Science World Journal Vol. 19(No 4) 2024 https://dx.doi.org/10.4314/swj.v19i4.38
www.scienceworldjournal.org
ISSN: 1597-6343 (Online), ISSN: 2756-391X (Print)
Published by Faculty of Science, Kaduna State University

ASSESSMENT OF RADIOACTIVITY AND RADIOLOGICAL HAZARDS ASSOCIATED WITH CLAY BRICKS IN JALINGO CITY AND ITS METROPOLIS, NORTH-EASTERN NIGERIA

[1]Maxwell Obia Kanu, [2]Nehemiah Bweseh Audu, [1*]Lucky Peter Kenda, [1]Terkaa Victor Targema & [1]Hyacinth Kevin Idu

[1]Department of Physics, Faculty of Science, Taraba State University, P.M.B. 1167, Jalingo, Nigeria
[2]School of Nursing and Midwifery Jalingo, Taraba State, Nigeria

*Corresponding Author Email Address: kendalucky1@gmail.com

ABSTRACT
This study estimates the radiation safety of soils used in making clay bricks, a common building material in Jalingo City and its surrounding areas. The activity concentration of the natural radioactive elements ^{238}U, ^{232}Th, and ^{40}K in the soils was measured using a gamma-ray spectrometer equipped with a 905-3 NaI (TI) crystal detector and a high photomultiplier measuring 7.62 cm by 7.62 cm. The average activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in the soils were 12.5±1.3, 26.7±1.7, and 65.1±5.2 $Bqkg^{-1}$ respectively, all of which were lower than the global average concentrations. The research also assessed the Radium equivalent activity, absorbed dose rates, and other radiological hazard parameters relevant to building materials. The mean Radium equivalent activity was 55.69 $Bqkg^{-1}$, below the safety limit of 370 $Bqkg^{-1}$. Additionally, the mean outdoor absorbed dose rate was 24.64 $nGyh^{-1}$, below the safety limit of 59.00 $nGyh^{-1}$, and the mean indoor absorbed dose rate was 46.08 $nGyh^{-1}$, below the safety limit of 84.00 $nGyh^{-1}$. All assessed hazard parameters, including annual effective dose rates (indoor and outdoor), lifetime cancer risk, annual gonadal effective dose, representative level index, and both external and internal hazard indices, were well below the established global safety limits. The activity concentration of the primordial radionuclides and the radiological hazard parameters were also lower compared to other parts of Nigeria and the world. As a result, the study concluded that the soils and the buildings constructed with them are radiologically safe and pose no hazard threats to the occupants.

Keywords: Natural radioactivity; local building material; exposure; radiological safety.

INTRODUCTION
Naturally Occurring Radioactive Materials (NORMs), also known as primordial radioactivity, have existed in the environment since the creation of the Earth. They include the 238U series, 232Th series, and the singly occurring 40K (Orosun et al., 2020a). These radioactive materials are found in geological formations such as granites, igneous, and sedimentary rocks. Through rock weathering processes, they are transported into the soil and rivers by rain (Orosun et al., 2019; Mbonu and Ben, 2021). The concentration of radionuclides in the terrestrial environment varies greatly across the world. In addition to NORMs, radioactive materials can also enter the environment through cosmic rays and human activities. Human activities that contribute to radioactive concentrations in the environment include nuclear wars, testing of nuclear equipment, nuclear accidents, and coal-fired power plants, among others (Dizman et al., 2019). NORMs naturally disintegrate into lighter nuclei, emitting ionizing radiation in the process. Since this process is natural and uncontrollable, radiation in the environment has become a reality that affects us. However, the anthropogenic contributions of radiation in our environment can be eliminated, making an assessment of radionuclides in the environment significant.
Humans live on soil, build with soil, and carry out agricultural activities on the soil. Radionuclides present in the soil can reach humans in several ways. For example, during agricultural activities, plants can absorb radionuclides along with nutrients from the soil as they grow, through root absorption, cell absorption, and foliar absorption. This makes the food chain a potential pathway for radiation transfer to humans (Thien et al., 2020).
When soil is used as a building material, it can be risky to live in buildings with high concentrations of radionuclides, as long-term external exposure to the soil can result in bioaccumulation or toxicity. This can lead to serious health problems such as prostate cancer, leukaemia, cognitive defects, increased risk of miscarriages in pregnant women, cataracts, thyroid nodules, and more (Mbonu and Ben, 2021; Dao et al., 2024). According to the IAEA (1996) document, natural radionuclides contribute 80% of the effective annual radiation dose, while artificial sources contribute 20%. Specifically, buildings expose humans to approximately 0.4 $mSvy^{-1}$ of indoor effective dose from gamma radiation through building materials (UNSCEAR, 2000; Omeje et al., 2018).
The assessment of radionuclides has become a popular area of research as scientists seek to understand the potential health hazards these substances pose. Researchers are studying radionuclide assessment in various media including drinking water, sediments, construction materials, aquatic foods, residential soil, and food crops (Eyrolle et al., 2020; Thien et al., 2020; Orosun et al., 2020a; Orosun et al., 2021; Gawad et al., 2024; Omeje et al., 2024 Endjambi et al., 2024). The goal is to develop an effective remediation strategy to mitigate the jeopardy associated with these substances. Radionuclides in building materials have also drawn the interest of researchers globally, with some results falling below the world safety limits, while others exceed these limits. For example, a study in Nepal found radionuclide concentrations in bricks to be below the world safety limits, yielding positive safety parameters. Similarly, assessments in the Gaza Strip and certain areas of the Peninsula also yielded positive results, with all radiological hazard parameters within the world safety limits (Abd Elkader et al., 2021). However, higher radionuclide concentrations in building materials in some parts of Spain were recorded above the safety limit (Mas Balbuena et al., 2021). Similarly, in the south Gondar zone of Ethiopia, higher radionuclide concentrations in cement were reported concerning the safety limits (Abate, 2022).

In Nigeria, various researchers have conducted radiological assessments of building materials, and their findings align with global trends. Adewoyin et al. (2022) evaluated the radiological risk of tiles used in Nigerian buildings and found that they pose no radiological hazards. Similarly, a study by Garba et al. (2023) assessed the radiological hazards in building materials such as sand, clay, Kaolin, and Gypsum in north-western Nigeria. Although the mean activity concentrations of 226Ra exceeded the safety limits set by UNSEAR (2000), the overall radiological hazard parameters were within safe limits. Additionally, an assessment of radiological hazards from building materials in Ota village, Ogun state Nigeria by Omeje et al. (2018) revealed a mean annual effective dose of 0.399 mSvy-1, which exceeds the world safe limit (0.07 mSvy-1) recommended by UNSEAR (2000).

The fact that not all radionuclide hazard assessments in Nigeria fall within safety limits is cause for concern. The variation in radiological results from city to city may be attributed to geological differences. For example, some rocks, such as granites, are known to contain more 238U and 232Th than others. Additionally, human activities that are likely to increase radionuclide concentrations in Nigerian soils include agriculture. Most crop-producing farmers in Nigeria use fertilizers to improve crop yield. Common fertilizers used include Nitrogen, Phosphorus, and Potassium (NPK). It has been established in the literature that phosphate fertilizers are capable of increasing 232Th and 238U concentrations in soil (Kant et al., 2006; Bramki et al., 2018; Porntepkasemsan et al., 2018). In Jalingo, the most used blocks for building are cement blocks. This applies also the rest of the urban and peri-urban areas of Taraba State. However, because of financial reasons, some people especially in the rural areas of Taraba state, and the remaining part of the country prefer sun-dried mud blocks. These blocks are made by mixing locally sourced clay with water, and they offer good thermal insulation and are well-suited for the hot and dry climate of Taraba State. Unfortunately, unlike cement blocks, sun-dried blocks are only used for small-scaled buildings such as single bedrooms, retail shops, two bedrooms, or retail shops and thereabouts. Alternatively, clay (burnt) bricks, also known as fired bricks or clay bricks, have been a staple building material for decades, in Nigeria, and some African countries (Baiden et al., 2014; Houle, 2018; Akinyele et al., 2020). Clay bricks are made from clay, abundant in Nigeria, and are produced by excavating it, mixing it with water, and forming brick moulds. These bricks are dried and then stacked in a kiln for firing. The high temperatures harden the clay, removing moisture and organic matter, and making the bricks durable (Akinyele et al., 2020; Monteiro and Vieira, 2024).

The clay bricks possess several advantages which make it preferable in some cases. Such advantages include fire resistance, strength and durability, aesthetic appeal, and environmental sustainability (Obianyo et al., 2021). The soil samples assessed in this study were for clay bricks. Therefore, there is an urgent need to determine their radionuclide safety owing to the fact that the current state of radiological safety assessment of building materials tends to overlook local materials, as the focus has been on materials in urban areas. This study aims to assess the radiological safety of soils used to make bricks, which are local building materials in the study area.

MATERIAL AND METHODS

The Study Area and the most common bricks used as building materials therein

The study was carried out using soils collected from two brick moulding sites situated in Jalingo Metropolis. The metropolis is located between latitudes 8° 50' N and 8° 55' N and between longitudes 11° 17' E and 11° 26' E (Kanu et al., 2021; Kanu et al., 2022a; Kanu et al., 2022b).

In Taraba State, Nigeria, different building materials and construction techniques are used to erect structures that withstand the region's unique environmental conditions and cater to the cultural preferences of its inhabitants.

Geology of the Study Area

Obaje (2009) provides a detailed description of the geology of the study area, as a part of the Nigerian basement complex. The major rock types found in the area are granites, migmatites, and gneiss. Additionally, the region also contains basalts that date from the Tertiary to Recent periods. The migmatites are formed by the transformation of massive gneiss particles into rocks with a dispersed texture and varying grain sizes, which are mostly porphyroblastic (Macleod, 1971). The metamorphic rocks of Precambrian age that are produced by this rock block are not differentiated (Grant, 1971). The region includes basic or intermediate intrusive granites that belong to the Pan African Older Granites. These granites have grains that vary in texture from fine to medium to coarse, as per McCurry (1976). In Jalingo, there are also some minor types of local rocks, such as dolerites and pegmatites. These are mostly found in the form of intrusive vein bodies and dykes.

Sample collection and preparation

Ten (10) samples were obtained from a clay bricks industry and were labelled TS accordingly. The soil samples were processed in a lab by homogenizing, grinding, and sieving them through a 2 mm mesh sieve to achieve a particle size of approximately 0.15 mm. After processing, the soils were dried. Each sample was then measured in uniformly sized cylindrical plastic containers, with 200 grams (200g) of soil in each container. The containers were sealed for 30 days for secular equilibrium between ^{226}Ra and ^{232}Th and their daughter radionuclides (Mustapha et al., 1997). The sample was prepared at the National Steel and Raw Material Exploration Agency (NSRMEA) in Kaduna and the gamma spectrometric measurement was done at the National Institute of Radiation Protection and Research (NIRPR) in Ibadan.

Sample Measurement

The gamma-ray spectrometer used for measurement was equipped with a 905-3 NaI (TI) crystal detector and a high photomultiplier measuring 7.62 cm by 7.62 cm. For differential spectrometry, three channels were utilized: the ^{40}K channel was identified by a 1460 KeV energy peak, the ^{238}U channel was identified by a 1764 KeV energy peak, and the ^{232}Th channel was identified at a 2614 KeV energy peak (Table 1). Orosun et al. (2020a) and Mbonu et al. (2021) have provided detailed explanations of the instrumentation and analysis techniques. The calibrations used in this study were adapted from Ibeanu (1999) and are presented in Table 2.

Equation (1) was used to evaluate the activity concentrations A $(BqKg^{-1})$ for the count rate of the corresponding peaks (A_n) in the samples (Jibiri and Esen, 2011).

 https://dx.doi.org/10.4314/swj.v19i4.38

$A\ (Bq\ \text{Kg}^{-1})\ =\ k\ An$ (1)

where $k = \frac{1}{\varepsilon P_\gamma M_s}$ and P_γ is the transition probability of the specific gamma – ray, M_s is the sample mass measured in Kg. Suppose we define the net background peak as A_b, then the Below Detection Limit (BDL) in units of $BqKg^{-1}$ can be used to calculate the lowest activity that is detectable in a given sample using equation (2) (Jibiri and Esen, 2011).

$DBL\ (Bq\ Kg^{-1})\ =\ 4.65\frac{\sqrt{A_b}}{t_b}$ k, (2)

where, t_b is the time (s) for background counting, and K is the factor used for converting counts per second (cps) to (Bqkg^{-1}). To convert the measurements to conventional units, we used conversion factors of 0.46, 0.031, and 0.046 for ^{238}U, ^{40}K, and ^{232}Th, respectively. Each sample has a counting time of 30,000 seconds. We obtained the gamma-ray background of the laboratory using an empty container, which gave us BDL values of 14.54, 3.84, and 9.08 Bqkg-1 for ^{40}K, ^{238}U, and ^{232}Th, respectively. By subtracting the respective BDL from each sample, we were able to determine their activity concentrations.

Table 1. Spectral Energy windows used in analysis using NaI (Tl) gamma spectroscopy system

Element analysed	Isotope Used	Ray Energy (KeV)	Energy windows `(KeV)
^{232}Th	^{208}Tl	2614.5	2460-2820
^{238}U	^{214}Bi	1764.0	1620-1820
^{40}K	^{40}K	1460.0	1380-1550

Table 2. Energy calibration for Quantitative spectra analysis

Isotope	Calibration Factor x 10^{-3}cps/ppm	x 10^{-4}cps/Bqkg^{-1}	Conversion factor (Bqkg-1/ppm)	Detection Limit Ppm	Bqkg^{-1}
^{40}K	0.026	6.431	0.032	454.54	14.54
^{238}U	10.500	8.632	12.200	0.32	3.84
^{232}Th	3.612	8.768	4.120	2.27	9.08

Source: (Ibeanu, 1999).

Radiological Hazard Parameters

Radium equivalent

The γ-ray radiation exposure to humans through buildings can be estimated via several hazard indices. The Radium Equivalent activity (Ra$_{eq}$) is useful in identifying the consistency of the exposure to the γ-ray radiation emanating from those buildings (Ahmed et al., 2018). Accordingly, it is expected that the radium equivalent activity should be lower than 370 Bqkg^{-1} in other to ensure radiological safety. In this study, the Radium equivalent was estimated using equation (3) (UNSCEAR, 2000).

$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K,$ (3)

where $A_U, A_{Th},$ and A_K are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K respectively.

The Absorbed Dose Rates (D)

The absorbed dose rates are crucial and basics of radiation health risk assessment, as they are the determinants of the biological effects of the ionizing radiation emphasised earlier (Orosun et al., 2020b). We obtained the outdoor absorbed dose rate (D$_{out}$) at 1 m above the ground using equation (4) as used for building materials, following the guidelines from UNSCEAR, (2000).

$D_{in}(nGyh^{-1}) = 0.92A_u + 1.1A_{Th} + 0.08A_K.$ (4)

Meanwhile, the indoor absorbed dose rates for typical Nigerian buildings whose dimensions were stated in Orosun et al. (2020b) as $4 \times 5 \times 2.8\ m$ in size, a thickness of 20 cm, and 2350 kgm^{-3} as the structure's density, can be calculated using equation (5) (UNSEAR, 2000; Orosun et al., 2020b)

$D_{out}(nGyh^{-1}) = 0.462A_u + 0.604A_{Th} + 0.042A_K$. (5)

Annual Effective Dose Rate (AEDR)

The annual effective dose rate is a stochastic measure of health risk due to exposure to gamma radiation. It is useful in estimating the tissue-weighted aggregate of the equivalent doses of gamma radiation received by the tissues and organs of the body (Orosun et al., 2020b). The indoor and outdoor AEDR exposure experienced by people living in houses built with those soils or members of the public were estimated using equations (6) and (7), where 0.8 and 0.2 were used as occupancy factors for indoors and outdoors respectively, and a conversion factor of 0.7SvGy^{-1} (UNSEAR, 2000; Orosun et al., 2020b).

$AEDR_{in}(mSvy^{-1}) = D_{in}(nGyh^{-1}) \times 8760(hy^{-1}) \times 0.7(SvGy^{-1}) \times 0.8 \times 10^{-6},$ (6)

$AEDR_{out}(mSvy^{-1}) = D_{out}(nGyh^{-1}) \times 8760(hy^{-1}) \times 0.7(SvGy^{-1}) \times 0.2 \times 10^{-6}.$ (7)

Excess Lifetime Cancer Risk (ELCR)

The excessive lifetime cancer risk which estimates the risk of contracting cancer upon exposure to the buildings was calculated using equation (8) (UNSCEAR, 2000)

$ELCR_{indoor} = AEDE_{in}(mSvy^{-1}) \times DL(years) \times RF(Sv^{-1}),$ (8)

where DL is taken to be 70 years, is the average duration of life (Orosun et al., 2020b), and RF is the fatal cancer risks per sievert (Risk Factor), and $AEDE_{in}$ maintains the definition from equation (6), and the risk factor used is 0.057 for stochastic effects (ICRP, 2007).

The Annual Gonadal Equivalent Dose (AGED)

Some organs in the body such as bone surface cells, bone marrows, and gonads, due to their sensitivity to radiation have attracted special consideration by regulatory bodies such as UNSCEAR. The annual gonadal equivalent dose is the hazard parameter used in assessing the safety of those organs. Accordingly, an AGED value that is higher than 0.3 $mSvy^{-1}$ is capable of causing leukaemia in the victims (UNSCEAR, 2000). The AGED emanating from those soils was calculated using equation (7) as stated by UNSCEAR (2000).

$$AGED\ (\mu Svy^{-1}) = 3.09A_U + 4.18A_{Th} + 0.314A_K, \quad (9)$$

where A_U, A_{Th}, and A_K are the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K respectively.

Representative Level Index (RLI)

Another useful tool used in assessing the safety of building materials is the RLI. Just like some of the other hazard parameters discussed earlier, RLI is commonly used to assess the level of exposure to gamma radiation due to the radionuclide concentrations from the samples understudy. RLI values have some relationships with the annual effective dose as detailed in Orosun et al. (2020b) and Ebongue et al. (2018). The RLI for residents dwelling in the buildings from those assessed soils was estimated using equation (8) as provided by UNSCEAR (2000).

$$RLI = \frac{A_U}{150\text{Bqkg}^{-1}} + \frac{A_{Th}}{100\text{Bqkg}^{-1}} + \frac{A_K}{1500\text{Bqkg}^{-1}} \leq 1. \quad (10)$$

Radiation Hazard Indices

Natural radionuclides in the soil and environments create an external field of radiation to which humans are exposed. Hazard indices are key parameters used in assessing the level of exposure.

It is recommended that the external and internal hazard indices be less than one according to UNSCEAR (2000). An external hazard index greater than one indicates a radium equivalent dose greater than 370 Bqkg-1, which signifies a significant exposure to gamma radiation. The hazard indices were calculated using equations (11) and (12) for the external and internal hazard indices, as specified by UNSCEAR (2000) and used by other authors such as Orosun et al. (2019) and Mbonu and Ben (2021).

$$H_{external} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810}, \quad (11)$$

$$H_{internal} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810}. \quad (12)$$

Table 3. Activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in the soil used in making bricks.

Sample Code	^{238}U (Bqkg^{-1})	^{232}Th (Bqkg^{-1})	^{40}K (Bqkg^{-1})
TH1	21.6 ±2.2	40.5 ±3.3	54.7 ±12.7
TH2	7.9 ± 0.8	22.1 ±1.3	60.5 ± 6.8
TH3	16.5 ±1.5	58.8 ± 3.5	91.7 ± 5.6
TH4	16.8 ±1.4	33.7 ±2.0	58.7 ± 4.6
TH5	13.9 ±3.0	34.8 ±2.1	66.2 ± 4.8
TH6	10.2 ±1.0	21.3 ±1.3	41.0 ± 8.6
TH7	10.3 ±0.9	18.9 ±1.1	92.6 ± 2.7
TH8	8.8 ±0.8	11.0 ±0.7	77.2 ± 2.5
TH9	7.4 ±0.7	9.5 ± 0.6	35.7 ± 1.8
TH10	11.9 ±1.0	16.3 ±1.0	73.1 ±5.0
Mean	**12.5±1.3**	**26.7±1.7**	**65.1±5.2**

RESULTS AND DISCUSSION

Activity Concentration of Radionuclides in the soils

Table 3 presents the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in soil samples, along with a brief statistical summary. The activity concentrations of ^{238}U, ^{232}Th, and ^{40}K ranged from 7.4±0.7 to 16.8±1.4, 9.5±0.6 to 58.80±3.50, and 35.70±1.80 to 92.60±2.70 Bqkg^{-1}, respectively. The mean activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in the soil samples were 12.50±1.30, 26.70±1.70, and 65.10±5.20 Bqkg^{-1}, respectively. It can be observed that the activity concentration of ^{238}U < ^{232}Th < ^{40}K.

The mean activity concentration of these radionuclides in the soils that measured below world safety limits provided by UNSCEAR (2000) followed a similar trend with some of the studies of radionuclide assessment in soils and other building materials in Nigeria and other parts of the world as shown by the comparison in table 4

In southeastern Nigeria, the radionuclide assessment in soils recorded 4.15, 1.64, and 134.13 BqKg^{-1} for ^{238}U, ^{232}Th, and ^{40}K, respectively, all below the recommended safety limits by Mbonu and Ben (2021). Similarly, the radionuclide concentration in the soils assessed in this study was recorded below the existing results in north-central Nigeria by Orosun et al. (2020b). Their radionuclide assessment in laterite soils yielded 43.89 and 38.79 BqKg^{-1}, respectively, for mean values of ^{238}U and ^{232}Th, exceeding the global limits of 32.00 and 30.00 BqKg^{-1} for 238U and ^{232}Th, respectively.

We observed that the concentrations of radionuclides in the soils are similar to those assessed in some other countries, as presented in Table 4. The average radionuclide concentration in the soils studied here indicates a lower risk than in Iraq, as reported by Ahmed et al. (2018). The average concentration of ^{238}U in this study (43.60 BqKg^{-1}) exceeds the safety limit of 30 BqKg^{-1} set by UNSCEAR (2000). Similarly, in a survey by Senthilkumar and Narayanaswamy (2016) on Indian soils, the mean activity concentration of ^{232}Th (39.60 BqKg^{-1}) was found to be higher than the global limit of 30 BqKg^{-1}.

Max	**16.8±**1.4	**58.8±3.5**	**92.6±2.7**
Min	**7.4±0.7**	**9.5±0.6**	**35.7±1.8**
World Average*	32.00	30.00	420.00

*= (UNSCEAR, 2000)

The sediments in Kuwait have high concentrations of ^{238}U and 40K (Saad and Al-Azmi, 2002). Additionally, building materials such as cement, red-clay bricks, and sand in Malaysia contain high activity concentrations of ^{238}U, ^{232}Th, and ^{40}K (Ibrahim, 1999). Similarly, soils in Cameroon and Gaza contain considerably high concentrations of ^{238}U, ^{232}Th, and ^{40}K above the global limit (Nguelem et al., 2016; Abd Elkader et al., 2021).

The average concentration of all the radionuclides evaluated in this study is within the global limits set by UNSEAR (2000). However, in Table 3, it can be observed that the values of ^{232}Th exceeded the global limit (30 BqKg^{-1}), with values as high as 58.80, 40.50, 34.80, and 33.70 BqKg^{-1}. Consequently, we have conducted a radiological hazard assessment associated with these soils, detailed in Table 5. In the following sections, we will discuss the implications of these findings.

Table 4. Comparison of the radionuclide concentration (Bqkg^{-1}) in soils and other building materials in different countries

Country	Media	^{238}U	^{232}Th	^{40}K	Reference
Iraq	Soils	43.60	19.40	321.80	Ahmed et al. (2018)
India	Soils	22.80	39.90	253.16	Senthilkumar and Narayanaswamy (2016)
Nigeria (north-central)	Soil (laterite mining field)	43.89	38.79	81.38	Orosun et al. (2020b)
Nigeria (Southeast)	Soils	4.15	1.64	134.13	Mbonu and Ben (2021)
Mexico	Soils	23.00	19.00	530.00	Mireles et al. (2003)
Kuwait	Sediments	36.00	6.00	227.00	Saad and Al-Azmi (2002)
Malaysia	Cement	51.00	23.00	832.00	Ibrahim (1999)
Malaysia	Red clay bricks	241.00	51.00	7541.00	Ibrahim (1999)
Malaysia	Sand	60.00	13.00	750.00	Ibrahim (1999)
Cameroon	Soils	99.00	157.00	671.00	Nguelem et al. (2016)
Nepal	Bricks	Nil	42.60	601.50	Shrestha et al (2024)
Gaza	Soils	39.60	73.60	589.00	Abd Elkader et al. (2021)
Jalingo, Nigeria	**Soils**	**12.50**	**26.70**	**65.10**	**Present study**
Global limit	**Soils**	32.00	30.00	420.00	UNSCEAR (2000)

Results of Radiological Hazard Parameters

We have explained the terms and formulas utilized in radiological hazard assessment in section 2.5. The results of the radiological hazard parameters are detailed in Table 5. The Radium equivalent dose, used to estimate the consistency of exposure to gamma radiation, ranges between 23.73 to 107.64 BqKg^{-1}, with a mean value of 55.69 BqKg^{-1}. This mean value is significantly lower than the 370 BqKg^{-1} specified in the UNSCEAR (2000) report. This indicates no consistent exposure to gamma radiation from the buildings constructed with these soils. It is worth noting that the Radium equivalent activity in Nigerian soils or building materials generally falls within the safe limit of below 370 BqKg^{-1}, as observed in Isinkaye and Agbi (2013), Orosun et al. (2020b), and Mbonu and Ben (2021). Nevertheless, we assess through other hazard parameters to get convincing reasons for any recommendation.

The outdoor absorbed dose rate of radiation emanating from these soils corresponds to the dose received in nano Greys per hour. For radiological safety, it is important to ensure that outdoor exposure to humans does not exceed 59.00 nGyh^{-1}. According to the findings of the study, the mean outdoor exposure is 24.64 nGyh-1, which falls within the established safety limit. The data indicates that even the highest value (46.99 nGyh^{-1}) remains well within the safe limit. Similarly, the average outdoor annual effective dose rate (AEDR) of radiation received from these soils is 0.03 mSvy^{-1}. Notably, even the maximum AEDRout value (0.06 mSvy^{-1}) is lower than the recommended safety limit of 0.07 mSvy^{-1} as specified by UNSCEAR (2000). The outdoor exposure parameters estimated from these soils align with similar trends observed in other parts of Nigeria. For example, a study on laterite mining fields in north-central Nigeria by Orosun et al. (2020b) reported a mean AEDRout value of 0.06 mSvy^{-1} and a mean value of 47.04 nGyh^{-1}, both well within the safety limits.

Table 5. Radium equivalent activity and the radiological hazards parameters.

Sample Code	Raeq ($BqKg^{-1}$)	Din ($nGyh^{-1}$)	Dout ($nGyh^{-1}$)	AEDRin ($mSvy^{-1}$)	AEDRout ($mSvy^{-1}$)	ELCR($\times 10^{-3}$)	AGED ($mSvy^{-1}$)	RLI	Hin	Hext
TH1	83.73	68.80	36.74	0.34	0.05	1.35	0.25	0.59	0.28	0.23
TH2	44.16	36.42	19.54	0.18	0.02	0.71	0.14	0.31	0.14	0.12
TH3	107.64	87.20	46.99	0.43	0.06	1.71	0.33	0.76	0.34	0.29
TH4	69.51	57.22	30.58	0.28	0.04	1.12	0.21	0.49	0.23	0.19
TH5	68.76	56.36	30.22	0.28	0.04	1.10	0.21	0.48	0.22	0.19
TH6	43.82	36.09	19.30	0.18	0.02	0.71	0.13	0.31	0.15	0.12
TH7	44.46	37.67	20.06	0.18	0.02	0.74	0.14	0.32	0.15	0.12
TH8	30.47	26.37	13.95	0.13	0.02	0.52	0.10	0.22	0.11	0.08
TH9	23.73	20.11	10.66	0.10	0.01	0.39	0.07	0.17	0.08	0.06
TH10	40.84	34.73	18.41	0.17	0.02	0.68	0.13	0.29	0.14	0.11
Mean	55.69	46.08	24.64	0.23	0.03	0.90	0.17	0.39	0.18	0.15
Max	107.64	87.20	46.99	0.43	0.06	1.71	0.33	0.76	0.34	0.29
Min	23.73	20.11	10.66	0.10	0.01	0.39	0.07	0.17	0.08	0.06
Acceptable Limits*	370	84.00	59.00	0.41	0.07	3.75	0.30	≤ 1	≤ 1	≤ 1

*(UNSCEAR, 2000)

The outdoor exposure assessed in this study is significantly low compared to other parts of the world. For example, Cameroonian soils assessed by Nguelem et al. (2016) had a mean outdoor dose rate of 188.2 $nGyh^{-1}$, which exceeds the world mean value of 60 $nGyh^{-1}$. Similarly, the mean outdoor dose rate for quartz in Egypt (Gawad et al., 2024) was 278.4 nGyh-1, with a corresponding mean value of the AEDRout (0.3 mSvy-1) surpassing the safety limit of 0.07 $mSvy^{-1}$.
The indoor hazard parameters assessed in this study follow a similar trend to their outdoor counterparts. The mean indoor absorbed dose rate is 46.08 $nGyh^{-1}$, and the mean AEDRin is 0.23 $mSvy^{-1}$, both measuring below the safety limits of 84.00 $nGyh^{-1}$ and 0.41 $mSvy^{-1}$ respectively. This indicates no potential radiological danger from living in the houses built with the bricks from those soils. The indoor hazard parameters are also considerably lower than in some other parts of Nigeria, such as the assessment of Kaolin in the Dahomey basin, Nigeria by Adagunodo et al. (2018).

The hazard parameters specific to risk assessment, such as the ELCR and the AGED, were also estimated. The ELCR ranged from 0.39×10^{-3} to 1.71×10^{-3}, with an average value of 0.90×10^{-3}. These values are considerably below the safety limit provided by UNSCEAR (2000). Similarly, the AGED ranged from 0.07 to 0.33 $mSvy^{-1}$, with an average value of 0.17 $mSvy^{-1}$, measuring below the world average value of 0.30 $mSvy^{-1}$ (Orosun et al., 2020b). It follows that the sensitive organs (gonads) in the bodies of the exposed victims living in these buildings are not encountering a radiological hazard threat.
Regarding the exposure to gamma radiation from the buildings built with those soils, the evaluated RLI ranged from 0.17 to 0.76, with a mean value of 0.39. For radiological safety in buildings, it is expected that the RLI should be less than unity (UNSCEAR, 2000). The mean value of the RLI as well as the maximum value were all less than unity. The RLI assessed in this study is considerably lower than other African countries such as Chad, whose radiological hazard assessment had a RLI ranging from 0.053 to 3.441 (Ebongue et al., 2018).
The external and internal hazard indices associated with the buildings built with these soils were also estimated. Results show that the H_{ext} ranged from 0.06 to 0.2, with an average of 0.15, while the H_{in} ranged from 0.08 to 0.34, with an average of 0.18. All the hazard indices are considerably less than one as recommended by UNSCEAR (2000) for safety in buildings. These values are considered safe since an external hazard index of less than 1 corresponds to a Raeq less than 370 $Bqkg^{-1}$, which implies no hazardous exposure to gamma radiation in these buildings.

Conclusion
This study assessed the activity concentrations of radionuclides ^{238}U, ^{232}Th, and ^{40}K in soils used for brick-making and evaluated the associated radiological hazard parameters. The mean activity concentrations of ^{238}U, ^{232}Th, and ^{40}K were found to be 12.5±1.3, 26.7±1.7, and 65.1±5.2 $Bqkg^{-1}$ respectively. These values, except for some instances of ^{232}Th were below the global safety limits set by UNSCEAR (2000).
The radiological hazard parameters, including radium equivalent activity (Raeq), absorbed dose rates, and annual effective dose rates (AEDR), were all significantly below the recommended safety thresholds, indicating minimal risk of radiological exposure. Both indoor and outdoor hazard indices and the gamma radiation risk (RLI) were well within safe limits.
Comparisons with studies from other regions showed that the radionuclide concentrations and hazard indices in the studied soils were generally lower than those reported in high-risk areas such as Cameroon, Egypt, and parts of India. This suggests that soils in the study area pose a lower radiological hazard, making them safe for use in construction.
In conclusion, the soils assessed in this study meet global radiological safety standards for use in building materials, with

https://dx.doi.org/10.4314/swj.v19i4.38

negligible risks of gamma radiation exposure to inhabitants. However, continued monitoring and adherence to safety guidelines are recommended to maintain safe building practices.

REFERENCES

Abate, T. (2022). Radioactivity and health risk assessments in cement samples commonly used as construction materials in the case of South Gondar Zone, Ethiopia. *EPJ Nuclear Sciences & Technologies*, *8*, 13.

Abd Elkader, M. M., Shinonaga, T., & Sherif, M. M. (2021). Radiological hazard assessments of radionuclides in building materials, soils, and sands from the Gaza Strip and the north of Sinai Peninsula. *Scientific Reports*, *11*(1), 23251.

Adagunodo, T. A., Hammed, O. S., Usikalu, M. R., Ayara, W. A., & Ravisankar, R. (2018). Data on the radiometric survey over a kaolinitic terrain in Dahomey Basin, Nigeria. *Data in Brief*, *18*, 814-822.

Adewoyin, O. O., Omeje, M., Akinwumi, S. A., Zaidi, E., & Funso, A. O. (2022, September). Estimation of Residents Exposure Risks to Radiological Parameters in Some Building Materials in Nigeria. In *IOP Conference Series: Earth and Environmental Science* (Vol. 1054, No. 1, p. 012018). IOP Publishing.

Ahmed, R.S., Mohammed R.S. and Abdaljalil, R.O. (2018). The Activity Concentrations and Radium Equivalent Activity in Soil Samples Collected from the Eastern Part of Basrah Governorate in Southern Iraq. *International Journal of Analytical Chemistry* (2018), 2541020. https://doi.org/10.1155/2018/2541020

Akinyele, J. O., Igba, U. T., Ayorinde, T. O., & Jimoh, P. O. (2020). Structural efficiency of burnt clay bricks containing waste crushed glass and polypropylene granules. *Case Studies in Construction Materials*, *13*, e00404.

Baiden, B. K., Agyekum, K., & Ofori-Kuragu, J. K. (2014). Perceptions on barriers to the use of burnt clay bricks for housing construction.Bramki, A., Ramdhane, M., & Benrachi, F. (2018). Natural radioelement concentrations in fertilizers and the soil of the Mila region of Algeria. *Journal of radiation research and applied sciences*, *11*(1), 49-55.

Bramki, A., Ramdhane, M., & Benrachi, F. (2018). Natural radioelement concentrations in fertilizers and the soil of the Mila region of Algeria. *Journal of radiation research and applied sciences*, *11*(1), 49-55.

Buzynnyi, M., & Mykhailova, L. (2024). Long-term study of uranium and radium-226 activity in drinking water in some regions of Ukraine and assessment of corresponding hypothetical irradiation doses. *Scientific Reports*, *14*(1), 2530.

Dao, N. Q., Ba, V. N., Mai, P. T. X., & Loan, T. T. H. (2024). Assessment of radiological doses of raw building materials and CEN room model using RESRAD-BUILD. *Annals of Nuclear Energy*, *202*, 110459.

Dizman, S., Görür, F. K., Keser, R., & Görür, O. (2019). The assessment of radioactivity and radiological hazards in soils of Bolu province, Turkey. *Environmental forensics*, *20*(3), 211-218.

Ebongue, A. N., & Njock, M. K. (2018). Assessment of natural radioactivity levels and the associated radiological hazards in some building materials from Mayo-Kebbi region, Chad. *Radioprotection*, *53*(4), 265-278.

Endjambi, T., Mapani, B., Shikangalah, R., Caspah, K., & Zivuku, M. (2024). Radiological hazards assessment of building materials used in Swakopmund, Namibia. *Journal of African Earth Sciences*, *213*, 105227.

Eyrolle, F., Lepage, H., Antonelli, C., Morereau, A., Cossonnet, C., Boyer, P., & Gurriaran, R. (2020). Radionuclides in waters and suspended sediments in the Rhone River (France)- Current contents, anthropic pressures and trajectories. *Science of the total environment,* 723, 137873.

Garba, N. N., Rabi'u, N., Aliyu, A. S. A., Kankara, U. M., Vatsa, A. M., Isma'ila, A., & Bello, S. (2023). Evaluation of radiological risk associated with local building materials commonly used in Northwestern Nigeria. *Heliyon*, *9*(5).

Gawad, A. E. A., Hanfi, M. Y., Tawfik, M. N., Alqahtani, M. S., & Mira, H. I. (2024). Assessment of radioactivity levels and radiation hazards in building materials in Egypt. *Nuclear Engineering and Technology*, *56*(2), 707-714.

Grant, N. F. (1971). A compilation of radiometric age from Nigeria, *Journal of Mining Geology*, 6: 37 – 54

Houle, R. J. (2018). From Burnt Bricks to Sanctification: Rethinking 'Church in Colonial Southern Africa. *South African Historical Journal*, *70*(2), 348-369.

Ibeanu, I. G. E (1999). Assessment of Radiological effects of tin Mining Activities in Jos and its environs. A PhD Thesis submitted to the Department of Physics, ABU Zaria.

Ibrahim, N. (1999). Natural activities of 238U, 232Th and 40K in building materials. *Journal of Environmental Radioactivity*, *43*(3), 255-258.

International Commission on Radiological Protection (ICRP), (2007). Compendium of Dose Coefficients Based on ICRP publication 60" Annals of the ICRP, 41.

Jibiri, N. N., & Esen, N. U. (2011). Radionuclide contents and radiological risk to the population due to raw minerals and soil samples from the mining sites of quality ceramic and pottery industries in Akwa Ibom, Nigeria. *Radioprotection*, *46*(1), 75-87.

Isinkaye, M. O., & Agbi, J. I. (2013). Natural radioactivity and associated radiation hazards of some commonly used building materials in southwest Nigeria. *Radioprotection*, *48*(3), 355-365.

Kant, K., Upadhyay, S. B., Sonkawade, R. G., & Chakarvarti, S. K. (2006). Radiological risk assessment of use of phosphate fertilizers in soil. *Iran. J. Radiat. Res.*, 4 (2): 63-70

Kanu, M. O., Targema, T. V., & Abednego, G. M. (2021). Preliminary Results of Air Pollution Status in Selected Roadsides in Jalingo, Taraba State Nigeria. *Indonesian Journal of Environmental Management and Sustainability*, *5*(3), 118-123.

Kanu, M. O., Targema, T. V., Isa, J., & Nyusamiya, J. (2022a). Assessment of Noise Pollution in a Hospital and a Tertiary Institution in Taraba State, Nigeria. *Journal of Material and Environmental Science*, *13*(10), 1137-1154.

Kanu, M. O., Joseph, G. W., Targema, T. V., Andenyangnde, D., & Mohammed, I. D. (2022b). On the Noise Levels in Nursery, Primary and Secondary Schools in Jalingo, Taraba State: Are they in Conformity with the Standards? *Present Environment & Sustainable*

Development, *16*(2).

Macleod, W. N., Turner, D. C., & Wright, E. P. (1971). The Geology of Jos Plateau. Geological Survey of Nigeria. *Bull*, *32*(2).

Mas Balbuena, J. L., Caro Ramírez, J. R., Hurtado Bermúdez, S. J., & Leiva Fernández, C. (2021). Assessment of natural radioactivity levels and radiation exposure in new building materials in Spain. *Radiation Protection Dosimetry, 194 (2-3), 178-185.*

Mbonu, C. C., Essiett, A. A. and Ben, U. C. (2021). Geospatial assessment of radiation indices in soils samples from Njaba, Imo State, South – Eastern Nigeria, *Environmental Challenges*, 4:100117, https://doi.org/10.1016/j.envc.2021.100117.

McCurry, P. (1976). A Generalized Review of the Geology of the Precambrian lower Paleozoic rocks. Northern Nigeria. In Kogbe, C. A. (ed.). Geology of Nigeria, Elizabethan Press, Lagos. PP 13 – 38

Mireles, F., Davila, J. I., Quirino, L. L., Lugo, J. F., Pinedo, J. L., & Rios, C. (2003). Natural soil gamma radioactivity levels and resultant population dose in the cities of Zacatecas and Guadalupe, Zacatecas, Mexico. *Health physics*, *84*(3), 368-372.

Monteiro, S. N., & Vieira, C. M. F. (2014). On the production of fired clay bricks from waste materials: A critical update. *Construction and Building Materials*, *68*, 599-610.

Mustapha, A. O., Narayana, D. G. S., Patel, J. P and Otwoma, D. (1997). Natural radioactivity in some building materials in Kenya and their contribution to indoor radon external doses. *Radiation Protection and Dosimetry,* 71 (1): 65 – 69. DOI: doi.org/10.1093/oxfordjournals.rpd.a032036

Nguelem, E. J. M., Ndontchueng, M. M., & Motapon, O. (2016). Determination of 226Ra, 232Th, 40K, 235U and 238U activity concentration and public dose assessment in soil samples from bauxite core deposits in Western Cameroon. *SpringerPlus*, *5*(1).

Obaje, N. G. (2009). Geology and mineral resources of Nigeria, Vol. 120 Lecture series in Earth Sciences, Springer, Berlin. https://doi.org/10.1007/978-3-540-92685-61

Obianyo, I. I., Mahamat, A. A., Stanislas, T. T., Ihekweme, G. O., Kelechi, S. E., Onyelowe, K. C., ... & Soboyejo, A. B. (2021). Production and utilization of earth-based bricks for sustainable building applications in Nigeria: Status, benefits, challenges and way forward. *Journal of Building Pathology and Rehabilitation*, *6*, 1-11.

Omeje, M., Adewoyin, O. O., Joel, E. S., Ehi-Eromosele, C. O., Emenike, C. P., Usikalu, M. R., ... & Mohammad, A. S. (2018). Natural radioactivity concentrations of 226Ra, 232Th, and 40K in commercial building materials and their lifetime cancer risk assessment in Dwellers. *Human and Ecological Risk Assessment: An International Journal*, *24*(8), 2036-2053.

Omeje, M., Orosun, M. M., Aimua, G. U., Adewoyin, O. O., Sabri, S., Louis, H., ... & Targema, T. V. (2024). Radioactivity distributions and biohazard assessment of coastal marine environments of niger-delta, Nigeria. *All Earth*, *36*(1), 1-19.

Orosun, M. M., Usikalu, M. R., & Oyewumi, K. J. (2020b). Radiological hazards assessment of laterite mining field in Ilorin, North-central Nigeria. *International Journal of Radiation Research*, *18*(4), 895-906.

Orosun, M. M., Usikalu, M. R., Onumejor, C. A., Akinnagbe, D. M., Orosun, O. R, Salawu, N. B., Olasunkanmi, N.K., Akinpelu, A., Adagunodo, T. A. & Achuka, J. A. (2021). Assessment of Natural Radionuclide Contents in Water and Sediments from Asa-Dam, Ilorin, Nigeria. *IOP Conf. Series: Earth and Environmental Science* 655 DOI:10.1088/1755-1315/655/1/012090

Orosun, M. M., Usikalu, M. R., Oyewumi, K. J., & Achuka, J. A. (2020a). Radioactivity levels and transfer factor for granite mining field in Asa, North-central Nigeria. *Heliyon*, *6*(6).

Orosun, M. M., Usikalu, M. R., Oyewumi, K. J., & Adagunodo, T. A. (2019). Natural radionuclides and radiological risk assessment of granite mining field in Asa, North-central Nigeria. *MethodsX*, *6*, 2504-2514.

Porntepkasemsan, B., Kulsawat, W., & Nochit, P. (2018). Impact of phosphate fertilizers on the uranium and thorium of cultivated soils profiles, Kamphaeng Phet, Thailand. In *Journal of Physics: Conference Series* (Vol. 1144, No. 1, p. 012072). IOP Publishing.

Saad, H. R., & Al-Azmi, D. (2002). Radioactivity concentrations in sediments and their correlation to the coastal structure in Kuwait. *Applied Radiation and Isotopes*, *56*(6), 991-997.

Senthilkumar, R. D., & Narayanaswamy, R. (2016). Assessment of radiological hazards in the industrial effluent disposed of soil with statistical analyses. *Journal of Radiation Research and Applied Sciences*, *9*(4), 449-456.

Shrestha, A. K., Shrestha, G. K., Shah, B. R., & Koirala, R. P. (2024). Assessment of radioactivity and radiological hazards associated with bricks in eastern Nepal. *Heliyon*, *10*(2).

Thien, B. N., Ba, V. N., Vy, N. T. T., & Loan, T. T. H. (2020). Estimation of the soil-to-plant transfer factor and the annual organ equivalent dose due to ingestion of food crops in Ho Chi Minh City, Vietnam. *Chemosphere*, *259*, 127432. Doi: 10.1016/j.chemosphere.2020.127432

UNSCEAR, (2000). Report to the General Assembly, with scientific annexes. *United Nations*.

Zhao, M. L., Ji, X., He, Z., & Yang, G. P. (2024). Spatial distribution, partitioning, and ecological risk assessment of benzotriazoles, benzothiazoles, and benzotriazole UV absorbers in the eastern shelf seas of China. *Water Research*, *248*, 120885.