Journal of Radiation Research and Applied Sciences xxx (2018) 1–7

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Journal of Radiation Research and Applied Sciences

journal homepage: http://www.elsevier.com/locate/jrras

Radiation exposure to dwellers due to naturally occurring radionuclides found in selected commercial building materials sold in Nigeria

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A R T I C L E I N F O

Article history:
Received 13 November 2017
Accepted 24 January 2018
Available online xxx

Keywords:
Radium equivalent
Gamma spectrometry
Radiological risks
Tiles
Marbles and sand

A B S T R A C T

The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K was measured in commonly building materials used in Nigeria from commercial supplier using High Purity Germanium Gamma (HPGe) detector. The mean activity concentrations in the samples were found to be 51.5 ± 9.3, 72.46 ± 17.65 and 217.05 ± 44.31 Bqkg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively. The highest radium equivalent (Ra_{eq}) of 273.9 Bqkg^{-1} was noted in Perfect Superfix White Cement (Nigeria) but found to be < 370 Bqkg^{-1} as the recommended dose limiting safe value for bulk media as presumed, the highest value of internal hazard index (H_{in}) and external hazard index (H_{ex}) of 0.894 and 0.744 respectively were also < 1. The absorbed dose rate (DR) with a value of 122.52 nGyh^{-1} noted in ceramic tile sample is higher than the weighted population world average value of 80 nGyh^{-1} by a factor of 1.53. The highest annual effective dose rate (AEDR) of 0.601 mSvy^{-1} reported in PNT ceramics but was found to be less < 1 mSvy^{-1}. The investigated materials have the values of H_{in}, H_{ex} and AEDR greater than 0.5 but less than1, showing that the dose impact exceeds the exemption dose level of 0.3 mSvy^{-1} for AEDR but complies to the upper limit of dose principle of 1 mSvy^{-1}.

1. Introduction

It is really of importance to understand better the risk accompanied with the exposure of a population to the radiations emitted from building materials (Joshua, Ademola, Akpanowo, Oyebanjo, & Olorode, 2009). This exposure occurs on a daily basis and the ability of the radionuclides to move rapidly in air allows them to be easily transmitted into the environment in which humans come in contact with (Gupta, & Chauhan, 2009). There are two major aspects of radionuclides that should be considered when describing the exposure of a population to the radiation they release; which are, their distribution among different rocks and their concentration. Also, the distribution of rocks can be classified into two major categories; the source rocks and their associated radionuclide escape and environmental migration processes. The concentration of these radionuclides depends on the rock geology; hence, igneous rocks will have a high concentration such as in granites (Ademola, 2009).

The major elements associated with the naturally occurring radioactive materials (NORM) are ^{238}U, ^{236}Th, and ^{40}K (Kant, Upadhyay, Sonkawade, & Chakarvarti, 2006). While the parent element ^{238}U does not have adverse effect on the environment, the inhalation of its daughter element ^{226}Rn is known to pose a risk of lung cancer. These three radioactive elements present themselves as the major contributors to radiation in the environment having several effects on the general public. It has been discovered that the general public spends 80% of their time indoors; this brings about a

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Peer review under responsibility of The Egyptian Society of Radiation Sciences and Applications.

https://doi.org/10.1016/j.jrras.2018.01.007

0.4 mSv exposure rate for an average individual indoors per year as estimated by (WHO, 2009). This indoor radiation exposure is due to the presence of these radioactive elements in the building materials. This research is based on analyzing two of the most common building materials prone to have radioactive elements in them, measuring their level of concentration and therefore the possible annual exposure rate of people around those materials.

^{226}Rn, a daughter element gotten as a result of the decay chain of ^{238}U has the strongest effect on humans as it poses a threat of lung cancer on victims that have prolonged exposure to it, it has also been seen to have effects on the skin causing skin cancer as well as the kidney and bone marrow (Sahu, Bhangare, Ajmal, & Pandit, 2016). Due to its high level of transmission, food and water can also be contaminated thereby having effects on the stomachs and other internal organs of victims after injection of those contaminated foods (Kendall & Smith, 2002).

This study is aimed at ascertaining the signature of each concentration of radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in different brands of building materials and their radiological health risks on dwellers in Nigeria.

2. Geologic materials used in the production of tile and marble ceramics

Tiles, marbles and some other building materials are one of the end products of some geologic materials. Geologic materials are natural materials such as sand and granite. Majority of the tiles used in Nigeria are imported and only few are manufactured locally. Raw materials for ceramic tiles include kaoline, plasticity clay, feldspar, and quartz. These materials are crushed into powder, press moulded, calcined at high temperature and finally turned into ceramic tile. A typical ceramic body basically has a tripartite composition, which includes: clay which is used as the body former, feldspar which is used as flux and quartz which serves as the filler. The clay used can be a single clay type or a mixture of clays (e.g. china clay, ball clay, fire clay and clays such as montmorillonite and illite clay etc.) which has to be plastic or miscible with water to form a plastic body that will give the tile its shape. Flux can be feldspar or nepheline having alkali oxides like Na_2O, K_2O, CaO which aids in firing the tile (sintering and densification). The filler which can be quartz (SiO_2), alumina (Al_2O_3), or zirconia (ZrO_2) gives mechanical strength to the tile. Apart from these basic raw materials, some additives (plasticisers, binders) and other raw materials of magnesia bodies such as calcium can also be added. Tiles usually have glaze coating on top which is made of glass frits which are in turn prepared from wide varieties of oxides and also have colourants.

3. Materials and methods

3.1. Sample collection and preparation for gamma analysis

The building material samples used for this work were purchased from the Nigerian commercial markets and the river sand was scooped from a nearby river at Igboloye village in Ota, Ogun state, Nigeria. Initial labeling and cataloguing was done for easy identification. The ceramic tiles and the marbles were broken into smaller pieces so as to allow further processing. All the samples were crushed using the Pascall Engineering Lab milling machine to pulverizable size. After each tile sample was crushed, the crusher or lab milling machine was thoroughly cleaned with high pressure blower (Wolf from Kango Wolf power tools, made in London, type 8793 and serial no: 978A) before the next sample was crushed. This whole process was repeated until all the samples were completely crushed into powder. The pulverizer used is the disk 'grinder/pulverizer' by Christy & Norris Limited. After each pulverizing process, the machine was cleaned properly and blown with high pressure blower to avoid cross contamination of the samples (Omeje, Wagiran, Joel, Adewoyin, & Kayode, 2016, Joel, Maxwell, Adewoyin, Cyril, & Saeed, 2017). A very fine power was achieved from the pulverized samples, but for homogeneity, a 250 μm sieve size was used and 1 kg of the sieved sample was weighed out. It was then placed in polythene nylon and labeled accordingly. High density polyethylene bottles (HDPB) were used to package the samples for radioactivity study. The bottles were washed with water and detergent and then rinsed six times with ordinary borehole water before making a final rinse with distilled water. The sieved samples of ceramic tiles, cement, river channel sand (sharp & plaster) and white cements (2 Nigerian made and 1 from UAE) that were contained in each bottle weighed 200 g; there was a total of 25 samples in all.

3.2. Gamma spectrometric analysis of the selected samples

Different brands of imported and locally produced ceramic tiles, marbles and cements used for building materials were purchased from different suppliers and were prepared according to IAEA TRS-295 (Holm & Ballestra, 1989). The samples were put in a plastic beaker container sealed for secular equilibrium. Analysis of the samples was conducted in Canada (Activation Laboratory Analysis System) using High-Resolution Germanium detector, Canberra Lynx™ Digital Signal Analyzer (DSA), a 32 K channel integrated signal analyzer and a top-opening lead shield (4" lead, copper/tin liner) to prevent high background counts with 50% relative efficiency and resolution of 2.1 keV at 1.33 MeV gamma energy of ^{60}Co. The Genie-2K V3.2 software locates and analyzes the peaks, subtracts background, identifies the nuclides. The efficiency curves for this analysis were corrected for the attenuation and self-absorption effects of the emitted gamma photons. CAMET and IAEA standards (DL-1a, UTS-2, UTS-4, IAEA-372 and IAEA-447) were used for checking the efficiency calibration of the system. For the activity measurements, the samples were counted for 86,400 s with the background counts subtracted from the net count. The minimum detectable activity of the detector was determined with a confidence level of 95% (Currie, 1968). The uncertainty errors were estimated keeping into account the associated errors from gamma courting emission probability and efficiency calibration standard of the system. The progeny of radium, ^{214}Bi and ^{214}Pb emits gamma line 609 keV, 934 keV, 2204 (Omeje et al., 2016, Joel et al., 2017) keV, 1764 keV and 351 keV, 295 keV were used but the resolution of radium was from the emission of 1764 keV since it has low self-attenuation effect at high energy. Since ^{232}Th cannot be directly detected, the estimated activity via its progeny ^{208}Tl and ^{228}Act using 2614.53 keV, (35.63%) 583 keV (30.3%) and 911 keV, 338 keV, 463 keV. The gamma line of 1461 keV (10.7%) was used to resolve ^{40}K. The activity concentrations were calculated according to the methods of (Debertin & Helmer, 2001) and (Davisson & Evans, 1952).

4. Results and discussion

4.1. Activity concentrations of ^{238}U, ^{232}Th and ^{40}K measured in building material samples

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K measured in the building material samples of different brands were found to be non-uniformly distributed as presented in Table 1.

4.1.1. Tiles

The activity concentrations of ^{226}Ra varied from 25.5 ± 7.5 to

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Table 1
The mean values and Standard Deviation of the Activity Concentrations of ^{226}Ra, ^{232}Th and ^{40}K ($Bqkg^{-1}$) for Different types of Building Materials.

Sample ID	Sample Origin	^{226}Ra ($Bqkg^{-1}$)	^{232}Th ($Bqkg^{-1}$)	^{40}K ($Bqkg^{-1}$)
Marble (India)	India	60.5 ± 3.5	59.5 ± 4.5	330 ± 10.5
Rose Marble (India)	India	55.5 ± 4.8	95.5 ± 6.9	140 ± 15.2
Royal Ceramics	Nigeria	58 ± 0.5	76 ± 6.2	630 ± 21.4
Goodwill Ceramics	Nigeria	53.5 ± 6.5	57 ± 8	240 ± 10.0
Royal Ceramics	Nigeria	40.5 ± 6.5	68 ± 6.5	380 ± 11.7
NISPRO	Nigeria	59.5 ± 2.5	78.5 ± 4	860 ± 16.4
Virony Glazed	China	30 ± 3.5	77 ± 3	290 ± 9.13
Time Ceramics	Nigeria	27 ± 7.5	96 ± 8.3	510 ± 13.6
Goodwill Vitrified	Nigeria	70.5 ± 2.6	81 ± 5.5	540 ± 14.3
PNT Vitrified Tiles	Nigeria	53 ± 3.5	67.5 ± 5.5	420 ± 12
PNT Ceramics	Nigeria	35.5 ± 7.4	67.5 ± 4.5	370 ± 10.5
IDDRIS Floor Tiles (China)	China	65 ± 11	89.5 ± 4.3	740 ± 14.4
Royal Ceramics	Nigeria	60 ± 2	54 ± 2.5	240 ± 9.5
Golden Crown	Nigeria	27 ± 9.5	41 ± 4	390 ± 11.6
Pumise	India	51.5 ± 3.5	51 ± 2.5	820 ± 15.2
Virony Ceramics	China	81.5 ± 7.5	41.5 ± 8.5	570 ± 13.3
PNT	Nigeria	55.5 ± 8	95.5 ± 9.2	940 ± 19.2
Elephant Portland Cement (Nigeria)	Nigeria	65 ± 8.5	73 ± 4	170 ± 8.2
Perfect Superfix White Cement	Nigeria	38 ± 2.5	51 ± 9.6	360 ± 11
JK White Cement (UAE)	UAE	28 ± 1.5	101 ± 8	850 ± 15.4
Joy White Cement (Nigeria)	Nigeria	53.5 ± 7.5	92 ± 10	140 ± 7.9
IBETO Cement (Nigeria)	Nigeria	65.5 ± 7.5	71 ± 6	380 ± 10.4
Sharp Sand Igboloye village, Ota (Nigeria)	Nigeria	76.5 ± 2.5	87 ± 8.5	670 ± 13.6
Dangote Cement (Nigeria)	Nigeria	25.5 ± 7.5	68 ± 5.5	430 ± 12.5
Mean		51.5 ± 9.3	72.46 ± 17.65	217.05 ± 44.31

81.5 ± 7.5 $Bqkg^{-1}$ with the lowest value of 27 ± 7.5 $Bqkg^{-1}$ reported in Time ceramic tile, whereas the highest value of 81.5 ± 7.5 Bqkg-1 was noted in virony ceramic tile. For 232Th, the activity concentrations varies from 41.5 ± 8.5 to 96 ± 8.3 Bqkg-1 with the highest value of 96 ± 8.3 Bqkg-1 noted in virony ceramic tile whereas a lower value of 41.5 ± 8.5 $Bqkg^{-1}$ was observed in virony ceramics. The activity concentration of ^{40}K measured in the samples varies from 240 ± 9.5 $Bqkg^{-1}$ to 940 ± 19.2 $Bqkg^{-1}$ with the highest value of 940 ± 19.2 $Bqkg^{-1}$ noted in PNT ceramic tiles whereas the lowest value of 240 ± 9.5 $Bqkg^{-1}$ was recorded in royal ceramic tiles.

4.1.2. Marbles

For the two major marbles selected for this study, the activity concentrations vary from 56.5 ± 4.8 Bqkg-1 to 60 ± 3.5 Bqkg-1, 59.5 ± 4.5 Bqkg-1 to 95.5 ± 6.5 Bqkg-1 and 140 ± 15.2 $Bqkg^{-1}$ to 330 ± 10.5 $Bqkg^{-1}$ for ^{226}Ra, ^{232}Th and ^{40}K respectively. It was observed that ^{226}Ra reported the highest value in Rose marble (India) ceramics, whereas the lowest value was found in Mable India. ^{232}Th noted higher in Rose marble (India) ceramics of size, and a lower value was found in Mable India. It was found that the highest activity of ^{40}K in the marbles reported in Mable India whereas the lower value was observed in Rose marble (India).

4.1.3. Cements

Activity concentrations of primordial radionuclides (^{238}U, ^{232}Th and ^{40}K) measured in different brands of cements varies from 25 ± 7.5 $Bqkg^{-1}$ to 65.5 ± 7.5 $Bqkg^{-1}$ for ^{238}U. The highest value of 65.5 ± 7.5 $Bqkg^{-1}$ was noted in Ibeto cement sample, whereas the lowest value of 25 ± 7.5 $Bqkg^{-1}$ was noted in Dangote cement. The activity level of ^{232}Th was found to range from 51 ± 9.6 $Bqkg^{-1}$ to 73.0 ± 4.1 $Bqkg^{-1}$ with the highest value reported in Elephant Portland cement (Nigeria) and the lowest value found in Superfix white cement (Nigeria). The level of activity concentrations for ^{40}K varies from 170 ± 8.2 $Bqkg^{-1}$ to 850 ± 15.4 $Bqkg^{-1}$ with a highest value of 850 ± 15.4 $Bqkg^{-1}$ observed in JK White cement (UAE) was found in Elephant Portland cement (Nigeria).

4.1.4. Sand

A measured radioactivity level in sharp sand collected from Igboloye village in Ota, Ogun state, Nigeria where commercial sands are sourced was found to have activity values of 76.5 ± 1.5 $Bqkg^{-1}$, 87 ± 8.5 $Bqkg^{-1}$ and 670 ± 13.6 $Bqkg^{-1}$ for ^{226}Ra, ^{232}Th and ^{40}K respectively.

4.2. Comparison of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the present building material samples and values reported in other countries

In this present study, comparison of the activity concentrations measured in building materials and others reported elsewhere are presented in Table 2. In contrast, it can be observed that the concentration of both tiles and marbles are closer to other country's reports for ^{226}Ra, ^{232}Th and ^{40}K radionuclides such as the values which were reported by [3] to be: 52 ± 2 to 131 ± 4, 59 ± 1 to 127 ± 2, and 491 ± 12 to 979 ± 16 for ^{226}Ra, ^{232}Th and ^{40}K respectively and by EU members Commission (2000) to be: 0 to 1000, 1 to 258, and 0 to 3200 in similar manner. Comparing the concentration values of cements under this study with other values obtained in other countries in Table 2, it can be observed that they are in good agreements and within range. For sand used in this present study, some values are distinctly lower than the values of ^{226}Ra, ^{232}Th and ^{40}K radionuclides obtained in this study except for ^{40}K that two values are far higher by factors of 1.18 and 1.50 respectively for sands obtained from China and South Korea.

4.2.1. Determination of the radiological parameters

4.2.1.1. Radium equivalent activity (Ra_{eq}). The level of radionuclides from ^{226}Ra, ^{232}Th and ^{40}K in the analyzed building materials is non-uniformly distributed. The Ra_{eq} activity of the measured radionuclides is used to compare the activity of each of ^{226}Ra, ^{232}Th and ^{40}K contents in the building materials. Ra_{eq} with unit as $BqKg^{-1}$ was calculated using Equation (1).

$$Raeq = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (1)$$

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Table 2
Comparing the Radioactivity Concentrations of ^{226}Ra, ^{232}Th and ^{40}K (Bqkg^{-1}) in various Building Media under Study.

Sample ID	Sample Origin	^{238}U (Bq/kg)	^{232}Th (Bq/kg)	^{40}K (Bq/kg)	Reference
TILES AND MARBLES					
Marble (India)	India	60.5 ± 3.5	59.5 ± 4.5	330 ± 10.5	Present Study
Rose Marble (India)	India	55.5 ± 4.8	95.5 ± 6.9	140 ± 15.2	Present Study
Royal Ceramics	Nigeria	58 ± 0.5	76 ± 6.2	630 ± 21.4	Present Study
Goodwill Ceramics	Nigeria	53.5 ± 6.5	57 ± 8	240 ± 10.0	Present Study
Royal Ceramics	Nigeria	40.5 ± 6.5	68 ± 6.5	380 ± 11.7	Present Study
NISPRO	Nigeria	59.5 ± 2.5	78.5 ± 4	860 ± 16.4	Present Study
Virony Glazed	China	30 ± 3.5	77 ± 3	290 ± 9.13	Present Study
Time Ceramics	Nigeria	27 ± 7.5	96 ± 8.3	510 ± 13.6	Present Study
Goodwill Vitrified	Nigeria	70.5 ± 2.6	81 ± 5.5	540 ± 14.3	Present Study
PNT Vitrified Tiles	Nigeria	53 ± 3.5	67.5 ± 5.5	420 ± 12	Present Study
PNT Ceramics	Nigeria	35.5 ± 7.4	67.5 ± 4.5	370 ± 10.5	Present Study
IDDRIS Floor Tiles (China)	China	65 ± 11	89.5 ± 4.3	740 ± 14.4	Present Study
Royal Ceramics	Nigria	60 ± 2	54 ± 2.5	240 ± 9.5	Present Study
Golden Crown	Nigeria	27 ± 9.5	41 ± 4	390 ± 11.6	Present Study
Pumise (Italy)	Italy	51.5 ± 3.5	51 ± 2.5	820 ± 15.2	Present Study
Virony Ceramics	China	81.5 ± 7.5	41.5 ± 8.5	570 ± 13.3	Present Study
PNT	Nigeria	55.5 ± 8	95.5 ± 9.2	940 ± 19.2	Present Study
Wall Tiles (Mean Values)	Nigeria	52–105	56–115	185–893	Ademola, 2009
Floor Tiles (Mean Values)	Nigeria	52–131	59- 127	491–979	Ademola, 2009
Building Materials	World	30 (0-1000)	34 (1 -258)	483 (0–3200)	European Members
CEMENT SAMPLES					
Elephant Portland Cement (Nigeria)	Nigeria	65 ± 8.5	73 ± 4	170 ± 8.2	Present Study
Perfect Superfix White Cement (Nigeria)	Nigeria	38 ± 2.5	51 ± 9.6	360 ± 11	Present Study
JK White Cement (UAE)	UAE	28 ± 1.5	101 ± 8	850 ± 15.4	Present Study
Joy White Cement (Nigeria)	Nigeria	53.5 ± 7.5	92 ± 10	140 ± 7.9	Present Study
IBETO Cement (Nigeria)	Nigeria	65.5 ± 7.5	71 ± 6	380 ± 10.4	Present Study
Dangote Cement (Nigeria)	Nigeria	25.5 ± 7.5	68 ± 5.5	430 ± 12.5	Present Study
Cement Sample	India	41.3–218.9	18.8–60.1	160.9–248.1	(Sharma, Singh, Esakki, & Tripathi, 2016)
Cement Sample	Pakistan	37 ± 3	28 ± 3	200 ± 14	(Rahman et al., 2012)
Cement Sample	India	54 ± 13	65 ± 10	440 ± 91	(Khandaker, Jojo, Kassim, & Amin, 2012)
Cement Sample	Turkey	55.6–86.71	7.19 ± 0.10	348.17–265.75	(Erees, Dayanıklı, & Çam, 2006)
Cement Sample	China	68.3 ± 3.6	51.7 ± 5.4	173.8 ± 8.6	(Xinwei et al., 2005)
Cement Sample	Egypt	134 ± 67	88 ± 35	416 ± 162	(Ahmed, 2005)
Cement Sample	Greece	20 ± 5	13 ± 3	247 ± 68	(Stoulos, Manolopoulou, & Papastefanou, 2003)
Cement Sample	Qatar	23.4 ± 0.6	12.2 ± 0.2	158.8 ± 4.3	(Al-Sulaiti et al., 2011)
Cement Sample					
SAND SAMPLES					
Sharp Sand (Igboloye) Ota. Ogun State	Nigeria	76.5 ± 2.5	87 ± 8.5	670 ± 13.6	Present Study
Sand	Pakistan	24 ± 2	39 ± 3	462 ± 16	(Rahman et al., 2012)
Sand	Qatar	13.2 ± 0.3	33.4 ± 0.05	225.5 ± 6.1	(Al-Sulaiti et al., 2011)
Sand	China	22.4 ± 1.9	25.1 ± 2.5	789.3 ± 45.0	(Ding, Lu, Zhao, Yang, & Li, 2013)
Sand	South Korea	28.98	56.37	1008	(Lee, Kim, Lee, & Kang, 2001)
Sand	India	2.27	21.72	352.8	(Ravisankar et al., 2012)

where C_{Ra}, C_{Th} and C_K are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K measured in BqKg^{-1} respectively. This radium equivalent activity defines the weighted sum of the individual activities of ^{226}Ra, ^{232}Th and ^{40}K with the idea that for ^{226}Ra, Ra_{eq} is 10 Bq kg^{-1}, for ^{232}Th, Ra_{eq} is 7 Bq kg^{-1} and for ^{40}K, Ra_{eq} is 130 Bq kg^{-1}. The same external and internal gamma dose rate is produced from the radium equivalent activity. The maximum value of Ra_{eq} in building materials must be less than 370 Bq kg^{-1} as recommended by[23]. This amount is equivalent to 1.5 mGryy^{-1} (UNSCEAR, 1988; Krieger, 1981). The radium equivalent activity values obtained from this present study varies from 115.66 to 273.9 BqKg^{-1} with the highest value of 273.9 BqKg^{-1} reported in Perfect Superfix White Cement (Nigeria) whereas the lowest value of 115.66 BqKg^{-1} was noted in Royal Ceramics tile. It can be observed that none of the Ra_{eq} values in all the measured samples exceeds the recommended limit of 370 BqKg^{-1} by UNSCEAR (1988), as presented in Table 3.

4.2.1.2. Absorbed dose rate (D_R). In this present study, the absorbed dose rates calculated from the obtained activity concentrations are presented in Table 3. The total air absorbed dose rate received in an open air 1 m above the ground due to gamma emission from the radionuclides of ^{238}U, ^{232}Th and ^{40}K in BqKg^{-1} available in an environment is calculated using Equation (2) (Beck, 1980; UNSCEAR, 1988; Omeje et al., 2016, Joel et al., 2017)

$$D_R = 0.462\ C_{Ra} + 0.604C_{Th} + 0.0417C_K < 80nGyh^{-1} \quad (2)$$

Considering the absorbed dose rates presented in Table 3, it can be observed that the highest value of 122.52 nGyh^{-1} was reported in virony ceramic tiles whereas the lowest value of 53.50 nGyh^{-1} was noted in royal ceramics. Comparing the absorbed dose rate in this present study with the standard value of 80 nGyh^{-1} recommended by UNSCEAR (1988), the highest value obtained in this present study is higher by a factor of 1.5.

4.3. The external absorbed dose rate

Details of the estimated outdoor external absorbed doses due to the existence of ^{226}Ra, ^{232}Th, and ^{40}sup> K are presented in Table 3. The outdoor external absorbed dose rate (D_{Ex}) at 1 m above the ground level is computed from the -radiation arising from ^{226}Ra, ^{232}Th, and ^{40}K assumed to be uniformly dispensed in the ground.

Table 3
The absorbed dose, radium equivalent (Ra_{eq}), external hazard index (H_{ex}) and internal hazard index (H_{in}).

Sample ID	Sample Origin	Ra_{eq} $BqKg^{-1}$	Absorbed Dose Rate (D_R) $nGyh^{-1}$	H_{ex}	H_{in}
Marble (India)	India	170.5	77.65	0.471	0.636
Rose Marble (India)	India	215.2	98.97	0.601	0.758
Royal Ceramics	Nigeria	153.5	69.15	0.421	0.567
Goodwill Ceramics	Nigeria	167.0	75.63	0.462	0.572
Royal Ceramics	Nigeria	238.0	110.77	0.670	0.831
NISPRO	Nigeria	162.4	72.46	0.448	0.529
Virony Glazed	China	203.6	91.73	0.566	0.639
Time Ceramics	Nigeria	227.91	104.01	0.633	0.823
Goodwill Vitrified	Nigeria	181.865	82.77	0.504	0.648
PNT Vitrified Tiles	Nigeria	160.515	72.6	0.445	0.541
PNT Ceramics	Nigeria	249.965	114.95	0.698	0.874
IDDRIS Floor Tiles (China)	China	155.7	70.34	0.428	0.590
Royal Ceramics	China	115.66	53.50	0.325	0.398
Golden Crown	Nigeria	187.57	88.79	0.532	0.672
Pumise	India	184.7	86.49	0.517	0.737
Virony Ceramics	China	264.5	122.52	0.744	0.894
PNT	Nigeria	182.5	81.21	0.498	0.674
Elephant Portland Cement (Nigeria	Nigeria	138.7	63.37	0.386	0.488
Perfect Superfix White Cement (Nigeria)	Nigeria	273.9	109.38	0.669	0.745
JK White Cement (UAE)	UAE	188.1	81.95	0.509	0.654
Joy White Cement (Nigeria)	Nigeria	196.3	88.99	0.542	0.719
IBETO Cement (Nigeria)	Nigeria	252.5	115.83	0.703	0.910
Sharp Sand Igboloye Ota	Nigeria	155.9	70.78	0.434	0.503
Dangote Cement (Nigeria)	Nigeria	202.9	89.16	0.552	0.702

For the conversion of -radiation emanating from ^{226}Ra, ^{232}Th, and ^{40}K, the facts of 0.436 $nGy\,h^{-1}\,Bq^{-1}\,kg^{-1}$ for ^{226}Ra, 0.599 $nGy\,h^{-1}\,Bq^{-1}\,kg^{-1}$ for ^{232}Th, and 0.0417 $nGy\,h^{-1}\,Bq^{-1}\,kg^{-1}$ for ^{40}K were employed for estimation of D_{Ex}. The conversion factors have been considered from literature of Beck, 1980; Akinloye, Isola, & Oladapo, 2012; Avwiri, Nte, & Olanrewaju, 2011; Qureshi et al., 2014. It has been reported by Akinloye et al. (2012) that, "^{137}Cs, ^{90}Sr, ^{87}Rb, ^{138}La, ^{176}Lu, and ^{235}U decay series have negligible contributions to the total dose emanating from the environment background.

The D_{Ex} was estimated using Equation (3) as given by Usikalu and Akinyemi (2007).

$$D_{Ex} = 0.436A_{Ra} + 0.599A_{Th} + 0.0417A_{k}\ (nGy\ h^{-1}) \tag{3}$$

The external absorbed dose from this present study varies from 53.50 to 122.52 $nGy\,h^{-1}$. The average outdoor external absorbed dose due to the existence of ^{226}Ra, ^{232}Th, and ^{40}K in the samples is 84.5 $nGy\,h^{-1}$. This value is higher than the world's average value of 59 $nGy\,h^{-1}$ [31] by the factor of 1.4.

4.3.1. External hazard index

The gamma ray radiation hazards index due to the specified radionuclides were assessed by external radiation hazard and was calculated using Equation (4) according to UNSCEAR, 2000.

$$H_{ex} = \frac{A_{Ra}}{370}\ \frac{A_{Th}}{259}\ \frac{A_K}{4810}\ 1 \tag{4}$$

where, $A_{Ra\sim}A_U$, A_{Th} and A_K are the average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} respectively.

For the radiation hazard to be acceptable, it is recommended that the H_{ex} be less than unity. The estimated H_{ex} for all the samples varies from 0.386 to 0.744 with highest value noted in Virony ceramics, whereas the lowest value reported in Portland elephant cement. This highest value from the present study is lower than the recommended value of ≤ 1 according to UNSCEAR, 2000.

4.4. Annual effective dose equivalent (AEDE)

The indoors annual effective dose equivalent received by human is estimated from the indoor internal dose rate (D_{in}), occupancy factor which is defined as the level of human occupancy in an area in proximity with radiation source; is given as 80% of 8760 h in a year, and the conversion factor of 0.7 Sv Gy^{-1} which is used to convert the absorbed does in air to effective dose (UNSCEAR, 2000; Usikalu & Akinyemi, 2007). The annual effective dose equivalent is estimated using Equation (5).

$$AEDR\ (mSv) = D_R\ (nGyh^{-1})\ x\ 8766h\ x\ 0.8\ (occupancy\ factor)\ x\ 0.7SvGy^{-1}\ (conversion\ factor)\ x\ 10^{-6} \tag{5}$$

The value of the AEDE ranges from 0.262634 to 0.60 mSv y^{-1} with a mean value of 0.43 mSv y^{-1}. The mean values from the samples is less than the world's average value of 0.7 mSv y^{-1} by a factor 6.0. Details of all the samples are recorded in Table 4.

5. Conclusion

The building materials analyzed for this present study, both locally produced, imported and extensively used for building purposes for inhabitants in Nigeria indicates variations in radioactivity level. The mean activity concentration of 51.5 ± 9.3 $BqKg^{-1}$ for ^{226}Ra, 72.46 ± 17.65 $BqKg^{-1}$ for ^{232}Th and 217.05 ± 44.31 $BqKg^{-1}$ for ^{40}K respectively were found in the samples. Considerably, higher activity concentrations were found in virony tiles, 60 × 60 mm and PNT ceramics with values of 81.5 ± 7.5 and 96 ± 8.3 for ^{226}Ra and ^{232}Th respectively but were found to be within the typical global range. The radium equivalent activity were found to be well below the recommended safe limit of 370 $BqKg^{-1}$. All the hazard indexes were below the safe level of 1. The dose rate in few samples was higher with the mean value higher than the world average by a factor of 1.53. This present study indicates that most of the building materials do not pose significant radiation hazard and are safe for

Table 4
The Annual Effective Dose (mSv).

Sample ID	Sample Origin	Annual Effective Dose (mSv)
SUPERFICIAL MATERIALS (Iγ ≤ 1 and ≤ 0.5)		
Marble (India)	India	0.381181
Rose Marble (India)	India	0.437683
Royal Ceramics	Nigeria	0.48584
Goodwill Ceramics	Nigeria	0.339455
Royal Ceramics	Nigeria	0.371265
NISPRO	Nigeria	0.543765
Virony Glazed	China	0.355703
Time Ceramics	Nigeria	0.450299
Goodwill Vitrified	Nigeria	0.510581
PNT Vitrified Tiles	Nigeria	0.406315
PNT Ceramics	Nigeria	0.35639
IDDRIS Floor Tiles (China)	China	0.564285
Royal Ceramics	China	0.345296
Golden Crown	Nigeria	0.262634
Pumise	India	0.440776
Virony Ceramics	China	0.424576
PNT	Nigeria	0.601446
(UNSCEAR, 2000; Veiga et al., 2006)	World Average	0.07
EC, 1999	Reference Level	–
Avwiri (2011)	World Average	–
BULK MATERIALS (Iγ ≤ 6 and ≤ 2)		
Elephant Portland Cement (Nigeria	Nigeria	0.398657
Perfect Superfix White Cement (Nigeria)	Nigeria	0.312553
JK White Cement (UAE)	UAE	0.536942
Joy White Cement (Nigeria)	Nigeria	0.402289
IBETO Cement (Nigeria)	Nigeria	0.436357
Sharp Sand Igboloye Ota	Nigeria	0.568605
Dangote Cement (Nigeria)	Nigeria	0.347456
(UNSCEAR, 2000)	World Average Value	0.7
Avwiri (2011)	World Average Value	–
EC, 1999	Reference Level	–

construction of dwellings, whereas DDRIS Floor Tiles (China) and PNT should be monitored for its natural radioactivity level when in use.

Acknowledgement

The authors would like to thank Covenant University management through Center for Research Innovation and Discovery research grant scheme with a No: CUCRID/VC/17/02/02/06-FS for their 100% financial support of this present study. The researchers appreciate Covenant University Ota for the grants given to embark on this research for the safety of our nation through Research Management Center Grant Scheme Number: CUCRID/VC/17/02/02/06-FS. Also, appreciation goes to Radiation Geophysics Research Group, Department of Physics, Covenant University Ota, for their scientific contribution to this work.

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Please cite this article in press as: Maxwell, O., et al., Radiation exposure to dwellers due to naturally occurring radionuclides found in selected commercial building materials sold in Nigeria, Journal of Radiation Research and Applied Sciences (2018), https://doi.org/10.1016/j.jrras.2018.01.007