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Determination of Natural Radioactivity Level in Rock Samples from Dangote Cement Plant, Obajana, Nigeria

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Abstract

To assess the possible health risk to those working, or living in the vicinity of the Dangote Cement factory Obajana Nigeria, the activity concentration of some Naturally Occurring Radioactive Material (NORMs) namely, ^{40}K, ^{238}U, and ^{232}Th at the mining site of Dangote Cement Company Obajana Nigeria, was measured using a sodium iodide (NaI (Tl)) based gamma spectroscopy. Five categories of samples including the raw materials and the finished product (cement) were collected and counted for 18000 seconds. Each of the analysed sample is a mixture of the sample type collected at different locations at the site. The results show that the concentration of ^{40}K, ^{238}U, and ^{232}Th in the analysed samples is between 417.25±22.28 and 1783±91.18 Bq/kg, 0.88±0.15 and 63.68±6.86 Bq/kg, and 12.90±0.75 and 29.77±1.73 Bq/kg respectively. The mean concentration of ^{238}U and ^{232}Th are below the recommended mean value, while that of ^{40}K is above the world average. The radiological parameters namely, the absorbed dose rate in air, annual effective dose, calculated using the measured activity concentrations were below the recommended values. However, the mean radium equivalent activity was slightly higher than the world average, due to high activity concentration of ^{40}K in some of the samples. This does not pose any immediate danger; hence, we conclude that there is no radiological risk to workers at the site.

Keywords

Cement, Detector, Gamma-ray, Obajana, Specific Activity

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1. Introduction

The knowledge of the distribution of radionuclide and radioactivity levels in the environment is significant for assessing the level of radiation exposure on humans [1, 2]. High -energy cosmic ray particle incident on the earth's atmosphere and radioactive nuclides found in the earth's crust are major contributors to natural radiation exposure and are present everywhere in the earth's environment [1, 3].

Human beings have always been exposed to natural ionizing radiation from within and outside the earth and this exposure to outdoor radiations from Naturally Occurring Radionuclides usually emanate from the topmost few centimeters of the soil [4]. The natural radioactivity in soil predominantly comes from the decay of ^{238}U, ^{232}Th series, and ^{40}K, with the emission of alpha particles, beta particles, and gamma rays capable of damaging body cells/organs due to prolonged exposure. [5, 6].

Radionuclides are constantly inhaled and ingested through the air we breathe, food chain, and drinking waters. This no doubt constitute a great proportion to background radiation to which humans are exposed such that once a threshold limit is

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exceeded in concentration, it endangers human health leading to ailments like, leukemia, kidney damage, genetic disorder, and prolonged effects results in cancer of the bladder, lungs, testis, etc. It is therefore strongly advised by the various regulatory bodies on radiation protection that the maximum permissible dose (ALARA Principle) must as a matter of necessity be constantly maintained.

Human activities (such as mining and farming) have contributed greatly to the distribution of radioactive isotopes. Hence, the need for constant measurement and evaluation of radiation exposure levels for a safe and healthy environment.

The in-depth knowledge of radionuclide concentrations and distribution because of mining activities is of paramount interest since it provides useful information in the monitoring of environmental radioactivity.

Obajana, where the Dangote Cement is located, is endowed with large deposits of limestone ($CaCO_3$), chalk, shale, clay, and sand, which are all raw materials for cement production. When these raw materials quarried, crushed, finely grounded, and blended to the appropriate chemical composition, the calcination process follows with burning the resulting calcium oxide together with silica, alumina, and ferrous oxide to form clinker; this clinker is then grounded or milled together with other constituents (like gypsum, slag, etc) to produce the finished product referred to cement. These processes can lead to the redistribution of radioactive materials that may be contained in the raw material listed above into buildings, and other construction works, and enhance indoor and outdoor exposure.

Studies have shown that the demand for cement is directly proportional to economic growth as such, many growing economies like Nigeria, that are striving for rapid infrastructural development which underlines the tremendous growth in cement production [9]. The cement industry no doubt plays a pivotal role in improving living standards worldwide by creating direct employment and providing multiple cascading economic benefits to associated industries. Despite the high level of popularity and profitability, the cement industry is faced with the challenges of environmental concerns and sustainability, hence the need for this present study.

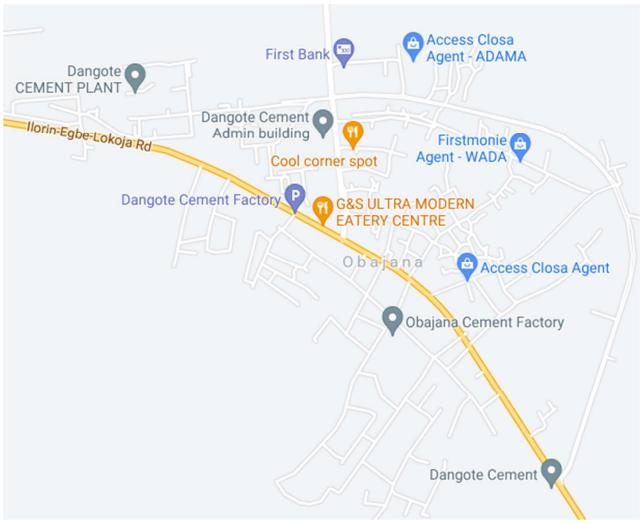
This study determines the radioactivity concentrations of ^{40}K, ^{238}U, and ^{232}Th in the raw materials from the mining site of Dangote Cement Plant, to ascertain the radiological impact of the mining activity on the factory worker. It became necessary due to the fast-growing populations and economic activities around Obajana. The measured activity concentration will be compared with regulatory standards to determine the potential radiological hazards associated with the exposure rate.

2. Materials and Methods

2.1. Study Area

Obajana is located between latitude 6° 24 'N - 7° 34 'N and longitudes 7° 49 'E – 8° 59 'E of the Greenwich meridian [7]. On the relative location, Obajana is about 220km from Abuja, the Nigeria Federal Capital Territory, and 43 km to Lokoja, 49km to Okene, and 40 km to Kabba. Geographically, it is located southwest of Abuja, see figure 1.

Geologically, the study area is underlain by basement complex rocks, predominantly composed of folded gneisses and metal sediments. The rock type found in the area include; schist, pegmatite, quartzite, limestone, granite, and granulite [8]. An over-burden soil of 2m to 8m thickness overlies the limestone, and two main types of landforms, namely, domed-shaped residual hills and river valleys characterize Obajana [8]. The high concentration of limestone, which is a major raw material for the manufacture of cement that prompted the establishment of Obajana Cement Factory. Obajana has an estimated limestone deposit of about 450,000,000 tones with a depth of between 30 and 60 meters, (Obajana Cement Project [9].



Source: Google Earth Image (2021).

Figure 1. Map of Obajana.

2.2. Samples Collection and Preparation

Table 1. Samples ID and type collected from Dangote Cement Plant, Obajana.

S/No	Sample ID	Sample Types	Sample Weight (gram)
1	S_1	Limestone	200
2	S_2	Granite	200
3	S_3	Clay	200
4	S_4	Laterite	200
5	S_5	Finished Product (Cement)	200

Five categories of samples collected at the Dangote Cement Plant, Obajana in Kogi State were analyzed namely; cement, limestone, granite, laterite, and clay (Table 1). Each sample ID is a mixture of the sample type collected at different locations at the site. The

dried rock samples were pulverized and homogenized using a grinder to allow it to pass through a sieve of 200μm mesh size. Samples were packaged in cylindrical beakers of dimension 9cm × 7cm (each weighing 200g), they were sealed using candle wax, petroleum jelly, and masking tapes to avoid the escape of radiogenic gases. The samples were then kept for thirty-five days to allow for radioactive secular equilibrium between parent radionuclides and their daughters.

Counting of the radionuclide was done by a gamma spectrometric system coupled with an 8cm -co-axial NaI (Tl) detector. The detector was calibrated for its energy and efficiency using radioactive point sources (^{241}Am, ^{137}Cs, and ^{60}Co) as obtained from the International Atomic Energy Agency (IAEA, 2005) [10] report. Samples were counted for a lifetime of 18000s each. The 1764 keV-line of ^{214}Bi for ^{226}Ra was used in the assessment of the activity concentration of ^{238}U while 2615 keV -line of Tl-208 was used for determining the activity concentration of ^{232}Th and the single 1460 keV-line of ^{40}K was used for its content evaluation. The specific activity concentration (A_i) for ^{40}K, ^{238}U, and ^{232}Th in each of the measured samples given in table 2, were computed using the relation below: [11]

$$A_i = \frac{NC_i}{\varepsilon \times y_i \times M \times T} \quad (1)$$

where; A_i is the ith radionuclide concentration, NC_i is the net-count of the ith radionuclide, ε is the efficiency of the detector to detect gamma rays at the energy of the ith radionuclide, y_i is the emission probability of the ith radionuclide (15.17 % for ^{238}U, 35.85 % for ^{232}Th and 10.6 % for ^{40}K), M is the sample mass in kg, T is the counting time 18000). All the raw data obtained from the detector were converted from count per second (cps) to conventional units (Bq/kg) using the calibration factor, to determine the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K respectively.

The absorbed dose rate at 1m above the ground and annual effective dose were calculated using equations 2 and 3 respectively, [10].

$$DR(nGy/h) = 0.462A_U + 0.604A_{Th} + 0.0417A_K \quad (2)$$

A_U, A_{Th}, and A_K are the activity concentrations of, ^{238}U, ^{232}Th, and ^{40}K respectively in Bq/kg and 0.462, 0.604, and 0.0417 are the conversion factors [9].

$$E_d = DR \times O_f \times C_C \times T \quad (3)$$

where E_d is the annual effective dose in (mS_v/y), DR is the value of absorbed dose rates in (nGy/h) O_f is the outdoor occupancy factor (0.2), C_C is the dose conversion coefficient $(0.7\times10^{-6}\, S_v/nGy)$ T is the time of exposure per year, (8760 for adult hr/y) [9].

The Radium Equivalent Activity (Ra_{Eq}) is a radiological index used to compare the specific activities of radionuclides using a quantity that factors the radiation hazards associated with them [10]. This quantity was calculated using equation 4 [11].

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \leq 37 \quad (4)$$

Where;

A_U, A_{Th}, and A_K are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K respectively. The values of the studied samples must be less than 370 Bq/kg for the radiation hazard to be negligible.

3. Results and Discussion

Table 2 presents the specific activity concentration of ^{40}K, ^{238}U, and ^{232}Th in the samples analyzed for Dangote Cement Plant, Obajana, and (five samples denoted by S_1, …. S_5), this shows that the radionuclides detected belong to the natural terrestrial radionuclides series of ^{238}U, ^{232}Th and the singly-occurring radionuclide ^{40}K [10] There was no artificial radionuclide detected in the samples.

Table 2. Specific Activity Concentration of Samples from Dangote Cement Plant, Obajana.

S/No	Samples	^{40}K (Bq/kg)	^{238}U (Bq/kg)	^{232}Th (Bq/kg)
1	S_1	1663.72±86.82	0.88±0.15	20.54±1.25
2	S_2	1783.13±91.18	34.53±3.43	29.77±1.73
3	S_3	1171.35±61.60	22.58±2.79	19.24±1.17
4	S_4	417.25±22.28	22.58±2.79	19.24±1.17
5	S_5	427.98±21.99	14.70±1.49	12.90±0.75
	Mean	1093.60±56.77	19.08±2.13	20.34±1.21
	World Average [9]	400.00	35.00	30.00

The average specific activity concentration of ^{238}U and ^{232}TH is below the world average, while that of ^{40}K is much greater than the recommended mean of 400 Bq/kg, [9] This we attribute to its large proportion in rocks; nonetheless, great caution must be exercised particularly for those working in the mines concerning exposure time and use of adequate shielding.

These results compared well with the results from similar studies at mining sites of other cement companies in Nigeria, [1, 10, 13, 14].

Table 3 gives the results of the absorbed dose rate at 1m above the ground, the annual effective dose, and radium equivalent activity for the study site.

Table 3. Radiological Parameters in Studied Building Materials Samples from Dangote Cement Plant, Obajana.

Samples ID	Absorbed Dose Rate ($nGy.h^{-1}$)	Annual Effective Dose ($mS_v y^{-1}$)	Radium Equivalent Activity (Bq/kg)
S_1	82.2±4.4	0.10 ±0.01	158.4±4.2
S_2	108.3±6.4	0.13±0.01	214.5±8.4
S_3	70.9±4.6	0.09±0.01	711.4±6.1
S_4	39.5±2.9	0.05±0.01	653.4±3.1
S_5	32.4±2.1	0.04±0.01	304.1±3.2
Mean	66.7±4.1	0.08±0.01	408.4±4.9
World Average	84.0	0.46	370.0

The mean absorbed dose of 66.65±4.08 nGy/h for Dangote Cement Plant, Obajana, is below the threshold level, as recommended [12, 15]. This shows that there is no risk to the public due to exposure.

The foundational effect of radiological risk to the public from exposure is determined from the estimation of annual effective dose (in mSv/y).

The mean Annual Effective Dose for the studied samples in Dangote Cement Plant, Obajana is presented in table 3, is less than UNSCEAR, 2000 recommended permissible value of 1 mSv/y. This indicates that the study sites are radiological safe for both the miners and the public.

The Radium Equivalent Activity is a radiological index used to compare the specific activities of radionuclides using a quantity that factors the radiation hazards associated with them [9]. The mean radium equivalent activity 408 Bq/kg for the study site is within the limit of experimental error when compared with the maximum permissible limit of ≤370 Bq/kg [16, 17]. Although the mean radium equivalent activity Ra_{eq} obtained for Dangote cement plant Obajana, is higher than the world average due to high potassium content, however, this does not pose any significant health risk, but caution should be exercised especially by the miners to mitigate long-term effect due to prolonged exposure.

4. Conclusion

The level of natural radioactivity in the samples collected from the Dangote Cement Plant, Obajana in Kogi State of Nigeria was determined using a well-calibrated gamma-ray spectrometry system.

The measured activity concentration for ^{40}K, ^{238}U, and ^{232}Th in sedimentary rock samples from different sampling sites of Dangote Cement Obajana, Kogi State, Nigeria vary based on sample type and location. Sample S_2 has the highest concentration of the three radionuclides of interest. The mean activity concentrations of ^{238}U and ^{232}Th are lower than the world mean as stipulated in the UNSCEAR, 2000, report.[12] ^{40}K has a mean value higher than the permissible level, therefore caution must be taken against prolonged exposure.

From the measured values, the average values of absorbed dose rate in air, annual effective dose, and radium equivalent activity were calculated [18], and these values are 66.7±4.1 nGy/h, 0.08±0.01mSv/y, and 408.4±4.9 Bq/kg respectively. The values for absorbed dose rate and annual effective dose are lower than the recommended maximum permissible limit and that of radium equivalent activity is slightly higher due to the ^{40}K content although this value is still within empirical error. Thus, we conclude that there is no immediate radiological hazards to workers of the cement factory, and the inhabitants of Obajana.

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