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EVALUATION OF NATURAL RADIOACTIVITY CONTENT IN GROUNDWATER SOURCES IN COMMUNITIES ALONG TANO BASIN, GHANA FOR RADIOLOGICAL RISK ASSESSMENT

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ABSTRACT: *The radionuclide concentrations in all water samples were measured using gamma spectroscopy method. The purpose of this study was to evaluate background radionuclides in groundwater sources in the communities, which border the Tano Basin for the radiological risk assessment. The average values of ^{226}Ra, ^{228}Ra and ^{40}K obtained are in the range of 0.14±0.01 to 1.38±0.22 Bq/L, 0.18±0.01 to 1.41±0.18 Bq/L and 0.46±0.02 to 5.92±0.10 Bq/L respectively. The committed effective dose and excess lifetime cancer risk were calculated for four age brackets. The average total annual effective dose for adults that take groundwater ranged from 1.20E-04 ± 8.70E-06 to 9.50E-04 ± 1.52E-04 mSv/y and that for teenagers, children and babies ranged from 9.04E-04 ± 6.07E-05 to 7.04E-03 ± 1.10E-03 mSv/y, 2.74E-04 ± 1.13E-05 to 2.06E-03 ± 2.13E-04 mSv/y and 1.17E-03 ± 7.21E-05 to 8.84E-03 ± 1.35E-03 mSv/y respectively. The excess lifetime cancer risk in adults ranged from 4.21E-04 ± 3.05E-05 to 3.32E-03 ± 5.32E-04. That for teenagers, children and babies ranged from 7.68E-04 ± 5.16E-05 to 5.98E-03 ± 9.37E-04, 1.65E-04 ± 6.79E-06 to 1.24E-03 ± 1.28E-04 and 5.85E-05 ± 3.61E-06 to 4.42E-04 ± 6.76E-05 respectively. Other parameters of the water samples are in the ranges of pH: 4.4 – 7.2, Temperature/OC: 29.1 – 32.9, Conductivity/μScm^{-1}:51.4 – 420, Salinity: 0.0 – 0.1 and Total Dissolved Solids (TDS)/mg/L: 31 – 252.*

KEYWORDS: Radioactivity, Gamma Radiation, Health Hazard, Excess Lifetime Cancer Risk

INTRODUCTION

Produced water generated from oil drilling activities has the potential to contain some level of radioactivity. Discharges of produced water from offshore oil and gas platforms are a continuous source of contaminants [1] to open environment, therefore the determination of naturally occurring radionuclides in groundwater is useful as a direct input to environmental and public health studies [2].

Radionuclides such as ^{238}U, ^{226}Ra, ^{216}Pb, ^{222}Rn and others are frequently dissolved in ground water sources [3]. Considering the carcinogenicity of ^{222}Rn [4] and high radiotoxicity of ^{226}Ra and ^{228}Ra, their presence in water and the associated health risks require particular attention [5]. The concentrations of these radionuclides vary due to the amount of radioelement present in bedrock and soil with which the water comes in contact [6], the origin [5], nature, i.e.

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prevailing lithology and geochemical characteristic [7], and is a function of the Th and U contents in the aquifer, the geochemical properties of the aquifer solids, and the half-lives of each isotope [8; 9).

At the time of the present study, produced water from the Jubilee Oil Field is disposed into the open sea. The only guideline regulating this discharge is the Environmental Protection Agency's guideline of oil-in-water content of 29mg/L for the discharge of produced water into the ocean. Despite this guideline, the produced water may still contain radionuclides as this is not regulated in the guideline. Additionally, there was flaring of natural gas from the wells since the inception of oil production in late 2010 to 2014 when the Atuabo gas processing facility was completed. Gas flaring comes with its attendant adverse environmental, economic and health effects [10].

As the background concentration of natural radioactivity in groundwater in most parts of Ghana is not known, the levels of ^{226}Ra, ^{228}Ra and ^{40}K were investigated in representative groundwater to establish background data on natural radioactivity levels and assess the radiological risk resulting from the consumption of this water.

Study Area

The study area comprises the major communities from Axim to Newtown which are situate along the coast bordering the Tano basin. The Jubilee field discovered in June, 2007 is located in the Gulf of Guinea, 60km off the Ghanaian coast. The wells are at a water depth between 1100 and 1300 meters and at a total depth between 3400 and 4200 meters. The field covers 110 km^2 which is about the size of 155 football pitches [11]. In geographical terms, the Jubilee field is a continuous trap with combined hydrocarbon columns in excess of 600 meters [12]. These communities consist mainly of the Birimian formation: metamorphosed volcanic, sedimentary and plutonic rocks with low grade metavolcanics and metasediments [13].

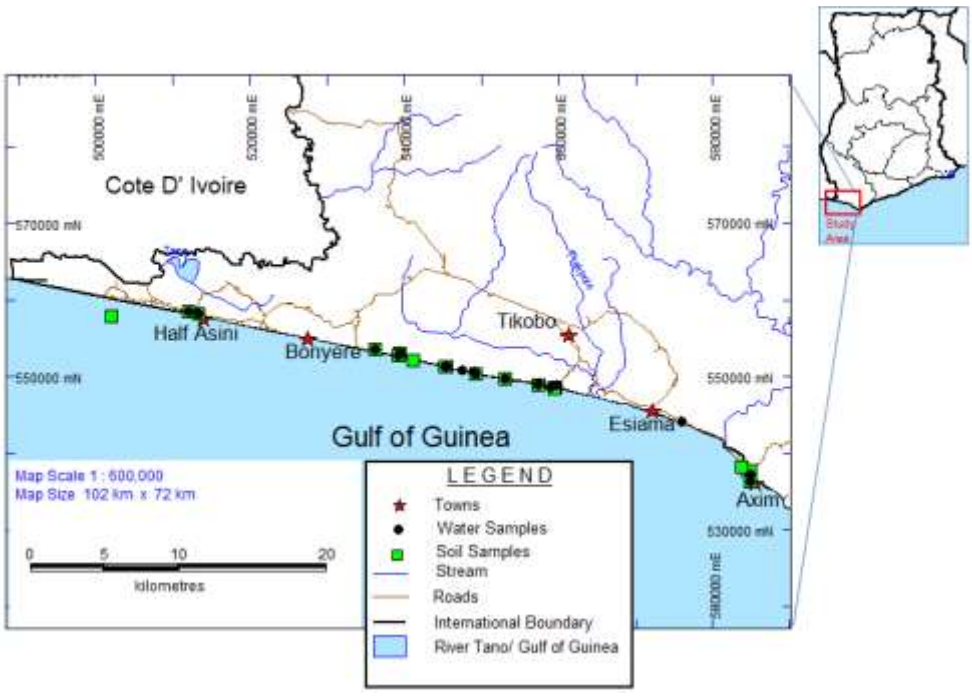

Fig. 1: Map of study area showing sampling locations

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METHODOLOGY

Sampling

The water samples were taken from the drinking water sources in the communities such as boreholes, taps and mechanized pipes. The samples were collected into labelled 500 ml plastic bottles. The bottles were acid washed with concentrated HNO_3 and treated with methylated spirit prior to sampling. This is to ensure that radionuclides remain in solution rather than adhering to the walls of the container and to remove anions from the container. The bottles were also filled to the brim without any head space to prevent the escape of radon and CO_2 being trapped in the water.

Gamma spectrometry of water samples

The activity concentrations of the radionuclides in the samples were measured using a High Purity Germanium Detector (HPGE) detector. Gamma rays of water samples were measured by direct instrumental analysis without pre-treatment. The gamma spectrometry system consists of an n-type HPGE detector (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 spectra were determined using an empty Marinelli beaker and used to correct the net peak area of gamma rays of measured isotopes. 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 1000ml and 1.0 g/m3 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 88Y (1838 keV) with certified uncertainties ≤3%.

The minimum detectable activities (MDA) were calculated according to formula

$$\mathbf{MDA} = \frac{\delta\sqrt{B}}{\eta.P.T.W}\ \mathbf{(Bq/kg)} \qquad \mathbf{(1)}$$

Where;

MDA is the minimum detectable activity

δ is the statistical coverage factor equal to 1.645(confidence level 95%),

B is the background for the region of interest of each radionuclide,

T is the counting time in seconds,

P is the gamma emission probability (gamma yield) of each radionuclide,

W is the weight of the sample container, and

η is the detector efficiency for the measured gamma ray energy.

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Determination of activity concentrations

The activity concentrations of ^{226}Ra, ^{228}Ra and ^{40}K was determined in the water samples using the following analytical expression as shown in equation [14].

$$\mathbf{Asp} = \frac{\mathbf{N_D e^{\lambda_p T_d}}}{\mathbf{p.Tc.\eta.m}} \qquad \mathbf{(2)}$$

Where;

N is the net counts of the radionuclide in the samples,

Td is the delay time between sampling and counting,

P is the gamma emission probability (gamma yield),

η is the absolute counting efficiency of the detector system,

Tc is the sample counting time,

m is the mass of the sample (kg) or volume (l),

$e\lambda pTd$ is the decay correction factor for delay between time of sampling and counting, and

$\boldsymbol{\lambda}$p is the decay constant of the

Dose calculations

The activity concentrations of ^{238}U in water samples was calculated from the average energies of 295.21 and 351.92 of ^{214}Pb and 609.31, 1764.49 keV of ^{214}Bi. The activity concentrations of ^{214}Pb and ^{214}Bi in secular equilibrium with their parents were assumed to represent ^{226}Ra activity concentration. The activity concentrations of ^{228}Ra was determined from the average energies of 238.63keV of ^{212}Pb, 583.19 and 2614.53 keV of ^{208}Tl and 911.21 keV for ^{228}Ac respectively. The activity concentration of ^{40}K was determined from the energy of 1460.83 keV. Effective doses (E_{ing}) from the ingestion of ^{226}Ra, ^{228}Ra, ^{40}K were estimated from the activity concentrations of each individual radionuclide and applying the yearly water consumption rate for adults of 730 L/year (2 L/day multiplied by 365 days for teenagers and adults), the dose conversion factors of ^{226}Ra, ^{228}Ra and ^{40}K taken from the GSR Part 3 and UNSCEAR report, [15; 16] using equation

$$\mathbf{HE}, \boldsymbol{\gamma_{ing}}\ (\boldsymbol{w}) = \boldsymbol{Asp}(\boldsymbol{w}).\ \boldsymbol{I}(\boldsymbol{w}).\ \boldsymbol{\Sigma DCF_{Ing}}\ (\mathbf{^{226}Ra,\ ^{228}Ra,\ ^{40}K}) \qquad \mathbf{(3)}$$

Where,

$\boldsymbol{HE}, \gamma_{ing}\ (\boldsymbol{w})$ is the annual effective dose from ingestion of water

Asp (w) is the activity concentration of the radionuclides in a sample in Bq/L,

I (w) is intake of water in litres per year, and

DCF_{Ing} is the ingestion dose coefficient in Sv/Bq taken from the GRS Part 3 [15].

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The committed effective dose is the arithmetic summation of the effective dose of the three radionuclide measured.

Table 1: Committed effective dose conversion factor (Sv/Bq) for members of the public [17; 15].

Radionuclide	Infant ≤ 1year	Children 1 – 12 years	Teenagers 13 – 17 years	Adults >17 years
^{226}Ra	4.7 E-06	6.2 E-07	1.5E-06	2.8E-07
^{228}Ra	3.0 E-05	3.4 E-06	5.3 E-06	6.2 E-07
^{40}K	6.2 E-08	2.1 E-08	7.6 E-09	6.2 E-09
Volume of Water/L/day	0.5	1.0	2.0	2.0

Excess Lifetime Cancer Risk (ELCR)

ELCR determines the probability of one developing cancer over a lifetime at a given exposure level. It is presented as a value representing the number of cancers expected in a given number of people on exposure to a carcinogen at a given dose [18]. An increase in the ELCR causes a proportionate increase in the rate at which an individual can get cancer of the breast, prostate or even blood [19]. Excess Lifetime cancer risk (ELCR) is given as [20]

$$\boldsymbol{ELCR} = \boldsymbol{E_T} \times \boldsymbol{DL} \times \boldsymbol{RF} \qquad (4)$$

Where:

ELCR is the Excess Lifetime cancer Risk

ET is the annual effective dose,

DL is the duration of life (estimated to 70 years for adults, 17 years for teenagers, 12 years for children and 1 year for infants), and

RF is the Risk Factor (Sv-1), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP uses RF as 0.05 for public [20].

RESULTS AND DISCUSSIONS

The concentrations of ^{226}Ra, ^{228}Ra, and ^{40}K varied from 0.14 ± 0.01 to 1.62 ± 0.30 Bq/L, 0.18 ± 0.01 to 1.42 ± 0.21and from 0.46 ± 0.02 to 2.51 ± 0.15 Bq/L. The values of ^{226}Ra in groundwater samples from Krisan (1.38Bq/L), Kengen 1 (1.13Bq/L), Half-Assini 1&3 (1.62 and 1.03 Bq/L) are close to the maximum contaminant levels of 1.85 mBq/L proposed in the USA [21] for drinking water. The average concentrations are 0.58 ± 0.061 Bq/L, 0.84 ± 0.09 Bq/L and 2.51 ± 0.15 Bq/L respectively for ^{226}Ra, ^{228}Ra and ^{40}K.

The low activity concentrations for ^{226}Ra and ^{232}Th for water samples indicates low radioactivity levels in the aquifer rocks [22]. Radionuclide concentrations in ground waters depend on the minerals derived from aquifer rocks [23], the communities have Birimian

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formation containing rocks such as schist, phyllite and greywackes [24]. It is suspected that the study locations cover an area with similar aquifer lithologies and have no significant differences in radionuclide solubilities and mobilities [25] because the concentrations of radionuclide's ^{226}Ra, ^{228}Ra and ^{40}K in are in the narrow range. Considering that the communities mostly engage in farming, the relatively high levels of ^{40}K activity recorded may be due to the use of potassium fertilizers leaching into groundwater [26]. The average concentration of ^{228}Ra of 0.084 ± 0.09 is higher than that of ^{226}Ra of 0.58 ± 0.06. This does not reflect the fact that ^{226}Ra which is a progeny of ^{238}U should be more soluble in water than ^{228}Ra, a progeny of ^{232}Th which shows high binding capacity with soil [27].

The Minimum Detectable Activities for ^{226}Ra, ^{228}Ra and ^{40}K are shown in Table 3 with estimated values of 0.05, 0.04 and 0.10 Bq/kg respectively.

Table 2: Activity concentrations of ^{226}Ra, ^{228}Ra and ^{40}K in Bq/L

Samples	ACTIVITY CONCENTRATION, Bq/L		
	^{226} Ra	^{228}Ra	^{40}K
WS 1	0.24 ± 0.06	0.54 ± 0.11	3.55 ± 0.58
WS 2	0.82 ± 0.03	0.73 ± 0.02	1.02 ± 0.10
WS 3	0.35 ± 0.02	0.88 ± 0.02	3.92 ± 0.10
WS 4	1.38 ± 0.22	1.12 ± 0.20	4.74 ± 0.52
WS 5	0.56 ± 0.03	0.95 ± 0.02	3.03 ± 0.22
WS 6	0.18 ± 0.01	0.85 ± 0.03	0.92 ± 0.10
WS 7	0.36 ± 0.02	0.78 ± 0.06	3.88 ± 0.09
WS 8	0.25 ± 0.01	1.42 ± 0.21	2.32 ± 0.14
WS 9	0.46 ± 0.07	0.89 ± 0.18	1.42 ± 0.15
WS10	0.14 ± 0.01	1.02 ± 0.03	5.92 ± 0.10
WS 11	0.37 ± 0.06	1.41 ± 0.18	4.64 ± 0.21
WS 12	0.15 ± 0.01	0.19 ± 0.02	0.78 ± 0.12
WS 13	0.61 ± 0.02	0.37 ± 0.04	2.61 ± 0.09
WS 14	1.13 ± 0.12	0.79 ± 0.02	1.37 ± 0.11
WS 15	0.22 ± 0.04	0.43 ± 0.05	0.84 ± 0.15
WS 16	0.73 ± 0.08	0.98 ± 0.10	2.33 ± 0.05
WS 17	0.21 ± 0.02	0.18 ± 0.01	0.46 ± 0.02
WS 18	1.62 ± 0.30	1.36 ± 0.20	0.68 ± 0.02
WS 19	0.16 ± 0.01	0.74 ± 0.08	3.85 ± 0.08
WS 20	1.03 ± 0.08	1.20 ± 0.22	1.84 ± 0.05
Minimum	**0.14 ± 0.01**	**0.18 ± 0.01**	**0.46 ± 0.02**
Maximum	**1.62 ± 0.30**	**1.42 ± 0.21**	**5.92 ± 0.10**
Mean	**0.58 ± 0.061**	**0.84 ± 0.09**	**2.51 ± 0.15**

Table 3: The minimum detectable activity concentrations of ^{226}Ra, ^{228}Ra, ^{40}K

Radionuclide	Minimum Detectable Activity, Bq/kg
^{226}Ra	0.05
^{228}Ra	0.04
^{40}K	0.10

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It was noted that the average activity concentration of ^{40}K exceeded that of ^{226}Ra and ^{228}Ra as expected. This can be explained by literature as ^{40}K was expected to be higher due to its higher percentage abundance in the environment whereas ^{238}U, ^{232}Th and their decay products ^{226}Ra and ^{228}Ra respectively are lower in the environment. This could be attributed to several factors that governed their occurrence in groundwater such as the geology, the mineralogy and the geochemistry of rock or solids aquifer and soil in the investigated sites [28].

Table 4: Total Annual Effective Dose and Excess Lifetime Cancer Risk (ELCR) in Adults (17 years and above)

Sample	Effective Dose (^{226}Ra, ^{228}Ra, ^{40}K), μSv/y	ELCR
WS 1	3.10E-01 ± 6.47E-02	1.08E-03 ± 2.26E-04
WS 2	5.03E-01 ± 6.09E-02	1.76E-03 ± 2.13E-04
WS 3	4.88E-01 ± 1.36E-02	1.71E-03 ± 4.76E-05
WS 4	8.10E-01 ± 1.38E-01	2.84E-03 ± 4.82E-04
WS 5	5.58E-01 ± 1.62E-02	4.26E-04 ± 1.61E-05
WS 6	4.26E-01 ± 1.61E-02	1.49E-03 ± 5.63E-05
WS 7	4.44E-01 ± 3.17E-02	1.55E-03 ± 1.11E-04
WS 8	7.04E-01 ± 9.77E-02	2.47E-03± 3.42E-04
WS 9	5.03E-01 ± 9.65E-02	1.76E-03 ± 3.38E-04
WS10	5.17E-01 ±1.61E-02	1.81E-03 ± 5.63E-05
WS 11	7.35E-01 ±9.47E-02	2.57E-03 ± 3.31E-04
WS 12	1.20E-01 ± 1.16E-02	4.21E-04 ± 4.07E-05
WS 13	3.04E-01 ± 2.26E-02	1.06E-03 ± 7.91E-05
WS 14	5.95E-01 ± 3.41E-02	2.08E-03 ± 1.19E-04
WS 15	2.43E-01 ± 3.15E-02	8.52E-04 ± 1.10E-04
WS 16	6.03E-01 ± 6.18E-02	2.11E-03 ± 2.16E-04
WS 17	1.26E-01 ± 8.70E-03	4.43E-04 ± 3.05E-05
WS 18	9.50E-01 ± 1.52E-01	3.32E-03± 5.32E-04
WS 19	3.85E-01 ± 3.86E-02	1.35E-03 ± 1.35E-04
WS 20	7.62E-01 ± 1.16E-01	2.67E-03 ± 4.07E-04
Minimum	**1.20E-01 ± 8.70E-03**	**4.21E-04 ± 3.05E-05**
Maximum	**9.50E-01 ± 1.52E-01**	**3.32E-03 ± 5.32E-04**
Mean	**5.04E-01 ± 5.61E-02**	**1.70E-03 ± 2.04E-04**

To assess public exposure due to intake of radionuclides ^{226}Ra, ^{228}Ra and ^{40}K through water, the annual effective dose received by adults, teenagers, children and infants were estimated. The recorded effective dose values ranged from 1.20E-04 ± 8.70E-06 to 9.50E-04 ± 1.52E-04, 9.04E-04 ± 6.07E-05 to 7.04E-03 ± 1.10E-03, 2.74E-04 ± 1.13E-05 to 2.06E-03 ± 2.13E-04 and 1.17E-03 ± 7.21E-05 to 8.84E-03 ± 1.35E-03 mSv/y respectively. The estimated average total annual effective dose from the ingestion of ^{226}Ra, ^{228}Ra, and ^{40}K over a year for all age groups are lower than the average value of 0.1mSv/y (100 μSv/y) recommended by the World Health Organisation (WHO) and the average value of 0.29 mSv/y (290 μSv/y) due to ingestion of radionuclides in drinking water and food recommended by UNSCEAR [16] for public exposure control to natural radiation. From the Radiation Protection point of view, the results revealed that infants and children are most susceptible to high dose related disease through intake of these waters.

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Table 5: Total Annual Effective Dose and Excess Lifetime Cancer Risk (ELCR) in Teenagers (13-17 years)

Sample	Effective Dose (^{226}Ra, ^{228}Ra, ^{40}K), μSv/y	ELCR
WS 1	2.37E+00 ± 4.95E-01	2.02E-03 ± 4.20E-04
WS 2	3.73E+00 ± 1.66E-01	3.17E-03 ± 1.41E-04
WS 3	3.81E+00 ± 9.98E-02	3.24E-03 ± 8.49E-05
WS 4	5.87E+00 ± 1.02E+00	4.99E-03 ± 8.65E-04
WS 5	4.31E+00 ± 1.11E-01	3.66E-03 ± 9.47E-05
WS 6	3.49E+00 ± 1.28E-01	2.97E-03 ± 1.08E-04
WS 7	3.43E+00 ± 2.55E-01	2.92E-03 ± 2.16E-04
WS 8	5.78E+00 ± 8.24E-01	4.91E-03 ± 7.01E-04
WS 9	3.95E+00 ± 7.74E-01	3.36E-03 ± 6.58E-04
WS10	4.13E+00 ± 1.28E-01	3.51E-03 ± 1.08E-04
WS 11	5.89E+00 ± 7.63E-01	5.00E-03 ±6.49E-04
WS 12	9.04E-01 ± 8.90E-02	7.68E-04 ± 7.56E-05
WS 13	2.11E+00 ± 1.77E-01	1.80E-03 ± 1.51E-04
WS 14	4.30E+00 ± 2.09E-01	3.66E-03 ± 1.78E-04
WS 15	1.91E+00 ± 2.38E-01	1.62E-03 ± 2.02E-04
WS 16	4.60E+00 ± 4.75E-01	3.91E-03 ± 4.04E-04
WS 17	9.29E+00 ± 6.07E-02	7.90E-04 ± 5.16E-05
WS 18	7.04E+00 ± 1.10E+00	5.98E-03 ± 9.37E-04
WS 19	3.06E+00 ± 3.21E-01	2.60E-03 ± 2.73E-04
WS 20	5.78E+00 ± 9.39E-01	4.91E-03 ± 7.98E-04
Minimum	**9.04E-01 ± 6.07E-02**	**7.68E-04 ± 5.16E-05**
Maximum	**7.04E+00 ± 3.29E-01**	**5.98E-03 ± 9.37E-04**
Mean	**3.87E+00 ± 7.62E-02**	**3.30E-03 ± 3.66E-04**

Table 6: Total annual effective dose and excess lifetime cancer risk (ELCR) in children (1-12 years)

Communities	Effective Dose (^{226}Ra, ^{228}Ra, ^{40}K), μSv/y	ELCR
WS 1	7.52E-01 ± 1.70E-01	4.51E-04 ± 1.02E-04
WS 2	1.10E+00 ± 3.39E-02	6.60E-04 ± 2.04E-05
WS 3	1.20E+00 ± 3.17E-02	7.21E-04 ± 1.90E-05
WS 4	1.74E+00 ± 2.13E-01	1.04E-03 ± 1.28E-04
WS 5	1.33E+00 ± 6.11E-02	7.97E-04 ± 3.67E-05
WS 6	1.10E+00 ± 3.17E-02	6.62E-04 ± 1.90E-05
WS 7	1.08E+00 ± 3.85E-02	6.48E-04 ± 2.31E-05
WS 8	1.84E+00 ± 8.15E-02	1.10E-03 ± 4.89E-05
WS 9	1.22E+00 ± 9.05E-02	7.32E-04 ± 5.43E-05
WS10	1.34 E+00 ± 3.17E-02	8.06E-04 ± 1.90E-05
WS 11	1.87E+00 ± 1.02E-01	1.12E-03 ± 6.11E-05
WS 12	2.76E-01 ± 3.39E-02	1.65E-04 ± 2.04E-05
WS 13	6.17E-01 ± 3.39E-02	3.70E-04 ± 2.04E-05
WS 14	1.25E+00 ± 5.66E-02	7.48E-04 ± 3.39E-05
WS 15	5.90E-01 ± 5.43E-02	3.54E-04 ± 3.26E-05
WS 16	1.40E+00 ± 5.20E-02	8.40E-04 ± 3.12E-05

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WS 17	2.74E-01 ± 1.13E-02	1.65E-04 ± 6.79E-06
WS 18	2.06E+00 ± 1.18E-01	1.24E-03 ± 7.06E-05
WS 19	9.84E-01 ± 3.85E-02	5.90E-04 ± 2.31E-05
WS 20	1.74E+00 ± 7.92E-02	1.04E-03 ± 4.75E-05
Minimum	**2.74E-01 ± 1.13E-02**	**1.65E-04 ± 6.79E-06**
Maximum	**2.06E-00 ± 2.13E-01**	**1.24E-03 ± 1.28E-04**
Mean	**1.19E-00 ± 7.21E-02**	**7.11E-04 ± 4.33E-05**

Table 7: Total Annual Effective Dose and Excess Lifetime Cancer Risk in BABIES (<1 YEAR)

Communities	Effective Dose (^{226}Ra, ^{228}Ra, ^{40}K), μSv/y	ELCR
WS 1	3.20E+00 ± 6.60E-01	1.60E-04 ± 3.30E-05
WS 2	4.71E+00 ± 2.50E-01	2.36E-04 ± 1.25E-05
WS 3	5.16 E+00 ± 1.28E-01	2.58E-04 ± 6.39E-06
WS 4	7.37E+00 ± 1.29E+00	3.68E-04 ± 6.45E-05
WS 5	5.72 E+00 ± 1.38E-01	2.86E-04 ± 6.89E-06
WS 6	4.82E+00 ± 1.74E-01	2.41E-04 ± 8.70E-06
WS 7	4.62 E+00 ± 3.47E-01	2.31E-04 ± 1.73E-05
WS 8	8.02 E+00 ± 1.16E+00	4.01E-04 ± 5.80E-05
WS 9	5.28E+00 ± 1.05E+00	2.64E-04 ± 5.24E-05
WS10	5.77E+00 ± 1.74E-01	2.89E-04 ± 8.70E-06
WS 11	8.09E+00 ± 1.04E+00	4.04E-04 ± 5.20E-05
WS 12	1.18E+00 ± 1.19E-01	5.89E-05 ± 5.97E-06
WS 13	2.58E+00 ± 2.37E-01	1.29E-04 ± 1.19E-05
WS 14	5.31E+00 ± 2.14E-01	2.66E-04 ± 1.07E-05
WS 15	2.55E+00 ± 3.10E-01	1.28E-04 ± 1.55E-05
WS 16	6.02E+00 ± 6.17E-01	3.01E-04 ± 3.08E-05
WS 17	1.17E+00 ± 7.21E-02	5.85E-05 ± 3.61E-06
WS 18	8.84E+00 ± 1.35E+00	4.42E-04 ± 6.76E-05
WS 19	4.23E+00 ± 4.47E-01	2.12E-04 ± 2.24E-05
WS 20	7.47E+00 ± 1.27E+00	3.74E-04 ± 6.37E-05
Minimum	**1.17E+00 ± 7.21E-02**	**5.85E-05 ± 3.61E-06**
Maximum	**8.84E+00 ± 1.35E+00**	**4.42E-04 ± 6.76E-05**
Mean	**5.11E+00 ± 5.67E-01**	**2.55E-04 ± 2.83E-05**

Average excess lifetime cancer risk (ELCR) for all water samples as contained in Tables 5 to 8 with the values for adults ranging from 4.21E-04 ± 3.05E-05 to 3.32E-03 ± 5.32E-04. That for teenagers, children and babies ranged from 7.68E-04 ± 5.16E-05 to 5.98E-03 ± 9.37E-04, 1.65E-04 ± 6.79E-06 to 1.24E-03 ± 1.28E-04 and 5.85E-05 ± 3.61E-06 to 4.42E-04 ± 6.76E-05 respectively. The average values of 1.70E-03 ± 2.04E-04, 3.30E-03± 3.66E-04, 7.11E-04 ±4.33E-05 and 2.55E-04 ± 2.83E-05 for adults, teenagers, children and babies (infants) respectively are within the range of the world average value of 10^{-4} [29]. The chances of the onset of stochastic effects are therefore insignificant for all the age groupings. Though the mean effective doses and excess lifetime cancer risk (ELCR) for all age groups seemed low, the

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possibility of onset of adverse health effects from prolonged exposure to these levels of radiation cannot be disregarded.

For the purely academic purposes, the average activity concentrations of ^{226}Ra, ^{228}Ra and ^{40}K obtained from the present study is compared to literature for groundwater from other parts of the world and observed to be within range as presented in Table 8.

Table 8: Comparison of measure activity concentrations of ^{226}Ra, ^{228}Ra and ^{40}K with data form literature

	^{226}Ra		^{228}Ra		^{40}K		
Country	**Av**	**Range**	**Av**	**Range**	**Av**	**Range**	**Reference**
Ghana	0.58	0.14 – 1.62	0.84	0.18 – 1.42	2.51	0.46 – 5.92	This Study
Ireland		< 7.5 - 730					[30]
Iran		0.12 – 2.84		0.26 – 7.47		2.93 – 7.17	[31]
Bangladesh			0.19		4.16		[32]
Ghana				0.17 – 2.84		0.72 – 8.86	[28]

Table 9: Summary of the physico-chemical parameters of sampled water.

Community	T/^{o}C	Cond./µScm^{-1}	Sal.	TDS (ppm)	pH
Axim 1	29.2	137.5	0.0	83	5.8
ABH	32.3	420	0.1	252	6.9
ALIS	29.5	120.9	0.0	73	5.5
Krisan	32.9	181.5	0.0	109	5.7
Nyale Kplole 1	32	216	0.0	129	5.5
Nyale Kplole 2	30.2	51.4	0.0	31	5.7
Atuabo 1	29.7	238	0.0	143	6.8
Ekebaku	35.1	104.6	0.0	63	5.5
Beyin 1	29.1	399	0.1	239	7.2
Beyin 2	30.4	263	0.0	158	6.7
Kengen 1	29.6	99.4	0.0	60	6.0
Kengen 2	29.5	416	0.1	250	6.1
Twenen	29.0	148.4	0.0	89	4.8
Half-Assini 1	29.9	238	0.0	143	6.1
Half-Assini 2	32.5	141.2	0.0	84	4.4
Half-Assini 3	29.2	234	0.0	140	7.2

CONCLUSIONS

The natural radioactivity levels of ^{226}Ra, ^{228}Ra and ^{40}K have been measured in groundwater using gamma ray spectroscopy. The activity profiles of the radionuclides have clearly showed low activity concentrations across the study areas. The high activity concentrations for ^{226}Ra and ^{228}Ra measured in water samples explain the relationship between the groundwater and

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bedrocks. The estimated total annual effective dose and the excess lifetime cancer risk calculated were within the world acceptable value for all age brackets. Though immediate health implication for the public may not be observed at the present level, but long term cumulative health side effects are highly probable. This work has established baseline information on the natural radioactivity status of ground water sources in the studied area and will serve as reference for future studies.

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