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Investigations of Possible Radiation Risks for Agricultural Farmlands used as Sand Winning Sites in Ghana

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Abstract

The radiological impact associated with naturally occurring radionuclides materials (NORMs) in cultivated lands as a result of the application of fertilizers has been investigated in a farming community in the Eastern Region of Ghana using gamma spectroscopy. The study was to determine the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in different brands of fertilizers available, and widely used as well as the levels of NORMs on agricultural lands where these fertilizers are applied for agricultural purposes. The radiological hazards associated with the storage and use of the fertilizers have been estimated in terms of ambient dose rates to workers during the handling of stockpiles in the warehouse and absorbed doses during farming activities. The risk indices such as the effective dose rate calculated for cultivated soils were found to be higher than their corresponding virgin soils but generally lower than the world averages and recommended limits. Radioactivity level index, radium equivalent values, internal and external exposure hazard indices were calculated for soil samples from the cultivated and virgin lands. Calculated values of these indices in soil samples were lower than the recommended limits and therefore pose no threat to the environment.

Keywords: Fertilizers; Radioactivity; Radionuclides; Effective dose

Introduction

The application of fertilizers to soils to improve soil fertility and crop yields has received significant interest in the 21st century, becoming a global practice. According to Khater and Al-Sewaidan [1] globally, more than 30 million metric tonnes of phosphate fertilizers are used every year to improve crop yields. The radioactivity content of phosphate fertilizers varies according to the geological origin of the phosphate ore and the method of production [2-4].

Fertilizers, particularly, phosphate fertilizers might contain elevated levels of naturally occurring radionuclides of the ^{238}U, ^{232}Th decay series as well as ^{40}K. Reports indicate that in 2019, Ghana experienced a significant increase in the importation of fertilizers (425,110 metric tonnes) evidently to support the Government's planting for food and jobs program [5].

The extensive use of these fertilizers is therefore likely to increase the radionuclide content of soils leading to a corresponding increase in doses to the public through external exposures from fertilized soils and a likely internal exposure from eating of foods cultivated on such soils [6-9]. Thus, prolonged use of fertilizers that contain naturally occurring radionuclide materials (NORMs) might result in significant radiological risks to the environment [10].

It has also been estimated that workers who handle fertilizers during packaging and transport are likely to receive additional external exposures at dose rates up to 0.8 $mGy.hr^{-1}$ [11].

Furthermore, the storage of huge stockpiles of phosphate fertilizers especially in warehouses may elevate the dose rates leading to significant exposures should gamma indices indicate high levels[12].

Therefore, the potential hazards associated with the level of NORMs in phosphate fertilizers must be studied and documented.

In this work, the radiological impact of NORMs (^{226}Ra, ^{232}Th, and ^{40}K) was investigated in the usage of phosphate and organic fertilizers in the New Juaben Municipality (NJM) farming area of the Eastern region of Ghana. The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in different brands of fertilizers available, and widely used in Ghana as well as the levels of NORMs on agricultural lands where these fertilizers are applied for agricultural purposes would be determined. The radiological hazards associated with the storage and use of the fertilizers would be estimated in terms of ambient dose rates to workers during the handling of stockpiles in the warehouse and absorbed doses during farming activities.

In this age of industrialization, some of these farmlands are being turned into sand winning sites. NORMs in mill tailings that are being used for construction in a mining community in Ghana have been determined by Gbadago et al [2].

Therefore, in this study NORMs from soils in these farmlands which are used as building materials was calculated as they could be sources of internal and external radiation exposure. The results of this study are considered part of baseline data for observing possible future anthropomorphic impact or associated radiological risks through fertilizer use. Soils from these farmlands could be assessed as building materials for regulatory purposes.

Study Area

New Juaben covers an area of 159 km^2 among the twenty-one (21) administrative districts in the Eastern Region of Ghana. On the North-East, it shares a boundary with East Akim district, to the South-East with Akwapem North, Yilo Krobo on the East and Suhum Kraboa Coaltar district on the West [13].

Koforidua is the capital town of the Eastern Region which serves as the central supplying channel of fertilizers to its villages and other districts famous for agricultural production. The rural fertile lands are very much adapted for small to medium-scale farming, cattle rearing, and poultry. According to Pabi and Attua [14], the geological feature of the northern section of the region is characterized by the Voltaian scarp which consists of chalk and coarse sandstone with some shales interstratified. The climatic zone of the Municipality falls within the semi-deciduous rain forest whiles its vegetation is typified by tall trees with evergreen undergrowth consisting of some commercial trees such as *Odum, Kyenkyen, Wawa*, and others used for furniture and construction [13].

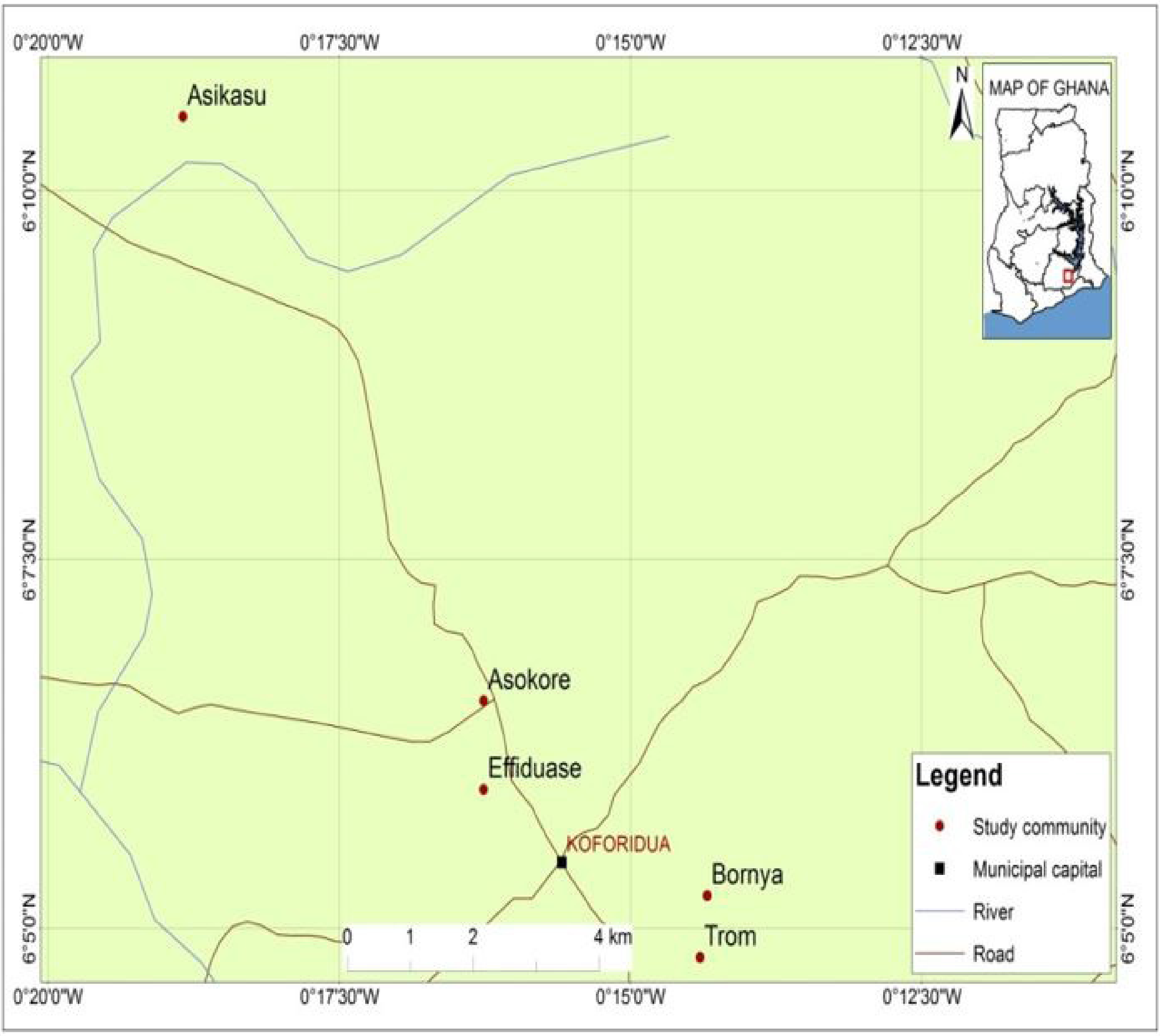

Figure 1: Map of New Juaben Municipality indicating the study communities

Materials and Methods

Sample collection and preparation

Twenty-eight (28) fertilizer samples made up of six (6) brands of phosphate fertilizers and one (1) brand of organic fertilizer available on the New Juaben Municipality market were collected from different fertilizer retail shops. Information on origin, form, and percentages of main components was collected and tabulated (Table 1). Using a digital survey meter RADOS RDS-200, in each of the fertilizer storage rooms, the ambient gamma dose rates were measured at 1 meter above ground and the average value recorded in μSv/h.

Fertilizer ID	Origin	Form	Main Components (%)		
			Nitrogen	Phosphorus	Potassium
FT1	Israel	Granulated	12	12	61
FT2	USA	Granulated	15	5	30
FT3	Israel	Powdered	19	19	19
FT4 (organic compost)	Ghana	Powdered	Unknown	Unknown	Unknown
FT5	Belgium	Granulated	23	10	10
FT6	Russia	Granulated	15	15	15
FT7	Ghana	Granulated	15	15	15

Table 1: Information on the fertilizer samples used in this work

In addition to the fertilizer samples, forty-nine (49) soil samples were taken from seven (7) farmlands in five (5) different farming communities (Asokore, Effiduase, Asikasu, Bornya, and Trom) in the municipality to assess the impact of NORMs from the application of fertilizers to the agricultural soils. Also, virgin soil samples (soils on which no fertilizers have been applied) were collected as control samples from the same towns. The soil samples were air-dried for 7 days and then oven heated at a temperature of 105°C for about 3-4 hours to completely remove moisture [15].

The samples were ground into a fine powder using a ball mill and sieved through a 500 μm mesh size pore into one Litre (1 L) Marinelli beakers, weighed, and then sealed for a month to establish secular equilibrium between short-lived daughters of ^{238}U and ^{232}Th decay series and their long-lived parent radionuclides before counting [7,15].

Specific activity measurement

For this study, a Canberra PC-based gamma-ray spectrometer consisting of an extended range coaxial germanium detector (XtRa), a high voltage power supply, a preamplifier, an ultra-low background cryostat: U- style integral, a multichannel analyzer (MCA), and a GENIE 2000 analytical software (for data acquisition, manipulation, and analysis of spectra on a computer) at the Ghana Atomic Energy Commission (GAEC) was used for spectrometric analysis of the samples. The detector crystal was cooled by liquid nitrogen at a temperature of -196 °C, provided in a 30 L Dewar. The relative efficiency of the detector was 40 % with energy resolutions of 1.10 keV and 2.0 keV at gamma-ray energies of 0.122 MeV and 1.332 MeV of ^{57}Co and ^{60}Co, respectively. An artificial multinuclear reference standard with an energy range of 60 keV to ~2000 keV was used for its energy and efficiency calibrations. The spectrum of the standard source was obtained by counting it for 36 000 s via the XtRa detector. The Minimum Detectable Activity (MDA) was also determined for the gamma spectrometer by counting for the same period (36 000 s) as would for the samples and an empty, clean and dry 1 L Marinelli beaker to obtain the background spectrum [16]. The gamma-emitting radionuclides within the uranium and thorium series were then used to quantify the activity concentrations of the parent radionuclides which cannot be measured directly [16,17]. ^{40}K is measured directly using the gamma energy line at 1460.82 keV. For ^{226}Ra, the gamma energy lines used were ^{214}Pb (351.93 keV) and ^{214}Bi (609.31 keV and 1764.49 keV) whiles for ^{232}Th, ^{212}Pb (238.63 keV), ^{208}Tl (583.19 keV) and ^{228}Ac (911.21 keV) gamma energy lines were used [16,18]. The specific activity concentration of NORMs in both the fertilizer and soil samples was calculated using the analytical expression [16].

$$A_{sp}(E,i) = \frac{N_{sam(E,i)}}{\varepsilon_\gamma(E).T_c.P_{\gamma(E,i)}.M_{sam}}$$

where: A_{sp} is the specific activities in Bq/kg of the radionuclides in a sample, $N_{sam\ (E,\ i)}$ is the net counts for the radionuclide, *i* at energy *E*, M_{sam} is the dry weight of the sample (kg), ε_γ is the photopeak efficiency, $P_{\gamma\ (E,\ i)}$ is the gamma emission probability of the radionuclide, *i* for a transition at energy *E* and T_c is the counting time. Interfering gamma lines were corrected using the following equation [2,19];

$$A_{C,E} = A_{T,E} - X_I \times \frac{f_{I,E}}{f_{T,E}}$$

where $A_{C,E}$ is the corrected radionuclide activity at energy *E* and $A_{T,E}$ is the activity being corrected at energy *E*. X_I is a corrected activity of the interfering nuclide, $f_{I,E}$ is the intensity of the interfering nuclide at energy *E* and $f_{T,E}$ is the intensity of $A_{T,E}$. The uncertainties were computed from;

$$\sigma_{C,E} = (\sigma_{T,E}^2 + \sigma_I^2 \times \frac{f_{I,E}}{f_{T,E}})^{\frac{1}{2}}$$

Ambient Gamma Dose rate in the fertilizer storage rooms

During sampling, the ambient gamma dose rates were measured in the fertilizer storage rooms using a digital survey meter, RADOS RDS-200 (Serial No. 241041) which is a multipurpose radiation meter useful for low dose rate measurements. The dose rate meter was calibrated at the Radiation Protection Institute's Secondary Standard Dosimetry Laboratory of Ghana Atomic Energy Commission with a calibration factor provided. At each fertilizer storage room, ten (10) measurements were made at 1 m above ground and the average value taken in µSv/h.

Estimation of absorbed and effective dose for farm soils

According to UNSCEAR [20,21], the absorbed gamma dose rates in the air at 1 m above the ground surface for the uniform distribution of radionuclides (^{238}U, ^{232}Th, and ^{40}K) can be calculated in nGy h^{-1} from

$$D(nGy.hr^{-1}) = 0.462C_{Ra} + 0.604C_{Th} + 0.0417\,C_K$$

where C_{Ra}, C_{Th}, and C_K are the average specific activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K, respectively, expressed in Bq kg^{-1}. The conversion factors used to compute the gamma dose rate (*D*) in air per unit activity concentration in 1 Bq kg^{-1} of sand correspond to 0.604 nGy h^{-1} for ^{232}Th, 0.462 nGy h^{-1} for ^{238}U, and 0.0417 nGy h^{-1} for ^{40}K [2,22].

The biological effects of ionizing radiation on humans are evaluated based on the effective absorbed dose rate. To evaluate the annual effective dose equivalent (AEDE), the conversion coefficient from absorbed dose in the air to effective dose of 0.7 × 10^{-6} mSv nGy^{-1} and outdoor occupancy factor of 0.2 proposed by UNSCEAR [20] were used. The effective dose rate in units of mSv y^{-1} was calculated as follows assuming 8760 h of exposure:

$$D_{eff}\ (mSv) = D \times 8760\ h \times 02. \times 0.7\ \times\ 10-6$$

Radium Equivalent activity and gamma radiation hazard indices

The estimation that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th, and 4810 Bq/kg of ^{40}K give the same gamma dose rate is used to calculate the radium equivalent activities (Ra_{eq}).

According to [23], the Ra_{eq} is given as;

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K$$

Where A_{Ra}, A_{Th}, and A_K are the activities of ^{226}Ra, ^{232}Th, and ^{40}K, respectively.

Also, [2] reports on the use of;

$$f_1 = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000} \text{and } f_2 = \frac{C_{Ra}}{200}$$

to measure the external and internal exposure indices respectively. The external exposure index f_1 describes the content of NORM in the building material and is also calculated using the concentrations of ^{226}Ra, ^{232}Th, and ^{40}K. The internal exposure index f_2, limits the concentration of ^{226}Ra due to the potential internal radiation exposure to ^{222}Rn and its decay products. This index will restrict radon concentrations in buildings to below 200Bq/m^3. For building materials, the indices must be less than unity, i.e. f_1 and $f_2 \leq 1$.

Radioactivity level index

Radioactivity level index (Iγ) is used to determine the level of risk associated with natural radionuclides in a specific material [2].

Radioactivity level index (Iγ) is given by;

$$I_\gamma = \frac{C_{Ra}}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \leq 1.$$

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

Results and Discussion

Activity Concentration in the Fertilizers and farm soils

The specific activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in seven fertilizer brands imported into the country have been measured and presented in Table 2.

Fertilizer ID	Activity Concentration (Bq/kg)		
	^{226}Ra	^{232}Th	^{40}K
FT1	<0.14	0.20 ± 0.04	5.4 ± 0.5
FT2	<0.14	<0.12	4902 ± 245
FT3	1.7 ± 0.6	<0.12	4734 ± 237
FT4 (Organic)	8.7 ± 0.8	7.9 ± 0.9	299 ± 15
FT5	108 ± 10	9.4 ± 1.3	2255 ± 113
FT6	<0.14	6.2 ± 1.0	5325 ± 267
FT7	11 ± 3.4	37.2 ± 7.5	3518 ± 176

Table 2: Activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the fertilizers

^{226}Ra activity concentrations were recorded in four of the fertilizer samples. FT5 recorded the highest activity concentration of ^{226}Ra. Except for FT5, all the fertilizer samples recorded activity concentrations less than the permissible value of 35 Bq/kg for ^{226}Ra. The concentration of ^{232}Th, varied from 0.2 to 37.2 Bq/kg with an average value of 12.2 ± 1.6 Bq/kg. Except for FT7, all of the fertilizer samples recorded values less than the permissible limit of 35 Bq/kg for ^{232}Th. All the fertilizer samples recorded ^{40}K activity ranging from 5.4 to 5325 Bq/kg with an average concentration of 3006 ± 69 Bq/kg. FT1 and FT4 are the only fertilizer samples that recorded lower values than the permissible value of 400 Bq/kg for ^{40}K. Among the three (FT4, FT5, and FT7), FT4 recorded relatively the lowest levels of activity. FT4 is an organic fertilizer and contains relatively lower concentrations of phosphate whereas the others are phosphate fertilizers and thus have rich content of phosphate. FT1 is also a phosphate fertilizer but recorded a relatively lower activity level of ^{40}K. This could be attributed to the variation in the geological settings where the ores are mined and also the chemical processing of the ores for the production of fertilizers. UNSCEAR [24] reports variations in the measured activity concentrations of naturally occurring radionuclides in phosphate fertilizers from different countries of a given radionuclide and type of fertilizer. The report shows that the concentrations differ significantly from one country to the other depending on the origin of the components.

Country	Mean Activity Concentration (Bq/kg)		
	^{226}Ra	^{232}Th	^{40}K
Ghana	32.10±2.60	12.20±1.60	3005.50±68.80
Serbia	87±8	BDL	4860±250
Italy	120	3.5	4000
Nigeria	24.87±0.02	45.04±0.04	305.33±0.19
India	340	25.2	906.5
Finland	54	11	3200
Saudi Arabia	64	17	2453

Table 3: Mean Activity Concentration of ^{226}Ra, ^{232}Th, and ^{40}K in the fertilizers compared to other published works

It is observed in Table 3 that the average activity concentration of ^{226}Ra of the fertilizers in this study is less than other published works [25, 11, 7, 26, 4] except for Nigeria [27]. The average activity concentration of ^{232}Th was also found to be higher than reported activity concentrations from Serbia (below the detection limit, BDL), Italy (3.5 Bq/kg), Finland (11 Bq/kg) but was lower than reported works in Nigeria (45.04±0.04 Bq/kg), India (25.2 Bq/kg) and Saudi Arabia (17 Bq/kg). The ^{40}K activity concentration of the fertilizers in this present work compared well with other published data in other countries are within the world mean range. Table 3 shows the mean value of ^{40}K in fertilizers in this present study to be about 10 times higher than the mean ^{40}K activity concentration in Nigeria, but it was found to be lower compared with the means obtained in Italy, Serbia, and Finland.

Soil ID	Activity Concentration (Bq/kg)		
	^{226}Ra	^{232}Th	^{40}K
ASI VIRGIN	13.30± 1.40	10.90± 1.40	207.50± 10.80
ASO-EFF VIRGIN	7.20± 0.80	6.70± 0.70	86.50± 4.50
BOR- TRO VIRGIN	6.40± 0.70	6.60± 0.70	123.0± 6.30
AVERAGE	**9.0±1.7**	**8.10±1.70**	**139.0±13.3**
TRO	10.90 ± 1.10	8.90 ± 0.90	186.30 ± 9.50
ASI	18.40 ± 1.80	16.90 ± 1.60	333.60 ± 16.90
ASO 1	14.40 ± 1.40	6.80 ± 0.70	191.50 ± 9.80
ASO 2	8.20 ± 0.90	5.60 ± 0.60	148.20 ± 7.60
BOR 1	12.00 ± 1.20	10.2 ± 1.0	109.60 ± 5.70
BOR 2	12.80 ± 1.20	12.10 ± 1.10	129.0 ± 6.6
EFF	11.0 ± 1.1	13.80 ± 1.30	344.10 ± 17.40
AVERAGE	**12.50 ±3.30**	**10.60 ± 2.80**	**206.0 ± 30.2**

(ASI VIRGIN, ASO-EFF VIRGIN, BOR-TRO VIRGIN are Virgin soils from Asikasu, Asokore, and Effiduase, and Bornya and Trom, respectively; TRO, ASI, ASO 1, ASO 2, BOR 1, BOR 2 and EFF- are cultivated farms from Trom, Asikasu, Asokore, Bornya, and Effiduase, respectively)

Table 4: Results of the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the cultivated farm soils and virgin soils

Table 4 shows the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in cultivated soils in the various communities namely, Trom, Asikasu, Asokore, Bornya, and Effiduase together with their respective virgin soils. The activity concentration of ^{40}K was generally higher than the activity levels of ^{226}Ra and ^{232}Th in the soils studied. Generally, except in a few cases, the results in Table 4 show the average activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the cultivated soils are relatively higher than that in the virgin (uncultivated) soils. This suggests that the use of phosphate fertilizers (mostly the NPK fertilizers) to enhance soil fertility in the New Juaben Municipality might be contributing to the enhancement of ^{226}Ra, ^{232}Th, and ^{40} K in the farm soils. Unlike radionuclides such as Uranium, Lead, Polonium, and Thorium, ^{226}Ra has a moderate level of decay and can accumulate in the soil. As a result, ^{226}Ra can easily be transferred from soil to plant thereby increasing the possibility of dietary exposure through agricultural and horticultural purposes [28]. In another study relating to the uptake of radionuclides from soil by plants, Markovic and Stevovic [29] report that ^{40}K has a high transfer factor as compared to ^{226}Ra and ^{232}Th due to the selective absorption of essential elements in the plants. On the other hand, the availability of ^{232}Th for root uptake in the plant is reduced as phosphate is added to the soil. This is due to the formation of phosphate salts that have low solubility.

According to UNSCEAR ([20]. the report, the world average value of the activity concentration of ^{232}Th is 30 Bq/kg and for ^{40}K is 400 Bq/kg in soil. The mean activity concentrations of ^{232}Th and ^{40}K in both the virgin and cultivated soil samples in this present study were far below the world average values as well as other similar studies in other countries. Hameed et al. [25] reports on the activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in India's virgin soil as 6.8±3.2 Bq/kg, 87.5±63.5 Bq/kg, and 419±51.8 Bq/kg, respectively. Whereas the cultivated soil recorded concentrations of 8.4±4.5 Bq/kg, 98.8±63.6 Bq/kg, and 436±59.2 Bq/kg of ^{226}Ra, ^{232}Th, and ^{40}K, respectively. Unlike many other countries of the world, statistics show that fertilizer use for agricultural purposes in Ghana is low possibly due to accessibility and financial constraints [30]. This may account for relatively lower activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in its cultivated soils.

Location	Effective Dose Rates (μSv/a)		
	Background	Fertilizer Storage rooms	Range
S1	221.80±2.20	491.10 ± 4.90	346.90-722.70
S2	229.70±2.30	336.60±3.40	202.40-462.50
S3	245.50±2.50	364.40±3.60	277.50-520.30
S4	198±2	154.50±1.50	40.50-231.30
S5	198±2	305±3	231.30-318
S6	221.80±2.20	554.50±5.50	404.70-664.90
S7	316.80±3.20	819.80±8.20	404.70-1272
S8	174.30±1.70	582.20±5.80	433.60-751.60

Table 5: Annual Average Effective Gamma dose rates in the various fertilizer storage rooms

Ambient dose rates measured in the storage rooms were relatively higher than those obtained for the background (Table 5). It is, therefore, possible that the storage of large quantities of fertilizers in closed warehouses may lead to high gamma radiation doses as well as the build-up of indoor radon concentrations in highly enclosed and poorly ventilated warehouses. The types of fertilizer, as well as the number of fertilizers stored in the storage rooms, could also contribute to high ambient dose rates. Though the average ambient gamma dose rates recorded in the storage rooms were higher than their respective background doses, they were found below the annual exposure limit of 1mSv (1000 μSv) for the public. However, the workers may need to limit the number of hours of stay in the warehouses to avoid prolonged exposures.

Absorbed and effective dose for farm soils

The results of the outdoor absorbed and effective dose rates in both the cultivated and virgin soils are shown in Table 6. The mean absorbed dose rate in the air at 1m above the ground calculated from the soil activity concentrations of both the virgin and cultivated lands were found to range from 14.8 nGy/h to 20.80 nGy/h. These values were found to be comparable to reported ranges of 18 - 93 nGy/h and relatively lower than the mean value of 59 nGy/h as reported by UNSCEAR [20].

Sample ID	D (nGy/h)	D_{eff} (mSv y^{-1})
ASI VIRGIN	21.40	0.03
ASO-EFF VIRGIN	11	0.01
BOR-TRO VIRGIN	12	0.02
AVERAGE	**14.80**	**0.02**
TRO	18.20	0.02
ASI	32.60	0.04
ASO 1	18.70	0.02
ASO 2	13.30	0.02
BOR 1	16.30	0.02
BOR 2	18.60	0.02
EFF	27.80	0.03
AVERAGE	**20.80**	**0.03**

Table 6: Results of the absorbed and annual effective dose rates, in both virgin and the cultivated farm soils

The annual effective dose, D_{eff} (Table 6), indicates a range of 0.01 to 0.03 mSv/y for the virgin soils and a range of 0.02-0.04 mSv/y for the cultivated soils. All these values are within the annual exposure limit of 1 mSv/y, for a member of the public as proposed by UNSCEAR [31].

Radiation hazard indices and radioactivity level index of farm soils used as building materials

The averages of radiation hazard indices and radioactivity level index of farm soils used as building materials are presented in Table 7.

Soil ID	Ra_{eq} (Bq/kg)	f_1	f_2	I_γ
ASI VIRGIN	44.86±4.23	0.17±0.02	0.07±0.01	0.34±0.03
ASO-EFF VIRGIN	23.44±2.15	0.09±0.01	0.04±0.004	0.17±0.02
BOR-TRO VIRGIN	25.30±2.19	0.10±0.01	0.03±0.003	0.19±0.02
TRO	37.97±3.12	0.14±0.01	0.05±0.01	0.29±0.02
ASI	68.25±5.39	0.26±0.02	0.09±0.01	0.51±0.04
ASO 1	38.87±3.16	0.15±0.01	0.07±0.01	0.29±0.02
ASO 2	27.62±2.34	0.10±0.01	0.04±0.01	0.21±0.02
BOR 1	35.03±3.07	0.13±0.01	0.06±0.01	0.26±0.02
BOR 2	40.04±3.28	0.15±0.01	0.06±0.01	0.29±0.02
EFF	57.23±4.29	0.22±0.02	0.06±0.01	0.44±0.03

Table 7: Average Radiation Hazard Indices of farm soil used as a building material

From Table 7, it is observed that the radium equivalent (Ra_{eq}) values of the farm soils are less than the maximum acceptable value of 370 Bq/kg [23] and ranges between 23.44 Bq/kg and 68.25 Bq/kg. The calculated values of external exposure and potential internal exposure indices, f_1 and f_2 were all below unity. Radioactivity level index (Iγ) which is used to determine the level of risk associated with natural radionuclides in a specific material in this case farm soil as a building material was also found to be below unity in all the soil samples analyzed.

Conclusions

The activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in phosphate and organic fertilizers applied on farms in the New Juaben Municipality were measured using gamma-ray spectrometry. The radiological impact of NORMs in the fertilizers applied on farmlands in the Municipality was evaluated.

The activity concentration of ^{226}Ra, ^{232}Th, and ^{40}K in the fertilizers indicate that fertilizers can be a rich source of supply of ^{226}Ra, ^{232}Th, and ^{40}K to agricultural soils if they are continuously applied year after year. The average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K were generally higher in the cultivated soils than that of the virgin soils but were far below that of world averages given in UNSCEAR [20].

The measured values suggest that the use of these fertilizers does not pose any serious radiological risk to the farmers. The absorbed and effective dose rates in the air at 1m above the ground, estimated for both the virgin and cultivated soil samples were also found to be much lower than the world average permissible limits. This implies that the radiological hazard associated with NORMs in cultivated soils through the application of fertilizers may be insignificant; however, continuous application of fertilizer may result in the accumulation of these radionuclides.

Radioactivity level and radiation hazard indices measured in farm soils used as building materials were found to be less than the recommended levels. It can be concluded that soils from the sampled sites pose no radiological threat to the environment if they are used as building materials. However, it is recommended that assessment of these soils for their radiological impact on the environment is done periodically.

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