LEVELS OF NATURAL AND ARTIFICIAL RADIOACTIVITY IN SOILS, WATER AND TUBER CROPS IN THE TANO- NORTH DISTRICT OF BRONG-AHOFO REGION; GHANA

BY

Eric Goode, Jude

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Department of Chemistry

College of Science

Kwame Nkrumah University of Science Technology, KNUST, Kumasi

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DECLARATION

I hereby declare that this submission is my own work towards the MPhil and to the best of my knowledge, it contains no materials 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 given in the text.

Goode, Jude Eric	……...……	……
(PG 6147111)	Signature	Date
(Student& ID)		

Dr. Godfred Darko	……...……	……
(Supervisor)	Signature	Date

Dr. Augustine Faanu	……...……	……
(Supervisor)	Signature	Date

Certified by

Dr. Ray Bright Voegborlo	……...……	……
(H. O. D. Chemistry)	Signature	Date

ABSTRACT

The levels of radionuclides in water, soil and tuber crops from the Tano-North District of Ghana have been determined. Gamma ray spectrometry was used to analyze the activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in the samples. Also the Gas-less Automatic Alpha/Beta counting system (Canberra iMatic ^{Tm}) was used to determine gross alpha and gross beta activity concentrations of the water. The estimated average annual effective dose due to ingestion of radionuclides in water by the public was 40.43 μSv/y, 20.08 μSv/y, 33.58 μSv/y, 53.45 μSv/y and 24.90 μSv/y for Duayaw/Nkwanta, Buokukruwa, Bomaa, Techire and Tanoso respectively. The average values for the annual effective dose from different locations in the district were lower compared with the recommended values of 100 μSv/y and 240 μSv/y by the World Health Organization and the United Nations Scientific Committee on the Effects of Atomic Radiations respectively. The average values for gross alpha and gross beta activities from the Tano-North District were 0.021 Bq/L and 0.094 Bq/L respectively. These average values were well below the guideline values of 0.5 Bq/L and 1.0 Bq/L for gross alpha and gross beta activities in the drinking water as recommended by the WHO. The result shows that, drinking water consumed by the inhabitants of the Tano-North District of Ghana does not pose any significant radiological health risk. The average activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in the soil from different farmlands in the study area were 23.19 Bq/kg, 31.10 Bq/kg, 143.78 Bq/kg and 2.88 Bq/kg respectively. Clearly, these averages were lower compared with the world average of 30 Bq/kg, 35 Bq/kg and 400 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. The estimated absorbed dose rate for the farmlands varied between 23.63 nGy/y to 50.51 nGy/y, which is within the worldwide range of 18 to 93 nGy/y. The activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in cassava ranges from 0.38 to 6.73 Bq/kg, 1.82 to 10.32 Bq/kg, 17.65 to 41.01 Bq/kg and 0.38 to 1.02 Bq/kg respectively.

Additionally, the activity concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in yam also ranges from 0.47 to 4.89 Bq/kg, 0.93 to 5.03 Bq/kg, 14.19 to 35.07 Bq/kg and 0.34 to 0.89 Bq/kg respectively. The average concentration factor for ^{238}U, ^{232}Th and ^{40}K in yam were 0.12, 0.11 and 0.17 respectively. Furthermore, the average concentration factor for ^{238}U, ^{232}Th and ^{40}K in cassava were 0.11, 0.12 and 0.2 respectively. Generally, the concentrations of the radionuclides in yam and cassava samples were low and would not result in a significant health effects to the consumers.

DEDICATION

This research work is dedicated to God, the provider of all grace and divine inspiration.

I also dedicate this work to my family.

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LIST OF ABBREVIATIONS

CNS	Central Nervous System
DCF	Dose Conversion Co-efficient of the Radionuclides
DNA	Deoxyribonucleic Acid
EU	European Union
FAO	Food and Agricultural Organization
GI	Gastrointestinal
GPS	Geological Position System
HPGe	High Purity Germanium Detector
IAEA	International Atomic Energy Agency
ICRP	International Committee for Radiological Protection
ILO	International Labour Organization
MCA	Multi-Channel Analyser
MDA	Minimum Detection Activity
NaI(TL)	Thallium-Activated Sodium Iodide
NORM	Naturally Occurring Radioactive Material
TF	Transfer Factor
UNSCEAR	United Nations Scientific Committee on Effects of Atomic Radiation
USGS	United State Geological Survey
WHO	World Health Organization.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Human beings are continuously exposed to various degrees of ionizing radiations from both natural and artificial radionuclide sources in the environment. However, the largest proportion of human exposure to radiation comes from natural sources. The issue of radiation exposure has become a continuing and inescapable feature of life on earth (UNSCEAR, 2008). Therefore, human societies have become concerned with environmental protection and management for the purpose of ensuring the safety of organisms against the effects of ionizing radiation.

The concentration of naturally occurring radioactive materials (NORMS) in food and water varies with factors such as local geology, climate and agricultural practices. There are local variations in the levels of human population exposure to radiation. This observation depends on a host of factors which include; the height above sea level, the amount and the type of radionuclides in soil, the composition of radionuclide in air, food, and finally, the quantity of radionuclide inhaled or ingested into the body of an organism. For example, there are specific areas on the surface of the earth where the levels of background radiations are relatively higher and even ten times higher than the world average. Some of the areas with such conditions are Kerala State in India and the Pocos del caldas plateau in Brazil (WHO, 2006). The main natural sources of radiation are radon gas, cosmic rays, gamma radiation from rocks and soil as well as radionuclides in food and water. Exposure to natural sources of radionuclide includes inhalation of radioactive gases, ingestion of naturally-occurring radioactive elements in food and water

as well as irradiation from radioactive elements in the soil (UNSCEAR, 2000a). Figure 1.1 shows the various terrestrial pathways of transfer of radionuclide and dose to human

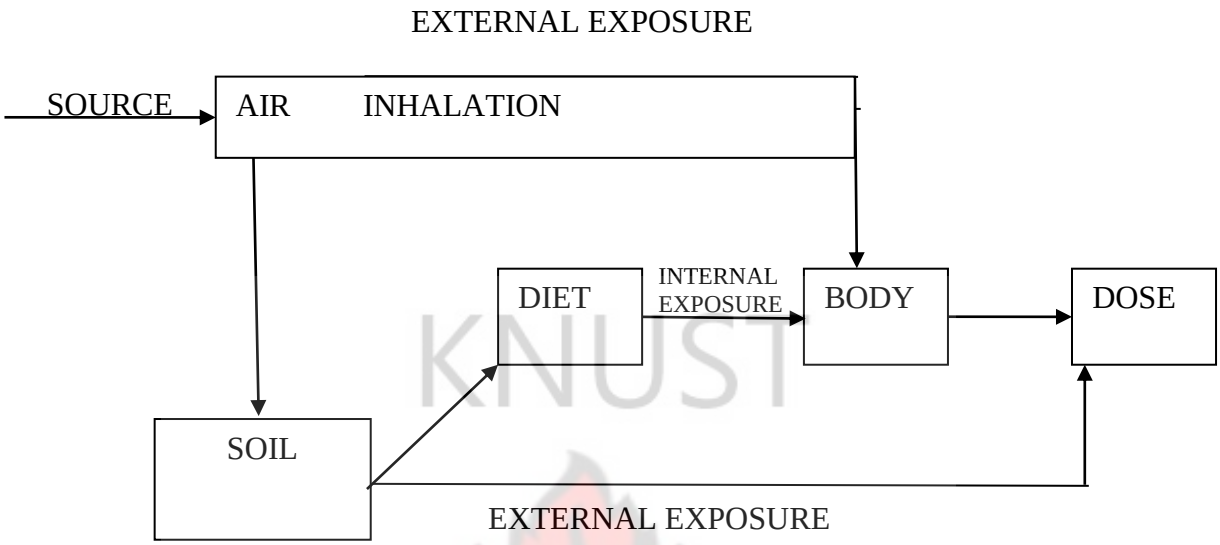

Fig 1.1 Terrestrial pathways of transfer of radio nuclides and dose to human (UNSCEAR, 2000a).

The issue of radiation exposure from natural sources has been considered as an issue of global concern. This has resulted in many developed countries taking necessary steps needed to determine the levels of background radiation in order to allay the fear of citizens' of any possible radiation exposure. In order to ascertain the radiation exposure of any human population, it is very important to estimate the potential dose from both natural (primodial) and anthropogenic radionuclide sources. In Canada for instance, the average dose due to naturally occurring background radiation is about 2 mSv per year. This was mainly due to inhalation of naturally occurring radon and its short-lived decay products like ^{214}Pb and ^{215}Po (WHO, 2006). Radionuclides may be present in the body and irradiate various organs with alpha and beta particles as well as gamma rays. Naturally occurring radioactive materials have been part of the human environment since creation primarily due to their long half-lives.

Anthropogenic activities have increased the environmental load of other artificial radionuclides. Even though many developed countries have taken steps to determine radioactivity distribution in their environments, not much research work has been carried out on the radiological quality of the environment in most developing countries. Adequate and accurate knowledge of radiological distribution of radionuclides levels in the environment is important for assessing the radiation exposure to the public (Faanu et al., 2011). It has been recommended by the International Commission on Radiological Protection that radiological protection of the environment must receive more emphasis than in the past (ICRP, 2007). Preliminary studies on groundwater from selected wells in the University of Cape Coast campus and its environs in the central region of Ghana reported an annual effective dose value of 1.7 times higher than WHO guidance levels of 0.1 mSv/y recommended for drinking water (Faanu et al., 2011).

1.3 Radioactive decay series

Some radionuclides have more than one mode of decay. For example, 66% of ^{212}Bi disintegrate by beta particle emission while the remaining 34% undergo alpha particle emission to ^{208}Tl. Radioactive decay, however, can occur in series with a number of daughter products which are also radioactive, and terminate at a stable isotope. In a closed system, a specific parent radionuclide can decay to its daughter elements and their activity grows gradually until radioactive equilibrium of the disintegration is reached. Thus the measurement of the concentration of any daughter element can be used to estimate the concentration of other element in the series. A typical mode of chain disintegration are the natural decay series of ^{238}U, ^{235}U and ^{232}Th. Out of the many radioisotopes that abound in nature, only ^{40}K, and the U and Th decay series have radioisotopes that produce gamma radiation of sufficient energy and intensity to be measured by gamma ray spectrometry. This is because they are relatively abundant in the

natural environment. Furthermore, the average crystal abundance of these isotopes are in the range of 2-3 ppm U, and 8-12 ppm Th (IAEA, 2003). Natural uranium is composed of three long-lived isotopes, ^{238}U, a small proportion of ^{235}U and an even smaller proportion of ^{234}U, the decay-series daughter of ^{238}U (Gilmore, 2008). Specifically, natural uranium is 99.274% ^{238}U, 0.7205% ^{235}U and 0.0056% ^{234}U and the 234/238 ratio is exactly the ratio of their half-lives as expected for nuclei in secular equilibrium (Loveland et al., 2006). Other isotopes can be synthesized (created by humans), but all uranium isotopes are natural. Uranium ores can be extracted and chemically converted into uranium dioxide (UO_2) or other chemical forms usable in industry.Uranium-238 (^{238}U) and ^{235}U are parent nuclides of two independent decay series while ^{234}U is a decay product of ^{238}U series. In the decay series of ^{238}U, the parent nuclide decay by alpha emission to ^{234}Th which in turn decay to ^{234}Pa and the chain decay continue until a stable ^{206}Pb is formed. The half-lives of the various radionuclides in the series are all much less than the half-life of ^{238}U (Gilmore, 2008). Therefore in an undisturbed source of ^{238}U, every daughter nuclide will be in secular equilibrium with the parent nuclide, where the activity of each daughter nuclide will be equal to the activity of ^{238}U. Since there are 14 radionuclides in the chain, the total activity of such a source will be 14 times the activity of the parent or any other individual nuclide. It should be noted that, not all the 14 daughter nuclides emit gamma radiation of significant amount. However, the following daughter nuclides: ^{234}Th, ^{234}Pa, ^{226}Ra, ^{214}Pb, ^{214}Bi and ^{210}Pb in the series emit significant gamma radiation that can be measured with ease (Gilmore, 2008). In practice, the activities of the daughter nuclides are measured and the value obtained used as the best estimate of the parent radionuclide (Gilmore, 2008). The radioactive decay in Uranium series is shown in Fig. 1.2

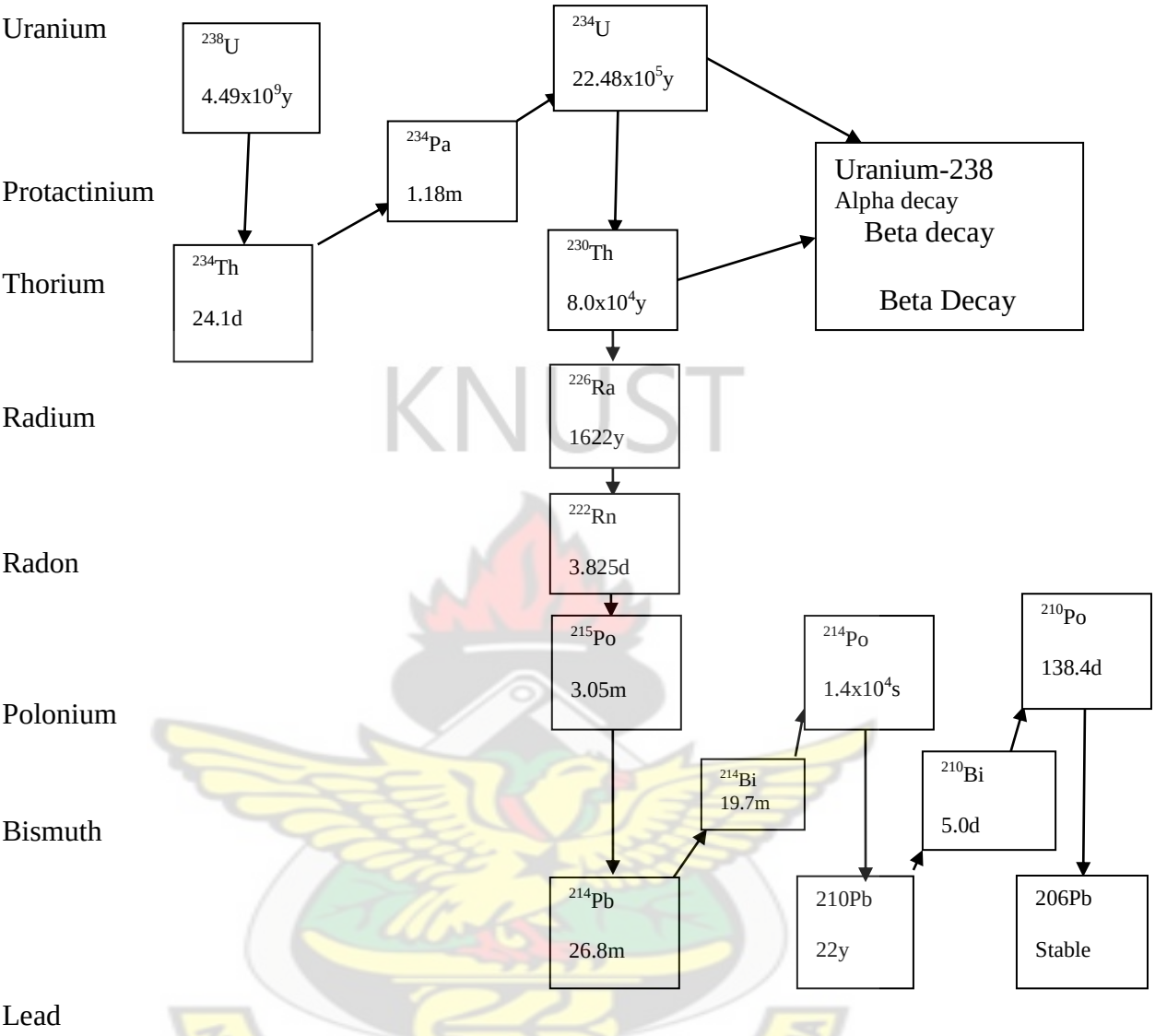

Fig 1.2 Radioactive decay in uranium Series (USGS, 1998).

Naturally occurring thorium has one single isotope, ^{232}Th. ^{232}Th has a long series of different radionuclides and each nuclide of ^{232}Th decays to an unstable daughter nuclide until a stable ^{208}Pb is formed (Gilmore, 2008). In the ^{232}Th decay series, only 4 of the daughter nuclides can be measured in gamma spectrometry and these radionuclides are; ^{228}Ac, ^{212}Pb, ^{212}Bi and ^{208}Tl.

Radioactive decay in Thorium series is shown in Fig. 1.3.

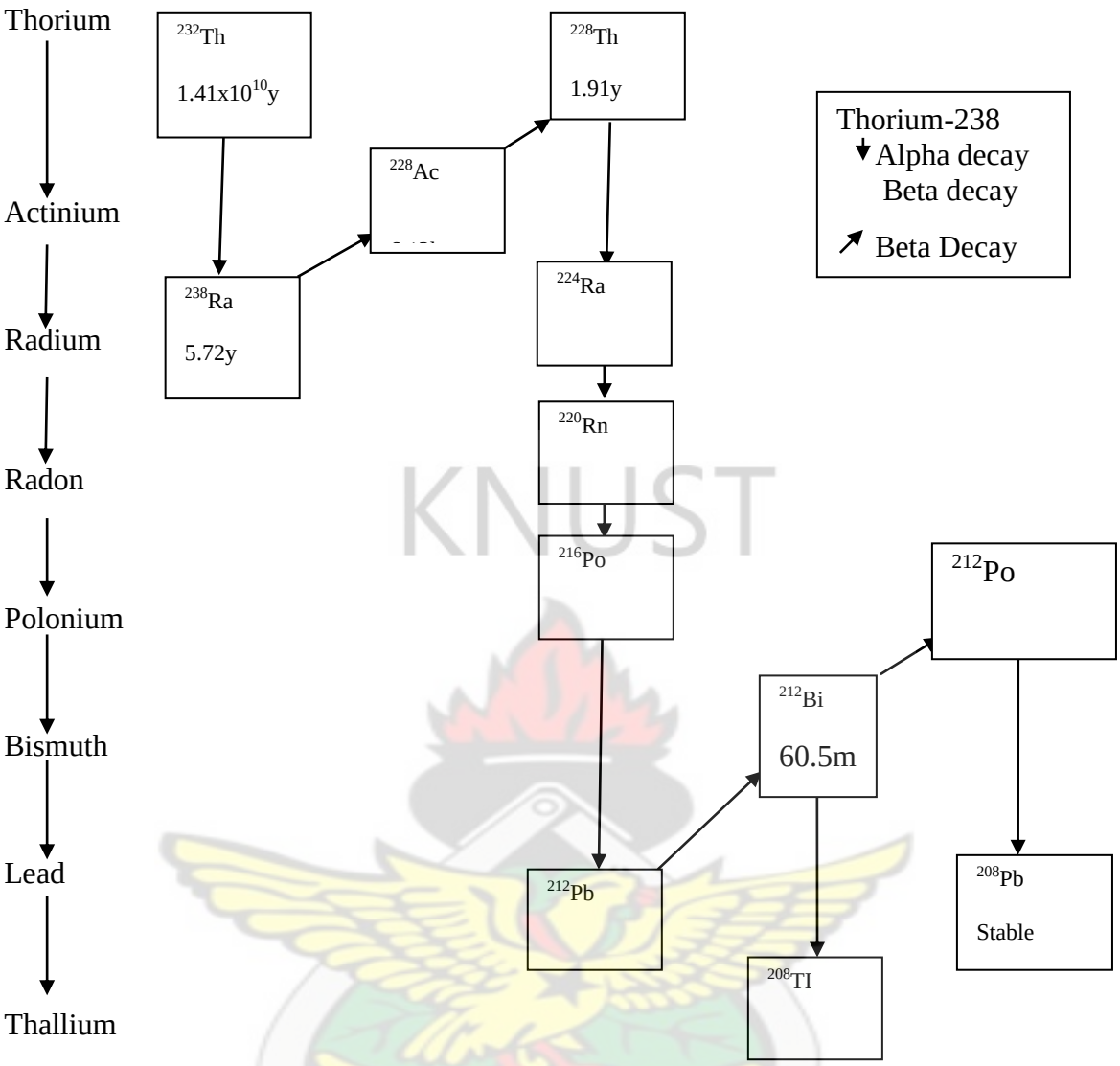

Fig 1.3: Radioactive decay in Thorium series (USGS, 1998).

The activity concentrations of natural radionuclides in groundwater are typically connected to the activity concentrations of uranium (^{238}U and ^{235}U) and Thorium (^{232}Th) and their decay products in the ground and bedrock (Shashikumar et al., 2011). Basically, the effect of groundwater interacting with bedrock is the release of soluble minerals into water. However, this depends on the mineralogical and geochemical composition of the water, the degree of weathering of rock, redox condition and the time for groundwater to be in contact with the soil or bedrock (Pia Vesterbacka, 2007).

1.4 Isotopes of potassium and caesium

There are 24 known isotopes of potassium of which three occur naturally: ^{39}K (93.30%), ^{40}K (0.012%) which is the radioactive isotope of terrestrial importance and ^{41}K (6.70%).

Potassium-40 (^{40}K) has a half-life of 1.3 x 10^9 years. It decays to ^{40}Ar with the emission of gamma rays with energy 1.460 MeV. Since ^{40}K occurs as a fixed proportion of K in natural environment, these gamma rays can be used to estimate the total amount of K present in any environmental material (Degerlier & Karahan, 2010; IAEA, 2003).

The specific activity of ^{40}K, calculated from its $1.3x10^9$ years half-life is $2.617x10^5$ Bq/g. Thus pure K contains activity concentration of 30.6 Bq/g. Human beings require potassium to sustain their biological processes. Upon ingestion, ^{40}K then moves quickly from the gastrointestinal track into the bloodstream. ^{40}K which enters the bloodstream is quickly distributed to all organs and tissues. The intake of ^{40}K is excluded from the international standards because they are controlled homeostically and not amenable to further control. Therefore, exposure to ^{40}K is an issue of only external exposure to a given source of radiation (IAEA, 2007).

For the artificial radionuclides such as caesium (Cs), there are eleven major radioactive isotopes of which ^{133}Cs is the only naturally occurring isotope that is non-radioactive. Only three of them have half–lives long enough to be of primary concern; ^{134}Cs, ^{135}Cs and ^{137}Cs with half–lives of 2.07 years, 2.3 million years and 30.170 years respectively. Among the isotopes of Cs, ^{137}Cs is the one of great concern because it emits both beta and gamma radiations. Caesium-137 constitutes most of the radioactivity still left after the Chernobyl disaster. Since the beginning of the Second World War in 1945, and with the commencement of nuclear weapon testing, Cs isotopes were released into the environment where it is absorbed readily into solution. It is also released to the surface of

the earth as a component of radioactive fallout. Once Cs enters ground water, it is deposited on soil surface and can be removed from the landscape primarily by particle transport. ^{137}Cs undergoes beta decay to ^{137m}Ba and then to nonradioactive ^{137}Ba through gamma ray decay process. In percentage terms, 6.5% of ^{137}Cs undergoes beta decay directly to the ground state of ^{137}Ba. The remaining decays to an excited nuclear state of ^{137}Ba which further releases gamma rays as it undergoes de-excitation and to drop to the ground state. Actually, the energy released 661.7 KeV is a property of ^{137m}Ba but it is conventionally regarded as the gamma ray energy of ^{137}Cs (Gilmore, 2008). The decay scheme of ^{137}Cs is shown in Figure 1.4.

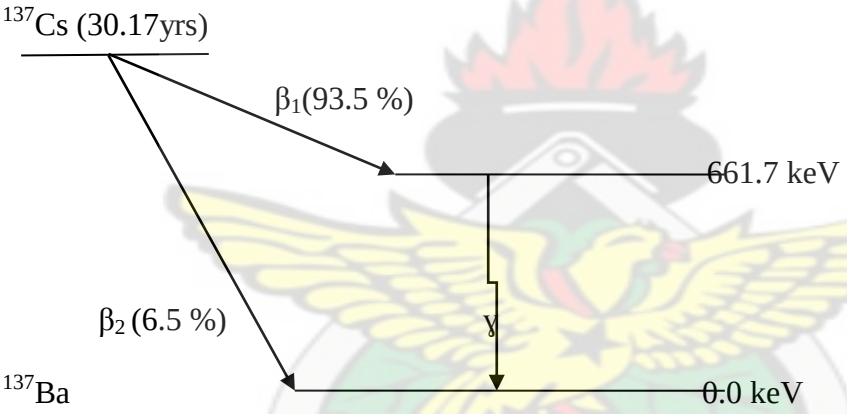

Fig 1.4: The decay scheme of ^{137}Cs (USGS, 1998)

Caesium-137 is produced by nuclear fission and can be transported as particulate matter from one place to another. Gastrointestinal absorption from food or water is the principal source of internal deposit of Caesium in the body of living organisms.

Even though radionuclides are widely distributed in nature, they have been found to depend on local geological conditions and as a result vary from the place to place (Xinwei et al., 2006). Detection of a given amount of radionuclide in a particular environment does not suggest that, the levels in a given country are the same at all places.

However, it encourages the determination of activity concentrations of various radionuclides and their distribution in other parts of the country.

1.5 Statement of the problem

Natural radioactivity in the environment comes mainly from primordial radionuclides in soils and rocks, which have long half-lives and therefore continue to remain for many years. It is evident that human activities through mining and generation of nuclear power have added artificial radionuclides to the environment. Undoubtedly, higher levels of radionuclide concentration in food and water have adverse effect on the health of people exposed to these radionuclides. Meanwhile, Tano-North district in the Brong Ahafo Region which is a major food basket in the country is experiencing increasing mining activities including small scale mining activities known as galamsey while most of the communities depend on borehole and surface water sources for domestic use.

Like many developing countries, the levels of natural and artificial radionuclides in groundwater, soil and tuber crops grown in the Tano-North District are not known. However, knowledge of the levels and distribution of radionuclides in the environment is necessary if levels of human exposure to radiation from radionuclides are to be controlled. This study therefore aims to determine the activity concentrations of natural radionuclides (^{238}U, ^{232}Th and ^{40}K) as well as artificial radionuclides (^{137}Cs) in water, root crops (cassava, yam, and cocoyam) and soils in the Tano-North District.

1.6 Objectives of the study

The main objective of the study is to determine the activity concentrations of natural radionuclides (^{238}U, ^{232}Th and ^{40}K) as well as an artificial radionuclide (^{137}Cs) in water, root tubers (cassava, yam, and cocoyam) and soil samples from the Tano-North District of Ghana. Specifically, the project will;

i. Determine the gross alpha/beta concentration of drinking water samples from the Tano-North district and compare it with WHO standards.
ii. Determine the activity concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in drinking water, soil and some tuber crops samples from the Tano-North district of Ghana.
iii. Calculate the radiation doses and compare it with recommended dose limits in water, soil, and tuber crops.
iv. Compare the concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in soil from selected farms to the concentration of the radionuclide in cassava and yam collected from such farms in the Tano-North District.
v. Assess the public health impact from the activity concentrations and calculated effective dose rate.

1.7 Justification of the study

Exposure to radiation over a long time is associated with health problems such as cancer. Regrettably, the public is unaware of the potential radiological hazards associated with the soil, food and water that they use. In addition, there is limited detailed radiological data on our environment, water and food items in Ghana. Related to the above, the Tano North District has no record of radiological assessment. The study is important and timely because radiological assessment of our environment is necessary especially when the environment and for that matter the district is of economic and social importance to Ghana and the inhabitants of the community. The database on radioactivity in drinking

water and associated radiation dose to the population of many communities is not available and are required to maintain human drinking water standards (Al-amir et al., 2012). Furthermore, the study will provide pioneering and baseline data for the district. This is an important requirement for establishing and maintaining standards regarding activity concentration of soil, tuber crops and water.

Measurement of natural radioactivity in soil is very important because it helps in monitoring changes in natural background activity with time as a result of any radioactivity release. The availability of data from such a study is very useful as it serves as vital information to all stakeholders concerned with food and drinking water quality. It will also complement data required for setting of guidelines on radiological safety for food and drinking water. Finally, levels of activity concentration obtained will serve as a reference for future studies in the district and the surrounding districts in the country.

CHAPTER TWO

LITERATURE REVIEW

2.0 Background

The various materials that constitute the environment may contain variable amount of primordial radionuclides and their decay products. The environment is also exposed to cosmic rays from outer space. Measuring the levels of natural and artificial radiation in the environment is crucial in implementing appropriate controls for the sake of radiological protection (Kinyua et al., 2011).

According to the IAEA (2003), NORMS in their unaltered state can pose potential radiological concerns. However, such unaltered NORMS are mostly not amenable to regulatory control. Practically, exposure to NORMS that have been altered in the process of exploitation of natural resource can be monitored and controlled with regards to acute exposure. Radiation exposure to a large population with dose about 1.5Sv increases cancer incidence and mortality (UNSCEAR, 2008). However, the effects of exposure to low doses of radiation are based on modelled projections which lend itself rather to estimation that is within an order of magnitude. Clearly there is lack of data on the effects of low dose human exposure which requires an intensive work for more scientific proofs (UNSCEAR, 2008).

In the Tano-North District, there have not been much industrial activities, as such, the levels of NORMS in the area are due to what exist naturally in the environment and not from human activities. Even though the district has been earmarked for mining of gold, small scale mining activities are on the low side. Through this study, adequate data on natural and artificial radionuclide concentrations will be established. This will help in

assessing any possible radiological hazard that the population could be exposed. Such a detailed baseline data will be made available to guide all stakeholders involved in the monitoring of the environment for environmental pollutants including radiation exposure.

2.2 Exposure to radiation

Contrary to the perception that radionuclides like ^{238}U, ^{232}Th and ^{137}Cs are isolated and can only be encountered in high-security radiation emitting facilities, traces of radionuclides occur almost everywhere: in soil, food, water and even in the human body.

Basically, the major ways by which humans become exposed to radiation are radiation from sources outside the body (external exposure), radionuclides that are ingested through consumption of food and water or as inhaled radioactive gases (internal exposure). According to UNSCEAR Report (2000a), the two main sources of exposure are cosmic rays that are released from outer space and from the surface of the sun and terrestrial radionuclides that occur in the earth crust in building materials and in dust, water and food and the human body at large (UNSCEAR, 2000b). The WHO has reported that exposure to radiation through anthropogenic sources account for 1% of total exposure with 43% from natural internal exposure. With regards to food and water, the natural internal exposure is 8%, while medical radiation exposure account for 20%. Cosmic rays also offer natural external exposure of 13% with the earth's gamma radiation imparting a natural external radiation exposure of 15% (WHO, 2006). A small percentage dose may seem insignificant, but every effort must be made to monitor the environment for radiation in order to control radiation dose released to man from the environment.

Ramasamy et al., (2009) emphasised that, the ultimate goal that any research on NORMS is to estimate and assess the radiation dose to mankind (Ramasamy et al., 2009). Therefore, in order to assess is the radiological hazards in any given environment, indices

such as absorbed dose rate, annual effective dose rate and lifetime risk should be calculated. According to Kurttio et al. (2006), alpha and beta radiations have least penetration ability and therefore are unable to penetrate deep into body tissues. However, when radionuclides are ingested, alpha and beta radiations have the ability to irradiate body cells of internal organs of which the kidney and bladder cells are the organs usually irradiated by these types of radiation (Kurttio et al., 2006).

On the other hand, it is realized that gamma radiation has higher penetration ability and hence higher potential of damaging cells even when the source remains outside the body.

2.3 Determination of radioactivity

The human senses are incapable of detecting ionizing radiation. The three main classifications of devices used in the determination of ionizing radiation are:

(i) Gas filled detectors (ionizing chambers, proportional counter and Geiger-Muller Counter)

(ii) Scintillation Counters (Organic phosphors, inorganic phosphors and the various types of scintillation counters)

(iii) Solid state detectors (Semiconductor detectors) (Choppin& Baisden, 1978)

In all cases of detection, radiation causes ionization upon interaction with detector leading to the production of a small electrical signal. This small electrical signal requires amplification making electronic instruments crucial in radiation detection.

Gas filled detectors depend on the interaction of electric field of moving particles with detector material (gas) to produce ionization which is converted to electrical pulse.

Scintillation counters require the use of scintillators, organic or inorganic crystals with special properties. The radiation from the source must be absorbed in the scintillator leading to re-emission of light photons (Choppin & Baisden, 1978).

The most widely used scintillation device employed in the determination of ionizing radiation is the NaI(Tl).

Solid state detectors; a metal is not useful for creating radiation detectors. Since ions created through the ionization of detector material must be mobile for subsequent collection by the electrodes, insulators are also not useful in most cases (Loveland et al., 2006). However, semiconductors such as Si or Ge are useful for creating radiation detectors. Upon interaction of a semiconductor material with radiation, electron-hole pairs are created which are collected by charge electrodes. The opposite movement of and electrons create an electrical pulse which is not smooth. Modern semiconductor devices are based on semiconductor junction which is capable of allowing the flow of current in only one direction (Loveland et al., 2006). It must be stated that important feature of semiconductor detectors are their superior energy resolution due to their lower ionization potential and compact size. High purity Germanium (HPGe) detector has become the solid state detector of choice in modern nuclear chemistry.

2.3.1 The HPGe detector

In the quantitative and qualitative determination of gamma-ray emitting radionuclides in environmental media, the popular and widely used procedure has been the use of germanium detectors in high-resolution gamma-ray spectrometry. This is a non-destructive technique which has a great advantage of not going through processes of sample preparation. The basis of gamma ray spectrometry is that each gamma ray photon has a discrete energy, which is characteristic of the source. Therefore, by measuring the

energies of gamma ray photons of any material, the source of the radiation can be determined with great accuracy.

In an IAEA report the only radio-isotopes of high-energy gamma ray of sufficient intensity to be used for gamma ray mapping are ^{40}K, ^{238}U and ^{235}U and ^{232}Th with its daughter nuclides (IAEA, 2003).

In the use of HPGe detectors in gamma ray spectrometry, radiation which does not originate from the sample is regarded as "background" and data from background measurement is subtracted during the data processing. These background radiations are cosmic background, atmospheric radon and instrumental background (IAEA, 2003).

Hossain et al., (2012) investigated the characterization of the NaI(Tl) and HPGE detectors in Malaysia. The measurement was performed for HPGE detector using multinuclide source produced by Eckert and Ziegler isotope products. The source was contained in a 500 ml marinelli beaker with activity of 2.995 kBq or 110.8 kBq. Some of the radionuclides used were ^{109}Cd, ^{60}Co and ^{137}Cs. For the NaI(Tl) detector s, ^{137}Cs and ^{60}Co with energies 662 KeV and 1332 KeV were used. It was found that the resolution of the detectors was directly proportional to the energy of the gamma-ray with its efficiency being exponentially proportional to the gamma-ray energy. In terms of resolution, the HPGe detector (GC2018 of diameter 60.5 mm and length 31.5 mm) was better than the NaI(Tl) detector (ORTEC 905-3, Size 2" x 2"). On the other hand the efficiency of NaI(Tl) detector was also higher than the HPGe detector (Hossain et al., 2012).

For ɣ-ray detection, the most spectacular aspect of the HPGe detector is its superior energy resolution. With the use of Ge detector the energy resolution was 1.75 KeV at the 1332 KeV of ^{60}Co is routinely obtained as compared with a typical 90-100 KeV for

NaI(Tl) detectors. This means the HPGe detector has a higher ability to resolve ɣ-ray spectra than other detectors (Loveland et al., 2006).

2.3.2 The NaI(Tl) detector

Thallium-activated sodium iodide (NaI(Tl)) is the most widely used inorganic scintillator. The extensive use of the NaI(Tl) detector is because of its relatively inexpensive nature, high stopping power for photons, its rugged nature and the ease with which it can be used. The fluorescence light output of the NaI(Tl) detector has a relatively slow decay time of almost 230 ns which limits its count rate. The energy resolution of the NaI(Tl) detector is rarely better than 6% for the 1332 KeV of ^{60}Co (as compared to the 0.13% typically with HPGe detectors). NaI(Tl) detectors are very efficient for ɣ-ray detection (with typical detection efficiency of 1-10%) (Loveland et al., 2006).

Table 1: Comparison of different Radiation Detection Instruments (Choppin & Baisden, 1978)

Instuments	Ionization Chamber	Proportion Counter	G.M Counter	Scintillation Counter	Solid State counter
Normal Detection State	gas	Gas	gas	Liquid or solid	Solid
Radiation usually counted	α, β	α, β	α, β, ɣ	α, β, ɣ	α, β, ɣ
Complexity of medium total system	Medium	High	Low	High	High
Particular Advantages	Simplicity	High count rate	Simplicity, adaptability	High count rate; high counting efficiency	Excellent energy resolution

2.4 Radioactivity in underground water

Water is a very important natural resource related directly to the survival of all living organisms and its quality therefore cannot be compromised. Water is available in all parts of the earth crust either as surface water or groundwater and it is exploited for agricultural, industrial and domestic purposes. The most economical and easiest way of providing smaller towns and communities with portable water in developing countries like Ghana is by drilling of boreholes and wells. The World Health Organisation declared that access to safe drinking water is essential to health, basic human right and a component of effective policy for health protection. From all indications, improvement in access to safe drinking water favours the poor in particular, whether in rural or urban areas and can be an effective part of poverty alleviation strategies (WHO, 2006). To effectively provide quality drinking water, social interventions should not only focus on just providing water for communities in need but there must also be sustainable programmes for surveillance, monitoring and assessment of drinking water quality. The World Health Organization frequently provides guidelines for drinking water quality and besides individual countries through well-established standard boards have internal mechanisms of monitoring water quality. In recent times, the determination of levels of concentration of radionuclides in drinking water is gaining prominence across the world with member countries of the European Union guided by clear guidelines to control population exposure to radiation. Montero et al. (1999) have stated that the radiological safeguards of drinking water are based on the control of natural and anthropogenic radionuclide concentration (Montero et al., 1999).

According to Forte et al. (2007) both ground and freshwater usually contain variety of radionuclides with the freshwater usually exposed to artificial radionuclide contamination as a result of radioactive fallouts (Forte et al., 2007). With regards to groundwater, the

radionuclides like ^{40}K, ^{238}U, ^{235}U and ^{232}Th all with long half-lives are usually present. These radionuclides are transferred to groundwater from aquifer rocks by erosion and dissolution mechanisms.

In describing chemical pollution of water and its subsequent health effects, Skeppstrom and Olofsson (2007), stated that apart from the risk of consumers of groundwater being exposed to anthropogenic pollution, groundwater naturally contains several chemical components which can bring about different kinds of health problems. Knowledge of the geology of bedrock from which water is drilled is very important since geology plays an important role in the determination of water quality and mineral composition of soil. A typical situation that is sometimes encountered is a condition where wells that are thought to have been drilled in low-uranium containing rock types which in reality are supplied with water from an intrusion of another rock type deep containing significant levels of NORMs. For example, Skeppstrom and Olofsson (2007), have reported that in the Stockholm archipelago of Sweden there are big differences in the concentrations of radon in groundwater from drilled wells even though the surface geological mapping showed similar rock types in the area (Skeppstrom & Olofsson, 2007).

Ibrahim et al., (2011) has suggested that groundwater in some parts of Yemen are not safe to be used as drinking water due to their higher activity concentrations of ^{226}Ra and ^{232}Th. Ibrahim et al., (2011) further concluded that high activity concentrations for ^{226}Ra and ^{232}Th in groundwater points to high activity levels in aquifer rocks which establishes a strong relationship between groundwater and bedrock with regards to radionuclide contamination. For example, it has been established by Kurttio et al. (2006) that water from bedrock frequently contain higher concentrations of natural radionuclides than other sources. This conclusion was arrived at as a result of a work conducted on various well water sources in Finland. Kurttio et al. (2006) stated that it is true that people who depend

on drilled wells appear to receive an order of magnitude of higher radiation dose compared with world population on the average. However, the levels are not associated with an increase in risk of bladder and kidney cancers. Their findings further revealed that there is no statistically significant association that could link linear long-transformed exposure variables and bladder or kidney cancer risk.

Even though there have been reports of high groundwater radioactivity in some parts of the world, work carried out so far in Ghana have reported safe levels of radionuclides concentration in water. In using WHO guidelines and permissible limits including other international criteria and guidelines established for radiological water quality, Adu et al. (2011) assessed the water quality from selected boreholes and Lake Bosomtwe using High-Purity Germanium (HPGe). They discovered that there were no correlations between radionuclides concentrations with temperature, pH and conductivity which are the physicochemical parameters measured. The study found that the calculated annual effective dose was much lower below the total annual effective dose from all radionuclides except for tritium and radon (WHO, 2004).

2.5 Soil radioactivity

Naturally occurring radionuclides of terrestrial origin also referred to as primordial radionuclides are present in various degrees in the various components of the environment. Those radionuclides with half-lives long enough comparable to the number of years the earth has been in existence as well as their progenies exist in substantial amount in rocks and soil. They therefore contribute significantly to population exposure.

According to Hafezi et al. (2005), radionuclides such as ^{40}K, ^{238}U and ^{232}Th which are present in trace amounts in soil represent the major source of external exposure due to gamma radiation. Hafezi et al., (2005), further reported that the concentration of ^{238}U,

^{232}Th and ^{40}K in Tiehran-Irane soils ranges between 12-31 Bq/kg, 14-36 Bq/kg and 267-867 Bq/kg respectively (Hafezi et ta., 2005). Comparing the result to the world average, Hafezi et al. (2005) concluded that the concentration levels of natural radioactivity of soil samples have wide range of values due to various factors including soil formation transport processes.

Al-kharouf et al., (2008) have reported that ^{238}U activity of Khan-Alzabelb surface soil is about 2.8 times higher compared to the world`s mean values reported by UNISCEAR (2000a). The ^{238}U and ^{235}U concentrations were nearly constant to dose level with vertical depth of 22 cm. They attributed this trend to the intensive cultivation of that land which requires soil mixing from different depths. Furthermore, from a depth of 22-32 cm, it was noted that, there is an abrupt increase of 60% in U levels (Al-kharouf et al., 2008).

With regard to levels of ^{232}Th and ^{40}K in topsoil, there is homogeneity in their distributions which is principally due to soil mixing. However, the work done by Al-kharouf et al., (2008), has indicated that, the activities of ^{232}Th and ^{40}K tend to decrease linearly in deep layer. This observation is linked to irrigation water which has the ability to dissolve ^{232}Th and ^{40}K components into solution and subsequently move under the effects heating by the sun toward the surface and is deposited by evaporation.

2.6 Food crops and radioactivity

Agriculture has been the backbone of the economy of many developing countries like Ghana. Many countries in Africa have laid down policies on the provision of sustainable food security. When people have sufficient food to eat, many of the nutrition-related problems are avoided and healthy citizen are available to work for the growth of respective countries. Children also have the greater chances of surviving. It is expected

that developing countries do not only concentrate on the provision of adequate food for their citizens but also food that is chemically and radiologically safe.

An important goal of the United Nations (UN) relating to sustainable food security is to assist members' states in ensuring that people have access to food that is sufficient, nutritionally adequate and above all considerably safe for human consumption (Jibiri et al., 2006). The presence of radionuclide in soil above a certain threshold leads to contamination of food crops since plants derived their nutrients for growth from the top-soil on which they are grown. Stream of water caries radionuclides dissolved in soil water to roots of plants for absorption and assimilation. Radionuclides in solution can then be incorporated through root hair and then to the root of plant for onward transfer to the leave system of plant. In most cases, this is facilitated by their chemical similarity with other element that the plants usually depend on for growth. However, it must be stated that the root uptake of radionuclide is a complex phenomenon, especially primordial radionuclides (Manigandan & Manikandan, 2008). Manigandan and Manikandan, in their work observed that there is low concentration of radionuclides in most plants with the exception of Evodia roxburghina, Eleaocar pus oblangus and Glochidion neilgherense could be attributed to physiological differences and other related factors (Manigandan & Manikandan, 2008). However, the activity of U, Th, and K in soil faintly varies within a depth of 0-20 cm. The soil to plant pathway for transfer of radionuclides is dependent on a number of factors, these include;

1. The chemical nature and reactivity of isotope which may affect the availability of isotope within soil water in the pore spaces around the plant roots.
2. The route of exposure (root versus folia exposure).
3. The plant species itself (physical structure, root-shoot ratio) and
4. The nutrient requirement of the plant (USNRC, 2012).

What makes radiological contamination a challenge is that contaminated food does not show any sign of contamination either from the outer periphery or from the innermost parts.

According to Salbu et al (2004), the absorption of radionuclides associated with particles can be in a form of direct dietary intake or an indirect process following particle weathering and soil-plant-animal transfer. This is dependent on soil water pH, organic matter, microbial activities and the vegetation present (Salbu et al., 2004).

The behavior of various radionuclides does not follow the same pattern in the environment due to their inherent differences in physicochemical properties; while some radionuclides such as radiocaesium, radioiodine and radiostrontium are environmentally mobile and hence bioavailable to plants, others have low solubility. Considering the first two months of the Chernobyl accident in 1986, ^{131}I was the major radionuclide of concern for human exposure through agricultural food chains. The pattern however changed as ^{137}Cs is now a major radionuclide for exposure in food items (UNSCEAR, 2008).

Vertical movement of radionuclides down any soil column could be as a result of different transport mechanisms like biological mixing and leaching. High degree of root uptake of radionuclides by plant is correlated with high degree of vertical movement. The physicochemical property of soil affects the rate of migration of radionuclides in soil. There can be a significant downward movement of the various radionuclides, however, much of the radionuclides activity remains in root region of the plant (UNSCEAR, 2008). Plants absorption of radionuclide from soil water is related to the ability of plant root to absorb different elements or compounds as well as the concentration of radionuclides in the soil.

Since plants uptake of radionuclide is strongly related to speciation, it is expected that U^{6+} which is more soluble would be more bioavailable compared to U^{4+} (Salbu et al., 2004). Studies have shown that similar concentrations of individual radionuclides in soil or water do not necessarily produce the same concentration once they get into tissue (Napier et al., 2003).

The ingestion of radionuclide through food is dependent on the concentration of radionuclides in the food consumed. According to IAEA (1989), it is recommended that food analysis for radionuclides to be based on the determination of radionuclides in individual food item rather than dealing with mixed diet sample. This therefore gives clues as to which counter measures should be put in place to reduce exposure to radiation (IAEA, 1989). It is therefore very important to assess radiological safety of edible part of food crops. This is because the ingestion of food crop loaded with NORMS has the potential of exposing human beings to high level of radiation dose.

Furthermore, radionuclides with relatively long half-lives are considered human health risk as they can get into the human system through the food chain and thereby increase the radiation burden for many years (Abu-Khadral et al., 2008). According to Awudu et al (2012), not much has been done on radiological food safety for food crops grown in Ghanaian soil. Awudu et al**,** (2012) is of the view that in assessing foodstuff for radionuclide contamination, it is very important to determine the baseline values or the level of radiation dose of both natural and anthropogenic received by the target population.

For example, another work done on the levels of radioactivity in some selected food crops in Jos-plateau, Nigeria reveals that the activity concentration of ^{40}K is higher in fruits and vegetables compared with tuber crops. In this particular investigation, the concentration

of ^{40}K in tomato was 32.27±3.12 Bq/kg for green leaves and 17.97±1.24 Bq/kg for cassava (Jwanbot et al., 2012). Therefore it is possible that the small amounts of fruits and vegetable consumed everyday may lead to ingestion of more ^{40}K than the large amount of tuber crops ingested daily. Furthermore, an investigation conducted on the determination of NORMS on the various foodstuffs sold in Mallam Atta Market in Accra reveals that, ^{40}K was detected in all food samples with reasonable activity concentrations. However, the highest concentration with regards to ^{228}U, ^{228}Th and ^{40}K were found in cassava with the lowest activity observed in potato, local and imported rice respectively (Awudu et al., 2012).

The presence of ^{40}K in reasonable concentration in all food crops is due to the fact that K is a macronutrient and there is a high expectation that the soil characteristics favour its immobilization and subsequent uptake by plant root (Awudu et al., 2012).

Furthermore, the work of Awudu et al (2012) reveals that, for selected food item ingested, cassava and plantain recorded the highest consumption rate and they incidentally are the food items which contribute so much to annual effective close of 38.31 and 21.85 µSv respectively (Awudu et al., 2012).

2.6.1 Soil to plant transfer of radionuclides

The main source of radionuclides contamination to plants is of terrestrial origin. Plants absorb radionuclides with similar chemical behaviour as essential nutrients. The root system of plants is capable of absorbing only a small part of radionuclides in the soil. There are two main routes by which vegetation may be contaminated.

The first process is by the direct contact of vegetation to radionuclide in contaminated soil through the root system and the other is contaminated by dust or air containing gaseous radionuclides. In the end, these radionuclide contaminants find their way into the

food chain either by direct consumption of edible plants parts or indirectly through the contamination of animal products like; milk, meat and egg (Khan, Ismail, & Khan, 2010). These processes significantly contribute to the total internal radiation dose received by human beings.

Soil to plants transfer of the various radionuclides varies enormously. The main factors which affect the transfer of a particular radionuclide are the type of crop and the soil type on which the plant grows on. Furthermore, the length of time for which the radionuclide has been in soil is also important. Moreover, factors such as crop variety, agricultural practice (especially fertilizer application) and weather conditions also affect the uptake of radionuclide from soil to plants (IAEA, 2006).

The migration and concentration of radionuclides in the soil-plant system is complex and assessment models commonly utilize is soil-plant concentration ratio, referred to as concentration factor (CF). Concentration factor helps in the estimation of the transportation of radionuclides through the food chain. It is also used in the radiological risk assessment to estimate the amount of radioactivity that could be present in food or organisms based on the calculated concentration in the source medium. This ratio describes the amount of radionuclide expected to enter a specific plant from soil. Soil-plant transfer factor is regarded as one of the most important parameter in environmental safety assessment for nuclear facilities (IAEA, 1996; Napier et al., 2003). This parameter is necessary for environmental transfer models, which are useful in the prediction of radionuclide concentration in agricultural crops for estimating impact to humans. Concentration factor is generally described as the ratio of the concentration of radionuclides dry weight in specific plant part to the concentration of radionuclide dry weight in soil (IAEA, 2006).

2.7 Health Effects of Ionizing radiation.

The level of exposure to radiation to an individual determines the subsequent health effect. The health effect of exposure to radiation depends on many factors, including the type of radiation, the amount of energy delivered, exposure time, the organs or tissues the radiation interacts with and characteristics of the exposed person (host factor such as age).

The most credible scenario of radiation exposure to people from contaminated environment is more internal exposure rather than external through inhalation or ingestion of radionuclides. Radionuclides in the body are referred to as internal emitters, because they continue to impart energy to the surrounding tissues from within and, thus, can continue to harm or affect body cells for an extended period.

Ingested radionuclides are absorbed into the blood and accumulate in specific tissues that they may damage them (ICRP, 2007). It should be noted that beside the radiological hazards of some elements such as natural uranium, it also induces chemical toxicity, especially nephroxity, which is more harmful than radio toxicity (Wrenn et al., 1985)

In accordance with its constitution and International Health Regulations, WHO is mandated to assess public health risks and provide technical consultation and assistance in association with radiation event (WHO, 2006). The main common types of radiations released by both natural and anthropogenic radionuclides are α, β and ɣ radiations. Both α and β have relatively low penetration effects and are usually a matter of health concern only in terms of internal exposure.

According to the European Commission, much is known on the likelihood of various health effects after human exposure to high radiation levels. However not much is known on low dose exposure (EU, 2002). Furthermore, while some scientists have the view that

there is low dose region where the likelihood of any health effect is very minimal, others claim that low dose risks are grossly underestimated. These divergent view points are a source of confusion on matters of radiation protection. This notwithstanding, the ICRP has recommended on effective dose limit of 1mSv in a year for the general public (Cember & Thomas, 2009).

In a report published in 2006 by UNSCEAR, it been stated that there is substantial epidemiological evidence linking the exposure to radiation by man at moderate levels or high level to solid tumors in many body organs and of leukemia (UNSCEAR, 2006). There is also increasing evidence of low-dose radiation exposure leading to increased incidence of cataract (UNSCEAR, 2010).

Furthermore, the WHO (2006) guideline for drinking water quality, points to the fact that there is evidence from both human and animal studies that exposure to low or moderate dose may increase the long term occurrence of cancer. Available animal studies suggest that the rate of genetic malfunction may be increased by radiation. The radiation dose resulting from the intake of radionuclides in the form of water or food depends on a number of chemical to biological conditions. These factors are; the fraction of the amount ingested that is absorbed into the bloodstream, the organs or tissue to which the radionuclides are carried to, and the biological half-life of each radionuclide. Other factors are the nature of radiation released upon the decay of specific radionuclide and the sensitivity of the irradiated organ or tissue to radiation (WHO, 2006).

The UNSCEAR in 2010, having employed the use of epidemiological data to examine the relationship between dose received and the risk of cancer induction which is simply a dose response relationship came out with the finding that there is the existence of a significant elevation in risk when exposed to doses ranging between 100 to 200 mGy.

However, there are numerous challenges involved in the attribution of specific case of disease to low-dose radiation exposure, these factors are;

i. The lack of specificity in the type or characteristics of disease induced by radiation,
ii. The issue of long time between exposure and the manifestation of disease usually in the order of years to decades,
iii. The high spontaneous incidence of diseases associated with radiation in the ageing general population.

Finally, it is obvious that epidemiological studies alone are unlikely to be able to help in the identification of significant elevation in risk much below 100 to 200 mGy, there is therefore the need for enhanced studies to truly establish the likelihood of risk due to the exposure to low dose ionizing radiation (Canu et al., 2011; UNSCEAR, 2010).

For simple classification, health effects due to radiation fall into two main categories. There are deterministic effects, in which upon exposures, the certainty of effect is very high under certain conditions and stochastic effects in which the effect may or may not occur at all (UNSCEAR, 2010).

2.8 Type of radiations and health effects

The types of ionizing radiations released by both natural and artificial radionuclides are alpha, beta and gamma radiations. Both alpha and beta radiations have less penetration effect and therefore are more significant internal source of exposure. However, gamma radiation has high penetration effect and can pose both internal and external exposure. Ionizing radiations have sufficient energy to remove electron from molecular orbital shells in tissue upon interaction. This has a high tendency of affecting the life of an organism at the cellular level. Most of the health effects caused by ionizing radiation

come from gamma radiation exposure for external exposure situations. Furthermore, gamma radiation poses the same health effects as high energy radiation like X-ray can cause.

The dose of radiation received by an individual determines the level of damage to tissue. The level of damage also depends on the sensitivity of the different tissues and organs in the body. Exposure to radiation beyond certain threshold (1 mSv/y) can lead to disorders in functioning of tissues. It can also lead to acute health effects such as skin redness, hair loss, radiation burns or acute radiation syndrome. However, when a low dose is delivered over a long time to an individual, there is greater likelihood for damaged cells to repair successfully in a matter of time. This long-term effect may still occur if the cell damage is repaired but incorporate errors.

Atypical condition is when a transformed irradiated cell still retains its capacity for cell division. This transformation may lead to cancer after several years of exposure. Furthermore, this type of risk is higher for children and adolescents as they are significantly more sensitive to radiation exposure than adults (WHO, 2006).

2.8.1 Deterministic effect of ionizing radiation

This is due to a whole-body or local exposure that causes sufficient cell damage or killing a whole cell, this thereby hinders proper functioning of an irradiated tissue or organ. The degree of damage of a deterministic event depends on dose rate impartment to the exposed person. For example, when different individuals with varying susceptibilities are exposed to radiation, the threshold given for deterministic effect of sufficient severity will occur at low dose rate in more sensitive people (Canu et al., 2011). However as the dose rate increases, more individuals are likely to experience the same effects until the whole group exhibit the various degree of deterministic effect at high dose (Niu et al., 2010).

According to Cember and Thomas (2009), all organs are not equally sensitive to radiation and for that matter, the pattern of response or disease syndrome in a situation of an overexposure depends on the magnitude of the dose.

According to a joint report published by the IAEA, WHO and ILO on occupational safety causing temporary sterility in normal males, for a single short exposure is about 0.15 Gy, while that for prolong exposure about 0.4Gy. A dose rate ranging between 3.5-6.0 Gy can lead to permanent sterility upon acute exposure. Furthermore, the threshold for permanent sterility to occur in a normal woman ranges from 2.5-6.0 Gy. For whole bone marrow acute exposure, the threshold dose rate of clinical effect is 0.5 Gy, with 0.4 Gy assigned for threshold dose rate for prolonged exposure. This issue of dose rate limitation in the current framework for radiation protection is directed at preventing the incident of deterministic effects (Niu et al., 2010).

2.8.2 Stochastic effects of ionizing radiation

This may occur if an irradiated cell is modified rather than killed. Such events are thought to be no-threshold phenomena. According to Cember and Thomas (2009), stochastic effects occur by chance and can be found in both exposed and unexposed individuals. Stochastic effects are therefore not unequivocally related to exposure to noxious agents, as drunkenness is to alcoholism. For this reason, when standards are even met, there is still a small possibility for the occurrence of stochastic effects. According to Simmons et al (1995), it is very difficult to completely eliminate stochastic effects but their occurrence can be minimized (Simmons, Lawson, & Mayall, 1995). Conventionally, modification that leads to changes in the DNA of a germ cell can lead to cancers in the somatic cells. On the other hand, if a cell is damaged by ionizing radiation hereditary effects are eminent in subsequent generations (Niu et al., 2010). Furthermore, the report

has stated that cancer suspected to have been induced by radiation cannot produce enough proves to ascribe direct causation.

2.8.3 Types of deterministic effects

A special type of deterministic effect is radiation syndrome resulting from acute whole body irradiation. Radiation events resulting from acute radiation syndrome are categorized into three classes as; Hemopoietic syndrome, GI syndrome and CNS syndrome

2.8.3.1 Hemopoietic Syndrome

Hemopoietic syndrome occurs when the whole body is exposed to gamma dose of magnitude 2 Gy. The major effect of Hemopoietic syndrome occurs in bone marrow and blood. Individuals exposed to gamma-ray dose of 140 mGy have experienced changes in blood count. Typically, Hemopoietic syndrome is characterized by depression or ablation of bone marrow. There is the likelihood of instantaneous restoration of bone marrow if a victim survives the physiological effects of denuding marrow (Cember & Thomas, 2009). According to Cember and Thomas (2009), while white blood cells are very sensitive to radiation, red blood cells count does not dwindle until about a week of exposure.

Death can be the ultimate effect of Hemopoietic syndrome occurring within the first two months after exposure if medical intervention is not satisfactory. However, the many symptoms associated with hemopoietic syndrome are nausea, vomiting, fatigue, epilation (loss of hair) which is certain within the second and third week of deterministic event and finally malaise (Cember & Thomas, 2009).

2.8.3.2 Gastrointestinal Syndrome

This is associated with dose of about 10 Gy or greater. GI syndrome can lead to complete destruction of bone marrow as well as intestinal epithelium. Early signs of GI syndrome

are severe nausea, vomiting and diarrhea. Finally death within several weeks upon exposure is most likely(Cember & Thomas, 2009)

2.8.3.3. Central Nervous System Syndrome

Central nervous system (CNS) syndrome is associated with total gamma dose rate of 20 Gy. This dose rate is capable of damaging the CNS and many other important organs of the body. Unconsciousness follows within minutes after exposure and death occur in a matter of hours to few days (Cember & Thomas, 2009).

CHAPTER THREE

MATERIALS AND METHODS

3.1 Background

This section describes the study area, the geology of the area, sample collection, sample preparation and the methods used in the analyses. Furthermore, mathematical formulae used for the calculation of activity concentrations of the natural radionuclides are also explained in detailed. Finally, the methods used in the determination of gross alpha and beta activities in water samples are explained.

3.2 Description of the study area

The Tano-North District is one of the twenty seven administrative districts of the Brong – Ahafo Region with Duayaw/Nkwanta as its administrative Capital. It was created in 2004 out from the previous Tano District. The Tano-North district shares boundaries with Offinso North district in the North-East, Ahafo Ano district in the South, both in the Ashanti Region. In the eastern part, the district shares boundaries with Tano-South and also shares boundaries in the West with Sunyani Municipal and Asutifi district of Brong-Ahafo Region. The district lies between latitude 7^{o} 00' N and 7^{o} 25' N and longitude 2^{o} 3' W and 2^{o} 15'W. The total land area covered by the district is 876 square kilometers making almost 1.8 percent of the total land coverage of the entire Brong-Ahafo Region. The district has a vast fertile land which is suitable for the cultivation of a wide range of cash and food crops. This condition makes agricultural activities the main backbone of the economy of the district. The major food crops grown in the district are maize, cassava, cocoyam, yam, and plantain, with cocoa, oil palm and coffee being the major cash crops cultivated in the area. The main source of water in the district is borehole. However, some of the communities depend on streams, rivers, springs and well as their

source of water. The above reasons make it imperative for baseline study such as this to establish baseline radioactivity levels which will serve as reference data for future studies. This is particularly important in event that the area will be exploited for mineral resources in future.

3.3 The geology and soil of the study area

The geology of the district is basically made of the middle Precambrian formation. Most of the parts are underlain by lower Birimian rocks with few areas such as Bosom-kese, Kwamisa underlain by granite. The lower Birimian rock formation in the district contains weathered phychites and schist which is the reason why ceramics and pottery activities is wide spread in the area. The district is located in the moist semi-deciduous forest zone of Ghana, and the soil basically consists of forest Ochrosols. Generally, the various types of soil in the district are fertile with abundant arable land which favours the cultivation of wide range of both food and cash crops.

3.4 Sample Collection

3.4.1 Water Sampling

Twenty (20) water samples were collected. The sources of the water samples were boreholes, well, spring as well as pipe borne water from the various towns and villages selected for the study. The water samples were collected into one and half litre (1.5 L) bottles and properly labelled. The bottles were acid washed with concentrated HNO^3 before they were filled with water. This is to ensure that the various radionuclides remain in solution or in the water sample rather than adhering to the inner sides of the bottle. Furthermore, the bottles were filled to the brim with water to prevent the accumulation of CO_2 gas at the top of the water which may dissolve in water leading to changes in water chemistry. The water samples were transported to the laboratory and stored in an air-

conditioned laboratory before necessary preparation for analysis. The pH, temperature, total dissolved solids (TDS) and conductivity of the water samples were determined using a four-in-one Combo pH and EC meter model number HI 98/29. The instrument was calibrated with a standard solution of 0.1M KCl for conductivity measurement. For the pH, the pH meter was calibrated with buffer solutions with pH 4.01, 7.00 and 14.00

3.4.2 Soil Sampling

The Soil samples were collected from ten farms that randomly selected from the various towns and villages in the district. The towns and villages where the farms were located are Duayaw/Nkwanta, Techire, Subriso, Bomaa, Bredi, Afrisipa and Boukrukruwa. Only farms where crops such as Cassava, yam and cocoa yam were grown were selected for the study. In addition the food crops must be ready for harvest. At each sampling location, the coordinates were measured and recorded using Geological Position System (GPS).

At any selected farm, soil samples were randomly collected within specific boundaries of the farm area. The soil samples were taken using a well cleaned hand trowel to a depth of 5-10cm where the roots of plants are located. Soil samples were randomly taken from various locations until composite sample of about six kilograms is obtained. The composite sample was mixed together thoroughly and a 2.5 kg of the soil sample was measured into a labeled polyethylene bags and then sealed. The samples were then conveyed to the laboratory for preparation and analysis.

3.4.3 Food Sampling

In each selected farm, cassava, yam and cocoa yam samples were collected. In each case, only matured crops which were ready for harvesting were taken. In the case of yam, samples were collected randomly from a given corner where yam is cultivated. However,

with cassava and cocoa yam, crop samples were randomly selected but not fully harvest as sampler were taken from many cassava and cocoa yam plants until about 3.0 kg of each was obtained. The food crops were thoroughly washed, packed into labeled polyethylene bags and conveyed to the laboratory for processing and analysis.

3.5 Sample preparation and analysis

3.5.1 Water

Each water sample was filtered to remove undesirable solid particles. The water samples were then prepared into one liter (1 L) Marinelli beakers for gamma spectrometry. The samples were counted on a high purity Germanium detector for 36000s (ten hours) to determine the radionuclides of interest. The activity concentrations of the radionuclides in the water samples were calculated in Bq/L from the measured counts.

3.5.2 Soil

In the Laboratory, the soil samples were air dried in trays for five days. Each soil sample was well homogenized after removing extraneous materials such as plant roots, stones and decaying organic matter from it. The soil samples were oven dried for 2-3 hours at a temperature of 105^{o}C until water was completely removed from all soil samples and a constant weight obtained. The soil samples were grounded into fine powder using a ball mill grinder and were then sieved through a 2 mm pore size mesh into a previously weighed Marinelli beaker. The beakers containing the soil samples were weighed again to obtain the weight of all soil samples. The beakers were covered, sealed with a paper tape to prevent the escape of gaseous radionuclides. The samples were then properly stored in the laboratory for thirty days to allow for secular equilibrium to be established between the long-lived parent radionuclides and their short-lived daughter radionuclides in the ^{238}U and ^{232}Th decay series. The samples were counted on the High Purity Germanium

(HPGE) detector for 36000s. The activity concentrations of the radionuclides earmarked for determination in the samples were determined on dry weight basis in Bq/Kg.

3.5.3 Food

The food samples were further washed peeled and then the edible part chopped into very small pieces. The chopped edible pieces were further washed and packed into labelled polyethylene bags and then properly kept in a refrigerator prior to freeze drying. The food samples were freeze dried using a freeze drier model Christ LMCV-1. The dried food samples were grounded into fine powder and then sieved through a 2 mm mesh. The grounded samples were then put into previously weighed and labelled Marinelli beakers. Each beaker containing a food sample was further weighed to obtain the weight of the food samples. The beakers were covered, and then sealed with paper tape and stored in the laboratory prior to analysis. The samples were then counted on a High Purity Germanium (HPGE) detector for 36000s. The activity concentration of the radionuclides of interest in the samples was determined on dry weight basis in Bq/kg.

3.6 Instrumentation and calibration

Direct instrumental analysis without pre-treatment (non-destructive) was used for the measurement of gamma rays for the soil, food and water samples using a High Purity Germanium detector (HPGE). The gamma spectrometry system consists of an n-type HPGE detector coupled to a computer based multi-channel analyser (MCA). The relative efficiency of the detector is 25% with energy resolution of 1.8 keV at gamma ray energy of 1332 keV of ^{60}Co. The identification of individual radionuclides was performed using their gamma ray energies and the quantitative analyses of radionuclides were performed using gamma ray spectrum analysis software, ORTEC MAESTRO-32.

The detector is mounted in a cylindrical lead shield (100 mm) lined with copper, cadmium and plexiglass (3 mm each) to reduce the background radiation. The detector is cooled in liquid nitrogen at a temperature of -196 ^{0}C (77 K). In order to determine the background distribution in the environment around the detector, ten empty Marinelli beakers were thoroughly cleaned and filled with distilled water and counted for 36000 s in the same geometry as the samples. The background spectra were used to correct the net peak area of gamma rays of measured isotopes. The background spectra were also used to determine the minimum detectable activities of ^{238}U (0.12 Bq/kg), ^{232}Th (0.11 Bq/kg) and ^{40}K (0.15 Bq/kg) of the detector.

3.6.1 Calibration of the gamma spectrometer

Before sample analysis, energy and efficiency calibrations were performed to ensure proper identification and quantification of the radionuclides of interest. The detector system was calibrated using the multinuclide reference standard material. The standard in 1.0 liter Marinelli beaker was measured using a counting time of 36,000 seconds to acquire spectral data.

The standard used for the energy and efficiency calibrations consisted of a mixed radionuclide in solid water supplied by the IAEA in 2006. The standard solution has the following radionuclides with the corresponding energies; ^{241}Am (59.54 keV), ^{109}Cd (88.03 keV), ^{57}Co (122.06 keV), ^{139}Ce (165.86 keV), ^{203}Hg (279.20 keV), ^{113}Sn (391.69 keV), ^{85}Sr (514.01 keV), ^{137}Cs (661.66 keV), ^{60}Co (1173.2 keV and 1332.5 keV) and ^{88}Y (898.04 keV and 1836.1 keV). However, only 4 radionuclides in the standard were selected for the energy calibration namely: ^{241}Am, ^{57}Co, ^{137}Cs, ^{60}Co.

This is because the radionuclides with short half-lives did not give any significant peaks for a standard purchase in 2006.

3.6.2 Energy calibration

Energy calibration was performed by matching the energies of the principal gamma – rays in the spectrum of the standard reference material to the channel number of the spectrometer. This was done both manually and by a computer.

The equation relating the energy and the channel number is given by the expression (3.1).

$$E_\gamma = A_o + A_1 CN \qquad (3.1)$$

Where; E_γ is the energy in keV, CN is the channel number for a given radionuclide, and A_o and A_1 are calibration constants for a given geometry. A graph of energy against channel number was plotted as shown in Figure 3.1.

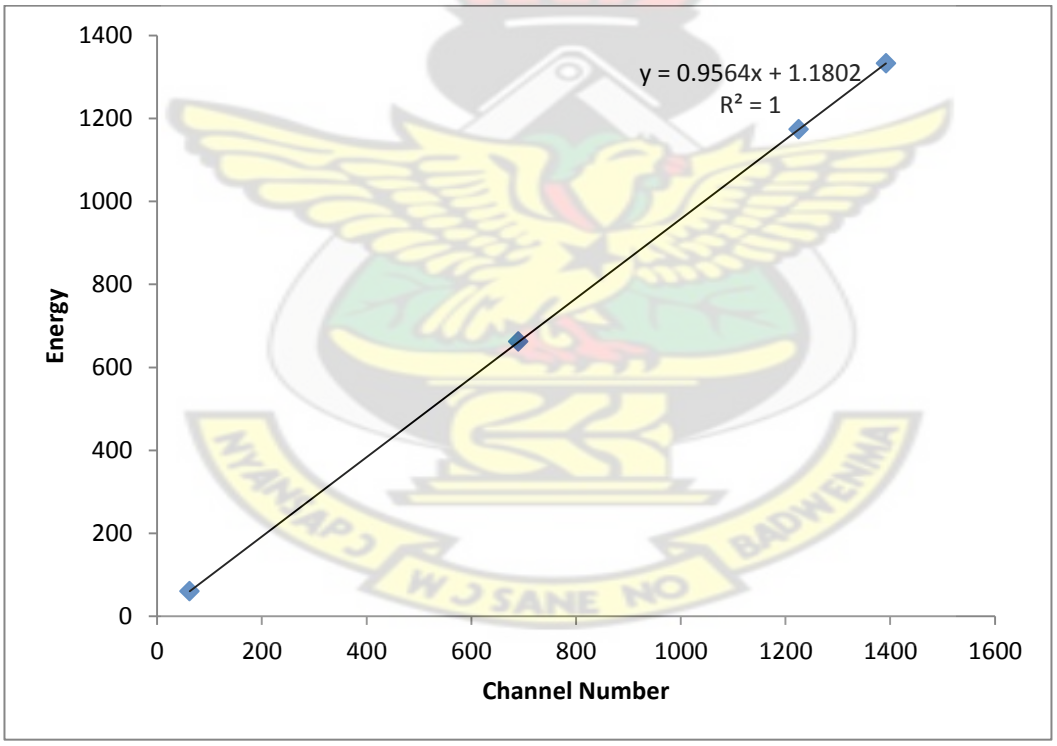

Figure 3.1: Energy calibration Curve.

The expression for the energy calibration is represented by the relationship below

$E_\gamma = 0.956CN + 1.180$ (3.2)

Where; 1.180 and 0.956 are the calibration constants.

3.6.3 Efficiency calibration

The efficiency calibration was performed by acquiring a spectrum of the calibration standard until the count rate at the peak of total absorption can be calculated with statistical uncertainty of less than 1 % at a confidence level of 95 %.

The net count rate was determined at the photo peaks for all the energies to be used for the determination of the efficiency at the time of measurement. The efficiency at each energy was plotted as a function of the peak energy and extrapolated to determine the efficiencies at other peak energies for the measurement geometry used.

The efficiency was then related to the count rate and the activity of the standard by the relation:

$$\varepsilon(E_\gamma) = \frac{N}{(A * P * t)} \tag{3.3}$$

Where, N is the full energy peak net count corresponding to the gamma photons with energy E_γ and gamma emission probability P, A is the activity of the standard source and t is the counting time. The efficiency is related to the energy by the expression (Gilmore and Hemingway, 1995).

$$\ln \varepsilon(E_\gamma) = a_o + a_1(\ln E_\gamma)^1 + a_2(\ln E_\gamma)^2 \tag{3.4}$$

Where; a_o, a_1, a_2 are calibrations constants for a given geometry and the other symbols have been defined earlier. The efficiency calibration curve is shown in Figure

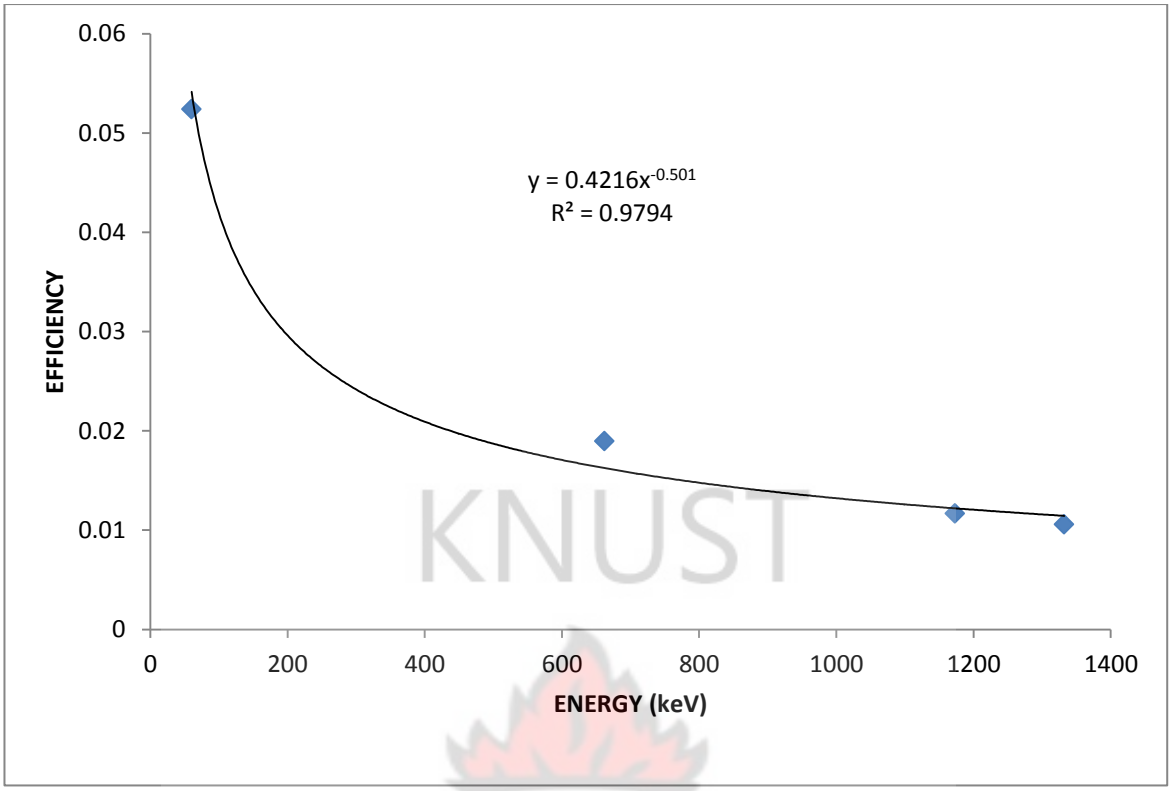

Figure 3.2: Efficiency calibration curve

From the efficiency calibration curve, the following expression was obtained using a first order polynomial:

$$ln\varepsilon = -0.864 - 0.501\ ln\, E_\gamma \qquad (3.5)$$

For E_γ > 100 keV

3.7 Calculation of activity concentration and estimation of doses

The activity concentration of ^{238}U was calculated from the average peak energies of 1746.49 of ^{214}Bi, and 609.31 keV of ^{214}Bi. Similarly, the activity concentration of ^{232}Th was determined from the average energies of 238.63 keV of ^{212}Pb and 911.21 keV of ^{228}Ac. The activity concentrations of ^{137}Cs and ^{40}K were determined from the energies of 662 keV and 1460.83 keV respectively. The analytical expression used in the calculation of the activity concentrations in Bq/kg for soil and foodstuffs and Bql^{-1} for water samples is shown in equation (1).

$$A_{ac} = \frac{N_{sam}\exp(\lambda T_d)}{P_E * \mathcal{E}(E) * T_c * M} \qquad (3.6)$$

Where; A_{ac} is the activity concentration, λ is the decay constant, N_{sam} is total net counts for the sample in the peak range, P_E is the gamma-ray emission probability, T_d is decay time between the sampling and counting, T_c is the counting time, ε(E) is the total counting efficiency of the detector system, M is the mass of sample (kg) or volume (l) and the expression exp (λT_d) is the correction factor for decay between sampling and counting (Oresengun et al., 2010).

The external gamma dose rate (D_γ) at 1.0 m above ground for the soil samples was calculated from the activity concentrations using the following equation (Amin et al., 2011).

$$D_\gamma\left(nGyh^{-1}\right) = DCF_K * A_K + DCF_U * A_U + DCF_{Th} * A_{Th} \qquad (3.7)$$

where; DCF_K, DCF_U, DCF_{Th} are the absorbed dose rate conversion factors for ^{40}K, ^{238}U and ^{232}Th in $nGy/h/Bqkg^{-1}$ and A_K, A_u and A_{Th} are the activity concentrations for ^{40}K, ^{238}U and ^{232}Th respectively.

DCF_K = 0.0417 $nGy/h/Bqkg^{-1}$; DCF_U = 0.462 $nGy/h/Bqkg^{-1}$; DCF_{Th}= 0.604 $nGy/h/Bqkg^{-1}$

The annual effective dose (E_γ) from external gamma exposure in an outdoor environment was calculated from the absorbed dose rate by applying equation 3.8.

$$E_\gamma = D_\gamma \times T \times F \quad (3.8)$$

where; E_γ is the annual effective dose in mSv, D_γ is the estimated absorbed dose rate in nGy/h, T is the outdoor exposure time (0.2×24×365d ≈ 1752 h/y) for members of the public and F is the dose conversion factor of 0.7 in Sv/Gy (UNSCEAR, 2000a).

For the water samples, the annual effective dose, $E_{ing}(w)$ ($mSvy^{-1}$) from ingestion of radionuclides consumed in water was calculated on the basis of the activity concentrations of the radionuclides. The daily water consumption rate was considered to be 2 liters per day and the conversion factor or dose per unit intake by ingestion of naturally occurring radionuclides for adult members of the public used were: 4.5 x 10^{-5} $mSvBq^{-1}$ for ^{238}U, 2.3 x 10^{-4}mSv/Bq for ^{232}Th and 6.2 x 10^{-6}mSv/Bq for ^{40}K (WHO, 2006). The annual effective dose owing to ingestion of ^{238}U, ^{232}Th and ^{40}K in water was calculated using equation 3.9.

The annual effective dose, $E_{ing}(w) = \sum A_w \times DCF_w \times I_W$ (3.9)

where; I_w is the annual water consumption rate which is 730 Ly^{-1}, A_w is the activity concentration of radionuclide in the water (Bq/l), and DCF_w is the ingestion dose coefficient (Sv/Bq) (Alam et al., 1999).

The intake of radionuclides in food is dependent on the concentration of radionuclides in the various foodstuffs and the amount consumed. It is obvious that food consumption depends on many factors, some of which concern the individual while others are group related. Information on the range and amounts of food consumed regularly by individuals

is required. The risk associated with an intake of radionuclides in the body is proportional to the total dose delivered by the radionuclides while staying in the various organs.

In general it is assumed that stochastic effects occur linearly with dose and usually the effective dose (E) is used to define this risk. The committed effective dose, E (mSv/y) to an adult individual due to intake of natural radionuclides in foodstuffs was calculated on the basis of the activity concentrations of the radionuclides. The committed effective dose owing to ingestion of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in foodstuffs was calculated using equation 2.

$$E_{ing}\,(FS) = \Sigma(A_{fs} \times I_{fs} \times IDCF_{fs}) \qquad (3.10)$$

Where; A_{fs}, is the average activity concentration of radionuclides (Bq/kg) in foodstuffs, I_{fs}, is the annual intake of foodstuffs (170 kg/year), $IDCF_{fs}$, is the dose conversion factors (Sv/Bq)

The dose coefficients for the public were 4.5×10^{-5}, 7.2×10^{-5} and 6.2×10^{-6}, 1.3×10^{-8} $mSvBq^{-1}$ of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs respectively (ICRP, 2007). The annual consumption rate of root tubers was calculated to be 170 kg /year.

3.8 Determination of natural radioactivity in water samples using gross alpha and gross beta counter

Twenty (20) water samples were taken from bore-holes, tap water, river water, and springs. The samples were analyzed for gross alpha (α) and gross beta (β) radioactivity. The water samples were acidified with 2 ml of concentrated HNO_3 Three hundred millilitres (300ml) of each water sample was evaporated to near dryness on a hot plate in a fume hood. The residue in the beaker was rinsed with 1M HNO_3 and evaporated again to near dryness. The residue was dissolved in small amount of 1M HNO_3 and transferred into a weighed 25 mm stainless steel planchet. The planchet with its content was heated

until all moisture was evaporated. It was then stored in a desiccator and allowed to cool and prevented from absorbing moisture.

The prepared samples were then counted to determine alpha and beta activity concentrations using the low background Gas-less Automatic Alpha/Beta counting system (Canberra iMatic^{TM}) calibrated with alpha (^{241}Am) and beta (^{90}Sr) standards. The system uses a solid state Passivated implanted Planar Silicon (PIPS) detector for alpha and beta detection. The alpha and beta efficiencies were determined to be 36.39±2.1% and 36.61±2.2% respectively. The background readings of the detector for alpha and beta activity concentrations were 0.004 and 0.011 Bq/L.

3.9 Estimation of total annual effective dose

The total annual effective dose (E_T) to members of the public was calculated using ICRP dose calculation method (ICRP, 1991; 2007). The analytical expression for the total effective dose is provided in equation (3.11).

$$E_T = E_\gamma(U, Th, K) + E_{ing}(W) + E_{ing}(FS) \qquad (3.11)$$

where; E_T is the total effective dose in Sievert (Sv), E_γ (U, Th, K) is the external gamma effective dose from the soil samples, E_{ing} (W) is the effective dose from the consumption of water and E_{ing}(FS) is the effective dose from the consumption of foodstuffs.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.0 Results

Table 4.1 indicates the geographical location where water samples were collected in the Tano-North District of Ghana, while Table 4.2 shows the physical parameters with regards to temperature, conductivity, pH and total dissolved solids (TDS). Furthermore, Table 4.3 shows the activity concentration and the calculated effective doses of ^{40}K, ^{238}U and ^{232}Th in the various water samples. Table 4.4 shows the activity concentrations of gross alpha and gross beta in water samples collected.

Table 4.1: Sample location with co-ordinates for water samples from Tano-North District of Ghana

Sample location	Sample ID	Location coordinates	Description of sampling location
Duayaw/Nkwanta	DUAW 1	N07° 09.833" W002°06.102"	Underground water(Domenbra)
	DUAW 2	N07° 09.815" W002° 04.658"	Underground water (Adinkramu)
	DUAW 3	N07° 10.636" W002° 05.833"	Borehole (hospital)
	DUAW 4	N07° 11.326" W002° 05.871"	Borehole (SEKESS)
Bookrukruwa	BOUW 5	N07° 07.172" W002° 04.405"	Borehole
	BOUW 6	N07° 07.188" W002° 04.419"	Borehole
	BOUW 7	N07° 09.478" W002° 05.135"	Mechanized Borehole
	BOUW 8	N07° 10.637" W002° 05. 881"	Borehole (Benchem)
Bomaa	BOMW 9	N07° 05.257" W002° 10.331"	Underground water (Main)
	BOMW 10	N07° 04.686" W002° 10.151"	Borehole
	BOMW 11	N07° 05.214" W002° 09.991"	Borehole (BOMSEC)
	BOMW 12	N07° 04.870" W002° 09.949"	Spring water
Techire	TECW 13	N07° 13.764" W002° 10.541"	Underground water (upper)
	TECW 14	N07° 13.722" W002° 10.660"	Underground water (lower)
	TECW 15	N07° 15.496" W002° 12.080"	Spring water (Afrisipa)
	TECW 16	N07° 15.335" W002° 12.295"	Underground water (Afrisipa)
Tanoso	TANW 17	N07° 16.738" W002° 15.779"	Raw water
	TANW 18	N07° 16.800" W002° 15.786"	Treated water
	TANW 19	N07° 16.594" W002° 14.708"	Borehole
	TANW 20	N07° 16.290" W002° 14.411"	Borehole
Bomaa	BOMW 21	N07° 05.470" W002° 09.772"	Borehole (Asikesi)

Table 4.2: Samples with their physical parameters for water samples collected from Tano-North District of Ghana

Sample location	Sample ID	Temperature/°C	Conductivity/µS/cm	pH	TDS/ ppm
Duayaw/Nkwanta	DUAW 1	24.7	138	5.92	70
	DUAW 2	24.5	151	5.86	77
	DUAW 3	24.6	94	5.74	48
	DUAW 4	24.4	57	5.62	31
Boukrukruwa	BOUW 5	26.6	139	5.63	75
	BOUW 6	24.5	193	5.73	91
	BOUW 7	24.5	75	6.20	37
	BOUW 8	24.4	200	6.31	100
Bomaa	BOMW 9	24.5	308	6.93	154
	BOMW 10	24.5	421	5.74	210
	BOMW 11	24.4	122	6.08	62
	BOMW 12	25.0	193	6.04	96
	BOMW 21	24.4	204	6.02	101
Techire	TECW 13	24.6	269	6.46	134
	TECW 14	24.6	415	6.36	204
	TECW 15	24.5	77	5.82	38
	TECW 16	24.5	364	7.23	70
Tanoso	TANW 17	24.5	139	7.23	70
	TANW 18	24.5	185	7.65	92
	TANW 19	24.4	330	5.97	165
	TANW 20	24.4	72	6.01	90

Table 4.3: Average activity concentration and effective dose due to ^{40}K, ^{238}U and ^{232}Th in water samples from Duayaw/Nkwanta in the Tano-North District of Ghana

Sample Location	Sample ID	pH	Activity concentration (Bq/L)			Committed effective dose (µSv/y)
			^{40}K	^{238}U	^{232}Th	
Duayaw/Nkwanta	DUAW 1	5.92	2.49±0.17	0.21±0.01	0.24±0.01	19.50±1.89
Duayaw/Nkwanta	DUAW 2	5.86	11.89±0.74	0.53±0.05	1.41±0.08	103.00±3.14
Duayaw/Nkwanta	DUAW 3	5.74	2.54±0.27	0.23±0.01	0.23±0.01	19.20±1.67
Duayaw/Nkwanta	DUAW 4	5.62	2.56±0.27	0.21±0.01	0.25±0.02	20.20±1.99
Average		5.79	4.87±0.36	0.30±0.07	0.53±0.13	40.43±2.17
Range			2.49-11.89	0.21-0.53	0.13-1.41	19.20-103.00
Guideline Level (WHO, 2004)						100

Table 4.4: Average activity concentration and effective dose due to ^{40}K, ^{238}U and ^{232}Th in water samples from Boukrukruwa in the Tano-North District of Ghana

Sample Location	Sample ID	pH	Activity concentration (Bq/L)			Committed effective dose (μSv/y)
			^{40}K	^{238}U	^{232}Th	
Boukrukruwa	BOUW 5	5.63	4.15±0.42	0.26±0.02	0.21±0.01	20.90±1.89
Boukrukruwa	BOUW 6	5.73	2.59±0.26	0.19±0.01	0.21±0.01	17.70±1.56
Boukrukruwa	BOUW 7	6.20	2.96±0.32	0.25±0.02	0.26±0.02	21.80±2.13
Boukrukruwa	BOUW 8	6.31	2.76±0.31	0.21±0.01	0.24±0.02	19.90±2.01
Average		5.97	3.12±0.33	0.23±0.02	0.23±0.02	20.08±1.89
Range			2.59-4.15	0.19-0.26	0.21-0.26	17.70-20.90
Guideline Level (WHO, 2004)						100

Table 4.5: Average activity concentration and effective dose due to ^{40}K, ^{238}U and ^{232}Th in water samples from Bomaa in the Tano-North District of Ghana

Sample Location	Sample ID	pH	Activity concentration (Bq/L)			Committed effective dose (μSv/y)
			^{40}K	^{238}U	^{232}Th	
Bomaa	BOMW 9	6.93	1.84±0.06	0.17±0.01	0.18±0.01	14.70±1.01
Bomaa	BOMW 10	5.74	12.00±1.12	0.99±0.07	1.36±0.07	105.00±4.52
Bomaa	BOMW 11	6.08	3.09±0.23	0.45±0.03	0.11±0.01	15.70±1.43
Bomaa	BOMW 12	6.04	2.32±0.14	0.15±0.03	0.28±0.01	20.91±1.67
Bomaa	BOMW 21	6.02	1.94±0.07	0.13±0.03	0.13±0.01	11.60±0.93
Average		6.16	4.24±0.32	0.38±0.02	0.41±0.02	33.58±1.91
Range			1.84-12.00	0.13-0.99	0.13-1.36	11.60-105.00
Guideline Level (WHO, 2004)						100

Table 4.6: Average activity concentration and effective dose due to ^{40}K, ^{238}U and ^{232}Th in water samples from Techire in the Tano-North District of Ghana

Sample Location	Sample ID	pH	Activity concentration (Bq/L)			Committed effective dose (μSv/y)
			^{40}K	^{238}U	^{232}Th	
Techire	TECW 13	6.46	12.38±1.16	0.73±0.05	1.47±0.08	109.00±6.18
Techire	TECW 14	6.36	2.47±0.12	0.24±0.02	0.24±0.02	19.80±1.88
Techire	TECW 15	5.82	7.60±1.11	0.18±0.01	0.18±0.01	60.40±4.56
Techire	TECW 16	7.23	2.57±0.13	0.26±0.02	0.26±0.03	24.60±2.47
Average		6.47	5.05±0.39	0.35±0.02	0.54±0.03	53.45±3.77
Range			2.47-12.38	0.18-0.73	0.18-1.47	19.80-109.00
Guideline Level (WHO, 2004)						100.00

Table 4.7: Average activity concentration and effective dose due to ^{40}K, ^{238}U and ^{232}Th in water samples from Tanoso in the Tano-North District of Ghana

Sample Location	Sample ID	pH	Activity concentration (Bq/L)			Committed effective dose (μSv/y)
			^{40}K	^{238}U	^{232}Th	
Tanoso	TANW 17	7.23	3.14±0.34	0.28±0.02	0.28±0.02	23.50±2.55
Tanoso	TANW 18	7.65	2.83±0.20	0.34±0.03	0.28±0.03	22.00±2.06
Tanoso	TANW 19	5.97	3.87±0.36	0.46±0.05	0.25±0.02	26.50±2.86
Tanoso	TANW 20	6.01	2.77±0.20	0.35±0.04	0.35±0.04	27.60±2.98
Average		6.72	3.15±0.27	0.36±0.03	0.29±0.02	24.90±2.61
Range			2.77-3.87	0.28-0.46	0.25-0.35	22.00-27.60
Guideline Level (WHO, 2004)						100

Table 4.8: Gross alpha and gross beta activity concentration in water samples from Tano North-District

	Gross alpha activity Activity		Gross beta activity Activity	
Sample Location	Sample ID	Concentration (Bq/L)		Concentration (Bq/L)
Duayaw/Nkwanta	DUAW1	0.029		0.157
	DUAW2	0.018		0.011
	DUAW3	0.017		0.127
	DUAW4	0.039		0.121
Boukrukruwa	BOUW5	0.011		0.181
	BOUW6	0.023		0.143
	BOUW7	0.028		0.127
	BOUW8	0.009		0.072
Bomaa	BOMW9	0.010		0.082
	BOMW10	0.007		0.099
	BOMW11	0.009		0.079
	BOMW12	0.012		0.094
	BOMW21	0.022		0.085
Techire	TECW13	0.015		0.049
	TECW14	0.009		0.089
	TECW15	0.010		0.052
	TECW16	0.022		0.091
Tanoso	TANW17	0.023		0.099
	TANW18	0.013		0.097
	TANW19	0.011		0.064
	TANW20	0.018		0.074
Min.		0.007		0.011
Max.		0.039		0.181
Average		0.021		0.094

4.1 Discussions

The activity concentrations of NORMS were measured in the various water samples collected from the Tano-North district. Also measurements were made for gross alpha and gross beta activities in the water samples.

4.1.1 Activity Concentration Of ^{238}U, ^{232}Th and ^{40}K in water samples

The activity concentration of radionuclides of natural origin in water samples taken from different locations in the study area was determined using a gamma detector. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K for water samples from Duayaw/Nkwanta are shown in Table 4.3. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K varied in the range 0.21 to 0.53 Bq/L, 0.23 to 1.41Bq/L and 2.49 to 11.89 Bq/L respectively. The average activities for ^{238}U, ^{232}Th and ^{40}K are 0.30±0.02 Bq/L, 0.53±0.04 Bq/L and 4.87±0.73 Bq/L respectively. The maximum activity concentration for ^{238}U, ^{232}Th and ^{40}K were measured from the underground water (Adinkramu) from Duayaw/Nkwanta with activities 0.53±0.05 Bq/L, 1.41±0.08 Bq/L and 11.89±0.74 Bq/L respectively.

The activity concentration ^{238}U, ^{232}Th and ^{40}K measured for water samples from Boukrukruwa are given in the Table 4.4. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K varied in the range of 0.19 to 0.26 Bq/L, 0.21 to 0.26 Bq/L and 2.59 to 4.15 Bq/L respectively. The calculated average activities for ^{238}U, ^{232}Th and ^{40}K are 0.23±0.01 Bq/L, 0.23±0.01 Bq/L and 3.12±0.32 Bq/L respectively.

The maximum activity due to ^{238}U, ^{232}Th and ^{40}K were recorded from borehole water with values 0.26±0.02 Bq/L, 0.26±0.02Bq/L and 4.15±0.42 Bq/L respectively. The lowest activities due to ^{238}U, ^{232}Th and ^{40}K were also measured from borehole water with values 0.19±0.01 Bq/L, 0.21±0.01 Bq/L and 2.59±0.26 Bq/L respectively.

Table 4.5 shows the activity concentration of ^{238}U, ^{232}Th and ^{40}K in water samples from Bomaa. The activity concentration for ^{238}U, ^{232}Th and ^{40}K varied in the range of 0.13to 0.99 Bq/L, 0.13 to 1.36 Bq/L and 1.84 to 12.00 Bq/L. The average activities for ^{238}U, ^{232}Th and ^{40}K were 0.38±0.03 Bq/L, 0.41±0.03 Bq/L and 4.29±0.32 Bq/L respectively.

The maximum activity for ^{238}U, ^{232}Th and ^{40}K were all measured from borehole water with values 0.99±0.08 Bq/L, 1.36±0.09 Bq/L and 12.00±1.12 Bq/L respectively. The lowest activity due to ^{238}U was recorded from borehole water located at Asukese in Bomaa with a value of 0.13±0.01 Bq/L. The lowest activity for ^{232}Th was also measured from borehole water located at Bomaa Senior High School with a value of 0.11±0.011 Bq/L. Furthermore, the lowest activity for ^{40}K was recorded from the main underground water at Bomaa with a value of 1.84±0.06 Bq/L.

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K for water samples from Techire are shown in Table 4.6. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K varied in the range of 0.18 to 0.73 Bq/L, 0.18 to 1.47 Bq/L and 2.47 to 12.38 Bq/L. The average values with respect to ^{238}U, ^{232}Th and ^{40}K were 0.35±0.02 Bq/L, 0.54±0.03 Bq/L and 5.05±0.59 Bq/L respectively.

The maximum activities for ^{238}U, ^{232}Th and ^{40}K were all recorded from underground water located at Amangoase in Techire with values 0.73±0.06 Bq/L, 1.47±0.08 Bq/L and 12.38±1.27 Bq/L respectively. The lowest activity due to ^{238}U and ^{232}Th were all measured from spring water with values 0.18±0.01 Bq/L and 0.18±0.011 Bq/L respectively. However, the lowest activity due to ^{40}K was measured from underground water located near the transformer in Techire with a value of 2.47±0.12 Bq/L.

Table 4.6 shows the activity concentrations of ^{238}U, ^{232}Th and ^{40}K for Tanoso. The activity concentration for the radionuclides varied in the range of 0.28 to 0.46 Bq/L, 0.25 to 0.35 Bq/L and 2.77 to 3.87 Bq/L respectively.

The maximum activity due to for ^{238}U, and ^{40}K were measured from borehole water with values 0.46±0.05 Bq/L and 3.87±0.35 Bq/L respectively, while the maximum value for ^{232}Th was recorded from another borehole water with a value of 0.35±0.02 Bq/L. The lowest activity for ^{238}U was measured from raw water from the Tano River with a value of 0.28±0.02 Bq/L. Finally, the minimum activity for ^{40}K was measured from another borehole with a value of 2.77±0.19 Bq/L.

From the result, the activity concentration of ^{238}U in all the water samples were about ten times below the WHO guideline level of 10.0 Bq/L in drinking water. It can also be deduced from the results that, the activity concentration of ^{232}Th in 85.71% of water samples were below the WHO guideline level of 1.0 Bq/L. However, water samples from Duayaw/Nkwanta (Adinkramu) 1.41 Bq/L, Bomaa (Borehole) 1.36 Bq/L and Techire (Amangoase) 1.47 Bq/L recorded activities higher than the WHO guideline levels of 1.0 Bq/L for ^{232}Th.

Tables above, the average activity concentration of ^{40}K were higher than all the other radionuclides. The maximum average activities of ^{40}K, ^{238}U and ^{232}Th are 5.05±0.59 Bq/L, 0.38±0.03 Bq/L and 0.54±0.03 Bq/L respectively. The maximum average activities for ^{40}K and ^{232}Th were measured from water samples collected from Techire and its environs with values 5.05±0.59 Bq/L and 0.54±0.03 Bq/L respectively. However, the maximum average activities for ^{238}U was measured from water samples collected from Bomaa and its environs with value of 0.38±0.03 Bq/L.

Even though the geology of the land from which the water samples taken is similar, there were variations in the activity values of NORMS in water. This could be attributed to the difference in depths of boreholes and wells. The occurrence and distribution of radioactivity in water largely depends factors such as; the local geological characteristics of the source, and the soil or rock from which the water interact with (Shashikumar et al., 2011).

Figures 4.1, 4.2, and 4.3 show a comparison of the average activity concentrations of ^{238}U, ^{232}Th and ^{40}K in water from towns and villages in the Tano-North District of Ghana

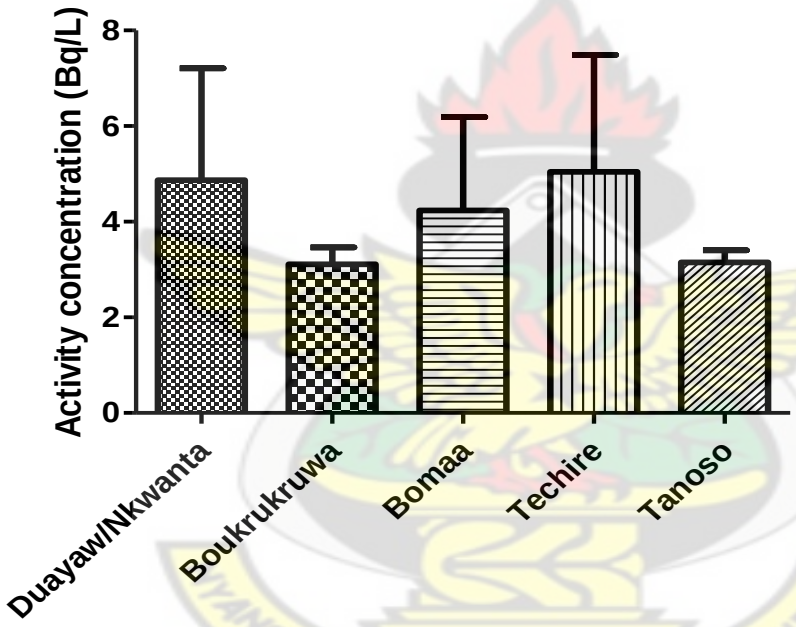

Figure 4.1: Average activity concentration of ^{40}K in water from different locations in the Tano-North District of Ghana

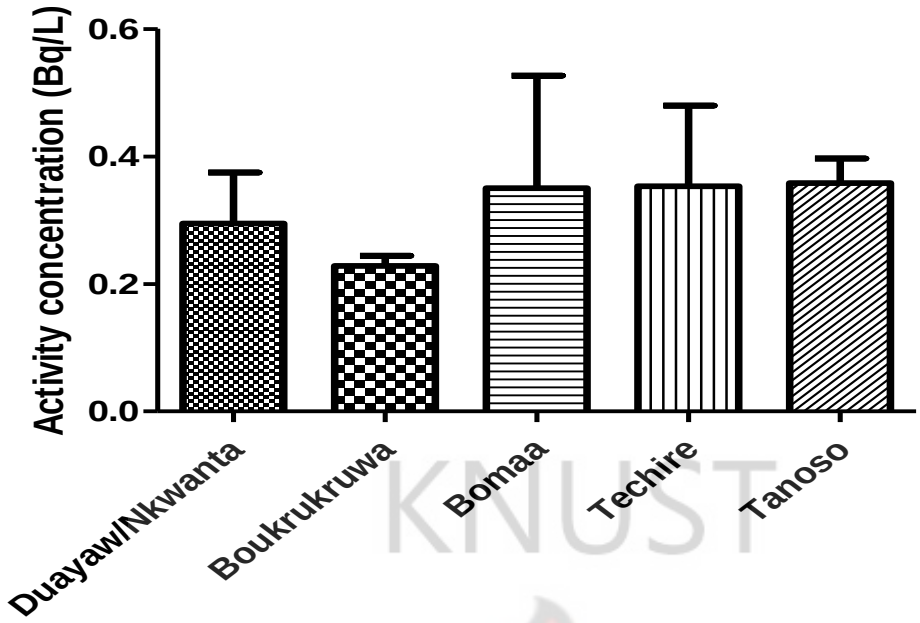

Figure 4.2: Average activity concentration of ^{238}U in water from different locations in the Tano-North District of Ghana

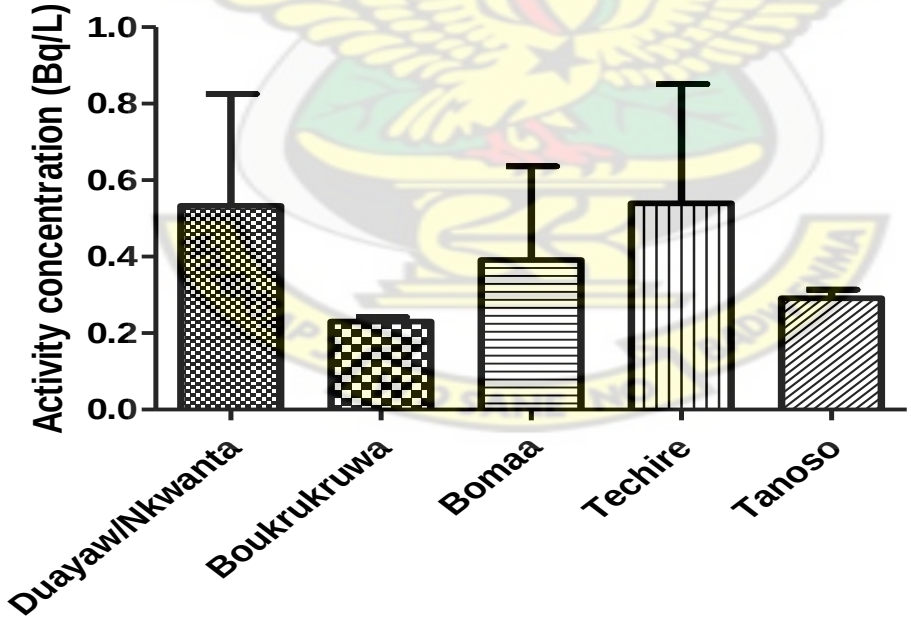

Figure 4.3: Average activity concentration of ^{232}Th in water from different locations in the Tano-North District of Ghana

4.1.2 The total annual committed effective dose due to the intake of ^{238}U, ^{232}Th and ^{40}K from water.

Radiological safety of drinking water is an important water quality parameter of concern. The regulation and guidelines values issued by most countries in the world are based on estimated average values of the WHO and the UNSCEAR.

Table 4.3 shows the estimated annual committed effective dose for water samples collected from Duayaw/Nkwanta. The annual effective dose varied in the range of 19.20 to 103.00 µSv/y with an average value of 40.43±2.17 µSv/y. The highest value for the annual committed effective dose was recorded from underground water (Adinkramu) with a value of 103.00±3.14 µSv/y. The lowest annual committed effective dose was also recorded from borehole water with a value of 19.20±1.67 µSv/y. Table 4.4 shows the estimated annual committed effective dose for water samples collected from Boukrukruwa. The annual committed effective dose varied in a range of 17.70 to 21.80 µSv/y with an average value of 20.08±1.89 µSv/y. The highest and the lowest annual committed effective dose were recorded from borehole water with values 21.80±1.89 µSv/y and 17.70±1.56 µSv/y.

Table 4.5 shows the estimated annual committed effective dose for water sampled from Bomaa. The annual committed effective dose varied in a range of 11.60 to 105.00 µSv/y with an average value of 33.58±1.91µSv/y. The maximum annual committed effective dose was measured from borehole water with a value of 105±4.52 µSv/y while the minimum value was measured from another borehole water with a value of 11.60±0.93 µSv/y.

The annual committed effective dose of water samples from Techire are shown in Table 4.6. The annual committed effective dose varied in a range of 19.80 to 109.00 µSv/y with

an average value of 53.45±3.77 µSv/y. The maximum annual committed effective dose was recorded from an underground water located close to an electricity transformer in Techire.

The annual committed effective dose of water samples from Tanoso are shown in Table 4.7. The annual committed effective dose varied in a range of 22.00 to 27.60 µSv/y with an average value of 24.90±2.61 µSv/y. The maximum committed effective dose was recorded from a borehole water with a value 27.60±2.98 µSv/y. However, the minimum committed effective dose was recorded from a treated water from the Tano-River with a value of 22.00±2.06 µSv/y.

Furthermore, the average annual committed effective dose for Duayaw/Nkwanta, Boukrukruwa, Bomaa, Techire and Tanoso were 40.43±2.17 µSv/y, 20.08±1.89 µSv/y, 33.58±1.91 µSv/y, 53.45±3.77 µSv/y and 24.90±2.61 µSv/y respectively. It can be deduced that, the inhabitants of Techire receive the highest radiation dose upon water ingestion, the inhabitants of Duayaw/Nkwanta come next while the people of Boukrukruwa receive the least effective dose due to NORMS in drinking water.

WHO recommends that the annual committed effective dose due to ingestion of radionuclides in water should not exceed 100 µSv/y (WHO, 2006). The value is acceptable by most WHO member states, the European Commission (EC, 2002).

The average annual committed effective dose in this study does not exceed the WHO guideline level of 100 µSv/y. However, water collected from a borehole water from Duayaw/Nkwanta (Adinkramu), borehole water from Bomaa and an underground water from Techire (Amangoase) were 103.00±3.1 µSv/y, 105.00±4.52 µSv/y and 109.00±6.18 µSv/y respectively, exceeding the recommended WHO guideline levels of 100 µS/y.

It must be stated that no harmful radiological health effects are expected from the consumption of drinking water if the committed effective dose are below 100 µSv/y. According to WHO (2006), if the activity concentration or effective dose levels are above the guideline levels, it does not indicate any immediate health risk, but rather, it should trigger further investigation into the determination of radionuclide responsible and their possible risk upon ingestion (WHO, 2006).

Finally, all the water samples recorded annual committed effective dose below the recommended value of 240.00 µSv/y from UNSCEAR, (2000a). Figure 4.4 represents a comparison of the average committed effective dose due to the ingestion of radionuclides in drinking water from towns and villages in the Tano-North District with the guideline and reference values for WHO and UNSCEAR respectively.

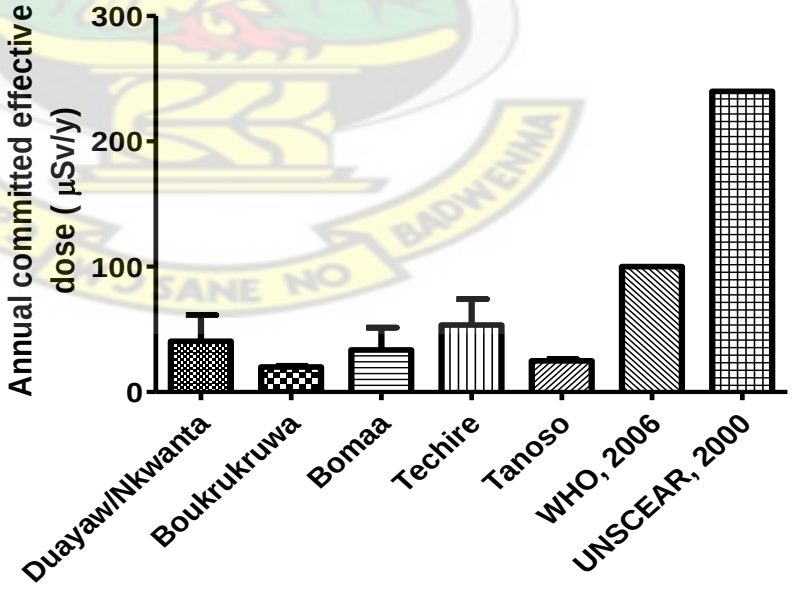

Fig. 4.4: Comparison of the average committed effective dose due to the ingestion of radionuclides in drinking water from the Tano-North District with the established averages used by WHO and UNSCEAR

4.1.3 Comparison of measured activity concentrations of ^{238}U, ^{232}Th and ^{40}K with data from literature.

The results of the activity concentrations of ^{238}U, ^{232}Th and ^{40}K radionuclides in this study were compared with the results of similar studies conducted in Ghana and other parts of the world. This is necessary in other to obtain an understanding on the relative distribution of these radionuclides in other parts of the world. Comparison of radionuclide concentrations across the world also helps in the prediction of the source of contamination from one locality or country to the other.

Table 4.9 contains the activity concentration values of ^{238}U, ^{232}Th and ^{40}K obtained from literature for water from different countries in the world including this present study.

Table 4.9: Comparison of the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in water from the study with data from Ghana and other countries in the world (Bq/L)

Country	^{238}U		^{232}Th		^{40}K		Type of water	Reference
	Average	Range	Average	Range	Average	Range		
Spain (Ebro River)	0.053	-	-	-	0.132	-	River	Pujol et al., 2000
Yemen	-	2.01-6.55	-	1.07-2.03	-	-	Spring	Ibrahim et al., 2011
Morocco	-	0.005-0.309	-	-	-	-	Well	Hakam et al., 2001
	-	0.003-0.016	-	-	-	-	Tap water	
Ghana (Bosumtwi)	0.008	-	0.001	-	0.897	-	Lake	Adu et al., 2011
Nigeria (Osun state)	-	-	-	-	98.07	-	Well	Tchokossa et al., 1999
	-	-	-	-	97.46	-	Borehole	
Ghana (Apewsika)	0.43	0.09-0.75	0.58	0.33-0.86	8.17	6.55-9.36	Well	Faanu et al., 2011
Ghana (Duayaw Nkwanta)	0.29	0.21-0.53	0.53	0.23-1.41	4.09	1.84-12.39	Underground	Present work
Ghana (Boukrukruwa)	0.23	0.19-0.25	0.23	0.21-0.26	3.11	2.59-4.15	Bore hole	Present work
Ghana (Bomaa)	0.38	0.15-0.99	0.41	0.08-1.36	4.24	1.86.12.00	Underground	Present work
Ghana (Techire)	0.35	0.18-0.73	0.55	0.23-1.47	5.04	2.47-12.38	Underground	Present work
Ghana (Tanoso)	0.36	0.28-0.46	0.26	0.19-0.31	3.15	2.77-3.87	Various	Present work

Comparatively, the average activity concentrations of ^{238}U in water from this study are higher than those published from other countries except that from Apewosika, Ghana (Faanu et al., 2011). Furthermore, activity concentrations of ^{232}Th in water samples were lower than the average for Apewosika (Ghana) and Yemen but higher than the average published by Adu et al. (2011) from Bosomtwi also in Ghana. The activity concentrations of ^{40}K in this present work were about 25 times lower compared with values recorded from well water and borehole water in Osun State, Nigeria (Tchokossa et al., 1999).

4.1.4 Gross alpha and gross beta radioactivity in the water samples

Gross alpha and gross beta analysis are generally performed to serve as a means of screening samples to assess the radiological quality of the water. The WHO recommended guideline values of gross alpha and gross beta in drinking water are 0.5 Bq/L and 1.0 Bq/L respectively. The recorded gross alpha and gross beta activity concentrations in water samples are shown in Table 4.4. The gross alpha activity concentration in water varied between 0.007 and 0.039 Bq/L. The highest gross alpha value was recorded from borehole water in Duayaw/Nkwanta with a value of 0.039 Bq/L while the lowest gross alpha concentration was recorded from the main underground water in Bomaa with a value of 0.007 Bq/L respectively. The gross beta activity concentration in water varied between 0.011 and 0.181 Bq/L with an average value of 0.091 Bq/L. The highest gross beta activity of 0.181 Bq/L was recorded from borehole water from Buokrukruwa, while the lowest gross beta value was recorded from underground water from Duayaw/Nkwanta (Adinkramu) with a value of 0.011 Bq/L. All the water samples measured gave gross alpha and gross beta values which were below the WHO guidelines of 0.5 Bq/L and 1.0 Bq/L respectively.

Table 4.10: Comparison of the recorded activity concentrations of gross alpha and gross beta in water with values from different countries

Country	Gross alpha (Bq/L)		Gross beta (Bq/L)		Reference
	Average	Range	Average	Range	
Spain (Ebro River)	0.093	0.070-0.150	0.213	0.130-0.300	Pujol et al., 2000
Spain (Bottled water)	-	0.010-1.520		0.010-0.380	Palomo et al.,2007
Turkey (Kastamonura)	0.009	-	0.271		Kam & Bozkurt, 2007
Turkey (Istanbul)	-	0.070-0.500		0.020-5.600	Gursel et al., 2000
	0.009		0.086		Degerlier & Karahan, 2010
Ghana (Tarkwa)	0.012	0.008-0.040	0.137	0.071-0.374	(Faanu et al., 2010)
Ghana (Tano-North)	0.017	0.011-0.039	0.091	0.011-0.181	Present work

Table 4.8 shows the activity concentration of gross alpha and gross beta recorded in the present study versus those published by literature. The activity concentrations of gross alpha and gross beta obtained in this present work is comparable to values published from different countries. The average gross alpha value of 0.017 Bq/L recorded in this study was slightly higher than average values from Turkey (Kastamonura), Ghana (Tarkwa), and Turkey (Istanbul) which are 0.009 Bq/L, 0.012 Bq/L, and 0.009 Bq/L respectively. However, the average gross alpha value of 0.093 Bq/L from Spain (Ebro River) is about five times higher compared with the average for this present study. On the other hand, the gross beta activity value of 0.091 Bq/L recorded in this study is 0.005 Bq/L higher than average gross beta value of 0.086 Bq/L from Spain (Istanbul). However, the average gross beta activity for this study is lower compared with 0.213 Bq/L, 0.271 Bq/L and 0.137 Bq/L from Spain (Ebro River), Turkey (Kastamonura), and Ghana (Tarkwa) respectively. These variations could be due to differences in the geological formation of the bedrock that interact with water and other factors including the activities of man in the given area.

Figure 4.5 also shows the diagrammatical representation of the comparison the activity concentration of the gross alpha and gross beta results in the water samples with the WHO recommended guideline values in drinking water.

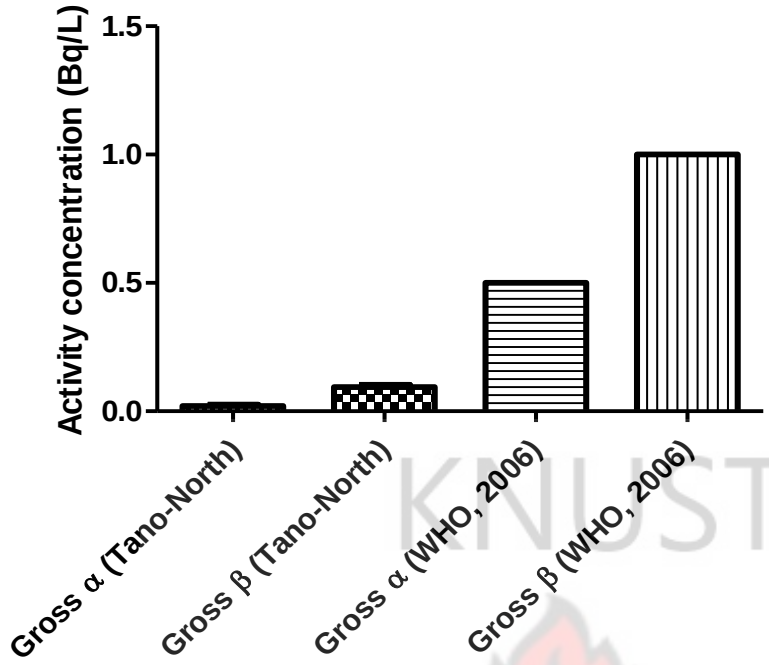

Figure 4.5: Comparison of the average gross alpha and gross beta activity concentrations from the Tano-North District to WHO guideline value

It can be observed from the Figure 4.5 that the average activity concentrations for gross alpha is about thirty times below WHO's recommended limit while the average gross beta activity is about twelve times below WHO's recommended limit. Therefore the ingestion of water from the Tano-North district does not pose any health problems due to gross alpha or beta emitters.

Table 4.11: Sample location with co-ordinates for soil and food samples from the Tano-North District of Ghana

Sample Location	Sample Identification			Location Co-ordinates	
	Soil	Cassava	Yam		
Bomaa	SOL 1	CAS 1	YAM 1	N07º06.110"	W002º10.326"
Subriso	SOL 2	CAS 2	YAM 2	N07º20.148"	W002º05.868"
Techire	SOL 3	CAS 3	YAM 3	N07º14.348"	W002º10.498"
Bredi No. 1	SOL 4	CAS 4	YAM 4	N07º11.313"	W002º05.194"
Koforidua	SOL 5	CAS 5	YAM 5	N07º12.432"	W002º07.814"
Afrisipa	SOL 6	CAS 6	YAM 6	N07º14.924"	W002º11.478"
Bredi No. 2	SOL 7	CAS 7	YAM 7	N07º12.471"	W002º05.266"
Benchem	SOL 8	CAS 8	YAM 8	N07º07.758"	W002º06.818"
Boukrukruwa	SOL 9	CAS 9	YAM 9	N07º07.763"	W002º04.661"
Duayaw/Nkwanta	SOL 10	CAS 10	YAM 10	N07º09.663"	W002º04.094"

Table 4.12: Activity concentration, absorbed dose rate, and annual effective dose due to ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in soil from different farms from the Tano-North District of Ghana (Bq/kg dry weight)

Sample ID	Activity concentration (Bq/kg)				Absorbed dose rate, $nGyh^{-1}$	Annual effective dose, mSv	Percentage contribution of radionuclide to absorbed dose rate (%)		
	^{238}U	^{232}Th	^{40}K	^{137}Cs			^{238}U	^{232}Th	^{40}K
Bomaa	33.77±2.35	46.42±3.79	164.76±6.09	2.53±0.12	50.51	0.06	30.89	55.51	13.60
Subriso	29.92±2.89	42.64±3.13	162.38±5.49	3.51±0.14	46.34	0.06	29.82	55.57	14.61
Techire	19.79±1.79	22.52±1.90	163.40±6.35	1.64±0.04	29.56	0.04	30.93	46.02	23.05
Bredi No. 1	21.38±1.86	33.89±2.69	132.49±4.29	3.64±0.14	35.87	0.04	27.53	47.07	15.40
Koforidua	34.47±2.72	48.17±3.80	159.29±5.53	3.92±0.15	51.66	0.06	30.82	56.32	12.86
Afrisipa	22.14±1.89	24.89±2.01	103.07±3.02	2.91±0.12	29.56	0.04	34.61	50.86	14.54
Bredi No. 2	18.59±1.23	18.89±1.11	87.07±2.13	1.91±0.10	23.63	0.03	36.85	48.28	15.37
Benchem	14.56±1.18	20.72±1.84	191.76±7.20	3.92±0.15	27.24	0.03	24.70	45.94	29.35
Boukrukruwa	17.33±1.99	23.22±2.01	190.48±7.11	3.39±0.12	29.97	0.04	26.71	46.79	26.50
Duayaw/Nkwanta	19.89±1.99	29.66±2.19	83.11±2.24	1.46±0.07	30.57	0.04	30.06	58.60	11.34
Min.	14.56±2.18	18.89±2.76	83.11±3.24	1.46±0.07	23.63	0.04	24.70	45.94	11.34
Max.	34.47±3.72	48.17±5.40	191.76±8.23	3.92±0.18	50.51	0.06	36.35	58.60	29.35
Average	23.19±1.99	31.10±2.45	143.78±4.23	2.88±0.12	35.49	0.04	30.24	52.10	17.66

Table 4.13: Activity concentration of radionuclide in cassava from different farms in the Tano-North District of Ghana (Bq/kg dry weight)

SAMPLE ID	Activity concentration(Bq/kg (Dry weight)				Committed effective dose, (μSv/y)
	^{238}U	^{232}Th	^{40}K	^{137}Cs	
Bomaa	1.40±0.10	2.43±0.11	38.21±3.76	0.55±0.03	23.50
Subriso	2.40±0.12	3.87±0.29	28.03±1.40	0.79±0.05	23.30
Techire	2.74±0.22	1.82±0.08	29.87±2.46	0.54±0.03	22.70
Bredi No. 1	0.38±0.02	4.85±0.35	19.89±1.11	0.48±0.03	32.60
Koforidua	6.73±0.42	10.32±0.64	27.76±2.42	1.02±0.06	63.70
Afrisipa	4.49±0.31	6.48±0.42	41.01±4.02	0.94±0.06	48.00
Bredi No. 2	1.75±0.06	0.84±0.04	17.65±0.89	0.88±0.05	12.80
Benchem	0.97±0.04	2.75±0.14	30.19±2.51	0.86±0.05	22.30
Boukrukruwa	0.77±0.03	1.84±0.09	39.08±3.85	0.57±0.03	21.10
Duayaw/Nkwanta	2.13±0.11	2.77±0.14	20.39±1.22	0.38±0.03	21.90
Min	0.38±0.56	1.82±0.29	17.65±1.89	0.38±0.03	12.80
Max	6.73±0.72	10.32±0.99	41.01±5.13	1.02±0.06	63.70
Average	2.67±0.14	3.99±0.23	29.21±2.36	0.70±0.04	29.19

Table 4.14: Activity concentration of radionuclide in yam from different farms in the Tano-North District of Ghana (Bq/kg dry weight)

SAMPLE ID	Activity concentration(Bq/kg Dry weight)				Committed effective dose µSv/y
	238U	232Th	40K	137Cs	
Bomaa	3.45±0.21	3.28±0.24	35.07±3.34	0.47±0.03	8.64
Subriso	2.43±0.15	3.35±0.25	29.58±2.43	0.34±0.02	25.10
Techire	1.72±0.09	1.74±0.04	24.59±1.43	0.47±0.03	5.03
Bredi No. 1	4.76±0.29	3.26±0.22	19.24±0.89	0.85±0.05	8.08
Koforidua	4.89±0.29	4.99±0.31	25.79±1.37	0.84±0.05	10.50
Afrisipa	4.54±0.28	5.03±0.41	17.79±0.66	0.77±0.05	9.67
Bredi No. 2	2.74±0.23	3.17±0.20	14.19±0.62	0.78±0.05	6.26
Benchem	0.74±0.03	0.93±0.08	24.19±1.42	0.75±0.04	3.52
Boukrukruwa	0.47±0.02	2.85±0.18	27.99±2.38	0.89±0.06	5.70
Duayaw/Nkwanta	2.02±0.14	3.01±0.19	20.34±0.95	0.97±0.07	6.54
Min	0.47±0.14	0.93±0.18	14.19±1.82	0.34±0.02	3.52
Max	4.89±0.49	5.03±0.61	35.07±4.93	0.89±0.06	10.50
Average	2.78±0.17	3.16±0.21	23.88±1.55	0.71±0.05	9.90

Table 4.15: Comparison of activity concentration of ^{238}U in soil to that of cassava and yam from different farms in the Tano-North District of Ghana

Farm	Activity concentration of ^{238}U, (Bq/kg)			Concentration factor (CF)	
	Soil	Cassava	Yam	Cassava	Yam
Bomaa	33.77	1.40	3.45	0.04	0.10
Subriso	29.92	2.40	2.43	0.08	0.08
Techire	19.79	2.74	1.72	0.14	0.09
Bredi No. 1	21.38	3.38	4.76	0.16	0.22
Koforidua	34.47	6.73	4.89	0.19	0.14
Afrisipa	22.14	4.49	4.54	0.20	0.20
Bredi No. 2	18.59	1.75	2.74	0.09	0.15
Benchem	14.56	0.97	0.74	0.07	0.05
Boukrukruwa	17.33	0.77	0.47	0.04	0.03
Duayaw/Nkwanta	19.89	2.13	2.02	0.11	0.10
Range	14.50-34.47	0.76-6.73	0.47-4.89	0.04-0.20	0.03-0.22
Average	23.19	2.67	2.78	0.11	0.12

Table 4.16: Comparison of activity concentration of ^{232}Th in soil to that of cassava and yam from different farms in the Tano-North District of Ghana

Farm	Activity concentration of ^{232}Th, (Bq/kg)			Concentration factor (CF)	
	Soil	Cassava	Yam	Cassava	Yam
Bomaa	46.42	2.43	3.28	0.05	0.07
Subriso	42.64	3.87	3.35	0.09	0.08
Techire	22.52	1.84	1.74	0.08	0.08
Bredi No. 1	33.89	4.85	3.26	0.14	0.10
Koforidua	48.17	10.32	4.99	0.21	0.10
Afrisipa	24.89	6.48	5.03	0.26	0.20
Bredi No. 2	18.89	0.84	3.17	0.04	0.17
Benchem	20.72	2.75	0.93	0.13	0.04
Boukrukruwa	23.22	1.83	2.85	0.08	0.13
Duayaw/Nkwanta	29.66	2.77	3.02	0.09	0.10
Range	18.89-46.42	1.84–10.32	0.93-5.03	0.04-0.26	0.04-0.20
Average	31.10	3.79	3.16	0.12	0.11

Table 4.17: Comparison of activity concentration of ^{40}K in soil to that of cassava and yam from different farms in the Tano-North District of Ghana

Farm	Activity concentration of ^{40}K, (Bq/kg)			Concentration factor (CF)	
	Soil	Cassava	Yam	Cassava	Yam
Bomaa	164.76	38.21	35.07	0.23	0.21
Subriso	162.38	28.03	29.58	0.17	0.18
Techire	163.40	29.87	24.59	0.18	0.15
Bredi No. 1	132.49	19.89	19.33	0.15	0.15
Koforidua	159.29	27.76	25.79	0.17	0.16
Afrisipa	103.07	41.01	17.79	0.40	0.17
Bredi No. 2	87.07	17.65	14.19	0.20	0.16
Benchem	191.76	30.19	24.19	0.16	0.13
Boukrukruwa	190.48	39.08	27.99	0.21	0.15
Duayaw/Nkwanta	83.02	20.39	20.34	0.25	0.24
Range	83.02 – 191.76	19.89-41.01	14.19-35.07	0.15-0.40	0.13-0.24
Average	143.78	29.21	23.88	0.21	0.17

4.1.5 Activity concentration of radionuclides in soil

The activity concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in Bq/kg on dry weight bases, calculated absorbed dose rate in nGy/h and the annual effective dose in µSv/y associated with soil samples are given in Table 4.12. From this table, the activity concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in soil ranges from 14.56 to 34.47 Bq/L, 18.88 to 48.17 Bq/k, 83.11 to 191.76 Bq/k and 0.183 to 1.46 Bq/k respectively. The concentration of ^{137}Cs notable is low compared with all the other radionuclides. This is because ^{137}Cs is not naturally found in the soil but could have been deposited presumably as a result of atmospheric transfer from a nuclear power plant accident or from the testing of nuclear weapons.

The result further reveals that the concentrations of ^{40}K in the soil samples were lower compared with the global average value of 400 Bq/kg. However, 80% of the soil sample determined for ^{238}U recorded lower concentrations compared with the global average of 30 Bq/kg while 70% of the soil samples measured for ^{232}Th was also

below global averages of 35 Bq/kg. However, soil samples from farms located in Bomaa and Koforidua recorded average activity concentration of 33.73 Bq/kg and 34.47 Bq/kg respectively for ^{238}U. These values from the two villages are higher in the range of 3.73 to 4.47 Bq/kg compared with the world average for ^{238}U. Furthermore, soil samples collected from farms located in Bomaa, Subriso, and Koforidua also recorded average activities of 46.42 Bq/kg, 42.64 Bq/kg and 48.17 Bq/kg for ^{232}Th respectively, which were also higher than the world average of 35.0 Bq/kg. Those soil samples with higher concentrations of ^{238}U and ^{232}Th greater than the global average could primarily be attributed to the presences of rock bearing high concentration of those radionuclides in the area.

Figure 4.6 below shows the graph comparing the average concentrations of natural radionuclides (^{238}U, ^{232}Th, ^{40}K) and ^{137}Cs in soil samples from ten different farms in the Tano-North District of Ghana.

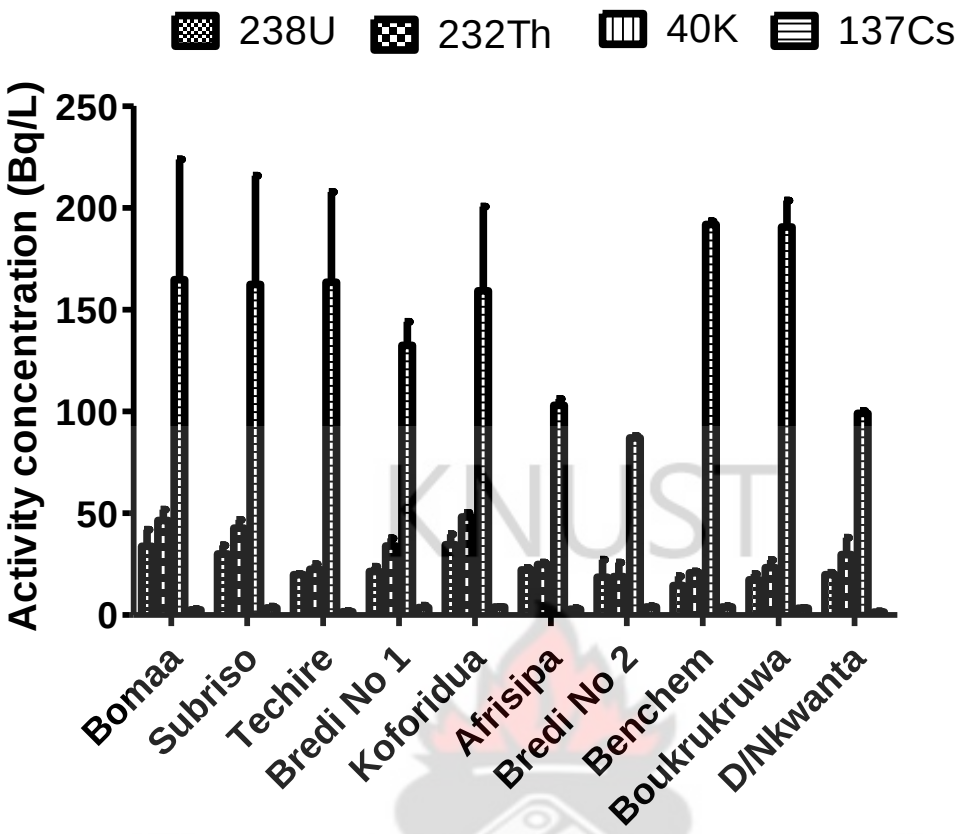

Fig. 4.6: A graph of activity concentration of natural radionuclide (^{238}U, ^{232}Th, ^{40}K) and ^{137}Cs in soil from selected farms in the Tano-North District of Ghana.

From Figure 4.12, it is very clear that the concentration of ^{40}K in the various farm lands is very high as compared with the other radionuclides. This condition of higher ^{40}K content in soil is an important requirement for plants growth. However, in terms of percentage contribution of radionuclides to absorbed dose rate, it can be seen from Table 4.12 that ^{40}K is the least contributor to absorbed dose rate to the farming population. Table 4.12 also shows the results of the absorbed dose rate and annual effective dose rate. The calculated annual effective dose ranges from 0.029 mSv/y to 0.063 mSv/y with an average value of 0.042 mSv/y. These results are insignificant and generally considered safe for the farming population of the study area. This means the study area contains radionuclides of insignificant levels to pose any significant health effect.

The activity concentration of ^{238}U, ^{232}Th and ^{40}K in soil from this study is comparable to activity concentration of reported studies from other countries. Table 4.13 shows the comparison of the activity concentration of ^{238}U, ^{232}Th and ^{40}K in soil from published report from other countries and similar work in Ghana.

Table 4.18: Comparison of the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in soil in different farms in the Tano-North and published data (UNSCEAR, 2000b)

Country	Concentration in soil, Bq/kg					
	^{238}U		^{232}Th		^{40}K	
	Mean	Range	Mean	Range	Mean	Range
Algeria	30.0	2.0 - 110.0	25.0	2.0 - 140.0	370.0	66.0 - 1150.0
Egypt	37.0	6.0 - 120.0	18.0	2.0 - 96.0	320.0	29.0 - 650.0
USA	35.0	4.0 - 140.0	35.0	4.0 - 130.0	370.0	100.0 - 700.0
India	29.0	7.0 - 81.0	64.0	14.0 - 160.0	400.0	38.0 -760.00
UK	-	2.0 - 330.0	-	1.0 - 180.0	-	0.0 - 3200
Ghana (Tarkwa)	15.0	8.0 - 26.0	27.0	9.0 - 67.0	157.0	60.0 - 249.0
Ghana (Present work)	23.2	14.6- 34.5	31.1	18.89 - 48.17	143.8	83.11 - 191.8
World Average	30.0	-	35.0	-	400.0	-

4.1.6 Activity concentration of radionuclide in Cassava and Yam

Generally, the presence of radionuclides in food crops is mainly due to the uptake of radionuclides from the soil by the root system of plants. Table 4.13 shows the activity concentration of radionuclides in cassava from different farms in the study area. The result shows that the concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs varied from 0.38 to 6.73 Bq/kg, 1.82 Bq/kg, 17.65 Bq/kg to 41.01 Bq/Kg and 0.38 to 1.02 Bq/kg respectively. The average values of the radionuclides are 2.674±0.14 Bq/kg, 3.799±0.23 Bq/kg, 29.207± 2.36 Bq/kg and 0.70±0.04 Bq/kg respectively. From Table 4.14, the activity concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in yam ranges between 0.47 to 4.89 Bq/kg, 0.93 to 5.03 Bq/kg, 14.19 to 35.07 Bq/kg and 0.34 to 0.89 Bq/Kg respectively. The average values for the radionuclides are 2.776±0.17 Bq/Kg, 3.162±0.21 Bq/kg, 23.879±1.55 Bq/kg and 0.714±0.05 Bq/kg in that order. It can be observed from the result that the concentration of all the radionuclides in cassava and yam is less than the amount in the corresponding farm lands. According to Ole (1989), for radionuclides to be absorbed by the root system of plants, they must be in the soluble form in the soil. Since all radionuclides in the soil cannot be in the soluble state, coupled with variations in the solubility of radionuclides, it is expected that the radionuclide concentration in the soil will be higher compared with that in food plants.

Additionally, there was a greater uptake of ^{40}K than the other radionuclides by cassava and yam as shown in Tables 4.13 and 4.14. This can be attributed to the fact that ^{40}K has a higher solubility than the other radionuclides. Additionally, it is an essential element which is required for plants growth and metabolism. Moreover, ^{40}K can be added to the soil through the application of fertilizer which is a common practice in the area.

The concentration of ^{137}Cs in cassava and yam is very low and this is due to the very low concentration of ^{137}Cs in soil which subsequently affect the absorption and utilization by plants. Generally, cassava accumulates slightly higher concentration of radionuclide compared with yam. This can be attributed to the longer time it takes for cassava to mature for harvesting compared with the maturity period for yam which is between 5 - 6 months.

Figures 4.7, 4.8, 4.9 and 4.10 show a graphical comparison of the activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs respectively to the corresponding farm lands.

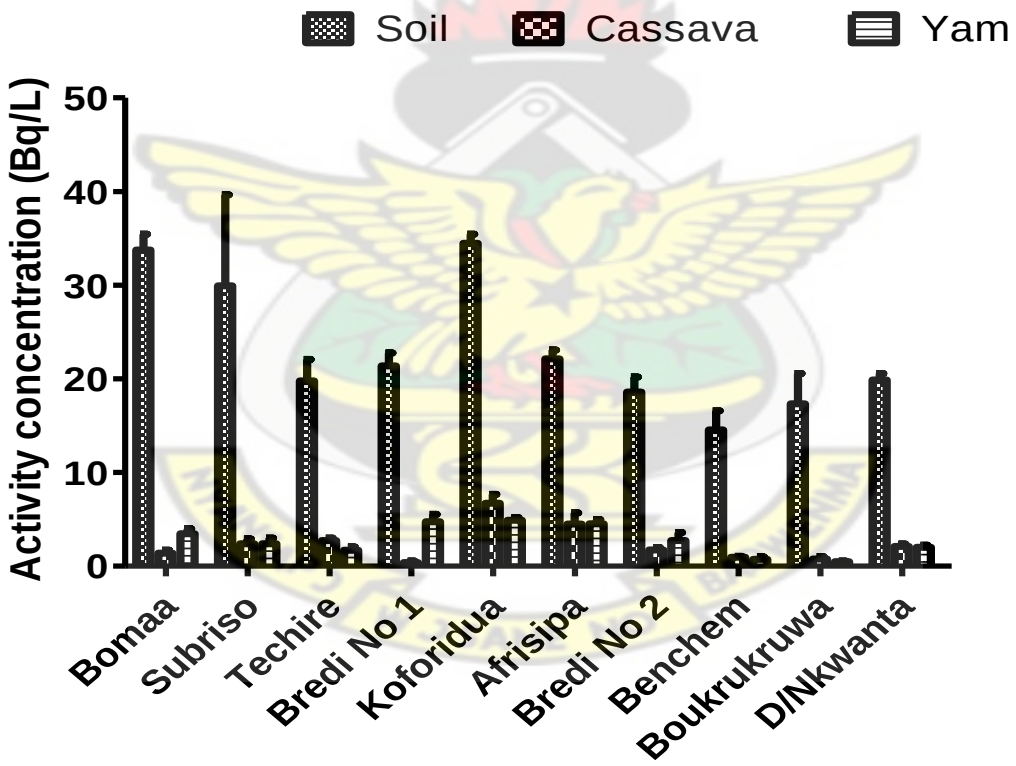

Figure 4.7: A graph of ^{238}U activity in soil, cassava, and yam in the selected farms within the study area

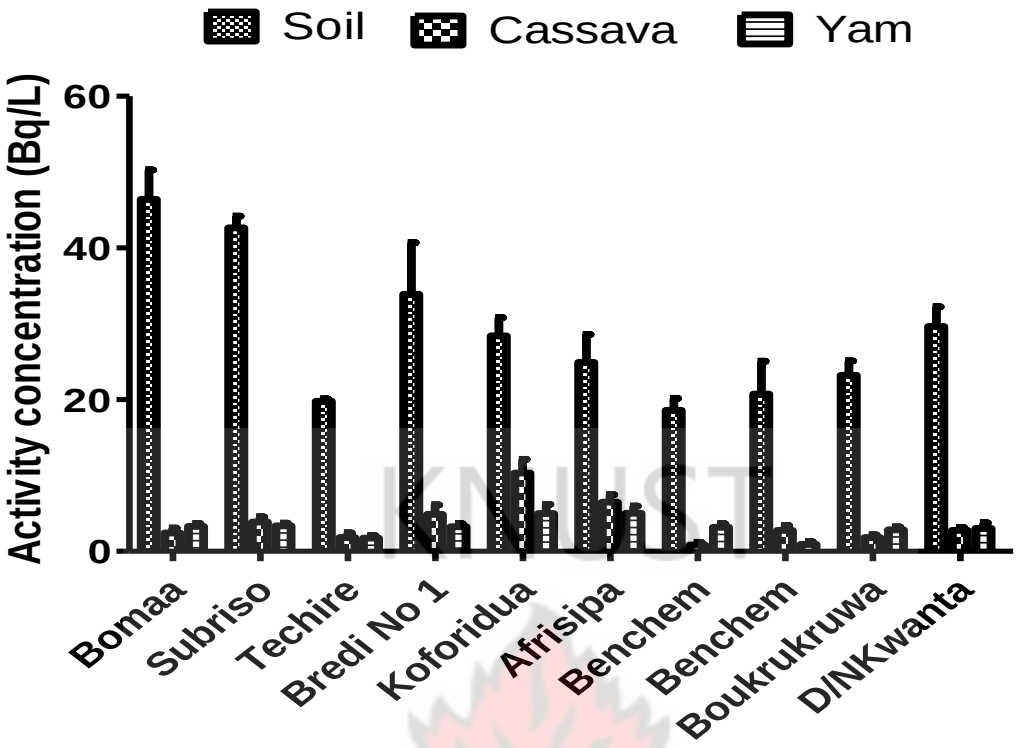

Figure 4.8: A graph of ^{232}Th activity in soil, cassava, and yam in selected farms within the study area.

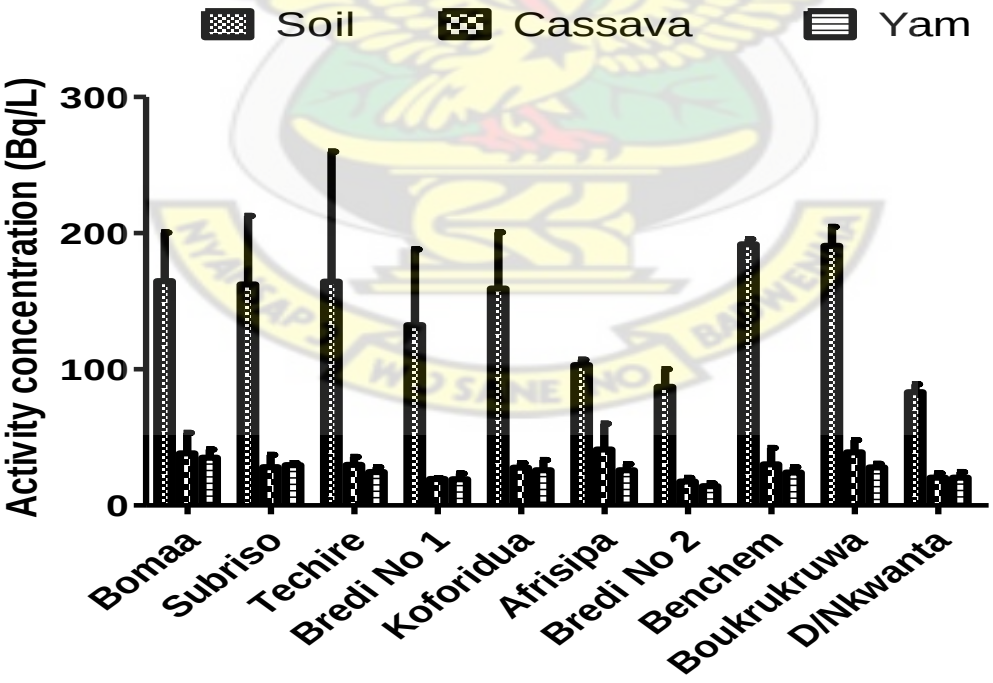

Figure 4.9: A graph of ^{40}K in soil, cassava and yam from the selected farms within the study area.

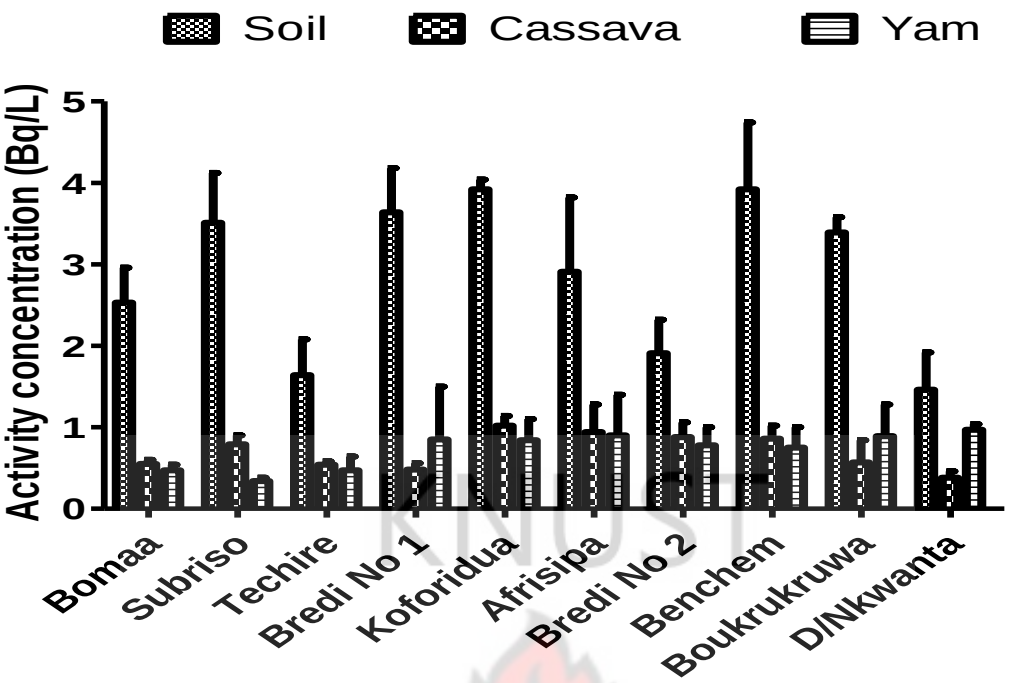

Figure 4.10: A graph of ^{137}Cs activity in soil, cassava and yam from the selected farms within the study area.

It is always necessary to estimate the contribution of individual food items to the total committed effective dose as a result of consuming food containing radionuclides. Cassava and yam form the major constituent of the staple food of the people of the Tano-North area which is fufu and ampesi respectively. Tables 4.13 and 4.14 represent the committed effective dose due to the consumption of cassava and yam respectively. The annual committed effective dose received by the population upon the consumption of cassava and yam in the study area ranges between 12.80 µSv/y to 63.70 µSv/y with and an average value of 29.19 µSv/y for cassava and 3.52 µSv/y to 10.50 µSv/y with an average value of 9.90 µSv/y for yam. Per the average values from Table 4.8 and 4.9, it can be deduced that the intake of cassava results in higher internal dose than the ingestion of yam. However the consumption of cassava and

yam from the study area does not pose any radiological health risk as the estimated committed effective dose was about half the WHO guideline level of 100 μSv/y.

4.1.7 Comparison of activity concentration of ^{238}U, ^{232}Th and ^{40}K in soil to cassava and yam in the study area.

The concentration of radionuclide in the food chain is governed by various factors including transport pathways, human activities, climatic conditions and physiochemical parameters which affect the transport and distribution of radionuclide to plants.

Tables 4.10, 4.11 and 4.12 show the concentration of ^{238}U, ^{232}Th and ^{40}K respectively in soil, cassava, and yam and their corresponding concentration factor for cassava and yam. The estimated concentration factor for ^{238}U in cassava ranges from 0.04 to 0.20 with an average value of 0.11, while that for yam ranges from 0.03 to 0.22 with an average value of 0.12 realized from Table 4.10 indicates that the concentration factor for ^{238}U in yam is slightly higher in yam compared to that of cassava.

The calculated concentration factor for ^{232}Th in cassava ranges from 0.04 to 0.26 with an average value of 0.12 while that of yam ranges from 0.04 to 0.20 with an average value of 0.11. On the contrary, the concentration factor for ^{232}Th in cassava is higher compared with that of yam. Finally, the estimated transfer factor for ^{40}K in cassava ranges from 0.15 to 0.40 with an average value of 0.2. However, that of yam ranges from 0.13 to 0.24 with an average value of 0.17. Again, cassava registered a higher average concentration factor for ^{40}K in cassava than in yam.

Generally, it can be observed that, ^{40}K recorded the highest concentration factor pointing to the fact that it is an essential plant nutrient. It can also be stated that generally, the factor of radionuclide absorption by plant from soil water is very low.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This research work was to determine radionuclide concentration in water, soil, cassava and yam grown in the Tano-North District of Ghana. Furthermore, the risk due to exposure to radiation by an adult member of the public through environmental media was estimated. Radionuclides consumed through food and water forms the major internal exposure pathways. However, soil contributes to direct gamma- ray external exposure and indirect exposure by releasing soluble radionuclide into water or releasing soluble radionuclide for plant absorption and their subsequent accumulation in plants storage organs. This research work is aimed at the determination of levels of ^{238}U, ^{232}Th, ^{40K} and ^{137}Cs in water, soil, cassava and yam from the Tano-North District of Ghana. The estimated average annual effective dose due to the injection of the NORMS in water by human population was 40.43 μSv/y, 20.08 μSv/y, 33.58μSv/y, 53.45μSv/y and 24.90 μSv/y for Duayaw Nkwanta, Buokrukruwa, Bomaa, Techire and Tanoso respectively. Clearly the estimated average effective dose for water collected from various locations in the Tano-North District were about half the 100μSv/y recommended by WHO. However, borehole water from Bomaa and another from Techire (Amangoase) recorded 105.00μSv/y and109μSv/y respectively. These values in the range of 5 to 9 μSv/y is above the WHO guideline for committed effective dose due to NORMS. On the contrary these values though slightly above WHO guideline levels are lower compared with the average level of 240 μSv/y due to the intake of NORMS in water established by the UNSCEAR. It can be stated with certainty that the ingestion of water by the inhabitants

of the Tano-North District will not result in any threat of stochastic effect in the near future.

The average activity concentration of ^{238}U, ^{232}Th, ^{40}K, and ^{137}Cs in soil samples from various farm lands in the district was estimated to be 23.19 Bq/kg, 31.10 Bq/kg, 143.78 Bq/kg and 2.88 Bq/kg respectively. The established absorbed dose rate for soil samples from selected farms ranges between 23.63 to 50.51 μSv/y, which is within the allowable range of 18 to 93 μSv/y established by UNSCEAR. Internal exposure due to the ingestion of radionuclides in cassava and yam has been established in the study. The average activity concentrations of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in cassava were determined to be 2.67 Bg/kg, 3.99 Bq/kg, 29.21 Bq/kg and 0.70 Bq/kg respectively. Furthermore, the mean activity concentration of ^{238}U, ^{232}Th, ^{40}K and ^{137}Cs in yam was also determined to be 2.78 Bq/kg, 3.16 Bq/kg, 23.58 Bq/kg and 0.71 Bq/kg respectively. These concentrations correspond to mean committed effective doses of 29.19 and 9.90 μSv/y for cassava and yam respectively. These values of 29.19 and 9.90 μSv/y due to the consumption of cassava and yam from the Tano-North District cannot be linked to any radiation hazard to the population.

5.2 RECOMMENDATIONS

5.2.1 Public

The result has been discussed with officials in charge of community water project in Duayaw- Nkwanta to educate the general public on issues relating to the presence and effects of radionuclides in water and other environmental media. Even though the levels of radionuclides as found in the study does not pose any health threat to the people in the area, the increasing mining and galamsey activities has the potential to alter these levels of radionuclides in the future. Hence, illegal mining and galamsey activities should be

checked by a concerted effort by all stakeholders to ensure that the environment is safe for agriculture.

5.2.1 Research Community

Moreover, in as much as the result for this work serve as a reference material for any future work on the presence of radionuclides in the environment of the study area and also complement data needed for formulating of guidelines, regulations and policies in the country by research scientist, there is the need to carry out similar studies on vegetables grown as the district is noted for its vegetables export.

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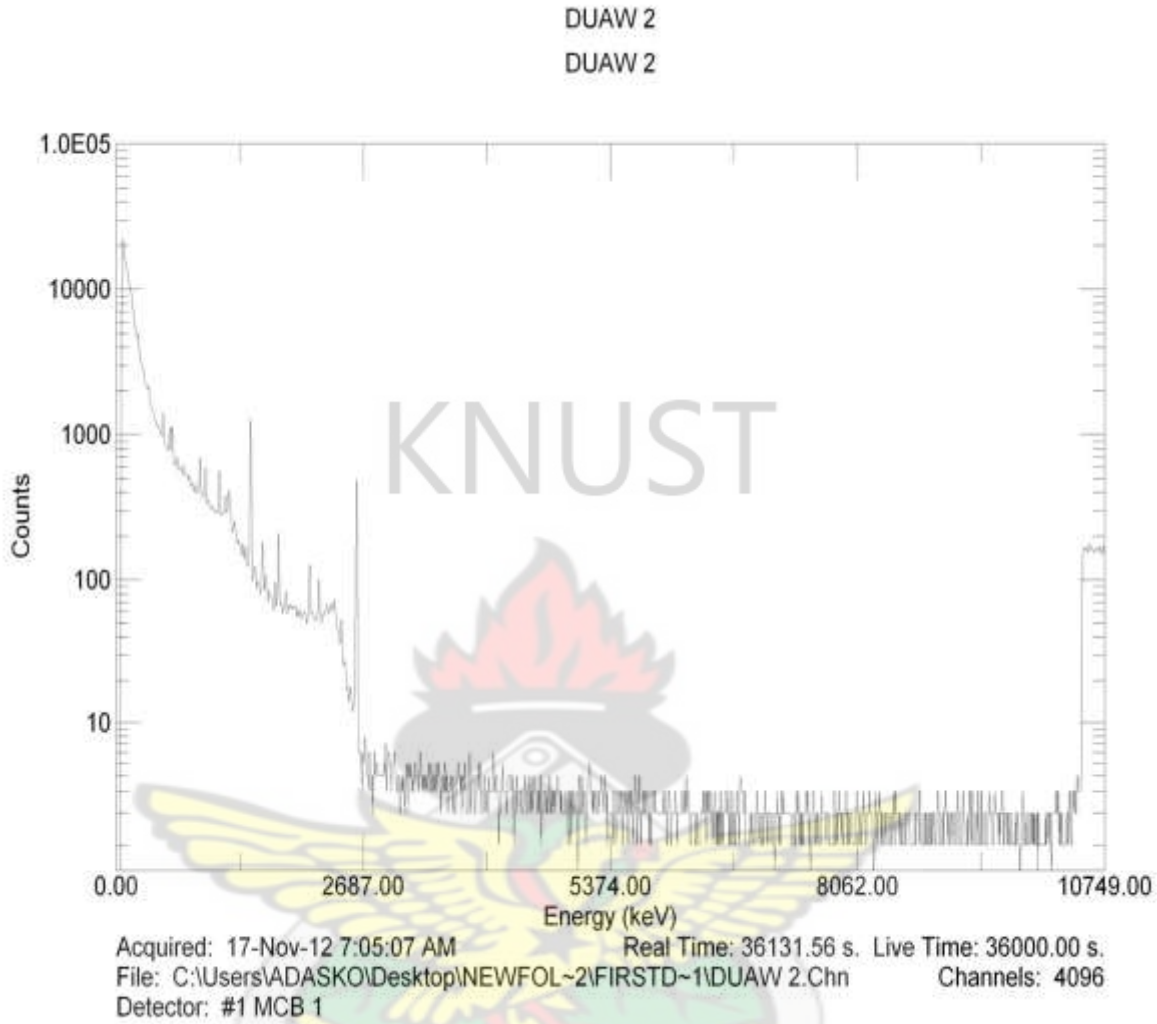
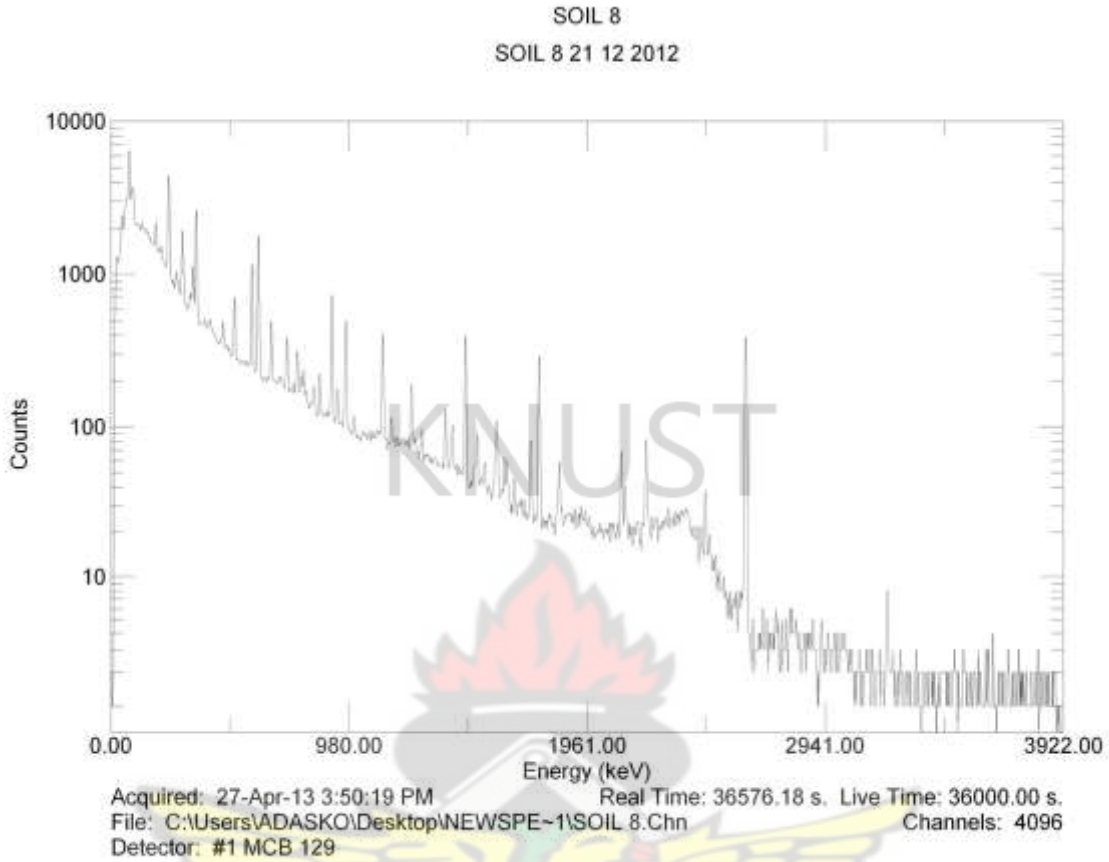
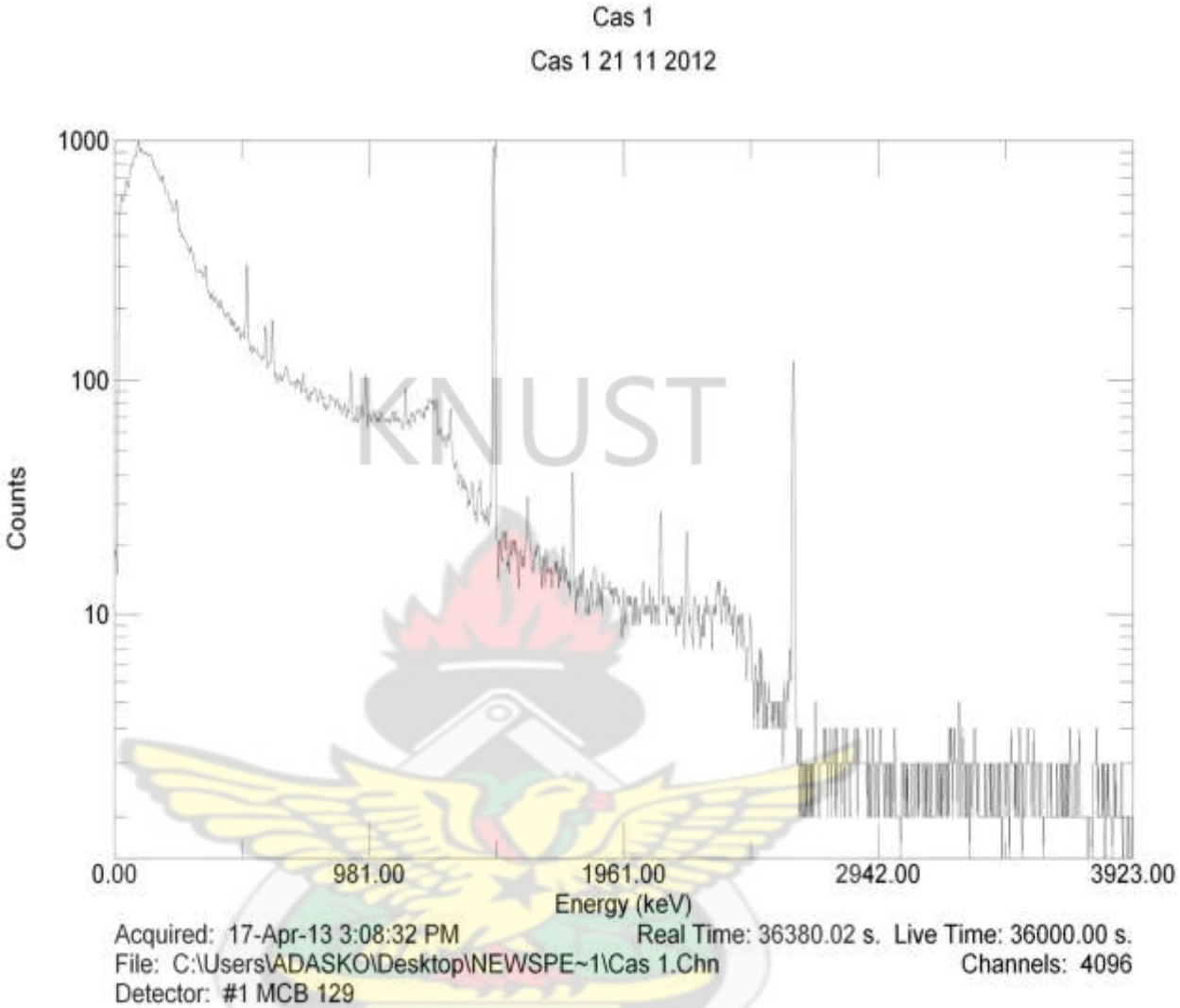
APPENDIX A: Example of Spectra Collected



APPENDIX B: Example of Spectra Collected



APPENDIX C: Example of Spectra Collected



APPENDIX D: Certificate of the Reference Standard

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016365
DKD-K-06501
06-02

Geometry Reference Source

Source no.	NW 146
Drawing	VZ-1520/2
Volume	approximately 1000 ml
Density	approximately 1.0 g/cm³
Construction	The radionuclidic mixture is homogeneously incorporated in the matrix of the source.

Nuclide	Gamma-ray energy [MeV]	Activity [Bq]	Emission rate [s^{-1}]
Americium-241	0.060	2.97E03	1.06E03
Cadmium-109	0.088	1.69E04	6.14E02
Cobalt-57	0.122	8.84E02	7.57E02
Cerium-139	0.166	9.66E02	7.71E02
Mercury-203	0.279	2.56E03	2.09E03
Tin-113	0.392	3.18E03	2.07E03
Strontium-85	0.514	3.89E03	3.83E03
Caesium-137	0.662	2.78E03	2.36E03
Yttrium-88	0.898	6.62E03	6.22E03
Cobalt-60	1.173	3.40E03	3.40E03
Cobalt-60	1.333	3.40E03	3.40E03
Yttrium-88	1.836	6.62E03	6.57E03

Reference date	1 February 2006 at 12.00 GMT
Leakage and contamination test	Wipe test according to ISO 9978.
Date of wipe test	10 February 2006
Measuring method	The activity was measured with a gamma spectrometer system consisting of a calibrated high purity germanium detector and a multi-channel analyser.
Traceability	Additional to the direct traceability to the PTB through the DKD this product complies with the requirements for traceability to NIST specified in the American National Standard "Traceability of Radioactive Sources to the NIST and Associated Instrument Quality Control (ANSI N42.22-1995)". As a requirement of the ANSI N42.22-1995 QSA Global GmbH participates in the NEI/NIST Measurements Assurance Program of the Nuclear Power Industry.
Uncertainty	The relative uncertainty of the activity is 3.0 %. The reported uncertainty, determined according to the DKD-3 report is based on the standard uncertainty multiplied by a coverage factor of k = 2, providing a level of confidence of 95 %. (Ref. NIST Technical Note 1297/"Guide to the Expression of Uncertainty in Measurement" ISO Guide, 1995)
Radioactive impurities	At the time of calibration the following radioactive impurities were detected: Cd-113m<40 Bq; Gd-153<1 Bq; Am-243<1 Bq
Quality assurance system	The quality assurance system of QSA Global GmbH was certified by Lloyd's Register Quality Assurance (LRQA) according to ISO 9001, issue 2000. Isotrak products meet the requirements of 10CFR50 Appendix B in the USA.

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