (AD in air) indicates that it ranges from 44.60-109.90 □Gyh^{-1}, with a mean of 70.34 □Gyh^{-1}. The annual effective dose equivalent (AEDE) outdoor ranges from 0.05-0.13 msvy^{-1} and has a mean of 0.09 msvy^{-1}. The excess life time cancer risk (ELCR) ranges from 0.19-0.47, with a mean of 0.30.

Table 1: Field data and radiological indices at the Nkaliki Pb-Zn Mine

Total count Bq/Kg	^{40}K Bq/Kg	^{238}U Bq/Kg	^{232}Th Bq/Kg	Ra$_{eq}$ Bq/Kg	H$_{ex}$ Bq/Kg	H$_{in}$ Bq/Kg	Rgi	AGED µsvy^{-1}	AD in Air □Gyh^{-1}	AEDE outdoor msvy^{-1}	ELCR	
851.10	711.80	32.10	107.90	241.21	0.66	0.74	1.77	770.87	109.90	0.13	0.47	
633.84	526.32	27.14	80.38	182.61	0.49	0.57	1.34	773.72	83.19	0.10	0.36	
501.13	404.88	34.55	61.70	153.96	0.42	0.51	1.12	490.18	70.23	0.09	0.30	
797.47	680.90	35.78	80.79	203.74	0.55	0.65	1.50	491.80	93.93	0.12	0.40	
715.74	619.20	24.68	71.86	175.12	0.47	0.54	1.30	568.59	80.81	0.10	0.35	
885.50	742.80	57.90	84.80	236.36	0.64	0.79	1.73	571.06	109.17	0.13	0.47	
607.37	495.20	40.72	71.45	181.02	0.49	0.60	1.32	578.00	82.77	0.10	0.36	
764.10	649.90	40.72	73.48	195.84	0.53	0.64	1.44	579.98	90.49	0.11	0.39	
663.39	557.10	32.00	74.29	181.13	0.49	0.58	1.33	582.11	83.05	0.10	0.36	
688.80	526.20	25.90	53.18	142.46	0.38	0.45	1.06	584.34	66.19	0.08	0.28	
528.10	433.00	46.80	48.30	149.21	0.40	0.53	1.08	467.55	68.98	0.08	0.30	
679.41	588.10	28.38	62.93	163.65	0.44	0.52	1.21	482.47	75.82	0.09	0.33	
602.91	495.20	40.72	66.99	174.65	0.47	0.58	1.27	535.41	80.07	0.10	0.34	
613.50	495.20	55.53	62.77	183.42	0.50	0.65	1.33	561.34	84.37	0.10	0.36	
618.68	526.20	25.90	66.58	161.63	0.44	0.51	1.19	589.46	74.28	0.09	0.32	Within the Mine
565.87	464.30	37.02	64.55	165.08	0.45	0.55	1.20	523.56	75.59	0.09	0.32	
544.89	464.20	27.10	53.59	139.48	0.38	0.45	1.03	530.00	64.38	0.08	0.28	
465.05	371.40	22.20	71.45	152.97	0.41	0.47	1.11	453.50	69.01	0.08	0.30	
637.66	557.10	13.57	66.99	152.26	0.41	0.45	1.13	483.88	70.13	0.09	0.30	
559.96	464.20	28.38	67.39	160.49	0.43	0.51	1.17	496.88	73.31	0.09	0.31	
473.72	371.00	33.30	69.42	161.14	0.44	0.53	1.16	515.14	72.90	0.09	0.31	
472.66	371.00	44.42	57.24	154.84	0.42	0.54	1.12	509.57	70.68	0.09	0.30	
425.70	344.00	40.70	41.00	125.82	0.34	0.45	0.91	493.02	58.02	0.07	0.25	
443.00	376.00	25.00	42.00	114.01	0.31	0.38	0.84	405.16	52.71	0.06	0.23	
485.00	406.00	32.00	47.00	130.47	0.35	0.44	0.95	370.87	60.22	0.07	0.26	
395.00	313.00	38.00	44.00	125.02	0.34	0.44	0.90	422.82	57.28	0.07	0.25	
399.00	250.00	37.00	42.00	116.31	0.31	0.41	0.83	399.62	52.96	0.06	0.23	
415.00	344.00	21.00	50.00	118.99	0.32	0.38	0.87	368.39	54.35	0.07	0.23	Outside the Mine
461.00	375.00	28.00	58.00	139.82	0.38	0.45	1.02	381.91	63.72	0.08	0.27	
340.00	281.00	20.00	39.00	97.41	0.26	0.32	0.71	446.71	44.60	0.05	0.19	
389.00	313.00	21.00	55.00	123.75	0.33	0.39	0.90	313.05	56.07	0.07	0.24	
473.00	407.00	17.00	49.00	118.41	0.32	0.37	0.87	393.07	54.54	0.07	0.23	
354.00	281.00	25.00	48.00	115.28	0.31	0.38	0.83	385.15	52.34	0.06	0.22	
409.00	344.00	27.00	38.00	107.83	0.29	0.36	0.79	366.12	49.87	0.06	0.21	
421.00	344.00	35.00	42.00	121.55	0.33	0.42	0.88	350.29	55.99	0.07	0.24	

All the maximum values occurred within the mine where fresh excavations were on-going, while the minimum values occurred outside the mine where measurements were taken as control. The mean values of the Ra$_{eq}$, H$_{ex}$, H$_{in}$, AD in air and AEDE oudoor are all below the world standards [1, 2]. On the contrary, mean values of the Rgi, AGED and ELCR are higher than the world standards [20-23]. High content of ^{40}K in the result suggests that the shales are potassium rich with very low percentage of thorium and Uranium.

Ameka Pb-Zn Mine: From the result of the field measurement at the Ameka Pb-Zn mine (Table 2), total count of radiation ranges from 224-971 Bq/ Kg, with a mean of 537.37 Bq/ Kg. ^{40}K again made the highest contribution to the total count in this mine by having values ranging from 125-826 Bq/ Kg and a mean of 439.42 Bq/ Kg. ^{238}U and ^{232}Th in this site has very low concentrations with their ranges and mean as 22-62 Bq/ Kg, 43.11 Bq/ Kg; and 45-63 Bq/ Kg, 54.72 Bq/ Kg respectively. Ra$_{eq}$ ranges from 117.07-196.57 Bq/ Kg, with its mean as 155.19 Bq/ Kg. The result of the H$_{ex}$ ranges

from 0.33-0.56 Bq/ Kg and has a mean of 0.44 Bq/ Kg. The H$_{in}$ ranges from 0.41-0.70 Bq/ Kg, with its mean as 0.54 Bq/ Kg. The Rgi ranges from 0.84-1.46. Its mean is 1.13. The AGED values for this mine ranges from 366.32-651.36 µsvy^{-1}, with a mean of 498.15 µsvy^{-1}. The AD in air ranges from 52.83-92.90 □Gyh^{-1} with a mean of 71.42 □Gyh^{-1}. The AEDE outdoor ranges from 0.06-0.11 msvy^{-1}, with a mean of 0.09 msvy^{-1}. Result of the ELCR ranges from 0.23-0.40, with a mean of 0.31.

The mean values of the Ra$_{eq}$, H$_{ex}$, H$_{in}$, AD in air as well as AEDE oudoor are all below the world standards [11, 12]. However, mean values of the Rgi, AGED and ELCR are higher than the world standards [23-26] suggesting an environment quite unsafe for human existence except some remedial measures are taken.

Sharon Pyroclastic Mine: Result of the field data and radiological indices from the Sharon pyroclastics mine (Table 3) indicates that the host rock which is the Abakaliki Pyroclastics has very low concentration of radioactive elements. This can be observed from the total count of radiation which ranges from 4.00-244.00 Bq/ Kg,

Table 2: Field data and radiological indices at the Ameka Pb-Zn Mine

Total count	^{40}K	^{238}U	^{232}Th	Ra$_{eq}$	H$_{ex}$	H$_{in}$		AGED	AD in	AEDE		
Bq/Kg	Bq/Kg	Bq/Kg	Bq/Kg	Bq/Kg	Bq/Kg	Bq/Kg	Rgi	μsvy^{-1}	Air □Gyh^{-1}	outdoor msvy^{-1}	ELCR	
820.00	719.00	43.00	58.00	181.30	0.51	0.61	1.35	598.20	85.10	0.10	0.37	
941.00	845.00	37.00	59.00	186.44	0.52	0.60	1.40	622.90	88.22	0.11	0.38	Within the Mine
760.00	657.00	43.00	60.00	179.39	0.50	0.60	1.32	587.34	83.70	0.10	0.36	
896.00	782.00	62.00	52.00	196.57	0.56	0.70	1.45	651.36	92.90	0.11	0.40	
971.00	876.00	33.00	62.00	189.11	0.52	0.60	1.42	632.69	89.49	0.11	0.38	
805.00	719.00	35.00	51.00	163.29	0.46	0.54	1.22	544.22	77.17	0.09	0.33	
739.00	657.00	32.00	50.00	154.09	0.43	0.50	1.15	511.55	72.58	0.09	0.31	
691.00	594.00	49.00	48.00	163.38	0.46	0.57	1.20	536.19	76.58	0.09	0.33	
415.00	313.00	48.00	54.00	149.32	0.42	0.53	1.07	471.07	67.94	0.08	0.29	
362.00	281.00	22.00	59.00	128.01	0.35	0.41	0.92	401.71	57.60	0.07	0.25	
224.00	125.00	42.00	57.00	133.14	0.38	0.47	0.93	406.79	59.08	0.07	0.25	
299.00	219.00	33.00	47.00	117.07	0.33	0.41	0.84	366.32	52.83	0.06	0.23	
320.00	219.00	51.00	50.00	139.36	0.40	0.51	0.99	434.48	62.96	0.08	0.27	Outside the Mine
339.00	250.00	26.00	63.00	135.34	0.38	0.44	0.97	421.18	60.56	0.07	0.26	
331.00	219.00	51.00	61.00	155.09	0.44	0.56	1.10	480.46	69.60	0.09	0.30	
280.00	187.00	44.00	49.00	128.47	0.37	0.47	0.91	398.75	57.78	0.07	0.25	
275.00	156.00	58.00	61.00	157.24	0.45	0.58	1.10	482.56	70.19	0.09	0.30	
389.00	281.00	52.00	56.00	153.72	0.44	0.56	1.09	481.87	69.65	0.09	0.30	
353.00	250.00	58.00	45.00	141.60	0.41	0.54	1.00	444.82	64.48	0.08	0.28	

Table 3: Field data and radiological indices at the Sharon Pyroclastics Mine.

Total count	^{40}K	^{238}U	^{232}Th	Ra$_{eq}$	H$_{ex}$	H$_{in}$		AGED	AD in	AEDE		
Bq/Kg	Bq/Kg	Bq/Kg	Bq/Kg	Bq/Kg	Bq/Kg	Bq/Kg	Rgi	μsvy^{-1}	Air □Gyh^{-1}	outdoor msvy^{-1}	ELCR	
8.00	0.00	8.00	0.00	8.00	0.03	0.04	0.05	24.72	3.70	0.00	0.02	
14.08	0.00	14.00	0.80	15.14	0.05	0.08	0.10	46.60	6.95	0.01	0.03	
28.00	0.00	11.00	17.00	35.31	0.10	0.13	0.24	105.05	15.35	0.02	0.07	
9.00	0.00	9.00	0.00	9.00	0.03	0.05	0.06	27.81	4.16	0.01	0.02	
4.00	0.00	1.00	3.00	5.29	0.01	0.02	0.04	15.63	2.27	0.00	0.01	Outside the Mine
27.00	0.00	17.00	10.00	31.30	0.09	0.13	0.21	94.33	13.89	0.02	0.06	
32.00	0.00	23.00	9.00	35.87	0.11	0.16	0.24	108.69	16.06	0.02	0.07	
33.00	0.00	22.00	11.00	37.73	0.11	0.16	0.26	113.96	16.81	0.02	0.07	
25.00	0.00	17.00	8.00	28.44	0.08	0.12	0.19	85.97	12.69	0.02	0.05	
35.00	0.00	26.00	9.00	38.87	0.12	0.18	0.26	117.96	17.45	0.02	0.07	
29.00	0.00	16.00	13.00	34.59	0.10	0.14	0.24	103.78	15.24	0.02	0.07	
51.00	31.00	1.00	19.00	30.56	0.08	0.09	0.22	92.12	13.24	0.02	0.06	
28.00	0.00	11.00	17.00	35.31	0.10	0.13	0.24	105.05	15.35	0.02	0.07	
23.00	0.00	14.00	9.00	26.87	0.08	0.11	0.18	80.88	11.90	0.01	0.05	
94.00	62.00	21.00	11.00	41.50	0.12	0.17	0.29	130.09	18.95	0.02	0.08	
31.00	0.00	10.00	21.00	40.03	0.11	0.14	0.28	118.68	17.30	0.02	0.07	
71.00	31.00	21.00	19.00	50.56	0.15	0.19	0.35	153.92	22.48	0.03	0.10	
55.00	31.00	11.00	13.00	31.98	0.09	0.12	0.22	97.94	14.24	0.02	0.06	
87.00	62.00	16.00	9.00	33.64	0.10	0.13	0.24	106.28	15.43	0.02	0.07	
85.00	62.00	14.00	9.00	31.64	0.09	0.12	0.22	100.10	14.51	0.02	0.06	
78.00	31.00	30.00	17.00	56.70	0.17	0.23	0.39	173.37	25.43	0.03	0.11	
52.00	31.00	8.00	13.00	28.98	0.08	0.10	0.20	88.67	12.85	0.02	0.06	
50.00	31.00	8.00	19.00	29.56	0.08	0.08	0.21	89.03	12.78	0.02	0.05	
47.00	0.00	17.00	30.00	59.90	0.17	0.21	0.41	177.93	25.97	0.03	0.11	
110.00	62.00	28.00	20.00	61.37	0.18	0.24	0.43	189.34	27.62	0.03	0.12	
61.30	31.00	17.00	13.30	38.41	0.11	0.15	0.27	117.73	17.19	0.02	0.07	
28.00	0.00	17.00	11.00	32.73	0.10	0.13	0.22	98.51	14.50	0.02	0.06	
75.00	31.00	21.00	23.00	56.28	0.16	0.21	0.39	170.64	24.90	0.03	0.11	
80.00	31.00	26.00	23.00	61.28	0.18	0.24	0.42	186.09	27.21	0.03	0.12	Within the Mine
127.90	93.90	10.00	24.00	51.55	0.14	0.17	0.37	160.33	23.06	0.03	0.10	
244.40	203.40	17.00	24.00	66.98	0.19	0.23	0.49	215.90	30.89	0.04	0.13	
229.00	187.00	23.00	19.00	64.57	0.18	0.24	0.47	208.46	29.96	0.04	0.13	
67.00	31.00	27.00	9.00	42.26	0.13	0.19	0.29	130.66	19.21	0.02	0.08	
93.00	61.00	21.00	11.00	41.43	0.12	0.17	0.29	129.78	18.91	0.02	0.08	

Table 4: Field data and radiological indices at the Umuoghara Baked Shale Mine.

Total count Bq/Kg	^{40}K Bq/Kg	^{238}U Bq/Kg	^{232}Th Bq/Kg	Ra_{eq} Bq/Kg	H_{ex} Bq/Kg	H_{in} Bq/Kg	Rgi	AGED μsvy^{-1}	AD in Air $\square Gyh^{-1}$	AEDE outdoor $msvy^{-1}$	ELCR	
764.00	657.00	42.00	65.00	185.54	0.52	0.61	1.37	605.15	86.26	0.11	0.37	
648.00	532.00	54.00	62.00	183.62	0.52	0.64	1.33	590.94	84.74	0.10	0.36	
594.00	500.00	53.00	41.00	150.13	0.43	0.55	1.10	490.15	70.25	0.09	0.30	
675.00	594.00	25.00	56.00	150.82	0.42	0.47	1.12	495.47	70.32	0.09	0.30	
566.00	470.00	43.00	53.00	154.98	0.44	0.53	1.13	500.11	71.62	0.09	0.31	
582.00	470.00	51.00	61.00	174.42	0.49	0.61	1.26	558.27	80.15	0.10	0.34	
550.00	438.00	51.00	61.00	171.96	0.49	0.60	1.24	548.35	78.80	0.10	0.34	Within the Mine
544.00	438.00	38.00	68.00	168.97	0.47	0.56	1.23	537.44	77.02	0.09	0.33	
541.00	438.00	54.00	49.00	157.80	0.45	0.57	1.14	507.46	72.94	0.09	0.31	
606.00	500.00	49.00	57.00	169.01	0.48	0.59	1.23	544.67	78.07	0.10	0.34	
576.00	470.00	32.00	74.00	174.01	0.48	0.56	1.27	553.90	79.22	0.10	0.34	
597.00	500.00	41.00	56.00	159.58	0.45	0.54	1.17	515.77	73.77	0.09	0.32	
579.00	470.00	35.00	74.00	177.01	0.49	0.57	1.29	563.17	80.61	0.10	0.35	
490.00	376.00	64.00	50.00	164.45	0.47	0.62	1.18	523.32	75.56	0.09	0.32	
466.00	376.00	41.00	49.00	140.02	0.40	0.49	1.01	448.07	64.33	0.08	0.28	
466.00	563.00	31.00	74.00	180.17	0.50	0.57	1.32	579.64	82.66	0.10	0.35	
520.00	438.00	26.00	56.00	139.81	0.39	0.45	1.03	450.20	64.23	0.08	0.28	
538.00	438.00	52.00	48.00	154.37	0.44	0.56	1.12	497.10	71.41	0.09	0.31	
443.00	376.00	32.00	35.00	111.00	0.31	0.39	0.81	361.74	51.72	0.06	0.22	
426.00	313.00	60.00	53.00	159.89	0.46	0.59	1.14	503.97	72.88	0.09	0.31	
232.00	156.00	44.00	32.00	101.77	0.29	0.39	0.72	318.08	46.21	0.06	0.20	
197.00	125.00	32.00	40.00	98.83	0.28	0.35	0.70	304.83	44.19	0.05	0.19	
162.00	63.00	55.00	44.00	122.77	0.35	0.48	0.85	373.40	54.63	0.07	0.23	
265.00	188.00	37.00	40.00	108.68	0.31	0.39	0.77	339.81	49.15	0.06	0.21	Outside the Mine
215.00	125.00	52.00	38.00	115.97	0.34	0.45	0.81	358.27	52.23	0.06	0.22	
179.00	94.00	44.00	41.00	109.87	0.32	0.42	0.77	336.48	49.04	0.06	0.21	
199.00	94.00	57.00	48.00	132.88	0.38	0.51	0.92	405.91	59.27	0.07	0.25	
203.00	125.00	39.00	39.00	104.40	0.30	0.39	0.73	322.28	46.82	0.06	0.20	
149.00	63.00	56.00	30.00	103.75	0.30	0.43	0.72	317.97	46.64	0.06	0.20	
167.00	94.00	37.00	36.00	95.72	0.27	0.36	0.67	293.95	42.79	0.05	0.18	
197.00	125.00	43.00	29.00	94.10	0.27	0.37	0.66	292.84	42.63	0.05	0.18	

with a mean of 62.11 Bq/ Kg. ^{40}K which was a major radioactive element in the first two mines is nearly absent in this mine. This is probably the reason for the total count of radiation encountered here. Its value ranges from 0.00-203.40 Bq/ Kg with a mean of 32.45 Bq/ Kg. ^{238}U ranges from 1.00-30.00 Bq/ Kg, with a mean of 16.52 Bq/ Kg. ^{232}Th ranges from 0.00-30.00 Bq/ Kg with a mean of 13.63 Bq/ Kg. Ra_{eq} ranges from 5.29-66.98 Bq/ Kg, with its mean as 38.04 Bq/ Kg. The result of H_{ex} ranges from 0.02-0.19 Bq/ Kg and has a mean of 0.11 Bq/ Kg. The H_{in} ranges from 0.02-0.24 Bq/ Kg, with its mean as 0.15 Bq/ Kg. The Rgi values range from 0.04-0.49. Its mean is 0.27. The AGED values for this mine ranges from 15.63-215.90 μsvy^{-1}, with a mean of 16.62 μsvy^{-1}. The AD in air ranges from 2.27-30.89 $\square Gyh^{-1}$ with a mean of 17.01 $\square Gyh^{-1}$. The AEDE outdoor ranges from 0.00-0.03 $msvy^{-1}$, with a mean of 0.02 $msvy^{-1}$. Result of the ELCR ranges from 0.01-0.13, with a mean of 0.07.

All the measured parameters are below the world's standard except ELCR. This identifies this mine as being very safe for human activities.

Umuoghara Baked Shale Mine: Result of the field data and radiological indices for the Umuoghara baked shale mine is as represented in Table 4. The total count of

radiation ranges from 149.00-764.00 Bq/ Kg, with a mean of 430.19 Bq/ Kg. ^{40}K ranges from 63.00-657.00 Bq/ Kg, with a mean of 341.72 Bq/ Kg. ^{238}U ranges from 25.00-64.00 Bq/ Kg, with a mean of 44.19 Bq/ Kg. ^{232}Th ranges from 29.00-74.00 Bq/ Kg with a mean values of 50.29 Bq/ Kg. Ra_{eq} ranges from 94.10-185.53 Bq/ Kg, with its mean as 142.42 Bq/ Kg. The result of the H_{ex} ranges from 0.27-0.52 Bq/ Kg and has a mean of 0.40 Bq/ Kg. The H_{in} ranges from 0.35-0.64 Bq/ Kg, with its mean as 0.50 Bq/ Kg. The Rgi values range from 0.66-1.37. Its mean value is 1.03. The AGED for this mine ranges from 292.84-605.15 μsvy^{-1}, with a mean of 452.71 μsvy^{-1}. The AD in air ranges from 42.63-86.26 $\square Gyh^{-1}$ with a mean of 65.15 $\square Gyh^{-1}$. The AEDE outdoor ranges from 0.05-0.11 $msvy^{-1}$, with a mean of 0.08 $msvy^{-1}$. Result of the ELCR ranges from 0.18-0.37, with a mean of 0.28.

Just like in the first two mines under evaluation, the mean values of Rgi, AGED and ELCR are higher than the world standards. Mining and quarrying of the Asu River Group shales is ongoing in this location. The high radiation could be observed from the total count. ^{40}K is the major contributor of the radiations by contributing about 79 % of the mean of the total count. This suggests that the Asu River Group Shales in Abakaliki area has high content of K-Feldspars. Results from this mine has

Table 5: Field data and radiological indices at the Nkalagu Limestone Mine.

Total count Bq/Kg	^{40}K Bq/Kg	^{238}U Bq/Kg	^{232}Th Bq/Kg	Ra$_{eq}$ Bq/Kg	H$_{ex}$ Bq/Kg	H$_{in}$ Bq/Kg	Rgi	AGED μsvy^{-1}	AD in Air □Gyh^{-1}	AEDE outdoor msvy^{-1}	ELCR	
761.00	532.00	16.00	213.00	361.55	0.98	1.02	2.59	1104.70	158.39	0.19	0.68	
630.00	407.00	17.00	206.00	342.92	0.93	0.97	2.44	1039.78	149.37	0.18	0.64	
848.00	594.00	10.00	244.00	404.66	1.10	1.12	2.90	1234.96	176.94	0.22	0.76	
561.00	407.00	19.00	135.00	243.39	0.67	0.71	1.75	749.18	107.41	0.13	0.46	
658.00	470.00	16.00	172.00	298.15	0.81	0.85	2.14	914.10	131.02	0.16	0.56	
562.00	376.00	13.00	173.00	289.34	0.79	0.82	2.07	879.87	126.29	0.15	0.54	
592.00	376.00	8.00	208.00	334.39	0.91	0.92	2.38	1010.72	145.12	0.18	0.62	
734.00	563.00	22.00	149.00	278.42	0.76	0.81	2.01	865.33	123.81	0.15	0.53	Within the Mine
732.00	501.00	11.00	220.00	364.18	0.99	1.01	2.61	1108.90	159.00	0.20	0.68	
888.00	657.00	15.00	216.00	374.47	1.02	1.05	2.70	1152.90	164.99	0.20	0.71	
548.00	394.00	16.00	138.00	243.68	0.66	0.70	1.75	748.42	107.29	0.13	0.46	
773.00	563.00	14.00	196.00	337.63	0.92	0.95	2.43	1037.07	148.50	0.18	0.64	
646.00	438.00	17.00	191.00	323.86	0.88	0.92	2.32	986.69	141.61	0.17	0.61	
683.00	470.00	18.00	195.00	333.04	0.91	0.95	2.38	1016.42	145.84	0.18	0.63	
387.00	219.00	16.00	162.00	264.52	0.72	0.76	1.87	794.49	114.44	0.14	0.49	
584.00	406.00	13.00	165.00	280.21	0.76	0.79	2.01	855.73	122.72	0.15	0.53	
650.00	438.00	6.00	206.00	334.31	0.91	0.92	2.39	1015.40	145.59	0.18	0.62	
574.00	406.00	15.00	153.00	265.05	0.72	0.76	1.90	811.75	116.39	0.14	0.50	
594.00	438.00	14.00	142.00	250.79	0.68	0.71	1.81	772.60	110.63	0.14	0.47	
621.00	438.00	16.00	167.00	288.54	0.79	0.82	2.07	883.28	126.66	0.16	0.54	
664.00	469.00	11.00	184.00	310.23	0.84	0.87	2.23	948.50	135.92	0.17	0.58	
594.00	438.00	18.00	138.00	249.07	0.68	0.72	1.79	768.24	110.06	0.13	0.47	
461.00	313.00	12.00	136.00	230.58	0.63	0.66	1.65	702.59	100.83	0.12	0.43	
509.00	375.00	17.00	117.00	213.19	0.58	0.62	1.53	657.84	94.27	0.12	0.40	
569.00	375.00	10.00	184.00	302.00	0.82	0.84	2.16	916.27	131.51	0.16	0.56	
461.00	289.00	17.00	155.00	260.90	0.71	0.75	1.86	790.02	113.61	0.14	0.49	
531.00	375.00	10.00	146.00	247.66	0.67	0.70	1.78	757.43	108.55	0.13	0.47	
578.00	375.00	15.00	188.00	312.72	0.85	0.88	2.23	948.44	136.23	0.17	0.58	
508.00	313.00	11.00	184.00	298.22	0.81	0.83	2.12	900.14	129.36	0.16	0.56	
475.00	313.00	7.00	155.00	252.75	0.69	0.70	1.81	766.56	110.00	0.13	0.47	
285.00	156.00	15.00	114.00	190.03	0.52	0.55	1.34	571.23	82.34	0.10	0.35	Outside the Mine
202.00	94.00	11.00	97.00	156.95	0.43	0.45	1.11	468.59	67.62	0.08	0.29	
238.00	94.00	16.00	128.00	206.28	0.56	0.60	1.45	613.62	88.65	0.11	0.38	
287.00	94.00	9.00	184.00	279.36	0.76	0.78	1.96	826.07	119.24	0.15	0.51	

displayed much similarity in character with results from the Nkaliki and Ameka Pb-Zn mines which all have the baked shales of Asu River Group as their host rocks. In the two aforementioned mines, the major material of interest is the Pb-Zn minerals which occurred as vein fillers in the fracture systems of the shales. Radiations encountered in those areas were generated by excavation of the shales in search of the minerals. However, in the present Umuoghara mine, radiations are generated by blasting and quarrying the same shales for construction purposes. The proximity of the result from Umuoghara baked shale mine to the results from the Pb-Zn baked shale mines suggest that the radiations are not product of mineralization but are from the host rocks which are the Asu River Group shales.

Nkalagu Limestone Mine: At the Nkalagu Limestone mine, the total count of radiation ranges from 202.00-888.00 Bq/ Kg, with a mean value of 469.96 Bq/ Kg (Table 5). Unlike in the baked shale mines, the percentage contribution of ^{40}K to the total count reduced while that of ^{232}Th increased. This is a product of change

in the rock geochemistry. ^{40}K ranges from 94.00-657.00 Bq/ Kg with a mean of 310.61 Bq/ Kg (About 66 % of the mean value of the total count). ^{238}U ranges from 6.00-24.00 Bq/ Kg, with a mean of 13.46 Bq/ Kg (About 6 % of the mean value of the total count). ^{232}Th ranges from 94.00-244.00 Bq/ Kg with a mean of 146.04 Bq/ Kg. Ra$_{eq}$ ranges from 156.95-404.66 Bq/ Kg, with its mean as 246.21 Bq/ Kg. The result of the H$_{ex}$ ranges from 0.43-1.10 Bq/ Kg and has a mean of 0.67 Bq/ Kg. The H$_{in}$ ranges from 0.45-1.12 Bq/ Kg, with its mean as 0.70 Bq/ Kg. The Rgi ranges from 1.11-2.90. Its mean value is 1.76. The AGED values for this mine ranges from 468.59-1,234.96 μsvy^{-1}, with a mean of 748.31 μsvy^{-1}. The AD in air ranges from 67.62-176.94 □Gyh^{-1} with a mean of 107.47 □Gyh^{-1}. The AEDE outdoor ranges from 0.08-0.20 msvy^{-1}, with a mean of 0.13 msvy^{-1}. Result of the ELCR ranges from 0.29-0.76 with a mean of 0.48.

The mean values of the Ra$_{eq}$, H$_{ex}$, H$_{in}$ and AEDE outdoor are all below the world standards. However, mean values of the Rgi, AGED, ELCR, as well as AD in air are higher than the world standards, suggesting an environment quite unsafe for human existence except some remedial measures are taken.

Table 6: Field data and radiological indices at the Amaeze Dolerite Mine.

Total count Bq/Kg	^{40}K Bq/Kg	^{238}U Bq/Kg	^{232}Th Bq/Kg	Ra$_{eq}$ Bq/Kg	H$_{ex}$ Bq/Kg	H$_{in}$ Bq/Kg	Rgi	AGED μsvy^{-1}	AD in Air □Gyh^{-1}	AEDE outdoor msvy^{-1}	ELCR	
334.00	289.00	23.00	22.00	76.71	0.22	0.27	0.57	252.62	36.05	0.04	0.15	
359.00	313.00	31.00	15.00	76.55	0.22	0.29	0.57	255.52	36.53	0.04	0.16	
364.00	313.00	28.00	23.00	84.99	0.24	0.31	0.63	279.69	39.97	0.05	0.17	
337.00	281.00	35.00	21.00	86.67	0.25	0.33	0.63	283.04	40.66	0.05	0.17	
404.00	344.00	36.00	24.00	96.81	0.28	0.36	0.71	318.20	45.58	0.06	0.20	
450.00	376.00	19.00	55.00	126.60	0.35	0.39	0.93	405.17	57.79	0.07	0.25	Within the Mine
464.00	407.00	14.00	43.00	106.83	0.29	0.33	0.79	349.17	49.53	0.06	0.21	
328.00	281.00	25.00	22.00	78.10	0.22	0.28	0.57	256.32	36.64	0.04	0.16	
3002.00	2942.00	33.00	30.00	302.43	0.83	0.91	2.48	1139.39	156.93	0.19	0.67	
509.00	438.00	41.00	30.00	117.63	0.34	0.43	0.87	387.87	55.46	0.07	0.24	
570.00	470.00	60.00	40.00	153.39	0.44	0.58	1.11	498.30	71.62	0.09	0.31	
282.00	219.00	36.00	27.00	91.47	0.26	0.34	0.66	291.99	42.14	0.05	0.18	
369.00	313.00	25.00	31.00	93.43	0.26	0.32	0.69	303.86	43.42	0.05	0.19	
490.00	438.00	9.00	43.00	104.22	0.29	0.31	0.78	343.33	48.53	0.06	0.21	
341.00	281.00	19.00	41.00	99.27	0.28	0.32	0.72	317.20	45.34	0.06	0.19	
467.00	376.00	39.00	52.00	142.31	0.40	0.49	1.03	454.43	65.22	0.08	0.28	
519.00	438.00	33.00	48.00	135.37	0.38	0.45	0.99	438.39	62.63	0.08	0.27	
415.00	344.00	27.00	44.00	116.41	0.33	0.39	0.85	373.99	53.50	0.07	0.23	
237.00	187.00	35.00	15.00	70.85	0.21	0.29	0.51	228.82	33.08	0.04	0.14	
307.00	250.00	30.00	24.00	83.57	0.24	0.31	0.61	270.52	38.86	0.05	0.17	
321.00	250.00	46.00	25.00	101.00	0.29	0.40	0.72	324.14	46.85	0.06	0.20	
127.00	62.00	30.00	35.00	84.82	0.24	0.31	0.59	258.22	37.60	0.05	0.16	
166.00	125.00	25.00	16.00	57.51	0.17	0.22	0.41	182.88	26.46	0.03	0.11	
179.00	125.00	16.00	38.00	79.97	0.22	0.26	0.57	247.03	35.59	0.04	0.15	
212.00	156.00	21.00	35.00	83.06	0.23	0.28	0.59	259.55	37.39	0.05	0.16	Outside the Mine
162.00	94.00	23.00	45.00	94.59	0.27	0.32	0.67	288.31	41.75	0.05	0.18	
127.00	62.00	27.00	38.00	86.11	0.24	0.31	0.60	261.49	38.03	0.05	0.16	
127.00	62.00	27.00	38.00	86.11	0.24	0.31	0.60	261.49	38.03	0.05	0.16	
97.00	31.00	33.00	33.00	82.58	0.24	0.31	0.57	249.52	36.48	0.04	0.16	
234.00	157.00	47.00	30.00	101.99	0.30	0.40	0.72	319.30	46.43	0.06	0.20	
182.00	125.00	35.00	22.00	76.09	0.22	0.30	0.54	238.86	34.71	0.04	0.15	

Amaeze Dolerite Mine: The total count of radiation at the Amaeze dolerite mine ranges from 97.00-3002.00 Bq/ Kg, with a mean of 402.65 Bq/ Kg (Table 6). ^{40}K ranges from 62.00-2942.00 Bq/ Kg with a mean of 340.29 Bq/ Kg (About 85 % of the mean value of the total count). ^{238}U ranges from 9.00-60.00 Bq/ Kg, with a mean of 29.94 Bq/ Kg (About 7 % of the mean value of the total count). ^{232}Th ranges from 15.00-55.00 Bq/ Kg with a mean of 32.41 Bq/ Kg. Ra$_{eq}$ ranges from 57.50-302.47 Bq/ Kg, with its mean as 102.49 Bq/ Kg. The result of the H$_{ex}$ ranges from 0.17-0.83 Bq/ Kg and has a mean of 0.29 Bq/ Kg. The H$_{in}$ ranges from 0.22-0.91 Bq/ Kg, with its mean as 0.36 Bq/ Kg. The Rgi ranges from 0.41-2.48. Its mean is 0.75. The AGED values for this mine ranges from 182.88-1,139.39 μsvy^{-1}, with a mean of 333.37 μsvy^{-1}. The AD in air ranges from 26.46-156.93 □Gyh^{-1} with a mean of 47.69 □Gyh^{-1}. The AEDE outdoor ranges from 0.03-0.19 msvy^{-1}, with a mean of 0.06 msvy^{-1}. Result of the ELCR ranges from 0.11-0.67, with a mean of 0.20.

The mean values of the Ra$_{eq}$, H$_{ex}$, Rgi, H$_{in,}$ AEDE outdoor as well as AD in air are all below the world standards, suggesting a good, non harmful environment. However, mean values of the AGED and ELCR are higher than the world standards.

DISCUSSION

The mean values of all radioactive parameters measured in the six mines understudy are represented in Table 7. Four (4) major rock types were encountered in the six mines. They are the baked shales of Asu River Group (Which underlie the Nkaliki Pb-Zn mine, Ameka Pb-Zn mine and Umuoghara baked shale mine), the Pyroclastics (Outcropping in the Sharon Pyroclastics mine), the Limestones (Outcropping at the Nkalagu Limestone mine) and Dolerites (Outcropping at the Amaeze Dolerite mine).

Correlation of Activity Concentration across the Mines: A correlation of mean values of the measured parameters across the mines (Table 7) shows that there are variations in the degree of radiations in line with differences in rock type. The baked shales have the highest radiation on total count, with their mean values being more than 500 Bq/Kg. The radioactive properties of the shales are approximately the same, both in mines where they are mineralized and places they occur alone. Potassium ^{40}K has been observed to be the major source of radiation within the study area. It contributed as much as 82 % of the total in the shales, 66 % in the limestones, 85 % in the Dolerite

Table 7: Mean values of measured radioactive parameters in the study area.

Locations	Total count Bq/Kg	^{40}K Bq/Kg	^{238}U Bq/Kg	^{232}Th Bq/Kg	Ra_{eq} Bq/Kg	H_{ex} Bq/Kg	H_{in} Bq/Kg	Rgi	AGED μsvy⁻¹	AD in Air □Gyh⁻¹	AEDE outdoor msvy⁻¹	ELCR
Nkaliki Pb - Zn mine	550.87	454.09	32.04	60.37	153.34	0.41	0.50	1.12	492.45	70.34	0.09	0.30
Ameka Pb -Zn mine	537.37	439.42	43.11	54.72	155.19	0.44	0.54	1.13	498.15	71.42	0.09	0.31
Sharon Pyroclastics mine	62.11	32.45	16.52	13.63	38.04	0.11	0.15	0.27	116.62	17.01	0.02	0.07
Umuoghara Baked Shale mine	430.19	341.72	44.19	50.29	142.42	0.40	0.50	1.03	452.71	65.15	0.08	0.28
Nkalagu Limestone mine	469.96	310.61	13.46	146.04	246.21	0.67	0.70	1.76	748.31	107.47	0.13	0.48
Ameze Dolerite mine	402.65	340.29	29.94	32.42	102.50	0.29	0.36	0.75	333.50	47.70	0.06	0.20
Standard					370.00	1.00	1.00	1.00	300.00	84.00	1.00	0.00029

Table 8: Major - element oxides (wt %)and trace elements (ppm) analysis of the Asu River Shales (After Obiora and Charan, 2011)

	8S	10S	24S	31S	32S
SiO_2 (wt %)	57.03	54.02	57.98	54.54	54.04
TiO_2	1.24	1.17	1.14	1.24	1.14
Al_2O_3	18.03	18.05	19.01	21.31	20.53
Fe_2O_3	6.82	10.62	10.25	10.07	10.58
MnO	0.02	0.14	0.12	0.04	0.17
MgO	1.04	1.88	1.58	1.97	2.51
CaO	0.52	0.48	0.16	0.17	0.68
Na_2O	0.82	0.76	0.81	0.73	0.93
K_2O	4.06	2.93	2.92	3.43	3.81
P_2O_5	0.15	0.08	0.1	0.13	0.1
LOI	9.84	9.23	6.1	6.5	5.29
Total	99.57	99.36	100.17	100.13	99.78
Sc (ppm)	4.94	18.64	21.58	23.55	21.72
Rb	245.27	168.39	186.17	225.68	229.62
Zr	117.66	66.76	70.29	149.31	66.58
Ba	349.87	255.63	305.85	549.95	427.14
Th	27.66	23.44	24.17	33.31	28.73
U	3.25	2.674	3.02	3.95	3.68

Table 9: Major - element oxides (wt %) analysis of the Nkalagu Limestone

Sample code	CaO %	MgO %	Al_2O_3 %	Si_2O %	Fe_2O_3 %	Total %
LST1	54.15	0.95	0.65	6.62	0.48	62.85
LST2	48.56	0.74	1.22	7.6	0.47	58.59
LST3	47.27	0.79	1.57	7.05	0.95	57.63
LST4	47.58	0.9	1.27	10.04	0.23	60.02
LST5	52.49	1.13	1.08	3.16	0.93	58.79
LST6	52.5	0.72	1.01	3.38	0.8	58.41
LST7	52.52	0.9	0.9	3.91	0.7	58.93
LST8	50.09	0.9	0.87	3.09	0.68	55.63
LST9	52.79	0.9	0.82	3.12	0.4	58.03
LST10	46.96	1.35	1.9	7.79	0.97	58.97
LST11	47.69	1.21	1.9	6.16	0.58	57.54
LST12	50.5	1.07	1.42	5.4	0.96	59.35
LST13	49.17	1.27	1.73	7.42	0.78	60.37
LST14	46.56	0.92	1.31	5.9	1.37	56.06
LST15	47.17	1.15	1.83	8.93	1.37	60.45

Table 10: Trace - element (ppm) analysis of the Nkalagu Limestone

Sample Code	Fe (ppm)	Mn (ppm)	Sr (ppm)	Zn (ppm)
NK/LST 15	3306	1543	1035	7.8
NK/LST 13	2463	214	667	11
NK/LST 11	2013	147	623	53
NK/LST 09	1828	93	600	4.5
NK/LST 02	1653	76	603	7

and 52 % in the pyroclastics. Following the ^{40}K is ^{232}Th in all the mines except in the Sharon Pyroclastics mine where ^{238}U was a bit higher than ^{232}Th. The above observation could be attributed to the mineralogical composition of the rocks. Geochemical study of the shales (Table 8) shows that oxide of potassium is relatively high when compared with Thorium and Uranium. Again, the percentage of Thorium is higher than that of Uranium, hence the reason for the degree of disparity in their activity concentrations, with Uranium being the least contributor. Field observation of the shale samples in hand specimen identified mica minerals in the form of muscovite being very abundant in them. Okogbue and Nweke [30] supports this. Since shales are made up of clay minerals, the relatively rich oxide of potassium probably came from the micas and clay mineral suite. This could account for the high radiation observed around the baked shales. Highest occurrence of radioactive elements in black carbonaceous shales when compared to other forms of sedimentary rocks has been previously reported [1]. Aside the three major elements analyzed, Table 8 shows that the Asu River Group shales

contain a reasonable quantity of Zircon, which is known for its ability to initiate skin irritation. This could be the reason for skin irritation which was encountered at the freshly excavated points in the Nkaliki Pb-Zn mine.

Second to the highest radiation came from the Limestones with a mean total count of about 470 Bq/Kg. ^{40}K contributed about 66 % of the total count while the remaining 34 % was jointly contributed by ^{232}Th and ^{238}U. Analysis of the oxides and trace elements of samples of Nkalagu Limestone (Tables 9 and 10) suggest that the oxide of Potassium is completely absent from the Limestone facies. An element which contributed about two-third of the total radiation cannot be said to be totally absent from the rock mineralogy. Even the trace elements (Table 10) do not indicate presence of any radioactive element. A critical look at Table 9 indicates that none of the oxides of any of the fifteen samples approximated to 100 %. They range from 55.63 % to 62.85 %, thereby suggesting the probability of a faulty analytical process.

Table 11: Major - element oxides (wt %) and trace elements (ppm) analysis of the Amaeze Dolerites

	CA08	CA08B
SiO_2 (wt %)	43.4	48.64
TiO_2	3.53	4.42
Al_2O_3	14.1	15.64
Fe_2O_3	13.6	15.19
MnO	0.17	0.09
MgO	3.28	4.54
CaO	9.48	1.22
Na_2O	3.06	4.67
K_2O	0.93	0.08
P_2O_5	0.86	0.73
LOI	7.47	4.61
Total	99.8	99.82
Sc (ppm)	17	18
Rb	13	<2
Zr	367	316
Ba	552	83
Th	3	2.3
U	1	0.5

Table 12: Major - Rock oxides (wt. %), trace elements (ppm), rare earth elements (ppm) analysis of Sharon Pyroclastics

	7AP	7BP	7CP
SiO_2 (wt %)	46.87	50.71	48.81
TiO_2	2.84	3.23	2.22
Al_2O_3	15.36	17.58	14.24
Fe_2O_3	14.68	12.21	10.37
MnO	0.12	0.05	0.16
MgO	11.24	10	10.34
CaO	6.08	1.89	8.35
Na_2O	2.36	3.85	4.23
K_2O	0.02	0.01	0.64
P_2O_5	0.4	0.43	0.59
LOI	5.4	7.06	12.91
Total	99.97	99.96	99.95
Sc (ppm)	11.98	21	17
Be	<1	2	2
V	239.46	254	175
Cr	95.77	270	380
Co	46.64	43	31
Ni	30.79	420	530
Cu	52.5	30	50
Zn	46.92	80	130
Ga	22.61	21	15
Rb	0.3	1.99	8
Sr	243.02	184	965
Y	10.5	20	19
Zr	51.49	247	144
Nb	30.11	56	33
Sn	<1	<1	3
Cs	0.07	<0.5	<0.5

High natural radioactivity level in rocks have been previously associated with high SiO_2, Na_2O, K_2O, Rb and Ba contents of the rock [17]. Comparing the geochemical data for the four rock types under study (Tables 8, 9, 10, 11 and 12) it can be observed that the other rocks agreed with the aforementioned except the limestones. For limestone to have second to the highest activity concentration in the study area, it could be inferred that its mineralogical composition is more than what is contained in Tables 9 and 10. Correlating the result of this radiometric data with the geochemical data for other rocks analyzed in this work, it can be deduced that oxides of potassium and other radioactive elements are probably present in the limestones. This would primarily explain the high radiation from the rock. Field observation indicates that the limestones in Nkalagu area are interbedded with thin beds of shales, clays and mudstones. Mining of the limestones simultaneously leads to excavation of the other rock types interbedded with them, though not needed in this case. Part of the radiations may have as well emanated from the adjoining rock lithologies.

Dolerite has a mean total count of about 403 Bq/Kg. Report on the geochemistry of the dolerites from the above mine suggests moderate presence of potassium oxide in the rocks (Table 11). It shows that the concentration of Thorium is higher than that of Uranium, which corresponds with the report of the present work.

The least radiation was encountered in the pyroclastics with a mean total count as low as 62 Bq/Kg. This suggests the pyroclastics as a very good construction material in this locality when considering impact on human lives. Evaluation of oxides and trace elements in samples of Sharon Pyroclastics (Table 12) indicate that Potassium oxide is very low while Thorium and Uranium were not detected, hence the very low total count observed. Depletion of potassium in the geochemistry of the Abakaliki Pyroclastics have been earlier reported in literature [12] and was attributed to secondary alteration in the form of spilitization and development of soda rich plagioclase. The reasonable presence of Zircon (Zr) may imply possible presence of both Thorium and Uranium, but in minute quantity. A common association of Zircon with the two aforementioned elements has been reported in places like Australia, India and Brazil [9]. Since potassium has majorly influenced radiation in the study area, the very low radiation encountered in the pyroclastics mine could be attributed to a very low amount of potassium in the chemistry of the rock.

Table 13: Comparison of the results of present work with similar published works

Country	^{40}K (Bq/Kg)	^{238}U (Bq/Kg)	^{232}Th (Bq/Kg)	Rock Types	References
India	512.45	11.12	79.05	Gneisses/ Schists	[23]
Pakistan	57	33	32	Marble	[24]
Turkey	359	15.85	33.8	Granite	[26]
Nigeria	420	38.85	45	Shale	[27]
Nkaliki mine, Nigeria	454.09	32.04	60.37	Shale	Present Study
Ameka mine, Nigeria	439.42	43.11	54.72	Shale	Present Study
Umuoghara mine, Nigeria	341.72	44.19	50.29	Shale	Present Study
Sharon mine, Nigeria	32.45	16.52	13.63	Pyroclastics	Present Study
Nkalagu mine, Nigeria	310.61	13.46	146.04	Limestone	Present Study
Ameze mine, Nigeria	340.29	29.94	32.42	Dolerite	Present Study
World Average	400.00	35.00	30.00		UNSCEAR,1993

A correlation of the geochemical data in Tables 8, 9, 10, 11 and 12 further explains the impact of potassium in determination of the total count from the mines. Shale which has the greatest percentage of K_2O among the four rock types had the highest value of total count, while the Pyroclastics with the least percentage of K_2O had the least value of total count.

Correlation of Radiological Parameters across the Mines: A correlation of radiological parameters across the mines indicates that they did not follow the same trend as the activity concentration. Result of the mean values of the radium equivalent dose (Ra_{eq}) across the mines (Table 7) shows that the highest values occurred within the limestones, followed by the shales, dolomite and finally, Pyroclastics. However, its values in mines are all below the standard limit which is 370 Bq/Kg. Similarly, a correlation of the external hazard index (H_{ex}) across the mines indicates the highest value to be in the limestones, while the least value again occurred in the Pyroclastics. All the values of the H_{ex} are less than one which is the World's minimum limit. A correlation of the mean values of the internal hazard indices (H_{in}) across the mines did not deviate from the former as the highest and least values occurred in the limestones and Pyroclastics respectively. However, the values of H_{in} from all the mines are below the maximum permissible limit of one. A correlation of the mean values of the representative gamma index (Rgi) across the mines indicates that the Rgi values from Limestones and shales mines are higher than the minimum standard of one, while those of pyroclastics and Dolomites are within the permissible limit. Results of the mean values of the Annual Gonadal Equivalent Dose (AGED) show that only the pyroclastics has a mean value that is less than the minimum standard 300 μsvy^{-1}. The limestone maintained highest value of radiological index with Rgi mean value that is more than twice the minimum standard. This could threaten the health of both workers in the mine and members of the community.

A correlation of the mean values of the absorbed dose rate in air (AD in air) across the mines indicates that only the Limestone mine has value that is above the dose limit of 84 $\Box Gyh^{-1}$, while the Shales, Dolerite and Pyroclastics are below the dose limit and so do not pose any threat to human life. A correlation of the mean values of the Annual effective dose equivalent (AEDE) outdoor indicates that all the mines have good values of less than one. A correlation of the mean values of the excess life cancer risk across the mines indicates that all the sites are capable of giving rise to cancer in human being depending on the duration of stay within that environment.

From the ongoing discussion, it can be observed that although the results of Ra_{eq}, H_{ex}, H_{in} and AEDE outdoor are good for all the mines, the results of Rgi, AGED, AD in air and ELCR indicate that the baked shales, dolerite and limestones in the study area are not good to be mined as construction materials as they pose serious threat to human health overtime.

A correlation of the results of the present study with similar works (Table 13) significantly justifies the accuracy of the present work. The differences in the results are traceable to differences in rock types. Variations in mineralogical composition of the rocks influenced their radionuclide concentrations. Result of laboratory measurement on the baked shales of Asu River Group in Abakaliki area by [8] (Table 13) is quite correlatable with the results from Nkaliki and Ameka mines (present study) which are shales of the same group. Highest radionuclide concentration was observed in the gneisses / schists, followed by shales, granite / dolerite, limestone, marble and finally, pyroclastics. According to Arafa [7] radionuclide concentration is more in carbonaceous than limestones. Again, high concentration of radionuclides is often associated with granitic rocks when compared with other forms of igneous rocks like the pyroclastics, due to high amount of K-Felspars and mica in them. Results of dolerite and granite are quite correlatable despite coming

from different regions. Both belong to the granitic family. This further supports the view that mineralogy is the key factor that influences radionuclide concentration in rocks. The large difference between the radionuclide concentration in limestone and marble is indicative of high influence of diagenetic alterations on the mineralogy cum radionuclide accumulation in rocks.

CONCLUSION

Field measurement of activity concentration of ^{40}K, ^{238}U and ^{232}Th indicate that their concentration varies from one mine to another depending on the rock type. This variation is largely dependent on the geology of the area which has influenced the mineralogy of the rocks. Highest concentration of radioactive elements occurred in the baked shales, followed by the limestones, dolerites and lastly, the pyroclastics. Potassium was a major contributor to the total count in all the mines. The high concentration of potassium in the study area came from muscovite and orthoclase which are part of the rock forming minerals. Analysis of the radiological parameters from the mines indicate that continuous mining of the limestones, shales and dolerite pose health risk on the lives of both the workers and the members of community and should be stopped forthwith except remedial measures are put into consideration. The present work has further emphasized the need for such baseline surveys before any mining activity could take off.

REFERENCES

1. Adagunodo, T.A., A.I. George, I.A. Ojoawo, K. Ojesanmi and R. Ravisankar, 2018. Radioactivity and radiological hazards from a kaolin mining field in Ifonyintedo, Nigeria. MethodsX, 5: 362-374.

2. Ademola, A.K., A.K. Bello and A.C. Adeniyi, 2014. Determination of natural radioactivity and hazard in soil samples in and around gold mining area in Itagunmodi, south-western, Nigeria. Journal of Radiation Research and Applied Sciences, pp: 1-7.

3. Agumanu, A.E., 1989. The Abakaliki and Ebonyi Formations: subdivisions of the Albian Asu River Group in the southern Benue Trough, Nigeria. J. Afr. Earth Sci., 9: 195-207.

4. Aghamelu, O.P. and C.O. Okogbue, 2013. Some Geological Considerations andDurability Analysis on the Use of CrushedPyroclastics from Abakaliki (Southeastern Nigeria) as Concrete Aggregate. Geotech Geol Eng, 31 (2):699-711DOI 10.1007/s10706-013-9619-5. 699-711.

5. Akande, S.O., A. Mucke and A.C. Umeji, 1990. Mineralogical, textural and paragenetic studies of the lead-zinc-copper ore in the lower Benue Trough and their genetic implications. J. Mining Geol., 26(2): 157-163.

6. Amakom, C.M. and O.P. Aghamelu, 2013. An investigation on the radiation hazards associated with the use of Abakaliki Pyroclastics from southeastern Nigeria as construction materials. Global Journal of Science Frontier Research Physics and Space Sciences, pp: 16-22.

7. Arafa, W., 2004. Specific activity and hazards of granite samples collected from the eastern desert of Egypt. J. Environ Radioact, 75: 315-22.

8. Asere, A.M. and I.R. Ajayi, 2017. Estimation of outdoor Gamma Rates and Lifetime Cancer Risk in Ateoteo Region, Ondo State, Southwestern Nigeria.

9. Benkhelil, J., 1989. The origin and evolution of the Cretaceous Benue Trough, Nigeria. J. Afr. Earth Sci., 8: 251-282.

10. Beretka, J. and PJ. Mathew, 1985. Natural radioactivity of Australian building materials, industrial wastes and by-products. Health Phys, 48:87-95. doi: 10.1097/00004032-198501000-00007.

11. Chukwu, A. and S.C. Obiora, 2014. Whole-rock geochemistry of basic and intermediate intrusive rocks in the Ishiagu area: further evidence of anorogenic setting of the Lower Benue rift, southeastern Nigeria. Turkish J. Earth Sci., 23: 427-443.

12. Chukwu, A. and S.C. Obiora, 2018. Geochemical constraints on the petrogenesis of the pyroclastic rocks in Abakaliki basin (Lower Benue Rift), Southeastern Nigeria. Journal of African Earth Sciences, 141: 207-220.

13. Colmenero Sujo, L., M.E. Montero Cabrera, L. Villalba, M. Renter´ıa Villalobos, E. Torres Moye, M. Garc´ıa Leon, R. Garc´ıa-Tenoro, F. Mireles Garc´ıa, E.F. Herrera Peraza and D. S´anchez Aroche, 2004. Uranium-228 and Thorium-232 Series Concentrations in Soil, Radon-222 Indoor and Drinking Water Concentrations and Dose Assessment in the City of Aldama, Chihuahua, Mexico, Journal of Environmental Radioactivity, 77: 205-219.

14. Duff, P.M.D., 1988. Holmes Principles of Physical Geology (4th Edition). Stanley Thornes Publishers LTD, United Kingdom, pp: 791.

15. European Commission, (EC)., 1999. Report on Radiological Protection Principle concerning the natural radioactivity of building materials. Directorate-General Environment, Nuclear safety and civil protection. Radiation Protection, 112: 1-16.

16. El-Arabi, A.M., G.E. Abel, A.G.E. Abbady and D. Khalif, 2007. Geochemistry and radioactive characteristics of the Garnatiferous Granite of Um-Sleimat area Egypt. Journal of Earth Science, 1: 9-20.

17. Faanu, A., O.K. Adukpo, L. Tettey-Larbi, H. Lawluvi, D.O. Kpeglo, E.O. Darko, G. Emi-Reynolds, R.A. Awudu, C. Kansaana, P.A. Amoah, A.O. Efa, A.D. Ibrahim, B. Agyeman, R. Kpodzro and L. Agyeman, 2016. Natural radioactivity levels in soils, rocks and water at a mining concession of Perseus gold mine and surrounding towns in Central Region of Ghana. US National Library of Medicine National Institutes of Health doi: 10.1186/s40064-016-1716-5.

18. Farrington, J.L., 1952. A preliminary description of Nigerian land-Zinc Field Econ Geol, 47: 485-508.

19. Grant, N.K., 1971. The south Atlantic Benue Trough and gulf of Guinea Cretaceous triple junction. Bull Geol. Soc. Am., 82: 2295-8.

20. Hashim, N.O., 2001. The levels of radionuclides and elements in selected Kenyan Coastal Ecosystem. Unpublished M.Sc Thesis (Physics) Kenyatta University.

21. Hoque, M., 1977. Petrographic differentiation of tectonically controlled Cretaceous sedimentary cycles, Southern Nigeria. Sedimentary Geology, 17: 235-245.

22. Igbal, M., M. Tufail and S.M. Mirza, 2000. Measurement of natural radioactivity in marble found in Pakistan using a NaI (TI) gamma-ray spectrometer. Journal of Environmental Radioactivity, 51: 255-265.

23. Ikhane, P.R., A.F. Folorunso, M.E. Nton and J.A. Oluwalaanu, 2009. Evaluations of Turonian Limestone Formation Exposed at NIGERCEM Quarry, Nkalagu, Southeastern Nigeria: A Geochemical Approach. Pacific Journal of Science and Technology, 10(2): 763-771.

24. Johnson, S.S., 1979. Radioactive surveys. Virginia Minerals, 25(2): 9-15.

25. Khater, A.E., M.A. Hussein and M.I. Hussein, 2004. Occupational exposure of phosphate mine workers: airborne radioactivity measurements and dose assessment. Journal of Environmental Radioactivity, 75: 47-57.

26. Murat, R.C., 1972. Stratigraphic and Palaeogeography of Cretaceous and Lower Tertiary in Southern Nigeria. In African Geology (Edited by Dessauvagie T. F. J and Whiteman A. Y). Ibadan University press Ibadan, Nigeria, pp: 251-276.

27. Nwachukwu, S.O., 1972. Tectonic Evolution of the Southern Portion of the Benue Trough, Nigeria. Geol. Mag, 109: 411-419.

28. Okogbue, C. and M. Nweke, 2018. The ^{226}Ra, ^{232}Th and ^{40}K contents in the Abakaliki baked shale construction materials and their potential radiological risk to public health, southeastern Nigeria. J. Environ. Geol, 2(1): 13-19.

29. Obiora, S.C. and A.C. Umeji, 2004. Petrographic Evidence for Regional Burial metamorphism of the sedimentary rocks in the lower Benue rift. Journal of African Earth Sciences, 38: 269-277.

30. Obiora, S.C. and S.N. Charan, 2011. Geochemistry of Regionally Metamorphosed sedimentary rocks from the lower Benue Rift: Implications for provenance and Tectonic setting of the Benue Rift Sedimentary suite. S Afr J. Geol., 114: 25-40.

31. Obiora, S.C., A. Chukwu, S.F. Toteu and T. C. Davies, 2016. Assessment of Heavy metal contamination in soils around lead (Pb)-zinc (Zn) mining areas in Enyigba, southeastern Nigeria. Jour. Geol. SOC. India, 87: 453-462.

32. Obiora, S.C., A. Chukwu and T.C. Davies, 2016. Heavy Metals and Health risk Assessment of arable soils and food crops around Pb-Zn mining localities in Enyigba, south eastern Nigeria. Journal of African Earth Sciences, 116: 182-189.

33. Obiora, S.C., A. Chukwu and T.C. Davies, 2018. Contamination of the Potable Water Supply in the Lead-Zinc Mining Communities of Enyigba, Southeastern Nigeria. Mine Water Environ. DOI 10.1007/s10230-018-0550-0

34. Offoegbu, C.O. and L.C. Amajor, 1987. Ageochemical comparison of the pyroclastics rocks from Abakaliki and Ezillo, southern Benue Trough, Nigeria. Jour. Min. Geol., 23(1 - 2): 45-52.

35. Okedeyi, A.S., A.M. Gbadebo, T.A. Arowolo and A.O. Mustapha, 2012. Measurement of Gamma Radioactivity Level in Bedrocks and Soils of Quarry Sites in Ogun State, South-Western, Nigeria. Research Journal of Physics, 6: 59-65.