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Public exposure to natural radioactivity and radon exhalation rate in construction materials used within Greater Accra Region of Ghana

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The natural radioactivity of ^{238}U, ^{232}Th, ^{40}K, radiological hazards and ^{222}Rn exhalation rate in building materials used within Greater Accra Region of Ghana, have been measured using Gamma spectrometry and CR-39. The results obtained are as follows ^{238}U (2.6–47.1 Bq/kg), ^{232}Th (3.6–43.0 Bq/kg), ^{40}K (62.8–1222.2 Bq/kg), radium equivalent (32.7–174.3 Bq/kg), internal hazard index (0.04–0.51), external hazard index (0.04–0.23), activity concentration index (0.10–0.63 mSv/y) absorbed dose rate (9.5–76.3 nGy/h), outdoor effective doses (11.6–93.6 μSv/y), indoor effective doses (46.5–374.1 μSv/y,) and excess lifetime cancer risk (0.04×10^{-3}–0.33×10^{-3}). ^{222}Rn exhalation rate (3.1×10^{-5}–11.4×10^{-5} Bq/m^2 h), ^{222}Rn activity (17.4–42.6 Bq/m^3), effective radium (0.19–0.64 Bq/kg). Positive correlation was found between ^{238}U and ^{222}Rn. The results were discussed in terms of limits to the accepted natural radioactivity levels and compared with similar studies reported in other countries. The gneiss rocks recorded excess lifetime cancer risk values of (0.32×10^{-3} and 0.33×10^{-3}) greater than the world value of 0.29×10^{-3} proposed by UNSCEAR, 2000. With exception gneiss rocks from Shai hills which recorded high value of cancer risk as compare to the world average value, all the studied building materials do not pose any radiological effects to the people of Greater Accra Region when used for construction.

Introduction

Studies on naturally occurring radioactive materials (NORMS) and radon exhalation rate in geological and processed building materials are of particular interest because possible human exposure to ^{238}U natural background radiation and constitutes the largest source of radiation exposure to the public [1]. Human exposure is principally to the whole body from

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external gamma rays of ^{238}U, ^{232}Th, ^{40}K and to the lungs from internal alpha particles such as ^{222}Rn. Radon is a gas that emanates from soil and rock in the ground as well as building materials as a result of decay series of ^{238}U [2,3]. Radon decays to form radioactive particles that can enter the body by inhalation. Inhalation of these short-lived decay products of radon has been associated to an increase in the risk of developing lung cancer [1]. The radiation exposure of humans may increase for those living in houses built from materials with radiation dose rate values above normal background radiation levels [1,4,5]. The construction materials commonly known to the general public in Ghana are soil, sand, clay bricks, cement, tiles, rocks, sandcrete and concrete blocks. The usage of these building materials depends on the prevailing environmental conditions and availability. Natural radioactivity and radon linked with Ghanaian building materials have not yet been evaluated. At the present time, Ghana does not have national guidelines specifying the acceptable radioactivity and radon levels in local geological and processed building materials but have been using international limits. Most of the studies done in Ghana have concentration of ^{238}U, ^{232}Th and ^{40}K on soil, rocks and other environmental samples [6–10]. The present work on natural radioactivity in geological and processed building materials in Ghana comes as a part of a broader project that has just been initiated on public and occupational radiation exposure control programme in soils, building materials, indoor, food and water. This study will aid in decision-making processes in setting up national guidelines for the control of radiation exposure in building materials in Ghana. Gamma spectrometry and solid nuclear track techniques are the most widely used methods [3,11–15]. In this study, gamma spectrometric and alpha techniques have been applied in the analysis of the concentration of the natural radionuclides of U, Th series and isotope of ^{40}K, and ^{222}Rn exhalation rate from building materials.

Material and methods

Geology of the study area

The Greater Accra Region is bordered on the north by the Eastern Region, on the east by the Volta region, on the south by the Gulf of Guinea, and on the west by the Central Region. The geology of the study area is made up of different types of rocks and soils. The main rock types of the study area are Precumbrian Dahomeyan schists, granodiorites, granitic gneiss, and amphibolites to late Precambrian Togo series comprising mainly quartzite, phillites, phylitones, and quartz breccias [16,17]. The soil of the study area is classified into four main groups: drift materials resulting from deposits by windblown erosion; alluvial and marine motted clays of comparatively recent origin derived from underlying shales; residual clays and gravels derived from weathered quartzites, gneiss and schist rocks, and lateritic sandy clay soils derived from weathered Accraian sandstone bedrock formations. In many low lying poorly drained areas, pockets of alluvial 'black cotton' soils are found. These soils have a heavy organic content, expand, and contract readily causing major problems with foundations and footings. In some areas, lateritic soils are strongly acidic and when saturated are prone to attack concrete foundations causing honeycombing. Near the foothills are the large areas of alluvial laterite gravels and sands [16,17]. Many of these deposits are being exploited in an uncontrolled manner for constructional purposes.

Sample collection and preparation

Geological and processed materials mostly used for construction in Ghana are soil, clay bricks, sand, cement (Portland, Dangote and Diamond Cement), rock, ceramics, gravel aggregate, concrete and sandcrete blocks. Geological and processed building materials data were obtained from Building and Road Research Institute (BRRI) of the Council for Scientific and Industrial Research, Kumasi, Ghana.

The data was used to determine the types of samples to be collected and the sampling points in selected areas in the Greater Accra, and Central regions of Ghana. Seventeen different types of construction materials weighing 1–2 kg were collected from different locations as shown in the Fig. 1.

Rocks and soils were collected from quarry, open-pits and construction sites. Granite and gneiss were from greater Accra and central part of Ghana. Cements and block samples were collected from Antis Cement Depot and Ghana Atomic Energy Commission (GAEC) block factory located in Haatso and Atomic respectively. Cement commonly used in Ghana for building are Portland cement from Ghana cement company, Diamond manufactured in Aflao in the Volta region of Ghana while Dangote cement from Lagos, Nigeria. Beach sand were collected along the coastal parts of the region. Though the tiles used for this study were collected within the region, their countries of origin are China, Spain and Brazil. The samples were taken from at least three (3) different locations of the same area into labeled black polythene bags and kept separated. Fifty one (51) samples were then sent to Centro Regionale di Radioprotezione, Agenzia Regionale la Protezione dell' Ambientale del Friuli Venzia Giulia, via 42 Colugna, 33,100 Udine, Italy for analysis.

The rocks, tiles and blocks samples were pulverized, homogenized, air-dried and sieved to a uniform mixture with a particle size of about 5 µm and 50 ml geometry respectively. The sealed samples were weighed stored at room temperature for a period of 3–4 weeks to allow ^{238}U and ^{232}Th decay series to reach radioactive equilibrium with the short-lived progenies and also to prevent escape of radon gas [6,7,10,13].

Fig. 1. Map of the study areas.

Measurements of activity concentration

The measurement of the activity concentration of the ^{238}U, ^{232}Th was by way of the daughter products. For a nuclide having more than one peak in the spectrum, the activity concentration was obtained as the weighted average activity at each peak. The emissions of ^{214}Bi (609.31, 1120.29, 1764.49 keV) and ^{214}Pb (295.22, 351.93 keV) were used to determine the activity of ^{238}U. The gamma emission lines of ^{212}Bi (727.33 keV), ^{228}Ac (209.25, 409.46, 463.0, 794.95, 911.20, 964.77, 968.97 keV) and ^{212}Pb (238.63, 300.09 keV) were used to evaluate the activity of ^{232}Th. ^{40}K was determined using its only γ-ray line of peak energy 1460.82 keV. Prior to sample measurement, the background was determined with an empty Marinelli beaker under identical measurement conditions as the samples. Counting time was 72,000 s. The data acquisition, display and on-line spectrum analysis were carried out using the Genie 2000 V3.3 (1) spectroscopy software from Canberra. The activity concentration (A_C) (Bq/kg) of each radionuclide in any given sample was calculated from the spectrum using the following analytical expression

$$Ac(^{238}\mathrm{U}, ^{232}\mathrm{Th}, ^{40}\mathrm{K}) = \frac{N_{sam}}{P(E) * \eta(E) * T_C * M_{sam}} \tag{1}$$

where, M_{sam} (kg) is the mass of sample, N_{sam} (cps) is the net peak area for the sample in the peak range, *P(E)* is the gamma emission probability, $T_c(s)$ is the counting time in seconds, and $\eta_{(E)}$ is the photo peak efficiency which had been obtained from the standard solution.

Determination of radon exhalation rate

Radon exhalation rate in geological and processed materials have been determined using tightly closed vessel technique with cylindrical jar. A known weight of a sample was placed at the bottom of the cylindrical jar and completely sealed for 1 month in order to establish equilibrium between radium and radon. Detection procedures were done by installing CR-39 detector at the top of chamber covering at a distance of 22 cm from the surface of the sample in order to count for only radon (^{222}Rn) and prevent thoron from evading the surface of the detectors [3,12]. The radon exhalation measurements were performed by placing the construction material at the bottom of glass containers with 10 cm diameter (D) and 25 cm height by the cylindrical vessel for 90 days. After the exposure, the detectors were removed and etched in 6.25 N solution of 90 °C for 4 h and 15 min at constant temperature followed by 15 min neutralization with of 36 ml of 96% diluted acetic acid. Finally detectors were washed in distilled water for (15) minutes to wash any excess chemicals and dried for four (4) days. The latent tracks formed on the detectors were scanned and counted in 144 fields using an optical microscope of 40× magnification objective lens. The tracks density left on track films were then used to evaluate the radon concentration. The following mathematical models were used to estimate radon parameters:

$$\text{Activity of radon concentration } C_{Rn}\left(\text{Bq/m}^3\right) = \frac{\varrho}{\varepsilon t} \tag{2}$$

where, ε is the calibration factor of detector (track/cm^{2}d/(Bq/m^3), ϱ is the measured surface density of tracks (tracks/cm^2) and t is the exposure time

$$\text{Radium Concentration, } C_{Ra}(\text{Bq/kg}) = C_{Rn}\frac{V_c}{MT_c} \tag{3}$$

where M= mass of building materials sample (kg)

$$\text{Radon Exhalation rate } E_{Rn}\left(\text{Bq/m}^2\text{h}\right) = \frac{\varrho V_c\,\lambda_{Rn}}{\varepsilon S_a T_c} \tag{4}$$

where, V_c volume of diffusion chamber (m^3), S_a is the surface area of the sample (m^2), λ_{Rn} is the decay constant of radon ($1/s$) and T_c is the effective exposure (s) in the diffusion chamber.

Results and discussion

Activity concentration

The activity concentration of ^{238}U and ^{232}Th have been determined using their daughter products as well as the isotope of ^{40}K, with only one peak. The results of the activity concentrations and radium equivalent activity in Bq/kg measured are presented in the form of range and mean values as shown in Table 1. The ^{40}K was found to be the most abundant and contributed significantly to the activity concentration in the building materials as compared to ^{238}U and ^{232}Th. The average activity concentrations of ^{40}K vary from 62.8 ± 12.5 Bq/kg in geological sample of sandstone from Tesano to 1222.2 ± 96.30 Bq/kg in gneiss rocks from Shai Hills. The highest average activity concentration of ^{238}U, was recorded as 47.10 ± 2.8 Bq/kg in processed sample of Dangote cement with the lowest value of 2.6 ± 0.5 Bq/kg coming from beach sand in Nugua. For ^{232}Th, the average activity concentration ranged from 3.6 ± 0.8 Bq/kg in beach sand from Labadi with a value of 45.6 ± 18.6 Bq/kg in granite from Dominase in the central part of Ghana. Highest activity concentration of radionuclides of ^{40}K, ^{238}U and ^{232}Th were obtained in Gneiss rocks, Diamond cement, granite rocks while the least radionuclides were found in sandstones, beach sand respectively. Beach sand appear to be the building material that contain the lowest radionuclides of ^{238}U and ^{232}Th. The reason for the difference in variation of the minimum and maximum activity concentrations of the ^{238}U, ^{232}Th and ^{40}K of the building materials were due to the topographical and geological differences within the sampling locations of the origin. Except Diamond, Portland, Dangote, clay brick and the soil from Oyibi, the average activity concentration of ^{238}U in all the construction materials in this studied were lower than world average value of 25 Bq/kg for soil [18]. Dangote cement recorded activity concentration of 1.9 times greater than the word average value for soil. The ^{232}Th activity concentration in building materials were also found to be less than 25 Bq/kg except granite from Kasoa, Dominase and gneiss rocks from Shai Hills in the central and Greater Accra Region of Ghana. The gneiss, granite, quartzite from Atomic and McCarthy, soil from Oyibi, tiles from China recorded activity concentration of ^{40}K far greater than world average of 370 Bq/kg [18]. Shai hills recorded highest ^{40}K concentration while sandstone from Tesano recorded 3.3 times greater and less than 5.9 times the world average value of soil proposed by UNSCEAR, 1988 respectively. The Table 2 showed comparison studies of average activity concentration with other studies in different countries.

Radium equivalent activity

Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K are not uniformly distributed in building materials. In order to compare the specific activities of construction materials containing different concentrations of ^{226}Ra (radium is equivalent to uranium under the secular equilibrium condition), ^{232}Th and ^{40}K, the radium equivalent activity Ra_{eq} is used. It was defined on the assumption that 370 Bq/kg of ^{226}Ra, 259 Bq /kg of ^{232}Th and 4810 Bq/kg of ^{40}K produce the same gamma-ray dose equivalent. It was calculated using the following equation [5,19–21].

$$Ra_{eq} = C_{Ra} + \frac{10}{7}C_{Th} + \frac{10}{130}C_K \tag{5}$$

where, C_{Ra}, C_{Th}, and C_K are the mean activities of ^{226}Ra, ^{232}Th, and ^{40}K (Bq/kg), in the building materials respectively. The maximum value of Ra_{eq} must be 370 Bq/kg to keep the external dose to 1.5 mSv/y [15]. The building material whose radium equivalent index exceeds 370 Bq/kg must be discarded to reduce radiation hazards associated with materials. It has been

Table 1
Activity concentration, radium equivalent activity, radon activity, radium concentration, radon exhalation rate in investigate materials.

Sample	Location	Activity concentration (Bq/kg)				Ra_{eq} (Bq/kg)	C_{Rn} (Bq/m^3)	C_{Ra} (Bq/kg)	$E_{Rn} \times 10^{-5}$ (Bq/m^2 h)
			^{238}U	^{232}Th	^{40}K				
Gravel	Ofankor	Range	11.5–12.6	12.3–13.1	76.7–87.8				
		Mean	12.1 ± 1.1	12.7 ± 1.8	82.3 ± 8.8	36.5 ± 1.6	24.8 ± 0.8	0.34 ± 0.1	6.0 ± 0.3
Gravel	Pokuase	Range	10.9–11.9	13.2–14.9	85.2–91.0				
		Mean	11.4 ± 1.1	14.1 ± 1.4	88.1 ± 8.8	35.8 ± 2.7	21.7 ± 2.2	0.33 ± 1.8	5.3 ± 0.2
Beach Sand	Nugua	Range	2.1–2.9	3.1–4.5	314.9–325.6				
		Mean	2.6 ± 0.5	3.8 ± 0.6	320.3 ± 27.4	32.7 ± 0.8	17.4 ± 0.7	0.19 ± 0.1	3.1 ± 0.2
Beach Sand	Labadi	Range	2.4–3.1	2.9–4.3	316.8–336.9				
		Mean	2.8 ± 0.5	3.6 ± 0.8	326.9 ± 29.0	33.1 ± 0.8	17.6 ± 0.7	0.21 ± 0.1	3.2 ± 0.1
Beach Sand	Sakumono	Range	2.6–3.0	3.7–4.5	342.5–351.7				
		Mean	2.9 ± 0.5	4.1 ± 0.7	347.1 ± 28.7	35.3 ± 1.4	17.9 ± 0.8	0.23 ± 0.1	3.6 ± 0.1
Portland	Haatso	Range	23.6–26.6	10.9–13.3	115.1–120.9				
		Mean	25.1 ± 1.5	12.1 ± 1.0	118.0 ± 13.4	51.2 ± 1.5	34.0 ± 1.0	0.41 ± 0.3	9.8 ± 0.6
Diamond	Atomic	Range	23.8–27.3	12.3–12.9	218.8–221.3				
		Mean	25.5 ± 1.5	12.6 ± 2.0	220.1 ± 21.4	60.5 ± 1.8	35.7 ± 1.7	0.43 ± 0.1	9.3 ± 0.6
Dangote	Atomic	Range	44.9–49.3	15.1–16.3	100.1–101.5				
		Mean	47.1 ± 2.8	15.6 ± 2.5	100.8 ± 11.8	77.1 ± 2.5	42.6 ± 2.1	0.64 ± 0.6	11.4 ± 2.1
Gneiss rock	Shai hills	Range	17.3–19.1	37.9–41.3	1198.2–1200.6				
		Mean	18.2 ± 1.7	39.6 ± 5.5	1199.4 ± 102.8	167.0 ± 6.4	28.9 ± 2.6	0.39 ± 0.2	7.9 ± 0.7
Gneiss rock	Shai hills	Range	18.1–3.6	36.6–49.4	1220.2–1224.2				
		Mean	18.9 ± 2.1	43.0 ± 5.7	1222.2 ± 96.3	174.3 ± 9.6	32.6 ± 1.7	0.40 ± 0.1	8.1 ± 1.3
Gneiss rock	Shai hill	Range	6.9–10.1	22.4–23.7	68.9–10739.6				
		Mean	19.0 ± 0.9	23.2 ± 2.7	874.7 ± 49.5	117.1 ± 7.4	32.7 ± 1.7	0.42 ± 0.1	9.1 ± 0.9
Sandstone	Achimota	Range	3.4–7.2	5.13–7.3	146.5–157.6				
		Mean	10.5 ± 0.8	12.4 ± 1.2	315.3 ± 24.7	51.7 ± 1.9	20.7 ± 2.1	0.33 ± 0.1	5.8 ± 0.1
Sandstone	Tesano	Range	3.5–3.70	4.4–5.8	55.8–69.7				
		Mean	3.6 ± 0.5	5.1 ± 1.0	62.8 ± 12.5	37.2 ± 1.3	18.2 ± 0.8	0.25 ± 0.2	3.7 ± 0.1
Quartzite	Atomic Hills	Range	9.5–15.8	16.9–23.7	435.2–454.5				
		Mean	12.7 ± 0.8	20.3 ± 2.2	444.9 ± 34.3	75.9 ± 0.1	24.6 ± 2.1	0.34 ± 0.1	6.0 ± 0.2
Quartzite	Weija	Range	3.3–6.4	11.0–13.5	310.0–350.0				
		Mean	9.7 ± 0.7	12.2 ± 1.0	330.0 ± 25.1	52.5 ± 1.0	20.0 ± 1.9	0.30 ± 0.1	5.1 ± 0.4
Quartzite	McCarthy	Range	3.5–6.1	4.3–6.8	317.3–492.8				
		Mean	4.8 ± 0.7	5.6 ± 0.7	405.1 ± 11.7	44.4 ± 0.4	18.6 ± 0.9	0.25 ± 0.1	3.9 ± 0.1
Granite	Kasoa	Range	9.6–11.8	43.5–47.6	584.9–889.2				
		Mean	10.7 ± 2.8	45.6 ± 18.6	738.6 ± 49.8	132.6 ± 3.5	21.7 ± 1.3	0.33 ± 0.1	5.9 ± 0.3
Granite	Dominase	Range	7.6–13.1	41.6–45.3	564.91–912.1				
		Mean	10.4 ± 2.1	43.5 ± 17.4	739.1 ± 46.5	129.3 ± 3.3	20.2 ± 1.3	0.32 ± 0.1	5.8 ± 0.2
Sandcrete	Atomic	Range	11.2–12.3	21.8–22.1	123.5–126.3				
		Mean	11.8 ± 1.1	22.0 ± 1.8	124.9 ± 14.2	48.5 ± 0.5	22.3 ± 1.6	0.34 ± 0.1	6.0 ± 0.3
Concrete	Atomic	Range	8.9–10.6	19.7–21.2	106.8–107.2				
		Mean	9.8 ± 0.9	20.5 ± 1.4	107.0 ± 13.9	42.7 ± 0.4	20.1 ± 0.9	0.32 ± 0.1	5.7 ± 0.3
Local Tiles	Haatso	Range	5.1–7.3	11.3–11.9	321.7–330.5				
		Mean	6.2 ± 0.6	11.6 ± 0.9	326.1 ± 27.5	45.5 ± 1.1	22.4 ± 0.9	0.28 ± 0.1	4.4 ± 0.1
River sand	Haatso	Range	6.9–7.3	10.6–11.9	106.8–116.4				
		Mean	7.10 ± 0.3	11.3 ± 0.9	111.6 ± 15.6	30.0 ± 0.1	23.8 ± 1.0	0.29 ± 0.1	4.5 ± 0.1
Clay bricks	Dodowa	Range	21.9–32.2	14.0–20.0	325.6–392.8				
		Mean	26.9 ± 2.4	17.0 ± 2.1	359.2 ± 25.9	78.8 ± 1.6	37.1 ± 2.0	0.44 ± 0.1	9.1 ± 2.1
Sand	Amansaman	Range	15.0–18.3	9.0–12.1	124.5–134.3				
		Mean	16.7 ± 1.4	10.6 ± 1.2	129.4 ± 15.8	44.4 ± 1.3	35.0 ± 2.3	0.36 ± 0.1	7.7 ± 1.5
Sand	Afienya	Range	12.7–15.4	15.4–21.6	89.2–121.7				
		Mean	14.1 ± 1.3	18.5 ± 2.3	105.5 ± 15.4	28.3 ± 0.2	34.0 ± 2.3	0.35 ± 0.1	7.4 ± 0.7
Sand	Oyarifa	Range	10.4–14.3	8.0–11.0	99.4–124.5				
		Mean	12.4 ± 0.6	9.5 ± 0.9	112.0 ± 12.6	35.8 ± 0.7	24.0 ± 2.3	0.31 ± 0.1	6.0 ± 0.5
Soil	Oyibi	Range	45.2–48.8	15.6–17.2	598.8–610.3				
		Mean	47.0 ± 4.1	16.4 ± 1.7	604.1 ± 35.0	130.0 ± 3.3	42.1 ± 2.8	0.63 ± 0.1	11.2 ± 4.0
soil	Pokuase	Range	14.2–19.5	8.9–3.5	97.8–113.1				
		Mean	16.9 ± 1.8	11.2 ± 2.4	100.5 ± 13.4	43.1 ± 0.6	32.1 ± 2.3	0.36 ± 0.1	7.7 ± 0.6
Tiles	china	Range	18.5–21.6	12.4–16.3	433.5–455.8				
		Mean	20.1 ± 2.2	14.4 ± 0.4	444.7 ± 35.7	77.3 ± 1.4	32.4 ± 1.9	0.42 ± 0.1	8.9 ± 0.2
Tiles	Spain	Range	16.8–19.3	12.5–13.4	357.0–364.4				
		Mean	18.1 ± 0.9	13.0 ± 0.7	360.7 ± 28.5	66.6 ± 1.1	28.9 ± 2.6	0.39 ± 0.2	7.9 ± 0.7
Tiles	Brazil	Range	13.5–14.9	18.5–21.4	398.6–412.4				
		Mean	14.2 ± 1.9	20.0 ± 2.3	405.5 ± 27.6	71.5 ± 0.9	34.1 ± 2.3	0.35 ± 0.1	7.4 ± 0.4

Table 2
Comparison activity concentration and radium equivalent activity with the present study (Ghana) to other studies in different countries.

Sample	Country	Activity concentration (Bq/kg)			Ra_{eq}	Reference
		^{238}U	^{232}Th	^{40}K		
Sand	Algeria	12 ± 1	7 ± 1	74 ± 7	28 ± 7.1	[22]
	Bangladesh	14.5 ± 8.2	34.8 ± 2.4	303.1 ± 141.9	87.5 ± 38.1	[23]
	Brazil	10.2	12.6	51.0	34.0	[21]
	Egypt	9.2	3.3	47.3	16.6	[24]
	Greece	18.0 ± 7.0	17.0 ± 10.0	367.0 ± 204.0	–	[25]
	India	9.4	52.1	65.5	84.2	[26]
	Kuwait	7.9 ± 0.7	7.2 ± 0.3	360.0 ± 14.0	45.4	[27]
	Malaysia	60.0 ± 3.0	13.0 ± 2.0	750.0 ± 53.0	136.0 ± 33.0	[28]
	Ghana	14.3 ± 1.1	15.4 ± 1.5	115.6 ± 14.6	36.2 ± 2.3	Present study
Cement	Algeria	41.0 ± 7.0	27.0 ± 3.0	422.0 ± 3.0	112.0 ± 8.1	[22]
	Bangladesh	62.3 ± 9.7	59.4 ± 7.4	329.0 ± 22.4	172.8 ± 19.8	[23]
	Egypt	31.3	11.1	48.6	50.9	[24]
	Greece	20.0 ± 5.0	13.0 ± 3.0	247.0 ± 68.0	–	[25]
	Albania	55.0 ± 5.8	17.0 ± 3.3	174.7 ± 48.9	–	[29]
	India	45.9	42.3	36.2	108.5	[26]
	Italy(Sicily)	38.0 ± 14.0	22.0 ± 14.0	218.0	92.0 ± 50.0	[30]
	EU	45 (4–422)	31(3–266)	216(4–846)	–	[31]
	Kuwait	12.6 ± 0.8	9.3 ± 0.5	240 ± 3	45.1	[27]
	China	68.3 ± 8.6	51.7 ± 5.4	173.8 ± 8.6	–	[32]
	China	52.0 ± 3(49–55)	103.0 ± 25(80–133)	310.0 ± 76(219–385)	–	[33]
	Malaysia	51.0 ± 1.0	23.0 ± 1.0	832.0 ± 69.0	188.0 ± 27.0	[28]
	Turkey	39.9 ± 18.0 (17.8–81.6)	26.4 ± 9.8 (7.8–48.8)	316.5 ± 88.1 (196.1–475.7)	–	[34]
	Qena city(Egypt)	134.0 ± 67.0	88.0 ± 35.0	416.0 ± 162.0	–	[35]
	Zambia	23.0 ± 2.0	32.0 ± 3.0	134.0 ± 13.0	79.0 ± 11	[20]
	Cameroon	27.0 ± 4.0	15.0 ± 1.0	277.0 ± 16.0	70.1	[13]
	Turkey	24.7 ± 1.6	20.7 ± 1.5	2493.1 ± 78.9	–	[36]
Portland	Ghana	25.1 ± 1.5	12.1 ± 1.0	118.0 ± 13.4	51.2 ± 1.5	Present study
Diamond	Ghana	25.5 ± 1.5	12.6 ± 2.0	220.1 ± 21.4	60.5 ± 1.8	Present study
Dangote	Ghana	47.1 ± 2.8	15.6 ± 2.5	100.8 ± 11.8	77.1 ± 2.5	Present study
Tiles	Zambia	52.0 ± 18.0	96.0 ± 22.0	–	–	[20]
	Cameroon	16.0 ± 1.0	14.0 ± 1.0	–	6.03	[13]
	S.Korea	44.0–82.0	34.0–96.0	310.0–1019.0	124.0–264.0	[3]
	China	64.0–131.0	55.0–107.0	561.0–867.0	200.0–331.0	[32]
	China	20.1 ± 2.2	14.4 ± 0.4	444.7 ± 35.7	77.3 ± 1.4	Present study
	Spain	18.1 ± 0.9	13.0 ± 0.7	360.7 ± 28	66.6 ± 1.1	Present study
	Brazil	14.2 ± 1.9	20.0 ± 2.3	405.5 ± 27.6	71.5 ± 0.9	Present study
Blocks	Upper Egypt	–	64.0	480.0	246.0	[35]
	Cuba		12.0 ± 7	595.0 ± 116.0	87.0 ± 19.0	[37]
	Israel	42.9	47.7	870.1	178.1	[38]
Concrete	Ghana	9.8 ± 0.9	20.5 ± 1.4	107.0 ± 13.9	42.7 ± 0.4	Present Study
Sandcrete	Ghana	11.8 ± 1.1	22.0 ± 1.8	124.9 ± 14.2	48.5 ± 0.5	Present Study
Clay Bricks	Algeria	65.0 ± 7.0	51.0 ± 5.0	675.0 ± 4.0	190.0 ± 9.5	[22]
	Bangladesh	29.5 ± 6.3	52.5 ± 12.2	292.3 ± 43.7	127.1 ± 9.9	[23]
	Brazil	46.8 ± 19.4	119.9 ± 110.6	322.0 ± 152.0	247.7 ± 170.3	[2]
	Albania	33.4 ± 6.4	42.0 ± 7.6	644.1 ± 64.2	–	[29]
	Egypt	24.5	24.4	227.0	77.0	[24]
	EU	47.0 (2–148)	48.0 (2–164)	598.0 (12–1169)	–	[31]
	Greece	35.0 ± 11.0	45.0 ± 15.0	710.0 ± 165.0	–	[25]
	China	58.6 ± 4.7	50.4 ± 3.5	713.0 ± 8.2	–	[32]
	China	46.0 ± 4.0 (39–53)	56.0 ± 7.0 (48 –66)	846.0 ± 67.0 (745–961)	–	[33]
	Turkey	31.2 ± 7.2 (24.7–49.0)	37.2 ± 7.8 (26.6–51.2)	775.8 ± 146.6 (587.3–1092.0)	–	[34]
	India	18.0	33.3	44.8	69.2	[26]
	Turkey	15.7 ± 1.1	3.8 ± 0.9	201.4 ± 4.4	–	[36]
	Kuwait	11.9 ± 0.7	6.6 ± 0.2	332 ± 4	41.6	[27]
	Malaysia	241.0 ± 3.0	51.0 ± 4.0	7541.0 ± 272.0	895.0 ± 107.0	[28]
	Qena city(Egypt)	33.0 ± 20.0	37.0 ± 2.0	511.0 ± 158.0	–	[35]
	Zambia	32.0 ± 2.0	81.0 ± 7.0	412.0 ± 19.0	180.0 ± 22.0	[20]
	Serbia	34.0 ± 4.0 (29–38)	43.0 ± 8.0 (35–53)	579.0 ± 104.0 (488–700)	–	[38]
	Cameroon	49.6 ± 0.3	91.0 ± 2.0	172.0 ± 4.0	193.3	[13]
	Ghana	26.9 ± 2.4	17.0 ± 2.1	359.2 ± 25.9	78.8 ± 1.6	Present study
Rocks	Brazil	31.0	73.0	1648.0	–	[39]
	Turkey	43.5–651	51–351	418–1618	–	[40]
	Turkey	9.44–27.31	51–351	418–1618	–	[41]
	Cameroon	427.6–485.8	32.8–39.7	427.6–485.8	–	[13]
	Nepal	17.0–100.0	24.0–260.0	32.0–541.0	–	[42]
	Nigeria	21.1–129.0	42.4–150.0	64.5–882.0	–	[43]

(continued on next page)

Table 2 (*continued*)

Sample	Country	Activity concentration (Bq/kg)			Ra_{eq}	Reference
		^{238}U	^{232}Th	^{40}K		
	Ghana	27.6–225.0	20.1–72.1	118.1–1443.8	98.8–414.4	[44]
	Egypt	–	10.50–183.00	2299.00–7356.00	–	[45]
	sandstone	12.9 ± 0.8	21.2 ± 1.2	490.0 ± 24.7	83.9 ± 1.6	Present study
	Gneiss	18.6 ± 1.9	41.3 ± 5.6	1210.8 ± 99.5	170.7 ± 3.4	Present study
	Granite	10.5 ± 2.45	44.5 ± 18.0	488.6 ± 48. 0	111.8 ± 0.2	Present study
	Quartzite	10.0 ± 0.7	13.5 ± 1.7	228.2 ± 27.0	60.0 ± 0.2	Present study
Soil	Jordan	28–84	22–82	145–560	–	[46]
	Turkey	115.0	192.0	1207.0	–	[14]
	Nigeria	38.7–54.0	91.1–100.9	286.5–308.5	–	[47]
	Spain	13.0–165.0	7.0–204.0	48.0–1570.0	–	[48]
	Ghana	16.4–74.6	12.0–44.7	21.5–498.6	46.9 – 135.7	[10]
	Italy	57.0–71.0	73.0–87.0	580.0–760.0	–	[49]
	Bangalore (India)	26.2	53.9	635.0	–	[50]
	Giresun (Turkey)	13.0–33.0	14–43	86–733	–	[2]
	China	112.00	71.2	672.0	266.0	[51]
	Ghana	31.9 ± 3.0	13.8 ± 2.1	352.3	86.6 ± 2.0	Present study
Beach Sand	South Africa	4.0	4.8	33.5	–	[52]
	Libya	10.5	9.5	270	–	[53]
	Western Antarctic	16.2	13.1	317.1	–	[54]
	India	124.0	1613.0	358.0	–	[55]
	Turkey	11.0–18.0	10.0–105.0	105.0–123.0	–	[56]
	Spain	5.0–19.0	5.0–44.0	136.0–1087.0	–	[57]
	Thailand	97.3–721.3	36.1–676.9	43.4–816	–	[58]
	Ghana	2.74 ± 0.5	3.8 ± 0.7	330.3 ± 27.4	33.7	Present study
Gravel	Bangladesh	25.3 ± 6.3	54.7 ± 12.9	228.4 ± 31.4	121.3 ± 22.6	[23]
	Egypt	9.8	3.5	62.4	19.7	[24]
	Cameroon	24.0 ± 3.0	139.0 ± 13.0	1161.0 ± 108.0	312.5	[13]
	Cameroon	19.4 ± 0.4	26.0 ± 2.0	304.0 ± 23.0	80.1	[13]
	Ghana	11.7 ± 1.1	13.2 ± 1.6	84.7	38.7	Present study

summarized in the Table 1 and ranging from 32.7 Bq/kg to 174.3 Bq/kg. Result showed that all the studied materials have values far less than the maximum admissible value of 370 Bq/kg [1,5]. It can be concluded that, all the investigated building materials would not pose any significant radiological hazard when used for construction. However, from the results, it is noticed that the Ra_{eq} varies considerably in the different materials and even in the same type of geological and processed materials from different areas as shown in Table 1. The studied building materials were also compared with different countries and revealed that radium equivalent activity differ from one country to another even for the same type of construction materials as shown in Table 2.

Radon exhalation rate, radon activity concentration and effective radium contents

The radon exhalation rate (E_{Rn}), radon activity concentration (C_{Rn}) and effective radium content (C_{Ra}) varies from 3.1×10^{-5} to 11.4×10^{-5} Bq/m^2 h, 17.4 to 42.6 Bq/m^3 and 0.19 to 0.64 Bq/kg, in building materials used for this study in Table 1. The maximum value of radon exhalation, radon concentration and radium contents were found in dangote cement while beach sand recorded the lowest of the three parameters. These results indicated that radon exhalation, activity concentration and radium contents are directly related to each in the investigated construction materials. The difference in the radon exhalation, concentration and radium contents could be due to minerals composition and geological formation of the origin of the materials [59–61]. It was observed that the radon exhalation rates from this study were less than the world average value of 1.25×10^{-4} Bq/m^{-2} h [61]. This indicated that building materials will not pose any radiological effect when used as construction materials. The radon risk associated with the building materials was examined by establishing the relationship between the uranium activity concentration and radon exhalation rates in construction materials. A positive correlation of $R^2 = 0.77$ was found as shown the Fig. 2, indicating that measured ^{222}Rn isotope was dependent on the decay of the ^{238}U radionuclide in the building materials.

Gamma activity concentration index

The gamma hazards of the building materials were calculated by adopting the following equation below, which is widely used at the investigation level for practical monitoring purposes [31].

$$I_x = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{300} \tag{6}$$

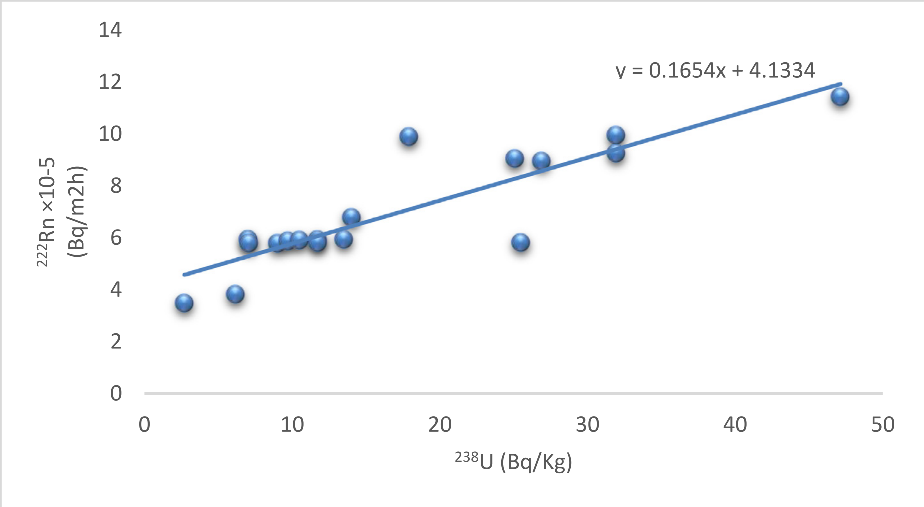

Fig. 2. Correlation between radon exhalation rate and uranium activity concentration.

Table 3
Gamma activity concentration index of EU building material (EC [62]).

Dose criterion	0.3 mSv/y	1 mSv/y
Materials used in bulk amounts e.g., bricks	$Ix \leq 0.5$	$Ix \leq 1$
Superficial and other materials with restricted use: tiles boards, etc	$Ix \leq 2$	$Ix \leq 6$

where, C_{Ra}, C_{Th}, C_K are the radium, thorium and potassium activity concentrations (Bq/kg) in the construction material respectively. The European Commission [62], proposed that activity concentration hazard could be classified into four classes, leading to two categories of materials used in bulk amounts and materials with superficial or restricted uses (Table 3).

Activity Concentration index (I_x) from this study was found to be in range of 0.10–0.63. Concrete block and gneiss obtained highest and lowest values respectively. This result therefore, indicating that building materials from this region are suitable for use in bulk amounts without restrictions. It is also met the dose criterion proposed by European Commission and annual effective dose of 1mSv [62].

External and internal hazards indices

To evaluate the external γ-radiation dose from building materials, according to ICRP (1991) the upper limit of radiation dose arising from building materials can be reduced to 1.5 mSv/y by using the conservative model proposed by [62,63]. This is by considering a finite thickness of walls and the existence of windows and doors. Taking these conditions into account, the equation used for the calculation of external hazard index (H_{ex}) is given as

$$H_{ex} = \frac{AC_{Ra}}{740} + \frac{AC_{Th}}{520} + \frac{AC_K}{9620} \leq 1 \tag{7}$$

where, AC_{Ra}, AC_{Th}, and AC_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, respectively, expressed in Bq/kg. This index must be less than unity so that the annual effective dose due to radioactivity in the construction material will be less or equal to 1.5 mSv/y [5].

The internal hazard index (H_{in}) was also calculated using the expression [63].

$$H_{in} = \frac{AC_{Ra}}{185} + \frac{AC_{Th}}{259} + \frac{AC_K}{4810} \leq 1 \tag{8}$$

where, AC_{Ra}, AC_{Th} and AC_K are the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, expressed in Bq/kg. The values of H_{in} must also be less than unity to have negligible hazardous effects of radon and its short–lived progeny to the respiratory organs. The summary of the result from Table 3, indicated that external and internal hazards ranged between 0.04–0.23 and 0.04–0.51. Concrete block from GAEC block factory and gneiss rocks from Shail Hills recorded lowest and highest hazards indices. Generally, it was found out that, values in this study do not exceed the recommended limits, indicating that the hazardous effects of these construction materials are negligible.

Table 4
Effective doses, absorbed doses, hazard indices, gamma activity index and cancer risk.

Sample	Dose rate (nGy/h)	I_x	Hazard indices		AEDE (μSv/y)		ELCR $\times 10^{-3}$
			H_{ex}	H_{in}	Indoor	Outdoor	
Gravel	12.1 ± 4.1	0.13 ± 0.01	0.05 ± 0.01	0.14 ± 0.02	59.5 ± 3. 9	14.9 ± 1.8	0.05 ± 0.01
Beach Sand	16.3 ± 5.1	0.12 ± 0.01	0.04 ± 0.01	0.04 ± 0.01	79.8 ± 2.7	20.0 ± 1.5	0.07 ± 0.02
Portland	13.8 ± 4.3	0.17 ± 0.02	0.06 ± 0.01	0.21 ± 0.04	65.1 ± 5.3	16.3 ± 2.1	0.06 ± 0.02
Diamond	18.0 ± 5.3	0.21 ± 0.01	0.07 ± 0.02	0.23 ± 0.06	88.6 ± 6.3	22.1 ± 3.1	0.08 ± 0.03
Dangote	13.8 ± 3.7	0.17 ± 0.01	0.09 ± 0.03	0.34 ± 0.05	77.6 ± 4.3	19.4 ± 1.9	0.07 ± 0.02
Gneiss	76.3 ± 6.1	0.63 ± 0.04	0.23 ± 0.03	0.51 ± 0.04	374 ± 11.9	93.6 ± 3.5	0.33 ± 0.04
Sandstone	37.2 ± 3.9	0.33 ± 0.05	0.12 ± 0.01	0.29 ± 0.03	183 ± 9.6	45.6 ± 4.2	0.17 ± 0.02
Quartzite	37.4 ± 2.8	0.32 ± 0.01	0.11 ± 0.01	0.17 ± 0.02	122 ± 4.8	39.9 ± 3.4	0.13 ± 0.04
Granite	47.2 ± 3.8	0.40 ± 0.03	0.08 ± 0.03	0.33 ± 0.06	149 ± 3.5	37.0 ± 2.0	0.13 ± 0.04
Sandcrete	11.3 ± 2.5	0.14 ± 0.01	0.05 ± 0.01	0.17 ± 0.02	55.6 ± 2.1	13.9 ± 2.1	0.05 ± 0.01
Concrete	9.46 ± 2.3	0.10 ± 0.01	0.03 ± 0.01	0.11 ± 0.04	46.5 ± 2.5	11.6 ± 1.8	0.04 ± 0.01
Local Tiles	26.5 ± 2.5	0.27 ± 0.02	0.10 ± 0.03	0.29 ± 0.04	130 ± 3.6	32.5 ± 1.5	0.11 ± 0.03
River Sand	16.0 ± 3.9	0.15 ± 0.01	0.06 ± 0.01	0.15 ± 0.03	78.4 ± 5.2	19.6 ± 1.1	0.07 ± 0.01
Clay Bricks	26.5 ± 1.9	0.27 ± 0.01	0.10 ± 0.01	0.29 ± 0.03	130 ± 3.3	32.5 ± 1.9	0.11 ± 0.02
Sand	12.6 ± 1.7	0.23 ± 0.01	0.09 ± 0.02	0.20 ± 0.03	131 ± 2.9	32.7 ± 2.3	0.11 ± 0.02
Soil	15.5 ± 2.0	0.15 ± 0.01	0.06 ± 0.03	0.15 ± 0.02	75.8 ± 1.9	19.0 ± 1.6	0.07 ± 0.01
Tiles	28.1 ± 2.6	0.26 ± 0.03	0.09 ± 0.02	0.25 ± 0.06	138 ± 3.8	34.5 ± 2.1	0.12 ± 0.03

Absorbed dose rate and effective dose rate

Absorbed dose rate

The absorbed dose rates *(D_R)* (nGy/h) due to gamma radiations is used to calculated doses in air at 1 m above the ground surface for the uniform distribution of radionuclides of ^{238}U, ^{232}Th and ^{40}K in building materials. It can be calculated with known activity concentration of ^{238}U, ^{232}Th and ^{40}K and based on the conversion factors as follows, 0.462 nGy/h per Bq/kg for ^{238}Ra, 0.604 nGy/h per Bq/kg for ^{232}Th and 0.0417 nGy/h per Bq/kg for ^{40}K [61]. It can be calculated using the equation below.

$$D_R(\text{nGy/h}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \tag{9}$$

Where C_{Ra}, C_{Th} and C_K, are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K expressed in (Bq/kg) in the construction materials. The absorbed dose (D_R) associate with this materials ranges from 9.5 to 76.29 nGy/h. It is observed that gneiss samples recorded the highest value (77.8 nGy/h), whereas the lowest value was found in concrete block (9.5 nGy/h). The studied values (Table 4) were lower or comparable to that of the published world average dose rate of 84 nGy/ h [61].

Annual effective dose equivalent (AEDE)

The annual effective dose equivalent (AEDE) in μSv/y to the public is calculated from the absorbed dose rate by using dose conversion factor of 0.7 Sv/Gy and the occupancy factor for outdoor and indoor 0.2 (5/24) and 0.8 (19/24) respectively [61].

The annual effective dose is determined using the following equations

$$\text{AEDE(Outdoor)}(\mu\text{Sv/y}) = 0.7\frac{Sv}{Gy} \times 24\text{ h} \times 365.25\text{ d} \times 0.2 \times 10^{-3} \times D_R\left(\frac{\text{nGy}}{\text{h}}\right) \tag{10}$$

$$\text{AEDE(Indoor)}(\mu\text{Sv/y}) = 0.7\frac{Sv}{Gy} \times 24\text{ h} \times 365.25\text{ d} \times 0.8 \times 10^{-3} \times D_R\left(\frac{\text{nGy}}{\text{h}}\right) \tag{11}$$

The calculated indoor and outdoor AEDE values are presented in Table 4. The minimum and maximum value for outdoor and indoor were found to be (11.6–93.6 μSv/y) and (46.5–374.1 μSv/y, respectively. All the studied samples recorded values far lower than the outdoor average effective dose of 460 μSv/y [61]. The values were also found to be less than the limit for public exposure control set by the International Commission on Radiological Protection and Organization for Economic Cooperation and Development–Nuclear Energy Agency [5,61].

Excess lifetime cancer risk (ELCR)

The probability of developing excess cancer as a result of radiation exposure to radioactive materials over a lifetime at a given exposure level is called Excess Lifetime Cancer Risk (ELCR) [1] and the mathematical expression is given as:

$$ELCR = AEDE \times DL \times RF \tag{12}$$

Where, *AEDE* is the annual effective dose equivalent, *DL* is the average duration of life time (estimated to be 70 years) and RF is the risk factor i.e., fatal cancer risk per sievert. For stochastic effects, ICRP uses *RF* as 0.05 for the public [64].

The values obtained for *ELCR* ranged from 0.04×10^{-3} to 0.33×10^{-3}. The quartzite from Weija and Gneiss from Shai Hills recorded lowest and the highest values respectively. All the values obtained were found to be lower than the world average value with exception of the gneiss rocks from Shai hills which recorded values (0.32×10^{-3} and 0.33×10^{-3}) greater than the world value of 0.29×10^{-3} [61]. It can be attributed to the high activity concentration of ^{40}K content present in the rocks within the areas.

Conclusion

The activity concentration of ^{238}U, ^{232}Th, ^{40}K and ^{222}Rn exhalation rate and its related hazards were determined from the construction materials within Greater Accra Region of Ghana using gamma and alpha techniques. The average activity concentrations for ^{238}U, ^{232}Th and ^{40}K were found in the range of 2.6 ± 0.5–47.1 ± 2.8, 3.6 ± 0.8–45.6 ± 18.6, 62.8 ± 12.5–1222.2 ± 96.3 Bq/kg, respectively. The lowest ^{238}U and ^{232}Th activity concentrations were found in both beach sand from Labadi and Sakumono. The Dangote cement and granite from Dominase recorded highest activity concentration. The lowest and highest activity concentration of ^{40}K were determined in quartzite from Weija and the gneiss from Shail hills. The radium equivalent activity ranging from 32.7 to 174.3 Bq/kg, which are lower than the maximum acceptable value of 370 Bq/kg reported by UNSCEAR. The radon exhalation rate, radon activity concentration and effective radium content varies from 3.1×10^{-5} to 11.4×10^{-5} Bq/m^2 h, 17.4 to 42.6 Bq/m^3 and 0.19 to 0.64 Bq/kg. Radon exhalation rate measured for this study was less than the average value of 1.25×10^{-4} Bq/m^2 h. The radiation hazards indices, were found to range from 0.04 to 0.23 for external and 0.04 to 0.51 for internal hazards. The activity concentration index was also found to vary from 0.10 to 0.63 lower than world acceptable value of 1.5 recommended by OECD. The absorbed dose rate vary from 9.5 to 76.3 nGy/h, and the corresponding effective dose for both indoor and outdoor dose rate were found to be 46.5–374.1 μSv/y and 11.6–93.6 μSv of which both exposures fell below the limit of 1.5 mSv/y recommended by the OECD. Its related Excess Lifetime Cancer Risk was also calculated to be 0.04×10^{-3} to 0.33×10^{-3} with gneiss rocks from Shai hills recording values greater than the world average value of 0.29×10^{-3} recommended by UNSCEAR.

From the above mentioned results, with exception gneiss rocks from Shai hills which recorded high value of cancer risk as compare to the world average value, all the studied building materials do not pose any radiological effects to the people of Greater Accra Region when used for construction.

Conflict of interest

Financial support for this study was provided by the International Atomic Energy Agency (IAEA) and Radiation Protection Institute, Ghana Atomic Energy Commission. There are no perceived or conflicts of interest.

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