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Natural Radioactivity Concentrations in Beach Sands from Some Tourists Resorts

[1]H. Lawluvi, [1]E.O. Darko, [2]C. Schandorf, [1]A. Fannu, [1]A.R. Awudu and [1]D.O. Kpeglo
[1]Radiation Protection Institute, Ghana Atomic Energy Commission
[2]School of Nuclear and Allied Sciences, University of Ghana, Legon

Abstract: Beaches along the coastlines in Ghana are important holiday destinations for tourists from many countries around the world. The radiological quality of sand from these beaches is very important to assess exposure of the public who use the beaches for recreational purposes and other activities. This study investigates the levels and hazards associated with the U-Th series and ^{40}K in beach sands from some renowned tourist resorts in the Greater Accra region of Ghana. Samples of beach sand from eleven beaches were analyzed using direct gamma-ray spectrometry. The total absorbed dose rate and the annual effective doses were calculated. The radiation hazards and risks associated with the use of the beach sand as construction material were also determined. The results show specific activities in the range 11.0-31.8 Bq/kg for ^{238}U, 0.5-1.5 Bq/kg for ^{235}U, 10.9-103.7 Bq/kg for ^{226}Ra, 16.8-231.2 Bq/kg for ^{232}Th and 68.3-183.9 Bq/kg for ^{40}K. Mean values of the absorbed dose rate, annual external effective dose, radium equivalent activity, external and internal hazard indices and the radiation level index are; 54.08 nGy/h, 0.066 mSv/y, 101.0 Bq/kg, 0.27, 0.36 and 0.71, respectively. The ^{235}U/^{238}U activity ratios calculated for the beaches is in the range of 0.032-0.053 with an average of 0.045±0.007 and that of the other radionuclides are close to unity, indicating only natural radionuclides were detected in the samples investigated. The results are within the values found in literature and show that the natural radionuclides in samples of the beach sand do not pose any significant risk to tourists and other holiday makers. Sand from the beaches is also safe for use as construction material, indicating the relevance in terms of the radiological quality of the beaches from both human and environmental health view points.

Key words: Beach sand, dose rate, environmental radioactivity, gamma spectrometry, hazard index

INTRODUCTION

Tourism is an important economic activity for many countries including Ghana. It is estimated that about one million Tourists visit Ghana every year. Important tourists' destinations and holiday resorts include beaches, national parks and other historic places of interests. The Greater Accra region in Ghana can boast of the largest number of beaches used as holiday resorts in the country. The environmental quality of these beaches and surroundings is an important attraction to large numbers of tourists and other holiday makers. Among the environmental quality parameters, radiological hazard play a significant role in assessing the exposure of the public to natural radioactivity due to the presence of the uranium-thorium series and potassium-40.

According to UNSCEAR report, the greatest contribution to mankind's exposure comes from natural background radiation, and the worldwide average annual effective dose per capita is 2.4 mSv (UNSCEAR, 2000). However, much higher levels of exposure are usual for inhabitants of natural High Background Radiation Areas (HBRAs) (UNSCEAR, 2000). Specific levels of terrestrial background radiation depend mainly on the geological and geographical conditions. Higher levels are usually associated with igneous rocks. Weathering and erosion of both igneous and metamorphic rocks in the environment transform rocks into sand deposits. Natural radioactivity in sand therefore originates mainly from the uranium (U) and thorium (Th) series and potassium-40 (^{40}K) (Alam *et al*., 1999; Singh and Mahayan, 2005)

The study of the distribution of radionuclides in the human environment allows the understanding of the radiological implications of these elements due to the gamma-ray exposure of the body and irradiation of lung tissues from inhalation of radon and its daughters (Singh and Mahayan, 2005). In particular, it is also important to assess the radiation hazards arising due to the use of soil or sand in the construction of dwellings. Therefore, the assessment of gamma radiation dose from natural sources is of particular importance as natural radiation is the largest contributor to the external dose to the world population (UNSCEAR, 2000, 1993). The dose rates vary depending upon the concentration of the natural

Corresponding Author: H. Lawluvi, Radiation Protection Institute, Ghana Atomic Energy Commission

radionuclides, ^{238}U, ^{232}Th, their daughter products and ^{40}K present in soil, sands and rocks, which in turn depend upon the local geology of each region in the world.

Low level measurements of environmental radioactivity are of particular importance in environmental protection and for studying processes in nature. Better instruments and more sensitive methods developed for identifying and determining radionuclides in trace concentrations help in understanding physical, chemical and biological processes in the geological and hydrological environments as well as the biosphere. Gamma-ray spectrometry is one of the best methods for the measurement of low level environmental radioactivity. Among the gamma-ray spectrometry methods, measurement of gamma-ray activity concentrations with germanium detectors has gained considerable attention (Radhakrishna *et al*., 1993; De Meijer *et al*., 2001; Kannan *et al*., 2002; Freitas and Alencar, 2004; Ramli, 1997).

This study was necessitated by the fact that no previous work has been conducted to provide a database on the distribution of radionuclides and their concentrations in beach sands along the coastlines in Ghana. Therefore, the objective of the present study is to measure the concentrations of natural radionuclides in an extensive selection of tourist and holiday resorts along the Atlantic coast of the Greater Accra Region using gamma spectrometry to determine the concentrations of ^{238}U, ^{235}U, ^{226}Ra, ^{232}Th and ^{40}K, and the hazards associated with the use of the beaches as tourist resorts as well as using the beach sands as construction materials (UNSCEAR, 1993; Radhakrishna *et al*., 1993; De Meijer *et al*., 2001). Additionally, the outdoor absorbed dose rates in air at 1m above ground surface due to the uniform distribution of the radionuclides were estimated, and the corresponding annual effective dose calculated. The results were compared with published data from other countries.

Experimental: The study was carried out at the Radiation and Waste Safety Department of the Radiation Protection Institute, Ghana Atomic Energy Commission from October, 2008 to September, 2010.

Sampling and sample preparation: The study focused on five of the six districts of the Greater Accra region of Ghana. The region lies between latitude 5º31′ to 5º46′ N of the equator and longitude 0º38′ to 0º16′ W of the Greenwich meridian. It covers an area of about 4540 km^2 with mostly sandy coastline of about 225 km stretching from Ada-Foah in the East to Langba in the West. Over 5 million inhabitants live in these areas according to projections in the year 2000 census report 9 (GSS, 2000). Three positions on each beach were identified and the coordinates of the sampling points marked using a Geo-Explorer II Global Positioning System (GPS) as shown in Table 1. The map of the study area is also shown in Fig. 1.

Table 1: Sampling sites and their coordinates taken at each location on the beaches

	Coordinates	
Sampling site	Long	Lat.
Korle-Gonnor	N 5º31′43.86″	W 0º13′33.21″
James town	N 5º31′57.35″	W 0º13′38.88″
La pleasure	N 5º33′35.67″	W 0º08′48.20″
Teshie	N 5º34′37.40″	W 0º13′42.31″
Ada - Paradise	N 5º46′23.40″	E 0º38′53.34″
Sakumono	N 5º36′37.26″	W 0º02′51.13″
Cocoloco	N 5º46′30.26″	E 0º37′59.91″
Koko	N 5º35′03.92″	W 0º05′28.21″
Nungua	N 5º34′59.81″	W 0º05′38.40″
Chorkor	N 5º31′32.64″	W 0º14′19.83″
Kokrobite	N 5º33′3 1.54″	W 0º15′19.20″

Ten samples of beach sands were collected from each site at depths up to 25 cm. In the laboratory, the samples were air dried at room temperature for 14 days. The samples were then oven-dried at 50ºC for 24 h in a slow-airflow drying cabinet, grounded into fine powder and screened with a sieve of mesh size 1 mm, homogenized and then sealed in 1000 mL Marinelli beakers. About 1 kg of each sample was used for the measurements. The samples were stored for some time after preparation before analysis (Penna-Franca *et al*., 1965; Eicholz *et al*., 1980; Selvasekarapandian *et al*., 2000; Sunta *et al*., 1982; Sunta, 1993).

Analysis of the samples by direct gamma spectrometry: Measurements of the specific activity concentrations of the natural radionuclides in the samples were performed using direct gamma-ray spectrometry. Prior to the analysis, energy and efficiency calibrations were performed in the energy range up to 2000 keV to identify and quantify the radionuclides in the samples. The detector system was calibrated using radionuclide reference standard in the form of solid water in 1.0 L Marinelli beaker obtained from Deutscher Kalibrierdienst (DKD) of Germany. A counting time of 20 h was used for each sample with correction for density and background.

The activity concentration of the radionuclides in the samples were calculated after decay correction using the expression

$$A = \frac{N_{sam}}{f_E . \eta(E) . T_C . M_{sam}} \quad (1)$$

where, A is the activity concentration of the radionuclides in Bq/kg in the samples, M_{sam} is the mass of sample (kg), N_{sam} is the sample net counts in the peak range, f_E is the

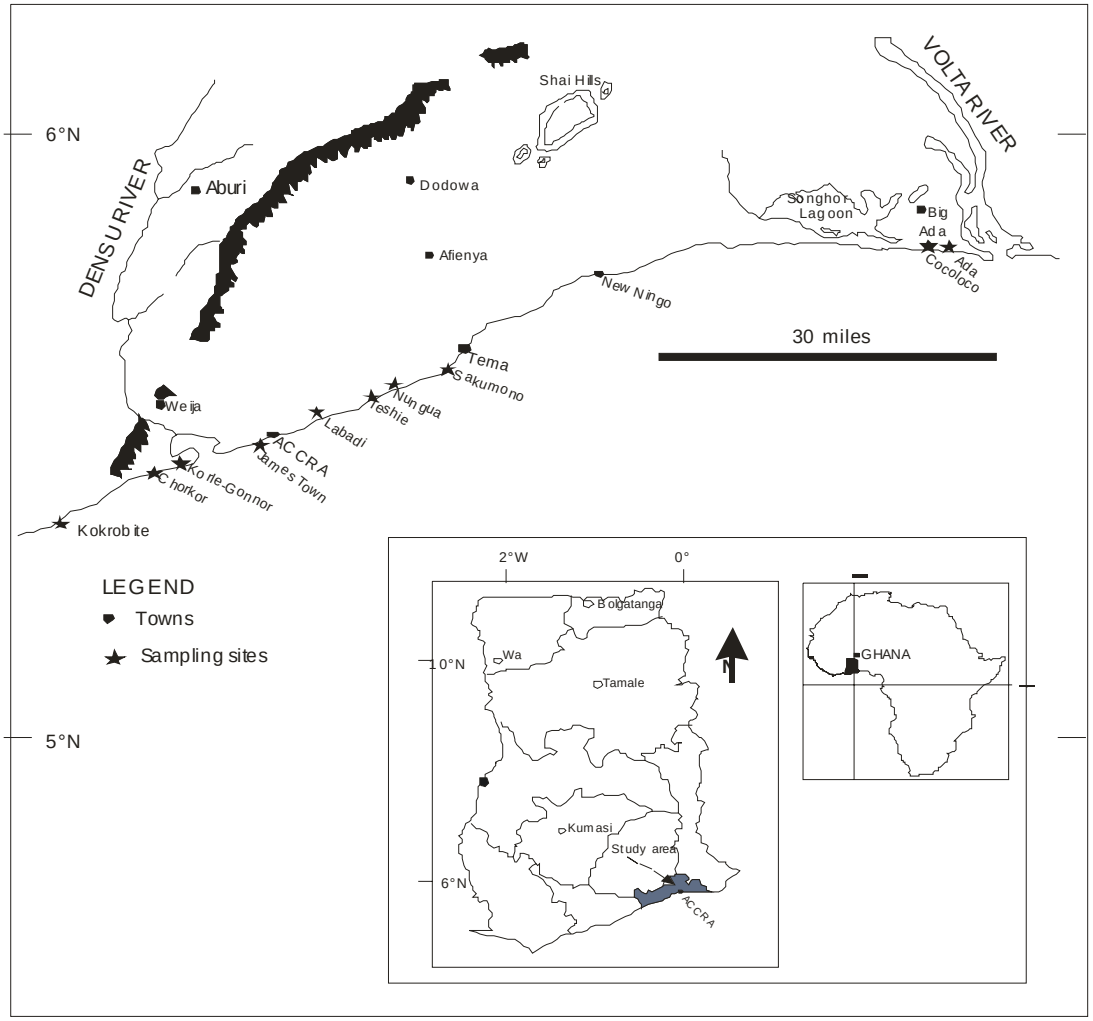

Fig. 1: Map of greater accra region showing the sampling points in the study area

gamma emission probability, T_c is the counting time and η(E) is the photopeak efficiency.

The activity concentration of ^{238}U was determined from the 63.3 keV peak of ^{234}Th, ^{226}Ra was determined from the average activity concentrations of 295.3 keV of ^{214}Pb and 1764.5 keV of ^{214}Bi. The activity concentration of ^{232}Th was determined from the average activity concentrations of ^{212}Pb (238.6 keV), ^{228}Ac (911.1 keV) and ^{208}Tl (2614.7 keV), and that of ^{40}K from 1460.0 keV. The activity concentration of ^{235}U was determined from the 185.7 keV gamma line, which was corrected by removing the contribution from the 186.2 keV of ^{226}Ra using the following equation:

$$A(^{235}U) = \frac{N_{186} - A(^{226}Ra).f_E(^{226}Ra).\eta_{186}.M.Tc}{\eta_{186}.f_E(^{235}U).M.Tc} \quad (3)$$

where, N_{186} is the total counts for the 186 keV doublet, $A(^{235}U)$ and $A(^{226}Ra)$ are the activity concentrations of ^{235}U and ^{226}Ra respectively, η_{186} is the detection efficiency of the 186keV line, $f_E(^{235}U)$ and $f_E(^{226}Ra)$ are the emission probabilities of the 185.7 and 186.2 keV gamma lines of ^{235}U and ^{226}Ra respectively, T_C is the counting time and M is the mass of sample.

The Minimum Detectable Activity (MDA) for each radionuclide ^{226}Ra, ^{232}Th and ^{40}K was calculated using the following equation:

$$MDA = \frac{1.645\sqrt{N_B}}{f_E.\eta(E).t_C.M} \quad (4)$$

where, 1.645 is the statistical coverage factor at 95% confidence level, N_B is the background counts at the

region of interest, t_C is the counting time, f_E is the gamma emission probability, $\eta(E)$ is the photopeak efficiency and M is the mass of sample. The MDA for each of the radionuclides were calculated as 0.30 Bq/kg for ^{238}U, 0.12 Bq/kg for ^{226}Ra, 0.11 Bq/kg for ^{232}Th and 0.9 Bq/kg for ^{40}K respectively.

Calculation of the absorbed dose rate and annual effective dose: The absorbed dose rate at 1 m above the ground (in nGy/h) due to U-Th series and ^{40}K was calculated using the following equation;

$$D(nGy/h) = \sum_{i=1}^{n} A_i . DCF_i \quad (5)$$

where, DCF_i are the dose coefficient in nGy/h per Bq/kg taken from UNSCEAR (2000) report (UNSCEAR, 2000) and A_i are the activity concentrations of the radionuclides.

In addition, the absorbed dose rates from external exposure were measured with a RADOS RDS-200 universal survey meter. The RDS-200 survey meter was manufactured by RADOS Technology of Finland. It has a sensitivity of 0.01μSv-10Sv in the energy range of 50 keV-1.3 MeV.

The annual effective dose equivalent, H_E, from external exposure to gamma rays from the beach sand was calculated from the absorbed dose rate using the expression (UNSCEAR, 2000):

$$HE = D(nGy/h) * 8760(h) * 0.2 * 0.7(Sv/Gy) \quad (6)$$

where, 0.2 is the occupancy factor for outdoor, 8760 is the total time of the year in hours and 0.7 SvG/y is the conversion factor for external gamma irradiation.

Hazard assessment: Beach sands have been used as building materials in Ghana by the coastal dwellers for many years. The ^{226}Ra, ^{232}Th and ^{40}K in the beach sands may therefore be a source of external exposure to gamma rays as well as internal exposure from inhalation of radon. Secondary, the distribution of the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K is not uniform throughout the beach sands. For regulatory purposes, assessment of building materials is made on the basis of radium equivalent activity, external and internal hazard indices, and the radiation level index.

Non-uniformity with respect to exposure to radiation has been defined in terms of radium equivalent activity (Ra_{eq}). This is used to compare the specific activities of ^{226}Ra, ^{232}Th and ^{40}K and represented by a single quantity taken into account the associated hazards. The radium equivalent activity, Ra_{eq} is based on the fact 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 rate. Thus, radium equivalent activity index for each sample was calculated using the relation (Sunta *et al*., 1982).

$$Ra_{eq} = A_{Ra} + 1.43A_{TH} + 0.077A_K \quad (7)$$

where, A_{Ra}, A_{Th} and A_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq/kg, respectively. In this study, the Ra, Th and K contents in the samples were determined and the Ra_{eq} calculated.

Similarly, the external hazard index (H_{ext}) represents the external radiation exposure associated with gamma irradiation from radionuclides of concern. The value of H_{ext} should not exceed the maximum acceptable value of one in order to keep the hazard insignificant. The external hazard index was calculated using the following equation (Sunta *et al*., 1982):

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{TH}}{259} + \frac{A_K}{4810} \leq 1 \quad (8)$$

Here, it is assumed that the same dose rate is produced from 370 Bq/kg of ^{226}Ra or 259 Bq/kg of ^{232}Th or 4810 Bq/kg of ^{40}K present in the same matrix.

Due to radiation hazard to the respiratory organs by ^{222}Rn (from the decay of ^{226}Ra) and its short lived decay products, the maximum permissible concentration of radium is reduced to half the normal limit (Sunta *et al*., 1982). The hazard index (H_{in}) relates to internal exposure by a particular exposure route, such as inhalation or ingestion. The presence of ^{226}Ra and ^{232}Th in building materials are sources of internal exposure due to inhalation of ^{222}Rn and ^{220}Rn and their progenies. Howeverhazard to respiratory organs due to ^{222}Rn and its progeny, a criterion for reducing the acce, the contribution of ^{220}Rn is negligible due to its shorter half life. In order to address the radiation ptable maximum concentration of ^{226}Ra to half the normal limit (i.e., 185 Bq/kg) was suggested according to published reports (Sunta, 1993). The internal hazard index due to radon inhalation was therefore calculated using the following equation:

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad (9)$$

where the parameters, A_{Ra}, A_{Th} and A_K, and the figures in the above equations have been defined earlier in the text.

To estimate the risk associated with natural radionuclides in specific materials, radioactivity level index (I?) proposed by NEA-OECD El (El Galy *et al*., 2008) was used. This index is defined as;

$$I_y = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_K}{1500} \quad (10)$$

Table 2: Average specific activities of ^{238}U, ^{235}U, ^{226}Ra, ^{232}Th and ^{40}K in sand samples from the beaches

	Average specific activity, A_{sp}(Bq/kg)				
Beaches	^{238}U	^{235}U	^{232}Th	^{226}Ra	^{40}K
Nungua	15.96±2.87	0.75±0.19	22.4±2.3	22.9±4.4	183.9±33.2
Cocoloco	11.07±2.68	0.42±0.13	19.4±3.7	20.8±5.2	92.6±22.5
Korle-Gonnor	15.19±3.19	0.79±0.22	17.8±2.9	27.9±5.7	86.7±20.9
Paradise	18.75±2.24	0.90±0.27	20.3±2.2	24.4±4.0	100.3±27.4
Koko	31.83±6.50	1.50±0.42	54.5±4.4	45.9±9.6	114.2±24.2
La Pleasure	24.80±5.51	1.24±0.46	231.2±42.5	103.7±12.7	140.2±27.8
James Town	12.64±3.53	0.67±0.20	17.6±3.7	20.4±3.1	116.9±22.2
Chorkor	26.13±3.68	1.28±0.38	16.8±2.1	10.9±2.9	78.3±19.5
Sakumono	19.20±4.36	0.71±0.25	21.3±3.4	24.3±3.4	68.3±16.9
Teshie	16.08±2.16	0.51±0.14	20.9±4.2	20.0±3.8	125.2±21.2
Kokrobite	29.28±7.12	1.23±0.41	26.6±5.5	25.8±4.6	97.7±18.3

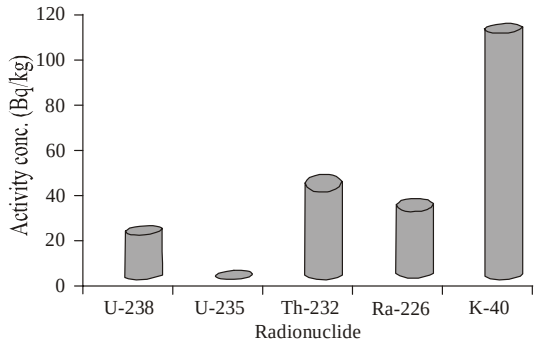

Fig. 2: Comparison of the average activity concentrations of ^{238}U, ^{235}U, ^{226}Ra, ^{232}Th and ^{40}K

where, the parameters, A_{Ra}, A_{Th} and A_K are defined earlier in the text. The value of this index should be less than one in order for the risk to be insignificant.

RESULTS AND DISCUSSION

The results of measurements of the radionuclides concentrations in the beach sand samples from the tourist resorts are shown in Table 2. The results show low activity concentrations of ^{238}U, ^{235}U, ^{226}Ra and ^{232}Th as well as the naturally occurring ^{40}K. The minimum activity concentration of ^{238}U was 11.07±2.68 Bq/kg in samples from Cocoloco beach, that of ^{235}U was 0.51±0.14 Bq/kg in samples from Teshie and that of ^{226}Ra was 10.9±2.9 Bq/kg determined in samples from Chorkor beach, while the maximum value of 31.8±6.5 Bq/kg, 1.5±0.46 Bq/kg, 103.7±12.7 Bq/kg were found in samples from Koko and La Pleasure beaches respectively. The activity concentrations of ^{232}Th are in the range 16.8±2.16-231.2±42.5 Bq/kg, with the minimum value for Chorkor beach and the maximum for La Pleasure beach. The lowest value of ^{40}K recorded was 68.3±16.9 Bq/kg, which was determined in samples from Sakumono beach. The highest value of ^{40}K was 183.9±33.2 Bq/kg, which was recorded in samples from Nungua beach.

The average values of the activity concentration of the radionuclides are plotted in Fig. 2. The figure indicates values for ^{238}U, ^{235}U, ^{226}Ra, ^{232}Th and ^{40}K as 20.08, 0.91, 31.4, 42.6 and 109.5 Bq/kg, respectively. The reported global average natural radionuclide contents in soil are 33, 32, 45 and 420 Bq/kg for ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K, respectively (UNSCEAR, 2000). The concentrations of the natural radionuclides in various types of beach sands from different parts of the world are also compared with data obtained in this study as shown in Table 3. It was observed that the values fall within the range of values obtained by some countries but much lower than others. Differences observed in the specific activities of the radionuclides from the beaches may be attributed to the geochemical composition and origin of the rock/soil types in the beaches, and different sand properties, such as density; humidity and porosity.

From the specific activity concentrations, the absorbed dose rates at 1m above ground due to terrestrial gamma rays were calculated. External exposure to gamma rays from natural radioactive elements occurs outdoors and indoors. According to UNSCEAR (UNSCEAR, 2000; 1993), 20% of the time is spent outdoors and 80% indoors, on the average, around the world. The calculated absorbed gamma dose rates in air due to the presence of the natural radionuclides in the beach sands and percentage contributions are given in Table 4. The calculated absorbed dose rates due to U-Th series and ^{40}K varied in the range 30.3-204.9 nGy/h with an average of 54.08 nGy/h, which is within the world average value of 59 nGy/h. The outdoor absorbed dose rates measured with a calibrated survey meter are also shown in Table 4 with an average value of 74.3 nGy/h. The difference between the calculated and the measured may be due to contribution from cosmic rays. The relationship between the measured and calculated dose rates are presented in Fig. 3. The figure shows good correlation ($R^2 = 0.89$) between the measured and calculated values of the dose rates.

In most of the beaches investigated, the mean values of annual effective doses outdoor (Table 4) were lower

Table 3: Comparison of the Specific Activities of ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K (Bq kg^{-1}) in sand samples from the Greater Accra Region and other studies in different beaches of the world

	A_{sp} (Bq/kg)				
Country	^{238}U	^{232}Th	^{226}Ra	^{40}K	Reference
Ghana	11.0-31.8	16.8-231.2	10.9-103.7	68.3-183.9	Present work
	20.0	42.6	31.4	109.5	
Brazi		l 12-349	6-180	47-527	Freitas and Alencar (2004); Penna-Franca *et al*. (1965)
India		300-600	36-400	158-405	Sunta (1993), Kalyani *et al*. (1990), Narayana *et al*. (1994)
India	400	2650	-	120	Mohanty *et al*. (2003)
Spain		5-44	5-19	136-1087	(Rosell *et al*. 1991)
Egypt		2.3-221.9	32.2-105.6	96-1011	El-Mamoney and Khater (2004); Ibraheim *et al*. (1993)
North Sinai		146	108	77	Seddeek *et al*. (2005)
Hong Kong		29.8	27.7	1210	Yu *et al.* (1992)
Iran	29-385	9-156	-	140-1172	Abdi *et al*. (2006)
Pakistan		52.5-67.6	36.9-51.9	680-784	Khan *et al*. (2005)
Bulgaria	590	340	460	1200	Peev and Mitov (1999)
Global average (soil)	2-690	1-360	1-440	0-3200	UNSCEAR (2000)
	33	45	32	420	

Table 4: Absorbed dose rates in air and annual effective dose due to ^{238}U, ^{226}Ra, ^{232}Th and ^{40}K in the beach sands

	Calculated dose rate (nGy/h)						
Beach	^{238}U	^{232}Th	^{226}Ra	^{40}K	Total	Measured dose rate (nGy/h)	Annual effective dose (μSv/y)
Nungua	7.37	13.53	10.58	7.67	39.15	77.90	48.02
Cocoloco	5.11	11.72	9.61	3.86	30.30	44.40	37.17
Korle-Gonnor	7.02	10.75	12.89	3.62	34.28	51.80	42.04
Paradise	8.66	12.26	10.35	4.18	35.45	51.90	43.48
Koko	14.71	32.92	21.21	4.76	73.60	82.80	90.26
La pleasure	11.46	139.64	47.91	5.85	204.86	174.0	251.24
James Town	5.84	10.63	9.42	4.87	30.76	68.70	37.72
Chorkor	12.07	10.15	5.04	3.27	30.53	54.50	37.44
Sakumono	8.87	12.87	11.23	2.85	35.82	50.60	43.93
Teshie	7.43	12.62	9.24	5.22	34.50	181.0	42.32
Kokrobite	13.53	16.13	11.92	4.07	45.65	79.60	55.98
Average	9.28	25.75	14.49	4.57	54.08	74.30	66.33

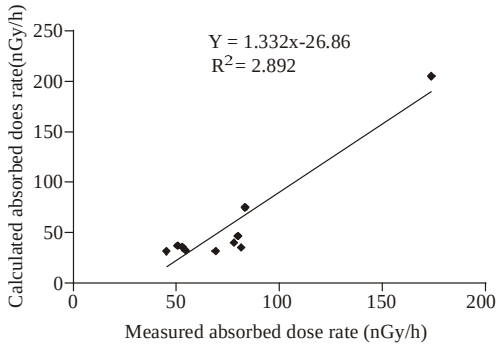

Fig. 3: Relationship between measured and calculated absorbed dose rates

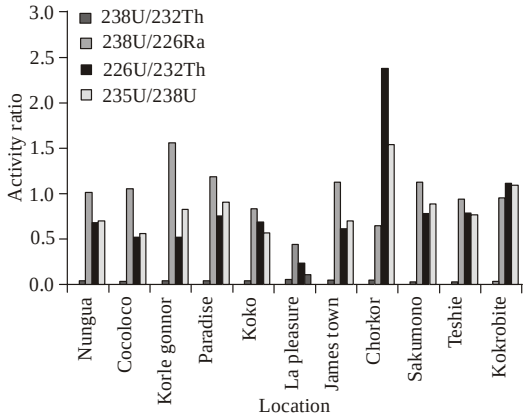

Fig. 4: Comparison of the activity ratios of the radionuclide's for the beaches investigated

than the worldwide average of 0.07 mSv/y published in UNSCEAR (2000). None of the beaches studied was considered a radiological hazard, because of the low values of gamma dose rates measured in about 91% of the samples. The annual external outdoor effective dose from terrestrial origin determined in this study varied from 37.2-251.2 μSv/y, with an average value of 66.3 μSv/y (0.066 mSv/y). This value is within the worldwide average normal background doses from radionuclides of terrestrial origin.

Table 5: Radium equivalent activity (R_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}) and radiation level index (I) of the samples studied

Beach	Req (Bq/kg)	H_{ex}	H_{in}	I
Nungua	69.09	0.19	0.25	0.50
Cocoloco	55.67	0.15	0.21	0.40
Korle-Gonnor	60.03	0.16	0.24	0.42
Paradise	59.15	0.16	0.22	0.43
Koko	132.63	0.36	0.48	0.93
La Pleasure	445.0	1.20	1.48	3.10
James Town	54.57	0.15	0.20	0.39
Chorkor	40.95	0.11	0.14	0.29
Sakumono	60.02	0.16	0.23	0.42
Teshie	59.53	0.16	0.21	0.43
Kokrobite	71.50	0.19	0.26	0.50
Average	100.75	0.27	0.36	0.71

Beach sand is used as building material by the people living mostly along the coast and therefore it is important to assess the gamma ray radiation hazards to humans. The results of the radium equivalent activity (Ra_{eq}) in Bq/kg, external hazard index (H_{ex}), internal hazard index (H_{in}) and the radiation level index (I?) obtained are presented in Table 5. The results show values of the Ra_{eq} in the range 59.5-445.0 Bq/kgwith an average value of 101.0 Bq/kg. With the exception of the La Pleasure beach, the rest of the values are within the accepted value of 370 Bq/kg. The corresponding average values for the external and internal hazards, and the radiation level indices are 0.27, 0.36 and 0.71, respectively. All the beaches studied have Ra_{eq}, H_{ex}, H_{in} and I lower than the accepted values, except La Pleasure beach which had values of 445.0 Bq/kg, 1.20, 1.48 and 3.10, respectively. For this reason, beach sand from La Pleasure beach is only recommended with caution for use in building constructions. Further studies are needed to confirm the relatively high values for the La Pleasure beach.

Figure 4 shows the average values of the ratios $^{238}U/^{232}Th$, $^{238}U/^{226}Ra$, $^{226}Ra/^{232}Th$ and $^{235}U/^{238}U$ for the beaches. The average value of $^{238}U/^{232}Th$ is 0.79 in the range 0.11 to 1.56, $^{238}U/^{226}Ra$ is 0.79 in the range 0.24 to 2.40 and $^{226}Ra/^{232}Th$ is 1.0 in the range 0.45 to 1.57. These values were found in all cases to be close to unity, which is similar to the average values for the continental crust (Eisenbud and Gesell, 1997). The average value of the ratio $^{235}U/^{238}U$ is 0.045 in the range 0.032 to 0.053, which close to the natural ratio of 0.046, indicating only natural uranium was measured in the beach sand samples.

CONCLUSION

Eleven renowned beaches in the Greater Accra Region of Ghana have been investigated using direct gamma spectrometry. The results from the studies indicated that La Pleasure beach had the highest average value of the calculated gamma dose rate with a value of 204.86 nGy/h and the lowest value being 30.30 nGy/h for Cocoloco beach. Even though the La Pleasure beach had a relatively high value of the gamma dose rate, this value is low, compared to values obtained for some beaches in other countries (Sunta, 1993; Narayana *et al*., 1994; Mohanty *et al*., 2003). However, the hazard indices Ra_{eq}, H_{ex}, H_{in} and I for the La Pleasure beach with values 445.0 Bq/kg, 1.20, 1.48 and 3.10, respectively exceeded the reference values, respectively. The overall calculated average absorbed dose rate and the annual effective dose from external exposure for all the beaches are 54.08 nGy/h and 0.066 mSv/y, respectively with the hazard indices being 101.0 Bq/kg, 0.27, 0.36 and 0.71 for the Ra_{eq}, H_{ex}, H_{in} and I?, respectively. The activity ratios of the radionuclides show that only natural radioactivity was detected in the samples with values similar to the average values for the continental crust.

The values show that the beaches can be regarded as areas with normal natural background radiation. The average radiation levels in the beaches do not pose any significant radiological hazard and could safely be used by tourists as holiday resorts. Sand from the beaches could also be used as construction materials and other purposes with minimal risks.

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