STUDY OF THE RADIOLOGICAL IMPACT OF SMALL-SCALE MINING ACTIVITIES AT DUNKWA-ON-OFFIN IN THE CENTRAL REGION, GHANA

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STUDY OF THE RADIOLOGICAL IMPACT OF SMALL-SCALE MINING ACTIVITIES AT DUNKWA-ON-OFFIN IN THE CENTRAL REGION, GHANA

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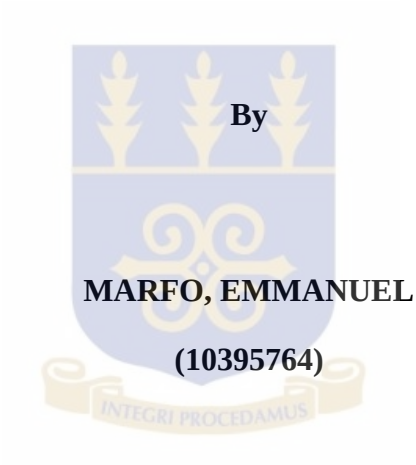

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DECLARATION

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

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DEDICATION

I dedicate this work to the Almighty God and Marfo`s family; especially to my mother and father, Rose Bosompim and James Berko Marfo respectively.

ACKNOWLEDGEMENT

First and foremost, I would like to express my profound gratitude to Almighty God for the safety and security during the whole period of this study.

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LIST OF ABBREVIATIONS

ADC – Analogue to digital converter

Bq/kg – Becquerel per kilogram

Bq/L – Becquerel per litre

BSS- Basic Safety Standards

DCF – dose conversion factor

EC- electrical conductivity

GPS – Geographical Positioning System

H_{ex} – external hazard index

H_{in} – Internal hazard index

HPGE – High purity germanium

IAEA- International Atomic Energy Agency

ICRP – International Commission for Radiological Protection

MCA – multi channel analyser

MDA – minimum detectable activity

NAI (Tl) – sodium iodide (Thallium)

nGy/h – nano Gray per hour

NORM- Naturally Occurring Radioactive Materials

Ra_{eq} – Radium equivalent activity

SCA – single channel analyser

SS – soil sample

SSDL – second standard dosimetry laboratory

TDS – Total dissolved solid

UNSCEAR- United Nations Scientific Committee on the effects of atomic radiation

WS – water sample

ABSTRACT

Small-scale (and artisanal) mining has been defined differently around the world. However, in Ghana, small-scale (gold) mining is defined as "mining (gold) by any method not involving substantial expenditure by an individual or group of persons not exceeding nine in number or by a co-operative society made up of ten or more persons". The activities in the mining sector have increased in recent times and as at 2008, a total of 212 mining companies were awarded mining leases and exploration rights. These mining operations consequently turn out large volumes of solid and liquid wastes in the form of waste dams; slime dams, tailings dams, which could contain elevated levels of NORM. Small-scale mining activities pollute rivers and streams nearby that serve as sources of drinking water for communities downstream. These activities are common in the study area. The general aim of the studies is to assess the radiological exposure to members of the general public living in Dunkwa community and its surrounding communities due to NORMS as a result of the small-scale mining activities. Direct gamma spectrometry and iMatic P-F Gas-less Automatic Gross Alpha/Beta counter was used to determine the concentration of naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K, and gross alpha and gross beta activity concentration respectively in the soil and water samples. The mean values of the gross-α and gross-β activity concentrations in the water sources were 0.002±0.001 Bq/L and 0.029±0.016 Bq/L respectively which are also below the WHO recommended guideline values for drinking water. The gross-α and gross-β activity concentrations of most soil samples in the study area are below the activity concentration of the control sample. The mean activity concentrations measured for ^{226}Ra (^{238}U), ^{232}Th and ^{40}K in the soil samples were 25.4±11.1, 29.4±15.6 and 225.9±93.8 Bq/kg respectively. For the water samples the mean activity

concentrations were 4.7±1.5, 2.7±0.4, 53.9±11.6 Bq/L for ^{226}Ra (^{238}U), ^{232}Th and ^{40}K respectively. The total annual effective dose to the public was estimated to be 0.95 mSv. The results obtained in the study area are within the recommended world average values with the exception of mean activity concentration ^{232}Th and committed annual effective dose of the water samples. The results thus indicate an insignificant exposure of the general public. The radiological hazard assessment as a result of ^{226}Ra (^{238}U), ^{232}Th and ^{40}K were also established. The radium equivalent activity (Ra_{eq}), External hazard index (H_{ex}) and Internal hazard index (H_{in}) varied in the range 32.8-173.4 Bq/kg, 0.1-0.4 and 0.1-0.6 with mean values of 87.0±38.9 Bq/kg, 0.2±0.1 and 0.3±0.1 respectively. The values of the Ra_{eq}, H_{ex} and H_{in} are below the acceptable values. Hence soils from the study area that could be used for building purposes might not pose any significant radiological hazard.

CHAPTER ONE

INTRODUCTION

This chapter provides the Background, Statement of problem, Objectives, Significance of research and Scope of research.

1.1 Background

According to Cember (1996) there are three sources of naturally occurring radioactive materials. The oldest source is cosmic radiation, which is believed to have originated about 13–14 billion years ago when the Universe was created. The second source is from primordial radioactive materials that were created when the earth was born about 4.5 billion years ago. The last source of naturally occurring radioactive (NORMS) materials is cosmogenic radioactivity. The production of cosmogenic radioactivity is a continuous process as cosmic radiation interacts with the atmosphere to produce radionuclides [Cember, 1996].

Radioactive materials such as radium, uranium, thorium and potassium have existed since the earth formation. The radioactive gas, radon is one type of radioactive material produced as U-238 and Th-232 decay. Human activities, such as the splitting of atoms in a nuclear reactor, can also produce radionuclides. Regardless of how they are produced, all radionuclides release radiation. Human beings are primarily exposed to natural radiation from the sun, cosmic rays, and naturally-occurring radioactive elements found in the earth's crust. Cosmic rays from space include energetic protons, electrons, gamma rays, and x-rays. Radon gas, which emanates from the ground, comes from the decay of naturally-occurring radium and is a major source of radiation exposure to the general public [EPA, 2007]. However, natural environmental radioactivity and the associated external exposure due to gamma radiation depend

primarily on the geological and geographical conditions, and appear at different levels in the soils of each region in the world [UNSCEAR, 2000].

The International Basic Safety Standards [IAEA, 1996] stipulates the fundamental requirements for the protection of health and the environment from ionizing radiation. These depend on the 1990 recommendations of the International Commission on Radiological Protection, (ICRP) [ICRP, 1991] on the regulation of Practices and Interventions. The International Basic Safety Standards is applied to both natural and artificial sources of radiation in the environment and the consequences on human and other species. The environment is defined within the framework of national laws and international legal instruments and may be considered to include human being, biota, abiota, physical surroundings and their interactions [IAEA, 2002].

Most materials may contain any of the primordial radionuclides or radioactive elements as they occur in nature. However, the concentration of NORM in most natural substances is so low that the risk is generally regarded as negligible. Higher concentrations may arise as a result of human activities. In most NORM, several or all of the radioactive isotopes of the three primordial decay series (^{235}U, ^{238}U and ^{232}Th) are present in small concentrations in the natural matrix. Irradiation of the human body from external sources is mainly by gamma radiation from radionuclides of the ^{235}U, ^{238}U and ^{232}Th decay series and ^{40}K [IAEA, 2005; UNSCEAR, 2000; Cember, 1996]. The worldwide average concentrations of radium, thorium and potassium in the earth's crust are about 40 $Bqkg^{-1}$, 40 $Bqkg^{-1}$ and 400 $Bqkg^{-1}$ respectively [Mustonen et al., 1997]. The annual global effective dose on average due to exposure to NORM has been estimated to be 2.4 mSv with a typical range between 1-10 mSv [UNSCEAR, 2000]. The main sources giving rise to this dose has been identified to

be cosmic rays, terrestrial gamma rays, inhalation mainly of radon gas and ingestion of materials with NORM [UNSCEAR, 2000]. Also, about 50 % of this global annual effective dose has been estimated to arise from radon exposure with a value of about 1.2 mSv [UNSCEAR, 2000]. A recent study on one mining company in Ghana have reported mean annual effective dose to be 0.69 mSv [Faanu, 2011].

Mining has been identified as one of the potential sources of exposure to NORM [UNSCEAR, 2000]. The methods of mining are of four basic types. Firstly, materials and minerals may be mined from open pits, surface mines, quarries, or other diggings open to the air and by far constitute the greatest number of mines in the world. Secondly, there are underground or deep mines, entered through shafts or tunnels. Thirdly, there is the recovery of minerals and fuels through boreholes. Finally, there is underwater mining or dredging [Encarta, 2005 cited in Joseph, 2008].

However, mining companies are not being regulated for NORM in most countries including Ghana since there are no guidelines for their regulation and monitoring by the Radiation Protection Board. With the recent increase in awareness and knowledge of the potential exposure situations of NORM, many countries are amending their legislations and putting in place measures to curtail the problems of NORM. Following the European Union Council Directive 96/29/EURATOM of 13th May 1996, where special provisions concerning exposure to natural sources of radiation were put in place, a network was to be created to enable member states to share expertise, to identify and also promote good practices [IAEA, 2004]. While the developed countries have identified NORM as potential problems and measures are being taken to address the issues, a little is being done in the developing countries. It

is also worth noting that, most of the NORM industries such as mining and mineral processing, oil and gas exploration and extraction and among others are located in developing countries such as Ghana [IAEA, 2005].

According to Hilson (2002) the earliest European attempts to extract gold on a large scale in Ghana concentrated in Tarkwa and Prestea in the late 19th century. The first official European gold mining company was the African Gold Coast Company which was registered on the 18/02/1878 [Hilson, 2002]. The activities in the mining sector have increased in recent times and as at 2008, a total of 212 mining companies were awarded mining leases and exploration rights [Aryee and Aboagye, 2008]. The mines also contribute to the development of the areas they operate with the provision of schools, hospitals, roads, among others [Goldfields, 2007]. These mining operations consequently turn out large volumes of solid and liquid wastes in the form of waste dams; slime dams, tailings dams, which could contain elevated levels of NORM. These materials could also be washed onto surface water bodies and farm lands. Drinking of water from these water bodies, grazing by animals on these farm lands and farming of crops on these lands could be a potential source of exposure to NORM.

Small-scale (and artisanal) mining has been defined differently around the world. However, as the United Nations (UN) and Intermediate Technology Development Group (ITDG) definitions quoted below show, “small-scale mining” is generally defined in terms of a given production ceiling, or the level of sophistication with which minerals are exploited. Small-scale mining is any single unit mining operation having an annual production of unprocessed material of 50,000 tonnes, or less as

measured at the entrance of the mine [UN, 1971]. Small-scale miners are "poor people; individuals or small groups who depend upon mining for a living; who use rudimentary tools and techniques (e.g. picks, chisels, sluices and pans) to exploit their mineral deposits" [ITDG, 2001]. In Ghana, small-scale (gold) mining is defined as" mining (gold) by any method not involving substantial expenditure by an individual or group of persons not exceeding nine in number or by a co-operative society made up of ten or more persons" [PNDC Law, 1989].

1.2 Statement of problem

Mining, no matter the scale of operation, has some degree of impact on the environment. The extent of damage depends largely on the mining and processing methods being adopted. Although legalized small-scale mining activities have some negative impacts on the environment, in most cases, they can be minimized and regulated through environmental permitting and regular monitoring by field officers [Aryee et al., 2003]. Small-scale mining activities pollute rivers and streams nearby that serve as a source of drinking water for communities downstream [Lombe, 2003 cited in Agyemang and Okoto, 2013]. These activities are common in the study area. Small-scale mining is often poverty driven and located in rural areas. Rivers such as Birim and Densu Rivers in the Eastern Region of Ghana are examples of rivers that serve as a source of drinking water for several communities but have been greatly affected by small-scale mining activities of which River Offin, Subin Ninta, Aponapon,Tuatian, Afiefi and Subin in the Dunkwa community are no exception [Amankwaah and Anim, 2003]. In addition, these form the basis why Dunkwa-on-Offin is chosen as the study area. In many cases, NORM industries such as mining and mineral companies have been in existence for long periods without any

knowledge of the radiological aspects of the mining activity [Faanu, 2011]. The aim and mandate has always been on how to regulate the use of the artificial radionuclides in the mines by the Radiation Protection Board (RPB) of Ghana. However, the potential hazard occurs when the operator of the practice or the regulatory authority is not aware of the problems associated with the enhanced levels of NORM (TENORMS) in raw materials, mine tailings just to mention a few. [Darko et al., 2010]. However, no protective or remedial actions are put in place so that doses to workers and the general public do not exceed the prescribed dose limits.

Dunkwa-on-Offin is the district capital of Upper Denkyira East Municipal and is noted for high incidence of small-scale mining activities. The small-scale mining activity currently undertaken is surface mining only and the process produce large volumes of tailings and waste that may contain NORM. The mine operates within the Dunkwa and its surrounding communities whose occupants depend on surface water, wells and boreholes as their source of water. Farming is a major occupation within the small-scale mine's operational concession. The soil, water bodies, air and crops serves as potential sinks for these radionuclides and sources for human beings which are the ultimate concern of this study. The above reasons form the fundamentals why Dunkwa-on-Offin community is the choice for study.

1.3 Objectives

The general aim of the studies is to assess the radiological exposure to members of the general public living in Dunkwa community and its surrounding communities due to NORMS as a result of the small-scale mining activities. The research focus is on the

determination of the levels and distribution of the naturally occurring radionuclides of the U/Th decay series and ^{40}K within the Dunkwa-on-Offin community.

The study seeks to achieve the following specific objectives;

1. To determine the activity concentrations of naturally occurring radionuclides in soil and water and the radiation doses from these activity concentrations and compare and contrast with international accepted reference value and similar work done in other countries.
2. To assess the hazards to the general public associated with these dose values.
3. Recommend suitable radiation protection programmes and measures for the small-scale mines if the need arises.

1.4 Significance of research

Ionizing Radiation such as the charged particles and the high energy photon is dangerous to the human health [Turner, 1995]. The main natural radioactive sources of ionizing radiation are the long lived ^{238}U, ^{232}Th and their decay series and ^{40}K. The radiological hazard can be the consequence of external or internal exposure. Radionuclides can enter the human body through inhalation and ingestion. The ingested radionuclides could be concentrated in certain parts of the body. For examples, ^{238}U accumulated in human lungs and kidney, ^{232}Th in lungs, liver and skeletal tissues and ^{40}K in muscles. Depositions of large quantities of these radionuclides in particular organs will affect the health condition of the human such as weakening the immune system, induce various types of diseases, and finally increase in mortality rate [Tawalbeh et al., 2011]. Legislators, regulators and operators have little knowledge of the radiological hazards and exposure level of these radionuclides in the Dunkwa community. Some studies conducted in this area indicate

that it is difficult to establish standards for the regulation of small-scale mining activities in the country. This research will go a long way to add to the data available to aid in formulating our guidelines and to educate and create awareness of the dangers associated with the enhanced levels of naturally occurring radionuclides resulting from small scale mining activities.

1.5 Scope of research

The study is focused at Dunkwa community where some selected sites or consignment of the small-scale mining operators is taken and put under study to assess the radiological exposure to the general public. In view of this, soil and water samples were collected at selected points for analysis by gamma spectrometry using a high purity germanium detector (HPGE) at Ghana Atomic Energy Commission (GAEC).

CHAPTER TWO

LITERATURE REVIEW

2.1 Background

Radioactivity of natural origin is mainly made up of the U/Th decay series and K-40. The average activity concentrations of ^{226}Ra, ^{232}Th, and ^{40}K in the Earth's crust are 35, 30, and 400 $Bqkg^{-1}$ respectively. Nevertheless, the enhanced levels of natural radionuclides causing annual doses of several mSv have been identified in some countries around the world, example Brazil, France, India, Nigeria, Iran [UNSCEAR, 2000, 1993, 1977]. Studies from Lawluvi (2009) into eleven (11) beaches in Greater Accra showed a mean annual effective dose of 0.19 mSv/year.

In Ghana, small scale mining has been a common anthropogenic activity over the past few decades. The regularization exercise by Ghana Mineral Commission has shown that two types of small-scale miners have emerged legal and illegal. Legal small-scale miners comprise those who have acquired mining licenses from the Minerals Commission of Ghana to cover their concessions or sites. Illegal small-scale miners are those mining ores without the requisite mining license and usually operate on concessions held by other companies. Illegal small-scale gold or diamond mining is popularly known in local parlance as "galamsey", which a corruption of the phrase is 'gather them (the gold or diamond) and sell'. By the end of 2001, 420 small-scale mining concessions had been licensed in the country. Of these, nine were diamond licenses and 411 were gold. Together these mines generated jobs for over 100,000 miners [Ghana Minerals Commission, 2002].

Mining and mineral activities impact negatively on the environment and the economy, the severity of the impact depends on methods used and whether the mine is small or large [Bell et al., 2001]. Studies of mining and health by type of mine process are divided into deep and open cast mines. Deep mines produce severe harms for employees in terms of their risks of high blood pressure, heat exhaustion, myocardial infarction and nervous system disorders. Studies of surface mining focus on coal, granite and rock mining and health risks related to dust breathing. In all levels of mining activities health risks occur with dust exposure [Stephens and Ahern, 2001].

2.2 Sources of radiation exposure

Ionizing radiation represents electromagnetic waves and particles that can ionize, that is to remove an electron from an atom or molecule of the medium through which they travel. Ionizing radiation may be emitted in the process of natural decay of some unstable nuclei or excitation of atoms and their nuclei in nuclear reactors, cyclotrons, x-ray machines and among others [UNSCEAR, 2000].

The basic quantity used to determine the exposure of living organism is the absorbed dose, for which the unit is the gray (Gy). However, the biological effects per unit absorbed dose vary with the type of radiation and the part of the body exposed. To take account of these variations, a weighted quantity called the effective dose is used, with unit of sievert (Sv). Also, to evaluate the effects of exposing a defined population group, the sum of all doses acquired by the members of the group, termed the collective dose (in units of man Sv), may be used. The value of collective dose divided by the number of individuals in the exposed population group is the per caput dose, in Sv [UNSCEAR, 2000].

2.3 Norms origin

All living organisms are continually exposed to ionizing radiation from the earth`s crust and space. There are two main sources of the exposure namely cosmic rays that originates from outer space and from the surface of the sun and terrestrial radionuclides that occur in the earth's crust, in air, in building materials, water, foods, and in the human body [UNSCEAR, 2000].

Report from UNSCEAR (2000) has shown that exposures to radiation from ^{40}K in food are fairly constant and uniform for all individuals everywhere on the earth's surface [UNSCEAR, 2000]. NORM concentrations in foods vary widely due to the differences in background levels, climate and the agricultural conditions that exist. The body content of ^{40}K is about 0.18 % for adults and 0.2 % for children. The natural abundance is about 1.17 x 10^{-4} % and specific activity concentration of 2.6 x 10^{8} Bq/kg and the corresponding annual effective doses from ^{40}K in the body are 165 and 185 μSv/yr for adults and children respectively. Again, the total annual effective dose from inhalation and ingestion of terrestrial radionuclides is 310 μSv of which 170 μSv is from ^{40}K and 140 μSv from the long-lived radionuclides in the uranium and thorium series [UNSCEAR, 2000].

Cosmic rays are more intense at higher altitudes, and concentrations of uranium and thorium in soils are higher in localized areas. On the average, the annual global effective dose due to exposure to NORM has been estimated to be 2.4 mSv with a typical range between 1-10 mSv [UNSCEAR, 2000]. The world-wide average annual effective doses for the various sources of radioactivity and radiation are shown in Table 2.1.

Human activities involving the use of radiation contributes radiation exposure in addition to the natural exposure. Examples are

i. Mining

ii. Use of ores containing naturally radioactive substances and

iii. The production of energy by burning coal that contains these substances [UNSCEAR, 2000].

Table 2.1: The worldwide average annual effective doses for the various sources of radiation [UNSCEAR, 2000].

Source	Worldwide average annual effective dose (mSv)	Typical range (mSv)
External dose		
Cosmic rays	0.4	0.3-10 [i]
Terrestrial rays	0.5	0.3-0.6 [ii]
Internal dose		
Inhalation (mainly radon)	1.2	0.2-10 [iii]
Ingestion	0.3	0.2-0.8 [iv]
TOTAL	**2.4**	**1.0-10**

[i] Range from sea level to high ground elevation.

[ii] Depending on radionuclide composition of soil and building materials.

[iii] Depending on indoor accumulation of radon gas.

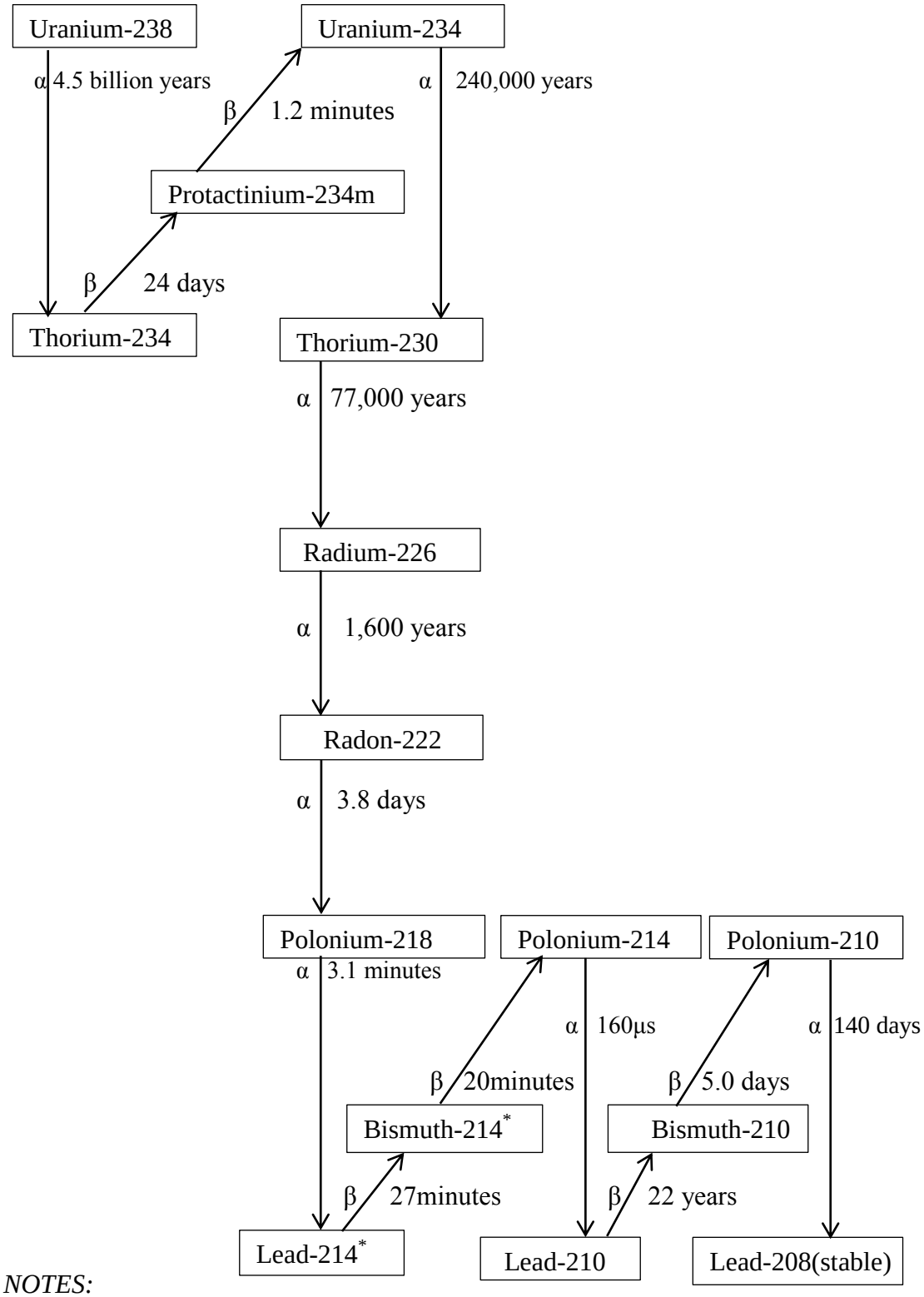
[iv] Depending on radionuclide composition of foods and drinking water.

2.3.1 Terrestrial radiation

Uranium, the most abundant primordial radionuclides have three isotopes namely ^{238}U (99.3 %), ^{235}U (0.7 %), and a trace quantity (about 5×10^{-3} %) is ^{234}U. The ^{238}U and ^{234}U belong to the same family called the uranium series, while the ^{235}U isotope of uranium is the first member of another series called the actinium series. Uranium is present everywhere in the world and is situated in the soil at average concentrations of about 3 ppm (parts per million) by weight, which corresponds to about 2 pCi or 74 mBq/g soil [Cember, 1996]. Thorium (Th), another naturally occurring radioactive

element, is about 4 times more abundant in the environment than uranium. The most abundant of the entire thorium isotope is ^{232}Th which is still the first member of another chain of successive radionuclides [Cember, 1996]. Figure 2.1, 2.2, 2.3 shows the decay series of uranium-238, uranium-235 and thorium-232 respectively.

The three decay chains is one of the main reasons for the general public health concerns about naturally occurring environmental radioactivity. The health hazard is not really associated with radon itself but from inhaled dust particles that had adsorbed radioactive radon daughters on their surfaces. Atmospheric concentrations of radioactivity from this source vary widely around the earth and the average atmospheric radon concentration is of the order of 2×10^{-6} Bq/mL (5×10^{-11}μCi/mL). Since the radioactive radon progeny are found on the surface of atmospheric particles and airborne particles are washed out of the atmosphere by rain, it is reasonable to expect increased background radiation during periods of rain [Cember, 1996]. Figure 2.1-2.3 shows the decay chain of U and Th decay series of radionuclides.



NOTES:
The symbols α and β indicate alpha and beta decay, and the times shown are half-lives. indicates the radionuclide is also a significant gamma emitter.*

Figure 2.1: The decay series of uranium-238 (4n+2)

Source: (Human Health Fact Sheet, 2005)

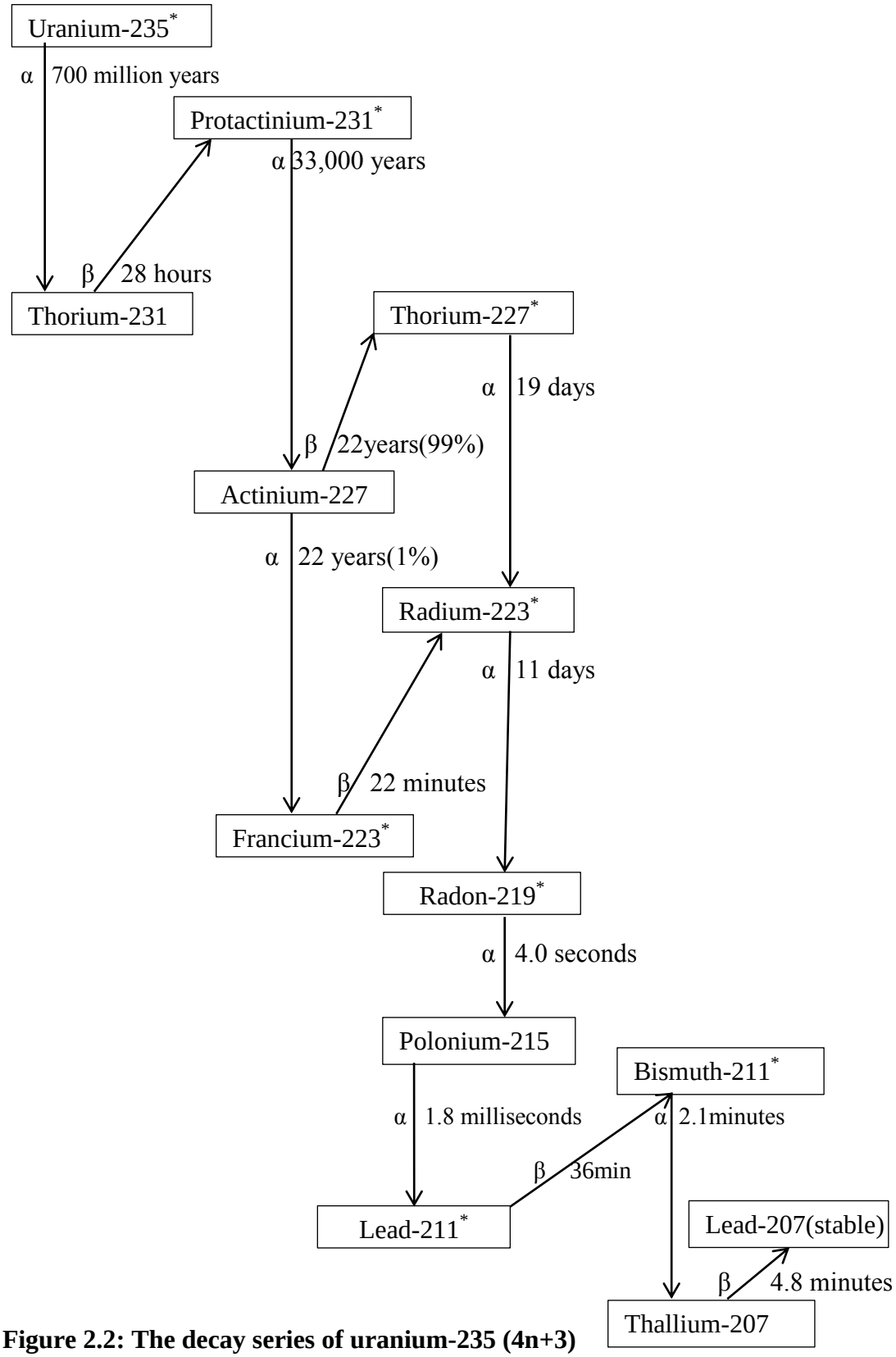
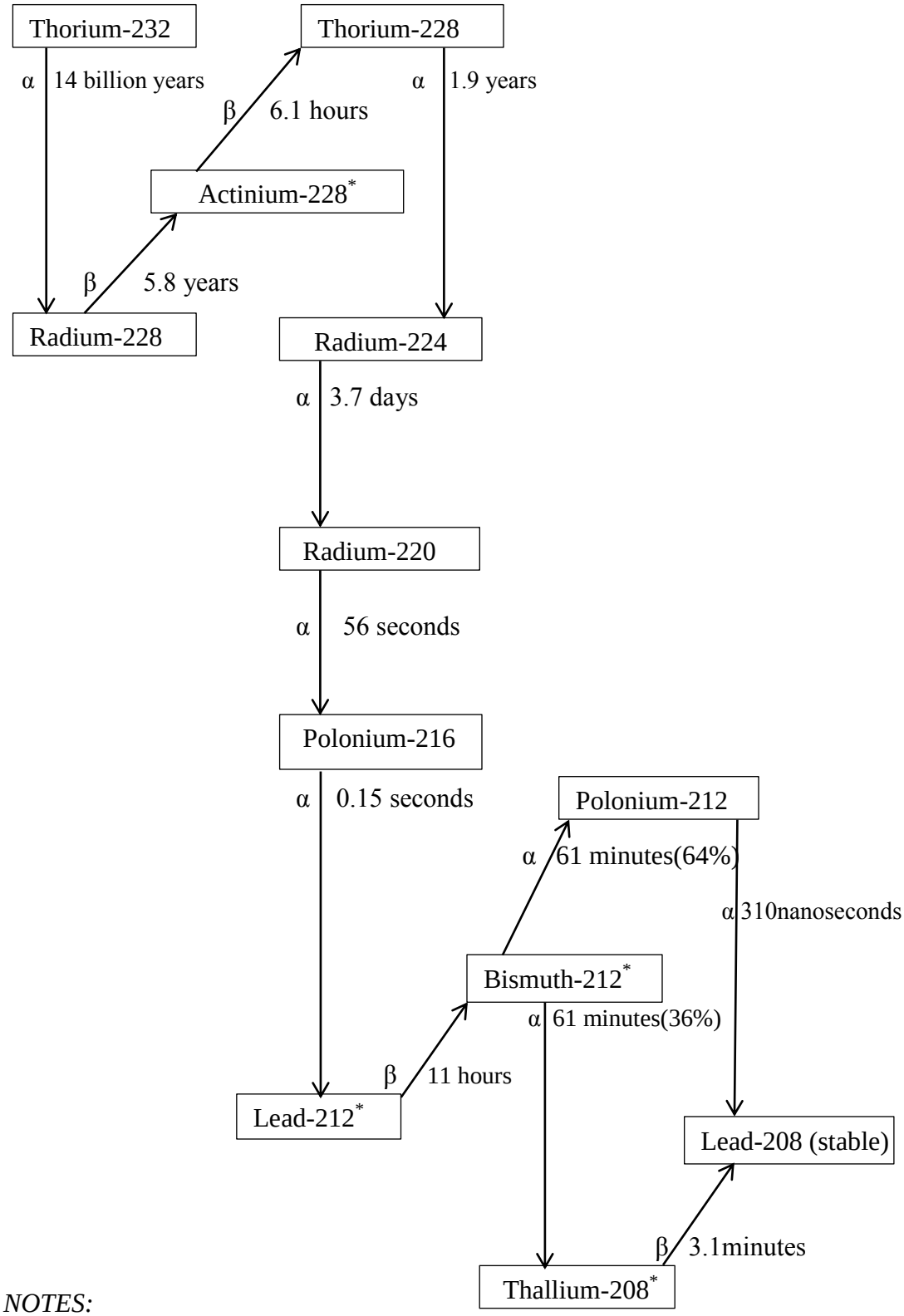


Figure 2.2: The decay series of uranium-235 (4n+3)

Source: (Human Health Fact Sheet, 2005)



NOTES:
The symbols α and β indicate alpha and beta decay, and the times shown are half-lives. indicates the radionuclide is also a significant gamma emitter.*
Figure 2.3: The decay series of thorium-232(4n+0)

Source: (Human Health Fact Sheet, 2005)

2.3.2 Cosmic rays and cosmogenic radionuclides

Cosmic rays refer to very high-energy particles from extra-terrestrial origin that hit the earth surface. One source is the sun, which emits mainly alpha particles and protons. The other radiation, consisting mainly of electrons and protons, originates beyond our solar system and is called galactic radiation. Interactions that occur between cosmic radiation and the earth`s atmosphere lead to the production of numerous cosmogenic radionuclides that bombard the earth's surface. Cosmic radiation intensity increases with altitude due to the decreased shielding effect of the atmosphere [Cember, 1996].

In addition, the production of cosmogenic radionuclides is a continuous phenomenon and a steady state has been established whereby the radionuclides are produced at the same rate as they decay. For instance tritium (^{3}H), the worldwide steady state inventory is estimated to be 34×10^{6} Ci (1.26×10^{18} Bq) and the estimated global inventory for radiocarbon (^{14}C) is 31×10^{7} Ci (1.15×10^{19} Bq). The long half-life of ^{14}C (5730 years) makes it an excellent tool for "radiocarbon" dating of organic artifacts from the historical past.

2.3.3 Artificial environmental exposures

Radioactive materials released to the environment and exposures of the general public have occurred in several activities and practices involving radiation sources. Nuclear weapons testing in the atmosphere have become the major man-made contributor to the exposure of the world's population. Reports from UNSCEAR have shown that this practice occurred from 1945 to 1980 and has test resulted in unrestrained release to the environment of large quantities of radioactive materials [UNSCEAR, 2000].

Nevertheless, environmental burden of ^{14}C before the arrival of nuclear bombs was about 1.5×10^{11} MBq (4 MCi) in the atmosphere, 4.8×10^{11} MBq (13 MCi) in plants, and 9×10^{12} MBq (243 MCi) in the oceans. Testing of nuclear weapons has resulted in an increase in the atmospheric level of radiocarbon. It is estimated that about 1.1×10^{11} MBq (3 MCi) ^{14}C were introduced into the air by all weapons tests conducted up to 1963, when atmospheric testing was stopped [Cember, 1996].

When accidents occur, environmental contamination and exposures might become significant. Chernobyl nuclear power plant accident was a notable example. There are several industries that utilize large volumes of raw materials containing natural radionuclides. Discharges from these industrial plants to air, water, food and the use of by-products and waste materials may contribute to elevated exposure of the general public [UNSCEAR, 2000].

2.4 Health Effects of Radiation Exposure

According to Turner (2007), it is generally assumed that biological effects on the cell result from both direct and indirect action of radiation. Direct effects are results of the initial action of the radiation itself whiles the indirect effects are caused by the later chemical action of free radicals and other radiation products. A typical example of a direct effect is a strand break in deoxyribonucleic acid (DNA) caused by an ionization in the molecule itself and for an indirect effect is a strand break that results when an OH radical attacks a DNA sugar at a later time (between $\sim 10^{-12}$ s and $\sim 10^{-9}$ s) [Turner, 2007].

From UNSCEAR (2000) radiation exposures can destroy living cells, causing death in some of them and modifying others. Most organs and tissues of the body are not affected by the loss of even considerable numbers of cells. However, if the number lost is large enough, there will be observable harm to organs and may lead to death. This type of harm occurs in individuals who are exposed to radiation in excess of a threshold level. Other radiation damage may also occur in cells that are not killed but modified, this damage is usually repaired. If the repair is not perfect, the resulting modification will be transmitted to further cells and may eventually lead to cancer. If the cells modified are those transmitting hereditary information to the descendants of the exposed individual, hereditary disorders may arise [UNSCEAR, 2000].

In addition radiation exposure has been associated with most forms of leukaemia and with cancers of many organs, such as lung, breast and thyroid, but not with some other organs such as prostate. However, radiation-induced cancer may manifest itself decades after the exposure and does not differ from cancers that arise spontaneously or are attributable to other factors. The major long-term evaluation of populations exposed to radiation is the study of the approximately 86,500 survivors of the atomic bombings of Hiroshima and Nagasaki. It has revealed an excess of a few hundred cancer deaths in the studied population [UNSCEAR, 2000].

2.5 Hypothesis of Radon

Radon is the largest contributor to natural source of human exposure to ionizing radiation in most countries including Ghana. In the general population most exposures occurs indoors, especially in small buildings such as houses [UNSCEAR, 2000]. However, radon is an inert gas with three naturally occurring isotopes of the

radioactive element namely, Radium (^{219}Rn) from the ^{235}U decay series; Thoron (^{220}Rn) from the ^{232}Th decay series; and Radon (^{222}Rn) from the ^{238}U decay series [UNSCEAR, 1993]. The noble gas ^{222}Rn produced in the uranium series can become airborne before decaying. Soil and rocks under houses and homes are ordinarily the main contributors to indoor radon, which is typically four or five times more concentrated than radon outdoors ^{222}Rn, which is a member of the uranium series [UNSCEAR, 1993].

However, some isotopes of radon are of lesser radiological importance. The parent nuclide, ^{232}Th, is somewhat more abundant than ^{238}U, but has a longer half-life. As a result, the average rate of production of ^{220}Rn in the earth is about the same as that of ^{222}Rn. However, the shorter half-life of ^{220}Rn, 56s, as compared with 3.82 days for ^{222}Rn, gives it a much greater chance to decay before becoming airborne. The contributions of the daughters of ^{220}Rn to lung dose are usually negligible compared with ^{222}Rn. Finally, the third (actinium) series produces ^{219}Rn which has a half-life of only 4 s making its contribution to airborne radon insignificant [Turner, 2007].

2.5.1 Measurement of Radon levels

Radon levels in the home or outdoors are expressed as the concentration of radon in units of picocuries per liter of air (pCi/liter) or Becquerel per cubic meter (Bq/m^3), and radon daughters are expressed in working levels (WL). Working level (WL) is a measure of the atmospheric concentration of radon and its progeny. A working level month (WLM) is defined as 170 hrs (2l.25 working days/month x 8 hrs/day) in a work place at one WL [Cember, 1996]. The U.S. Environmental Protection Agency

radioactivity limits for drinking water quality indicating the concentration of U, Ra, Rn and other radionuclides are shown on Table 2.2.

In addition, the WL unit was quenched for use in radon occupational exposure assessment since often there was incomplete information on the degree of equilibrium with daughter progeny. The dose delivered in one litre of air resulting in the emission of 1.3×10^5 MeV of potential alpha energy is working levels (WL) [Cember, 1996].

Table 2.2. U.S. Environmental Protection Agency Radioactivity Limits for Drinking Water [Redrawn from Cember, 1996]

RADIONUCLIDE	CONCENTRATION LIMIT
Gross alpha, excluding Rn and U	15 pCi/L
Beta–gamma emitters	4 mrems/yr
Combined $^{226}Ra + ^{228}Ra$	5 pCi/L
Tritium	20,000 dpm/L
^{90}Sr	8 pCi/L
Uranium, natural	30 µg/L

2.6 Radiological impact of Radon

When an individual spends a lot of time in an atmosphere contaminated with radon and its decay products, the body part that receives the significant dose of ionizing radiation is the bronchial epithelium whiles extra thoracic airways and the skin may also receive appreciable doses. In addition, organs such as the kidney and the bone marrow may receive low doses [Kendall & Smith, 2002]. However, if an individual drinks water in which radon is dissolved, the stomach will also be exposed.

Radon (^{222}Rn) decays into a series of short-lived progenies, two of which are ^{218}Po and ^{214}Po, are alpha emitters. When an alpha particle is emitted in the lung as a result of ingestion or inhalation, it deposits all of its energy locally within a small thickness

of adjacent tissue. To proceed, an alpha particle from ^{214}Po, for instance, imparts its 7.69 MeV of energy within about 70 μm. A 1MeV beta particle from ^{214}Bi, on the other hand, deposits its energy over a much larger distance of about 4000 μm. The dose to the cells of the lung from the beta (and gamma) radiation from radon daughters is very small compared with that from the alpha particles. The "radon problem," technically, is that of alpha-particle irradiation of sensitive lung tissue by the short-lived daughters of radon and the associated risk of lung cancer [Turner, 2007].

2.7 Mining as a potential source of Enhanced NORMS

NORM includes radionuclides associated with the ^{238}U / ^{232}Th decay chains as well as ^{40}K. However, these radionuclides are long lived and have some daughter radionuclides that are also long lived, such as ^{226}Ra. The distribution of radionuclides in the geosphere depends on the distribution of the geological media from which they are originated [IAEA, 2003].

Rivers and estuaries are the recipients of discharges and effluents from industry and geological materials eroded by natural processes. Owing to their geochemical behaviour, many metals, including heavy metals and radionuclides, accumulate in river sediments, typically in the fine grained [IAEA, 2003].

Reports from OECD/NEA have shown that majority of all past and present world uranium mining has taken place using conventional (underground and open pit) mining methods. The use of in situ teaching (ISL), phosphate or metal ore by-product and mine water recovery combined has averaged since 1994 less than 21% of all

production, whereas the once predominant underground mining method has been decreasing relative to open pit mining over the same period [OECD, 2000].

According to Darko et al., (2010) studies on two of the mining companies in Ghana to assess the levels of general public exposure to radiation have reported an average annual effective dose of 0.3±0.06 mSv. Faanu et al., (2011) also investigated into one of the gold mining companies in Ghana. The results showed the mean values of the gross α and gross β to be 0.012 and 0.137 Bq/L respectively. These values are therefore below World Health Organization (WHO) recommended guidelines values for drinking water. However, similar studies are needed to be carried out in all the potential NORM industries and mines in Ghana so that effective guidelines could be formulated for the purpose of radiation protection of the public and the workers [Darko et al., 2010].

In addition to the assessment of the radiological hazard of NORMs in a mine, Radium equivalent concentration (Ra_{eq}), the external and internal hazard indices need to be calculated. Ra_{eq} is a widely used hazard index. It is based on the estimation that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K produce the same gamma-ray dose rate [Xinwei et al., 2006]. The values of the external and internal hazard indices must be less than 1.0 for the radiation hazard to be considered negligible that is the radiation exposure due to the radioactivity from the construction material can also be limited to 1.5 mSv/yr [Beretka and Mathew, 1985]. Also, radon and its short-lived products are hazardous to the respiratory organs and as a result, the internal exposure to radon and its daughter products is quantified using the internal hazard index.

2.8 Mining in Ghana

Mining, simply means, the process of extracting essential minerals and materials from the earth's crust. The process involves excavations in underground mines and surface excavations in open-pit mines [Encarta, 2009].

West Africa has for centuries been one of the world's most important gold mining regions. Ghana is today the most significant gold producing country in this area. Prospective gold regions are situated in the western part of the Ghana. Numerous hard rock deposits can be found and significant quantities have also been re-deposited in local water-bodies thus alluvial gold. These gold deposits promoted the development of many successful ancient West African civilizations, and attracted both Arabic and European merchants. The country of Ghana has taken its name from the Ancient Kingdom of Ghana, which was located about 800 km north of present Accra the capital town now (Hilson 2002a, cited in Asklund and Eldvall, 2005).

The legal framework for registration of small-scale gold and diamond mines, mineral production and sales in the sector was established in Ghana in 1989. The Small-scale mining law, PNDCL 218 [Anon, 1989a] led to the establishment of the Small-scale Mining Project within the Ghana Minerals Commission. The Small-scale Mining Project now called Small-scale Mining Department has the responsibility of providing technical assistance to prospective and registered small-scale miners in Ghana and promoting their activities. The Mercury Law, PNDCL 217 [Anon, 1989b] legalized the purchasing of mercury for gold recovery purposes from authorized dealers and the Precious Minerals Marketing Corporation (PMMC) Law by PNDCL 219 [Anon, 1989c].

Studies from Stephens and Ahern (2001) revealed that, mining remains one of the most perilous occupations in the world, both in terms of short-term injuries and fatalities, but also due to long term impacts such as cancers and respiratory conditions such as silicosis, asbestosis and pneumoconiosis. In Ghana, gold mining communities in particular have experienced contaminations of surface and ground water bodies [Davis et al., 1994].

2.8.1 Small-Scale Gold Processing methods

In Ghana there are two main types of mines namely small-scale mining and large-scale mining. The general processing techniques are handpicking, amalgamation, cyanidation, flotation, electrowinning and roasting of ore [Akosa et al., 2002].

Methods of mining deployed by small-scale miners of precious minerals depend on the type of deposit and its geographical location. In view of the poor financial base of small-scale miners, a great majority rely solely on traditional/manual methods of mining, which are largely artisanal, whereby simple equipment like shovels, pick-axes, pans, chisels and hammers. The methods used in the small-scale mining of precious minerals in Ghana, however, can be categorized into the following three groups:

- Shallow alluvial mining;
- Deep alluvial mining; and
- Hard rock (lode) mining.

Shallow alluvial mining techniques, popularly called “dig and wash”, are used to mine shallow alluvial deposits usually found in valleys or low lying areas. Such deposits have depths not exceeding three (3) metres. Vegetation is initially cleared and the soil

excavated until the gold-rich layer is reached. The mineralized material is removed and transported to nearby streams or rivers for sluicing to recover the gold. A significant proportion of the industry's operations are of this type since reaching these deposits and treating such ores are relative ease. For similar reasons, illegal mining are predominantly of this type [Aryee et al., 2003].

Deep alluvial mining techniques are used to mine deep alluvial deposits found along the banks of major rivers such as the Ankobra, Tano, and Offin and and among other rivers. These methods involve excavating a pit and digging until the gold bearing gravel horizon is reached, which is typically located at depths of 7 to 12 metres. Terraces or benches are constructed along the pits sides to prevent collapse. The gold bearing gravel is then removed and sluiced to recover the gold [Aryee et al., 2003].

Hard rock mining techniques are only employed to mine gold bearing reefs, which can be found close to the surface or deep-seated. Holes are sunk to intercept the reefs and when accomplished, the reefs are worked along the strike. Where such reefs are weathered, small-scale miners use chisels and hammers to break ore. In cases where ore is hard, explosives are commonly used, despite being prohibited throughout Ghana [Aryee et al., 2003].

During much of the 20th Century, dredging operations were conducted along several sections of the Offin River Valley, from ca. 20 km downstream from Dunkwa to ca. 60 km upstream. Dredging of the Offin River first began in 1904 [Robert, 2010]. The following items summarize the characteristics of the Offin River deposits:

a. The Offin River is 25 m wide, and flows on a floodplain between 0.5 km and 1 km in width. The Offin River Valley is 1.5 to 3 km wide and the valley floor tends to lie between 15 and 20 m above the river.
b. Birrimian metasedimentary rocks form a weathered surface 6 to 8 m below the current surface. Several major broad channels cut an additional 1 – 2 m into the bedrock. A few narrow channels cut into the bedrock to 18 m below the present surface.
c. Unconsolidated basal gravels varying in thickness from 0.5 to 8 m lie across the Offin River valley. The gravels contain large pebble to cobble size clasts, up to 15 cm in diameter, in a matrix of quartz and heavy minerals. Essentially, all gold is contained in these basal gravels.
d. Overburden, from bottom to top, consists of 2 – 8 m of coarse sands containing plant fragments, silt, and silty clay. The modern channel of the Offin River has cut 5 m through the overburden; however the channel has not reached the gold-bearing basal gravels.
e. Gravel layers 3 – 7 m thick generally contain gold. However, gravel layers, 7 – 10 m thick are generally barren. Along the northern part of the Offin, gold is concentrated in a band, 300 to 600 m wide, which contains gold values above 0.13 gm/yd^3. High-grade sections are scattered and isolated [Robert, 2010].

2.8.2 Study of radiological hazard from a gold mining in Nigeria

In 2013, Girigisu et al., researched into Begega artisanal gold mining exercise in Zamfara state of Nigeria. The aim was assessing the radiological levels in the soils from Begega. The soil samples were pick from the field of Begega and the analysis was carried out using 76×76 mm NAI(Tl) detector crystal optically coupled to a

photomultiplier tube (PMT) with data acquisition software Maestro by camberra Nuclear Products (version 1990) according to Girigisu et al.,(2013). The results from Girigisu et al., (2013) show mean activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th to be 370.79±7.98 $Bqkg^{-1}$, 18.3±1.77 $Bqkg^{-1}$ and 16.86±0.94 $Bqkg^{-1}$ respectively. The mean annual effective dose rate is 0.033$mSvyr^{-1}$ which is much lower compared to 0.07 $mSvyr^{-1}$ UNSCEAR baseline. These values interms of radiological risk assessment are low and should not cause health concerns. [Girigisu et al., 2013].

2.8.3 Assessment of NORMS in a mining company, Ghana

Faanu et al., (2011) carried out a study in Tarkwa Gold mine and its surrounding communities in Ghana with the aim of determining the exposure of the general public to naturally occurring radioactive materials from the processing of gold ore. Faanu et al., (2011) used direct gamma spectrometry and neutron activation analysis techniques to analyse soil, rock, water and dust samples from the mining environment. Seventy two samples were randomly collected within selected areas of the mine concession and the surrounding communities. They included 38 soil/rock samples, 29 water samples and 5 dust samples according to Faanu et al., (2011). The mean activity concentrations measured for ^{238}U, ^{232}Th and ^{40}K in the soil/rock samples were 15.2, 26.9 and 157.1 Bq/kg respectively. For the water samples, the mean activity concentrations were 0.54, 0.41 and 7.76 Bq/kg for ^{226}Ra, ^{232}Th and ^{40}K respectively. The mean activity concentration measured for the dust samples were 4.90 and 2.75μBqm^{-3} for ^{238}U and ^{232}Th respectively. The total annual effective dose to the public was estimated to be 0.69mSv. The results in this study compares well with recommended world averages [Faanu et al., 2011].

2.9 Radiation measurement techniques

Human beings do not have any sense organs that can detect ionizing radiation. As a result, they depend entirely on instruments for the detection and measurement of radiation. Some of the instruments include: gas filled detectors (ionisation chamber counters, proportional counters, and Geiger-Muller counters), scintillation counters, and solid state detectors (semi-conductor detectors). The fundamental requirement of any such instrument is that its detector interacts with the radiation in such a manner that the magnitude of the instrument's response is proportional to the radiation effect or radiation property being measured. For the detector to respond, the radiation must have undergone one of the following interactions:

i. Photoelectric effect
ii. Compton scattering
iii. Pair production.

The result of the interaction in a detector is the appearance of a given amount of electric charge within the detector's active volume [Cember, 1996]. Health physics instruments are designed for a number of different applications, such as routine environmental monitoring; monitoring occupational exposure; measuring contamination of surfaces, air, and water; measuring radon and its progeny [Cember, 1996].

2.9.1 Nuclear Spectroscopy

Nuclear spectroscopy is defined as the analysis of radiation sources or radioisotopes by measuring the energy distribution of the source. A spectrometer is an instrument that separates the output pulses from a detector, usually a scintillation detector or a

semiconductor detector, according to size. This technique has found widespread application in x-ray and gamma-ray analysis using NaI(TI) scintillation detectors and HPGe (high-purity germanium) semiconductor detectors, in beta analysis using liquid scintillation detectors or plastic scintillation detectors, and in alpha analysis using semiconductor detectors. Nuclear spectrometers are available in two types, either a single-channel instrument or a multichannel analyzer (MCA).

The essentials of a single-channel spectrometer consist of the detector, a linear amplifier, a pulse-height selector, and a readout device, such as a scaler or a ratemeter. The main use of the single-channel analyzer is to discriminate between a desired radiation and other radiations that may be considered as noise. Thus, the single-channel spectrometer is used to measure one radiation in the presence of another or to optimize the signal-to-noise ratio when a low-activity source is being measured in the presence of a significant background. Figure 2.4 shows a singled-channel analyzer.

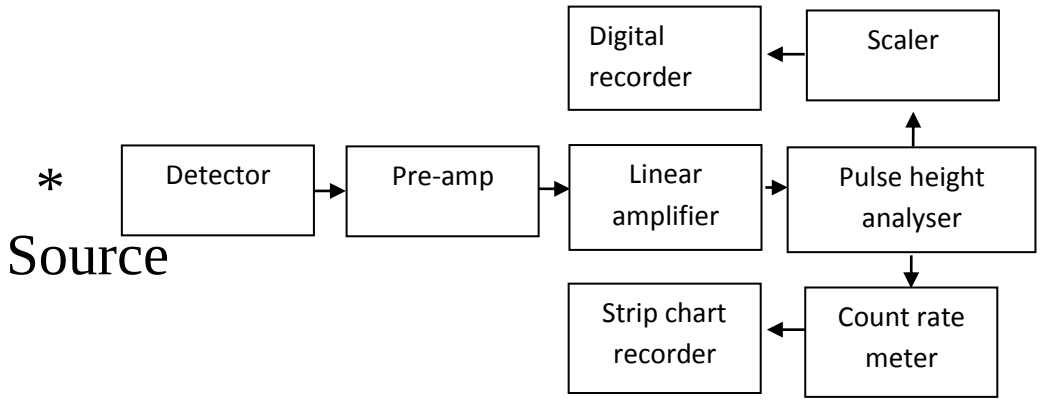


Figure 2.4: Block diagram of a singled-channel gamma spectrometer

Source: [Redrawn from Cember, 1996]

A MCA (Figure 2.5) also has an analog-to-digital converter (ADC) instead of a pulse height selector to sort all the output pulses from the detector according to height. The

MCA also has a computer-type memory for storing the information from the ADC. The output from the ADC is a logic pulse that is stored in a channel whose number, or "address" is determined by the number of clock pulses that were counted during the discharge of the capacitor. Most MCA are built with a number of channels varying by a factor of 2 over a range of 128 to 4096 each with a storage capacity of 105 to 106 counts per channel [Cember, 1996].

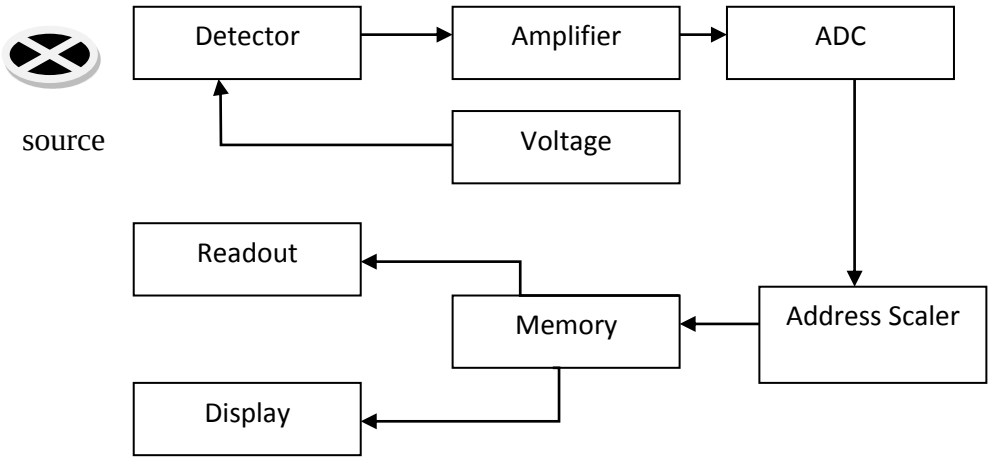


Figure 2.5: Block diagram of a multichannel analyzer

Source: [Redrawn from Cember, 1996]

The basis for nuclear spectroscopy is the location of spectral lines arising from the total absorption of charge particles or photons. For this reason, the resolution of the detector is important if spectral lines closed together are to be separated and observed. Energy resolution may be viewed as the extent to which a detector is able to distinguish between two closely lying energies (radioisotopes). The definition of energy resolution is given in terms of the full width at half maximum (FWHM), ΔE divided by the location of the full energy peak midpoint, as in equation

$$percent\ resolution = \frac{\Delta E}{E} \times 100\ \% \qquad (1)$$

Gamma radiation can also be measured using a scintillation detector consisting of Sodium Iodide crystal activated with thallium (NaI(Tl)) and optically coupled to a

photomultiplier tube. The thallium activator present as an impurity in the crystal structure to the extent of 0.2 % converts the energy absorbed in the crystal to light. Sodium Iodide (NaI(Tl)) detectors have higher efficiency than high purity germanium (HPGe) detectors because of the high density of the crystal and high effective atomic number [Cember, 1996].

2.10 Physical parameters associated with the Small-scale mines

The study area is noted of its rampant mining and mineral activities for both small scale, medium scale and large scale mining activities.

The main source of water supply to occupants in the study area is ground water and to some large extent river. There is therefore the need to determine the concentration of ^{238}U, ^{232}Th and ^{40}K as well as physical parameters of the study area to assess the quality of the water sources.

The physical parameters such as potency of hydrogen (pH), temperature and conductivity are determined in the study area and these are known to influence the concentration of many pollutants by changing their availability and toxicity. The temperatures at which environmental samples are collected and at which physico-chemical measurements are made are prudent for data correlation and interpretation [Lawson, 2011; Tay et al., 2009]. The pH of water is a measure of the acid-base equilibrium and in most natural waters is controlled by the carbon dioxide-bicarbonate-carbonate equilibrium system. An increased carbon dioxide concentration will therefore lower pH and vice versa. Temperature will also affect the equilibria and the pH. In pure water, a decrease in pH of about 0.45 occurs as the temperature is

raised by 25 °C. The pH of most raw water lies within the range 6.5–8.5. In addition, exposure to extreme pH greater than 11 results in irritation to the eyes, skin, and mucous membranes as well as low pH has been reported [WHO, 1996]. The conductivity is also an important indicator when it comes to minerals and salts in a water body and thus has a relation with the total dissolved solids (TDS) in the water body. One other physical parameter that is of interest in water treatment is Total Dissolved Solids/Solvents (TDS), which is a measure of salt and solids dissolved in water. The TDS and conductivity are directly related since both indicate the ionic strength of water and the purity of water. TDS is in units of mg per unit volume of water (mg/L) or parts per million (ppm). TDS is made up of inorganic salts, as well as a small amount of organic matter [WHO, 1996].

CHAPTER THREE

STUDY AREA

In this chapter, the location and size of the study area, climate, relief and drainage, soil, geology and mineralogy and demographics characteristics are described into details.

3.1 Description of the study area

The study area is Dunkwa-on-Offin and its surroundings. Dunkwa-On-Offin or simply Dunkwa is a town and the capital of the Upper Denkyira East Municipal District in the Central Region of south Ghana. Dunkwa-on-Offin is selected as the study area because of the high incidence of practices of small scale mining and "galemsay" activities.

3.1.1 Location and Size

The Upper Denkyira East Municipal District is one of the thirteen Administrative Districts of the Central Region. It lies within latitudes 5°. 30' and 6°. 02' north of the equator and longitudes 1° W and 2° W of the Greenwich Meridian. Dunkwa-On-Offin has a 2013 settlement population of 33,379 people. It shares common boundaries with Bibiani - Anhwiaso Bekwai and Amansie West Districts on the north, Wassa Amenfi West and Wassa Amenfi East Districts on the northwest and west respectively, Twifo-Hemang-Lower Denkyira and Assin North Municipal on the south, Obuasi Municipality on the southeast and Amansie Central on the northeast. Figure 3.1 shows the location of Dunkwa-on-Offin in Ghana and Figures 3.2 and 3.3 shows the concession of the small scale mines and the surrounding communities where sampling was carried out. The Upper Denkyira East Municipal covers a total land area of 1700 square kilometres, which is about 17% of total land area of the Central Region [Upper

Denkyira East Municipal District Assembly, 2006]. Plates 3.1 to 3.4 show some of the locations within the mines and the communities where sampling was carried out.

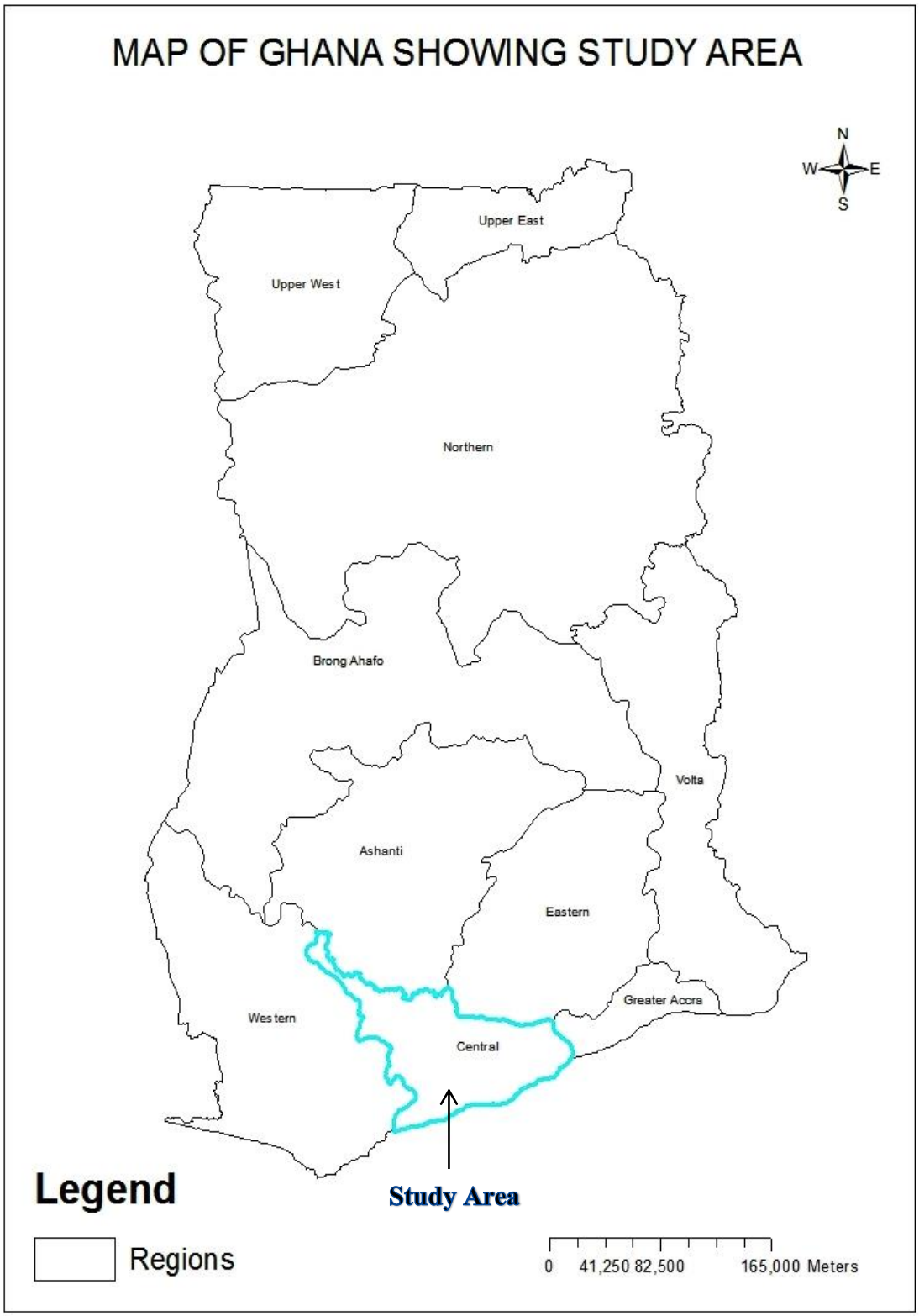


Figure 3.1: Location of study area in Ghana

Figure 3.2: Layout of Dunkwa-on-Offin showing the administrative setup

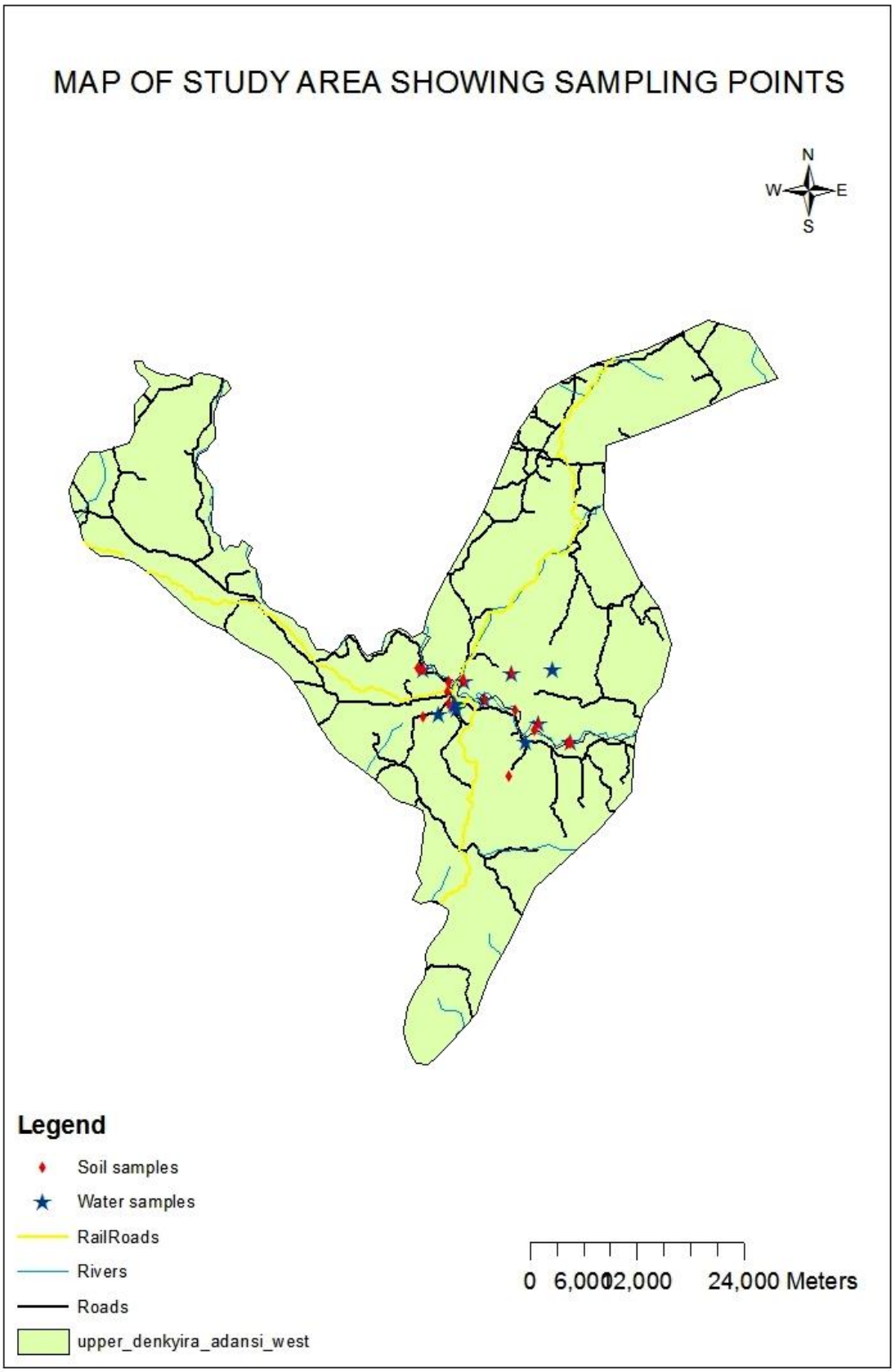


Figure 3.3: Layout of Dunkwa-on-Offin showing the sampling points

Plate 3.1: Tailings dam

Plate 3.2: Contaminated river

Plate 3.3: Small-scale mining site

Plate 3.4: Borehole in Mfuom community

3.1.2 Climate

The Municipality falls within the semi equatorial zone with its characteristics. The mean annual temperatures are 29ºC on the hottest months and about 24ºC in the coolest months. There are two rainfall regimes, but the total annual mean rainfall is between 1200mm and 2000mm. The first rainy season is from May to June with the heaviest in June, while the second rainy season is from September to Mid-November. The main dry season is from late-November to February [Upper Denkyira East Municipal District Assembly, 2006]. Data obtained from the Ghana Meteorological Agency at Dunkwa-on-Offin shows the total annual rainfall figures measured for the year 2011 was 1607.5 mm with an average of 134.0 mm and for the year 2012 was 1414.9 mm with an average of 117.9 mm. Figure 3.3 and 3.4 shows the rainfall pattern for the year 2011 and 2012 respectively. Figure 3.5 shows the data obtained from the Ghana Meteorological Agency at Dunkwa-on-Offin during the study period. The total annual rainfall figures measured for the study period (2013) was 1129.0 mm with mean rainfall of 94.1±75.1mm. The highest rainfall 234.9 mm was recorded in October.

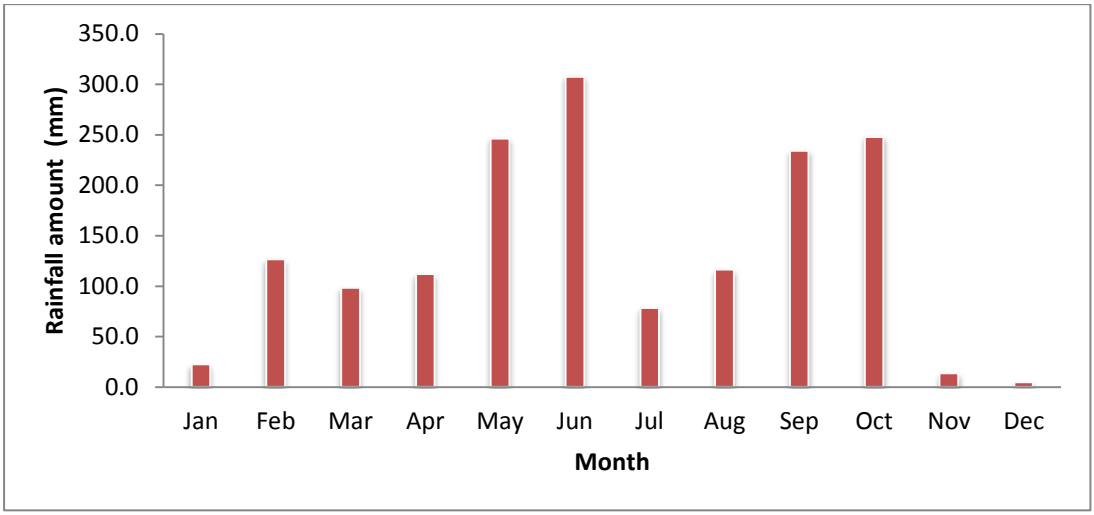


Figure 3.4: Rainfall data for the year 2011

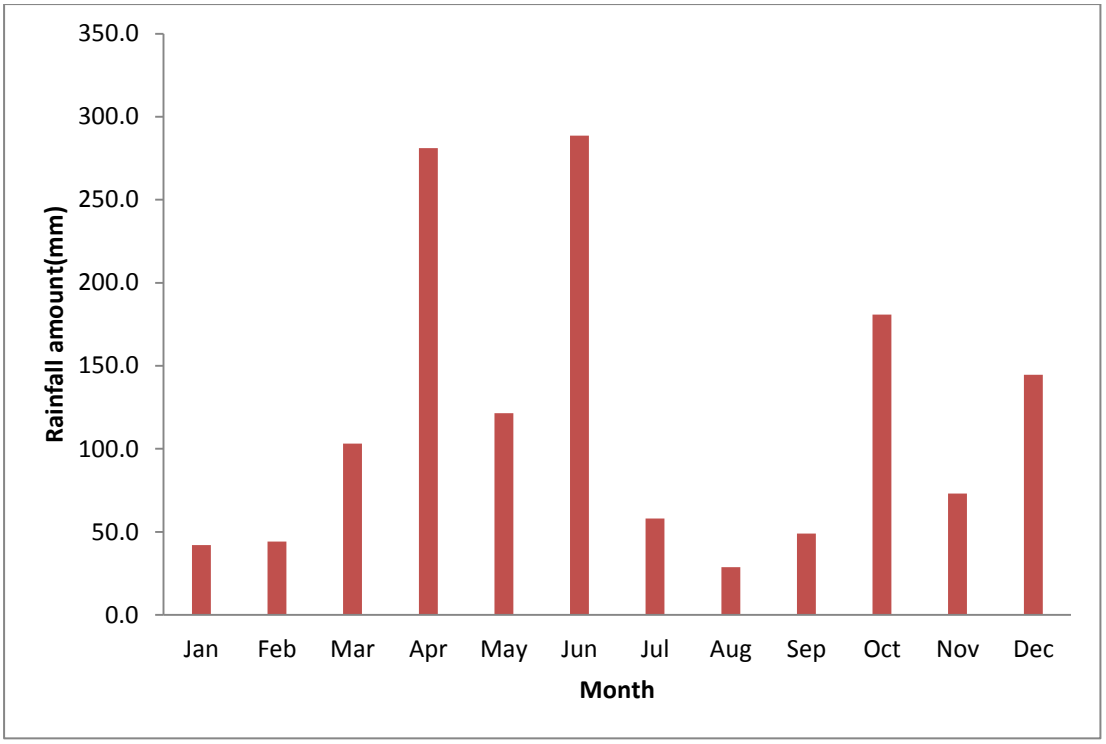


Figure 3.5: Rainfall data for the year 2012

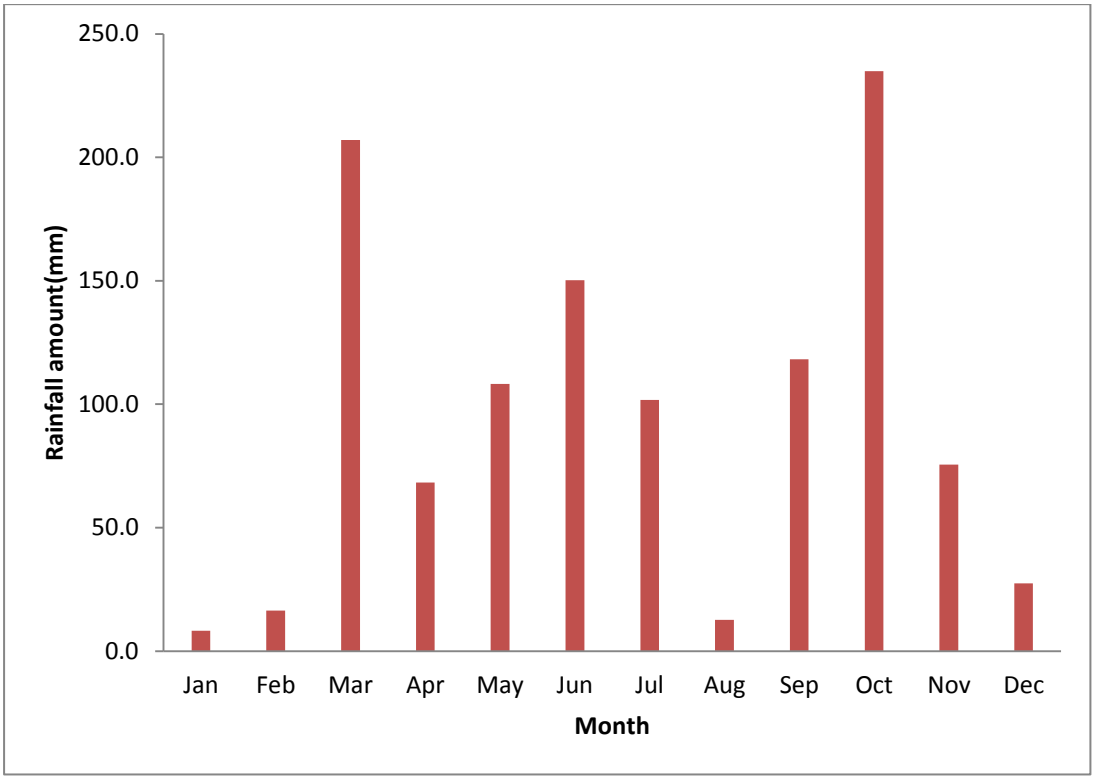


Figure 3.6: Rainfall data for the year 2013

3.1.3 Vegetation

The Upper Denkyira East Municipal District falls within the semi-deciduous forest zone. It consists of three layers which do not differ much from the rain forest. The trees in this forest zone do not shed all their leaves at the same time nor are they of the same species. Trees of the lower layer and some of the topmost layers stay evergreen throughout the year. This is due to the generally moist condition of the area. Due to increasing cocoa and mining activities in the area, especially in the northern part of the Municipality, very little of the original forest remains, and most of what is left are secondary forests. The forest contains various valuable timber species such as Mahogany and Wawa [Upper Denkyira East Municipal District Assembly, 2006].

3.1.4 Conditions of the Natural environment

Forestry is one of the important sectors of the district. The district has three major forest reserves which are all rich in wildlife and lumber. They include the Benso-Benn, Oppong Manse and Minta Forest Reserves. They consist of different species of tropical hardwood of high economic-value trees like Odum, Mahogany, Edinam and Wawa. Lumbering has therefore been an important economic activity in the district. However, this has been creating environmental problems, as there is no proper management of the forest reserves. The reserves is been encroached by illegal chainsaw operators whose activities, if not checked, will deprive the Municipality of the needed forest resources for development. Frequent outbreak of bushfires has also contributed to the depletion of forests and other forms of environmental degradation in the Municipality. Most of the known wildlife such as the deer and monkeys, which were mostly found in the forests, now face extinction. It is, however, important that the Forestry Service Commission and the Municipality Assembly initiate a more

intensive afforestation programme to preserve some of the important economic tree species to ensure ecological balance in the municipality. Sustainable harnessing of existing forest resources is also to be encouraged [Upper Denkyira East Municipal District Assembly, 2006, 2013].

3.1.5 Relief and Drainage

The area falls under a forest-dissected plateau, rising to about 250m above sea level. There are pockets of steep sided hills alternating with flat-bottomed valleys. Dunkwa, the Municipal Capital, has a series of high lands circling it. The major river in the area is the River Offin. A number of streams which are tributaries of either the river Offin or Pra flow through the district. Prominent among them are the Subin Ninta, Aponapon and Tuatian in the south, Afiefi and Subin in the north [Upper Denkyira East Municipal District Assembly, 2006].

3.1.6 Soil

The principal soil found in the area is forest ochrosols. The colour of these soils is between brown and orange. The soil is not highly leached as oxysol. Due to the reduction in the amount of rainfall, the soils contain greater quantities of soil nutrients and are generally alkaline. From the view point of crop production, they are the best soils in the country. Tree crops such as cocoa and oil palm thrive in the area. Cocoa covers about 50% of the Municipality of the entire arable land. Other crops like cassava, plantain and maize also do well [Upper Denkyira East Municipal District Assembly, 2006].

3.1.7 Impact of Human Activities

Many of the areas hit by the illegal mining activities have been degraded. There are abandoned mined-out pits, heaps of gravel dotted all over and in some instances streams have been silted. Conflicts resulting from payment of compensation are also common in most of the areas in addition to reclamation blues. The use of mercury in the gold extraction process also negatively affects the environment and the communities, if not properly handled. Juvenile delinquency is also raising its ugly head in the mining communities in addition to overstretched social amenities [Upper Denkyira East Municipal District Assembly, 2006].

3.1.8 Geology and Mineralogy

The rocks in the Municipality are predominantly of Birimian and Tarkwaian formation. The Birimian formation consists of metamorphosed sediments as phyllites, schist and lava. This accounts for the Municipality's rich mineral deposits particularly alluvial gold deposit along the valleys of River Offin and its tributaries and gold deposits inland [Upper Denkyira East Municipal District Assembly, 2006].

3.1.9 Demographic Characteristics

3.1.9.1 Population Size and Growth Rate

The total population of the Municipality is currently projected at 72,956 by 2012. The inter-censual population growth rate increased slightly from 2.8% between 1960-70 to 3.1% to 1970-84 to 3.2% from 1984-2000. That is, the population of the district has been growing averagely at a moderate rate of 3.1% per annum for the past four decades (1970-2010). The current growth rate of 3.1% is higher than the national growth rate of 2.7% per annum. In order to combat poverty and provide meaningful

living for the people of the municipality, programmatic measures should be embarked to reduce the growth rate [Upper Denkyira East Municipal District Assembly].

Table 3.1: Population size and Growth rate [Population census reports for 1960, 1970, 1984, 2000, 2010 and 2011, Dunkwa-on-Offin]

YEAR	POPULATION SIZE	GROWTH RATE
1960	34,011 (before split of the district)	2.8
1970	44,468 (before split of the district)	2.8
1984	68,329 (before split of the district)	3.1
2000	62,496 (after split of the district)	3.2
2010	84,808 (after split of the district)	3.1
2011	70,762 (after split of the district)	3.1

3.1.9.2 Rural Urban Split/Spatial Distribution of Population

The Upper Denkyira East Municipal is mainly rural. Results of the 2000 Population and Housing Census indicate that the District has only one urban settlement thus Dunkwa-On-Offin, with a population of 26,215. The population of Dunkwa now stands at 35,346 (projected). This means that the proportion of the urban population is only 41.68%. This shows that as much as 58.32% of the populations live in rural areas (settlements with less than 5000 inhabitants). Table 3.2 shows the populations of 20 largest settlements in the Municipality. The rural nature of the Municipality implies that poverty reduction interventions in the Municipality have to focus on rural development strategies, especially the promotion of agriculture, agro-processing, marketing, feeder road improvements, the provision of basic social and economic infrastructure as well as group and community empowerment.

Table 3.2: Populations (projections) of Major Settlements [Statistical Department, 2000, 2008, 2010, Dunkwa-on-Offin]

NO.	TOWN	YEAR		
		2000	2008	2010
1	Dunkwa-On-Offin	26,215	33,317	35,346
2	Asikuma	1,643	2,097	2,229
3	Kyekyewere	2,376	3,033	3,223
4	Atechem	2,440	3,114	3,310
5	Mbraiam	831	1,060	1,126
6	Mradan	669	853	906
7	Abesewa	720	919	976
8	Achiase	741	946	1005
9	Meretweso	703	896	952
10	Buabin	1450	1,850	1966
11	Buabinso	1400	1,787	1,899
12	Denyase	650	821	881
13	Kyebi	1232	1,572	1670
14	Agyenpoma	1297	1,656	1760
15	Ntontom No. 1	785	1,000	1062
16	Zion Camp	730	932	990
17	Zion No. 2	630	804	854
18	Akropong	1015	1,295	1,376
19	Asma Camp		1215	1,291
20	Badowa	820	1046	1,111
21	Mfuom	-	-	3241

CHAPTER FOUR

MATERIALS AND METHODS

In this chapter, sample collection, sample preparation and the method used are described. Activity concentrations of the natural radionuclides are also described in detail using mathematical models. Sampling was carried out from 13/11/13 to 29/11/13. The following main exposure pathways such as direct gamma exposure, radon inhalation, ingestion of contaminated water sources for workers and the general public were considered and that forms the basis for the types of samples collected for the study.

4.1 Sample collection

4.1.1 Soil sampling

Soil samples were collected from the following locations within Dunkwa and the surrounding communities including; Dunkwa Township Nyamebekyere, Brentuo, Babianiha, Amoafo, Akropong, Buabinso, Tekyikrom and Abesewa. Pre-survey was carried out in the study area to determine the sampling points. The selection of the sampling locations was based on the accessibility to the public and closeness to the small-scale mine. Based on these criteria, 20 soil and 12 water sampling locations were identified. Geo Explorer II Global Position System (GPS) with serial number 28801-00 and version 2.11 was used to record the location of the sampling sites. The sampling technique adopted for the soil was random. Random sampling is the arbitrary collection of samples within the defined boundaries of the area of concern. Soil sampling locations were chosen using a random selection procedure. The arbitrary selection of sampling points requires each sampling point to be selected independent of the location of all other points, and results in all locations within the

area of concern having an equal chance of being selected. Each location was divided into grid cells and samples taken at different points were mixed together to give a representative sample [IAEA, 2004]. The soil samples were taken using a coring tool to a depth of 5-10 cm. At each sampling location, soil samples were taken from at least five different sections of the area into labelled plastic bags. One kilogram (1 kg) of each sample was collected for analysis. The samples were then transported to the laboratory for preparation and analysis.

4.1.2 Water sampling

Water samples were collected from water sources within Dunkwa and the surrounding communities where small-scale mining activities are carried out. These communities include; Dunkwa Township, Nyamebekyere, Brentuo, Babianiha, Amoafo, Akropong, Buabinso, Tekyikrom and Mfoum. The water samples were taken from rivers, streams, tap water, borehole and wells used for irrigation, domestic and other purposes within the study area. The samples were collected into labelled two and half litres (2.5 L and 5 L) plastic bottles. The bottles were washed with concentrated nitric acid (HNO_3) before the bottles were filled with the water to ensure radionuclides remain in solution rather than adhering to the walls of the container. The bottles were also filled to the brim without any head space to prevent carbon dioxide (CO_2) being trapped and dissolving in water, which might affect the chemistry of the water sample, example pH. The water samples were then transported to the Laboratory and stored in a fridge prior to preparation and analysis. The potency of hydrogen(pH), conductivity, temperature and the total dissolved solids of the water samples were measured in the field using combo pH and EC meter model HANNA pH (HI 98129).

The pH meter was calibrated with standard buffer solutions with pH 4.01, 7.0 and 9.21. Plate 4.1, shows the setup of the equipment used in the field.

Table 4.1: Location of the soil sample areas and their coordinates

Sample code	Description of sampling location	Coordinates
SS1	Mining premises, Dunkwa	N 5˚59'32.58" W 1˚43'10.53"
SS2	Mining premises,Nyamebekyere	N 5˚59'48.90" W 1˚48'50.28"
SS3	Mining premises,Nyamebekyere	N 5˚59'46.34" W 1˚48'48.67"
SS4	Mining premises,Nyamebekyere	N 5˚59'43.16" W 1˚48'31.10"
SS5	Farm,Brentuo	N 5˚53'27.19" W 1˚43'18.03"
SS6	Farm,Babianiha(control)	N 5˚56'54.63" W 1˚48'32.20"
SS7	Mining site,Amoafo	N 5˚55'21.85" W 1˚39'40.25"
SS8	Mining site,Amoafo	N 5˚55'22.59" W 1˚39'33.06"
SS9	Mining site,Amoafo	N 5˚55'26.84" W 1˚39'37.41"
SS10	Mining site,Akropong	N 5˚56'09.39" W 1˚41'45.22"
SS11	Farm,Akropong	N 5˚56'09.93" W 1˚41'44.96"
SS12	Mining site,Akropong	N 5˚56'32.56" W 1˚41'29.96"
SS13	Market,Dunkwa Township	N 5˚57'44.30" W 1˚46'58.21"
SS14	Farm,Buabinso	N 5˚57'17.56" W 1˚42'54.59"
SS15	Mining site,Buabinso	N 5˚57'55.00" W 1˚44'47.19"
SS16	Mining site,Tekyikrom	N 5˚59'03.85" W 1˚46'03.77"
SS17	Mining site,Tekyikrom	N 5˚59'05.22" W 1˚46'07.21"
SS18	Mining site,Abesewa	N 5˚58'59.37" W 1˚46'57.63"
SS19	Mining site,Abesewa	N 5˚59'01.89" W 1˚46'56.26"
SS20	Old mine site,Dunkwa Township	N 5˚58'26.81" W 1˚47'02.66"

SS-Soil sample

Table 4.2: Location of the water sample areas and their coordinates

Sample code	Description of sampling location	Coordinates
WS1	River,Dunkwa	N 5˚59'32.75" W 1˚43'10.57"
WS2	Conserved water,Nyamebekyere	N 5˚59'46.13" W 1˚48'32.24"
WS3	River,Adwuman	N 5˚55'25.25" W 1˚42'15.24"
WS4	Tap water,Dunkwa Township	N 5˚57'42.65" W 1˚46'40.66"
WS5	Borehole,Mfoum(control)	N 5˚57'06.42" W 1˚47'36.23"
WS6	River,Amoafo	N 5˚55'25.78" W 1˚39'32.68"
WS7	River,Akropong	N 5˚56'32.56" W 1˚41'29.96"
WS8	Borehole,Dunkwa Township	N 5˚57'37.28" W 1˚46'35.91"
WS9	Well,Dunkwa Township	N 5˚57'26.10" W 1˚46'32.61"
WS10	River,Buabinso	N 5˚57'57.76" W 1˚44'47.19"
WS11	River,Tekyikrom	N 5˚59'03.51" W 1˚46'03.18"
WS12	Well,Dunkwa Township	N 5˚59'46.90" W 1˚40'38.49"

WS-Water sample

Plate 4.1: Instruments used during field work

4.2 Sample preparation for direct gamma spectrometry

4.2.1 Soil sample

At the laboratory, the samples were spread in trays and allowed to dry at room temperature for two (2) weeks and then air dried and then oven dried at a temperature of 105^{o}C for between 3 to 4 hours until the samples were well dried with a constant weight [IAEA, 1989]. The samples were then ground into fine homogenous powder using a ball mill grinder and sieved through a 2 mm pore size mesh. They were then transferred into a weighed 1000cm^{3} (1 litre) Marinelli beakers. The Marinelli beakers with its content were then weighed again to determine the weight of the sample. The beakers were covered and sealed with a paper tape to prevent the escape of the gaseous radionuclides in the sample. The samples were then stored for 30 days to allow for secular equilibrium between the long-lived parent radionuclide and their short-lived daughter radionuclides.

4.2.2 Water sample

The water samples were transferred into the 1000cm^3 Marinelli beaker after filtration to remove all solid particles and debris in the water. The samples were counted on a high purity germanium detector for 36000s. The activity concentrations of the radionuclides in the sample were reported in Bq/L.

4.2.2.1 Physical parameters

The potency of hydrogen (pH), conductivity, temperature and the total dissolved solids of the water samples were measured in the field and in the laboratory using combo pH and EC meter model HANNA pH (HI 98129). The pH meter was calibrated with standard buffer solutions with pH 4.01, 7.0 and 9.21

4.3. Analysis of samples using direct gamma spectrometry

The method of the gamma-ray analysis reported in published research works [Darko & Faanu, 2007; Merdanoglu & Altinsoy, 2006] was adopted for this study. The gamma spectrometer used for the analysis consists of an ORTEC GEM Coaxial n-type high purity germanium (HPGe) gamma-ray detector with ORTEC Multichannel Analyzer (MCA) and MAESTRO-32 evaluation software for spectrum acquisition and processing. The detector is located inside a cylindrical lead shield of 5 cm thickness with internal diameter of 24 cm and height of 60 cm. The lead shield is lined with various layers of copper, cadmium and plexil glass each of 3 mm thick. The relative efficiency of the detector was 25% with energy resolution of 1.8 keV at gamma-ray energy of 1332 keV of ^{60}Co.

The detector was calibrated with respect to energy and efficiency prior to analysis. A Standards of known concentrations of radionuclides homogenously distributed on solid water in a 1 L marinelli beaker was used for calibration of the gamma spectrometry system. The standard was supplied by Deutscher Kalibrierdienst (DKD-3), QSA Global GmBH, Germany. Appendix 1 shows the calibration certificate. Background measurements were taken and subtracted in order to obtain net counts for the samples. The spectrum obtained from the standard was used to carry out energy and efficiency calibrations which were used in the determination of the activity concentrations of the radionuclides in Bq/kg and Bq/L for soil, and water respectively.

4.3.1 Energy calibration of the gamma-ray spectrometry system

Energy calibration enables qualitative analysis or identification of radionuclides in a spectrum. The HPGe detector energy calibration (that is to establish the channel number of multichannel analyser (MCA) in relation to gamma-ray energy) was made by counting standard radionuclides of known activities with well-defined energies within the energy range from 60-2000 keV [IAEA, 1989]. In other words the identification is done by matching the energies of the principal gamma-rays observed in the spectrum to energies of the gamma rays emitted by the radionuclides in a standard reference sample. The calibration standard on the gamma detector was counted for ten (10) hours (36000s) to produce well defined photo peaks. The channel number corresponding to the centroid of each full energy event on the MCA was recorded and plotted to obtain a linear curve with second order polynomial. The linear curve obtained from the data points is an indication that the system is operating properly [IAEA, 1989]. The formula relating the energy and the channel number is given as

$$E = Ao + A_1 CN \quad (2)$$

Where;

E is the energy, CN is the channel number for a given radionuclide, A_0 and A_1 are calibration constant for a given geometry. A graph of energy against channel number was plotted as shown in Figure 4.2.

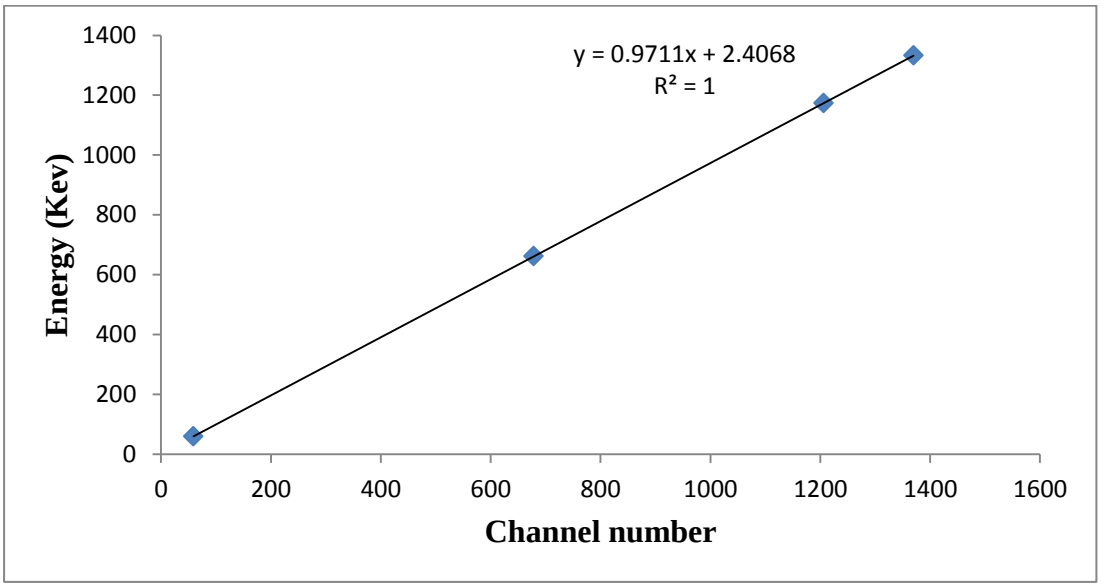


Figure 4.1: Energy calibration Curve

From the energy calibration curve the following expression was obtained:

$$E = 2.4068 + 0.9711 CN \quad (3)$$

4.3.2 Efficiency calibration

The mixed radionuclides standard used for the energy calibration was also used for the efficiency calibration. The efficiency calibration was done using radioactive mixed nuclide 146A standard provided by DEUTSCTHER KALIBRIEDIENST. The efficiency of the detector refers to the ratio of the actual events registered by the detector to the total number of events emitted by the source of radiation [IAEA, 1989]. An accurate efficiency calibration of the system is necessary to quantify radionuclides present in the sample. The standard was counted on the detector for 10 hours (36000 s). The net counts for each of the full energy events in the spectrum was

determined and their corresponding energies used in the determination of the efficiencies. The standard was in a sealed Marinelli beaker of the same geometry as the samples. Using equation (3) and known concentration from the certificate, counting efficiency for each photopeak was calculated using Microsoft excel spread sheet and corresponding efficiency plotted against energy to obtain an efficiency curve. Hence, efficiency of all other photopeaks was determined from the calibration curve. The efficiency calibration curve was made using different energy peaks covering the range up to 2000keV. The efficiency calibration was performed by acquiring a spectrum of the standard until the count rate of total absorption could be calculated with statistical uncertainty of less than 1% at confidence level of 95%. The expression used to determine the efficiencies is given as follows [Darko et al., 2007].

$$n(E) = \frac{N_T - N_B}{P_E A_{STD} T_{STD}} \quad (4)$$

Where;

P_E is gamma emission probability for energy (E),

$\eta(E)$ is the efficiency of the detector,

N_T is the total counts under a photopeak

N_B is the background count

A_{STD} is the activity (Bq) of the radionuclide in the calibration standard at the time of calibration,

T_{STD} is the counting time of the standard

The efficiency is related to energy by the expression;

$$In\varepsilon(E) = B_0 + B_1 InE + B_2 (InE)^2 \quad (5)$$

Where;

$B_0, B_1 \; and \; B_2$ are calibration constants for a given geometry and the other symbols have their usual meanings. The efficiency calibration curve is shown in Figure 4.3

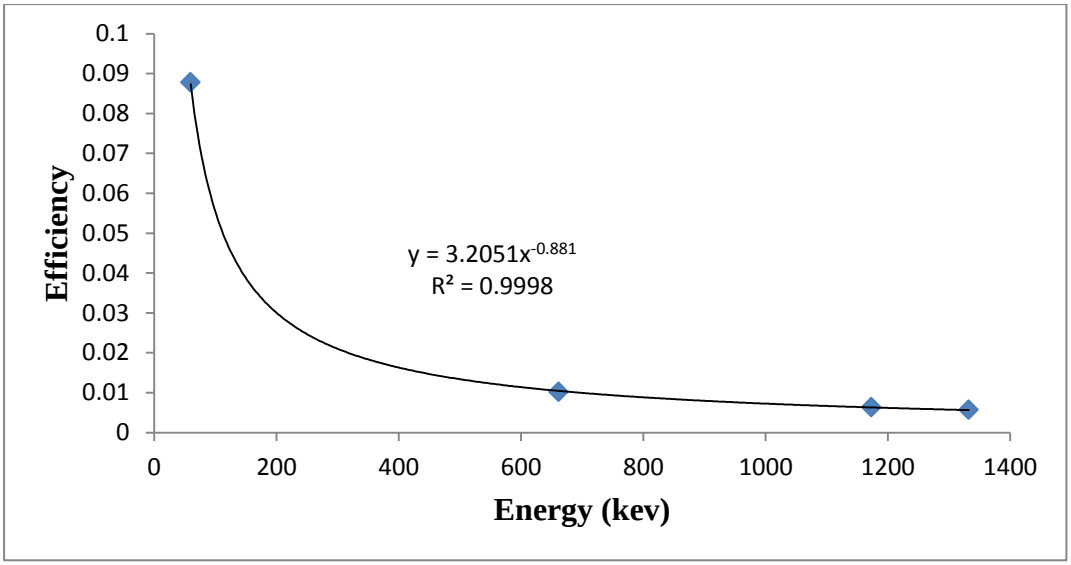


Figure 4.2: Efficiency calibration curve

From the efficiency calibration curve, the following expression was obtained:

$$In\varepsilon = 1.16 - 0.88 InE_{\gamma} \quad for\ E_{\gamma} > 100\ kev \tag{6}$$

4.4 Gross alpha and beta measurements

4.4.1 Soil sample

Twenty (20) soil samples were taken from the small-scale mining sites in the Dunkwa community and the surrounding communities were analysed for gross alpha (α) and beta (β) radioactivity. 0.04g of the grinded homogenous soil samples were measured and leached by adding 0.01M of nitric acid to trap the radionuclides and also to make the samples compact.

The prepared samples were counted for 200 minutes to determine gross alpha and beta activity concentration using iMatic P-F Gas-less Automatic Gross Alpha/Beta counter with serial number 9796 calibrated with alpha (^{241}Am) and beta (^{90}Sr) standard sources. The alpha and beta efficiencies were determined to be 36.47% and

49.23% respectively. The background readings of the detector for alpha and beta activity concentrations were 0.00 and 0.00 cpm respectively.

4.4.2 Water sample

Twelve (12) water samples taken from bore-holes, tap water, rivers and waste water from the small-scale mine site were analysed for gross alpha (α) and beta (β) radioactivity. The water samples were filtered prior to analysis. About 2ml of concentrated 65% of nitric acid were added to each of the filtered water samples in a 1litre container and left overnight thus 24 hours. 300ml of the sample were then measured into 500ml beaker and evaporated on a hot plate (SB500) at 90˚C in a fume hood (chamber) until it reduces to 25ml. The 25ml residues were then transferred into a weighed labelled stainless steel planchets on a hot plate and evaporated to dryness until all the residue samples are finished. The planchets were then put in desiccators to cool for about 10 minutes and also to prevent it from absorbing moisture.

The prepared samples were counted for 200 minutes to determine gross alpha and beta activity concentration using the iMatic P-F Gas-less Automatic Gross Alpha/Beta counter with serial number 9796 calibrated with alpha (^{241}Am) and beta (^{90}Sr) standard sources. The alpha and beta efficiencies were determined to be 36.47% and 49.23% respectively. The background readings of the detector for alpha and beta activity concentrations were 0.00 and 0.00 cpm respectively.

4.5 Calculation of Specific activity concentrations (C_{sp})

The determination of count rates for each photopeak and activity concentration of detected radionuclides depend on the establishment of secular equilibrium in the samples. The activity concentrations of ^{238}U was determined from the average activity

concentration of 351.9 keV of ^{214}Pb and 1764.5 keV of ^{214}Bi in the samples and the daughter gamma ray lines of 238.63 keV of ^{212}Pb, 2614.53 keV of ^{208}TI and 911.21 keV of ^{228}Ac was used to determine ^{232}Th. The activity concentration of ^{40}K was determined using the gamma ray line at 1460.8 keV. The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the soil and water samples were calculated using the following analytical expression (7) as shown [Darko et al., 2010].

$$C_{sp} = \frac{N_D e^{\lambda_p t_d}}{PT_c \eta m} \qquad (7)$$

Where;

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

t_d is the delay time between sampling and counting,

P is the gamma emission probability (gamma yield),

η is the absolute counting efficiency of the detector system,

T_c is the sample counting time,

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

$e^{\lambda ptd}$ is the decay correction factor for delay between time of sampling and counting

λ_p is the decay constant of the parent radionuclide.

4.6 Estimation of annual effective dose from external gamma dose rate measurements

The outdoor external gamma dose rate was measured using RDS-200 Universal Radiation Survey Meter, which had been calibrated at the Secondary Standard Dosimetry Laboratory (SSDL) at the Radiation Protection Institute of the GAEC. At each location, five measurements were made at 1 meter above the ground and the average value taken in nGy/h. The annual effective dose ($E_{\gamma, ext}$) was then estimated

from the measured average outdoor external gamma dose rate from the equation (8) below.

$$E_{\gamma,ext}(mSv/yr) = D_{\gamma,ext}T_{exp}DCF_{ext} \quad (8)$$

Where;
$D_{\gamma,ext}$ is the average outdoor external gamma dose rate nGy/h,

T_{exp} is the exposure duration per year, 8760 hours (365 days) and applying an outdoor occupancy factor of 0.2,

DCF_{ext} is the absorbed dose to effective dose conversion factor of 0.7 Sv/Gy for environmental exposure to gamma rays [UNSCEAR, 2000].

4.7 Determination of radiological hazard indices

4.7.1 Radiological equivalent activity index (Ra_{eq})

The radiological risk of NORM in soils in the study area which may be used as building materials was assessed in order to compare the specific activities of building materials containing concentration of radium, thorium and potassium. A single quantity called radium equivalent activity (Ra_{eq}), takes into account the radiation hazard associated with the building materials and is calculated using Beretka and Mathew (1985) formulas shown in equation (9)

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (Bq/kg) \quad (9)$$

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

In the definition of Ra_{eq}, it is assumed that 370 Bq/kg of ^{226}Ra, 259 Bq/kg of ^{232}Th and 4810 Bq/kg of ^{40}K produce the same gamma ray dose rate. The above criterion only considers the external hazard due to gamma rays in building materials. The

maximum recommended value of Ra_{eq} in raw building materials and products must be less than 370 Bq/kg for safe use. This means that the external gamma dose must be less than 1.5 mSv/year.

4.7.2 External Gamma dose rates

The absorbed dose rates due to gamma radiation in air at 1m above the ground for the uniform distribution of the naturally occurring radionuclides (^{226}Ra, ^{232}Th and ^{40}K) was calculated based on guidelines provided by UNSCEAR (2000) and it is given as equation (10)

$$D = 0.462C_{Ra} + 0.604C_{Th} + 0.0417C_K \ (nGy/h) \quad (10)$$

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

4.7.3 Annual effective dose

To estimate the annual effective dose, two main parameters were taken into consideration namely (i) conversion coefficient from the absorbed dose in air to effective dose and (ii) the occupancy factor. Annual estimated averaged effective dose equivalent received by a member was calculated using a conversion factor of 0.7*Sv/Gy*, which is use to convert the absorbed dose rate to annual effective dose equivalent with an outdoor occupancy of 20% and for indoor 80% [UNSCEAR, 1993]. The annual effective dose is determined as shown in equation (11)

$$D_{af}\ (mSv/yr) = (Absorbed\ dose)\ nGy/h \times 0.7Sv/Gy\ (Conversion\ coefficient) \times occupancy\ factor \times 8760h \quad (11)$$

4.7.3.1 Committed effective doses (E_{ing})

In the case of the water samples, the committed effective doses (E_{ing}) were estimated from the activity concentrations of each individual radionuclide and applying the yearly water consumption rate for adults of 730 L/year (2 L/day multiplied by 365 days) and applying equation (12).

$$E_{ing}(w) = I_w \sum_{n=1}^{3} DCF_{ING}\,(U, Th, K) C_{sp}(w) \qquad (12)$$

Where, C_{sp} (w) is the activity concentration of the radionuclides in a sample in Bq/L, I_w is the intake of water in litres per year, and DCF_{Ing} is the ingestion dose coefficient of ^{238}U, ^{232}Th and ^{40}K in Sv/Bq taken from ICRP 72 [ICRP, 1996]

4.7.4 External hazard index (H_{ex})

The external hazard index (H_{ex}) is a parameter to keep the external gamma radiation dose from building materials to less than 1.5mGy/yr or unity. The model below was used as dose criterion to calculate external hazard index [Beretka and Mathew, 1985]. This is shown in equation (13)

$$H_{ex} = C_{Ra}/370 + C_{Th}/259 + C_K/4810 \qquad \leq \quad 1 \qquad (13)$$

Where; C_{Ra}, C_{Th} and C_K are the specific radioactivity activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. The value of the external hazard index must be less than unity for the external gamma radiation hazard to be considered negligible. The radiation exposure due to the radioactivity from construction materials is limited to 1.5 mSv/y [Beretka and Mathew, 1985].

4.7.5 Internal hazard index (H_{in})

The calculation of internal hazard index was based on the fact that radon and its daughters are also hazardous to the respiratory organs [Beretka and Mathew, 1985]. This is shown in equation (14)

$$H_{in} = C_{Ra}/185 + C_{Th}/259 + C_K/4810 \quad \leq \quad 1 \qquad (14)$$

Where; C_{Ra}, C_{Th} and C_K are the specific radioactivity activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively. For construction materials to be considered safe for construction of dwellings, the internal hazard index should be less than unity.

4.7.6 Estimation of total effective dose

The total effective dose, E_T, is calculated, by summing the individual equivalent doses due to external irradiation from the soil and ingestion of water according to ICRP publication 60 [Vennart, 1991] and represented in the form of equation(15)

$$E_T = D_{ext}\ (\text{Ra, Th, K}) + E_{ing}(w) \qquad (15)$$

Where;

D_{ext} (Ra, Th, K) is annual external equivalent dose from external gamma radiation from the soil.

$E_{ing}(w)$ is annual equivalent dose from ingestion of Ra, Th and K in the water sample.

4.8 Statistical analysis of the samples

Pearson correlation matrix technique in statistics in Microsoft excel was used to find the correlation between the various variables. This is because correlation measures the degree to which two variables behave in a particular way and also measures the strength and direction of the linear relationship between two quantitative variables.

The technique was deployed to observe how the quantitative variables such as temperature, pH, conductivity, total dissolved solids (TDS) and the activity concentrations of the interested radionuclides affect each other.

Pearson's correlation coefficient between two variables is defined as the covariance of the two variables divided by the product of their standard deviations.

a. For a population

Pearson's correlation coefficient when applied to a population is commonly represented by the Greek letter ρ (rho) and may be referred to as the population correlation coefficient or the population Pearson correlation coefficient. The formula for ρ is:

$$\rho_{x,y} = \frac{\operatorname{cov}(X,Y)}{\sigma_X \sigma_Y} = \frac{E\left[(X-\mu_X)(Y-\mu_Y)\right]}{\sigma_X \sigma_Y} \tag{16}$$

Where, cov is the covariance, σ_X and σ_y are the standard deviation of X and Y respectively, μ_X and μ_y are the mean of X and Y respectively, and E is the expectation [David, 2009].

b. For a sample

Pearson's correlation coefficient when applied to a sample is commonly represented by the letter r and may be referred to as the sample correlation coefficient or the sample Pearson correlation coefficient. A formula for r can be obtained by

substituting estimates of the covariance and variances based on a sample into the formula above. Thus, the formula for r is:

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}} \quad (17)$$

Where

$\bar{X}$ and $\bar{Y}$ are sample mean of X and Y respectively

Correlation is a measure of the linear dependence between two variables X and Y, giving a value between +1 and −1 inclusive, where 1 is perfect positive correlation, 0 is no correlation, and −1 is perfect negative correlation [David, 2009].

CHAPTER FIVE

RESULTS AND DISCUSSIONS

In this research work, Thirty-two (32) composite samples were sampled randomly within the selected areas of the small-scale site of the study area. This is made up twenty (20) soil and twelve (12) water samples. Direct gamma spectrometry and iMatic P-F Gas-less Automatic Gross Alpha/Beta counter was used to determine the concentration of the naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K and gross alpha and gross beta activity concentration respectively in the soil and water samples.

5.1 Gross-α and gross-β activity concentrations determination

A Graphical representation of the results of gross-α and gross-β activity concentrations in soil samples are shown in Figure 5.1 and Figure 5.2 respectively. Also, the results of gross-α and gross-β activity concentrations in water samples are shown in Table 5.1.

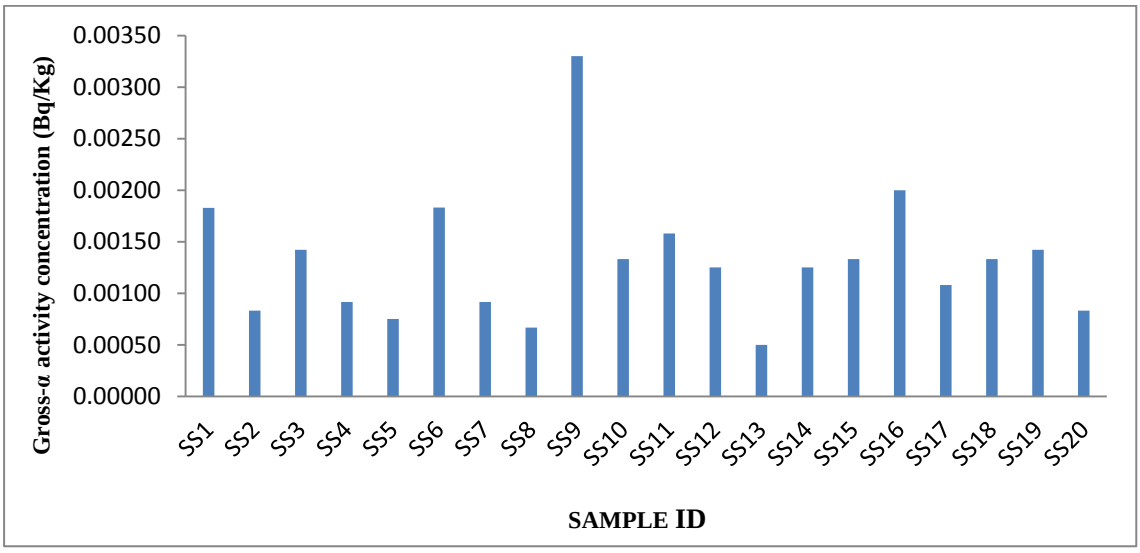


Figure 5.1: Gross-α activity concentration (Bq/kg) in the various soil samples

The activity concentrations of gross-α and gross-β in the soil samples collected in the various host communities and the control community in the study area are shown in

Figure 5.1-5.2. From Figure 4.1 about 84% of the gross alpha activity concentrations of the soil samples are less than the control (SS6) and 16% of the gross alpha activity concentrations of the soil samples are more than the control (SS6). The later may be attributed to an increase in NORM content as a result of the mining activities in the areas.

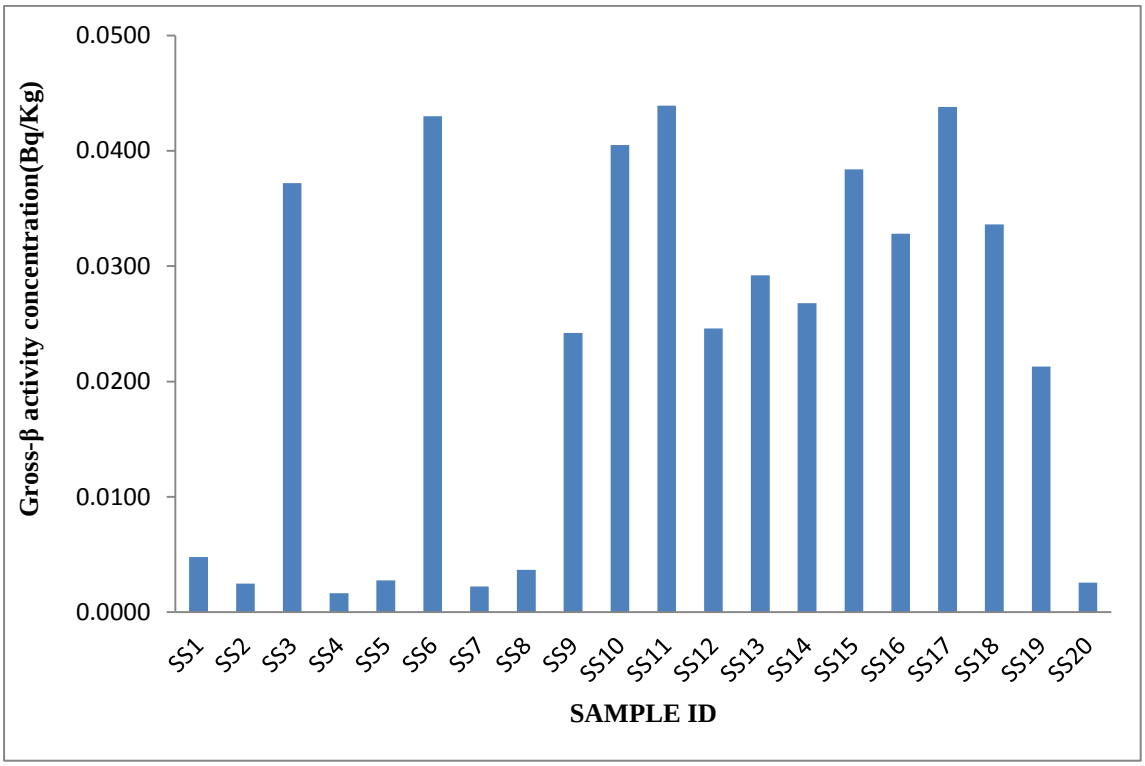


Figure 5.2: Gross-β activity concentrations (Bq/kg) in the different soil samples

The results of Figure 5.2 also show that 89% of the gross beta activity concentrations of the soil samples are less than the control (SS6). This indicates that only 11% of the study area has an increase in NORM content as a result of the small-scale mining activities in the areas.

Table 5.1: Gross-α and gross-β activity concentrations (Bq/L) in water samples from the various communities

Community	Activity concentration(mBq/L)	
	gross alpha	gross beta
Dunkwa	2.0	28.0
Nyamebekyere	1.0	4.0
Adwuman	2.0	42.0
Amoafo	2.0	45.0
Akropong	1.0	5.0
Buabinso	1.0	39.0
Tekyikrom	1.0	34.0
Mfoum(control)	2.0	34.0
Range	1.0-2.0	4.0-45.0
Mean±SD	2.0±1.0	29.0±16.0

SD-Standard deviation

Table 5.1 shows the activity concentrations of gross-α and gross-β in the water samples collected in the various communities in the study area. The activity concentration of gross-α in the water samples varied in a range of 0.001 Bq/L to 0.002 Bq/L with a mean value of 0.002 Bq/L. For gross-β, the activity concentration varies in the range of 0.004 Bq/L to 0.045 Bq/L with a mean value of 0.029 Bq/L. Gross-α and gross-β analysis are used as a screening tool to determine the total radioactivity in a sample.

According to WHO, the standard for screening levels for drinking water is 0.5 Bq/L for gross-α and 1.0 Bq/L for gross-β [WHO,2004]. Comparing the results obtained from the studied area with the WHO guideline values shows that all the values of the gross-α and gross-β are lower than the WHO standard values indicating that all the water sources in the study area do not have significant radioactivity and that do not pose any significant radiological hazard.

5.2 Physical parameters of the water samples

The results of physical parameters of the water samples are shown in Table 5.2. The physical parameters of the water samples are the following pH, temperature, conductivity and total dissolved solid (TDS). The water samples were taken from rivers, streams, tap water, borehole and wells used for irrigation, domestic and other purposes within the study area.

Table 5.2: Statistical summary of the physical parameters of the water samples

Community	pH	Tempt(˚C)	TDS(ppm)	Conductivity(µS/cm)
Dunkwa	5.9	30.8	152.2	304.4
Nyamebekyere	4.0	32.4	38.0	76.0
Adwuman	6.5	26.6	40.0	80.0
Amoafo	6.8	28.5	79.0	157.0
Akropong	7.0	30.2	75.0	150.0
Buabinso	7.1	30.9	83.0	164.0
Tekyikrom	7.6	30.4	158.0	313.0
Mfoum(control)	4.9	29.0	26.0	52.0
Range	4.0-7.6	26.6-32.4	26.0-158.0	52.0-313.0
Mean±SD	6.2±1.2	29.9±1.8	81.4±50.1	162.1±99.6

SD-Standard deviation

The pH of water is a measure of the acid-base equilibrium and in most natural waters is controlled by the carbon dioxide-bicarbonate-carbonate equilibrium system. The pH is also influenced by acidity of the bottom sediment and biological activities. The WHO recommended pH range for drinking water is 6.50-8.50 [WHO, 2004]. The safest pH level of drinking water is 7 which is the pH of pure water. According to WHO (1996) extreme exposure to pH values greater than 11 can results in eye and skin irritation and exposure to low pH values can also result in similar effects. The pH value of the water in the study area varied in the range of 4.0 in Nyamebekyere to 7.6 in Tekyikrom with a mean value of 6.2 as shown in Table 5.2. The lowest pH value recorded at Nyamebekyere was waste water obtained at the small-scale mining site. Most of the water samples were slightly acidic whilst others were near neutral or

slightly basic. Comparing the pH range from the studied area to the WHO recommended pH range for drinking water indicates that most of water sources in the study area compares well with WHO recommended pH and thus is suitable for drinking.

From Table 5.2, the temperature of the water sample varies in the range of 26.6 ˚C to 32.4˚C with a mean value of 29.9˚C. The lowest and highest temperatures were obtained in Adwuman and Nyamebekyere respectively. Although temperature has effect on the pH of water but temperature can not be used as a drinking water quality measure that should have effect on human beings. For that matter, human beings can drinks any water provided the other conditions of the water are favourable.

TDS is an indicator of a measure of salt and solids dissolved in water. A high concentration of TDS is also an indicator that harmful contaminants could warrant further investigations. Sources of dissolved solids are leaves, silt, planktons and sewage. The WHO recommended value of TDS in drinking water is in the range of 600-1000 mg/L [WHO, 2004]. The TDS of the water samples in the studied area varies in the range 26 mg/L in Mfuom to 158 mg/L in Tekyikrom with a mean value of 81.4 mg/L. The results in the study area are all below the WHO recommended value. Based on this the water in the study area is suitable for drinking.

Conductivity is the measure of the ionic strength of water. According to WHO (2004) the recommended value of conductivity for drinking water is 700 µS/cm. Dissolved solids could directly influence water conductivity, the higher the dissolved solids the higher the conductivity. The conductivity of the water in the study area varies in the

range 52 µS/cm in Mfoum to 313 µS/cm in Tekyikrom with a mean value of 162 µS/cm. The result of the conductivity of the study area is far below the guideline value recommended by WHO. Based on this the water in the study area is safe for drinking.

5.3 External Gamma Dose rate at 1m above the ground

5.3.1 Soil

Table 5.3: Average absorbed dose rate and effective dose at 1m above the ground at the soil sampling points.

Location code	Ambient dose eqivalent rate (nGy/hr)	Absorbed dose rate (nGy/hr)	Estimated annual effective dose (mSv/yr)	
	Measured	Calculated	Measured	Calculated
SS1	68.00	15.22	0.08	0.02
SS2	38.00	23.53	0.05	0.03
SS3	34.00	20.16	0.04	0.02
SS4	44.00	20.48	0.05	0.03
SS5	46.00	53.17	0.06	0.07
SS6	36.00	43.65	0.04	0.05
SS7	54.00	28.46	0.07	0.03
SS8	62.00	78.77	0.08	0.10
SS9	54.00	46.05	0.07	0.06
SS10	58.00	34.46	0.07	0.04
SS11	32.00	22.50	0.04	0.03
SS12	56.00	19.44	0.07	0.02
SS13	42.00	71.06	0.05	0.09
SS14	68.00	36.54	0.08	0.04
SS15	56.00	48.14	0.07	0.06
SS16	38.00	33.03	0.05	0.04
SS17	60.00	29.41	0.07	0.04
SS18	50.00	48.22	0.06	0.06
SS19	46.00	37.08	0.06	0.05
SS20	60.00	58.86	0.07	0.07
Range	32.00-68.00	15.22-78.77	0.04-0.08	0.02-0.10
Mean±SD	50.10±11.10	38.41±17.57	0.06±0.01	0.05±0.02

SD-Standard deviation

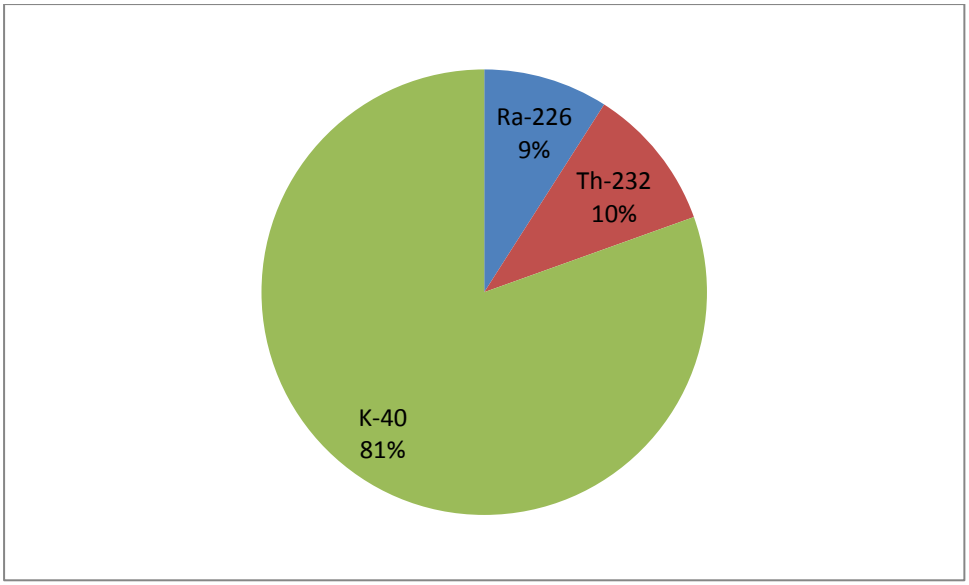


Figure 5.3: Percentage contribution to the total annual absorbed dose outdoor in air due to ^{226}Ra, ^{232}Th and ^{40}K from soil samples in the study area.

Table 5.3 shows both the calculated absorbed dose rate due to the presence of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples and measured absorbed dose rate in air at 1m above the ground. The measured absorbed dose rate varied in the range value of 32.0 (SS1) to 68.0 (SS14) nGy/hr with an average value of 50.1 nGy/hr and that of calculated absorbed dose rate also varied in the range value of 15.2 to 78.8 nGy/hr with an average value of 38.5 nGy/hr. Five samples from the measured absorbed dose rate and two samples from the calculated absorbed dose rate having high values may be attributed to the influence of the small scale mining activities in the areas. UNSCEAR reported that the worldwide average values for the relative contribution to mean dose rate in air from ^{226}Ra, ^{232}Th and ^{40}K to be 25%, 40% and 35% respectively. The world average value of absorbed dose rate as estimated by UNSCEAR is 60 nGy/hr [UNSCEAR, 2000, 1993]. From the results it can be deduced that the average absorbed dose rate from both measured and calculated values are below the recommended value of UNSCEAR (2000). Figure 5.3 shows the percentage contribution of ^{226}Ra, ^{232}Th and ^{40}K to the total absorbed dose in the soil in the study

area. The decreasing order of percentage contributions are as follows ^{40}K (81%)> ^{232}Th (10%)> ^{226}Ra (9%).

According to UNSCEAR (2000), in normal background areas, the average annual effective dose from terrestrial radionuclides is 0.46 mSv/yr. The measured annual effective dose rate varied in the range of 0.04 to 0.08 mSv/yr with an average value of 0.06±0.01 mSv/yr and that of calculated annual effective dose rate also varies in the range value of 0.02 to 0.10 mSv/yr with an average value of 0.05±0.02 mSv/yr. In the determination of these values, a dose conversion factor of 0.7 Sv/Gy, and outdoor occupancy factors of 0.2 were applied [UNSCEAR, 2000, 1993]. Therefore the annual effective doses obtained are well below the worldwide average of normal background dose received from terrestrial source.

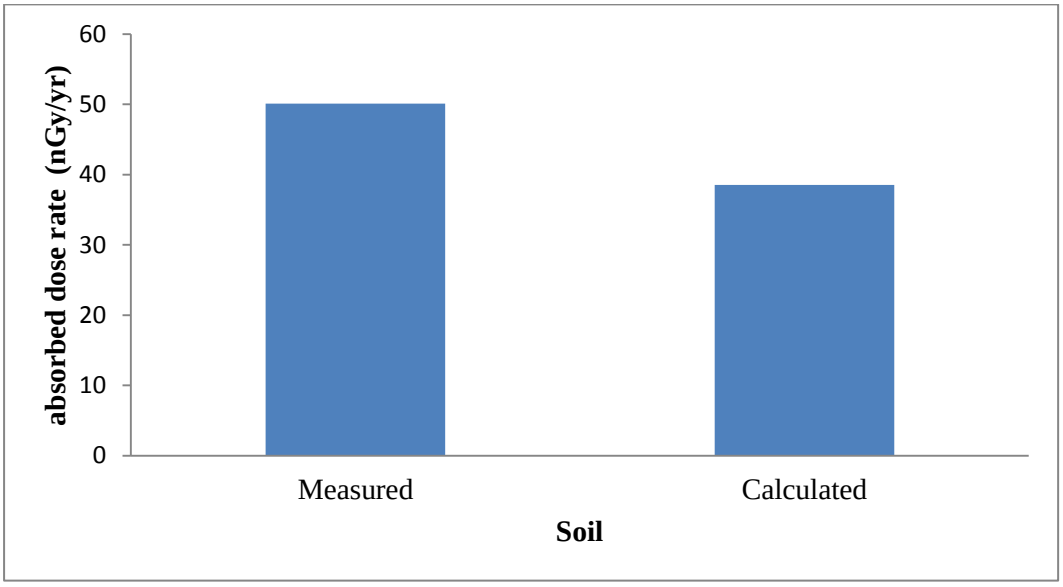


Figure 5.4: Comparison of calculated mean absorbed dose rate due to ^{226}Ra, ^{232}Th, ^{40}K and the measured absorbed dose rate in air above 1m

From Figure 5.4 a comparison was drawn between the mean absorbed dose rate calculated from the soil activity concentration with the mean absorbed dose rate measured in air. The calculated absorbed dose rate is 38.5 nGy/hr and the measured absorbed dose rate is 50.1 nGy/hr. Hence the measured absorbed dose rate is 11.6 nGy/hr more than the calculated. This could be as results of cosmic rays and cosmogenic radionuclides originating from the atmosphere.

Table 5.4: Correlation analysis (Pearson Correlation Matrix Method) used to assess the correlation between ^{226}Ra (^{238}U), ^{232}Th and ^{40}K respectively due to soil samples.

Radionuclides	Ra-226	Th-232	K-40
Ra-226	1.00		
Th-232	**0.90**	1.00	
K-40	**0.86**	**0.79**	1.00

NOTE: The correlation coefficients in bold letters are those considered

In order to determine the effect of one radionuclide on another, the Pearson Correlation Matrix Method in Microsoft excel 2000 was adopted. This method was used to assess the correlation between ^{226}Ra, ^{232}Th and ^{40}K activities concentration due to soil samples and the results are in Table 5.4. The results show a strong positive correlation between Ra, Th and K activities concentration. The order of increasing positive correlation is as follows K vs Th (0.79) < K vs Ra (0.86) < Th vs Ra (0.90). This implies thorium and radium seems to coexist well and have a greater influenced on each other compared to the rest.

5.3.2 Water

Table 5.5: Measured average absorbed dose rate and annual effective dose (outdoor) at 1m above the ground at the water sampling sites

Location code	Measured ambient dose eqivalent rate (nGy/hr)	Estimated annual effective dose (mSv/yr)
	Average	Measured
WS1	72.00	0.09
WS2	52.00	0.06
WS3	74.00	0.09
WS4	80.00	0.10
WS5	64.00	0.08
WS6	44.00	0.05
WS7	50.00	0.06
WS8	50.00	0.06
WS9	80.00	0.10
WS10	48.00	0.06
WS11	36.00	0.04
WS12	52.00	0.06
Range	36.00-80.00	0.04-0.10
Mean±SD	58.50±14.90	0.07±0.02

SD-Standard deviation

The measured absorbed dose rate values obtained at the water sampling sites are as shown in Table 5.5. The measured absorbed dose rate varied in a range 36.0 to 80.0 nGy/hr with mean value of 58.5±14.9 nGy/hr. The corresponding mean annual effective dose rate was 0.07±0.02 mSv in a range of 0.04-0.10 mSv/yr. The world average value of absorbed dose rate as estimated by UNSCEAR (2000) is 60 nGy/hr [UNSCEAR, 2000]. In normal background areas, the average annual effective dose from terrestrial radionuclides is 0.46 mSv [UNSCEAR, 2000]. The high absorbed dose rate values of 72.0, 74.0, 80.0 and 80.0 nGy/hr are obtained from WS1, WS3, WS4 and WS9 respectively. The high values reported in this study compare quiet well with similar studies conducted by Faanu (2011) in Ghana [Faanu, 2011]. The mean absorbed dose rate value of 58.5 nGy/hr is below the UNCEAR (2000) guideline

value whiles the mean annual effective dose rate value of 0.07±0.02 mSv/yr is also well below the worldwide normal background radiation levels.

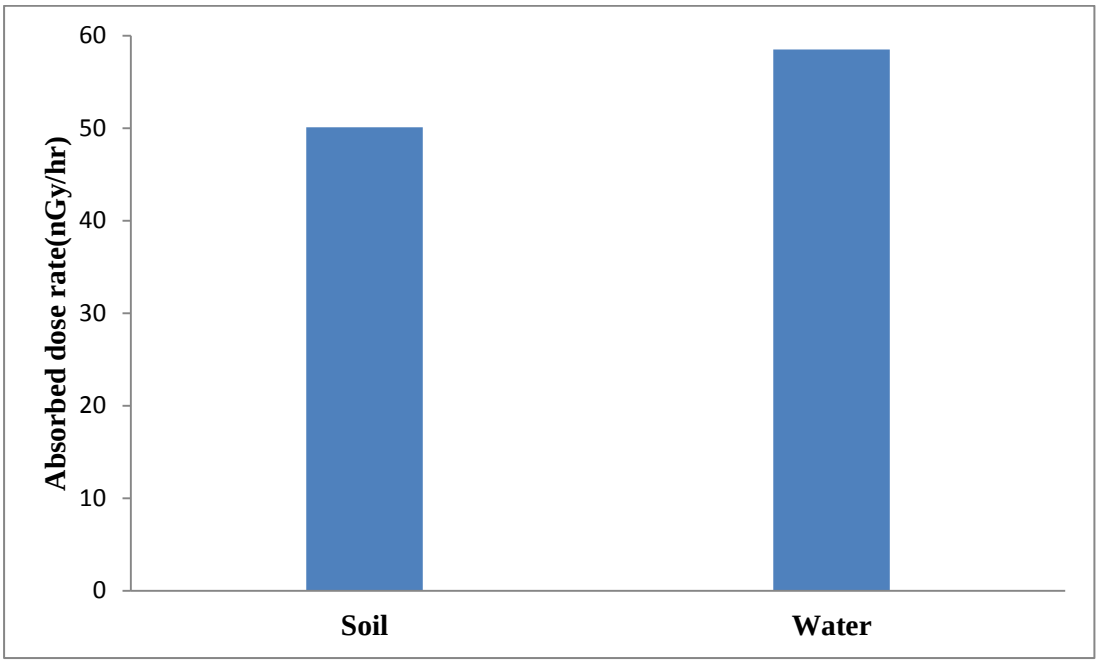


Figure 5.5: Comparison of absorbed dose rate from direct air measurement at 1m above the ground at soil and water sampling points.

The direct mean absorbed dose rate measurement at 1m above the ground at soil and water sampling sites were compared and the results are in Figure 5.5. The absorbed dose rate for soil and water are 50.1 and 58.5 nGy/hr respectively. The two results from the sampling areas compare well with each other and are below the recommended guidelines from UNSCEAR (2000) report which is 60 nGy/hr.

5.4 Activity concentration

5.4.1 Soil

Table 5.6: Average specific activities of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples

Location code	Specific Activity (Bq/kg)		
	Ra-226(^{238}U)	Th-232	K-40
SS1	11.8±2.3	9.5±0.2	96.5±2.3
SS2	20.7±6.0	9.8±0.8	192.9±3.2
SS3	11.2±3.5	17.2±13.5	111.0±2.7
SS4	14.6±3.4	11.1±0.1	169.8±3.2
SS5	32.7±14.2	42.3±17.6	300.1±4.4
SS6	30.2±12.0	33.0±11.1	234.1±10.2
SS7	18.7±7.7	22.8±13.3	144.8±4.0
SS8	45.3±11.7	67.5±5.1	409.0±5.4
SS9	28.4±6.0	33.3±13.0	307.0±4.9
SS10	18.3±3.9	34.5±13.0	123.3±5.3
SS11	14.4±4.4	17.8±9.5	122.7±2.6
SS12	12.0±3.4	14.9±9.2	118.1±3.6
SS13	43.0±7.1	57.0±7.2	402.0±7.2
SS14	22.8±5.2	30.5±11.0	181.5±3.6
SS15	31.0±8.1	35.9±8.5	291.9±4.4
SS16	18.2±4.4	24.5±17.6	234.8±4.9
SS17	15.2±3.2	21.5±4.4	224.5±5.3
SS18	35.9±8.8	29.8±11.5	327.5±5.4
SS19	22.8±6.0	27.1±13.1	243.9±5.0
SS20	43.2±16.6	49.1±5.3	221.7±4.1
Range	11.2-45.3	9.5-67.5	96.4-409.0
Mean±SD	25.4±11.1	29.4±15.6	225.9±93.8

SD-Standard deviation

The specific activity concentrations of the ^{226}Ra, ^{232}Th and ^{40}K in all the soil samples has been determined in the study area and the results are shown in Table 5.6. The mean specific activity of ^{226}Ra (^{238}U) is 25.4 Bq/kg in a range of 11.2 to 45.3 Bq/kg. For ^{232}Th the mean activity concentration is 29.4 Bq/kg in a range of 9.5-67.5 Bq/kg and that of ^{232}K is 225.9 Bq/kg in range is 96.4 to 409.0 Bq/kg. The mean activity concentration of ^{40}K is higher than that of ^{226}Ra and ^{232}Th. This can be attributed to fact that potassium is usually the most dominant nuclide in the world. The highest

activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were obtained in samples taken from a mining site at Amoafo a community in the study area. This could also be attributed to the geology of the sampling site. The worldwide average activity concentration due to U, Th and K in soil samples are 35, 30 and 400 Bq/kg [UNSCEAR, 2000]. From the results obtained the mean activity concentration of ^{226}Ra (^{238}U), Th and K are lower than the world average values.

Table 5.7: Comparison of activity concentration of ^{226}Ra,^{232}Th and ^{40}K in soils in the study area with published data (Faanu, 2011, Darko et al., 2010; UNSCEAR, 2000)

Country	Specific Activity (Bq/kg)					
	Ra		Th		K	
	Range	Mean	Range	Mean	Range	Mean
Ghana(This work)	11-45	25	10-68	29	96-409	225
Ghana(Mine)•	8-26	15	9-67	27	60-249	157
Ghana(Mine 1)*	-	29	-	25	-	582
Ghana(Mine 2)*	-	35	-	21	-	682
Algeriaˆ	2-110	30	2-140	25	66-1150	370
Egyptˆ	6-120	37	2-96	18	29-650	320
United Statesˆ	4-140	35	4-130	35	100-700	370
Indiaˆ	7-81	29	14-160	64	38-760	400
Malaysiaˆ	49-81	60	63-110	82	170-430	310
Lithuaniaˆ	3-30	50	9-46	25	350-850	600
United Kingdomˆ	2-330	-	1-180	-	0-3200	-
Hungaryˆ	12-66	29	12-45	28	79-570	370
Spainˆ	-	-	2-210	33	25-1650	470
World Averageˆ	-	33	-	45	-	420

Legend: ˆ UNSCEAR 2000 Report, * Darko et al., 2000 for Ghana (Mine 1 and 2 values), • Faanu, 2011 PhD thesis (Mine values)

Table 5.7 shows a comparison of specific activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples in the study area to similar published research works in Ghana and other countries [Faanu, 2011, Darko et al., 2010; UNSCEAR, 2000]. The results in this study area compares well with data from other published data from other

countries. The results therefore do not show any significant difference from the published works.

5.4.2 Water

Table 5.8: Statistical summary of pH, activity concentration and committed effective doses of the water samples

Location code	Type of water	pH	Specific Activity (Bq/L)			Committed effective dose (mSv)
			^{238}U/Ra-226	Th-232	K-40	
WS1	River	7.3	5.7±4.5	3.1±0.4	62.1±2.1	1.0
WS2	Mine process water	4.0	1.0±0.1	3.5±0.9	19.8±1.7	0.7
WS3	River	6.5	5.8±1.3	2.4±1.8	55.2±2.8	0.8
WS4	Tap water	5.8	3.6±2.3	2.5±1.8	56.1±2.8	0.8
WS5	Borehole	4.9	4.4±3.4	2.5±1.1	51.5±2.4	0.8
WS6	River	6.8	7.0±3.6	2.7±2.0	61.0±2.6	1.0
WS7	River	7.0	5.1±3.5	3.0±2.1	56.1±2.6	0.9
WS8	Borehole	6.4	5.5±3.2	2.8±1.8	58.8±2.2	0.9
WS9	Well	4.8	5.6±3.2	2.7±1.9	59.02.6	0.9
WS10	River	7.1	4.8±3.5	3.0±1.9	60.8±2.3	0.9
WS11	River	7.6	4.2±2.8	2.2±1.9	46.2±2.3	0.7
WS12	Well	5.3	3.8±2.7	1.9±0.7	59.2±2.4	0.7
Range		4.0-7.6	1.0-7.0	2.1-3.5	19.8-62.2	0.7-1.0
Mean±SD		6.2±1.2	4.7±1.5	2.7±0.4	53.9±11.6	0.9±0.1

SD- standard deviation

Table 5.9: Correlation analysis using Pearson correlation matrix method to assess the correlation between ^{226}Ra, ^{232}Th and ^{40}K and the physical parameters of the water samples

Parameters	pH	Conductivity (µS/cm)	TDS (ppm)	Tempt (˚C)	^{226}Ra	^{232}Th	^{40}K
pH	1.00						
Conductivity(µS/cm)	-0.10	1.00					
TDS(ppm)	-0.09	**1.00**	1.00				
Tempt(˚C)	0.11	-0.06	-0.06	1.00			
^{226}Ra	**0.59**	0.18	0.18	-0.20	1.00		
^{232}Th	-0.14	-0.21	-0.21	**0.57**	-0.24	1.00	
^{40}K	**0.53**	0.27	0.27	-0.20	**0.82**	-0.39	1.00

× Correlation coefficients in bold letters are those considered.

The specific activity concentration of ^{226}Ra, ^{232}Th and ^{40}K and the committed effective dose of the water samples are presented in Table 5.8. The range of activity concentration of ^{226}Ra, ^{232}Th and ^{40}K are 1.0-7.0 Bq/L, 2.1-3.5 Bq/L and 19.8-62.2 Bq/L with mean values of 4.7 Bq/L, 2.7 Bq/L and 53.9 Bq/L respectively. The committed effective dose rate has a mean value of 0.9±0.1 mSv/yr with a range of 0.7 to 1.0 mSv/yr. From Table 5.8, it can be observed that most of the water sources investigated are surface waters such as rivers whiles few are from boreholes and well water from underground. The main source of water supply to the study area is underground water from boreholes, tap water and wells, and likewise the main source of water supply to the mining site at the study area is surface water. There is high concentration of potassium activity concentration followed by radium and then to thorium in the water samples. The relative high concentration of potassium could be attributed largely to the use of potassium rich fertilizers for farming in the community. This is because most farms are found downstream along the rivers. According to World Health Organization (WHO) the recommended guideline levels for U, Th and K committed annual effectives dose rate in drinking water are 10 Bq/L, 1.0 Bq/L and 0.1 mSv respectively. From Table 5.8, it can be observed that the mean activity concentration of $^{226}Ra(^{238}U)$ is 0.47 times less than the guideline value and that of Th is greater than the guideline level by a factor of 2.7 [WHO,2004]. The committed annual effective dose to an adult was calculated to be 0.9 mSv and this value is about nine times higher than the WHO and the European Union guidance level of 0.1 mSv [WHO, 2004]. The reasons for this could be attributed to geological and geochemical considerations.

Pearson correlation analysis was used to find the correlation coefficient between the activity concentration of natural radionuclides and the physical parameters in water samples as presented in Table 5.9. The results show no significant correlation between most of the variables. However, there was a stronger positive correlation between total dissolved solids (TDS) and conductivity with a value of 1.0 followed by a strong positive correlation between ^{40}K and ^{226}Ra with a value of 0.82 followed by pH and ^{226}Ra with a value of 0.59 and lastly followed by pH and ^{40}K with a value of 0.53. This implies that a strong relation exist between TDS and conductivity. It also suggests that the potency of hydrogen contributes to the high activity concentration of both ^{40}K and ^{226}Ra in the water shown in Table 5.8.

5.5 Total annual effective dose

Table 5.10: Exposure pathway, the estimated annual effective dose from soil and water to the general public

Number	Exposure pathway	Average annual effective dose, mSv	Percentage Contribution (%)
1	External irradiation ^{226}Ra, ^{232}Th and ^{40}K in soil sample by gamma spectrometry	0.05	5.26
2	Ingestion ^{226}Ra, ^{232}Th and ^{40}K in water sample by gamma spectrometry	0.90	94.73
	Total annual effective dose	0.95	100.00

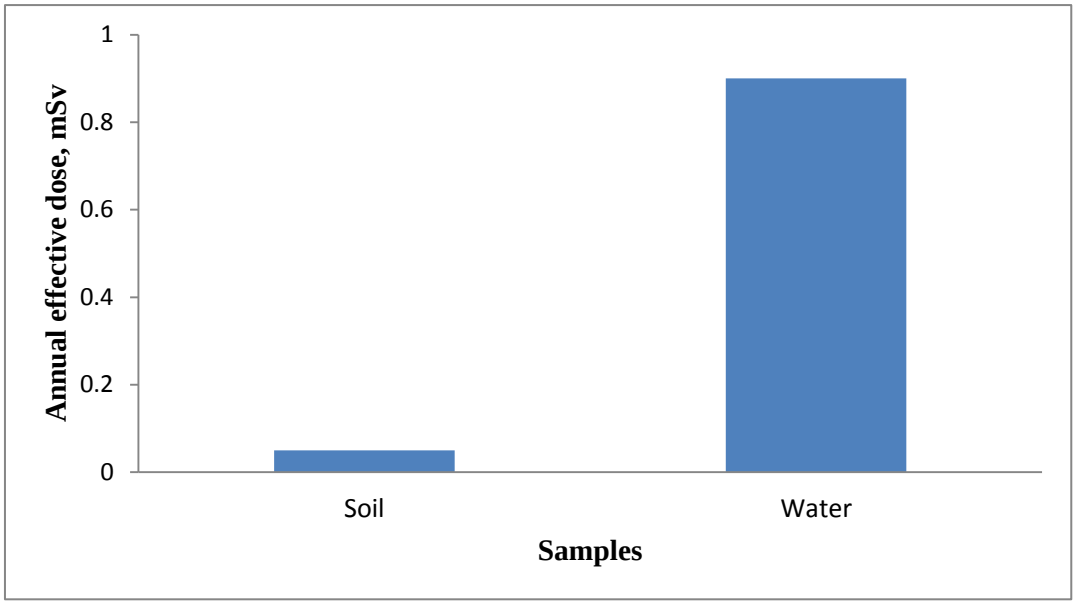


Figure 5.6: A comparison of annual effective dose of the soil and water samples from the study area.

The total annual effective dose rate which includes the contribution from ingestion of water and external irradiation due to ^{226}Ra, ^{232}Th and ^{40}K in the soil is 0.95 mSv/yr as presented in Table 5.10. The recommendations of ICRP in its publication 60 and 103 stipulate that, any exposure above the natural background radiation be kept as low as reasonably achievable but below the individual dose limits, which for occupationally exposed workers is 20 mSv average over 5 years but not exceeding 50 mSv in any single year and for members of the public is 1 mSv/year. From Table 5.10, it can be deduced that the highest contribution to the total effective dose was ingestion of water (95%) compared to 5% of external irradiation due to ^{226}Ra, ^{232}Th and ^{40}K in the soil sample.

Figure 5.6 shows a comparison of annual effective dose calculated from the soil and water. From Figure 5.6, it can be observed that the dose from ingestion of water contributes more to exposure to the populace than external irradiation of ^{226}Ra, ^{232}Th and ^{40}K in soil. In a nutshell, the total annual effective dose in the study area is less than the world recommended value of 1mSv/yr.

5.6 Radiological Hazard Assessment

Table 5.11: Results of radium equivalent activity (Raeq) and hazard indices of the soil samples from the study area.

Location code	Ra_{eq},Bq/kg	Hazard Index	
		Internal(H_{in})	External(H_{ex})
SS1	32.8	0.1	0.1
SS2	49.6	0.2	0.1
SS3	44.3	0.1	0.1
SS4	43.4	0.2	0.1
SS5	116.3	0.4	0.3
SS6	95.4	0.3	0.2
SS7	62.5	0.2	0.2
SS8	173.4	0.6	0.4
SS9	99.7	0.3	0.2
SS10	77.2	0.3	0.2
SS11	49.3	0.2	0.1
SS12	42.3	0.1	0.2
SS13	155.5	0.5	0.4
SS14	80.4	0.3	0.2
SS15	104.7	0.4	0.3
SS16	71.4	0.2	0.2
SS17	63.3	0.2	0.2
SS18	103.7	0.4	0.3
SS19	80.4	0.3	0.2
SS20	130.5	0.5	0.4
Range	32.8-173.4	0.1-0.6	0.1-0.4
Mean±SD	87.0±38.9	0.3±0.1	0.2±0.1

SD-Standard deviation

In order to assess whether the soil in the study area could be used for building purposes without giving out significant exposures to members in the study area, the following hazard assessments were made; radium equivalent activity index (Ra_{eq}) in Bq/kg, external (H_{ex}) and the internal hazard (H_{in}). The radiological risk of NORM in soils in the study area which may be used as building materials was assessed in order to compare the specific activities of building materials containing concentration of radium, thorium and potassium. The purpose of putting controls on the radioactivity

of building materials is to limit the radiation exposure due to materials with enhanced or elevated levels of natural radionuclides. The doses to members of the public should be kept as low as reasonably achievable. The maximum recommended value of Ra_{eq} in raw building materials and products must be less than 370 Bq/kg for safe use. This means that the external gamma dose must be less than 1.5 mSv/yr. To keep the external gamma radiation dose from building materials to 1.5 mSv/yr or unity, External hazard index (H_{ex}) and Internal hazard index (H_{in}) were deployed. The internal hazard index helps to check the hazardous nature of radon and its short-lived products. The external and internal hazard indices must also be less than unity in order to keep the radiation hazard insignificant. The results of radium equivalent activity (Ra_{eq}) and hazard indices of the soil samples from the study area are presented in Table 5.11. The radium equivalent activity (Ra_{eq}), External hazard index (H_{ex}) and Internal hazard index (H_{in}) varied in the range 32.8-173.4 Bq/kg, 0.1-0.4 and 0.1-0.6 with mean values of 87.0±38.9, 0.2±0.1 and 0.3±0.1 respectively. The values of the Ra_{eq}, H_{ex} and H_{in} are below the acceptable values. Hence, soils from the study area that could be used for building purposes might not pose any significant radiological hazard and thus are considered safe for use as building materials.

CHAPTER SIX

CONCLUSION AND RECOMMENDATION

6.1 CONCLUSION

Thirty-two (32) composite samples were investigated randomly within the selected areas of the small-scale mining sites of the study area. The general aim of the studies is to assess the radiological exposure to members of the general public living in Dunkwa community and its surrounding communities due to NORMS as a result of the small-scale mining activities.

In this study, the gross alpha and gross beta activity concentration, activity concentration of ^{238}U, ^{226}Th and ^{40}K in water and soil samples as well as absorbed dose rate have been determined. In addition, the annual effective dose rate and radiological indices have also been determined.

The gross-α and gross-β activity concentrations of most soil samples in the study area are below the activity concentration of the control sample. From the results 16% of the activity concentration of gross-α of the study area are more than the control, whiles for the gross-β activity concentration 11% of the study area has an increase in NORMs content as a result of the small-scale mining activities in the areas. This result, however, does not suggest that the general public may receive such amount of doses in those areas. This is because most of the areas are restricted to public access.

The gross-α and β activity concentration in the water samples were well below the WHO recommended guideline value. This means that the water sources when used

for domestic and consumption purposes may not pose any significant radiological hazard.

In addition to the radiological study of the small-scale mining activities in the study area, the physical parameters of the water sources in the mines were also determined. The physical parameters measured in the water sources are pH, temperature, conductivity and total dissolved solids (TDS). The conductivity and total dissolved solids (TDS) were all within the recommended value by WHO. For the pH, most of the water investigated in the study area were mostly acidic. Water taken from mine process water has the most acidic content of 4.0 which could be attributed to the geochemical activities at the mining site. However the public do not depend on this water for drinking. Even though most of the water sources are slightly acidic, they have most of the pH values within the acceptable limit recommended by WHO.

The mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the soil samples are 25.4, 29.4 and 225.9 Bq/kg respectively, and 4.7, 2.7 and 53.9 Bq/L respectively for water samples. The results from the study area compared well with other similar studies carried out in other countries including Ghana and are below the recommended UNSCEAR guideline value.

The results of absorbed dose rate from both external irradiation due to ^{226}Ra, ^{232}Th and ^{40}K and the measured ambient dose rate are all below the UNSCEAR recommended value.

The total annual effective dose from ingestion of ^{226}Ra, ^{232}Th and ^{40}K in water samples and external irradiation of ^{226}Ra, ^{232}Th and ^{40}K in soil samples was 0.95 mSv/yr. This suggests that the total annual effective dose of the study area is less than the world recommended value of 1mSv/yr. In addition, the maximum contributor is from exposure due to ingestion of the water sources which could be attributed to the mining practices in the study area.

In order to assess the radiological hazard to the general public in the study area. Hazard indices both external and internal and the radium equivalent were established for the soil samples. The mean radium equivalent activity, internal and external hazard were found to be 87.0 Bq/kg, 0.3 and 0.2 respectively. From the results it can be concluded that all the values are within the world acceptable limit. Hence, soils from the study area which could be used for building purposes might not pose any significant radiological hazard and thus are considered safe for use as building materials.

To conclude, it can be inferred that the worldwide average annual effective dose for normal background is higher than the measured average annual effective dose as well as the calculated in the study area. Also the total annual effective dose recommended by ICRP for the public compares well with the standard value of 1mSv/yr. These doses can not be attributed to the activities of the small scale mining alone but also largely to the illegal mining activities in the area especially those mining in the surface water sources. It was also found out that most of the exposures originate from the water sources due to ingestion of the radionuclides and this is where most of the illegal mining activities take place called dredging. Hence, the increased total annual

effective dose due to the mining practices might not result to any radiological hazard to the general public. A major concern raised now is with radiological safety of small scale miners since the present practice of the miners are unprofessional such as lack of usage of nose mask to prevent against inhalation of radon gas and the principles of radiation protection is not practised.

In conclusion the data obtained from the study will go a long way to serve as a radiological baseline data for Dunkwa-on-Offin and its host communities. Future works also need to be carried out in order to add up to the available data to aid in formulating regulation and guidelines of NORM in Ghana.

6.2 RECOMMENDATION

From the conclusion drawn it brings into light that most practices such as mining and mineral companies are ignorant of the potential problems associated with enhanced levels of NORMS in raw materials and mine tailings just to mention a few.

A. Radiation Protection

I therefore recommend and challenged the Radiation Protection Board (RPB) to intensify their creation of awareness of NORMS in the country by liaising with Environmental Protection Agency to organise educational programs on safe mining practice.

B. Research Institutes

The following areas are recommended for further studies:

1. Due to time constraint and limited resources, the study did not assess the radiological activity concentrations of all the mining communities. Further studies can be extended to cover the remaining communities in the study area.
2. According to IAEA (2003) the problem of NORM goes hand in hand with elevated concentrations of other elements that are considered toxic or hazard such as arsenic or heavy metals. I therefore recommend that studies could be done to assess the potential hazards associated non-radioactive substance.
3. Further research should be conducted to determine internal dose to the public and the mine workers. For example dust samples
4. Assessment of the levels of activity concentration of U/ Th decay series and K in a variety of food in the study area.
5. Transfer factors of radionuclides from soil to plants in the study area

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APPENDIX 1

Geometry Reference Source

Source no.	NW146
Drawing	VZ-1520/2
Volume	approximately 1000ml
Density	approximately 1.0 g/cm^3
Construction	The radionuclide mixture is homogeneously incorporated in the matrix of the source
Reference date	1 February 2006 at 12.00 GMT
Leakage and Contamination test	Wipe test according to ISO 9978
Date of wipe test	10th February 2006

Nuclide	Gamma-ray energy [keV]	Activity[Bq]	Emission rate [s^{-1}]
Americium-241	60	2.97E03	1.06E03
Cadmium-109	88	1.69E04	6.14E02
Cobalt-57	122	8.84E02	7.57E02
Cerium-139	166	9.66E02	7.71E02
Mercury-203	279	2.56E03	2.09E03
Tin-113	392	3.18E03	2.07E03
Strontium-85	514	3.89E03	3.83E03
Caesium-137	662	2.78E03	2.36E03
Yttrium-88	898	6.62E03	6.22E03
Cobalt-60	1173	3.40E03	3.40E03
Cobalt-60	1332	3.40E03	3.40E03
Yttrium-88	1836	6.62E03	6.57E03

Measuring method

The activity was measured with gamma spectrometer system consisting of a calibrated high germanium detector and a multichannel analyser

Traceabiltiy

Additional to the direct taceability to the PTR tomugh the DKD this product complies with the requirement for taceability to NIST specified and the American National Standard ‘Traceability of Radioactive Source to the NIST and Associated Instrument

Quality Control (ANSI N42.22-1995'. As a requirement of the ANSU N42.22-1995 QSA Global GmbH participates in the NEVNIST 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 the covered factor of k=2 providing a level of confidence of 95% (Ref. NIST Technical Note 1297,'Guide to the Expressior of Uncertainty in Measurement' ISO Guide, 1995)

Radioactive impurities

At the time of calibration the following radioactive impurities were detected: Cd-133m<40Bq, Cd-153<1Bq; 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 D in the UCA

APPENDIX 2

Gross-α and gross-β activity concentrations (Bq/kg) in soil samples

SAMPLE ID	Activity concentration(Bq/kg)	
	gross alpha	gross beta
SS1	0.00183	0.0048
SS2	0.00083	0.0025
SS3	0.00142	0.0372
SS4	0.00092	0.0017
SS5	0.00075	0.0027
SS6	0.00183	0.0430
SS7	0.00092	0.0022
SS8	0.00067	0.0037
SS9	0.00330	0.0242
SS10	0.00133	0.0405
SS11	0.00158	0.0439
SS12	0.00125	0.0246
SS13	0.00050	0.0292
SS14	0.00125	0.0268
SS15	0.00133	0.0384
SS16	0.00200	0.0328
SS17	0.00108	0.0438
SS18	0.00133	0.0336
SS19	0.00142	0.0213
SS20	0.00083	0.0026
Range	0.0050-0.0033	0.0017-0.0439
Mean±SD	0.0013±0.0006	0.0229±0.0164

SD-Standard deviation

Gross-α and gross-β activity concentrations (Bq/L) in water samples

SAMPLE ID	ALPHA(Bq/L)	BETA(Bq/L)
WS1	0.0013	0.0403
WS2	0.0009	0.0040
WS3	0.0018	0.0421
WS4	0.0017	0.0307
WS5	0.0019	0.0338
WS6	0.0023	0.0445
WS7	0.0006	0.0045
WS8	0.0054	0.0323
WS9	0.0008	0.0317
WS10	0.0013	0.0391
WS11	0.0012	0.0341
WS12	0.0009	0.0045
Range	0.0006-0.0054	0.0040-0.0445
Mean±SD	0.0017±0.0013	0.0285±0.0152

SD-Standard deviation

Statistical summary of the physical parameters of the water samples

Sample code	pH	Conductivity(µS/cm)	TDS(ppm)	Tempt(˚C)
WS1	7.3	150.0	75.0	32.9
WS2	4.0	76.0	38.0	32.4
WS3	6.5	80.0	40.0	26.6
WS4	5.8	262.0	131.0	28.7
WS5	4.9	52.0	26.0	29.0
WS6	6.8	157.0	79.0	28.5
WS7	7.0	150.0	75.0	30.2
WS8	6.4	255.0	128.0	35.0
WS9	4.8	617.0	309.0	28.7
WS10	7.1	164.0	83.0	30.9
WS11	7.6	313.0	158.0	30.4
WS12	5.3	238.0	118.0	28.8
Range	4.0-7.6	52.0-617.0	26.0-309	26.6-35.0
Mean±SD	6.2±1.2	209.5±151.9	105±76.1	30.2±2.3

SD-Standard deviation