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Radiological Risk Assessment of Building Materials Used in Federal College of Education (Technical) Akoka, Lagos State, Nigeria

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Abstract

Multiple building constructions necessitating a regular influx of different soils for building purposes within Federal College of Education (Technical) Akoka, in Lagos State, Nigeria spurred a radiological risk assessment of selected soil samples. Five (5) construction points were identified and ten (10) soil samples were collected. A gamma spectrometer was used to evaluate the natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) present in the soils. IAEA-certified standard materials of RGU-1, RGTh-1, and RGK-1 were used to determine the full peak efficiencies of gamma energies 609, 1120, and 1764 keV for ^{238}U, 2614 keV for ^{232}Th and 1460 keV for ^{40}K. Activity concentration, absorbed dose, annual effective dose equivalent, hazard indices, and excess lifetime cancer risk (ELCR) were estimated to assess possible radiological risks in the building soil samples. Results from the analysis revealed the highest radioactivity among soil samples was 674.3 Bq/kg from ^{40}K and the lowest was 18.5 Bq/kg from ^{226}Ra. The absorbed dose (D) varies from 65.8 nGy/h to 215.3 nGy/h with an average value of 136.6 nGy/h, and the annual effective dose equivalent ranged from 0.081 mSv/y to 0.264 mSv/y with an average value 0.168 mSv/y. The internal and external hazard index ranged from 0.49 −1.46 and 0.39 − 1.32 respectively which is not completely below the hazard index threshold value ≤ 1 as recommended by UNSCEAR. The ELCR values ranging from $0.222 \times 10^{-3} - 0.726 \times 10^{-3}$ with an average value of 0.461×10^{-3} predicted an insignificant carcinogenic risk with the probability of four persons in every 10,000 persons.

Keywords: Absorbed dose; Annual Effective Dose Equivalent; ELCR; External Hazard Index (Hex); Gamma spectrometer; Internal Hazard Index (Hin).

I. INTRODUCTION

Humans are susceptible to radiation from the sun, space, and naturally occurring radioactive materials on Earth. Radon, an inert, colourless, and odourless gas usually released from soils and trapped in structures is one of the main factors that expose humans to natural radiation. Exposure to natural radiation can also come from the use of naturally occurring radioactive elements due to some human activities. Mining ore and constructing buildings using natural resources that can include radioactive materials are examples of these activities [1].

Radionuclides from the uranium-238, thorium-232, and potassium-40 decay series are examples of naturally occurring radioactive materials (NORMs), and they can be found in building supplies such as granite, concrete, bricks, and tiles.

These naturally occurring radioactive elements (NORM) cause radiological concerns when present in gamma-emitting construction materials. Even at normally modest rates, long-term exposure to gamma radiation from these materials can raise the risk of cancer, especially if levels surpass safety thresholds. Lung cancer risk may also rise with prolonged inhalation of radon and its decay products from uranium or thorium present in some of these building materials. Internal radiation exposure can result via ingestion (particularly by children through hand-to-mouth contact) and inhalation of radioactive dust from building materials [9][10]. To ensure the safety of the college population, it is crucial to determine the radiological risk connected with these building materials used for the concurrent constructions within the study area.

In identifying possible radiation exposure pathways and enabling the implementation of mitigation measures for human risks, particularly in residential areas and high-traffic sites, radiological risk assessment in soil materials is essential for maintaining public health and safety. Furthermore, it assists in guaranteeing compliance with national and international radiation protection rules and regulations, including those established by the World Health Organization (WHO) and the International Atomic Energy Agency (IAEA). Risk assessments also give essential data for policymakers, regulators, and stakeholders to make informed decisions, and enable the implementation of targeted solutions to decrease exposure, such as soil remediation, waste management, and public awareness campaigns.

Several studies have shown the effective application of gamma spectrometry in radioactive analysis on farm soils [3] building materials [5], soil samples around fertilizer factories [6], and well water [2], while studies on radiological estimation and hazard indices have been carried out using various techniques, including gamma spectrometry to identify and quantify radionuclides on different types of building materials including syenite building blocks in southwestern, Cameroun [11], stone dust in building materials in South Africa [13], and brick, clay and sandy soils, cement, and tiles in India [12], with values within safe limits for inhabitants. This study investigated the radiation levels in construction materials and their potential risks to the college community.

II. MATERIALS AND METHODS

A. Study Area

The study area, Federal College of Education (Technical), Akoka, Lagos State, Nigeria, shown in Fig. 1, lies between Longitude N06º31’10” and N06º31’30”, and Latitude E3º22′ 55″ and E3º23′ 5.3″.

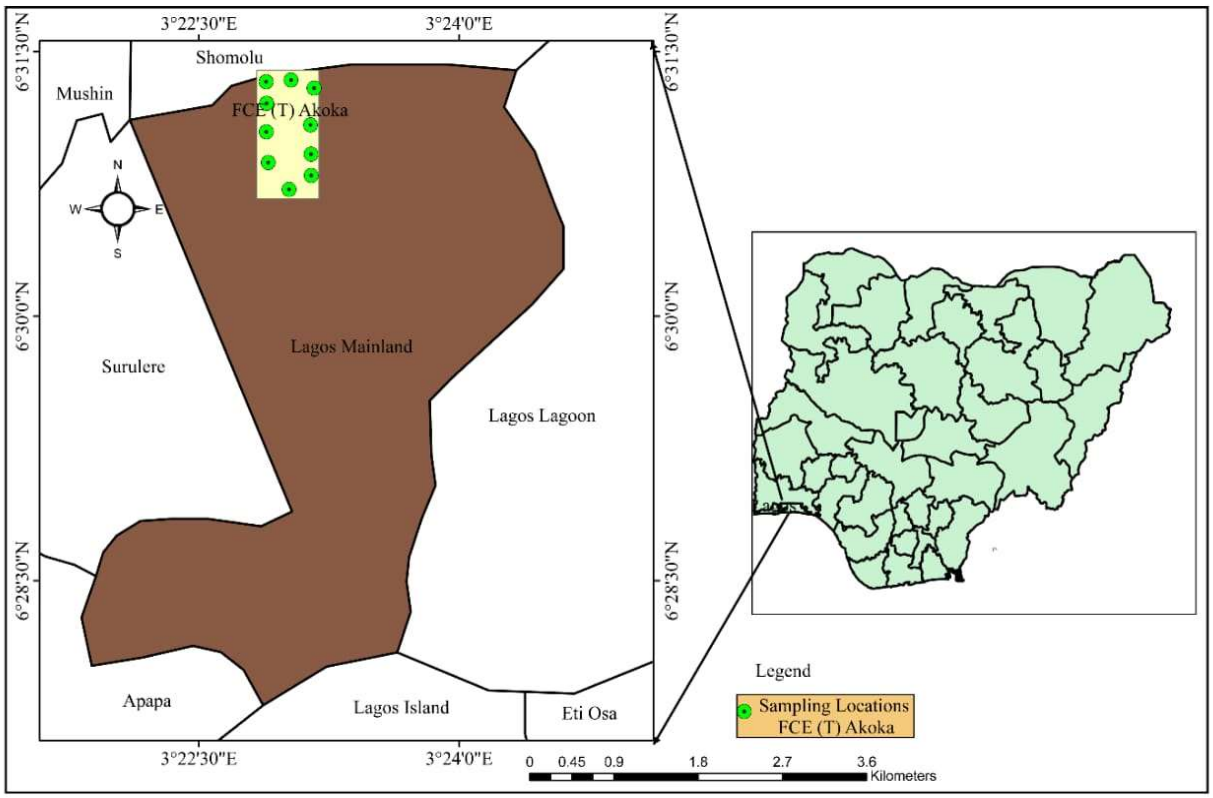

Fig. 1. Map of Federal College of Education (Technical) Akoka, Lagos State, Nigeria.

B. Materials

Ten (10) different soil samples were collected from different construction points including sharp sand, silt, loamy soil, coarse soil, clay soil, and their combinations. Plastic holders of 360 cm^3 volume capacity were used for both soil storage for secular equilibrium and holders for gamma spectrometry. NaI (scintillation) detector was used for gamma spectrometric analysis.

C. Methods

1) Sample Collection and Preparation

The sample preparation began with soil weighing for wet weight and then was sun-dried for about two weeks. The samples were reweighed several times until a constant weight was maintained. The dry weight was pulverized to obtain fine-grained soil samples and homogeneity after which they were sealed in plastic containers, labelled according to the sampling location and stored at room temperature to attain secular equilibrium for 30 days.

2) Radionuclide Analysis Using Gamma Spectrometry

Activity measurements were performed using a gamma-ray spectrometer. The detector comprises a 2"×2" (50.8 mm diameter by 50.8 mm thickness) Tl-activated NaI crystal and a photomultiplier tube (PMT) hermetically sealed together in a metallic casing of diameter 58.4 mm and height 132.0 mm.

The lead shield is cylindrical and has 59.1mm thickness, 151.2mm inner diameter, and a movable lid of 59.1mm thickness. The lead shield helps to reduce the background count rate of the detector by attenuating and/or absorbing some of the background radiation including components of x-ray and gamma-ray emitted from materials in the surrounding of the spectrometer, other than the sample being analyzed.

The background radiation around the detector was estimated by counting the empty sample container in the same geometry as the standards. The background count rate was subsequently subtracted from the sample count rate before calculating the activity concentration of radionuclides in the samples using (1).

$$c_s - c_b = c_n \quad (1)$$

c_s is the sample count rate, c_b is the background radiation count rate, and c_n is the net count rate of the sample.

3) Activity Concentrations of ^{40}K, ^{232}Th and ^{238}U

The activity of a given mass (m) of radionuclide, is given by (2):

$$A = \lambda N = \frac{\lambda \times N_A \times m}{M} \quad (2)$$

Where λ is the decay constant, equal to $\frac{0.623}{T_{1/2}}$; N is the number of atoms in the given mass (m) of the radionuclide, N_A is Avogadro's number (i.e. number of atoms in 1 mole of the radionuclide), M is the molecular mass, i.e., the mass of 1mole of the radionuclide in grams, and $T_{1/2}$ is the half-life of the radionuclide. Equation (2) can be verified by considering that the Currie (Ci) a unit of activity, was originally defined as the activity of 1g of radium (^{226}Ra). One Currie is also equal to 3.7×10^{10} decays per second. While the activity concentration was obtained using (3):

$$A_C = \frac{C_n}{\varepsilon(E) P_\gamma m} \quad (3)$$

Where ε(E)is the efficiency of detecting gamma rays of energy E by the detector, C_n is the net count rate under the photo peak corresponding to the gamma energy, P_γ is the photon emission probability of the gamma rays of energy E emitted by the radionuclide of interest, A_C is the activity concentration of the radionuclide in the sample and m is the mass of the sample.

In this study, IAEA-certified standard materials of RGU-1, RGTh-1, and RGK-1 were used to determine the full peak efficiencies of gamma energies 609, 1120, and 1764 keV for ^{238}U, 2614 keV for ^{232}Th and 1460 keV for ^{40}K.

D. Risk Assessment Evaluation

1) Absorbed Dose Rate (D)

The guidelines provided by [7] were used to calculate the absorbed dose rate for outdoor air (D) in $nGyh^{-1}$, above the ground surface at about 1m expressed as:

$$D(nGyh^{-1}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \quad (4)$$

Where, C_{Ra}, C_{Th}, and C_K are activity concentrations in Bq/kg for Radium, Thorium, and Potassium respectively.

2) Annual Effective Dose Rate (D_{eff})

To estimate the annual outdoor effective dose (D_{eff}), the conversion coefficient from absorbed dose rate in the air to effective dose, 0.7 $SvGy^{-1}$ for adults, with the outdoor occupancy factor (0.2) proposed by [7] is used. The annual effective dose rate ($mSvyr^{-1}$) was calculated using (5):

$$D_{eff}(mSvyr^{-1}) = D(nGyh^{-1}) \times \frac{8760h}{yr} \times 0.7\ SvGyr^{-1} \times 0.2 \quad (5)$$

Where D is the External gamma absorbed dose rate in $nGyh^{-1}$, 0.7, the conversion factor in $SvGy^{-1}$ (Adult), 8760, the time in a year (hour), and 0.2, the external occupancy factor.

3) Internal and External Hazard Indices

The internal (H_{in}) and external hazards (H_{ex}) indices to gamma-ray radiation in the soil samples used for the building constructions were calculated using (6) and (7) [5][4][2].

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (6)$$

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \quad (7)$$

Where, A_U, A_{Th} and A_K are the specific activity of ^{238}U, ^{232}Th and ^{40}K in $Bqkg^{-1}$, respectively.

4) Excess Lifetime Cancer Risk

Excess lifetime cancer risk was evaluated by applying D_{eff} values using (8).

$$ELCR = D_{eff}\ (mSvyr^{-1}) \times DL \times RF \quad (8)$$

Where DL is the average life duration (55 years) and RF is the fatal cancer risk factor per sievert, Sv-1. For low-dose background radiation that can give rise to a stochastic effect,

a fatal cancer risk factor of 0.05 for the public was recommended [8]. The Monte Carlo simulation is used for ELCR probabilistic projections.

III. RESULTS AND DISCUSSIONS

The activity concentration of naturally occurring radionuclides in ten different soil samples in a College of Education in Lagos state has been determined and shown in Table I, with the activity concentration of 40K in the soil samples ranging from 76.0 $Bqkg^{-1}$ to 674.3 $Bqkg^{-1}$ with a mean value of 341.26 $Bqkg^{-1}$. The highest activity concentration of ^{40}K was recorded for sample DOFA 4 while sample DOFA 3 had the lowest activity concentration. ^{226}Ra activity concentration varies from 18.5 $Bqkg^{-1}$ to 53.5 $Bqkg^{-1}$ with a mean value of 32.69 $Bqkg^{-1}$. The lowest activity was recorded for sample SOT-2 while the highest activity was recorded for sample DOFA-2. The activity concentration of ^{232}Th ranges from 19.9 $Bqkg^{-1}$ to 179.2 $Bqkg^{-1}$, with a mean value of 153.77 $Bqkg^{-1}$. The activity concentration of K-40 was relatively high in all the samples followed by Th-232. However, the activity concentration of Ra-226 was relatively low across the ten soil samples analyzed and soil samples DOFAA1, SOS, and SOT showed BDL for activity concentrations of thorium and uranium.

Table I. Cumulated Radiological Assessment of Soil Samples.

	Activity Concentrations			Absorbed Dose	Annual Effect. Dose	Hazard Index		ELCR ($\times 10^{-3}$)
Sample ID	K-40	Ra-226	Th-232	D ($nGyh^{-1}$)	D_{eff} (mSv/yr)	Hex	Hin	
DOFA-3	76	27.4	179.2	124.065	0.152	0.78	0.86	0.418
DOFA-4	674	49.3	272.2	215.291	0.264	1.32	1.46	0.726
EOB-1	323.2	25.3	119.2	97.163	0.119	0.6	0.66	0.328
EOB-2	597.6	19.9	263.6	193.328	0.237	1.2	1.25	0.652
DOFA-2	437.5	53.5	175.4	148.902	0.183	0.91	1.06	0.502
LT	272	34.9	63.5	65.820	0.0807	0.4	0.49	0.222
SOT-2	318.9	18.5	148.9	111.781	0.137	0.69	0.74	0.377
			Mean	136.622	0.168	0.843	0.931	0.461

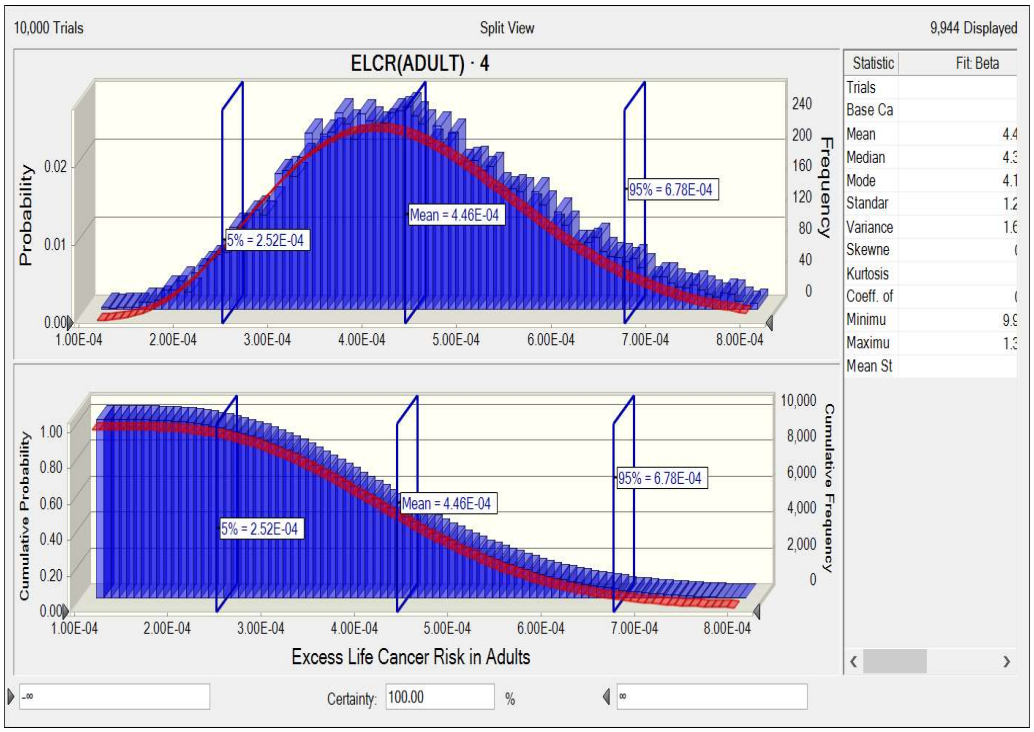

Fig. 2. Monte Carlo simulation on ELCR.

The absorbed dose (D) varies from 65.8 nGy/h to 215.3 nGy/h with an average value of 136.6 nGy/h, and annual effective dose equivalent ranged from 0.081 mSv/y to 0.264 mSv/y with an average value 0.168 mSv/y. The evaluated average absorbed dose is above the world average of 57 nGy/h, comparable to a similar study conducted in some communities within Bayelsa state, Nigeria [1]. The Hex ranged from BDL to 1.32 for the ten (10) soil samples, while all other soil samples were below the baseline that is ≤ 1 according to [7] except for two soil samples from DOFA-4 and EOB-2, with both having Hex greater than unity, thus raising some safety concerns. Also, H_{in} from the ten soil

samples ranged from BDL to 1.46. Seven (7) out of the ten (10) samples had values below the baseline value of ≤1 while the remaining three had values greater than unity. The soil samples with high H_{ex} were the same as those with high H_{in} with DOFA-2.

The excess lifetime cancer risk ranged from $0.222 \times 10^{-3} - 0.726 \times 10^{-3}$ with an average value of 0.461×10^{-3}. Fig. 2 shows a prediction of likely cancer risk from the ELCR values derived from the soil samples, with a mean value of 4.46×10^{-4}, predicting four (4) people likely to have cancer in 10,000 people with time. By risk characterization, the carcinogenic risk from these building materials is insignificant. Thus, continuous monitoring and assessment of radiological risk possibilities is hereby recommended. Also, periodical checks of building materials and random checks within completed buildings is necessary to maintain adherence to radiation protection policy and regulations for safety purposes.

IV. Conclusion

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K measured in some soil samples used for building construction purposes in Federal College of Education (Technical) Akoka, Lagos State, Nigeria have been determined using the gamma-ray spectrometer. For each sample used in this study, the activity concentration, absorbed dose, annual effective dose equivalent, external and internal hazard indices and ELCR have been determined to assess the radiological hazards from the building materials. The results obtained show ELCR probability among the people of the college community is four persons likely to have cancer among every 10,000 persons. This radiological risk characterization is insignificant.

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