Determination of Natural Radioactivity and Hazard in Soil and Rock Samples in a Mining Area in Ghana

A. Faanu[1*], E. O. Darko[1] and J. H. Ephraim[2]
[1]*Radiation Protection Institute, Ghana Atomic Energy Commission, P. O. Box LG 80, Legon, Accra, Ghana*
[2]*Department of Chemistry, Kwame Nkrumah University of Science and Technology, Kumasi*
Corresponding author; *E-mail: afaanu@yahoo.co.uk.*

Abstract

The activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K in soil, rock, waste and tailing samples were measured by gamma spectrometry using high-purity germanium detector. In addition, radiological hazard assessments due to these natural radionuclides were carried out. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K determined were 13.61 $\pm$ 5.39 Bq/kg, 24.22 $\pm$ 17.15 Bq/kg and 162.08 + 63.69 Bq/kg, respectively. The average annual effective dose was 0.17 + 0.09 mSv. The average radium equivalent activity concentration in the sample was 61.00 Bq/kg. The calculated external and internal hazard indices were less than unity with average values of 0.16 and 0.20, respectively. The result of the ^{222}Rn emanation fraction varied in a range of 0.51–0.80. The results obtained show that soil, rock and waste materials that may be used for construction of buildings may not pose any significant radiological hazards to the inhabitants in the study area.

Introduction

Natural sources of radiation are known to be the most significant means by which the public are exposed to radiation. These are mainly due to the primordial radionuclides, such as ^{40}K and radionuclides from the ^{238}U and ^{232}Th decay series. Uranium and thorium occur at trace levels in the earth crust, and 0.018% of the total amount is potassium is ^{40}K (Mujahid *et al*., 2008). Also most minerals in the earth's crust contain small, but measurable concentrations of naturally occurring radioactive materials (NORM). Geochemical properties associated with mining and mineral processing may result in elevated concentrations of ^{238}U and ^{232}Th (White & Rood, 2001). The health concern from NORM is associated primarily with the generation and release of ^{222}Rn gas, produced through the radioactive decay of ^{226}Ra (a member of ^{238}U decay series). The inhalation of ^{222}Rn has been associated with increased risk of lung cancer (NAS, 1988).

Even though the concentrations of these radionuclides are widely distributed, the levels have been found to depend on the local geological conditions, and as a result vary from place to place (Xinwei *et al*., 2006). The specific levels in soil are related to the types of rock from which the soil originates. Higher radioactivity levels are associated with igneous rocks such as granite and lower levels with sedimentary rocks. The content of U and Th generally increases with SiO_2 content during differentiation, fractional crystallisation, partial melting, etc. in the final stage of magmatic procedures (Mason & Moore, 1982).

The increase of U with both SiO_2 and alkali content is usually more marked than the increase of Th. Uranium and thorium are enhanced mainly in accessory minerals such

as orthite or allanite, monazite, zircon, appetite and shene which are constituents of granitic rocks (Mason & Moore, 1982). There are exceptions, however, as some shale, and phosphate rocks have relatively high content of radionuclides (Uosif, 2007). If these materials contain significant levels of naturally occurring radioactive materials and are used for building purposes, it may lead to exposure of the inhabitants of the study area (UNSCEAR, 2000).

Mining has been identified as one of the potential sources of exposure to NORM (UNSCEAR, 2000). In Ghana there are more than 200 mining companies operating from small, medium to large scale mining. There is limited data on the levels of environmental radioactivity concentrations and public exposure due to mining and mineral processing activities of mines in Ghana (Darko *et al.,* 2005; Darko *et al.,* 2010). Consequently, there is general lack of awareness and knowledge of the radiological hazards and exposure levels by legislators, regulators and operators. As a result measurement of radioactivity to determine the presence and concentrations of these radionuclides in soils, which could be used as building materials by communities in and around the mines is important for developing guidelines.

Soil and rocks in the study area require investigation to quantify the activity concentrations of uranium, thorium and potassium in the materials. Knowledge of radon emanation fraction would also play an important role in characterisation of radon source strengths in soil which could be used as building materials. Radon emanation fraction is defined as the fraction of radon atoms formed in a solid that escapes from the solid and is free to migrate (White & Rood, 2001). The physical properties of the Ra-bearing material determine the radon emanation fraction of the material (Tanner, 1980).

The objective of this present study was to measure the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soils, wastes, rocks and tailings in Tarkwa Gold Mine and its surrounding communities to assess the radiological hazards and risk associated with exposure of the public. The results from the study will serve as a baseline data in data bank for the Radiation Protection Board of Ghana, as part of a national programme to establish data on environmental radioactivity in Ghana.

Materials and methods

Study area

The study area is Tarkwa Goldmine and its surrounding communities in the mines area of concession. The Tarkwa Goldmine is located in the Wassa West District in the Western Region of Ghana. The Tarkwa township is located at latitude 5^{o} 15$^{'}$ N and longitude 2^{o} 00' W. The mine is about 4 km from Tarkwa township. Fig. 1 shows the concession of the mine and the surrounding communities where sampling was carried out. The concession of the mine covers an area of 294.606 km^{2}. Table 1 shows the communities and the population distribution around the mines. Tarkwa township lies within the main gold belt of Ghana that stretches from Axim in the southwest to Konongo in the northeast (Kortasi, 2004). The total population of the Tarkwa township is about 80,000 (Kuma, 2007), with an estimated population of the District being 236,000 (IFC, 2003; Darko *et al.,* 2010). In

Fig. 1. Location map of the study area.

TABLE 1
Communities and the population distribution around the mines [GFGL, 2007]

#	*Community*	*Location coordinates*	*Population (2004 estimates)*
1	Abekoase	N 5^0 22$'$ 24.39$''$ W 2^0 01$'$ 07.49$''$	400
2	Brahabebom	N 5^0 18$'$ 47.44$''$ W 1^0 59$'$ 56.72$''$	1500–1800
3	Huniso	N 5^0 22$'$ 59.51$''$ W 2^0 03$'$ 55.51$''$	1500–2000
4	New Atuabo	N 5^0 19$'$ 22.34$''$ W 1^0 58$'$ 36.40$''$	5500–6000
5	Pepesa	N 5^0 19$'$ 56.60$''$ W 2^0 00$'$ 11.36$''$	1500–1800
6	Samahu	N 5^0 21$'$ 54.82$''$ W 1^0 59$'$ 58.46$''$	1500
7	Tarkwa township	N 5^0 17’13.58" W 1^0 59’ 55.31"	80,000

addition there are eight communities dotted around the mine.

Geology of the mining area

Geologically, the gold ore is located within the Tarkwaian system, which forms a significant portion of the stratigraphy of the Ashanti Belt in south-western Ghana. Intrusive igneous rocks contribute to about 20% of the total thickness of the Tarkwaian system in the Tarkwa area. The ore body consist of a series of sedimentary banket quartz reef units similar to those mined in the Witwatersrand area of South Africa, where the gold ore is associated with uranium in commercial quantities. The local geology is dominated by sedimentary Banket series, which consists of a well-sorted conglomerates and pebbly quartzite with clasts generally considered to be Birimian in origin and containing significant gold mineralization, hosting the Tarkwa ore body. The rocks of the Tarkwaian system consist of the Kawere Group, the Banket series, the Tarkwa Phyllite and the Huni Sandstone. Most of the rocks that resemble sandstone at the surface are weathered equivalents of parent quartzite (Kuma & Younger, 2001).

Gold ore is the alluvial type and non-sulphidic associated with the conglome-rates of the Tarkwaian formations. Two main methods are used by the Tarkwa Goldmine to recover gold from the ore. The carbon in leach (CIL) and the heap leach (HL) methods are being employed. The geological map of the study area is shown in Fig. 2.

Hydrogeology and climatology of the study area

Hydrogeologically, most of the major towns and villages except Tarkwa township in the Wassa West District depend on groundwater as the main source of water supply through boreholes and hand-dug wells (Kortasi, 2004). The groundwater occurrence is associated with the development of secondary porosity through fissuring and weathering since the area lacks primary porosity due to the consolidated nature of the rocks. Two types of soils exist in the Tarkwa-Prestea area, and these are forest oxysol in the south, and forest ochrosol-oxysol integrates in the north [Kortasi, 2004]. The characteristics of the soils in the area are shown in Table 2 (Kuma & Younger, 2001).

The climate of Tarkwa is the tropical type characterised by two wet seasons;

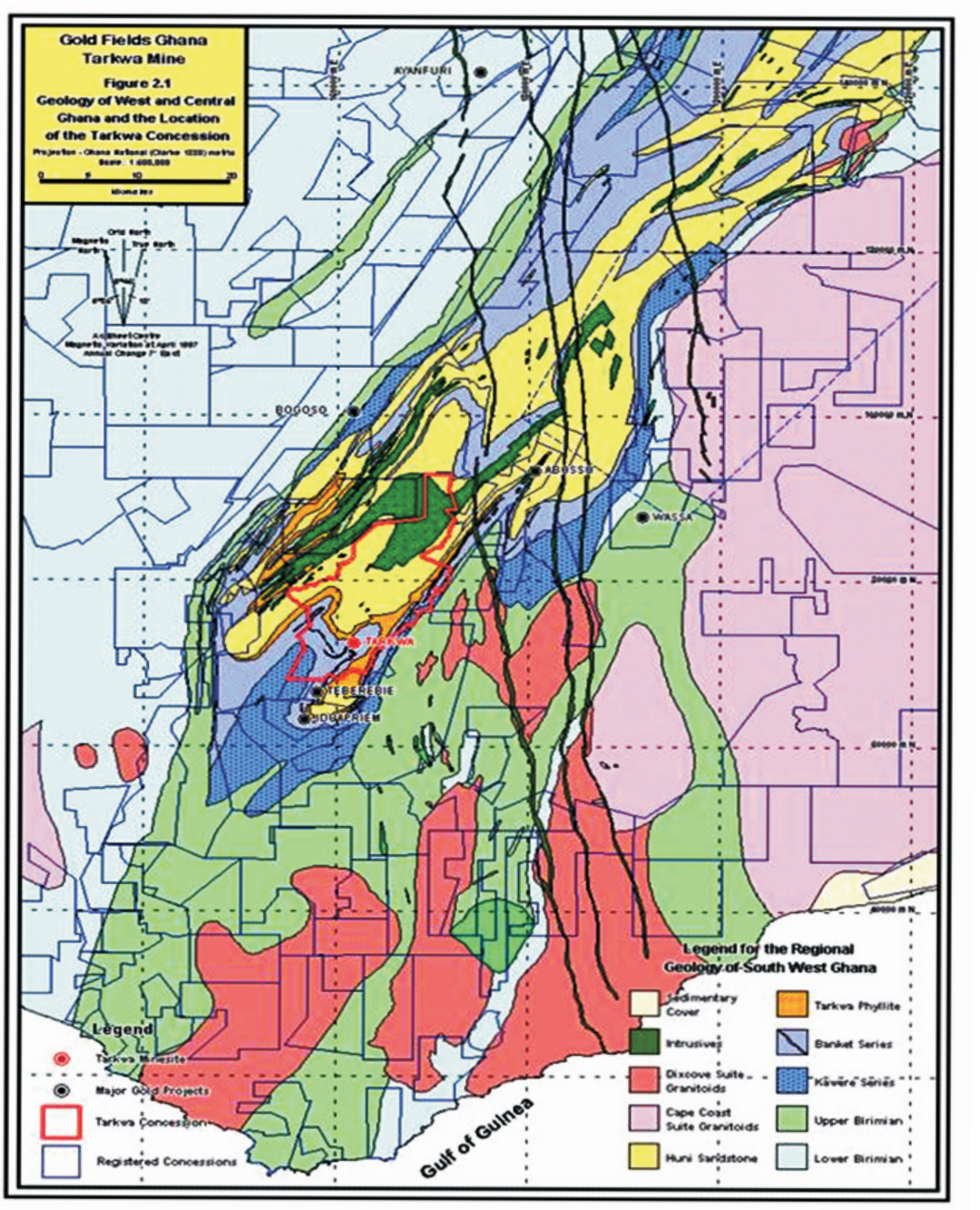

Fig. 2.Geological map of the study area.

TABLE 2
Characteristics of soils in the study area (Kuma and Younger, 2001)

Soil type	*Texture*	*Percentage*			
		Gravel	*Sand*	*Silt*	*Clay*
Banket series	Silty-sand	2	59	29	10
	Laterite	69	14	10	7
Huni	Silty-sand	2	55	33	10
Kawere	Silt sand	0	47	40	13
Tarkwa phyllite	laterite	62	9	13	16
Weathered dyke	Silt	3	20	64	13

March–July and September-November. Data obtained from the mines Environmental Department shows that the total annual rainfall figures measured for the year 2008 was 1744 mm with an average of 145 mm. The average rainfall figure from January to July 2009 was 256.6 mm in a range of 2.2 mm in January to 283 mm in June. The relative humidity for the area measured was in the range of 73–98% with an average of 86%. The average atmospheric pressure was about 1002 mbar in the range of 990–1007 mbar, and outdoor temperature in the range of 28–39 °C with an average value of 34 °C.

Sampling and sample preparation

Thirty-eight soil/rock samples were collected randomly within selected areas of the mine concession and also in the communities, and analysed by gamma spectrometry to determine the activity concentration of radionuclides. The sample types included soil, rock, waste and tailings. Fig. 1 shows the sampling locations. At the laboratory, each of the soil/rock samples were air-dried in trays for 7 days and then oven-dried at a temperature of 105 °C until all moisture was completely lost. The samples were then grinded into a fine powder using a ball mill, and sieved through a 2-mm pore size mesh into 1-litre Marinelli beaker. The Marinelli beakers with the samples were hermetically sealed and stored for 4 weeks for the short-lived daughters of ^{226}Ra (in the ^{238}U decay series) and ^{232}Th decay series to attain secular equilibrium with their long-lived parent radionuclides.

Instrument calibration and measurements

The activity concentrations of the radionuclides in the samples were measured using a High Purity Germanium Detector (HPGD). The gamma spectrometry system consists of an n-type HPGD (ORTEC) coupled to a computer based multi-channel analyser (MCA) mounted in a cylindrical lead shield (100 mm thick) and cooled in liquid nitrogen. The relative efficiency of the detector was 20% with energy resolution of 1.8 keV at gamma ray energy of 1332 keV of ^{60}Co. The radionuclides were identified using gamma ray spectrum analysis software, ORTEC MAESTRO-32.

The background radiation distribution in the environment around the detector was determined using 1 litre Marinelli beaker which was thoroughly cleaned and filled with

distilled water and counted for 36000 s and in the same geometry as the samples. The background spectra were used to correct the net peak area of gamma rays of measured isotopes. The minimum detectable activity of ^{226}Ra (^{238}U decay series) was 0.12 Bq/kg, ^{232}Th was 0.11 Bq/kg and ^{40}K was 0.15 Bq/kg.

The energy and efficiency calibration were performed using multi gamma solid water standard in a 1-litre Marinelli beaker in the energy range of 60 keV to ~2000 keV. The standard radionuclides are uniformly distributed in solid water with volume and density of 1000 ml and 1.0 g/m^3, respectively (source number, NW146) and manufactured by QSA Global GmbH, Germany. The gamma emitting radionuclides used for the calibration in the Marinelli beaker geometry were ^{57}Co (122 keV), ^{137}Cs (662 keV), ^{60}Co (1173 and 1333 keV) and ^{88}Y (1838 keV) with certified uncertainties $\leq$ 3%.

Calculation of activity concentration and estimation of doses

The activity concentration of ^{226}Ra was calculated from the average energies of 351.92 of ^{214}Pb and 609.31 of ^{214}Bi, respectively. Similarly, the activity concentration of ^{232}Th was determined from the average energies of 583.19 of ^{208}Tl and 911.21 keV of ^{228}Ac. This was based on the assumption that secular equilibrium has been established between the long-lived parent radionuclides ^{238}R and ^{232}Th, and their short lived daughter radionuclides. The activity concentration of ^{40}K was determined from the energy of 1460.83 keV. The analytical expression used in the calculation of the activity concentrations is given by Equation (1) in Bq/kg.

$$A_{sp} \quad \frac{N_D e^{\ pt_d}}{p.T_c.\ (E).M} \qquad (1)$$

where N_D is the net counts of the radionuclide in the samples, t_d is the delay time between sampling and counting, P is the gamma emission probability (gamma yield), (E) is the absolute counting efficiency of the detector system, T_c is the sample counting, M is the mass of the sample (kg), $e^{(\ ptd)}$ is the decay correction factor for delay between time of sampling and counting, and $_p$ is the decay constant of the parent radionuclide.

Radiation hazard indices

In the determination of radon emanation fractions (EF), the soil and rock samples were air-dried for 1 week and finally oven-dried to remove any additional moisture from the samples. The dried samples were each transferred into a 1-litre Marinelli beaker without any treatment (i.e. coarse and bulky samples were not broken down before measurement) hermetically sealed and counted for 2 h, and then allowed to stay for 4 weeks for secular equilibrium to be established between ^{226}Ra and its short-lived daughter nuclides of ^{214}Pb and ^{214}Bi. The net peak area of ^{226}Ra was determined from average peak areas of ^{214}Pb and ^{214}Bi. The samples were categorised as follows: granular samples of soil and gravel (GS); mixed granular and massive samples of soil and rock (M); massive rock samples (MS) and fine particle samples of tailings (F). The radon emanation fraction was determined using the following method described by White & Rood (2001). In this method, the emanation fraction is determined from the net count rates after sealing the sample container (C_1) and the net count rate at secular

equilibrium (C_2). The EF determination is based on the increase of ^{222}Rn concentration during the time interval between sealing (t_1) and after 30 days (t_2), and expressed mathematically as follows;

$$C_1 = A_0 + N(1 - e^{-\lambda t1}) \quad (2)$$

$$C_2 = A_0 + N(1 - e^{-\lambda t2}) \quad (3)$$

A_o and N are determined by solving equations (2) and (3) as follows: Equations (2) and (3) were simplified by substituting x for $1\text{-}e^{-\lambda t_1}$ and y for $1\text{-}e^{-\lambda t_2}$. The results for N, A_o and EF are given in equations (4), (5) and (6), respectively.

$$N \quad \frac{C_1 \quad C_2}{x \quad y} \quad (4)$$

$$A_o \quad \frac{xC_2 \quad yC_1}{x \quad y} \quad (5)$$

$$EF \quad \frac{N}{A_o \quad N} \quad (6)$$

where A_o is the count rate of ^{222}Rn present in a sample at sealing time t_1, N is the net count rate of ^{222}Rn emanated after time t_2, λ is ^{222}Rn decay constant (s^{-1}). The emanation fraction (EF) was calculated from Equation (6).

The radiological hazard of the NORM was determined by calculating the radium equivalent concentration (Ra_{eq}), the external and internal hazard indices. The term radium equivalent activity (Ra_{eq}) in Bq/kg is normally used to compare the uniformity in radiation of material containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K. It is based on the estimation 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 (Xinwei *et al.,* 2006). Ra_{eq} is a widely used hazard index and was determined using Equation (7) (Beretka & Mathew, 1985).

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (7)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K, respectively.

The values of the external and internal hazard indices must be less than one for the radiation hazard to be considered negligible i.e. the radiation exposure due to the radioactivity from the construction material is limited to 1.5 mSv/y (Beretka & Mathew, 1985). Also, radon and its short-lived products are hazardous to the respiratory organs and as a result, the internal exposure to radon and its daughter products is quantified using the internal hazard index.

The external hazard index (H_{ex}) was calculated from Equation (8) and the internal hazard index (H_{in}) from Equation (9).

$$H_{ex} \quad \frac{C_{Ra}}{370} \quad \frac{C_{Th}}{259} \quad \frac{C_K}{4810} \quad 1 \quad (8)$$

$$H_{in} \quad \frac{C_{Ra}}{185} \quad \frac{C_{Th}}{259} \quad \frac{C_K}{4810} \quad 1 \quad (9)$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

The external gamma dose rate from the soil/rock samples in outdoor air at 1 m above the ground was calculated from the activity concentrations using Equation (10) (Uosif, 2007).

$$D(nGyh^{-1}) = 0.0417A_k + 0.462A_U + 0.604A_{Th} \quad (10)$$

where A_K, A_{Ra} and A_{Th} are the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th, respectively. The effective dose was calculated from the absorbed dose rate by applying the dose conversion factor of 0.7 Sv/Gy and an outdoor occupancy factor of 0.2 (UNSCEAR, 2000).

In addition, the cancer and hereditary risks due to low doses were estimated using the ICRP cancer risk assessment methodology (ICRP, 1991; 2007). The lifetime risks coefficient of fatal cancer recommended in the 1990 recommendations by the ICRP are 5×10^{-2} Sv^{-1} for the members of the public and 4×10^{-2} Sv^{-1} for occupationally exposed workers (ICRP, 1991; 2007). The risk of exposure of low doses and dose rates of radiation to members of the public in Tarkwa and surroundings as a result of the mining and mineral processing of the mine was estimated using the 2007 recommended risk coefficients (ICRP, 2007) and an assumed 70 years lifetime of continuous exposure of the population to low level radiation. According to the ICRP methodology:

Fatality cancer risk = total annual effective dose (Sv) × cancer nominal risk factor.

Hereditary effect = total annual effective dose (Sv) × hereditary nominal effect factor.

Results and discussion

Table 1 shows the communities around the mine and the population distribution of the study area. The estimated population of the study area was 93,500 people. Table 2 shows the soil characteristics of the study area. There are two types soil in the study area, namely forest oxysol in the south which is porous and highly leached, and forest ochrosol-oxysol integrates in north which is less leached. The soil types of the Goldmine is more of the Banket series with mixed soil texture of silt-sand with patches of laterite and are generally considered as clayed soil-types (Kortasi, 2004).

The results of the activity concentrations, absorbed dose rates, annual effective dose, radium equivalent activity and hazards indices are shown in Table 3. The average activity concentration of ^{226}Ra was 13.61±5.39 Bq/kg in a range of 2.26 Bq/kg from a waste rock sample taken at Makulu waste dump (SS_{12}) to 30.57 Bq/kg from a soil sample in a cocoyam/cassava farm near the Agricultural Hill closed to Teberebie pit of the mine. The average activity concentration of ^{232}Th was 24.22±17.15 Bq/kg in the range of 6.00 Bq/kg from soil sample taken at Huniso community to 93.64 Bq/kg from a soil sample in the cassava/ cocoyam farm at Agricultural Hill. For ^{40}K, the average activity concentration was 162.08±63.69 in a range of 39.81 Bq/kg in a waste dump in the mine to 551.72 Bq/kg in the same soil sample at Agricultural Hill. The reported total uncertainties are based on random (counting statistics) and systematic errors (uncertainty in efficiency, calibration source uncertainty) involved in producing the final nuclide activity concentration. In general, the activity concentrations of radionuclides in the different types of samples are variable and do not show any particular pattern. The reasons for the variations in the activity concentrations could be due to differences in soil characteristics and geological properties from one location to another as shown in Table 2.

The average activity concentrations ^{226}Ra, ^{232}Th and ^{40}K in this study are lower than the worldwide average values of 32, 45 and 420 Bq/kg, respectively (UNSCEAR, 2000). It is also worth noting that the ^{226}Ra activity concentrations, in all the 38 composite samples had values less than the worldwide average. For ^{232}Th the values in all the

TABLE 3

Results of the average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K together with their total uncertainties, total absorbed dose, annual effective dose, radium equivalent activity and hazard indices of the samples in the study area

Community	*Activity concentration, Bq/kg*			*Absorbed dose rate, nGy/h*	*Annual effective dose, mSv*	*Ra_{eq}, Bq/kg*	*Hazard index (H_{in})*	*External internal (H_{ex})*
	^{226}Ra	^{232}Th	^{40}K					
Abekoase	16.78 ± 1.05	13.75 ± 1.22	125.81 ± 10.75	21.18	0.14	46.12	0.13	0.17
Brahabebom	18.11 ± 1.14	37.50 ± 1.20	163.79 ± 13.40	38.08	0.24	84.36	0.23	0.28
Huniso	5.22 ± 0.46	6.00 ± 0.68	61.19 ± 5.64	9.05	0.06	18.51	0.05	0.06
New Atuabo	13.45 ± 0.97	35.18 ± 2.40	194.58 ± 15.47	35.49	0.22	78.73	0.21	0.25
Pepesa	14.63 ± 0.88	10.47 ± 0.99	60.44 ± 5.56	14.50	0.09	34.26	0.09	0.13
Samahu	15.59 ± 0.97	19.21 ± 1.51	132.62 ± 11.02	24.04	0.15	53.27	0.14	0.19
Tarkwa	23.05 ± 1.33	67.16 ± 1.33	248.88 ± 19.48	62.72	0.39	138.26	0.37	0.44
Mine (rock)	8.56 ± 0.78	20.39 ± 1.65	194.87 ± 18.31	23.32	0.13	55.51	0.13	0.15
Mine (tailings)	7.18 ± 0.66	14.67 ± 1.26	190.66 ± 15.09	19.98	0.13	42.83	0.12	0.14
Mine (soil)	13.49 ± 0.94	17.90 ± 1.40	247.99 ± 19.45	27.16	0.17	58.19	0.16	0.19
Range	2.26–30.57	6.00–93.64	39.81–551.72	9.09–79.79	0.06–0.49	18.51–179.37	0.05–0.48	0.06–0.57
Average±Stdev	13.61 ± 5.39	24.22 ± 17.15	162.08 ± 63.69	27.55 ± 15.10	0.17 ± 0.09	61.00 ± 33.33	0.16 ± 0.09	0.20 ± 0.10

TABLE 4
Radon emanation coefficient of the soil, tailings and rock samples

Location	*Number of samples*	*^{226}Ra, Bq/kg average ±SD*	*EF ± SD*
Mine soil Tarkwa (GS)	6	19.65 ± 2.47	0.53 ± 0.03
Mine rock Tarkwa (MS)	6	19.38 ± 10.06	0.55 ± 0.03
Mine north Heap Leach (M)	6	9.20 ± 0.35	0.53 ± 0.03
Mine south Heap Leach (M)	3	8.27 ± 1.07	0.55 ± 0.03
Mine Tailing (F)	6	10.31 ± 2.19	0.51 ± 0.03
Mine Waste (Rock) (MS)	12	8.52 ± 1.31	0.54 ± 0.03
Mine Pit (Teberebie) (M)	3	8.80 ± 0.63	0.80 ± 0.04
Mine Pit (Pepe) (M)	6	10.20 ± 0.93	0.53 ± 0.03
Mine Pit (Kontraverchy) (M)	6	9.74 ± 1.90	0.54 ± 0.03
Mine Pit (Akontansi) (M)	9	10.12 ± 1.82	0.53 ± 0.05
Ore Stockpile (MS)	3	6.50 ± 0.42	0.52 ± 0.03
Plant Site (M)	6	15.52 ± 5.72	0.52 ± 0.03
New Atuabo community (GS)	6	11.15 ± 1.75	0.52 ± 0.03
Goldfields Clubhouse (GS)	3	32.41 ± 7.13	0.56 ± 0.03
Brahabebom community (GS)	3	6.20 ± 0.54	0.52 ± 0.05
Samahu community (GS)	9	15.71 ± 6.51	0.63 ± 0.04
Boboobo community (GS)	3	29.80 ± 5.08	0.56 ± 0.03
Abekoase community (GS)	6	14.47 ± 5.13	0.54 ± 0.03
Huniso community (GS)	3	14.83 ± 4.01	0.57 ± 0.03
Pepesa community (GS)	3	19.54 ± 2.21	0.51 ± 0.03
UMAT/Agric Hill (GS)	6	28.91 ± 1.10	0.58 ± 0.03

Legend: GS- granular samples; M- mixed samples (granular and massive); MS- massive samples; F-fine particles samples, UMAT- University of Mines and Technology; EF-emanation fraction and SD-standard deviation.

samples are lower than the world average except values in soil samples in farms at Agricultural Hill and University of Mines and Technology in Tarkwa. The ^{40}K activity concentrations in all soil/rock samples have values less than the worldwide average value except soil sample at Teberebie pit of the mine. The results of the activity concentrations in this study compared quite well with similar studies that have been carried out in other countries as shown in Table 5. This implies that the rock of the area which is sedimentary have low levels of radioactivity.

The results of the calculated absorbed dose rate in the soil/rock samples varied in a range of 9.05-79.79 nGy/h with an average value of 27.55 nGy/h. The average absorbed dose rate in this study is lower than the worldwide average value of 60 nGy/h estimated from soil concentrations (UNSCEAR, 2000). The corresponding estimated annual effective dose was 0.17 mSv/year. The natural radioactivity in building materials is usually determined from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K. In order to assess if the soil/rock in the study area could be a source of public radiation exposure if used for building purposes the following hazard assessments

TABLE 5

Comparison of the average activity concentrations, the radium equivalent activities (Ra_{eq}) of soil, rocks, waste and tailings of the study area with published data.

Country	*N*	*Specific activity concentration, Bq/kg*			*Ra_{eq}*	*Reference*
		^{226}Ra	*^{232}Th*	*^{40}K*	*Bq/kg*	
Australia	7	51.5	48.1	114.7	129.4	Beretka and Mathew (1985)
Austria	18	26.7	14.2	210	63.1	Sorantin and Steger (1984)
Algeria	12	41	27	422	112	Amrani and Tahtat (2001)
Brazil	1	61.7	58.5	564	188.8	Malanca *et al.* (1993)
China	46	56.5	36.5	173.2	122	Zinwei (2005)
Egypt	85	78	33	337	151	El Afifi *et al.* (2006)
India	1	37	24.1	432.2	104.7	Kumar et al. (1999)
Japan	16	35.8	20.7	139.4	-	Suzuki et al. (2000)
Netherlands	6	27	19	230	71.9	Ackers et al. (1985)
Tunisia	2	21.5	10.10	175.5	49.7	Hizem et al. (2005)
Turkey	145	40	28	248.3	99.1	Turhan and Gurbuz (2008)
Ghana	38	12.5	23.9	206.2	62.5	This work

Legend: N- number of samples

were used; radium equivalent (Ra_{eq}) activity in Bq/kg, external (H_{ex}) and the internal hazard (H_{in}). The radium equivalent activity is related to the external gamma dose from the terrestrial radionuclides and the internal dose due to radon and its decay products of ^{210}Pb and ^{210}Po.

In this study, the average radium equivalent activity in the samples was 61.00 Bq/kg in a range of 26.81–179.37 Bq/kg. The average external and internal indices were 0.16 and 0.20, respectively. The maximum acceptable value of Ra_{eq} in building materials must be less than 370 Bq/kg for the material to be considered safe for use. The values of the Ra_{eq}, H_{ex} and H_{in} are below the acceptable values. This indicates that soil and other materials in the study area that might be used for building purposes for shelter may not pose any significant radiological radiation hazard and, thus, regarded safe.

The results of ^{222}Rn emanation fraction (EF) in the samples and the average activity concentration of ^{226}Ra are shown in Table 6. The result of the EF varied in a range of 0.51 in mine tailings (fine particles) to 0.80 in a mine pit samples containing granular and massive particles. The result from the study has also confirm previous studies which indicates that the variation of EF is independent of the ^{226}Ra content in the sample, and is strongly correlated with the grain surface density (White & Rood, 2001). The results in this study for both granular and massive samples also showed that the EF of the different types of samples are almost the same contrary to what has been reported in earlier EF studie,s where the smaller the grain size the higher the EF as follows EF(GS)>EF(M)>EF(MS). Generally, the ^{222}Rn EF of different Te-NORM wastes can be ordered as follows: mining > gypsum > oil

and gas > coal power plant (Afifi *et al.,* 2004). The EF values in this study are compared with similar studies as shown in Table 6.

The radiological fatality cancer risks for the population and severe hereditary effects based on ICRP risk assessment methodologies (ICRP, 1991; 2007) were carried out and the results shown in Table 7. The estimated lifetime fatality cancer risk and the lifetime hereditary effect were 6.5×10^{-4} and 2.4×10^{-5}, respectively. This means that approximately seven persons out of 10,000 people are likely to suffer from cancer related diseases from irradiation due to low background radiation exposure. In the case of lifetime hereditary effect, approximately two people out of 100, 000 are likely to suffer from some form of hereditary diseases. This means that the lifetime fatality cancer risk is slightly above the USEPA acceptable range of risks of 1×10^{-6} to 1×10^{-4} values for the population of the study area.

TABLE 6
Comparison of activity concentration of ^{226}Ra and ^{222}Rn emanation fraction (EF) of the study with different NORM waste from various industrial activities

Industrial activity concentration, kBq/kg	*^{226}Ra activity*	*^{222}Rn EF*	*Reference*
Oil and gas production			
Oklahoma	76.1	0.087	USEPA (1993)
Michigan	15.4	0.138	USEPA (1993)
Phosphate industry			
Gypsum	1.2	0.200	USEPA (1993), Egidi and Hull (1997)
Slag	1.26	0.010	USEPA (1993), Egidi and Hull (1997)
Power plants generation			
Coal ash	0.14	0.020	USEPA (1993), Egidi and Hull (1997)
Metallurgical processing			
Uranium mining	0.92	0.300	White & Rood (2001)
Rare earth's	666	0.300	White & Rood (2001)
Gold mining	0.013	0.554	This work

TABLE 7
Estimated risk due to radionuclides in soil and rock samples

Mode of exposure	*Average annual effective dose, mSv/year*	*Fatality cancer risk to population per year*	*Lifetime fatality cancer risk to population*	*Severe hereditary efects per year*	*Estimated lifetime hereditary effects*
External irradiation due to U, Th and K in soil/rock samples	0.17	$9.4 \times 10^{-}$	$6.5 \times 10^{-}$	$3.4 \times 10^{-}$	$2.4 \times 10^{-}$

Conclusion

The activity concentrations of the naturally occurring radionuclides of ^{226}Ra, ^{232}Th and ^{40}K in soil, rock, wastes and tailing samples were determined by gamma spectrometry. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the samples were estimated to be 13.61 Bq/kg, 23.86 Bq/kg and 162.08 Bq/kg, respectively. The average radium equivalent activity in the samples was 61.00 Bq/kg. The absorbed dose rate due the radionuclides in the samples was calculated to be in a range of 9.05 to 79.79 nGy/h with an average value of 27.55 nGy/h. The corresponding annual effective dose was calculated to be 0.17 mSv/year. The external and the internal hazard indices in all the samples were less than unity with average values of 0.16 and 0.20, respectively. The values of the radon emanation fraction of the samples were less than unity with values ranging from 0.51 to 0.80. On the basis of the radium equivalent activity, radon emanation fractions, hazard indices, the absorbed dose rate and annual effective dose of all the samples studied, it can be concluded that these materials if used for construction of dwellings by the inhabitants of the study area might not pose any significant radiation hazard. The results in this study compare well with some studies in other countries and show some variations in other countries. Any variation could be attributed to differences in geological formations.

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