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ASSESSMENT OF NATURAL RADIOACTIVITY LEVELS AND RADIATION HAZARDS IN RAW MATERIALS USED FOR CEMENT PRODUCTION AT ASHAKA CEMENT COMPANY

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ABSTRACT

Natural radioactivity levels from sixteen samples due to radionuclides present in Limestone, Gypsum, Fly-Ash and Iron-Ore, used in cement production at Ashaka cement company were determined, employing gamma-ray spectrometry technique involving NaI(Tl) detector. Measurements and analysis were carried out and the mean radioactivity concentrations due ^{226}Ra (^{238}U), ^{232}Th and ^{40}K from the materials were found to range from (11.27 – 16.76) Bq/kg, (13.76 – 35.73) Bq/kg and (117.23 - 212.00) Bq/kg, with an average value of 14.95 Bq/kg, 21.04 Bq/kg, and 168 Bq/kg, respectively. Radiological risk indices associated with the above results, i.e. Radium equivalent (R_{aeq}), internal (H_{in}) and external (H_{ex}) hazards, Absorbed dose (D), Annual effective doses (AEDE), Life time cancer risk (LCR) were also computed. The mean results obtained indicate the following: R_{aeq} = 59.65 Bq/Kg, D = 27.45 nGy/hr, H_{in} = 0.77, H_{ex} = 0.16, $AEDE_{indoor}$ = 0.045, $AEDE_{outdoor}$ = 0.011, LCR_{indoor} = 0.105, and $LCR_{outdoor}$ = 0.026. The largest contribution to total mean activity of ^{238}U, ^{232}Th and ^{40}K among the samples come from Fly-Ash, Gypsum, Iron-Ore and Limestone, at 76%, 85% and 80%, respectively. Also, a good correlation of 0.95 between activity of ^{238}U and ^{232}Th was observed in the samples. The highest and lowest absorbed doses determined are from Gypsum and Limestone at 37.77 nGy/hr and 22.08 nGy/hr, respectively. The results obtained indicates that the materials are safe to be used as components of building construction based on limits set by international scientific and regulatory agencies including ICRP, IAEA and UNSCEAR.

Keywords: Gamma-ray spectrometry, NORM, Radiological risk factors, Building materials

INTRODUCTION

Early investigations of soil and rock materials show that they contain measurable amounts of natural radionuclides, including the primordial Uranium (^{238}U), Thorium (^{232}Th) in the forms of decay chains and the singly occurring Potassium (^{40}K). These radionuclides can also be found in air, building materials and public water supplies, etc. and exposure to these natural sources of radiation is often influenced by human activities (Varshney et. al. 2010; Amrani & Tahat, 2001). Building materials, for instance, cause excess external gamma exposure solely due to their exposure geometry when compared with that of an undisturbed earth's crust. When these materials are used as components in building construction, they may cause substantial radiation exposure if they contain elevated levels of these Naturally Occuring Radioactive Materials (NORMs). The concentration of natural radionuclides in building materials is important in the assessment of population exposures to radiation, since most individual spend 80% of their time indoors (El-Taher, 2010; UNSCEAR, 2000; UNSCEAR, 1993, ECRP, 1999).).

Cement is one of the most important building materials used for making concrete, building

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blocks, conjugate layers between building bricks. The raw materials which are used in the cement production industry are commonly obtained from rocks such as limestone, iron-ore, sand and gypsum and they may be of radiological hazard on human life.

Human exposure pathways to these radiation include ingestion of contaminated water, inhalation of soil dust, and the direct exposure to gamma ray emitted from the primordial radionuclides in the indoor and outdoor environments, etc. According to Isinkaye (2014) and UNSCEAR (2000), the health risk due to radiation exposure is from the gamma-rays and associated irradiation of lung tissues due to inhalation of radon (^{222}Rn) gas, a decay products of (^{238}U). The radon particles have a tendency to attach themselves as aerosols in ambient air. When we breathe or inhale radon and its daughter product along with the normal air, it gets attached to the inner walls and membranes of the respiratory system and being a helium nucleus (alpha emitter), it can cause damage due to their alpha activity (Khan *et al.,* 2001). Some of the common hazards that could arise from the inhalation of radon gas include cancer of the lung and skin and also kidney diseases. A knowledge of dose limit due to public exposure including building interiors becomes necessary for the purpose of monitoring radiation level in the environment,

Gamma spectrometry is a very a powerful tool employed in the study of natural radioactivity. It can be used to detect, identify and quantify gamma emitting radionuclides, and also for simultaneous analysis with little or no sample preparation, and therefore suitable for natural radioactivity study and monitoring compared to other methods. Previous work employing this technique include El-Araby et. al. (2021), Rilwan et. al. (2020), Taqi et. al. (2018), Abojassim & Hasim (2019).

The aim of this research is to assess the radiation health risk due to NORMs in Fly Ash, Gypsum, Iron Ore, and Lime Stone, that are used in the production of cement at Ashaka Cement Company, near Bajoga, Gombe State, employing gamma-spectrometric technique using thallium activated sodium Iodide NaI(TI) detector. This would be achieved by determining the radioactivity levels of ^{238}U, ^{232}Th and ^{40}K in the materials, and subsequent evaluation of hazard indices due to radiation exposure associated with the raw materials. The NaI(TI) detector has poor energy resolution but better detecting efficiency relative to a HPGe detector. The relative large detector area of the NaI(TI) increases the probability of detecting gamma radiation and therefore an advantage for detecting gamma rays of low and intermediate energies that may arise from the ^{238}U, ^{232}Th and ^{40}K nuclides (Gilmore, 2008).

MATERIALS AND METHODS

Study Area

Ashaka Cement Company is located near Bajoga Town, Gombe State, North-East, Nigeria, as shown in Figure 1.

The Company was established 1974 following a detailed geological survey by Blue Circle Industries and is currently by being owned by Lafarge-Holcim. The major raw materials used in Ashaka cement are Limestone, Gypsum, Fly-ash and Iron Ore.

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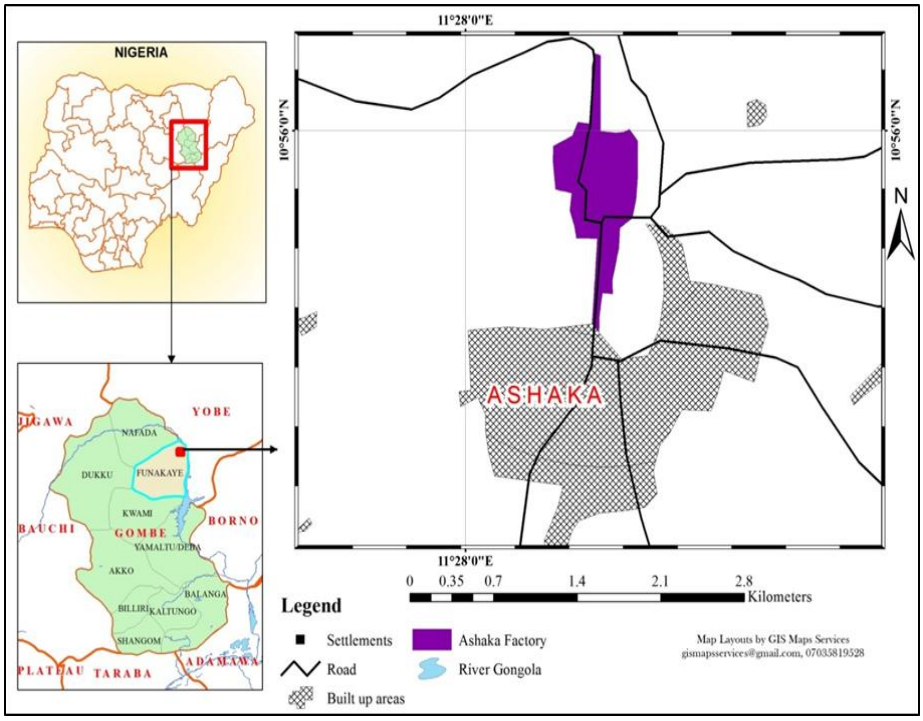

Figure 1: Map of the study area showing location of Ashaka Cement Company

Sample Collection and Preparation

A total of Sixteen (16) samples made up of four (4) each from Limestone, Iron-ore, Fly-ash and Gypsum, were collected from top surface soil at different places within the study area, making up a representative sample. Each of the four (4) groups were later mixed-up together in order to have a homogenized sample for each material. They were later put into a polythene bag and carefully labelled as *LS, IO, FA* and *GP*, *representing* Limestone, Iron-Ore, Fly-Ash Gypsum, respectively, then taken to Centre for Energy Research and Development (CERD), University of Ibadan for gamma-ray spectroscopy measurements.

At the laboratory, the samples were air dried at room temperature (27°C) for Seven (7) days to remove moisture, and then later crushed into fine powder in order to have same matrix as the standard samples. This is to ensure that the sample adequately fill up the entire volume of the Marinelli Beaker, which has the same configuration with the detector. With the exception of FA (Fly-Ash) which was already in standard form, the grinding time for the three sample (which depends on their hardness) are as follows: *LS* (50 secs) *IO* (120 secs), and *GP* (60 secs).

Each samples (weighing 500g) were packaged and tightly sealed into a radon-impermeable cylindrical plastic containers that were selected based on the detector configuration. Prior to measurement at the Centre, they were kept for four (4) weeks in order for the ^{222}Ra and ^{220}Rn achieve secular equilibrium.

Measuring System

Samples collected from the mining sites were measured with a detector that is hermitically sealed and consists of a high-resolution NaI(TI) crystal, a photomultiplier tube, an internal magnetic light shield, an Aluminum housing and a 14 pin connector coupled to a Pre-amplifier, Amplifier, Multichannel Analyzer, and a PC with Maestro software for

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the gamma-spectrum analysis. The detector was calibrated for efficiency using IAEA-385 Standard source prior to samples' measurement, and has the following specifications: energy resolution of 7.5% specified at the 662 *keV* peaks of ^{137}Cs, which is capable of identifying the different gamma-ray energies of the radionuclides considered in this study. The detector has an Aluminum window 0.5mm thick and density 147 mg/cm^2; reflector oxide, 1.6mm thick and density 88 mg/cm^2; magnetic light shield lined steel; and operating voltage of 902 V dc. Energy calibration was carried out using a reference material involving ^{137}Cs, ^{60}Co and ^{241}Am sources as done previously in Isinkaye & Shitta (2010). The counting time for spectral acquisition is 54,000 seconds (15 hours) and the detector configuration measures 7.6 cm × 7.6 cm in dimension.

Sample analysis

The radiological risk factors associated with the raw materials were determined from the following parameters:

Specific activity concentration (Ac)

The specific activity concentration due to ^{238}U, ^{232}Th and ^{40}K in Bq/kg assuming secular equilibrium for the different nuclides in the decay chains; specifically from ^{238}U and ^{232}Th, is given as (El-Taher, 2010):

$$A_c = \frac{C_n}{E_f P_\gamma t_s\, m} \qquad (1)$$

where A_c is the specific activity concentration of a particular nuclide, C_n the net count of the corresponding full energy peak, E_f the absolute full-energy peak detection efficiency, P_γ the emission probability per decay corresponding to the specific gamma-ray energy, t_s the counting time in second and m the mass of soil sample in Kg.s.

Radium equivalent activity (Ra_{eq})

This hazard index was used to estimate the suitability of any material which contains Uranium (Radium), Thorium and Potassium that can be used as component of building construction, assuming a maximum radium equivalent of 370 Bq/kg. It is expressed in eq. (2) as follows (Mantazul, 1979):

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \qquad (2)$$

where A_{Ra} is the activity of ^{226}Ra (^{238}U), $A_{Th}$is the activity of ^{232}Th and A_k is the activity of ^{40}K (all in Bq/kg). The maximum radium-equivalent activity is 370 Bq/kg (Al-Sulaiti*, et. al.,* 2010).

External Hazard (H_{ex}) and Internal Hazard (H_{in}) Indices

The external and internal hazard indices was used to evaluate a potential hazard associated with radiological effects. It is calculated from ^{232}Th, ^{226}Ra (^{238}U) and ^{40}K in order to minimize the annual external gamma radiation dose to 1mSv/y and is obtained using equations (3) and (4):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \qquad (3)$$

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (4)$$

where, A_{Ra}, A_{Th}, and A_K are the specific activities (in Bq/kg) of ^{226}Ra, ^{232}Th and ^{40}K, respectively. The external and internal hazard index should be less than unity (< 1) for the radiation hazard to be safe and negligible. This index is a dimensionless quantity.

Absorbed Dose rate (D)

This was used to assess radiation dose rate D (in nGy/h) in the environment and was determined using equation (5) (*IAEA, 1999*):

$$D = 0.462A_{Ra} + 0.604A_{Th} + 0.042A_K \qquad (5)$$

The terms A_{Ra}, A_{Th}, and A_K are the activity concentration of ^{238}U, ^{232}Th and ^{40}K (all in Bq/kg), respectively.

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Annual Effective Dose Equivalent (AEDE)

The AEDE was determined from the absorbed dose D in air using a conversion factor of 0.7 SvG/y for gamma-ray exposure in the environment for a year given an outdoor occupancy factor of 0.2 (UNSCEAR, 2000) as shown in equation (6):

$$AEDE_{(out)} = D \times 8760 \times 0.2 \times 10^{-3} \quad (6)$$

For indoor measurement, an occupancy factor of 0.8 is used, thus modifying equation *(6)* to *(7)* below:

$$AEDE_{(in)} = D \times 8760 \times 0.2 \times 10^{-3} \quad (7)$$

Lifetime Cancer Risk (LCR)

Lifetime cancer risk is the likelihood that a person who is free of a certain type of cancer will develop or die from that type of cancer during their lifetime. This risk was estimated for indoor and outdoor occupancy and is determined as follows:

$$LCR\ (indoor) = E_{in} \times LE \times RF \quad (8)$$

$$LCR\ (outdoor) = E_{out} \times LE \times RF \quad (9)$$

where E_{in} and E_{out} are the annual effective doses (*AEDE*) equivalent for indoor and outdoor respectively. *LE* is the life expectancy (70 years) and *FR* is the fatal risk factor per Sievert, for low-dose background radiation. According to ICRP-60 (1991) and Agbalagba (2017), *FR* is considered to produce stochastic effects and uses a cancer risk factor of 0.057 for public exposure.

RESULTS AND DISCUSSIONS

Radioactivity concentration due to ^{238}U, ^{232}Th, ^{40}K and Radium equivalent

Specific activity concentration of natural radionuclides due to Uranium, Thorium and Potassium in Fly-Ash, Gypsum, Iron-Ore, and Limestone were evaluated and presented in Table 1.

Table 1: Radioactivity concentration due to ^{238}U, ^{232}Th, ^{40}K and Ra_{eq} from sampled materials.

Sample code	Activity concentration (Bq/kg)			
	^{238}U	^{232}Th	^{40}K	Ra_{eq}
FA	16.76±2.81	17.80±1.25	117.23±13.32	51.24±4.35
GP	15.62±2.31	13.76±0.89	156.12±13.12	47.32±4.084
IO	16.76±2.12	16.85±1.20	212.00±13.38	56.52±4.18
LS	18.27±2.04	35.73±2.34	187.52±10.31	83.53±3.67
min.	15.62	13.76	117.23	47.32
max	18.27	35.73	212.00	83.53
mean	16.85	21.04	168.22	59.65
*world mean**	35	30	400	< 370
*world range**	17 - 60	11 - 64	140 - 850	-

**UNSCEAR, 2000*

Results of measurements in the Limestone indicate a maximum concentration of 18.27 Bq/kg and 35.73 Bq/kg from ^{238}U and ^{232}Th, respectively. The maximum concentration from ^{40}K was recorded in Iron-Ore at 212.00 Bq/kg, whereas the maximum concentration recorded for Ra_{eq} is 76.74 Bq/kg in the Limestone sample. Also, the activity concentration in the Gypsum due to ^{238}U, ^{232}Th, ^{40}K and Ra_{eq} were found to be 15.62 Bq/kg, 13.76 Bq/kg, 156.12 Bq/kg and 44.70 Bq/kg, respectively. The evaluated mean radioactivity concentration due ^{238}U, ^{232}Th, ^{40}K and radium equivalent in the materials are 16.85 Bq/kg, 21.04 Bq/kg, 168.22 Bq/kg and 55.66 Bq/kg, respectively. The results obtained for R_{aeq} (at 55.66 Bq/kg) is well below the maximum permissible limit of 370 Bq/kg (UNSCEAR, 2000) and therefore, the materials are radiologically safe to be used as

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components of building materials. The variation in the results are also shown in Figure 2 and in general, all the values obtained from ^{232}Th are generally higher than that from ^{238}U across all the measured samples.

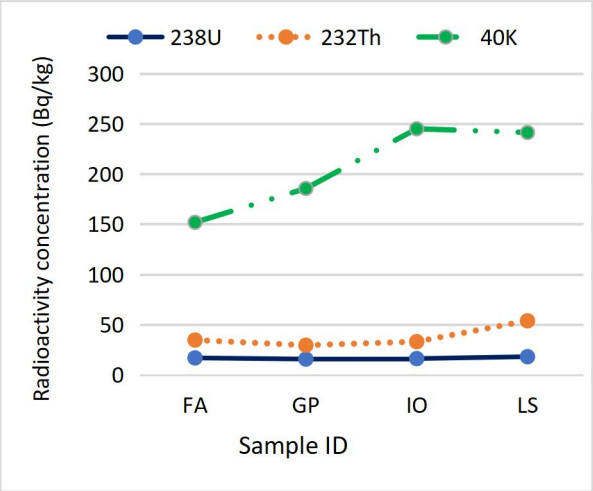

Figure 2: Variation of radioactivity due to ^{238}U, ^{232}Th and ^{40}K across the samples.

Contributions of Samples to total radioactivity

The contribution of each sample to overall measured radioactivity is given in Figure 3.

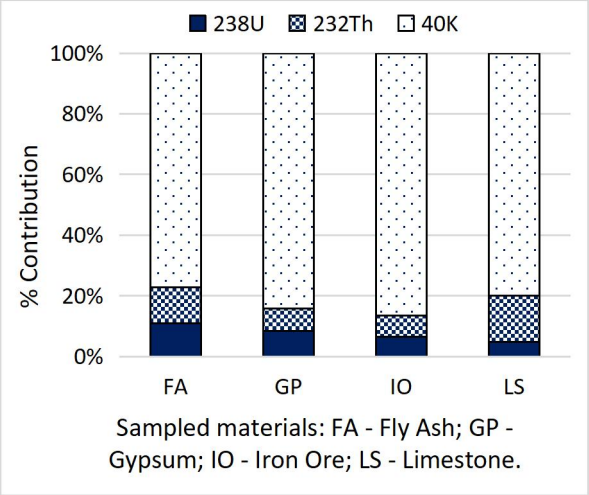

Figure 3: Concentrations of radionuclides in the measured samples.

Radioactivity concentration ratio: $^{238}U/^{232}Th$, $^{232}Th/^{40}K$ and $^{238}U/^{40}K$

A plot radioactivity concentration between ^{238}U and ^{232}Th were determined as shown in Fig. 4.

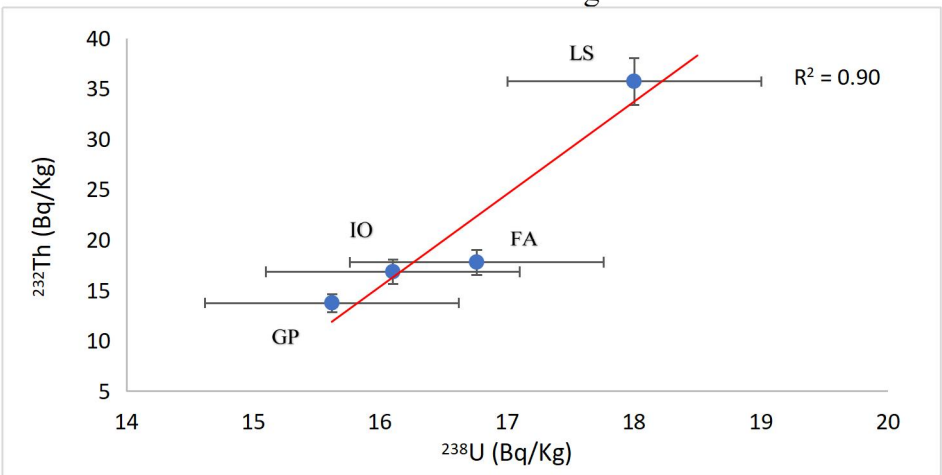

Figure 4: Activity ratio of ^{232}Th and ^{238}U due to Gypsum, Iron Ore, Fly Ash and Lime Stone

The plot shows a coefficient of $R = 0.95$, indicating a strong correlation between the Uranium and Thorium nuclides within the materials. In contrast, a weak correlation of $R = 0.28$ and $R = 0.09$ from Figure 5 and Figure 6 were obtained from (^{232}Th and ^{40}K) and (^{238}U and ^{40}K), respectively.

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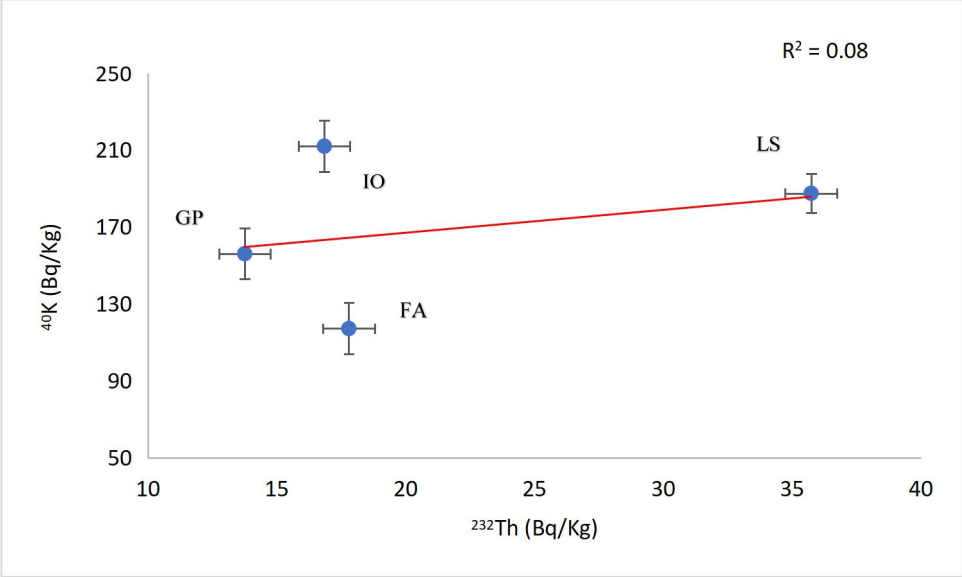

Figure 5: Activity ratio of ^{232}Th and ^{40}K due to Gypsum, Iron-Ore, Fly Ash and Lime Stone

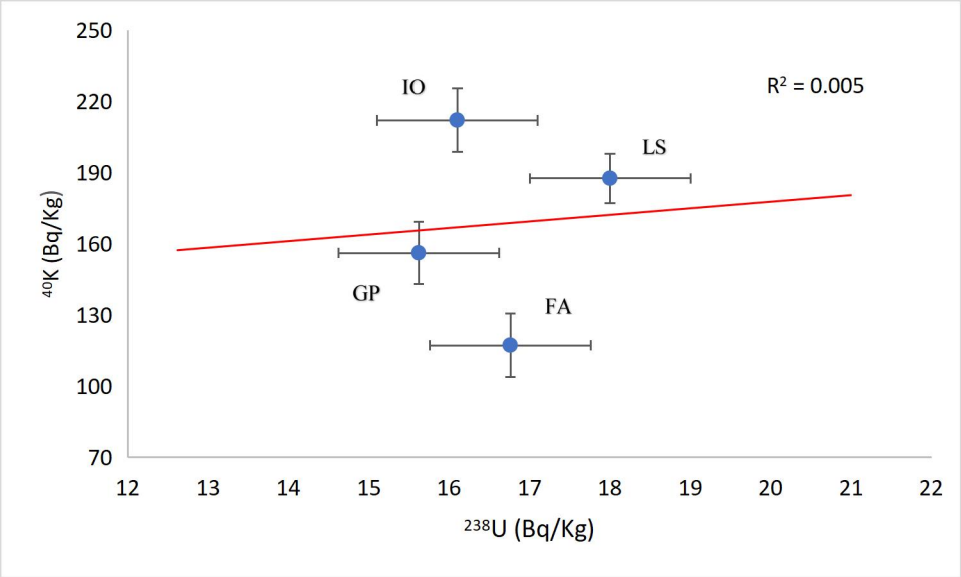

Figure 6: Activity ratio of ^{238}U and ^{40}K due to Gypsum, Iron Ore, Fly-Ash and Lime-Stone

A good correlation may indicate common origin and/or similar physico-chemical properties between the radionuclides. Fig.4 (*R = 0.95)* may indicates common geological source matrix for both uranium and thorium, showing similar chemical behavior and/or properties between the elements. It also means that there is no significant fractionation and/or leaching due to chemical and/or physical weathering of the two elements in that environment. An error bar indicate uncertainty in the measured parameter. The long error bars in Fig. 4 and Fig. 5 from ^{238}U indicate that the values are more spread out. Nevertheless, the overall uncertainty are within accepted range and therefore the results reliable. On the other hand, the weak correlations observed in Fig.5 (*R = 0.28*) and Fig.6 (*R = 0.09*) shows relative leaching of one of the nuclides relative to the other, and

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thus might be of separate sources viv-a-vis their respective physical and/or chemical behaviors, as they interact with geological matrix (Omoniyi *et. al.* 2013).

Radiological risks factors

The computed radiological risk factors from the sampled materials are given in Table 2.

Table 2: Radiological risk parameters associated with the materials sampled in this study.

Sample code	D (nGy/h)	H_{ex}	H_{in}	AEDE (mSv/yr)		LCR	
				indoor	outdoor	indoor	outdoor
FA	23.42	0.14	0.56	0.023	0.006	0.092	0.023
GP	22.08	0.13	0.68	0.022	0.005	0.087	0.022
IO	26.52	0.15	0.92	0.026	0.007	0.104	0.026
LS	37.77	0.21	0.93	0.034	0.009	0.136	0.034
mean	27.45	0.16	0.77	0.045	0.011	0.105	0.026
*world mean**	55	< 1	< 1	0.41	< 1	< 1	< 1

** UNSCEAR, 2000*

The results indicate a maximum and minimum doses of 37.77 nGy/h and 22.08 nGy/h from Limestone and Gypsum, respectively. The evaluated mean dose from all the samples is 27.54 nG/h, about 50% below the world mean value of 55 nGy/hr (UNSCEAR, 2000). The internal (H_{in}) and external (H_{ex}) hazard indices give a measure of health risk associated with indoor or outdoor inhalation of radon gas due to building materials or dose exposure outdoor. Results obtained are less than unity, indicating that the materials making up the samples are radiologically safe for human use, since values obtained are 0.16 and 0.77 for the internal and external hazard indices, respectively. The evaluated Annual effective dose equivalent (AEDE) for all the samples are also below the annual limit of 1 mSv/yr for individual members of public (USNRC, 1991; IAEA, 1999).

Factors associated with cancer risk *(LCR*) due to radiation exposure is also given in Table 2. According to ICRP-60 (1991), the fatal cancer limit considered for stochastic effect is 0.057, and from this results, the risks are low at 0.105 and 0.026 for indoor and outdoor exposures, respectively. Evaluated results from hazard indices and LCR showed that values from indoor(s) are always greater than outdoor in both cases i.e. (*H: 0.77 > 0.16*) and *(LCR: 0.105 > 0.026*), indicating that staying indoors is potentially hazardous relative to outdoors, provided the radiation dose exceeds the threshold limit.

Results from current work compared with other countries

Limestone

Table 3 and Figure 7 compares the radioactivity concentration of Limestone from Nigeria and some countries.

Table 3: Radioactivity concentration of ^{238}U, ^{232}Th, ^{40}K and Ra_{eq} due Limestone from this study relative to some countries

Countries	^{238}U(Bq/kg)	^{232}Th(Bq/kg)	^{40}K(Bq/kg)	Ra_{eq}(Bq/kg)	Reference
Italy	11.00	12.00	22.00	27.57	*Rizzo et al., (2001)*
Egypt	27.80	46.60	66.00	90.67	*El-Taheer 2011*
Brazil	11.00	12.00	205.00	41.67	*Malanca et. al.,1993*
Algeria	16.00	13.00	36.00	34.89	*Varshney et. al. 2010*
Pakistan	29.25	14.07	60.20	51.33	*Rafique et. al., (2011)*
Nigeria (Ashaka)	*18.00*	*35.73*	*187.52*	*76.74*	*This study*

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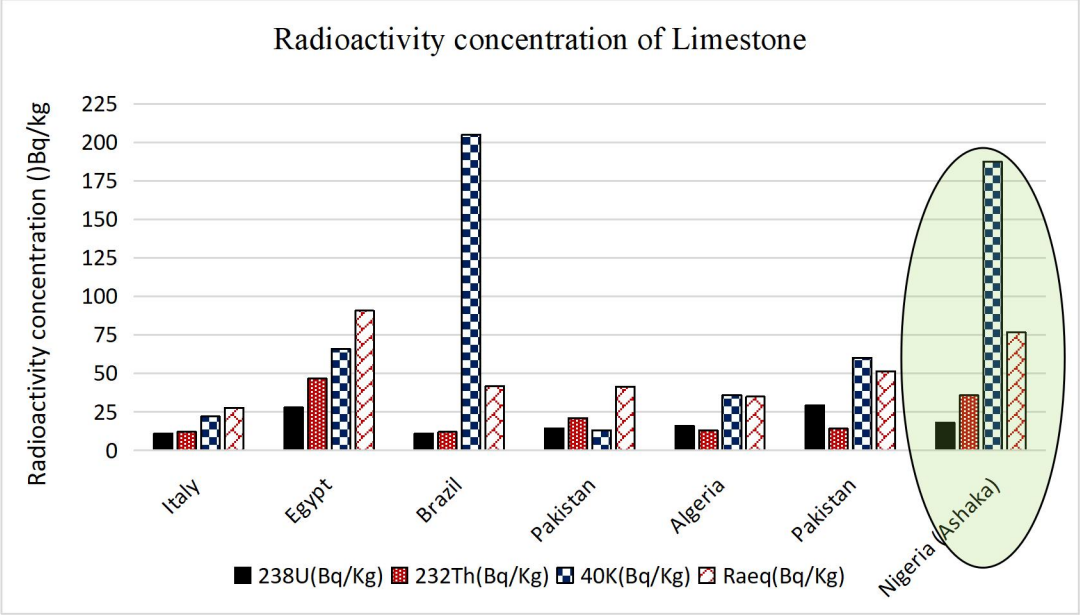

Figure 7: Radioactivity concentration of ^{238}U, ^{232}Th, ^{40}K and Ra_{eq} due to Limestone compared to other countries.

From the Table, results obtained for ^{238}U at 18.00 from Ashaka Cement Company is greater than that of Italy (11.00 Bq/kg), Brazil (11.00 Bq/kg) and Algeria (16.00 Bq/kg), but less than that of Egypt and Pakistan at 27.80 Bq/kg and 29.25 Bq/kg, respectively. For ^{232}Th and ^{40}K, their maximum activities at 46.60 Bq/kg from Egypt and 205.00 Bq/kg from Brazil exceeds results from this study (Nigeria) at 35.73 Bq/kg and 187.52 Bq/kg due to ^{232}Th and ^{40}K, respectively. The Radium equivalent activity (Ra_{eq}) due to Limestone from these countries, including that of Nigeria, are well below the recommended limit of 370 Bq/kg. The result obtained from this study (76.74 Bq/kg) is greater than that of Italy, Brazil, Algeria, and Pakistan; the maximum value being recorded is from Egypt at 90.67 Bq/kg. The results were also presented in Figure 7.

Gypsum and Fly-Ash

Table 4 and Table 5 compare the radioactivity concentrations of Gypsum and Fly-Ash in this study compared with other countries. A summary of the result is given in Table 6.

Table 4: Radioactivity concentration of ^{238}U, ^{232}Th, ^{40}K and Ra_{eq} due to Gypsum from this study compared to some countries

Countries	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Raeq(Bq/kg)	Reference
Saudi Arabia	9.00	6.50	184.80	31.29	*Al-Dadi et. al.,(2014)*
Cyprus	8.30	2.80	20.90	13.38	*Tzortzi et. al., (2003)*
Italy	3.80	2.00	32.00	8.74	*Rizzo et. al., (2001)*
USA	9.00	1.00	10.00	11.01	*Angela (2012)*
Egypt	37.60	42.27	499.30	128.46	*Korna et. al., (2014)*
Pakistan	29.25	4.07	60.22	38.93	*Rafique et. al.,(2011)*
Nigeria (Ashaka)	*15.62*	*13.76*	*156.12*	*44.70*	*This study*

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Table 5: Radioactivity concentration of ^{238}U, ^{232}Th, ^{40}K and Ra_{eq} due to Fly-Ash from this study compared to some countries

Countries	^{238}U(Bq/kg)	^{232}Th(Bq/kg)	^{40}K (Bq/kg)	Ra_{eq}(Bq/kg)	Reference
Iraq	28.74	27.61	951.43	136.24	*Ahmed et al., (2016)*
Poland	134.90	74.70	649.90	277.57	*Bem et al., (2002)*
Turkey	25.20	50.50	205.40	103.64	*Turhan et al., (2010)*
Belgium	15.00	13.60	112.00	40.49	*Trevisi et al., (2012)*
USA	40.00	30.00	400.00	108.00	*Markkanen, (1995)*
Nigeria (Ashaka)	*16.76*	*17.80*	*117.23*	*47.86*	*This study*

Table 6: A summary of evaluated radioactivity concentrations (^{238}U, ^{232}Th and ^{40}K) and Ra_{eq} due to Gypsum and Fly-Ash from other countries compared to this study.

Sample	^{238}U (Bq/kg)		^{232}Th (Bq/kg)		^{40}K (Bq/kg)		Ra_{eq} (Bq/kg)	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Gypsum	Italy	Egypt	USA	Egypt	USA	Egypt	Italy	Egypt
	3.80	37.60	1.00	42.27	10.00	499.30	8.74	128.46
Nigeria	*15.62*		*13.76*		*156.12*		*44.70*	
	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum
Fly-Ash	Belgium	Poland	Belgium	Poland	Belgium	Iraq	Belgium	Poland
	15.00	134.90	13.60	74.70	112.00	951.43	40.49	277.57
Nigeria	*16.76*		*17.80*		*117.23*		*47.86*	

From Table 4, the radioactivity concentration of ^{238}U at 15.62 Bq/kg obtained in this study is higher that of Saudi-Arabia, Cyprus, Italy and USA, but less than that from Egypt and Pakistan at 37.60 Bq/kg and 29.25 Bq/kg, respectively. Similarly, results of ^{232}Th, ^{40}K and Ra_{eq} at 13.76, 156.12 and 44.70 (all in Bq/kg) indicates variations with that of other countries, which this may not be unconnected with the local geology of the areas, in addition to Physico-chemical properties of the terrestrial environment. For example, result of ^{232}Th (13.76 Bq/kg) from this work is higher than all the countries, except that of Egypt which is 42.27 Bq/kg.

Available information on the radioactivity concentration of Iron-Ore (as raw materials in cement production) were scanty and not detailed enough, thus not captured in Table 6.

CONCLUSION

A study on the radioactivity level of raw materials for Cement were determined using gamma-ray spectrometry. The mean activity concentrations due to ^{238}U, ^{232}Th and ^{40}K in these materials were found to be 14.95 Bq/Kg, 21.04 Bq/Kg, and 168 Bq/Kg for Limestone, Gypsum, Fly-Ash and Iron-Ore, respectively. Results of radium equivalent from these samples were also found to be 51.24 Bq/kg for Fly-Ash, 47.32 Bq/kg for Gypsum, 56.52 Bq/kg for Iron-Ore, and 83.53 Bq/kg for Limestsone, with a mean of 56.65Bq/kg for all the samples, and all are well below the maximum permissible limit of 370 Bq/kg.

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The largest contribution to total mean activity of ^{238}U, ^{232}Th and ^{40}K in the samples come from Fly-Ash, Gypsum, Iron-Ore and Limestone at 76%, 85% and 80%, respectively. A good correlation of 0.95 between activity of ^{238}U and ^{232}Th was also observed in the samples, while the highest and lowest absorbed doses are from Gypsum and Limestone at 37.77 nGy/hr and 22.08 nGy/hr, respectively. Similarly, the evaluated radiological health indices (Absorbed dose, Annual effective dose, and Cancer risk) were within the threshold values. The overall results indicates that the materials are safe to be used as component in building construction.

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