

Article

Levels and potential effect of radon gas in groundwater of some communities in the Kassena Nankana district of the Upper East region of Ghana

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Abstract

Levels of radon gas in groundwater should be of interest due to its variation and exposure to the public since it is now patronized due to unusual interruption of surface water supplies. Dissolved Rn-222 in sampled groundwater has been analyzed using High Purity Germanium (HPGe) Detector and Nuclear Track Detector (N.T.D) techniques at the Kassena Nankana District in the Upper East region of Ghana. The radon concentrations obtained ranges from 7.86×10^{-6} to 8.18×10^{-5} Bq/l with a mean of 4.38×10^{-5} Bq/l using the Gamma Spectrometry (G.S) whiles that of N.T.D ranged from 5.40 to 46.74 Bq/l with a mean of 19.54 Bq/l. In terms of Bq/m³, the concentrations ranged from 1.2×10^{-2} to 8.1×10^{-2} with a mean of 3.67×10^{-2} and 200.00 ± 0.23 to 1731.00 ± 1.73 with a mean of 723.7 Bq/m³. The estimated annual effective dose by inhalation ranged from 6.05 to 40.66 mSvy⁻¹ with a mean value of 21.91 mSvy⁻¹ using N.T.D, whiles that of G.S ranged from 1.39×10^{-4} to 2.45×10^{-3} mSvy⁻¹ with a mean value of 1.14×10^{-3} mSvy⁻¹. Also the estimated annual effective dose by ingestion ranged from 1.71×10^{-5} – 1.32×10^{-4} μSvy⁻¹ with a mean value of 5.60×10^{-5} μSvy⁻¹ obtained using N.T.D technique. G.S ranged from 2.87×10^{-11} to 2.99×10^{-10} μSvy⁻¹ with a mean value of 1.60×10^{-10} μSvy⁻¹ respectively. The concentrations delineate that inhabitant need to be advised on levels of 222Rn in water.

Keywords radon gas; groundwater; track etch detector (LR-115 II); gamma spectrometry; Ghana.

1 Introduction

Water is very essential in the daily lives of humans. In Ghana, the major uses of water are for mainly human water supply for house hold activities, irrigation, and livestock watering. Sometimes certain amount goes into the industrial sectors. The demand of it has risen because of rapid increase in population, rainfall variability, increase in environmental degradation, pollution of rivers, draining of rivers and urbanization in the world especially in the developing countries in Africa although availability changes from season to season (Gyamfi et al., 2012; Zakaria et al., 2012). Due to this, inhabitants in big cities and some rural areas have resorted to groundwater (<http://www.groundwater.org/gi/docs/GWBASICS2.pdf>). The main source of the country's water supply is the river system (surface water). The Volta River covers 70% of Ghana, comprising of the north, centre and east. Whiles the rest covers the south and southwest. Groundwater which is just explained as water which accumulates underground (http://pub.usgs.gov/gip/gw/how_a.html) as a result of rain, snow and sleet which then seeps into the ground because of gravity. It reaches a soil depth where the pore spaces are already

filled or saturated with water. It therefore resurfaces to become wells and boreholes. Fractures and joints serve as the plumping system for groundwater flow in many areas and they are the routes by which groundwater can move through igneous rocks and metamorphic rocks. Its porosity and permeability is very important for water supplies and hydrocarbons reservoirs. These joints and fractures (also known as Fault Lines) are fractures which show evidence of relative movements due to friction and rigidity of rocks. Stresses then build up in the rocks and when it reaches a level that exceeds the strain household, the accumulated potential energy is released as strain. This focused into a plane along which relative motion is accommodated forming a fault. They also serve as routes for Radon-222 gas which is an alpha emitter and also has a half-life of 3.82 days. This gas is a daughter product of Radium 226 found in the decay series of Uranium-238 which is the earth's chief ore. Therefore the routes provided by these fault lines serve as the region where groundwater moves through radon-contaminated soils, becoming radioactive since radon is highly soluble in water. This gas is not often found in surface water since aerator dissipates the radon gas. When this radon gas is inhaled into a person's lungs, alpha particles emitted by the radon gas may damage lung tissue and cause lung cancer. This risk is increased if the persons smoke cigarettes (Yalim et al., 2007; Mehra et al., 2007; Singh et al., 1999; Al-Tamimi and Abumurad, 2001). Different methods have been used in measurements of radon gas and uranium in groundwater such as nuclear track detection, Na (I) Iodide detectors, liquid scintillation counting and gamma and alpha spectroscopy. Relatively among the methods (N.T.D) is the cheapest of all. This has made the closed can technique popular in measurement of radon gas in water (Baykara and Doçgru, 2006; Kumar et al., 2006; Hakl et al., 1995; Singh et al., 1999; Radolić et al., 2005). It is therefore necessary to monitor the levels of radon gas in groundwater since it is much patronized by residents as potable water due to insufficient supply of treated water. Especially in the Northern sector of Ghana, where living is mainly on subsistence farming, and is faced with severe problem of water supply, climatic severity, distance from ports and poverty. In this study, radon gas levels and assessment of annual effective doses by inhalation and ingestion have been reported using close can technique and the gamma spectrometry system at the Kassena Nankana District of the Upper East of Ghana.

2 Study Area

The Kassena Nankana Area is mainly rural with a population of estimated to be 92, 188 with a population density of 92 person per square kilometer. The district is one of the nine (9) assemblies in the Upper East region. The district shares boundaries to the North with Kassena-Nankana West district and Burkina Faso, to the east with Kassena Nankana West District and Bolgatanga Municipal Assembly, to the West with the Builsa District and South with the Mamprusi District in the Northern region <http://www.modernghana.com/news/207210/1/kassena-nankana-district-in-focus.html> as shown in Fig.1. The Kassena-Nankana District lies within the Guinea Savannah woodlands. It falls approximately between latitude $11^{\circ} 10'$ and $10^{\circ} 3'$ North and longitude $10^{\circ} 1'$ West. The area covers a total land area of about 55 km North-South and 53 km East-West.

The geology of the district comprises granite and shale which forms part of the Birimian formation of Ghana as shown in Fig.2. The two main types of soil present within the District are namely savannah ochrosols and groundwater laterite. The savannah ochrosols are porous, well drained, loamy, milky, acidic and interspersed with patches of black of dark-grey clay soils. The soil is suitable for cultivation and hence accounts for the arable land site which comprises of most parts of the Tono Irrigation Project site where both wet and dry season farming activities are concentrated. The groundwater laterites are developed mainly over shale and granite which covers approximately 60% of the District's land area. Due to the underlying rock type (granite), they become waterlogged during the rainy season and dry out during the dry season, thus causing

cemented layers of iron-stone (hard pan), which makes cultivation difficult (<http://www.modernghana.com/news/207210/1/kassena-nankana-district-in-focus.html>; Quashie et al., 2011).

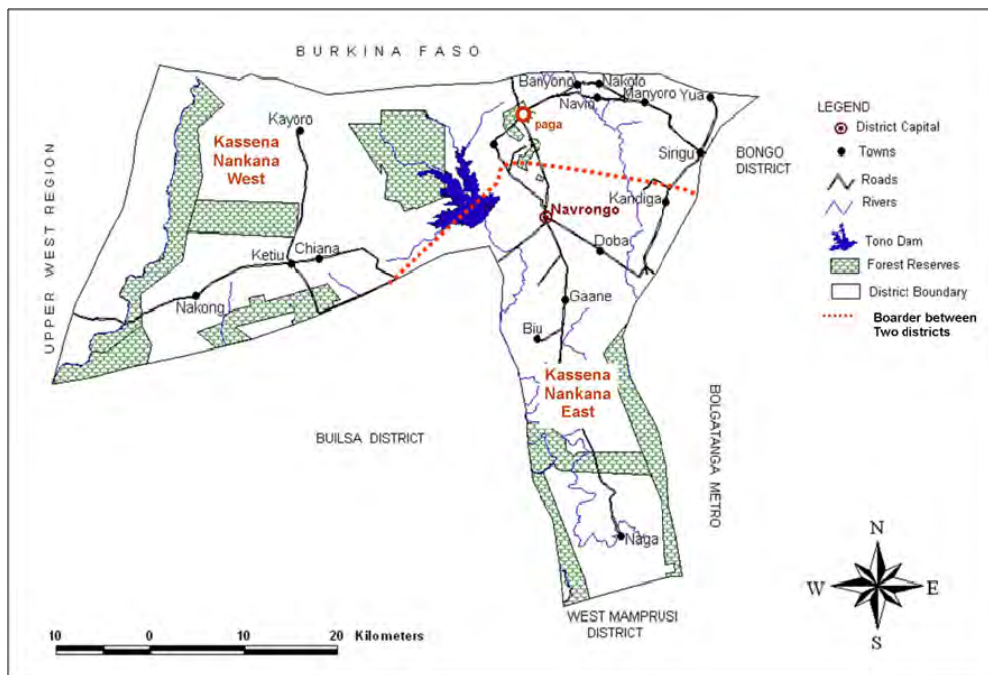


Fig. 1 Map of the Kasena Nankana District (Source: Kasena Nankana East District Assembly)

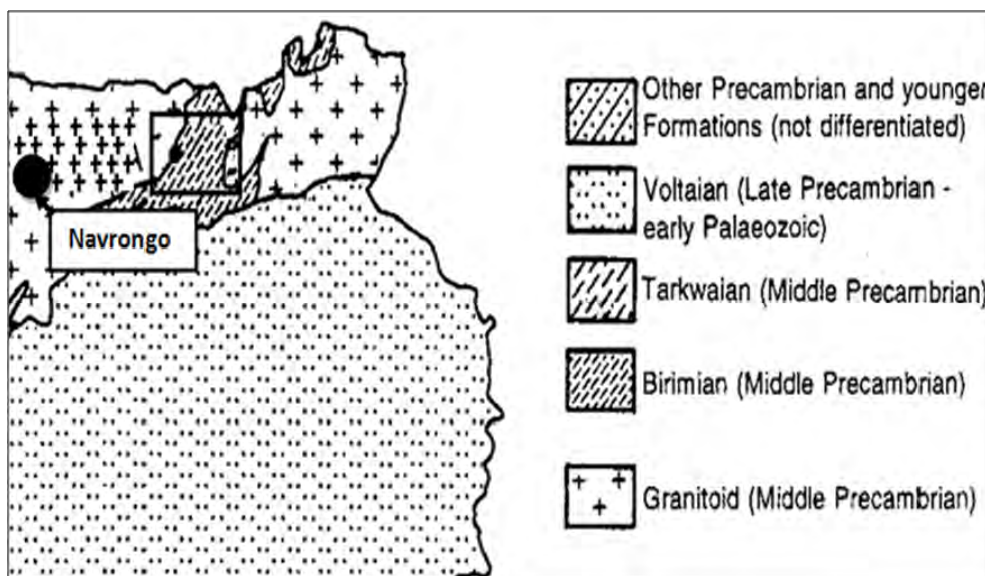


Fig. 2 Geological map of Upper East (Source: Extracted from WaterAid Ground water Quality: Ghana Document)

3 Methodology

3.1 Sampling

Water samples were collected from boreholes within the Navrongo, Gonia, Paga and Vonania Communities from the period of 20th – 22nd December, 2010. Water samples were fully filled into an air tight clean polythene bottles. This was done to avoid degassing during sample collection.

3.2 Radon measurement using track detection

The samples were then sent to the nuclear track detection laboratory, Ghana Atomic Energy Commission, where radon gas was monitored for period of three months. Eight hundred ml (800 ml) of each sample were measured into another clean polyethylene bottles with a wide neck washed with nitric acid to avoid contamination followed by labeling. LR-115 (Type II) nuclear track detector cut into the size of 2 cm × 2 cm were placed on the inner part of the lids of the bottles with its sensitive part exposed to the water. The bottles were tightly sealed leaving a gap between the surface of the water and the detectors for a period of three months. This was to allow enough accumulation of radon gas from the water samples and also for radon gas to attain secular equilibrium with its daughters. After the monitoring period, the detectors were detached from each lid, hanged on copper wires, labeled and were chemically etched by suspending them in 2.5 M Sodium hydroxide (NaOH) solution at a temperature of 60°C for period of 90 min. The spark counter technique was used for the track evaluation of the exposed detectors. The detectors were stripped from their backing and counted four times where the average was calculated.

The track density was calculated using the formula:

Track density (ρ) = average number of count / area of electrode for the spark counter

The soil radon gas concentration was calculated using the formula

$$\text{Concentration}(kBqm^{-3}) = \rho / \varepsilon T$$

where ρ is the track density, ε is the calibration factor of the radon sampler, $T(\text{hrs})$ is the exposure time in hour.

3.3 Radon measurement using gamma spectrometry

At the Laboratory, the water samples were transferred into 1Liter Marinelli beakers and kept for four weeks before the analysis. This was done to enable the daughter radionuclides to attain secular equilibrium with the parent.

The gamma-spectrometry system consists of a detector couple to a desk top computer with Maestro 32 MCB configuration software for spectrum acquisition and evaluation. The detector crystal has a diameter of about 36 mm and thickness of about 10 mm. It is housed in an aluminum canister with 0.5 mm thick beryllium entrance window. 5 cm thick lead brick surrounds the detector to prevent external background radiation.

Original Radon concentration was obtained by counting after 30 days, where it will have virtually decayed and only remaining radon in secular equilibrium with Radium-226.

Efficiency and energy calibrations were carried out prior to the analysis. The water samples were therefore counted for presence of radionuclide with Radium-226 for a counting time of 36000 seconds. Radon concentration in the samples was calculated by measuring the parent nuclide which is radium in the water. Thus the specific activity concentration was obtained using the formula below.

$$A_{sp} = \frac{N_{sam} \exp(-\lambda T_d)}{P_E * \varepsilon(E_\gamma) * T_c * M_{sam}}$$

where M_{sam} is the mass of the sample; N_{sam} is the net counts for the sample in the peak range; P_E is the emission probability; T_c is the counting time; $\varepsilon(E_\gamma)$ is the photopeak efficiency, and T_d is the delay time between sampling and counting.

3.4 Estimation of annual effective dose by inhalation

The radon gas concentrations obtained using both methods was used to estimate the annual effective doses indoors and annual absorbed dose in the air since water for household activities is stored indoors. The annual effective dose was calculated using the formula as below.

$$E(mSv y^{-1}) = D_{Rn} \bullet W_R \bullet W_T$$

where D_{Rn} - annual absorbed dose; W_{Rn} - Radiation weighting factor for alpha particles (20) according to ICRP, 1991; W_T - Tissue weighting factor for the lung (0.12) according to ICRP, 1991. But in calculating D_{Rn} , a value of 9.0×10^{-6} mSv h⁻¹ per Bqm⁻³ was used for the conversion factor (effective dose received by adults per ²²²Rn activity per unit of air volume) and also a 0.8 equilibrium factor for ²²²Rn outdoor. An occupancy factor of 0.4 was assumed based on the period dwellers spend in their rooms out of the 24 hours, that is

$$\frac{9 \text{ hrs}}{24 \text{ hrs}} = 0.375 \cong 0.4$$

Therefore for a calculated radon concentration, the annual absorbed dose was calculated using the equation below.

$$D_{Rn}(mSv y^{-1}) = C_{Rn} \bullet D \bullet F \bullet T$$

where C_{Rn} - Rn-222 concentration; F- Rn-222 equilibrium factor outdoor (0.8); T- Indoor Occupancy time ($0.4 \times 24 \text{ hrs} \times 365 \text{ days} = 3504 \text{ h y}^{-1}$); D- Dose conversion factor ($9.0 \times 10^{-6} \text{ mSv h}^{-1} \text{ per Bqm}^{-3}$).

3.5 Estimation of annual effective dose by ingestion

The estimated annual effective dose by ingestion was calculated because of habitual consumption of water by dwellers. It was computed using the formula below:

$$DW = C_w \bullet CR_w \bullet D_{cw}$$

where DW is the annual effective dose ($\mu\text{Sv y}^{-1}$) due to ingestion of radionuclide from the consumption of water; C_w is the concentration of Rn-222 in the ingested drinking water (Bq l^{-1}); CR_w is the annual intake of drinking water (1 y^{-1}), and D_{cw} is the ingested dose conversion factor for ²²²Rn (Sv Bq^{-1}). A dose conversion factor of $5 \times 10^{-9} \text{ Sv Bq}^{-1}$ was used as suggested by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). Annual effective dose due to intake of Rn-222 from drinking water is calculated considering that an adult. An average of 730 L water was estimated annually for an adult (Age > 18 y) (Cevik et al, 2006).

4 Results and Discussion

4.1 Radon Concentration

The Rn-222 concentrations obtained for the borehole water samples at the Kassena Nankana District of the Upper East Region of Ghana using N.T.D and Gamma spectrometry techniques are presented in Fig. 3 and Fig. 4. The radon concentrations obtained ranges from 7.86×10^{-6} to $8.18 \times 10^{-5} \text{ Bq/l}$ with a mean of $4.38 \times 10^{-5} \text{ Bq/l}$ using the Gamma Spectrometry (G.S) whiles that of N.T.D ranged from 5.40 to 46.74 Bq/l with a mean of 19.54 Bq/l. In terms of Bq/m^3 , the concentrations ranged from 1.2×10^{-2} to 8.1×10^{-2} with a mean of 3.67×10^{-2} and 200.00 ± 0.23 to 1731.00 ± 1.73 with a mean of 723.7 Bq/m^3 as shown in Table 1. High and low readings were recorded at Kayoro, Nania, Paga and Paga Border. About 50% of the sample sites recorded a considerable amount of Rn concentrations using both techniques. Variation in concentrations in both methods may be due to difference in procedures of measurement. The concentrations are comparable to other reported works on radon concentration in groundwater (Rajashekara et al., 2007; Abdallah et al; 2007, Cosma et al., 2008; Al-Bataina et al., 1997). Sampling locations such as Navrongo and Paga recorded high concentration in both methods. High concentrations obtained may be attributed to the geology of the study area which is more of granite in nature. This granite nature forms the basement full of relicts of high grade metamorphic rocks, archean granitic which contains higher concentrations of radium-226 and other radionuclide belonging to the

uranium and thorium series. Also it may be due to the fact that boreholes are more stagnant and there is no loss of radon concentration due to lack of aeration (Rajashekara et al., 2007). These present results show that 100% of the bore holes monitored using G.S had radon water concentration within international standard limits such as the alternative maximum contamination level (AMCL) which is 146 Bq/L and the European Union reference level of 1000Bq/L. Whiles 60% of the boreholes monitored using N.T.D exceeded the limit of U.S Environment Protection Agency proposed limit of 11 Bq/L. This very alarming, since dwellers mostly store water for house hold activities indoors which in such cases contributes much to indoor radon gas.

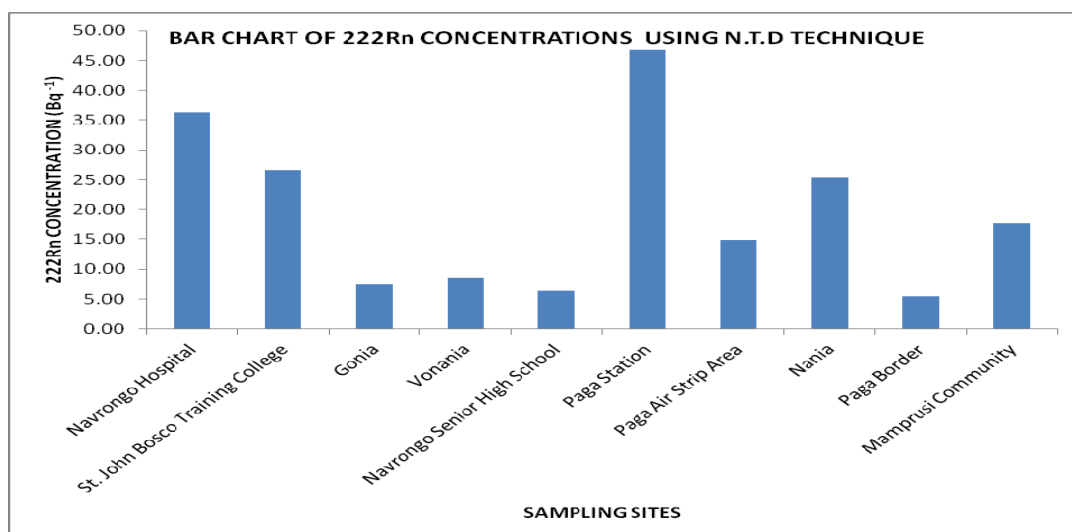


Fig. 3 222Rn concentrations using N.T.D technique

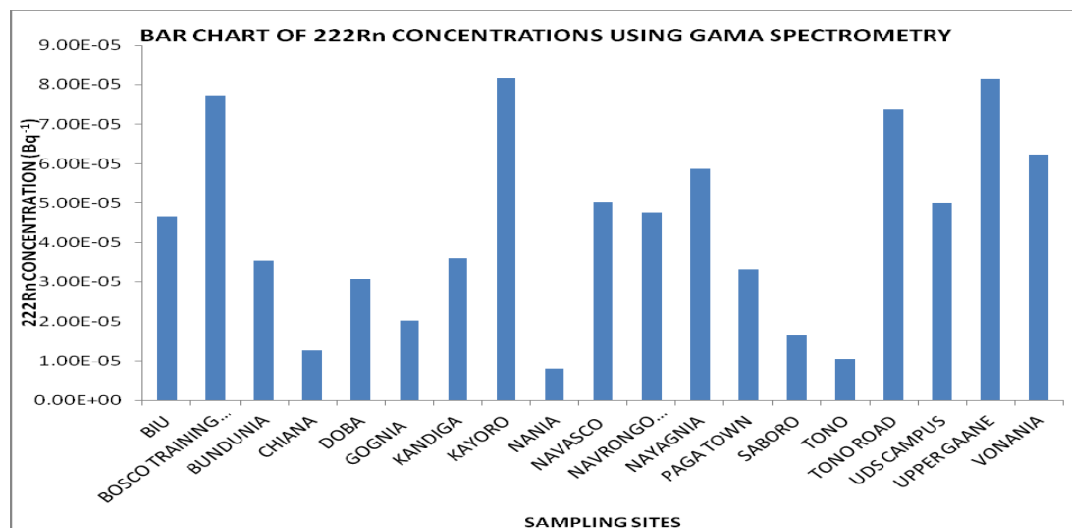


Fig. 4 222Rn concentrations using Gamma spectrometry

Table 1 Radon levels obtained using high purity germanium detector and nuclear track

Gamma spectroscopy		Nuclear track	
Sampling Site	²²² Rn Concentration (Bq/m ³)	Sampling Site	²²² Rn Concentration (Bq/m ³)
BIU	4.6×10^{-2}	NAVRONGO HOSPITAL	1343.00 ± 1.34
BOSCO TRAINING COLLEGE	7.7×10^{-2}	ST. JOHN BOSCO TRAINING COLLEGE	988.00 ± 0.99
BUNDUNIA	3.5×10^{-2}	GONIA	276.00 ± 0.26
CHIANA	1.2×10^{-2}	VONANIA	319.00 ± 0.32
DOBA	3.0×10^{-2}	NAVRONGO SENIOR HIGH SCHOOL	235.00 ± 0.23
GOGNIA	2.0×10^{-2}	PAGA STATION	1731.00 ± 1.73
KANDIGA	3.6×10^{-2}	PAGA AIR STRIP AREA	548.00 ± 0.55
KAYORO	8.1×10^{-2}	NANIA	939.00 ± 0.94
NANIA	7.0×10^{-3}	PAGA BORDER	200.00 ± 0.20
NAVASCO	5.0×10^{-2}	MAMPRUSI COMMUNITY	658.00 ± 0.66
NAVRONGO TOWNSHIP	4.7×10^{-2}		
NAYAGNIA	5.8×10^{-2}		
PAGA TOWN	3.3×10^{-2}		
SABORO	1.7×10^{-2}		
TONO	1.0×10^{-2}		
TONO ROAD	7.0×10^{-3}		
UDS CAMPUS	5.0×10^{-2}		
UPPER GAANE	8.1×10^{-2}		
VONANIA	6.2×10^{-2}		

4.2 Annual effective dose

The estimated annual effective dose by inhalation ranged from 6.05 to 40.66 mSvy⁻¹ with a mean value of 21.91 mSvy⁻¹ using N.T.D as graphically represented in Fig. 5, while that of G.S ranged from 1.39×10^{-4} to 2.45×10^{-3} mSvy⁻¹ with a mean value of 1.14×10^{-3} mSvy⁻¹ as shown in Fig. 6. Also the estimated annual effective dose by ingestion ranged from 1.71×10^{-5} – 1.32×10^{-4} μSvy⁻¹ with a mean value of 5.60×10^{-5} μSvy⁻¹ obtained using N.T.D technique as shown in Fig. 8 and G.S also ranged from 2.87×10^{-11} to 2.99×10^{-10} μSvy⁻¹ with a mean value of 1.60×10^{-10} μSvy⁻¹ as represented in Fig. 7. Since the effective dose depends on the mean radon concentrations, the areas which recorded high concentrations also had high values of annual effective dose. The present results show that 100% of water samples analyzed with N.T.D had their annual effective dose exceeding the annual effective dose limit of 1 mSvy⁻¹.

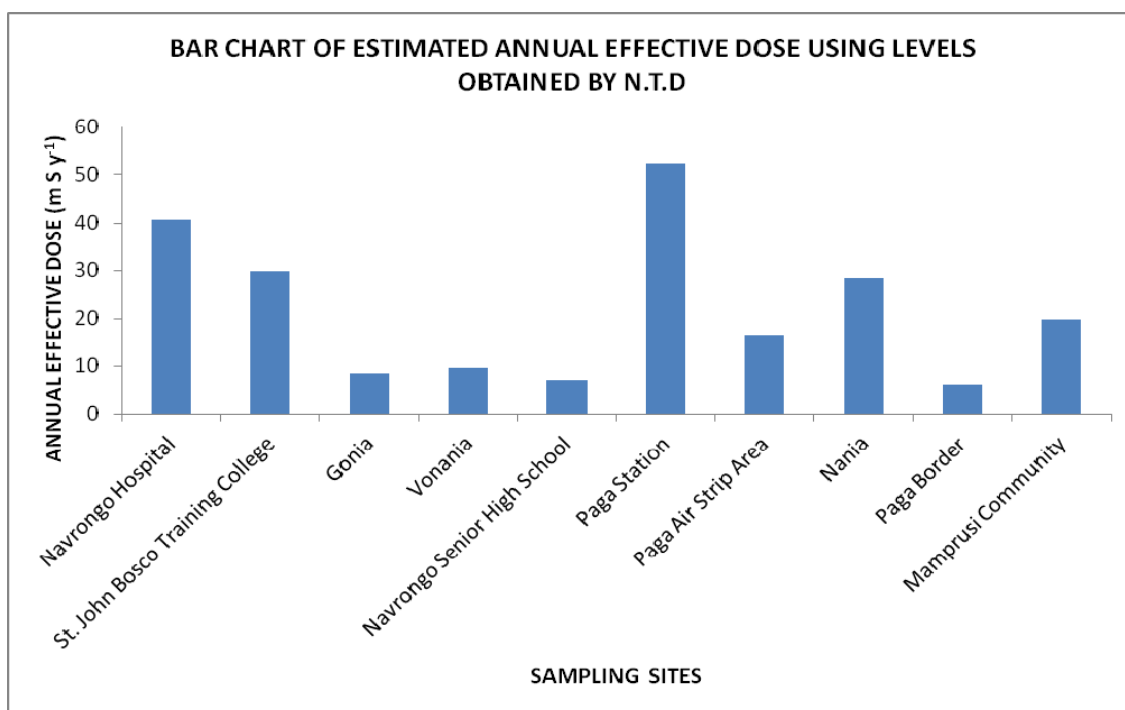


Fig. 5 Estimated annual effective dose by inhalation using levels obtained by N.T.D

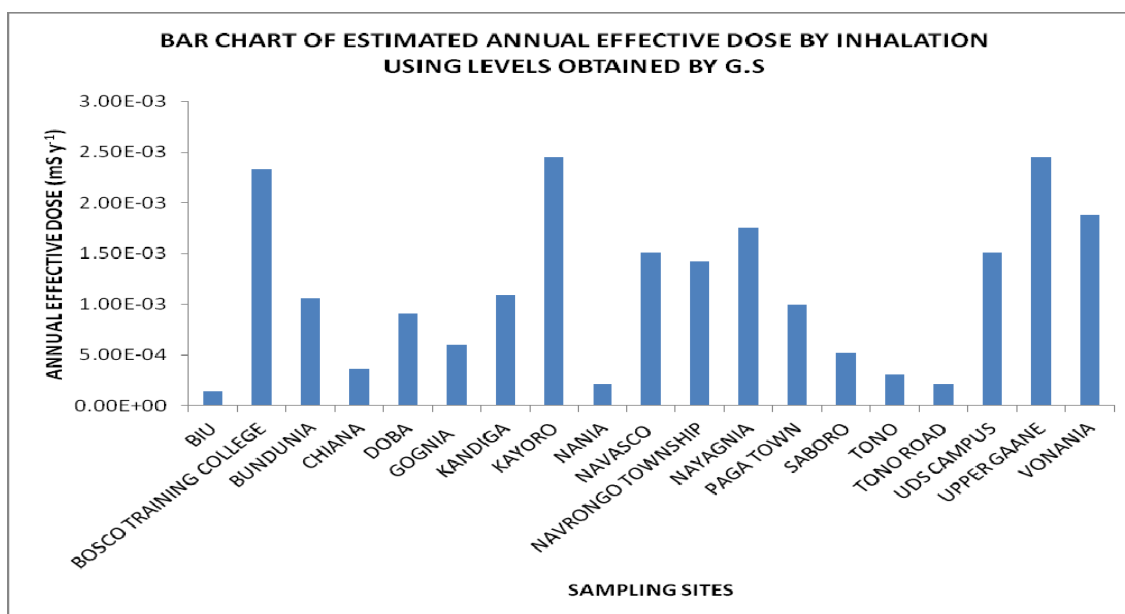


Fig. 6 Estimated annual effective dose using levels obtained by G.S

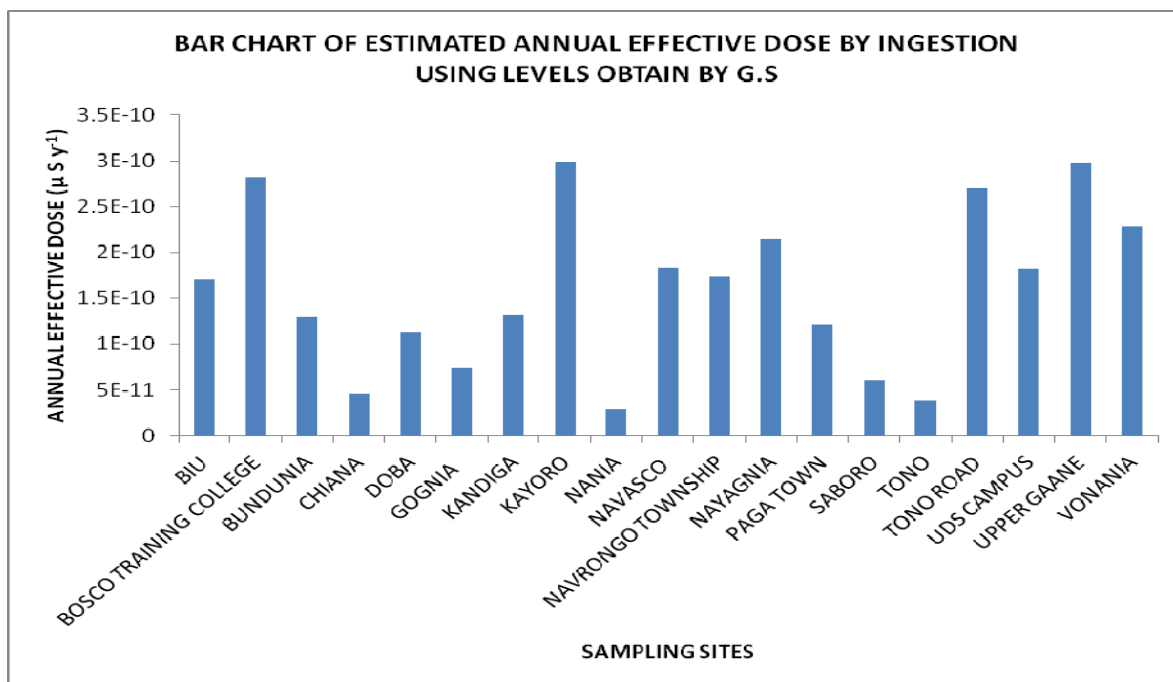


Fig. 7 Estimated annual effective dose by ingestion using levels obtained by G.S

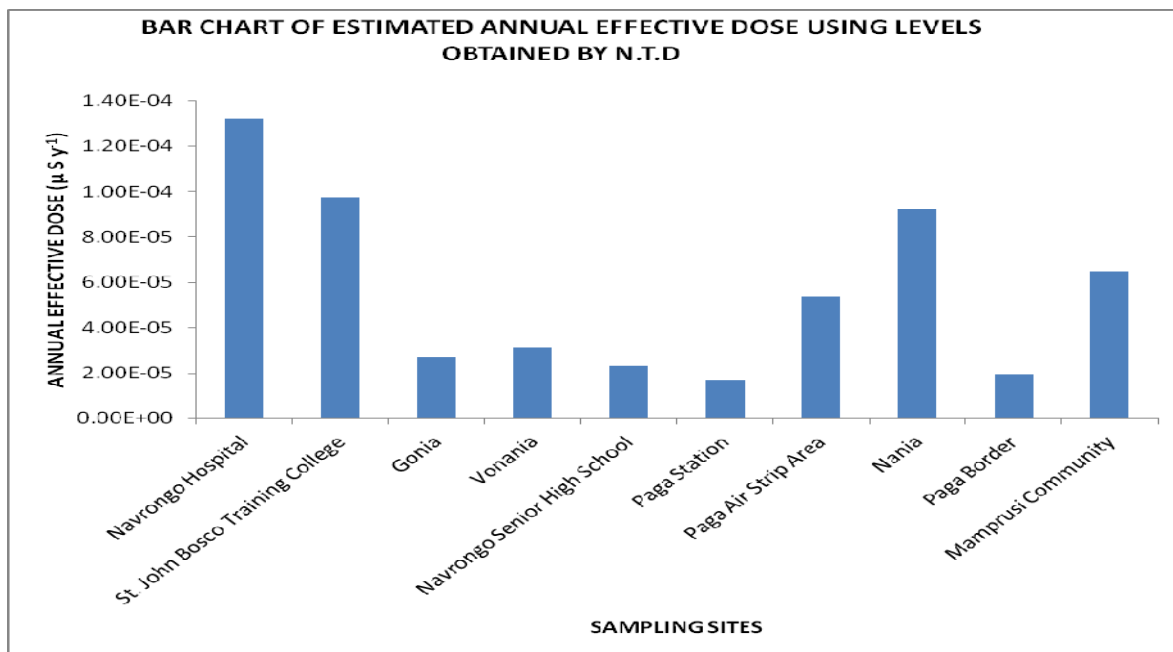


Fig. 8 Estimated annual effective dose by ingestion using levels obtained by N.T.D

5 Conclusion

Ground water samples (Borehole) collected from 29 locations in the Kassena Nankana in Upper East region of Ghana has been analyzed for ^{222}Rn concentrations using N.T.D and HPGe Detector. Where the radon concentrations varied due to difference in procedures of measurement, geology of the study areas and stagnant nature of bore holes which prevent loss of radon concentration due to lack of aeration. 60% of the radon concentration obtained using N.T.D exceeded the internal limit proclaimed by regulatory bodies thereby compelling annual effective dose to exceed the permissible effective dose of 1 mSv^{-1} . Therefore, it is recommended that detailed study of ^{222}Rn dissolved in groundwater at these studied areas should be conducted with different methods for comparable reasons and also advice dwellers to store groundwater in a well ventilated area for the escaped radon gas to be diluted.

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