DETERMINATION OF THE RADON CONCENTRATION IN UNDERGROUND WATER IN SELECTED AREAS IN AND AROUND KUMASI

by

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Declaration

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Abstract

Radon (^{222}Rn) is a radioactive noble gas of natural origin that may be found anywhere in soil, air and different types of water: surface, borehole, well and spring. It is worth to carry out surveys for the radon in water for radiation protection as well as for geological considerations. The research presentes here was carried out in selected towns in and around Kumasi for the determination of radon concentration in groundwater. The major towns from which samples were taken are , Mowire, Kronum, Aburaso, Medoma, Kenyase, Buokrom, Bomfa, Ayeduase, Kotei, Tikrom. All the samples are used for domestic purposes such as cooking,drinking,bathing and washing. Waters from boreholes and wells in the selected towns were sampled and the radon concentration level measured. The Roll's method was used for the radon concentration analysis on all the 100 samples. The results shows that, the minimum radon concentration in groundwater was 13015.934 Bq/m^3 and it was found at Bomfa, and the highest was found to be 964628.480 Bq/m^3 , recorded at Mowire. It is believed that this variation of levels is mainly due to the difference in rock type,soil type and geology of the area as well as the depth of the water samples. This information can be used to estimate the possible health hazards from radon in the selected towns in the future from environmental point of view. The data would promote public awareness related to risk of radon exposure.

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List of Symbols and Acronyms

pCi/l	Picocuries per litre
Bq/m^3	Becquerel per cubic meter
pCi/l	pico curies per litre
EPA	Environmental Protection Agency
Bq/l	Becquerel per litre
^{238}U	Uranium - 238
^{235}	Uranium - 235
^{222}Rn	Radon - 222
^{236}Ra	Radium
WHO	World Health Organization
MCL	Maximum Contamination Level
^{232}Th	Thorium-232
^{220}Rn	Thorium
GS	Gamma Spectrometry
NTD	Nuclear Track Detector

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CHAPTER 1

INTRODUCTION

1.1 Background

On global scale, groundwater had been gaining increasing attention as essential and vital water resource. Its demand had been rising rapidly in the last several decades with the overpopulation and enhanced standards of living. It is one of the sources of freshwater for many communities owing to its relatively low susceptibility to pollution in comparison to surface water, and its relatively large storage capacity. Both groundwater and surface water may contain many constituents, including micro-organisms, gases, radioactive particles, inorganic and organic materials. Scientists assess water quality by measuring the amounts of the various constituents contained in the water (Hem, 1985). Several environmental problems are seriously threatening Ghana and especially Kumasi. Deterioration of groundwater quality is considered one of the main problems that exerts huge pressure on our economy and there is the need for urgent response because it had not received serious investigation. Exposures to radioactive materials is one of these water quality problems that has not been investigated widely and will be the subject of focus in this study.

1.2 Radon

Radiation and radioactive isotopes constitute a natural part of of our environment. High concentrations of these radiactive isotopes in the environment can be a threat to our health. The highest fraction of the natural radiation we receive comes from the radiactive gas radon, (Irene et al., 2013). Radon is a chemically inert, radioactive gas, that decays by alpha particle emission with a half-life of 3.82 days. Radon originates from the disintegration of radium and both elements are part of the ^{238}U decay series. Radon is ubiquitous in soil and rock in varying concentrations depending on the Radon concentration and several factors. Radon is soluble in water, and therefore, is present and able to travel in ground water. It is a colourless, odorless, tasteless, radioactive noble gas that generally lacks activity toward other chemical agents. However, it occasionally forms clathrate compounds with some organic compounds and may form ionic or covalent bonds with highly reactive elements such as oxygen or fluorine. Radon is the heaviest noble gas and exhibits the highest boiling point, melting point, critical temperature, and critical pressure of all noble gases. Radon's isotopes, are radioactive, include mass numbers ranging from 200 - 226. Radon-222 ^{222}Rn, formed in the ^{238}U decay chain, is the most important isotope because of its relatively long half-life of 3.82 days. The short half-life beta- and gamma-emitting decay products of ^{222}Rn achieve equilibrium with the parent isotope within several hours.

1.3 Radon in Groundwater

Radon, ^{222}Rn is a naturally occurring, radioactive gas formed within the ^{238}U decay series. According to the U.S. Environmental Protection Agency (EPA), radon is a carcinogen and the second leading cause of lung cancer in the U.S. It is estimated that 3,000 - 33,000 lung cancer

deaths in the U.S. are associated with radon (NRC, 1999). On average, radon accounts for roughly 55% of one's annual radiation dose, with the remaining coming from medical (11%), internal (11%), terrestrial (8%), cosmic (8%), and other sources (NCR). Radon originates in the ground, where its radioactive parents are found. It can escape from the ground and build up in low concentrations in outside air and accumulate in basements and homes (Eisenbud and Gesell, 1997). The EPA has set an action level of 0.15 Bq L^{-1} (4 pCi L^{-1}) for indoor air (EPA, 1986). A becquerel (Bq) is a measure of activity equal to one disintegration per second. One curie (Ci) is equal to 3.7×10^{10} Bq. Since radon can dissolve and remain in groundwater until dispensed and aerated, kitchen and bathroom appliances provide an additional pathway for radon into a building. Radon in water can raise the average indoor radon concentration, and also locally raise the exposure near water-using appliances where high concentrations of radon occur. Radon is released when water is used for cleaning, bathing, dish and clothes washing, and flushing toilets. Basements of homes usually have the largest concentrations of radon, because of its close proximity with the soil. Many studies had investigated the transfer of radon from water into air, and on average, there is 10^{-4} Bq L^{-1} in air per Bq L^{-1} in water as first proposed by (Prichard and G ESELL, 1975). The EPA is concerned with the exposure due to radon in water and is working to set national standards on the amount of radon in water.

1.4 Radon and its Application

Radon in groundwater has been studied to evaluate the health hazards of radon in water (Hess et al., 1987), as a precursor to earthquakes ; as an indicator of effluent stream reaches, as a tool for uranium, geothermal, and oil and gas exploration and to estimate aquifer porosity. From the health perspective, radon in public water supplies has recently become

a topic of concern. Radon in public water supplies, can be a significant source contributing to the overall concentration of radon in air within a building. To date, the United States Environmental Protection Agency (USEPA) has not established a health standard for radon in public water supplies but is considering levels between 160 and 2000 pCi/l. The average radon concentration in public water supplies of the United States generates a lifetime risk of 1 death in 10,000 people, the highest level of risk allowed for any contaminant under the Safe Drinking Water Act.The USEPA may decide on a Maximum Contamination Level (MCL) of as low as 160 pCi/l. Radon level of about 160 pCi/l has the same estimated risk level as the MCL for radium (5 pCi/L) in drinking water. This risk level is based on a lifetime (70 years) excess cancer risk rate of 10. If the USEPA sets a standard at 160 pCi/l, more than 50% of the ground water supplies in the United States will be out of compliance.

1.5 Health Effects

There are no immediate symptoms of radon exposure. However, long-term radon exposure (anywhere between 5 and 25 years) has been linked to lung cancer. Long-term radon exposure through drinking water has been linked to stomach cancer. Health effects of radon, most notably lung cancer, have been investigated for several decades. Initially, investigations focused on underground miners exposed to high concentrations of radon in their occupational environment. However, in the early 1980s, several surveys of radon concentrations in homes and other buildings were carried out, and the results of these surveys, together with risk estimates based on the studies of mine workers, provided indirect evidence that radon may be an important cause of lung cancer in the general population. Epidemiological studies have shown that radon in homes increases the risk of lung cancer in the general population. Other health effects of radon have not consistently been established. The proportion of all lung

cancer issues associated to radon is estimated to lie between 3% and 14%, depending on the average radon concentration in the country and on the method of calculation. Radon is the second most imperative cause of lung cancer after smoking in many countries. However, it is the primary cause of lung cancer among people who have never smoked. There is no known threshold concentration below which radon exposure presents no risk. Even low concentrations of radon can result in a small increase in the risk of lung cancer. The majority of radon-induced lung cancer cases are caused by low and moderate radon concentrations rather than by high radon concentrations, because in general less people are exposed to high indoor radon concentrations.When dissolved in water and ingested, radon can affect the cells in the stomach walls and may cause complications.

1.6 Evidence that ^{222}Rn Progeny Exposure Causes Lung And Stomach Cancers

Radon-222 progeny is another name for the decay products or ^{222}Rn daughters. Laboratory animals exposed to high concentrations of ^{222}Rn progeny display lung carcinoma, emphysema, pulmonary fibrosis, and a shortened life span. The International Agency for Research on Cancer, however, has classified ^{222}Rn as a human carcinogen primarily on the basis of findings in underground miners exposed to ^{222}Rn progeny. The lung cancer risk attributable to progeny exposure has been examined in over 20 populations of underground miners, including uranium, fluorspar, shale, and metal miners from the United States, Canada, Australia, China, and Europe. The findings from these studies overwhelmingly document that ^{222}Rn progeny exposure causes lung cancers in miners. An analysis of the pooled data from 11 major studies involving 68,000 miners found that lung cancer was linearly related to ^{222}Rn progeny concentrations in underground mines and that overall about 40% of miners' lung cancers were attributable to ^{222}Rn progeny exposure. A subset analysis

of the miner data suggests a synergistic (sub-multiplicative) effect for combined exposure to ^{222}Rn progeny and cigarette smoke. Other factors possibly influencing the relationship between ^{222}Rn progeny exposure and lung cancer include age at exposure, age at risk, exposure rate, sex, other carcinogens, and nonspecific inflammation of the airways. No data are available to determine whether the risk estimates attributable to ^{222}Rn for male miners are applicable to non-mining women.

1.7 Problem Statement

Several environmental problems are threatening Kumasi and the surrounding towns, and one pf these problems is the groundwater quality. Most of the previous studies done on the quality of groundwater were focused on the chemical, physical, and microbiological analysis, but not much on natural radiation analysis has been done.The number of people who depend on groundwater such as boreholes and well water as their main source of water supply is increasing. This is because, the government water supply is not reliable. These sources of water do not undergo quality examination with respect to natural radiation, which is the leading cause of lung and stomach cancer. There is therefore the need to research on the quality of groundwater water with regards to the natural radiation contamination and compare it to international standards.

1.7.1 Objectives of the study

The main objectives of this project are as follows:

1. To investigate natural radiation pollution in groundwater of selected areas in Kumasi

and some of the communities around, depending on measurements of Radon concentration in selected boreholes and wells in the selected areas.

2. This project aims to check the levels of radon in various boreholes and well water samples in in Kumasi and the nearby communities. In Ghana, a lot of water samples have not been analyzed.

3. This work also seeks to compare the results with the World Health Organization (WHO) standards so as to have an idea of the risk level with respect to cancer.

CHAPTER 2

LITERATURE REVIEW

The health risk that radon pose to human health has necessited alot of research to carried out globally. Many researches have been done in different countries to determine the radon concentration level in groundwater. This chapter takes a review of what other researchers have done on the determination of radon concentration in groundwater, the method used and the results obtained.

In 2012, a research was carried out in the Kassena Nankana District of the Upper East region in Ghana, (Asumadu-Sakyi et al., 2012). The research focused on the levels and potential effect of radon gas in groundwater. Dissolved Rn-222 in sampled groundwater was analyzed by using High Purity Gemanium (HPGe) Detector and Nuclear Track Detector (N.T.D) techniques. The radon concentrations obtained ranged 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) while that of N.T.D. ranged from 5.40 – 46.74 Bq/l with a mean of 19.54 Bq/l. It was revealed that the estimated annual effective dose by inhalation ranged from 6.05 to 40.66 mSv^{-1} with a mean value of 21.91 mSv^{-1} using the N.T.D, while that of G.S. ranged from 1.39×10^{-4} mSv^{-1} to 2.45×10^{-3} mSv^{-1}. Also the estimated annual effective dose by ingestion ranged from 1.71×10^{-5} to 1.32×10^{-4} μSvy^{-1} with a mean value of 1.60×10^{-10} μSvy^{-1} respectively.

In 1997 (Freyer et al., 1997), worked on the topic: Sampling and Measurement of Radon-222 in water in Germany. The aim of their work was to develop and test a low cost radon measurement method, including sampling, transportation and analysis, which allows rapid

measurement of many samples with high reproducibility. The method used in their research was, The LIquid Scintillation Spectrometry. Different water sampling, devices (submersible pump, membrane pump, bailer) were compared to check their applicability for the sampling method to measure radon concentration. A submersible pump and a membrane pump were used simmultaneously in an observation well for continuous sampling. It was found that, the radon-222 concentration of samples collected with the submersible pump was (2690 ± 60) cpml^{-1}. and those collected with the membrane pump amounted to (2670 ± 100) cpml^{-1}. Both methods of sampling gave same results and are recommended as effective methods of sampling water for radon-222 measurement. For the determination of the activity concentration of radon-222 in groundwater, the method described by Horiuchi and Murakami (1981) was adopted and modified. The measurement results were taken in count per minute (cpm) and calibrated by means of gamma spectroscopy in units of Bq. It was found that the method applied in the was useful for measurement of radon-222 concentration in groundwater samples as well as in other water samples like drinking water, surface water or spring water.

In 2003, (Tadeuz et al., 2004) in Poland, carried out a research on the topic : Radon concentration in groundwater of the Polish part of the Sudety Mountain (SW Poland). The method adopted in the research was the PicoRad method, based on the liquid-Scintillation counter Packard-Canberra TRI CARB 1900 TR, for the determinations. It was discovered that the concentration of radon-222 oscillated between 0.2 and 1645 Bq/dm^3. It was concluded that, the obtained results only allowed speaking about typical or the most frequent values of radon concentration in the groundwaters of the Polish part of the Sudety. The results of the research made it possible to declear that the Sudetes as a whole were an anomalous area when it comes to the occurrence of high radon concentration in the groundwaters of Poland.

(Adilson et al., 2004), conducted a research on the topic: Direct measurement of radon activity in water from various natural sources using nuclear track detectors. In the research, the measurement technique was based on the exposure of a piece of Makrofol E plastic foil (approximately 2×3 cm, 200 μ thick) to the alpha particle emitted by radon emanated from the water samples (Nikolaev and NewAuthor2, 1999). As the half-life of radon-222 is 3.82 days, the chosen exposure period was 30 days during which 99.5% of radon nuclei contained in the water samples decayed. The radon monitoring system comprised two tightly coupled cup-type containers, one of which was a detection device (a 300-ml polyethylene flask with detector foil attached to the cup bottom) and the other a water container. The water container had approximately 100 ml of air above the water surface for the collection of emanating radon. There was a round hole of diameter of approximately 3 cm in the lid of the detection device covered by a fiberglass filter (Ahlstrom grade 121). The function of this filter was to diminish the evaporation of the water samples and to discriminate against thoron ^{220}Rn ($t_{1/2}$ = 55.6 sec) by hindering its diffusion into the sensitve volume of the detection device. Due to this filter, most of thoron decayed before reaching the detection chamber with its plastic foil. After the irradiation, the plastic foils were etched at 70^0 for 120 minutes in PEW solution (15% KOH, 40% ethyl alcohol, and 45% water, w/w/w). The etched alpha particle tracks were counted with an optical microscope equipped with a video camera and a personal computer; the magnification was 620×. It was found that, the measured radon radioactivities ranged from 0.95 to 36.00 Bq/l for groundwaters, from 0.30 to 0.54 Bq/l for sea waters, from 0.39 to 0.47 Bq/l for tap waters, from 0.43 to 2.40 Bq/l for river waters, and amounted to 2.35 Bq/l for water from Santos / Sao Vicente public water supply. It was concluded that, as pointed out by Alabdua'aly (1999), even when initial radon activities are high, the actual levels consumed by population will actually be much lower due to radon losses during transportation and bottling. In the year 1999, in Algeria, D. Amrani, D.E.

Cherouti conducted a research on the topic, Groundwater radon measurement. (Amrani et al., 2000). In the research, groundwater was sampled using submersible pump and a few casing volumes were evacuated prior to sample collection. Groundwater was collected by gently filling a leak-tight plastic bottle. Spring water was also collected using the same kind of bottle. They were over-filled directly and capped under the water, then, then removed from the sampling source. The water samples were measured using two methods, the scintillation cell technique and the electret ion chamber (EIC) with an analysis bottle. The scintillation cell measurement required that, a gas is bubbled through the water to carry the radon into an evacuated and isolated Lucas [ZnS(Ag) - coated] alpha scintillation cell, model pylon LC 300A. The water degassing procedure using a vacuum water degassing system [PYLON model WG-1001] is described i details by the manufacturer (com, 1991) and elsewhere (Whittaker et al., 1987) The method uses a photomultiplier tube, which which is incorporated into a portable radon monitor (Pylon AB-5), To measure the alpha disintegration from radon and its progeny. Sampls were counted approximately 3 hours after degassing the sample, when when the radon activity has come to an equilibrium, for 5×5 minutes intervals (total counts were corrected for cell background determination determined prior to counting). In the second method, radon in groundwater was also measured using short-term electrets in standard ion chamber (Kotrappa and Jester, 1993). In this method the electret ion chamber is placed in a leak-proof analysis jar containing a small but but known quantity of water. The amount of radon in air that that is then measured can be related to the concentration of radon in the water samples. The exposure time period for samples was 3 days. The radon concentration obtained by the two methods were compared. It was found that, the values of the ^{222}Rn activity concentration measured by EIC were higher than those measured by the SC method, and the variation of the results in this study ranged from 8.8 to 25.3%. ^{222}Rn concentration plotted as a functions of sample temperatures and well depths. The distribution

of data points on the plot presented no linear correlation and the results were in agreement with a similar studies performed elsewhere Paulus et al. (1998).

CHAPTER 3

BACKGROUND OF RADON

3.1 Sources of Radiation

Radiation is inevitable in life,naturally present in our environment and had been since the birth of this planet. Consequently, life has evolved in an environment which has significant levels of ionizing radiation. Radiation comes from outer space (cosmic), the ground (terrestrial), and even from within our own bodies. It presents in the air we breathe, the food we eat, the water we drink, and in the construction materials used to build our homes. Alpha particle radiation is the major source of natural radiation in our environment. It is derived from radioactive decay of colourless, inert gas, Radon (^{222}Rn) and leading cause to cancer in the most world.

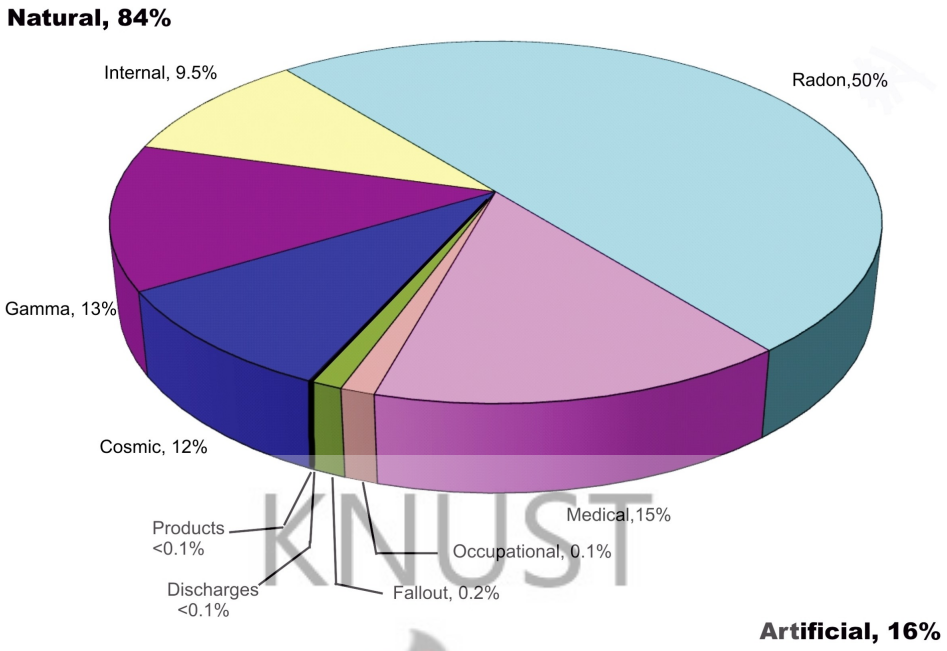


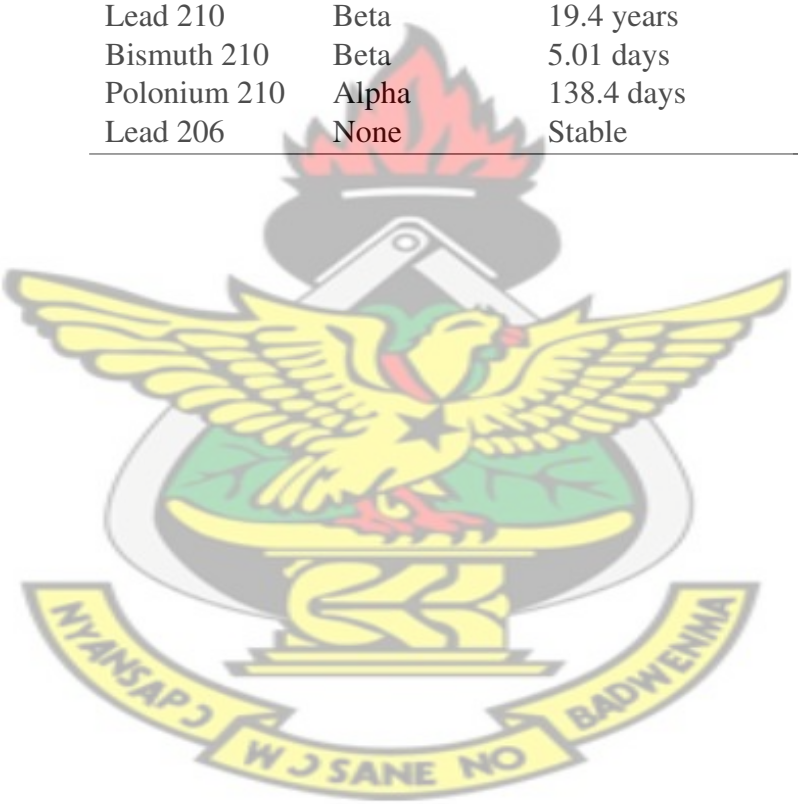
Fig. 3.1: Sources and average distribution of natural background radiation for the world population (UNSCEAR, 1986)

Figure 2.1 shows that more than eighty percent (84%) of human exposure comes from natural sources: Radon gas, the human body, outer space, rocks and soil. The remaining percent (16%) comes from man-made radiation sources, primarily medical X- rays.The largest fraction of natural radiation exposure comes from Radon, a radioactive gas, due to decay of radium contained in rocks and soil as part of the uranium radionuclide chain. The most abundant sources of natural background radiation are 238 U of life time $T_{1/2}$ = 4.5 billion years, and Thorium ^{232}Th of half life time t = 14 billion years in sediment rock. Both of these elements decay to Radon gas but Thorium decays to ^{220}Rn called Thoron which has half life time of only 55 second, whereas Uranium decays to ^{222}Rn called Radon which has half life time of 3.82 days. Since radon is a gas, it can enter buildings through openings or cracks in the foundation. The Radon gas itself decays into radioactive solids, called Radon daughters. The Radon daughters attach to dust particles in the air, and can be inhaled. The inhalation of Radon daughters has been linked to lung cancer. Below is a table and figures

that shows the Uranium decay series.

Table 3.1: **The Uranium Disintegration Series**

ELEMENT	RADIATION	HALFLIFE
Uranium 238	Alpha	4,500,000,000 years
Thorium 234	Beta	24.1 days
Protactium 234	Beta	1.17 minutes
Uranium 234	Alpha	247,000 years
Thorium 230	Alpha	80,000 years
Radium 226	Alpha	1602 years
Radon 222	Alpha	3.82 days
Polonium 218	Alpha	3.05 days
Lead 214	Beta	27 minutes
Bismuth 214	Beta	19.7 minutes
Polonium 218	Alpha	0.00001 seconds
Lead 210	Beta	19.4 years
Bismuth 210	Beta	5.01 days
Polonium 210	Alpha	138.4 days
Lead 206	None	Stable



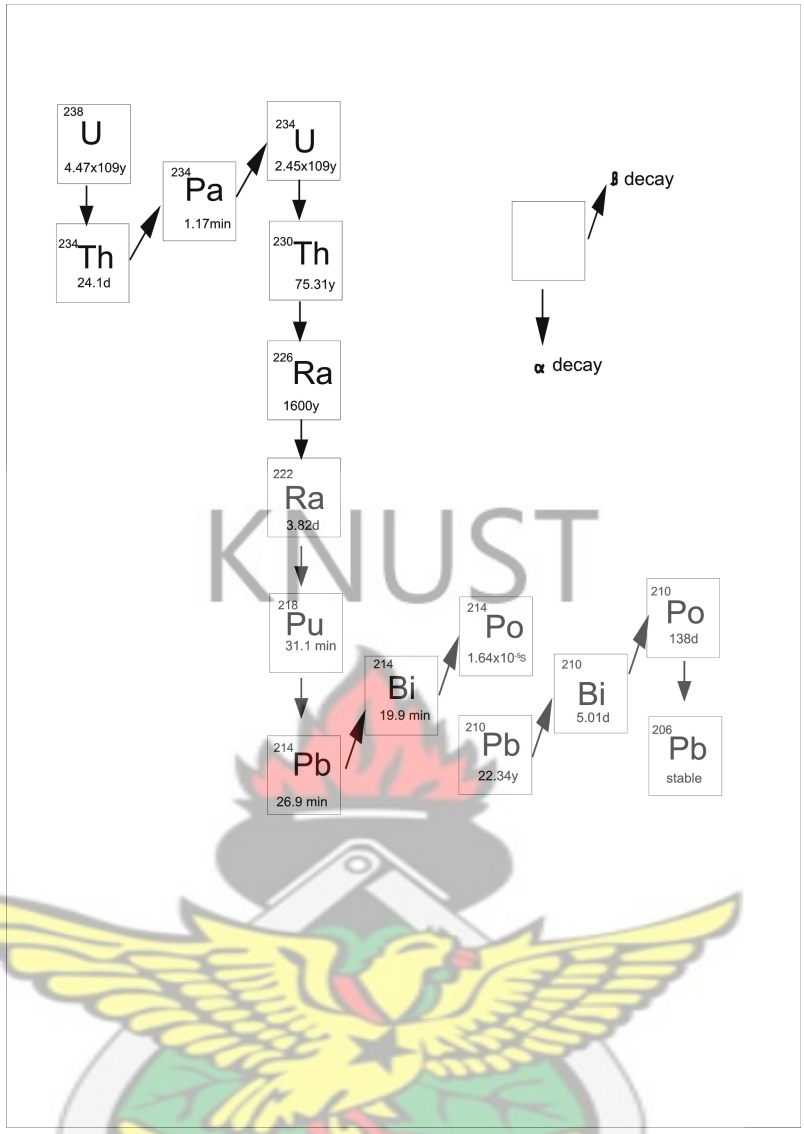


Fig. 3.2: Decay series of 238U

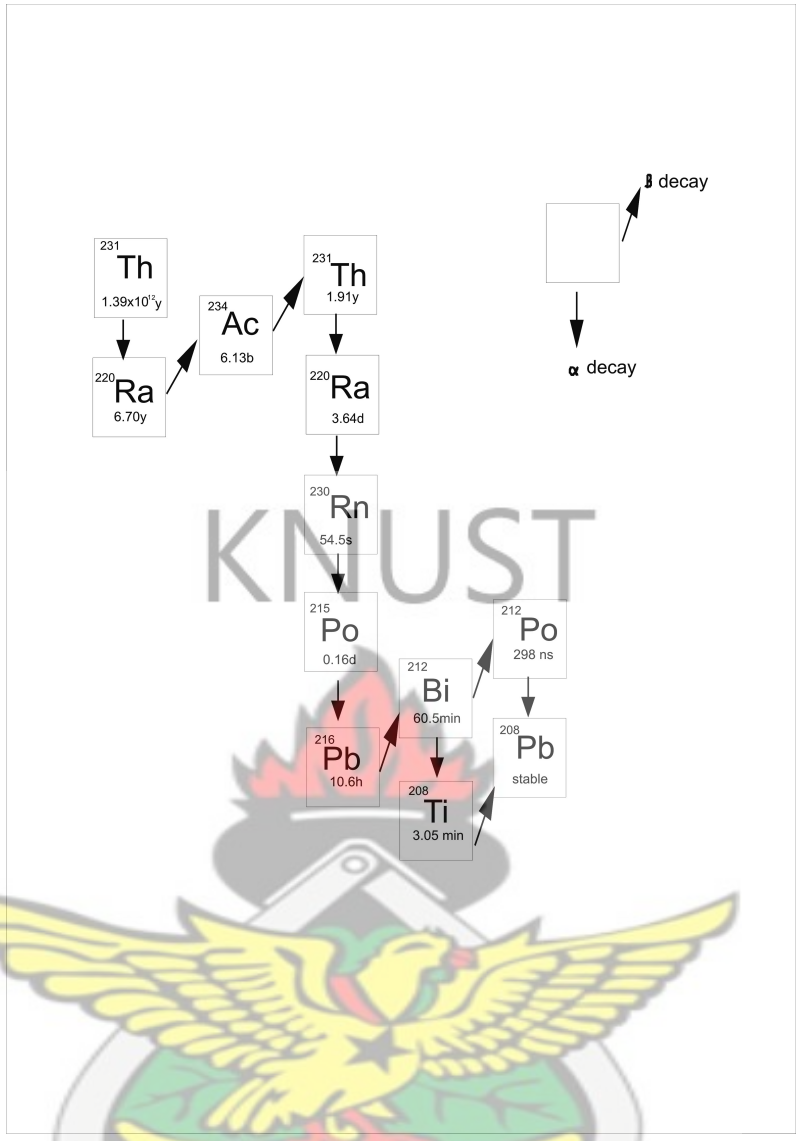


Fig. 3.3: Decay Series of 232U-TH (Mahmoud, 2003)

The uranium content of sandstone and shale is commonly related to the uranium content of the sediments from which they formed. Radon concentrations in ground water from sandstone and shale can therefore be highly variable if these sediments were derived from different sources (Almahallwi, 2004). It can accumulate up to dangerous concentrations and may cause substantial health damage after long-term exposure. Radon can also be found in drinking water and sometimes measurable. This may be due to some radioactive minerals that derived from the source rocks in the underground. The aim of the present study is to investigate Radon pollution in groundwater in selected areas in kumasi and its environs.

3.1.1 Radon

Radon is a natural radioactive gas discovered in the 1900s by Dorn, who called it radium emanation. Since 1923, it has been called Radon. The atomic number of Radon is 86, and the atomic weight is 222. Radon is a naturally occurring, colorless, odorless gas that is soluble in water. It is radioactive, which means that it breaks down - or "decays" - to form other elements. Radon occurs as a product of uranium decay. Uranium is a natural radioactive material found in varying amounts in all rocks, soil, concrete and bricks. It occurs everywhere on earth, especially in rocky and mountainous areas. Radon occurs as three natural isotopes (see Table 2.2), derived from three different radioactive decay chains, commencing with ^{238}U, ^{232}Th and ^{235}U. ^{222}Rn is that most commonly discussed in this research. Radon-220 ($t_{1/2}$ = 56 sec.) called a part of thorium (^{232}Th) series, also known as thoron in non-porous material is comparable to the activity of Radon-222, the much shorter half-life time of thoron causes its concentration in air to be relatively low and therefore usually of second interest. The third isotopes is Radon-219 ($t_{1/2}$ = 3.92 sec) called actinon in reference to its presence in actinium (^{235}U) decay chain. This nuclide does not contribute to the low natural abundance of (^{235}U) and the very short half-life time of ^{219}Rn as shown in the following table (cen, 1999). Radon is an unstable radionuclide that disintegrates through

Table 3.2: **Half-life's of the three natural isotopes of Radon**

Isotope	Common name	Half life	Decay Chain Commencing with
222-Rn	Radon	3.8 days	238-U
220-Rn	Thoron	54.5 seconds	235-Th
219-Rn	Actinon	3.92 seconds	232-U

short lived decay products before eventually reaching the end product of stable lead. The short lived decay products of Radon are responsible for most of the hazard by inhalation. The rate of Radon's radioactive decay is defined by its half-life, which is the time required

for one half of any amount of the element to break down. The half-life of ^{222}Rn is 3.82 days. A common unit of radioactivity measurement is picocuries per liter (Radomir and Saeed, 1997). Underground rocks containing natural uranium continuously releases Radon into water in contact with it (groundwater). Radon is readily released from surface water; consequently, groundwater has potentially much higher concentrations of Radon than surface water. Radon moves from its source in rocks and soils through voids and fractures. It can enter buildings as a gas through foundation cracks or dissolve in the ground water and be carried to water-supply wells. The amount of Radon in air or water commonly is reported in terms of activity with units of picocuries per liter of air or water. An activity of 1 pCi/L (picocuries per liter) is about equal to the decay of two atoms of Radon per minute in each liter of air or water (Otton, 1992). This study will refer to Becquerel per m^3 as the Radon concentration (one pCi/l = 37Bq/m^3). 1 Becquerel (1 Bq) = 1 disintegration of atom per second. While Radon easily dissolves into water, it also easily escapes from water when exposed to the atmosphere, especially if it is stirred or agitated. Consequently, Radon concentrations are very low in rivers and lakes, but could still be high in water pumped from the ground. Some natural springs, contain Radon, and were once considered healthful. Radon that decays in water leaves only solid decay products which will remain in the water as they decay to stable lead. Radon is also found in the water in homes, in particular, homes that have their own well rather than municipal water. Radon can move through cracks in rocks and through pore spaces in soils according to the, United Nation Scientific Committee on Atomic Radiation (UNSCEAR, 1986). Radon moves more rapidly through permeable soils, such as coarse sand and gravel, than through impermeable soils, such as clays cen (1999)

3.2 Sources of Radon

3.2.1 Water

Groundwater is one of the main source of water in Kumasi and the surrounding towns. The groundwater is used for domestic, agriculture, and industrial purposes. As a consequence of continuous growth in environmental pollution that is steadily increasing in the Kumasi and it environs, there is a need to investigate the presence of natural radiation in groundwater. This may be due to some radioactive minerals that is derived from the source rock in the earth crust, where the greatest portion of the radiation exposure comes from naturally occurring radiation sources such as Radon.Radioactive pollution monitoring system in groundwater should be investigated, since limited research has been done in the past. Most of studies carried out is on the chemical and geophysical quantitative and qualitative analysis in the water resources in Kumasi. However, less attention has been given to determination of the radionuclide in water. Radon in water is responsible for the whole body internal radiation dose that may be more harmful than Radon in air meaning, determination of Radon in groundwater has also been of major interest because of its harmful health, which causes lung and stomach cancers. An important factor affecting the amount of radon in ground water in many areas is the predominant underlying rock type. Many factors that affect the formation and movement of radon in the ground are as follows: the uranium content, grain size, permeability of the host rock and the nature and extent of fracturing in the host rock (Otton, 1992) . These factors are functions of rock type. Climatic factors such as barometric pressure and rainfall can affect the concentration of radon in ground water over time. These factors can be difficult to evaluate in a regional study, however, because of the overwhelming effects of other variables on radon concentration. Radon distribution in

ground water in areas underlain by igneous and metamorphic rocks and limestone follows a general geographical pattern related to rock type. Radon concentrations in ground water from subunits underlain by sandstone and shale are much more variable than those from subunits underlain by other rock types. Of these three subunits, one has a median radon concentration less than 300 pCi/l, one a median radon concentration between 300 - 5pCi/l and 1,000 pCi/l, and one a median radon concentration greater than 1,000 pCi/l. The uranium content of sandstones and shales is commonly related to the uranium content of the sediments from which they are formed. Radon concentrations in ground water from sandstones and shales can therefore be highly variable if these sediments were derived from different sources. Also, shales contain more uranium, on average, than do sandstones. Different relative amounts of sandstone and shale among these three subunits could therefore result in different median radon concentrations. Groundwater pollution is a complex phenomenon which results from natural and/ or anthropogenic factors. It has negative impact not only on our health but also on society and the economy and the overall quality of life. This problem is predominant in the coastal areas which are considered as the most density populated areas in the world (Narayana et al., 2006). In many coastal regions in the world, severe deterioration of the quality of groundwater resources is due to over exploitation of the groundwater for good quality water source. Coastal areas and especially the southern part of the Mediterranean region, experiences unacceptable groundwater quality related mainly to human activities (Almahallwi, 2004). Many families in Ghana rely on private, household wells and boreholes groundwater as their source of fresh water. The quality of drinking water is affected by the depth of groundwater from the surface, because polluted varies with depth and regional based. Human activities can alter the natural composition of groundwater causing undesirable change in groundwater quality in the form of contamination or pollution. Groundwater may contain some natural impurities or contaminants, even with

no human activity or pollution. Natural contaminants can come from many conditions in the watershed or in the ground. Water moving through underground rocks and soils may pick up magnesium, calcium and chlorides (Almahallwi, 2004). Some ground water naturally contains dissolved elements such as arsenic, boron, selenium, or Radon, a gas formed by the natural disintegration of radioactive uranium in soil. Whether these natural contaminants are health hazard depends on the amount of the substance present. Radon itself is radioactive, ejecting an alpha particle and forming the element polonium. Some people who are exposed to Radon in drinking water may have increased risk of getting cancer over the course of their lifetime, especially stomach and lung cancer (UNSCEAR, 1986). Radon accumulates in groundwater due to two different sources, firstly the radioactive decay of dissolved radium (Radon's immediate parent in the uranium decay chain), and secondly the direct release of Radon from the mineral matrix from minerals (in surrounding rocks) containing members of the uranium decay chain (Otton, 1992). The relationship between drinking water and indoor Radon concentration is an important challenge for environmental radiation and one that is perhaps underestimated. During domestic water use, as the water is heated and the Radon becomes less soluble, Radon from water is degassed into the indoor air cen (1999). Radon in groundwater could be derived from two different sources (Senior, 1998):

1. Radioactive decay of dissolved radium (the immediate precursor to Radon in the decay chain).

2. Direct release of Radon from the mineral matrix from minerals containing members of the uranium/thorium decay series. Once Radon is formed in radium-bearing material, some of it leaves the grains to the pore space. This fraction is relatively free to move between the pores and its transport is possible as shown below in the figure (2.4). Radon can therefore reach the air or water to which humans have access, provided that

transport is sufficiently rapid to be completed before the Radon decays (Mose et al.).

The small water supply systems are often closed systems with short water transit times that do not allow Radon to be completely removed or decayed. Radon then escapes from the water into the indoor environment depending on usage of the water for showers and washing as shown in figure (2.5). Radon in drinking water is found only in groundwater supplies (the insoluble Radon gas quickly degasses in surface water supplies). In many countries, some homes obtains their drinking water from groundwater sources (springs, wells and boreholes). Underground water often moves through rock containing natural uranium and radium that produce Radon. This is the basis for water from deep drilled wells normally indicating a much higher concentrations of Radon than surface water from rivers, lakes, and streams (David et al., 1989). Most of the Radon in indoor air comes from soil underneath the home and the walls. As uranium disintegrates, Radon gas form and seeps into the house. Radon from soil can get into any type of building; homes, offices, and schools, and into higher floors of the of the building. Radon gas can also dissolve and accumulate in water from underground sources, such as wells. The factors that affect the formation and movement of Radon in the ground are as follows: the uranium content, grain size, permeability of the host rock and the nature and extent of fracturing in the host rock. Radon concentrations in ground water vary because of dilution by recharge or changes in contributing areas of the aquifer because of pumping (Senior, 1998).

It has been noted that radon concentration in water can vary for a number of reasons. However, the radon content in a borehole may provide the key to understanding the radon pumped out of the well. It is clear that the aquifer mineralogy (the presence and emissivity of the parent radium) establishes some baseline radon concentration in ground water. From

there, the flow in and out and subsequent mixing in a borehole may control the variations noted over time. In a borehole intersecting multiple bedrock fractures, each could have separate flow rates and radon concentrations supplying the well. This will affect the temporal variation of radon in water, especially if the water-table level or cone of depression drops thereby eliminating some fractures from supplying the well. The more fractures a well may have, with their separate flow rates and radon concentrations, may make the mixing problem a complicated one. Although for crystalline rock aquifers, it is common for only a few fractures to produce all the flow in the well. Since the inflow points down a borehole may be signaled by a change in radon con- centration, radon concentration profiles with depth may be a useful tool. This would show any differences or similarities in radon concentration in the vertical column of water in a well. This can be indirectly measured by a gamma-ray log of the well. A gamma-ray log measures naturally occurring gamma-ray radiation with a detector that is lowered down the well. Radon itself does not produce gamma rays, but a few of its short lived daughters do (214 Pb and 214 Bi). It is possible to directly measure the radon content in the water by taking a water sample from discrete intervals in the well. This method packs off an interval of the well column and allows a pump to draw water exclusively from one area. The areas with elevated radon levels (and also uranium in adjacent rock measured by neutron activation analysis) were correlated to fractures zones with high flow conductivity. Another study took a more detailed look at the radon depth profile and correlations with temporal variations of radon while pumping a well. Both nested piezometers (small diameter pipes installed into the subsurface and an open borehole. The nested piezometers had a screen length (interval open to the ground between 0.5 - 5 m over 100 m for 10 discrete intervals in the ground. Samples were taken from the piezometers with pressurized stainless steel bailers. The goal was to make depth measurements before and after pumping (2 well volumes) to get horizontal ground-water flow. They hypothesized

that the natural ground-water flow would be pro- portional to the ratio of the purged to unpurged radon concentrations. This would only be true in nested piezometers where the sample point is well mixed. Where there would be low flow, the stagnant water at that depth would have low radon concentration due to the decay of radon. At high flow areas, there would be newer, replenished water entering the well. From the radon measurements, the flow rates were determined, which agreed with other borehole logging parameters such as electrical conductivity and temperature gradients. In addition, they looked at the radon concentration over time while pumping from two of the 10 nested piezometers. For one, the radon concentration increased while pumping and after one well volume removed, the level became constant with time. The initial and final radon concentration even agreed with the concentration at that depth for the unpurged and purged measurements, respectively. For the other case, the increase was less, which led the authors to suggest that they may have been drawing water from greater distances. The results from the nested piezometers verified a relation between radon depth pro- files and temporal radon changes while pumping. The temporal effect has been clearly noted in open boreholes (much like private wells). Unlike nested piezometers with a small screen length (the part of the pipe open to the ground), open boreholes are screened or open most of their drilled length. A casing closes off a top portion of the borehole from the ground. Unpurged water samples at 5 m intervals were taken with either the bailer or a dialysis membrane diffusion cell left in place for a period of time. The open borehole was not pumped. From the unpurged profiles, a variation in radon was observed. They believe increases in radon concentration signals active areas of ground-water inflow and hydraulically active fractures. There may be vertical flow in the well, which was not accounted for in these studies. To rule out other causes of variation, they performed alpha spectroscopy on the drilling chips and found little variation of the parent radium as a function of borehole depth. They concluded the radium content in the surrounding rock must

not dominate radon content of the enclosed water. Borehole geophysicists send a variety of tools down a borehole to measure parameters to survey a well. Commons tools include temperature sensors, calipers (to measure diam- eter and locate fractures), flow meters (using either a impeller or heat pulse), gamma-ray detectors, and electrical conductivity probes . This last tool can be used to explore the inflow and outflow of water in a well. This is done by first replacing the well column with de-ionized water. Next, an electrical conductivity probe is continuously lowered and raised while the well is pumped. Since the well is being pumped, any inflow points will supply ground water of some salinity into the de-ionized water column. Running the electrical conductivity probe up and down the well will show the time evolution of fluid electrical conductivity. The hydraulically active zones will be evident as a peak in conductivity. Further, this peak will skew and spread in the direc- tion of the water velocity under pumping condition. With a proper model, the individual flow rates from each inflow can be determined. The spirit of this experiment may work for with radon. The natural radon flowing into the well under pumping con- ditions and the mixing in the well that follows could provide the same information. The radon method would save the lengthy step in the flowing electrical conductivity method of replacing an entire well volume with de-ionized water.

3.2.2 Soil

The major source of Radon in the atmosphere emanating from soil is derived from rocks. These rocks contain some levels uranium, where the decay of ^{238}U through ^{226}Ra gives Radon. Certain types of rock, including granites, dark shale, light-colored volcanic rocks, sedimentary rocks containing phosphate and metamorphic rocks recorded to have higher average uranium contents (Virk and Singh, 1993). Because Radon is a gas, it has much

greater mobility than uranium and radium, which are fixed in the solid matter in rocks and soils. Radon can more easily escape from the rocks and soils into fractures and openings in rocks and also into the pore spaces between grains of soil as shown in figure2.4.

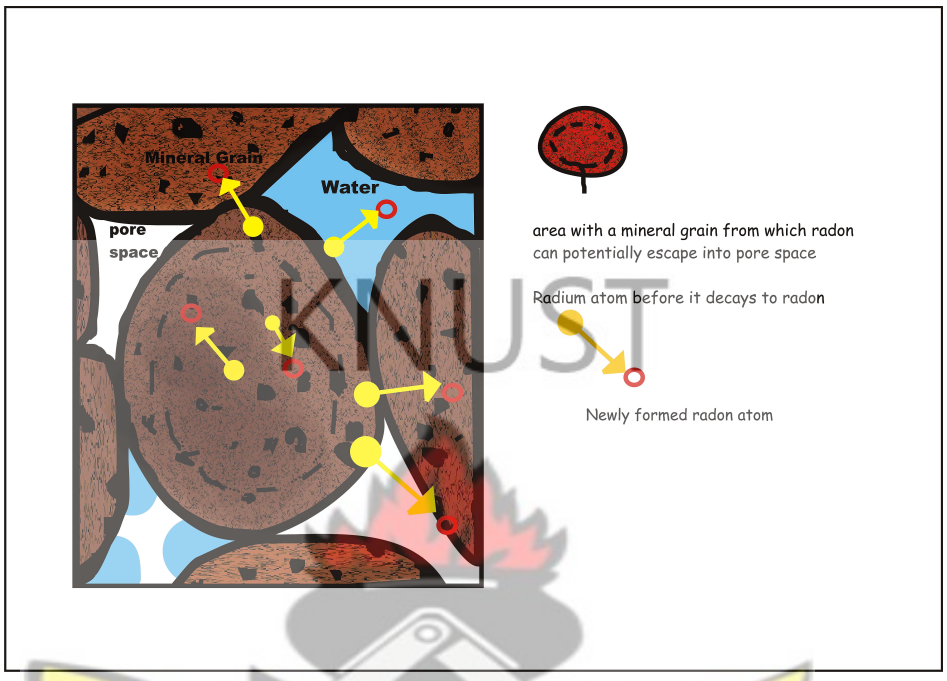


Fig. 3.4: Migration of Radon through pore space and water (Otton, 1992)

3.3 Guidelines for Radon Concentration in water

The World Health Organization (WHO) Guidelines for Drinking Water Quality and the European Commission recommends that, controls should be implemented if Radon in public drinking water supplies exceeds 100 Bq/m^3, treatment of the water source should be undertaken to reduce the Radon levels to well below 100 Bq/m^3. The United States has proposed a Maximum Contaminant Level for Radon of 150 Bq/m^3 for private water supplies epa (2001). Many countries have defined an Action Level of Radon concentration to guide their program to control domestic exposure to Radon. The Action Level is not a boundary between safe and unsafe, but rather a level at which action on reduction of Radon level

will usually be justified. Some people may choose to take action when the radon level is approaching Action level. For example, many countries consider Radon concentration in the air of 200 Bq/m^3 as an Action Level at which mitigation measures should be put in place to reduce Radon level in homes. In USA People who have private wells are encouraged to test their well water to ensure that Radon levels meet Environmental Protection Agency's newly proposed standard Action Level of 150 Bq/m^3. In addition, exposure to uranium in drinking water may cause toxic effects to the kidney. To protect public health, EPA (Environmental Protection Agency) had established drinking water standards for several types of radioactive contaminants, combined radium 226/228 the standard is 200 Bq/m^3,gross alpha standard 500 Bq/m^3 [20,21]. The Norwegian Radiation Protection Authority had also recommended an action level of 500 Bq/m^3 for Radon in domestic water, and 200 Bq/m^3 in household air [22]. Radon in water is responsible for the whole body internal radiation dose that may be more harmful than Radon in air. Therefore, determination of Radon in groundwater is of keen interest to Ghana.

3.4 Radon Concentration in Different Countries

Since Radon is a carcinogen for lung and stomach, many scientists at different countries have given attention to study Radon concentration in air, soil and water in overall the world. Scientist had various experimental and technical possibilities that are available to measure the radon concentration in soil, air and water. A study by Mose and others found that cancer incidence increase as the amount of Radon in household water increases. This study includes the previously mentioned sources of natural radiation such as Radon in groundwater (Punjab and Himachal Pradesh States, India), showed that Radon concentration values in drinking

water had a wide variation depending on its source and location. The Radon concentration values in hand pump groundwater have been found to be higher than the values from other sources. The recorded Radon concentration in these samples had been found to vary from 10 to 48Bq/m^3. The Radon concentration had also been measured in some thermal springs and these values had been found to be much higher than from other sources of groundwater. Mineral water has the minimum Radon concentration compared with groundwater sources . Another study of Radon concentration in groundwater was measured in Israel and result showed that the decay of Radon in western Galilee was 150-570 pCi/l, and in the Dead Sea area from 2000-5000 pCi/l. Another research showed that 50 % of the drilled wells in Stockholm County have a Radon content exceeding 100 Bq/m3 and 11 % have as much as 1000Bq/m^3 . During the 1990s, several surveys of Radon concentrations in Norwegian groundwater had been carried out, including a nationwide study by the Norwegian Radiation Protection Authority and the Geological Survey of Norway. About 13.9 % investigated boreholes in Precambrian and Paleozoic crystalline bedrock yielded water with Radon concentrations excess of the recommended action level of 500Bq/m^3. The highest levels are usually found in granites (up to 20000Bq/m^3), but concentrations vary considerably between boreholes within each lithology . Groundwater in superficial Quaternary sediments typically had Radon concentrations well below the recommended action level . Guideline values (action levels) of Radon vary among countries, and have been measured and estimated in different countries. Table (2.3) shows the domestic Radon concentration and action level in different countries.

*Not Availabe

Table 3.3: **Domestic Radon Concentrations and Action Levels in Different Countries**

Country	**Average Radon Concentration in homes** (Bq/m^3)	**Action level**(Bq/m^3)
Finland	123	100
Germany	50	250
Ireland	60	200
Israel	*	200
Lithuania	37	100
Luxembourg	*	250
Norway	51-60	200
Poland	*	400
Russia	19-250	*
Sweden	108	100
Switzerland	75	400
United Kingdom	20	200
European Community	*	400
USA	46	150
Canada	*	800

CHAPTER 4

METHODOLOGY

4.1 Description of Experimental Site

The figure below is a map that shows the various towns or sites from which the underground water samples were collected. The GPS was used to take the geographical location on the surface of the earth where the samples were picked. The map also shows other features such as first class road, second class road, railways and rivers. The names of the towns are shown on the map and from each town, a number of water samples were taken.

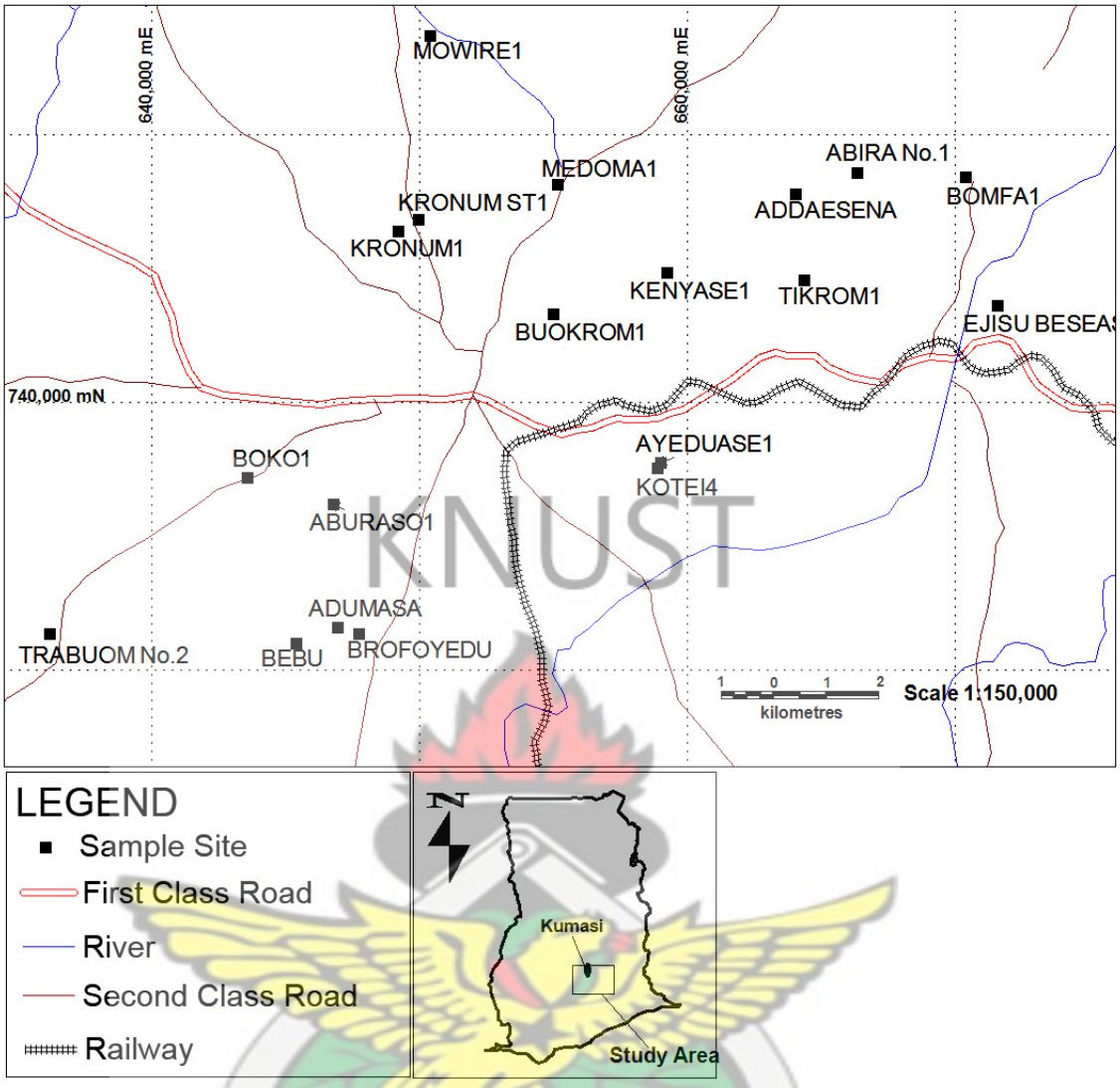


Fig. 4.1: Map showing the towns from which the samples were collected

4.2 Geology of project site

There are two main rock types for all the towns from which the underground water samples were taken. Some of the towns are distributed over the rock type known as the besin type granitoid. Examples of these towns are Mowire, Kronum, Medoma, Kenyase, Buokrom, Bomfa, Ayeduase, Kotei, and Tikrom. Aburaso and Trabuom also have the major rock type to be the birimian metavolcanic rock. An important factor affecting the amount of radon in groundwater in the predominant underlying rock type. Many factors that affect the formation

and movement of radon in the ground - the uranium content, grain size, and permeability of the host rock and the nature and extent of fracturing in the host rock (Otton, 1992) - are functions of rock type. Climatic factors such as barometric pressure and rainfall can affect the concentration of radon in ground water over time. These factors can be difficult to evaluate in a regional study, however, because of the overwhelming effects of other variables on radon concentration. Radon distribution in groundwater underlain by igneous and metamorphic rocks and limestone follows a general geographical pattern related to rock type.

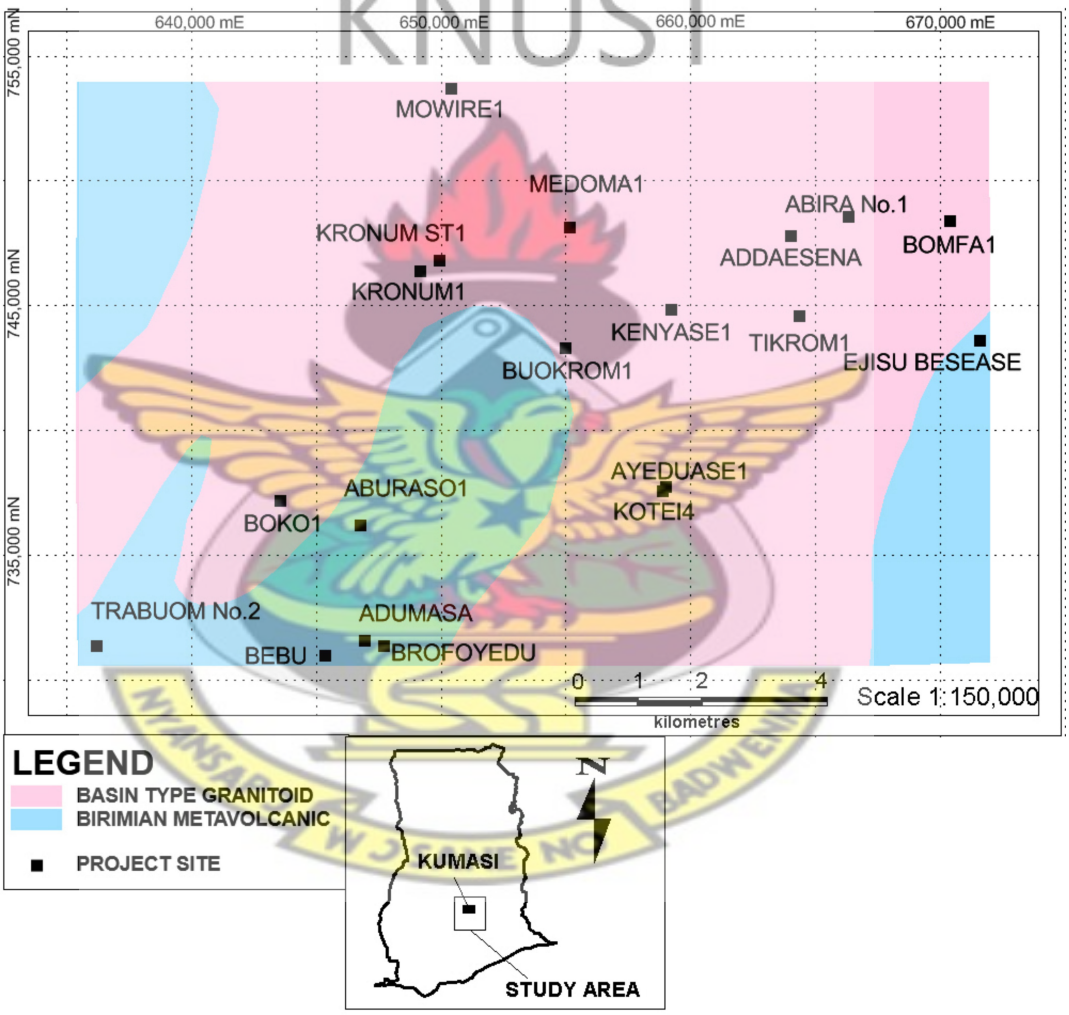


Fig. 4.2: Geological structures of the towns under study

Most igneous and metamorphic rocks in the study areas are of predominantly granitic composition. These rocks contain higher concentrations of uranium, on average, than do limestones. Rocks of this type contain much less uranium, on average, than do limestones

or granitic rocks. Radon concentrations in ground water underlain by sandstone and shale are much more variable than those underlain by other rock types. The uranium content of sandstones and shales is commonly related to the uranium content of the sediments from which they formed. Radon concentrations in ground water from sandstones and shales can therefore be highly variable if these sediments were derived from different sources. Also, shales contain more uranium, on average, than do sandstones (Hem, 1985).

4.3 Elevation of study areas

A contour map of the study areas was plotted by using the coordinates of the sample point as recorded by the GPS, and the elevation. This was done to study if there is any relationship between the elevation of the sample point with respect to radon concentration in the water sample. The towns with low elevations include Trabuom, Atwimah Boko,

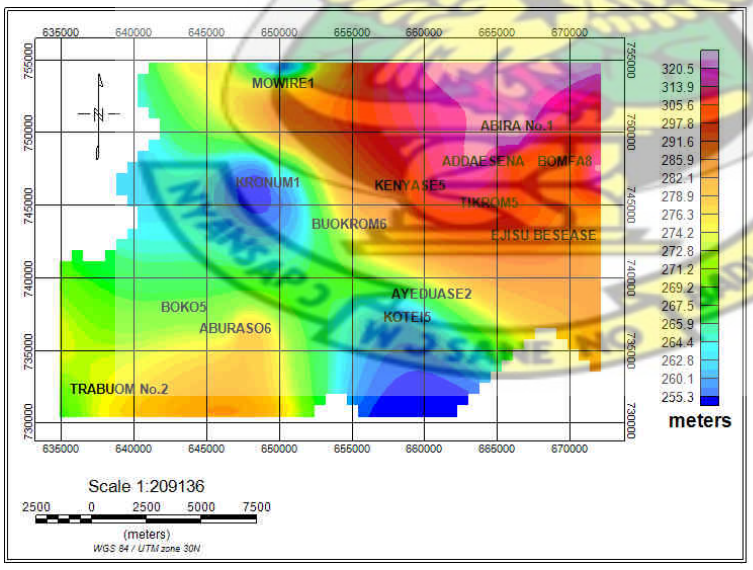


Fig. 4.3: Contour map of the elevation of the study area

Ayeduase, Kotei and Mowire. The rest of the towns are relatively on high elevations. The radon concentration in the water samples recorded at higher elevations can be compared to

that at lower elevations. This can be used to draw a conclution if there is any correlation between the elevation and the radon concentration in the water sample collected from that particular point.

4.4 Methods Used

4.4.1 Determination of background of Scintillation Cell

Twenty of the lucas cells were used for collecting radon gas from water sample from each site. In other to calculate the radon concentration of each water sample, it is required that the background reading of the cell was taken.The background reading of the cell was one of the parameters needed to calculate the radon concentration in the water sample.The following were the steps taken in the determination of the background reading of the cell:

1. Compressed nitrogen gas was used to flush the cells using two tube connectors connected firmly to the valves of the cell. One of the tubes connects to the nitrogen gas source and the other tube leads to the outside of the laboratory.

2. The cells were flushed for about 30 minutes each after which all tube connectors were disconnected.

3. The AB-5 was switched off, the cap was removed and the scintillation cell was mounted to the AB-5. After 30 seconds of mounting the cell to the AB-5, the AB-5 is then turned on.

4. In the Continuous mode, the AB-5 was programmed for an interval length of 30 minutes.

5. The AB-5 was allowed to count for four readings within a time interval of 2 hours.

6. The counting was stopped and the values for the counts were recorded for the set time.

7. The average count was determined and and converted to count per minute and then recorded. This gave the current background level of the system.

4.4.2 Sampling Water

In order to study radon in ground water from an open borehole, it is necessary to adequately sample the water. Generally speaking, there are two basic means to collect a sample of water, either draw water out with a pump or send down a bailer to collect a sample. Clearly, these two methods have differing effects on the well. When water is pumped, the water in the well evacuates and/or new ground water is drawn from the surrounding aquifer. In the above studies, when the radon in water was observed over time to show temporal variations, it was performed by pumping water out of the well from some arbitrary depth. However, using a bailer only takes a small volume of water from a desired depth. Collecting a sample with a bailer will mix water in the well but has minimal effect on the aquifer. There are commercial products available called discrete interval samplers for sam- pling at depth in a column of well water. Parker and Clark (2002) reviews a variety of these samplers. There are a few basic designs. One type is made from a stainless steel tube with a collection vial housed inside. It has inlet and exhaust ports designed such that the collection vial does not fill until it has remained stationary for a few seconds. Another bailer is made from a flexible polyethylene bag with a floating ball check valve. It can be maneuvered with proper up and down movements to fill the bag. A third type involves applying positive pressure (above the ambient pressure of the water to be sampled) to the sampling vessel while the

sampler is lowered and raised. This involves running a tube from the sampler to the surface where an inert gas can be applied with an air pump or gas cylinder. The sampler is outfitted with floating check valves to allow water to flow under the desired pressure differences between the inside and ambient water. It is clear that the application of positive pressure to the sample will keep it from leaking and ensure a water sample from a discrete depth in the well. However, the unit is expensive and the application of a gas at a correct pressure before and after every sample adds to the labor involved. A fourth type uses a diffusion bag lowered down to a depth in a well. It relies on the diffusion across the membrane. The obvious drawback of this method is the long (several days) waiting period for equilibrium across sampler membrane. Aside from those samplers mentioned, a pump can also be used to take samples from a discrete interval. The pump (if submersible) or the tube from a surface driven (or peri- staltic) pump can be lowered to discrete depths. This process can be aided by placing packers above and below the pump point. Typically these packers, like balloons, can be inflated when in position to block off other parts of the well. That interval can then be pumped to purge that portion of the well or simply pumped long enough to collect a sample at the surface. The major drawback of all of these discrete interval samplers for measuring radon is the ability to collect a sample following the protocol for liquid scintillation analysis. The water collected for radon analysis must first be drawn into a syringe where a fixed volume can be obtained. It is also ideal for the water entering the syringe to have minimal radon loss due to degassing. In order to use these samplers for radon analysis, modifications would need to be made to allow a syringe to draw water from the collected water. Of the samplers mentioned, the pressurized sampler seems to be the most suited for the task of collecting water for radon analysis. The positive pressure applied during transit ensures no leaking of water into the empty sampler on the way down, as well as keeping the high pressure inside during removal of the sampler from the well. The other designs claim to resist

the pressure changes while the sampler is in transit, but it remains to be shown how well they resist loss or out-gassing of radon. The sampling methods discussed above are technical and efficient methods in sampling the water such that, the radon gas lost from the water as a results of the sampling can be minimized. In this work, the source of the groundwater was well water and boreholes.

Fig. 4.4: Well water as a source of groundwater

Below is a picture of the boreholes from which samples were taken. The water could only be collected by the use of the pump. The was no othe information on the borehole and as a result, the depth of the water could not be found.

Fig. 4.5: Borehole water as a source of groundwater

In this work, none of the two methods of sampling discussed above was employed in the sampling of the waster. This is because, we wanted to get the radon concentration in the water as fetched by the people who depended on the particular well or borehole as the source of water for deinking and other domestic activities.

The total number of underground water samples collected for this project was One Hundred (100). This number of water samples were collected from eight different towns in and around Kumasi. At each site a number of the water samples were collected depending on the average number of people depending on that water as their main source of drinking, cooking,

washing, bathing and all other domestic activities. The separation between any two samples collected from the same towns was also considered so that, the samples were uniformly distributed throughout that particular town.

4.4.3 Water Sample Degassing Method

Samples of water (approximately 200 cm^3) were collected from the boreholes and wells. The sampling time, ie, the time at which the water sample was collected (T_s) was recorded. The pump was plug in the pump connector and the cell inserted into the scintillation cell connector. The system was then evacuated to a minimum of 27 inches of mercury (Hg) at sea level barometric pressure. (At higher altitudes, the average barometric pressure was taken into account when the minimum evacuation of the cell was determined).The pump was disconnected. It was ensured that the drierite, ie the drying agent was blue. The drierite turns pink as it absorbs moisture. It should be replaced at this stage to avoid the possible condensation in the cell. Ensuring that the ON/OFF and bypass valves were closed, 190 ml of a sample was quickly transferred into a sample cylinder and sealed tightly by inserting a diffusion stone and rubber stopper rapidly and carefully. The bubbler was promptly connected with the first line going into the bubbler inlet. Then the exhaust dryer connection was plugged in and some bubbling was observed for a few seconds. The ON/OFF valve was then opened and a fine steady bubbling was maintained for a timed period of about 4 to 5 minutes. After the vacuum gauge indicated three inches or less of mercury, the bypass valve was opened slowly for 5 to 10 seconds to wash out radon from the tubing into the cell. The bypass and the ON/OFF valves were closed and the bubbler disconnected from the exhaust dryer connector. The above steps were repeated for each samples collected.

Fig. 4.6: The water degassing process at the laboratory

In order to count, the scintillation cell was placed in a radiation monitor approximately 3.5 hours after sampling.This was done to ensure that the radon activity had come to secular equilibrium. The cell was counted three times five minutes intervals. The counts and time were then recorded.

Fig. 4.7: The counting process

To use the cell for other water samples, the residual radon must be must be flushed out of the cell. To flush the residual radon out the system, the cell was positioned back on the water degassing system.The bubbling apparatus was installed but without water in the cylinder. The inlet and exhaust lines were connected to their respesctive connectors and the ON/OFF and BYPASS valves closed. With the help of a hand pump or an electric pump, the cell was evacuated to a minimum of 27 inches of mercury (Hg) at sea level barometric pressure. The BYPASS valve was opened. The process was repeated 2 or 3 times. This method was repeated for each cell, each measurement and each site.

CHAPTER 5

RESULTS AND DISCUSSION

This chapter aims to evaluate the overall significant results that were obtained throughout this thesis work. The radon concentrations of the water samples from the various towns are discussed under subtitles which bears the name of the towns.

5.1 Variation Of Radon Concentration With Latitude At Study Areas.

In each of the study towns, the source of groundwater are randomly located. The boreholes and the well water samples were not collected along any profile line. Despite the random locations of the source of water samples, the exact location of the sample on the surface of the earth was taken by the GPS. The radon concentration variation with respect to the latitude for each of the towns were studied for each of the towns and they are discussed in subsection.

5.1.1 Kronum

At kronum, eighteen samples were collected and analysed. A scatter plot was drawn to show the trend of the variation of the radon concentration in the samples.

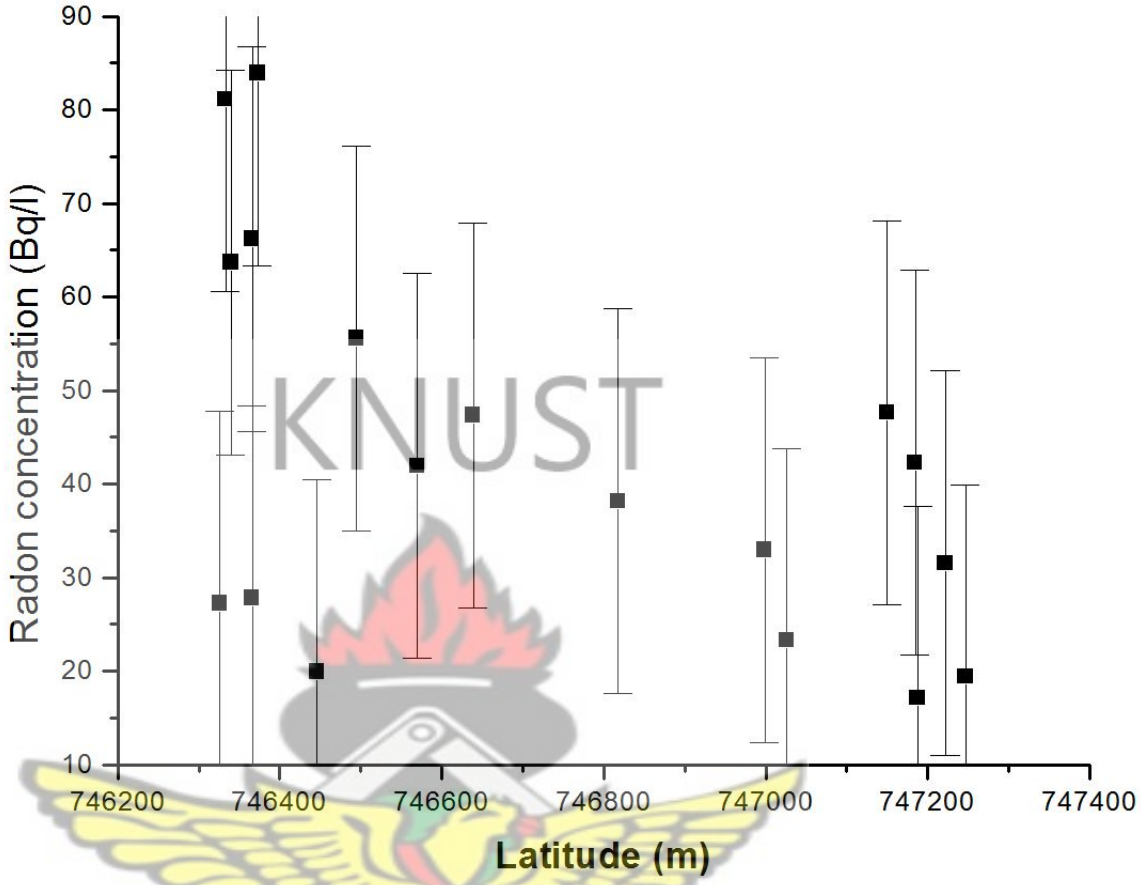


Fig. 5.1: Variation of radon concentration with latitude for samples from kronum

The plot shows that all the samples were taken between latitude 746200 and 747400 and the radon concentration in the generally decreases. Some few samples deviated from the generally decreasing trend. This could be as a result of the shift in the soil type and the sub-structures of the rock type. The Radon concentration values obtained in the underground water samples collected in Kronum are relatively low as compared with that of other towns or sites. The minimum and the maximum values of the radon concentration are respectively 17.095 and 83.890 in Bq/l. The values are low as a results of the fact, the depth of the water was low as compared to other areas. Other factors that might contribute to the low values of

the radon concentration in the water sample might be the type of soil and type of rock at that area. The mean value is 42.593 Bq/l and the standard deviation is 20.547 Bq/l.

5.1.2 Kenyase and Abira

Kenyase and Abira are towns located in the Kwabere district after Buokrom and before Antoa. Again the water samples are randomly distributed in the town and they are not in any pattern or along any profile. From the GPS data, it can be seen that most of the samples were taken around the same latitude. It can be seen that, most of the samples have concentration with small difference between the samples. This could be as a result of the same rock type at that area. Three samples were also taken from different points which are a little far from the others. This three samples are near each other and it can be seen that, the radon concentration in those samples are almost the same.

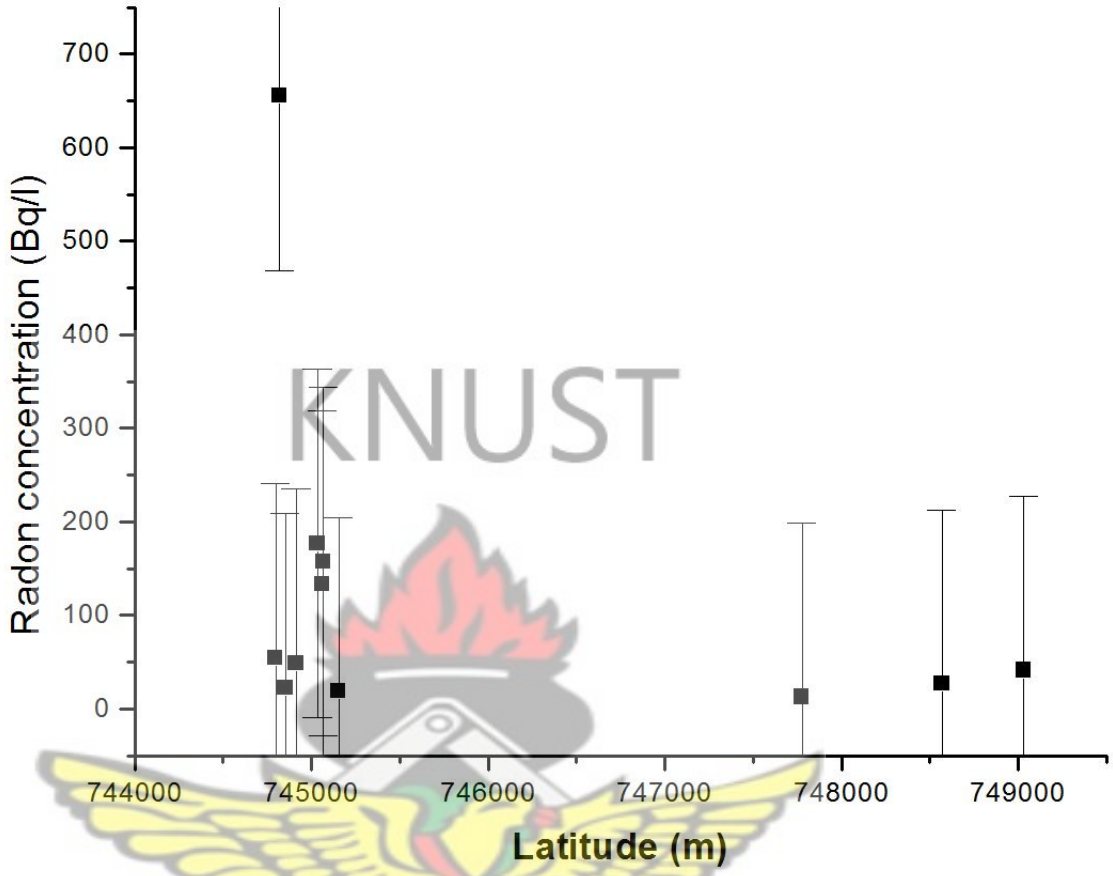


Fig. 5.2: Variation of radon concentration with latitude for samples from Kenyase and Abira

The Radon concentration in each water sample in Kenyase at different locations measured in Bq/l are given in figure 5.2. The arithmetic mean of measurements was 133.229 Bq/l, with a range of values between 18.500 and 654.945 in Bq/l with average standard deviation of 192.481 Bq/l . The results indicate that the difference between the minimum and maximum Radon concentrations in Kenyase is very high. This large variation in Radon concentrations may be due mainly to the difference in the soil type, rock type and the depth of these wells.

5.1.3 Buokrom

Ten samples were collected in buokrom and analysed. The plot shows that the samples are scattered and no trend is easily identified.

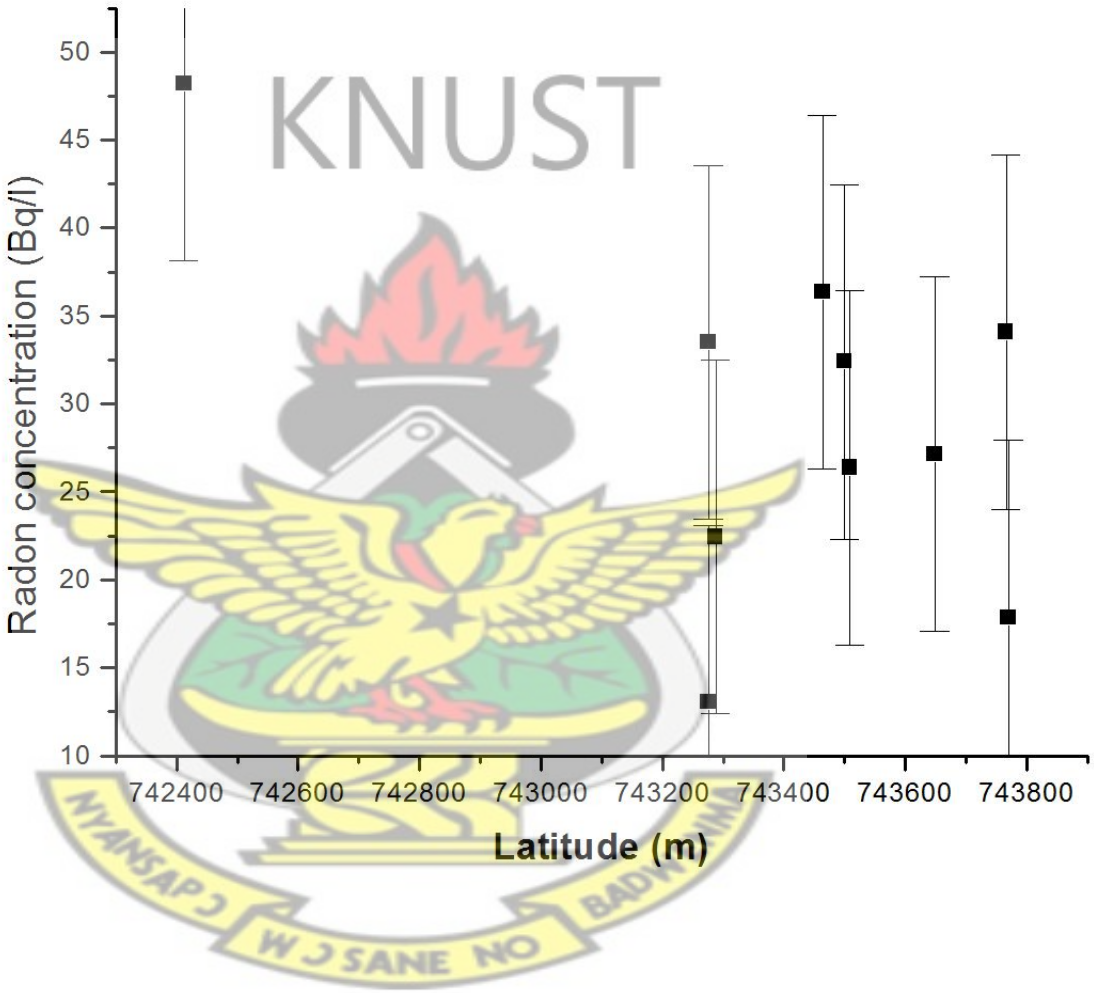


Fig. 5.3: Variation of radon concentration with latitude for samples from Buokrom

Figure 5.3 shows the radon concentration values against latitude obtained underground water samples collected at Buokrom. The values are low as compared with that of other towns like Mowire and Tikrom. However, the results is not very far from that obtained in Kenyase. The two towns are not not far from each other.How close the values are could be due to the

proximity and similarities in the soil type and also that of the water samples in the two towns are not very different. The minimum and the maximum values are 4.818 and 13.034 in Bq/l. The values are low as a results of the fact, the depth of the water was low as compared to other areas. Other factors that might contribute to the low values of the radon concentration in the water sample might be the type of soil and type of rock at that area. The mean value is 29.135.836 Bq/l and the standard deviation is 10.068 Bq/l.

5.1.4 Ayeduase and Kotei

A generally increasing trend is noticed in the radon concentration in the samples collected from Ayeduase and Kotei with respect to the latitude. The water samples were not collected in any profile line since the source of the samples were collected randomly from different houses and hostels. Each sample served a house as the main source of water for all domestic activities.

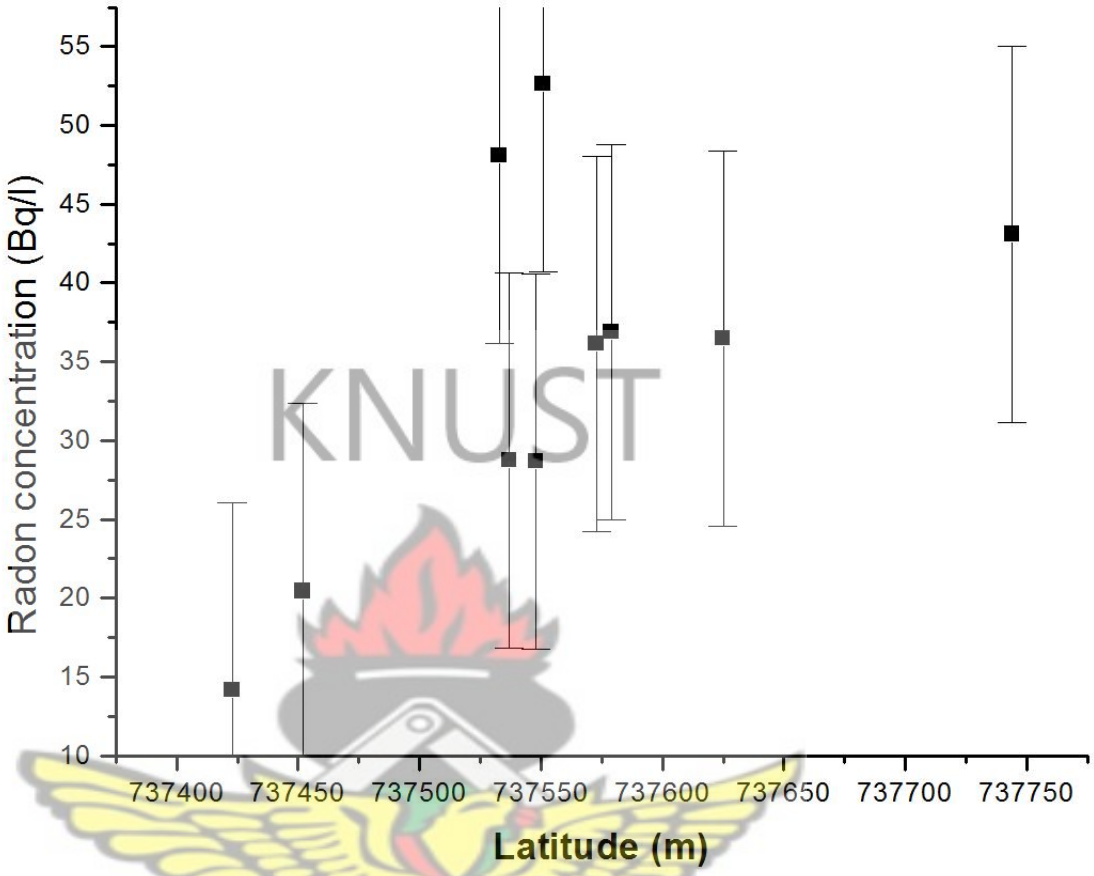


Fig. 5.4: Variation of radon concentration with latitude for samples from Kotei and Abira

The Radon concentration in each water sample in Ayeduase and Kotei at different locations measured in Bq/l with respect to the latitude are given in figure 5.4. The arithmetic mean of measurements was 34.266 Bq/l with a range of values between 12.637 and 52.634 Bq/l and with average standard deviation of 12.615 Bq/l. The results indicate that the difference between the minimum and maximum Radon concentrations in this area is very high. This large variation in Radon concentrations may be due mainly to the difference in the soil type, rock type and the depth of these wells.

5.1.5 Bomfa

Ten samples in all were collected from Bomfa. From the GPS data, it could be seen that most the samples were collected around the same latitude. Bomfa is not a big town and and therefore the source of the groundwater were close to each other. It was only one sample that was a little far from the rest of the others. From the plot, it can be seen that the concentration of radon in the sample are not very far from each other.This could be as a result of the same rock and soil type at the place. The Radon concentration values obtained in the underground

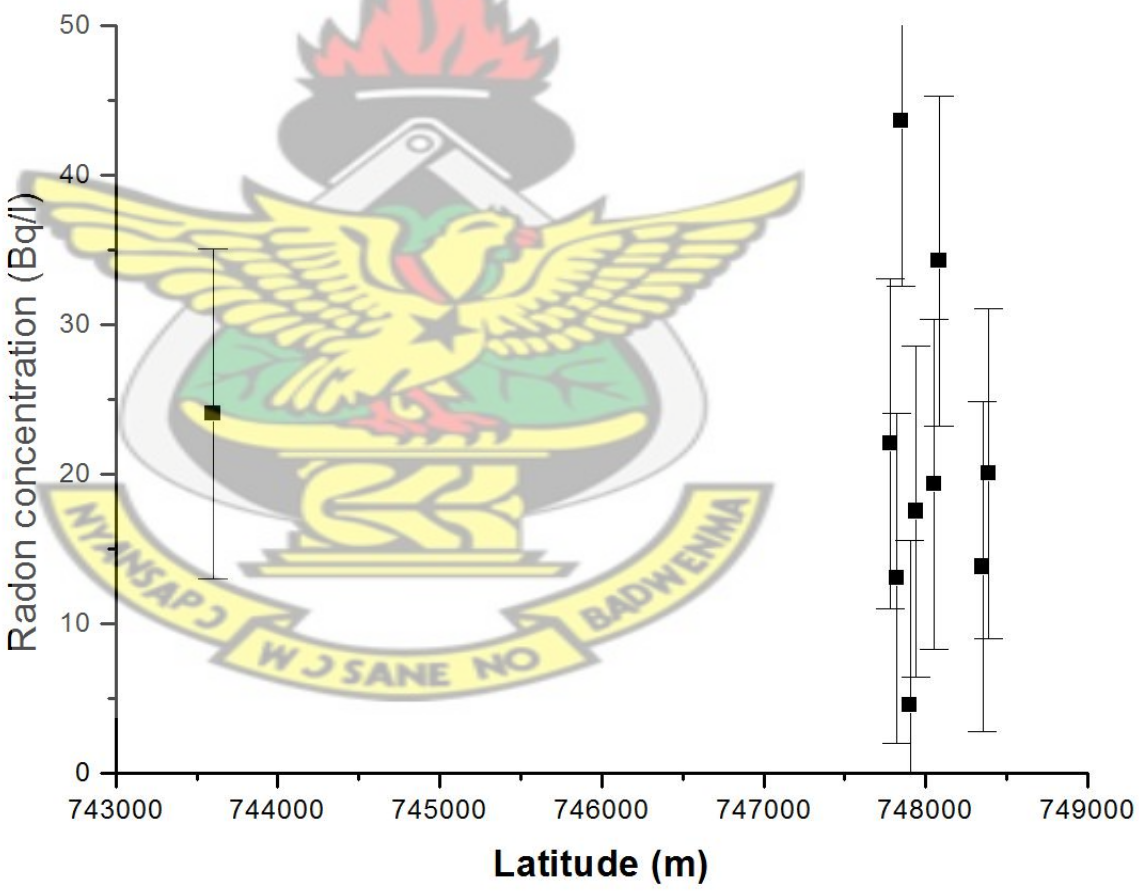


Fig. 5.5: Variation of radon concentration with latitude for samples from Bomfa

water samples collected at Bomfa are also low as it is clear on the figure 5.5, as compared

with that of other towns like Mowire and Tikrom. The minimum and the maximum values are 13.017. and 43.570. in Bq/l . The values are low as a results of the fact, the depth of the water was low as compared to other areas. Other factors that might contribute to the low values of the radon concentration in the water sample might be the type of soil and type of rock at that area. The mean value is 21.184 Bq/l and the standard deviation is 11.044 Bq/l.

5.1.6 Mowire

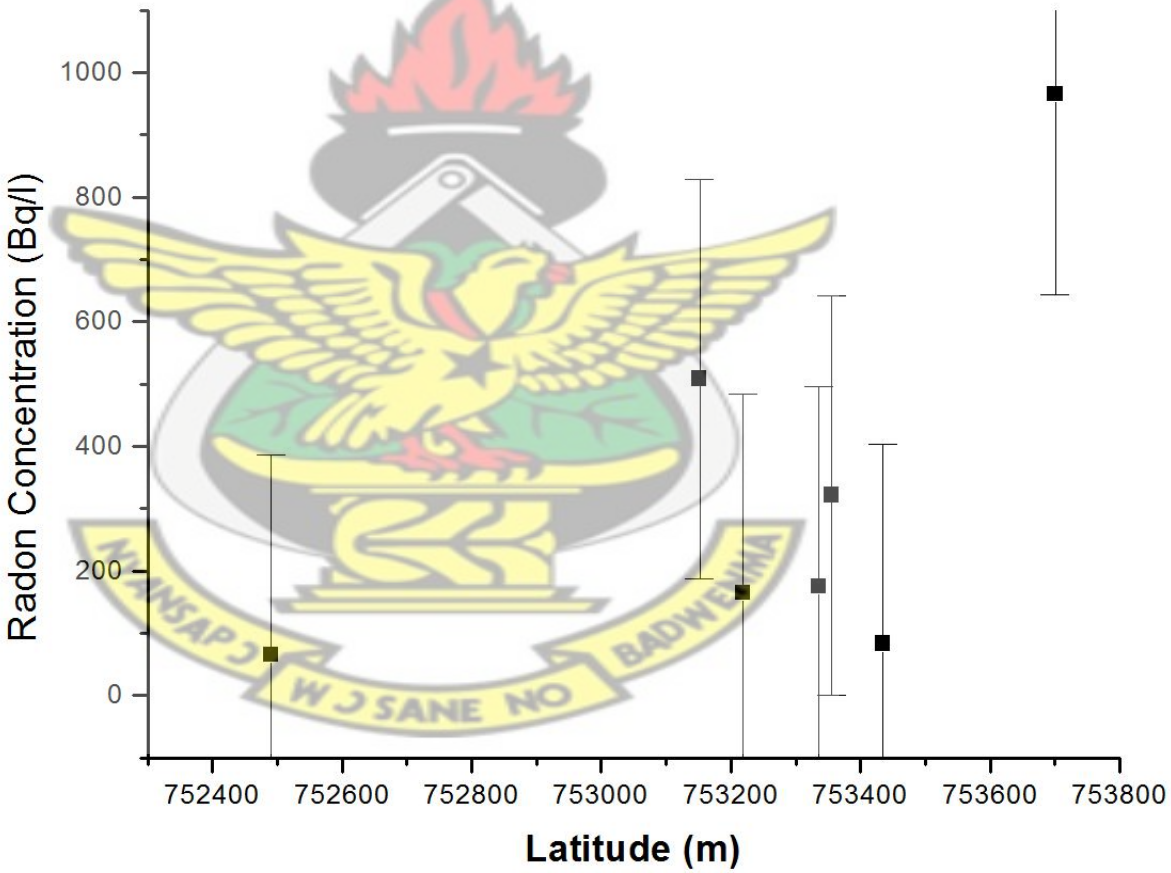


Fig. 5.6: Variation of radon concentration with latitude for samples from Mowire

The Radon concentration in each water sample in Mowire at different locations measured in Bq/l are given in figure 5.6. The arithmetic mean of measurements was 325.667 Bq/l with

a range of values between 64.555 and 964.629 Bq/l and with average standard deviation of 320.896 Bq/l. The results indicate that the difference between the minimum and maximum Radon concentrations in Mowire is 900.074 Bq/l which is very wide as compared to the remaing sites. This large variation in Radon concentrations may be due mainly to the difference in the soil type, rock type which might be very rich in radioactive sources and the depth of these sample collected.

5.1.7 Tikrom

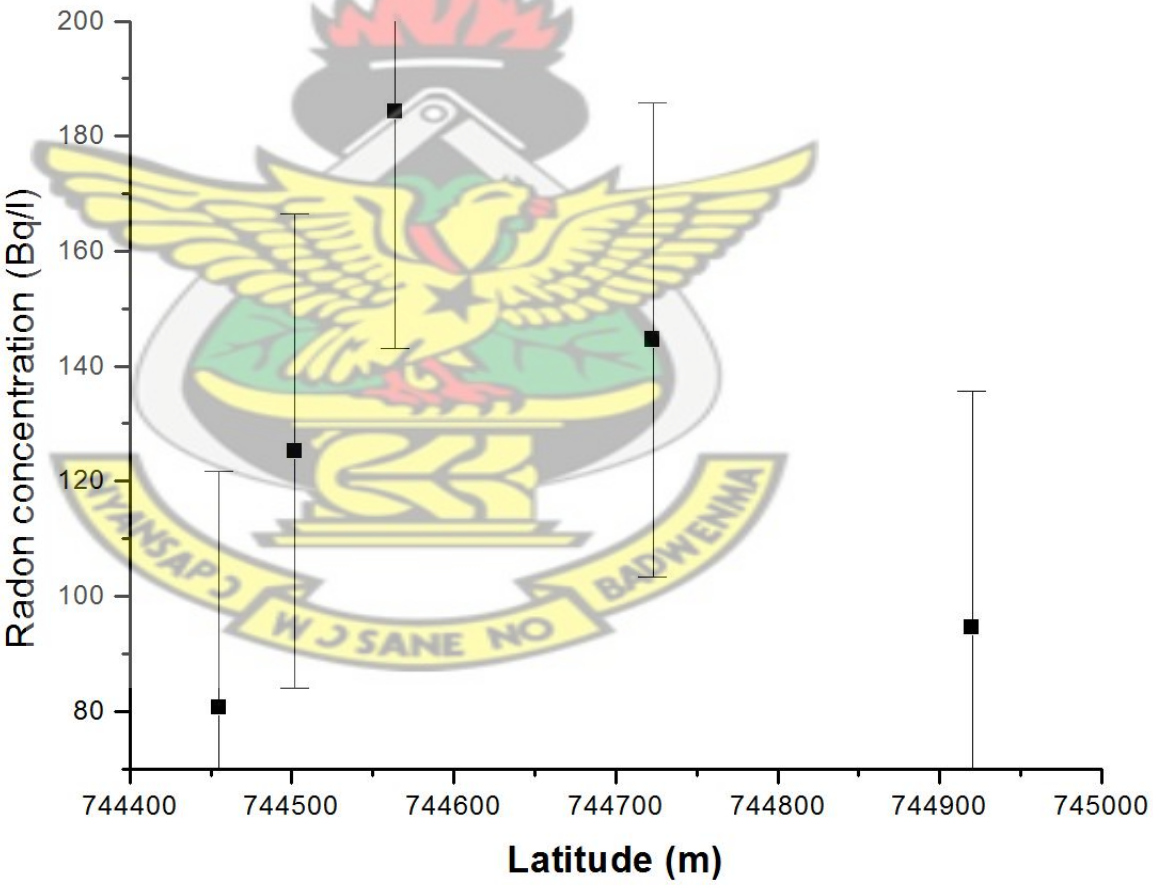


Fig. 5.7: Variation of radon concentration with latitude for samples from Tikrom

Five samples were taken from tikrom in all. The Radon concentration in each water sample

in Tikrom at different locations measured in Bq/l are given in figure 4.7. The arithmetic mean of measurements is with a range of values between 94.450 and 783.553 Bq/l and with average standard deviation of 41.205 Bq/l. The results indicate that the difference between the minimum and maximum Radon concentrations in Tikrom is 689.053 Bq/l which is very wide as compared to some of the other sites. This large variation in Radon concentrations may be due mainly to the difference in the soil type, rock type and the depth of these sample collected.

5.1.8 Trabuom and Atwima Boko

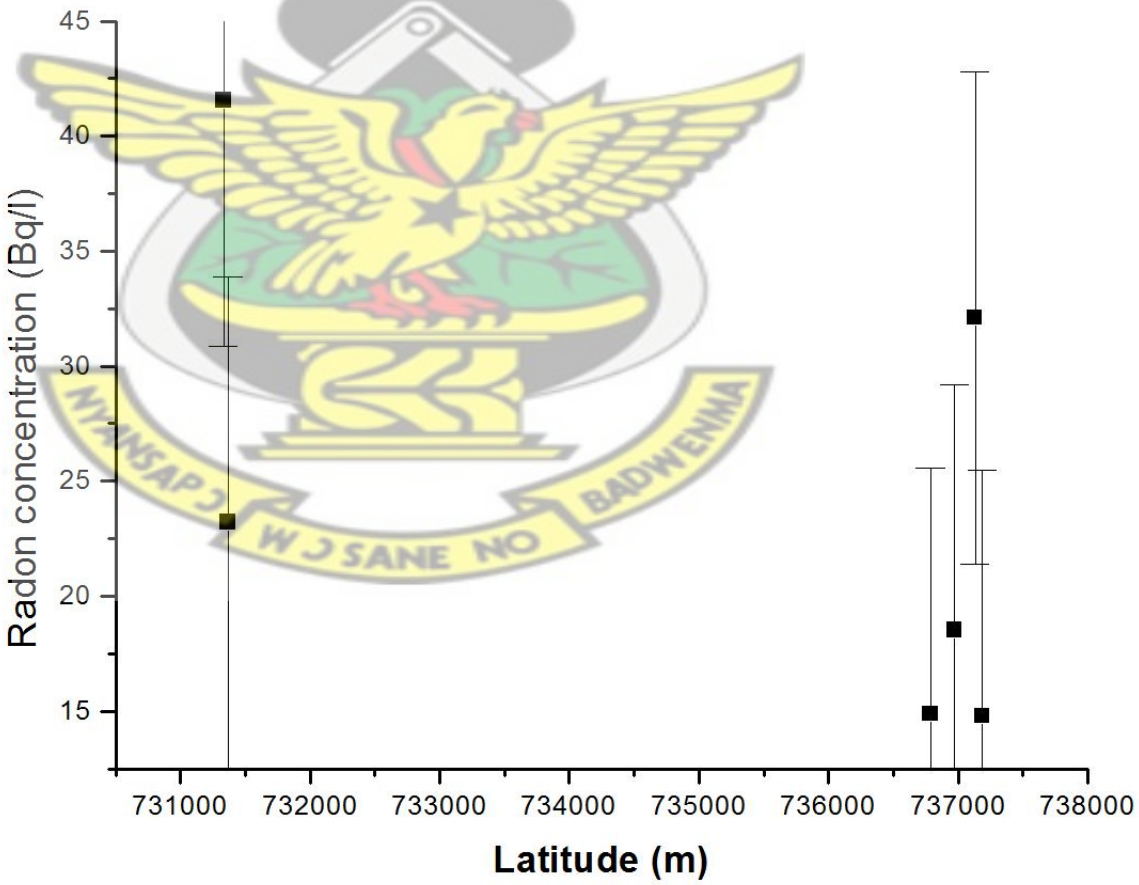


Fig. 5.8: Radon concentration of water samples from Trabuom and Atwimah Boko

Five samples were collected in Atwimah Boko and two from Trabuom. The two samples from trabuom was taken from school and are the two main water source for students and masters. The radon concentration values of the samples in the school are 23.202 and 4.171 in Bq/l. At Atwimah Boko, the radon concentration values are low. These values are due to factors that determine the radon concentration in water which include, the soil type, the depth of the water as well as the the type of rock in the area. The average radon concentration value is 24.760. Bq/l, with a standard deviation of 9.892 Bq/l.

5.2 Average Radon concentrations of sample sites

In other to compare the level of radon in the samples from all the sites, the average of the radon concentration in all the eight sites were calculated. The table below shows the average radon concentration for all the sites or towns from which the water samples were collected.

Table 5.1: **Average radon concentration in the study area**

LOCATION	AVERAGE RADON CONCENTRATION (Bq/l)
Bomfa	20.444
Buokrom	29.135
Kenyase	133.229
Kronum	42.593
Mowire	325.666
Tikrom	125.801
Ayeduase	21.184
Atwima Boko	24.760

From the bar graph, it can be seen that, Mowire recorded the highest average radon concentration among all the towns. Bomfa recorded the least average radon concentration in the water samples. The difference could be as a result of the change in the soil type, the type of rock in the area, the depth of the water sample, as we move from one site to another.

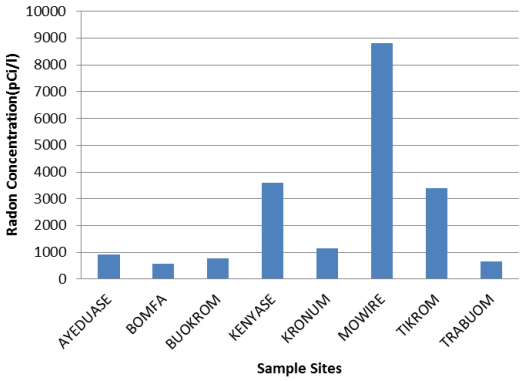


Fig. 5.9: Bar graph of average radon concentration at working sites.

5.3 INTERPRETATION OF CONTOURING MAP OF RADON CONCENTRATIONS

In order to understand the spatial variation of radon concentration for all the water samples collected, the geographic locations (X and Y) of each sample and their corresponding measured radon concentrations were used to draw a contour map of the study area. The GEOSOFT software program was used in drawing the contour map of the study area. The result is as illustrated in fig. 5.10 From the contour map,it can be seen that the radon concentration in the water samples in the study area generally increases from the south to the north. However, the trend changes at kronum, where low radon concentrations were recorded. The change in the trend towards the north is believed to be as a result of the shift in the geology, the type of soil and other factors such as the depth of the samples. There is also the possibility of change in the sub-structures in the main geology of the sample in the same major rock type in the study area. More and extensive survey is needed to explain the shift in the radon concentrations in the samples as we move from one place to another.

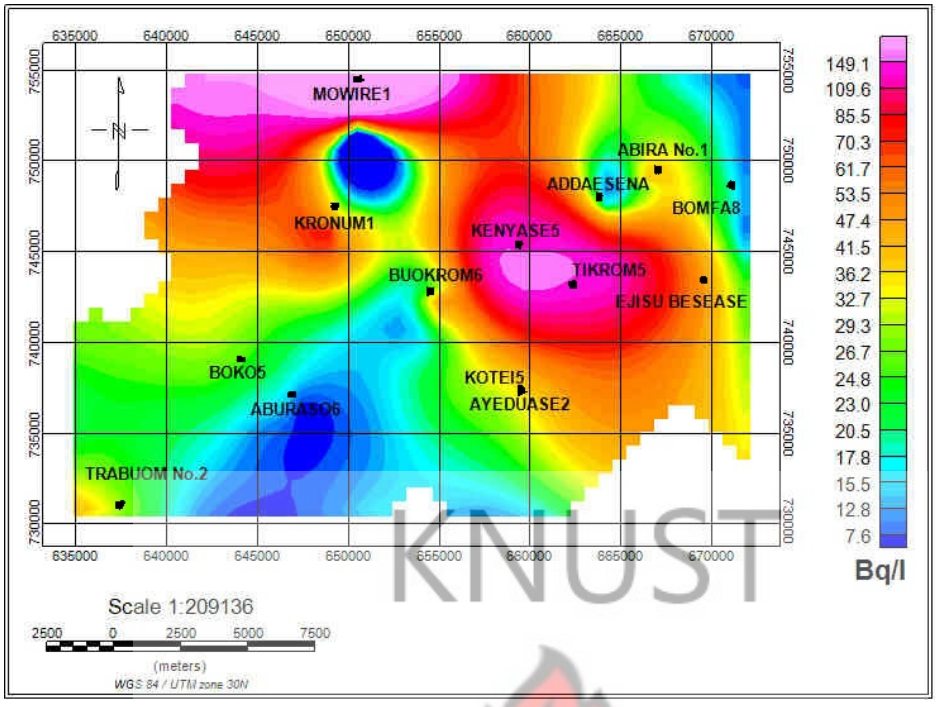


Fig. 5.10: Contour map radon concentration for the study area

5.4 Variation of radon concentration with elevation

One of the objectives of this research was to study the effect of the elevation of the water sample points above sea level on the radon concentration in the water samples collected in the study area. Therefore the elevation of each sample was measured by using the GPS. It was realized that, some of the towns from which samples were taken were at higher elevatios and the rest at lower elevations. The towns at higher elevations include Bomfa, Tikrom, Medoma, Tikrom and Kenyase. The towns at lower elevations are Kronum, Mowire, Trabuom, Atwimah Boko and Aburaso. Considering the towns at higher elevation, it was identified that, there is no appreciable linear correlation between the radon concentration and the elevation of that particular town above sea level. The samples collected from Tikrom recorded high values of radon concentration as compared to Bomfa. The average radon concentration of the underground water samples at Tikrom was 125.801 Bq/l and that of Bomfa was 21.184 Bq/l. The average elevation of Tikrom and Bomfa above sea level are

respectively 308.8 m and 302.1 m. It can be seen that, the the difference in the average elevation of the two towns is 6.7 m. This small difference is an indication that the two towns are almost of the same elevation above sea level. However, the difference in the average radon concentration between the two towns was 104.618 Bq/l It therefore stands to reason that, the wide difference in the radon concentration of two sites which are almost at the same elevation will be due to other factors. The same is true for sample sites at lower elevations. Mowire is almost at the same elevation as kronum, but the radon concentration at mowire is far higher than that at kronum. Fig 5.11 is a 3-D view of the contour map of the study area

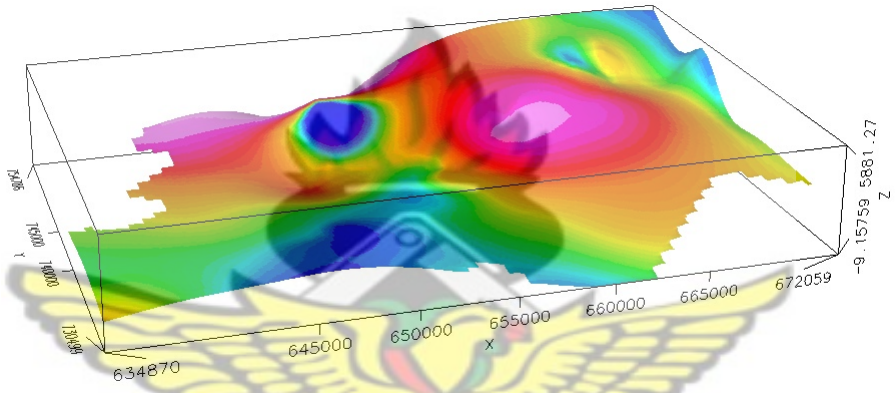


Fig. 5.11: 3-D Contour map of radon concentration with elevation for the study area

that shows the elevation of the study area. The towns of higher elevations and those at lower elevations can also be seen. Mowire that recorded the highest radon concentration is at a relatively lower elevation. Bomfa recorded the least radon concentration but it is at a higher elevation with respect to Mowire. Other towns in the study area also showed a similar pattern and therefore, it can be said that the radon concentration does not depend on the elevation of the sample point above the sea level.

In other for the people who depend on the high radon concentration water samples, precautions should be taken in other to decrease the health risk associated with high levels of radon. Rondon is very mobile and volatile gas. Its concentration in water can be reduced

when boiled to about 100^0C. It is therefore suggested that, water fetched from wells and boreholes with high concentration of radon should be boiled before use. As radon is a gas, it id readily lost from water over time or due to agitation of the water. For this reason, the installation of a holding tank, an aeration unit or an agitation system between the source and the domestic tap will significantly reduce the level of radon in the tap water. Proven radon in drinking water remediation products are commercially available.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Results obtained show that the radon levels in underground water vary from one sample to another at the same site. The variation of the radon concentration levels could be mainly due to the difference in rock type, soil type, depth of the well and the geology of the area. At Kronum, the minimum radon concentration was found to be 462.035 pCi/l and the maximum radon concentration was determined to be 2267.286 pCi/l. This shows an increase of 390.72% increase in the radon concentration from the minimum to the maximum radon concentration in the samples from Kronum. Kenyase recorded an increase of 854.18% with the minimum and maximum radon concentrations of 499.993 pCi/l and 4770.831 pCi/l respectively. The minimum and maximum radon concentrations for the samples taken from Buokrom were, 352.282 pCi/l and 1302.199 pCi/l respectively, which shows an increase of 269.65% from the minimum to the maximum radon concentrations. At Ayeduase and Kotei, the minimum and maximum radon concentrations were found to be 382.239 pCi/l and 1422.542 pCi/l respectively, shows a 272.16% increament. Bomfa recorded a minimum radon concentration value of 122.105 pCi/l and a maximum value of 1177.573 pCi/l. This showed an inrease of 864.39%. Mowire recorded the highest percentage inrease of 1394.28% from the lowest to the highest radon concentrations in the samples collected

from that site. The lowest and the highest radon concentrations at Mowire were found to be 1744.718 pCi/l and 26071.047 pCi/l respectively. At Tikrom, the maximum and minimum radon concentrations were found to be 2554.054 pCi/l and 21177.097 pCi/l respectively. This shows an increase of 729.16%. At Atwima Boko and Trabuom, the lowest radon concentration in the samples collected was found to be 399.040 pCi/l and the highest was also found to be 1122.737 pCi/l. Among all the project sites, Atwima Boko and Trabuom showed the least percentage increase of 181.36% .

The relation of Radon concentration with other factors was also investigated in this project work with respect to elevation of the sample point. The results showed that there is no linear correlation between the radon concentration and elevation of the selected towns above sea level. The proposed maximum permissible concentration of radon in water is 11Bq/l, (USEPA, 1991). For all the samples collected, the minimum value of the radon concentration in groundwater was found to be 122.105 pCi/l (4.518 Bq/l). This far below the permissible value. This was recorded at Bomfa. The maximum radon concentration value was found to be 26071.047 pCi/l (964.629 Bq/l). It can be clearly seen that, the maximum value recorded is 87.694 times greater than the permissible value. Table 5.1 also shows the average radon concentration in groundwater for each town and it can be seen that, the average values are greater than that of the permissible value. The difference in the radon concentration values can be as a result of the type of soil and type of rock at that particular location. The people who depend on those sources of water, are over exposed to radon and they are prone to radon hazards.

6.2 RECOMMENDATIONS

Based on this work, the following are recommended for any future project in this field:

1. All of the boreholes from which samples were taken lacked some important informations. The depth of the water is a key factor that affects the concentration of radon in water. Since no information on the depth of to water sample, it was impossible to study the variation of radon concentration in water with depth. It is therefore recommended, that borehole drilling companies should leave detail informations on at the location of the borehole for research and academic purposes.

2. More efficient and effective methods for the sampling of well water should be developed. Significant amount of the radon concentration in wells can be lost as the water is transferred out from the well.

3. Enhanced strategies, methods and safe tools for measuring Radon levels in water are strongly recommended, and methods for taking remedial actions should be taken into account.

4. Maps for the radiation pollution in groundwater and the other type of water in different places is recommended.

5. Epidemiological studies of the general population to determine lung and stomach cancer incidence due to high level of radiation is important. This would give a good motivation to remedy the area of radiation pollution and to protect people of radiation risks.

6. It is also recommended that, the existing equipments should be upgraded to get better and very accurate results.

7. The lack of correlation between Radon concentrations in groundwater with respect to elevation of the underground water indicated that the number of samples collected per geological and geographical factors needed to be increased, performed and analyzed as a function of geological and geographical location.

8. It is recommended that more research should be carried out to cover other underground water in the area of study.

9. Government should decide to issue grants for equipment for reducing the Radon concentration in drinking water used by residents on a daily basis.

10. It is suggested that more studies to be carried out on Radon before and after the dry season because Radon concentrations in groundwater vary with time because of dilution by rainfall.

11. It is necessary to involve radiation guidelines within Ghana standards to check groundwater quality.

12. More investigation about the radioisotopes in different places in Kumasi and other part of the country is is recommended.

13. Obtaining uranium and radium concentrations of aquifer materials and groundwaters is recommended. This would indicate the relative equilibrium between these elements.

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Appendix A

A.1 Evaluation of Radon Concentration in Water

Each of the water sample collected was taken throughout the degassing process. All parameters needed to determine the radon concentration in each sample were recorded. The formula for calculating the amount of radon in the water sample is given by the equation:

$$A = \frac{(C - B) \times 1000}{F \times 6.66 \times D \times S \times V}$$

Where:

A = Rn-222 Activity in pCi/l.

C = Gross Count Rate (CPM).

B = Background Count Rate (CPM).

F = Cell Counting Efficiency (Normally 0.745).

D = Degassing Efficiency (0.9 for 300A, 0.7 for 110A without the external water trap).

S = Correction for the decay of radon from sample time T_s to count time T_c.

V = Sample volume = 190 ml.

A.2 TABLES OF RESULTS OF THE RADON CONCENTRATIONS IN GROUNDWATER FROM ALL THE SELECTED TOWNS

Table A.1: **Radon concentration of water samples from Kronum**

Location	Concentration (pCi/l)
Kronum 1	1788.755
Kronum 2	2192.856
Kronum 3	2267.286
Kronum 4	538.217
Kronum 5	1501.163
Kronum 6	1132.938
Kronum 7	1279.206
Kronum 8	1719.920
Kronum 9	734.882
Kronum 10	750.387
Kronum 11	1031.014
Kronum 12	889.928
Kronum 13	628.643
Kronum 14	1286.385
Kronum 15	1142.231
Kronum 16	462.035
Kronum 17	851.673
Kronum 18	523.436

Table A.2: **Radon concentration 0f water samples from Kenyase and Abira**

LOCATION	CONCENTRATION (pCi/l)
Kenyase 1	17701.213
Kenyase 2	1468.034
Kenyase 3	596.348
Kenyase 4	4770.831
Kenyase 5	3592.795
Kenyase 6	499.993
Kenyase 7	1311.063
Kenyase 8	4243.190
Abira 1	722.851
Abira 2	1101.456

Table A.3: **Radon concentration for each sample collected in Buokrom**

Location	Concentration (pCi/l)
Buokrom 1	905.605
Buokrom 2	352.281
Buokrom 3	606.319
Buokrom 4	1302.199
Buokrom 5	875.502
Buokrom 6	712.646
Buokrom 7	982.506
Buokrom 8	733.589
Buokrom 9	482.373
Buokrom 10	921.257

Table A.4: **Radon concentration of water samples from Ayeduase and Kotei**

Location	Concentration (pCi/l)
Ayeduase 1	1164.098
Ayeduase 2	976.811
Ayeduase 3	1299.868
Ayeduase 4	775.033
Kotei 1	985.884
Kotei 2	551.749
Kotei 3	382.239
Kotei 4	776.695
Kotei 5	1422.542

Table A.5: **Radon concentration of water samples from Bomfa**

Location	Concentration (pCi/l)
Bomfa 1	540.487
Bomfa 2	371.763
Bomfa 3	924.338
Bomfa 4	521.544
Bomfa 5	1177.573
Bomfa 6	122.105
Bomfa 7	594.966
Bomfa 8	351.798
Bomfa 9	472.036
Ejisu Besease	648.781

Table A.6: **Radon concentration of water samples from Mowire**

Location	Concentration (pCi/l)
Mowire 1	26071.047
Mowire 2	8683.784
Mowire 3	4723.229
Mowire 4	2232.854
Mowire 5	1744.718
Mowire 6	4424.014
Mowire 7	13732.965

Table A.7: **Radon concentration of water samples from Tikrom**

Location	Concentration (pCi/l)
Tikrom 1	4978.713
Tikrom 2	3383.216
Tikrom 3	21177.097
Tikrom 4	3907.118
Tikrom 5	2554.054

Table A.8: **Radon concentration of water samples from Trabuom and Atwimah Boko**

Location	Concentration (pCi/l)
Trabuom 1	627.079
Trabuom 2	1122.737
Boko 1	399.040
Boko 2	867.474
Boko 3	500.427
Boko 4	402.069
Boko 5	765.445

Appendix B

B.1 GENERAL DESCRIPTION OF THE LABORATORY EQUIPMENTS USED

B.1.1 AB-5

The AB-5 is portable monitor and data acquisition unit which has a wide range of optional accessories for measuring different types of radioactive decay. Some accessories mount directly onto the AB-5 front panel while others connect via a cable to the AB-5's rear panel. Some AB-5 accessories are used to collect samples of radioactive material such as radon gas, thoron gas, etc. Others are used to receive collected samples of radioactive materials and others are placed in close proximity to areas to be measured. In this thesis the AB-5 was used for the latter. A scintillator in the AB-5 generates light pulses in response to the energy particles being released by the radioactive material. These light pulses are amplified (multiplied) by a photomultiplier tube (PMT) and converted into electrical pulses. These pulses are sent to a printed circuit board in the AB-5 where a microprocessor - based integrated circuit, counts and records the pulses over defined intervals set by the user.

Fig. B.1: The AB-5 ACCESORY

B.1.2 Lucas Scintillation Cell

Scintillation cells, such as the Pylon Model 300A cells are airtight metal cylinders which have a transparent window at one end and a means of in taking air the other end. The AB-5 a built in pump that can draw air into the cells or the cell can be evacuated with a vacuum pump in order to draw air into the cell. Once inside the cell, radon gas decays into its daughter products such as alpha particle emitters. Like all scintillation cells, the 300A cell has an alpha sensitive scintillator lining the interior of the cell. The scintillator which is silver activated zinc sulphide produces light pulse when it is struck by alpha particles. When an alpha particle strikes the activated sulphide, the alpha particle becomes a Helium atom and the sulphide de-excites by emitting photons. (i.e. light pulses).The window in the cell enables equipment such as the AB-5 to count the light pulses. It is important to keep the scintillation cell away from light and the cell cover should be used at all times.

Fig. B.2: The Lucas Cell

B.1.3 Vacuum Water Degassing System

The WG-1001 System is designed to extract gasses containing radon from water samples and place them in the lucas type cell to allow measurement of the amount of radon present in the water. The system is evacuated with the supplied hand pump or via a user provided electronic vacuum pump. Air is then drawn through a porous diffusion stone into a measured quantity of water (190ml). The air scrubs the radon from the water and the air mixture flows via the drying tube into a scintillation cell. A fine metering valve regulates the rate at which air passes through the water sample and the drying tube removes moisture which potentially condense in the cell. The flow rate is related to the efficiency of scrubbing the radon. A five minute bubbling period has been found to scrub 85to 95% of the dissolved radon from a 190 ml water sample when a model 300A scintillation cell is used. For a 110A cell, the amount is 65 to 75%.The scintillation cell is placed in the radon monitor and its alpha activity is determined.

Fig. B.3: The water degassing process at the laboratory

Appendix C

C.1 Used Softwares

- LaTeX : typesetting and layout
- CorelDRAW X5 : graphics
- Matlab : For average and standard deviation compitation. also used in the line graphs.
- Golden Surfer 9 Software .
- Grapher
- Geosoft