GAMMA RADIATION EXPOSURE LEVELS DUE TO RADIONUCLIDES IN SOILS FROM SELECTED GOLD MINES IN KARAMOJA

BY

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DECLARATION

I, Chelangat Kadafi, declare that the work presented in this Dissertation is my own and has not been presented to this Institution or any other Institution for any award. I confirm that where I have quoted from the works of other authors, the source is always provided. With the exception of such quotations, this Dissertation is my own work.

Signed .....

Date 16/01/2016.....

APPROVAL

This Dissertation was carried out under our close supervision and is hereby submitted to Senate for award of Master of Science in Physics of Kyambogo University.

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DEDICATION

This work is dedicated to my mother, Chebet Irene.

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I would like to first thank the Almighty God Who is the source of wisdom and knowledge. He has guided me during desperate times. May His name be Praised.

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ABSTRACT

The aim of this study was to determine radiation exposure levels due to gamma ray emitting radionuclides in soils from selected gold mines in Karamoja and the associated hazard indices. The people of Karamoja use poor methods of mining gold, therefore they are exposed to ionizing radiation of unknown concentrations. In this study, 60 samples from Rupa, Nakabaat, Morulem, Acerer, Nabulatuk and Morita were analysed using a NaI (Tl) gamma-ray detector. The activity concentrations of natural radionuclides ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K in soils were measured by gamma spectroscopy using sodium iodide detector. In addition, radiological assessment due to these radionuclides was also carried out. To ensure quality control, the samples collected from the sites were transferred to polythene bags, labeled and double-bagged. They were transported in boxes whose background radiation emissions were measured with an identifier. The average activity concentrations of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K were 49.26 ± 1.58, 44.29 ± 0.74, 16.57 ± 0.40 and 599.64 ± 7.33 Bqkg^{-1} respectively. The mean absorbed dose rate was 50.44 ± 1.48 nGhr^{-1} which is below the world average dose rate of 60 nGhr^{-1}. Radium equivalent values for the area studied ranged from 83.83 ± 2.33 to 186.12 ± 3.52 Bqkg^{-1} with mean of 117.22 ± 2.30 Bqkg^{-1} which is below the world average of 370 Bqkg^{-1}. The mean external and internal hazard indices were both below unity. Therefore, though the results in the study indicated higher levels of natural radionuclides in soils of Karamoja region than the world average values, the mining activities pose no significant radiological hazard to the population and the soils from these areas can be safely used for construction purposes. The observed unprofessional practices such as lack of use of gas masks while working in the dust-filled mine caves could expose workers to possible risks from inhalation of respirable crystalline silica and radon gas; therefore miners must be educated and sensitized on the effects of exposure to radiation by the Atomic Energy Council of Uganda. These can be done by introducing Safety and Health awareness days. People of Nabulatuk and Acerer in Nakapiripirit district where concentrations of radionuclides are twice the world average levels must be advised to reduce on the time they spend in mines.

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Chapter 1

Introduction

1.1 Background of the study

Uganda is blessed with a lot of minerals such as limestone, Copper, Uranium, Jypsum, Nickel, Cobalt, Tin, Lead, Talca and Gold (Mutaizibwa, 2012). Karamoja region, found in North-Eastern Uganda is one of the regions endowed with these minerals (Mutaizibwa, 2012). According to Office for Co-ordination of Humantarian Affairs (OCHA) Report (2008), it is estimated that 82% of the Karamojong population live in poverty. This has therefore caused many of them to either go for cattle rustling or mining. Over the last decade, the UPDF (Uganda Peoples' Defence Force) campaign on forced disarmament to rid the region off guns has reduced cattle raiding between neighboring groups and has led to loss of livestock. With the increasing encroachment on their land by other people especially licenced miners over recent generations and increasingly extreme weather patterns whch can not favour farming, families have turned to artisanal mining for subsistence.

It is estimated that 18,000-20,000 men, women and children are carrying out unlicenced Artisanal and Small scale Mining (ASM) of gold, marble, limestone and gemstones (Ecological Christian Organisation (ECO) report, 2011). ASM is typically distinguished from formal mining by the use of crude, manual and hazardous methods, poor environmental standards, low capital investment and lack of planning. ASM in Karamoja has some of the highest rates of women miners in the Uganda ($40 - 70\%$) (Ecological Christian Organisation (ECO) report, 2011). Gold is most famous for its use in jewellery which is mostly due to its brilliant yellow luster and its never

fading beauty. For this reason, it has been used to decorate buildings, artwork and furniture (UNSCEAR, 2000). Since gold has a ready market, especially in the black market, gold mining is the most dominant practice in this region (Mutaizibwa, 2012).

According to the Department of Geological Survey and Mines, and the ECO report, (2011), five out of the seven districts have that make up Karamoja region have gold. Gold occurs in deformed high-grade metamorphic rocks of the type of the Mozambique Belt that stretches from north to south Karamoja in the Upe region. The major gold mines in Karamoja are, Rupa and Nakabaat in Moroto district, Acerer, Katikikele, Morita and Nabulatuk in Nakapiripirit district, Alerek and Morulem in Abim district, Karita and Rata in Amudat district, Lopedo and Sodoku in Kaabong district.

Gold mining in Karamoja is carried out manually, using shafts, iron rods, matchetes and sticks to dig tunnels and in cases where gold is associated with hard rock (e.g. in quartz veins) rather than alluvial deposits, rock is ground to mineral tailings and washed using plastic basins and, in some locations, calabashes. Miners do not use gas masks to prevent inhalation of dust (Houdet et al., 2014). This therefore puts miners at a risk of acquiring respiratory related illnesses. Miners may be occupationally exposed to radiation during extraction, transportation and processing of the minerals. They may experience internal exposures to Radon and their short-lived decay products as a result of ingested dust, where as external exposures to radiation arise from the surrounding.

Background exposures from normal levels of naturally occurring radioactive materials (NORM) are present in all environmental materials. Its estimated that 80% of the dose contribution in the environment are derived from natural radionuclides while 20% are from other sources such as nuclear processes (IAEA, 1996). However, mining has been identified as one of the potential sources of exposure to NORM (Faanu, 2011). Higher exposures arise from such human activities because they involve extraction from underground and disposal of large quantities of materials into the environment containing ^{40}K and other radionuclides in the decay series of ^{235}U and and ^{238}U. Gamma radiation from these radionuclides is the main source of external irradiation to the human body (Kinyua et al., 2011; Said et al., 2010). Exposure of the general public living near the mines may also arise from radionuclides which may be directly ingested through drinking water or uptake through the food chain

with vegetables, fish, milk, meat etc and from the reuse of the mine wastes (tailings and mine waters). People also live and farm around the mining areas and this puts them at a risk of acquiring radiation related sickneses (Ademola et al., 2014; Cathy & Linda, 2009).

Although literature shows that studies on activity concentrations of radionuclides in mines have been done in other countries, such as Nigeria, Ghana, Kenya and Saudi Arabia (e.g Ademola et al., 2014; Girigisu et al., 2013; Abdulkarim & Umar, 2013; Osoro et al., 2011; Aguko et al., 2013), there seems to be little information about activity concentrations of radionuclides and radiological indices associated with this radionuclides in mining areas in Uganda and particulary in Karamoja region.

1.2 Problem Statement

Human beings are exposed to radionuclides resulting from both artificial and natural sources such as mining and cosmic rays. Mining has been identified as one of the potential sources of exposure to these radionuclides (Faanu, 2011). Extra-legal or informal miners (not regulated or sanctioned by law) in Karamoja region may number up to 18,000 Men Women and Children seasonally, depending on rainfall and security conditions. However, the methods used for mining gold are extremly manual as no machinery is used at all (Houdet et al., 2014; Margeret et al., 2010). As a result, minners expose themselves to a number of risks including constant exposure to dust which may contain long lived Radionuclides (UNSCEAR, 2000). Also, since miners dig and enter upto about 20 metres underground without masks, inhalation of radon decay products in poorly ventilated underground mines can lead to exposure in excess of the radiation exposure limits. This may therefore cause high incidence of lung cancer in mine workers (Enid et al, 2012). It is unfortunate that data regarding levels of natural radioactivity in soils in gold mines and corresponding doses to the population for the Karamoja region is scanty.

1.3 Aim of the Study

To determine radiation exposure levels due to gamma ray emitting radionuclides in soils from selected gold mines in the Karamoja and the associated hazard indices.

1.4 Objectives of the Study

The objectives of this study were to:

(i) establish the gamma ray emitting radionuclides in the soil samples

(ii) calculate the activity concentrations of gamma ray emitting radionuclides from the soils.

(iii) evaluate external and internal hazzard indices.

(iii) evaluate the absorbed dose rate and annual effective dose.

1.5 Significance of the Study

Since very little is known about activity concentrations of radionuclides in the Karamoja region, this study will be helpful in establishing reference and baseline data for radioactivity concentration levels in Karamoja region which will be useful in evaluation of public exposure to radiations. Such data will be helpful in implementing precuationary measures, as per the rule that exposure should be "As low as reasonably Achievable" (ALARA). This study may also be important for the radiation protection authorities such as the Atomic Energy Council (AEC) in implementing radiation protection standards for the genaral population in the country. Such data will also be useful in assessing the biological effects of natural radioactivity in the environment and detect any future artificial release of radioactive nuclides. The people of Karamoja will use this data to take precuationary measures to protect themselves from gamma radiations and hence reduce any risk of genetic mutations. The data generated from this study will also be useful in conducting further research in this same field.

1.6 Scope of the Study

This study only considered gold mines in the Karamoja sub-region in North-Eastern Uganda (Fig 1.1), made up of seven districts: Abim, Amudat, Kaabong, Kotido, Moroto, Napak and Nakapiripirit. Six major gold mining areas were considered: Rupa

and Nakabaat in Moroto district, Morulem in Abim district and Acerer, Morita and Nabulatuk in Nakapiripirit district. The aim of research was to determine the radiation exposure levels due to the Gamma ray emitting radionuclides in the soils of this region and the associated hazard indices. This is majorly due to their prominence in the soils and the health risk posed by these nuclides (Tawalbeh, 2012). The radionuclides of interest were Radium, Thorium, Uranium and Potassium. The activity concentration of these radionuclides was determined so as to evaluate the hazard indices and dose rates. The study was limited to the objectives stated above. This study took six months.

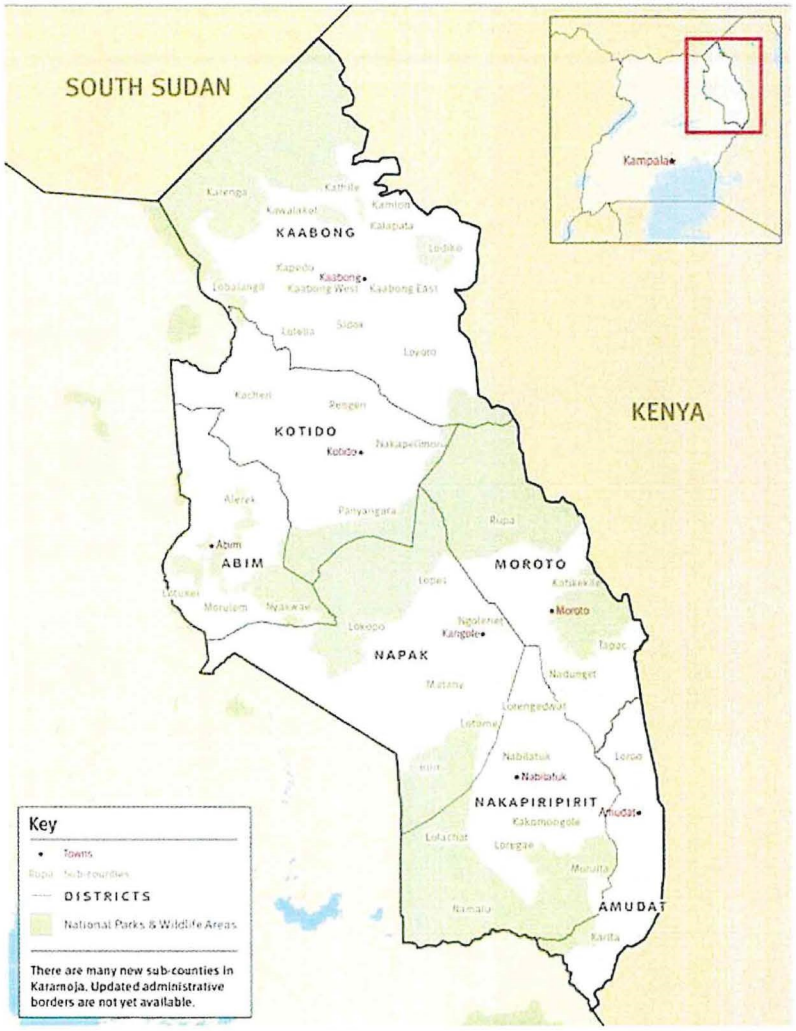

FIGURE 1.1: A map of Karamoja showing the major gold mines: Source: Google maps 2015

Chapter 2

Review of related Literature

2.1 Introduction

This chapter deals with the theory of ionising radiation and reviews related literature in line with the objectives of the study. The work done by other researchers which is related to the objectives of this study is also presented objective by objective.

2.2 Establishing the gamma ray emitting radionuclides in soil

Radionuclides such as ^{40}K, ^{232}Th, ^{238}U and ^{226}Ra occur naturally in soils. These nuclides are inco-orporated metabolically into plants and ultimately find their way into food and water (Tawalbeh et al., 2012). Gamma radiation from these radionulides represents the main source of external irradiation for the human body (Kinyua et al., 2011; Said et al., 2010). The instrumental technique used in establishing radionuclides, gamma ray interaction with matter, sources of radionuclides and the biological effects of these radionuclides are clearly discussed in the following subsections.

2.2.1 Gamma spectroscopy

This is an instrumental technique used by scientists to understand gamma rays, radioactivity and the ways in which gamma ray energies are distributed. It allows the

observation of energy peaks and intensity of gamma radiation that is emitted by a source. It also measures the level of activity concentration of naturally occurring radioactive materials in soils and building materials in the environment (Glenn, 2000; Esendu, 2012). There are principally two detectors of major importance in the detection of gamma rays; inorganic scintillators, such as sodium iodide thallium activated crystals (NaI(T1)) and solid state semiconductors such as the hyper pure germanium (HPGe) or lithium drifted germanium (Ge(Li)). NaI(TI) detectors have a higher sensitivity but poorer energy resolution than HPGe and Ge(Li) detectors. The choice of gamma detector is based upon: the required resolving power; the detector efficiency; and the simplicity of the arrangement (Glenn, 2000; Lilley, 2001; Cember, 2009).

In the case of scintillation detectors, absorption of energy by ionisation can result in an electron being elevated from the valence band to the conduction band, thus leaving a hole in the valence band. In a pure crystal such as NaI, the return of the electron into the valence band is an inefficient process and results in the emission of a photon, a condition known as scintillation. However, typical forbidden band widths in pure crystals lead to resulting photon emissions with too high an energy to lie within the visible region (Tsoulfanidis, 1995). To enhance the probability of visible photon emission during the de-excitation process, small amounts of an impurity or "activator" such as thallium (TI) are commonly added to the inorganic scintillator. The impurities create energy states within the forbidden band through which the electron can de-excite back to the valence band. Thus the transition is less than the full forbidden band gap, and the transition will give rise to a visible photon which forms the basis of the scintillation process (Tsoulfanidis, 1995; Glenn, 2000).

NaI(TI) has the highest light yield of all known scintillation materials. It has a linear response to electrons and gamma rays. Although NaI(T1) can be easily machined into required sizes and shapes, it is fragile and easily damaged through mechanical and thermal shocks and is also hygroscopic (Cember, 2009). The light collection from a scintillator must be as efficient as possible and be reflected towards the photomultiplier tube which converts the light signals into electrical signals. To achieve this, the scintillator must be as transparent as possible and surrounded by a reflector usually graded MgO powder (Tsoulfanidis, 1995; Cember, 2009).

These light collection conditions affect the eventual energy resolution of the detector in two distinct ways: The statistical broadening of the response function will worsen

as the number of scintillation photons which contribute to the measured pulse is reduced through self absorption and internal reflectance and the uniformity of light collection will determine the variation in signal pulse amplitude as the position of the photon interaction is varied throughout the scintillator (Tsoulfanidis, 1995; Cember, 2009). The highest light transfer between crystal and photomultiplier tube is achieved through direct coupling. The photomultiplier consists of two electronic systems mounted within the same unit: a photosensitive cathode which converts the photons into photoelectrons and a multiplicator tube where the electrons are repeatedly multiplied by secondary emission from dynodes (Tsoulfanidis, 1995; Cember, 2009; Glenn, 2000).

2.2.2 Gamma-ray interaction with matter

There are three principal types of radiation emitted by radioactive substances, i.e., Alpha, Beta and Gamma Radiation. Alpha and Beta particles involve high-speed electrically charged particles with mass while gamma radiation involves electromagnetic energy (Cathy & Linda, 2009). Gamma radiation also known as gamma rays is an electromagnetic radiation of extremely high frequency and consists of high energy photons. In alpha decay, an unstable nucleus disintegrates into a lighter nucleus and an alpha particle. An alpha particle consists of two protons and two neutrons (Borrelli, 1999; Flury, 2006). Nuclei heavier than lead, such as Thorium, Radon, Plutonium and Uranium, decay through Alpha emission (Cathy & Linda, 2009). When nuclei undergoes alpha decay, there is reduction in both mass and charge on the final nucleus (Krane, 1988; Gilmore, 2008), i.e

$$ {}^{A}_{Z}X \longrightarrow {}^{A-4}_{Z-2}Y_{N-2} + {}^{4}_{2}He \tag{2.1} $$

From the law of conservation of energy (Lilley, 2001), the energy liberated during the decay process is given by

$$ Q = (m_p - m_D - m_\alpha)c^2, \tag{2.2} $$

where m_p, m_D, m_α are the masses of parent, daughter and alpha particle respectively. Combining energy and momentum rules, Equation (2.2) can be expressed as

$$ E_\alpha = \frac{Q}{(1 + \frac{m_\alpha}{m_D})}. \tag{2.3} $$

In Beta decay, electrons are ejected by the nucleus (Lilley, 2001). They are high-speed electrons (Cathy & Linda, 2009). Beta decay emission is either through negative beta particle emission (Negatron) or a positive beta particle emission (Positron). An alternative process to positron decay is called Electron capture (Lilley, 2001). These emissions are discussed below.

(i) Negative beta decay (β^-): This is a type of radioactive decay which involves spontaneous creation and emission of electrons from the nucleus of a radioactive nuclide which has excess of neutrons relative to more stable isobars in the the mass parabola (Gilmore, 2008; L'Annunziata, 2007). The beta particle posses an electric charge of -1. This is expressed as

$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z+1}Y + e^- + \nu^-, \tag{2.4} $$

where ν^- is an antineutrino.

(ii) Positve beta decay (β^+): This is a type of radioactive decay in which a positron is emitted. This results from a high proton to neutron in a given nucleus ratio. The proton emits a positron, and is then converted to a neutron. The positron posses an electric charge of +1 (Borrelli, 1999; Flury, 2006; Krane, 1988). It can be written as

$$ {}^{A}_{Z}X \longrightarrow {}^{A}_{Z-1}Y + e^+ + \nu, \tag{2.5} $$

where ν is a neutrino and e^+ is a positron.

(iii) Electron Capture: This is an alternative process to positron decay. This occurs when the proton to neutron ratio is high in a given nucleus (Lilley, 2001; Krane, 1988). If a neutron defficient atom is to attain stability by positron emission, then the atom should exceed the weight of the daughter by atleast two electron masses (Cember & Johson, 2009). Electron capture can be illustrated as

$$ {}^{A}_{Z}X + e^- \longrightarrow {}^{A}_{Z-1}Y + \nu. \tag{2.6} $$

In this process, an atomic electron from the K-shell interacts with one of the protons in the nucleus and a neutron is consequently formed. The subsequent vacancy in the electron cloud is then filled by Auger process (Gilmore, 2008).

Considering negative beta decay, the tranformation energy, Q is the difference between initial and final nuclear mass (Krane, 1988), i.e.,

$$Q_{\beta-} = (m_P - m_D - m_e)c^2, \tag{2.7}$$

where m_p, m_D, m_e are the masses of parent, daughter and electron respectively. The decay energy is shared between the antineutrino and electron and appears as kinetic energy of the particle. The Q value can therefore be re-written as

$$Q_{\beta-} = (m_P - m_D - m_e)c^2 = E_e + E_{\nu-}, \tag{2.8}$$

where E_e and $E_{\nu-}$ are energy of the electron and antineutrino respectively. In the case of a positron, the tranformation energy of initial and final states can be written as (Krane, 1988)

$$Q_{\beta+} = (m_P - m_D - 2m_e)c^2. \tag{2.9}$$

Gamma radiation is an electromagnetic radiation and has no electric charge (Gilmore, 2008). It's similar to light rays and x-rays in its nature. Gamma rays occur at very high frequency. When a nucleus emits an alpha or beta particle, the daughter nucleus is usually left in an excited state. It can "jump" down to a lower state or ground state by emitting a gamma photon (Krane, 1988; Harvey, 1969). There are many interaction mechanisms responsible for gamma rays absorption in matter. However three of them are the most significant in radiation measurements. These are, photo-electric absorption, Compton scattering and pair production. These processes lead to transfer of some or all of the photon energy to the energy of the electron (Krane, 1988).

In photoelectric absorption, an absorber atom interacts with a photon, which then completely vanishes. In its place, a photoelectron is ejected from one of the atoms bound shells (Krane, 1988). For typical gamma ray energies, the photoelectron will be created from the K-shell or the most tightly bound of the atom (Glenn, 2000). The energy of the photoelectron is given by

$$E_{e-} = h\nu - E_b, \tag{2.10}$$

where E_b is the binding energy of the photoelectron in its original shell. In addition to the photoelectron, the vacancy that is created due to the interaction is quickly filled

by rearrangement of electrons and capture of a free electron. Therefore characteristic X-rays or Auger electron may be emitted (Glenn, 2000)

In Compton scattering, there is an interaction between the incident gamma photons and an electron in the absorber (Glenn, 2000). The scattered gamma-ray photon is deflected to another direction with respect to its original direction and a portion of its energy is transferred to the electron, which is called the recoil electron (Fig 2.1). The energy transferred to the electron can vary from zero to a large portion of gamma energy because it depends on all the possible angles of scattering (Krane, 1988; Glen, 2000). This process differs from photoelectric effect in that the photon transfers only a fraction of it's energy to the electron and only the free electrons in the outer orbitals are involved in the process.

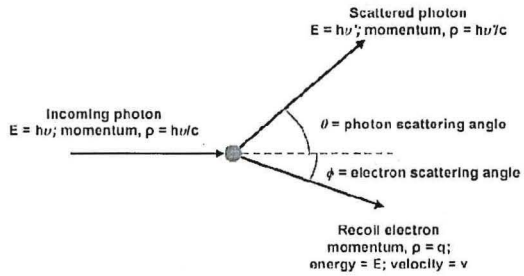

FIGURE 2.1: Schematic diagram for compton scattering: Source: Alpen, (1998)

The shift in wavelength and the scattering angle of the photons are related by equation (Cember, 2009;)

$$(\lambda_f - \lambda_i) = \frac{h}{m_e c}(1 - \cos\theta) \tag{2.11}$$

where λ_i is the initial wavelength, λ_f is the wavelength after scattering, h is the Planck constant, m_e is mass of the electron at rest and θ is the scattering angle.

The maximum energy that a photon can tarnsfer to an electron is when $\theta = 180^0$. The scattering angle can be any angle between 0^0 and 180^0 and the smaller the angle, the smaller the amount of energy transfered to the electron (Tsoulfanidis, 1995; Cember, 2009). The probability for compton scattering depends on the the number of electrons available as scattering targets and therefore increases with mass number (Alpen, 1998)

In Pair production, the incident photon creates an electron positron pair in the field. In this mechanism of energy transfer, the photon, passing near the nucleus of an atom, is subjected to strong field effects from the nucleus and may disappear as a

photon and reappear as a positive and a negative electron pair (Krane, 1988; Alpen, 1998). At higher energies (above 5 MeV) pair production becomes more and more important. The energy required to create an electron-positron pair has to be at least 1.02 MeV. All the excess energy carried in by the photon above 1.022 MeV appears in the form of kinetic energy, shared by the electron and positron. When these kinetic energies are lost through the absorbing material, two annihilation photons of energy are created as secondary products of the interaction (Krane, 1988; Glenn, 2000).

2.2.3 Sources of Radioactivity

There are majorly two sources of environmental radioactivity: Natural and man-made sources (Anthropogenic sources) (Alaamer, 2008; Kinyua et al., 2011). Human beings are continuosely exposed to radiation of both natural and artificial origin (Laith, 2013). The naturally occuring radiation arises mainly from terrestial radioactive nuclides which are widely distributed in the earth's crust (Kinyua et al., 2011). The extra-terestial sources arising from cosmic rays also contribute to natural radioactivity (Alaamer, 2008, Kinyua et al., 2011).

These radionuclides can further be categorised into two, i.e., Primordial and Cosmogenic radionuclides. Primordial radionuclides are those that were formed before the creation of the earth and are still in existance (Masitah et al., 2008). Cosmogenic radionuclides are those arising from cosmic ray interactions. Inhalation and ingestion of primordial radionuclides can lead to irradiation of the organs inside the body. Airborne radionuclides such as ^{22}Rn can enter the human body by inhalation process and represents a significant source of internal exposure (Lilley, 2001).

Some of the radioactive nuclides in the environment are due to the use of radiation for different purposes. Nuclear weapon testing is one such activity which can lead to release of radiations to the environment (UNSCEAR, 2000). It can also be as a result of Nuclear accidents, for example Chernobyl reactor accident in 1986 (Qin-Hong et al., 2010; UNSCEAR, 2000) and the Fukushima reactor accident in 2011. Other activities that can lead to release of radiations are mining and farming (Horst et al., 1998). The major artificial source of annual dose received by the worldwide population is from the use of radiation for medical purposes (Lilley, 2001).

2.2.4 Biological Effects of Radiation

Human beings have always been exposed to radiations (Kinyua et al., 2011). When a human body is exposed to radiation, either from external or internal sources, ionistaion and excitation of atoms and molecules occurs. The interaction of radiation with biological organs can result into damage of living cells. Damaged cells can trigger some diseases such as cancer, Teratogenic effects including mental retardation and birth defects, chromosomal abnormalities and inheritable diseases (Cathy & Linda, 2009). These radiations majorly affect the DNA of a person and if there are no repairs, mutation arises and persists (Cathy & Linda, 2009).

Biological effects of radiation on a cell result from both direct and indirect actions of radiation. Direct effects are produced by direct action of radiation on the human body. Indirect effects are caused by chemical reaction of the radicals and other radiation products, this usually happens at a later time. The effects of radiation exposure can be divided into stochastic effects and Deterministic effects (Cember & Johson, 2006).

For deterministic effects, the severity of the response to radiation increases with dose (Cember & Johson, 2009). Deterministic effects only occur once the threshold of exposure has been exceeded (Goodman, 2010). This therefore means that the higher dose one is exposed to, the greater is the effect. Deterministic effects of radiation are caused by significant cell death or damage. The physical effects occur when the cell death burden is large to cause obvious functional impairment of the tissue or organ (Cathy & Linda, 2009; Goodman, 2010). Such effects include Skin Erythema which occurs 1 to 24 hours after dose has been received (Goodman, 2010), sterility occurs after 2.5 to 3.5 Gy of the dose have been received (Linda & Cathy, 2009; Goodman, 2010) and teratogenesis (Fetal death) occurs when high levels of doses are exposured to a pregnant mother. The threshold dose for this effect is higher (greater than 20 Gy) than other deterministic effects.

Stochastic Effects occurs in a statitical manner. It occurs randomly and the probability of occurence is dependent on the dose of radiation (Martin & Harbson., 2006). Stochastic effects occur due to ionising effect of symmetrical translations taking place during cell division (Goodman, 2010). Cancer induction and genetic effects in future generations are expected to be as a result of this effect. If a large population is

exposed to radiation, then accumulated incidence of cancer can be expected (Cathy & Linda, 2009). The risk of developing solid cancer (abnormal cellular growths in "solid" organs such as the breast or prostate) increases with increasing dose, although the age at which exposure takes place is highly relevant (Goodman, 2010). A decline in radiosensitivity takes place with age, making young children more susceptible to radiation-induced malignancies, although the malignancies risk for the population as a whole is 5% (Goodman, 2010). Radiosensitivity is the probability of a cell or tissue suffering an effect per unit dose of radiation. It is highest in cells which are highly mitotic. For this reason, the basal epidermis, bone marrow, thymus, gonads, and lens are highly radiosenitive, whereas Muscles, bones, and nervous system tissue have a relatively low radiosensitivity.

2.3 Activity concentration of gamma ray emitting radionuclides from the soils

The material of the Earth was created in a series of nuclear processes which began with the Big Bang; and as a result nuclides were formed (Abdulkarim & Umar, 2013). Many of the nuclides were radioactive, and most have decayed away. A few of these radionuclides have half-lives longer than or comparable to the age of the Earth (Kinyua et al., 2011), and they are still in existance. Gamma radiation from these radionulides represents the main source of external irradiation for the human body (Kinyua et al., 2011; Said et al., 2010). Radioactivity and Radioactive decay are discussed in the following subsections.

2.3.1 Radioactivity

When an atomic nuclei is unstable, it will undergo spontaneous tranformation into a more stable nucleus called the "daughter". This process is called radioactivity. Radioactivity is a random process and the spontaneous tranformation of radioactive nuclides is a statistical procedure (Ing.Ivan, 2009), as a result, ionising radiations are produced (Borrelli, 1999). This leads to production of ion pairs as a result of interaction with biological material and may therefore affect the fundamental structures of biological materials. The main natural radioactive sources of ionising radiations are the long lived Uranium, Thorium and their decay series, and ^{40}K (Tawalbeh et

al., 2012). All naturally occuring and majority of artificially produced radioactive nuclei are either α -active, β -active or both and can emit a combination of α, β or γ radiations (Lilley, 2001). The probability of decay of a certain nucleus is independent of its age and each nucleus of the same isotope has the same decay probability. The decay probability is a fundamental property of an atomic nucleus and remains equal at all time (Flury, 2006; L'Annunziata, 2007). In a case where a daughter nucleus is not stable, the process continues until a daughter nucleus reaches stability (Lilley, 2001). Mathematically, the law can be expressed as

$$\frac{dN}{dt} = -\lambda N, \tag{2.12}$$

where λ is the decay constant, N, the number of radioactive atoms of a given source at a given time. The solution to the Equation (2.12) at t=0 is given by

$$N = N_0 e^{-\lambda t}. \tag{2.13}$$

The strength of radioactivity is called activity (A). Activity is defined as the number of atoms that decay per unit time (L'Annunziata, 2007; Krane, 1988). It's given by

$$A = \lambda N. \tag{2.14}$$

Usually the rate of decay can be characterised in terms of specific time frame known as half life (L'Annunziata, 2007). The half life, $t_{\frac{1}{2}}$ is the time required for one half of a certain number of active nuclei to decay (Borrelli, 1999). The dacay constant is related to half life by

$$\lambda = \frac{0.693}{t_{\frac{1}{2}}}. \tag{2.15}$$

2.3.2 Serial Radioactive Decay

This occurs when a parent nucleus forms a daughter product which is also radioactive (Krane, 1962, L'Annunziata, 2007). Consider a radioactive decay which begins with a radioactive parent nucleus, P with decay constant λ_p into daughter, D with decay constant λ_D and finally into a stable grand-daugther, G, i.e

$$P \longrightarrow D \longrightarrow G \tag{2.16}$$

It follows that the number of nuclei of P, D, and G at time, t will be given by the equations (L'Annunziata, 2007)

$$\begin{aligned} \frac{dN_P}{dt} &= -\lambda_P N_P \\ \frac{dN_D}{dt} &= \lambda_P N_P - \lambda_D N_D \\ \frac{dN_G}{dt} &= \lambda_D N_D \end{aligned} \tag{2.17}$$

where N_P and N_D are the number of parent nuclei and daughter nuclei present respectively. The solution to equation 2.17, for the number of daugther nuclei present is given by

$$N_D(t) = N_p(0)\frac{\lambda_P}{\lambda_D - \lambda_P}(e^{-\lambda_P t} - e^{-\lambda_D t}). \tag{2.18}$$

If the "grand-daughter" of a radioactive decay is still unstable, then the process continues until another product is formed. Therefore its possible to have a series of decay chains (Kapla, 1962; Lilley, 2001) and this is called radioactive equilibrium. There are two major types of radioactive equilibrium: Secular and Transient equilibrium.

Secular Equilibium occurs when the half life of the parent is much greater than that of the daughter (Lapp & Andrews, 1972; Krane, 1988; Kapla, 1962). It therefore follows from equation 2.18 that Since $\lambda_P << \lambda_D$, then $\lambda_P \simeq 0$ and $e^{-\lambda_D t} \backsimeq 1$, and therefore

$$N_D(t) = N_P(0)\frac{\lambda_p}{\lambda_D}(1 - e^{-\lambda_d t}). \tag{2.19}$$

As time increases, $e^{-\lambda_D t}$ will be neglected, and Equation (2.10) reduces to

$$N_D\lambda_D = N_P\lambda_P. \tag{2.20}$$

Therefore, for secular equilibrium, activity of the parent equals activity of the daughter.

In Transient Equilibrium, the half life of the parent is greater than that of the daughter and therefore, $\lambda_P < \lambda_D$. It follows from Equation (2.18) that,

$$N_D(t) = N_P(0)\frac{\lambda_P}{\lambda_D - \lambda_P}e^{-\lambda_p t}. \tag{2.21}$$

Since $N_P(t) = N_P(0)e^{-\lambda_p t}$, Equation (2.21) can be expressed as

$$\frac{N_D}{N_P} = \frac{\lambda_p}{\lambda_D - \lambda_P}. \tag{2.22}$$

Equation (2.21) shows that the parent and the daughter nuclides will decay at the same rate (Lapp & Andrews, 1972). In the case where the parent has short-lived half life, $e^{-\lambda_P t}$ can be neglected. Therefore, Equation (2.18) becomes

$$N_D(t) = N_P(t)\frac{\lambda_P}{\lambda_D - \lambda_P}e^{-\lambda_D t}. \tag{2.23}$$

This is called No equilibrium.

In other countries, studies on activity concentrations of radionuclides in mines have been done and published, such as Nigeria, Ghana, Kenya and Saudi Arabia (e.g Ademola et al., 2014; Girigisu et al., 2013; Abdulkarim & Umar, 2013; Osoro et al., 2011; Aguko et al., 2013).

Girigisu et al., (2013) carried out determination of activity concentration levels of radionuclides in soils from Bagega artisanal gold mining exrcises in Bagega Zamfara State, Nigeria. They found the mean values of activities of ^{40}K, ^{226}Ra and ^{232}Th respectivily were 370.79 ± 7.98 Bq kg $^{-1}$, 18.3 ± 1.77 Bq kg $^{-1}$ and 16.86 ± 0.94 Bq kg $^{-1}$. Abdulkarim & Umar also investigated Natural Radioactivity around Gold mining sites in Birin, Gwari North Western Nigeria. They found mean values of activity concentrations of ^{40}K and ^{226}Ra to be below UNSCEAR average levels whereas that of ^{232}Th was above average. In Ghana, Faanu et al., (2011) did research on determination of Natural Radioactivity in Soil and Rock Samples in a Mining Area in Ghana. They found activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K to be 13.61 ± 5.39 Bq kg $^{-1}$, 24.22 ± 17.15 Bq kg $^{-1}$ and 162.08 ± 63.69 Bq kg $^{-1}$, respectively. Aguko et al., (2013) carried out an assesment of radiation exposure levels associated with gold mining in Sakwa Wagusu, Bondo District, Kenya. They found mean values of activity concentrations of ^{40}K ^{232}Th and ^{226}Ra were all more than the world tolerable average values. They recommended that the area be considered a High Background Radiation Area (HBRA).

2.4 Evaluation of the Hazard indices

The radiation hazards associated with radionulides is determined by calculating the Radium equivalent Activity (Ra_{eq}). It is weighted sum of the activities of ^{226}Ra, ^{232}Th and ^{40}K. It is based on the assumption that 370 Bq kg^{-1} of ^{226}Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K produce the same gamma radiation dose rate (Alaamer, 2008; Kinyua et al, 2011; Girigisu et al, 2013; Masitah et al, 2008; Said et al, 2010; Muhamad et al, 2004; Ashiraf et al, 2000; Laith et al., 2013). It is calculated using the equation

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.07C_K \tag{2.24}$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} respectively.

The external hazards due to natural radionuclides of ^{226}Ra, ^{232}Th and ^{40}K are defined in terms of external or out door radiation hazard index denoted by H_{ex} (Said et al, 2010, Tufail et al, 1992, Alaamer, 2008, UNSCEAR, 2000). It is calculated using equation

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \tag{2.25}$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} respectively. The hazardous effects of radon and it's short-lived progenies to the respiratory organs should be taken into consideration. The internal exposure to radon and it's daugther products is quantified by internal hazard index, H_{in} (Girigisu et al, 2013, UNSCEAR, 2000, Kinyua et al, 2011, Said et al, 2010). This is given by the equation

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \tag{2.26}$$

where C_{Ra}, C_{Th} and C_K are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} respectively.

The values of external or out door radiation hazard index denoted by H_{ex} and internal hazard index, H_{in} must be unity for radiation hazards to be negligible.

2.5 Evaluation of absorbed dose rate and annual effective dose

The ingested and inhaled radionuclides could be concentrated in certain parts of the body, for example human lungs, kidney, liver, skeleton tissues, and musles. This may weaken the immune system, and present the most risk of human health (Cathy & Linda, 2009; Tawalbeh et al., 2012). To determine how much of these radionuclides are inhaled and ingested, radiological assessment in terms of Radium equivalent activity, Absorbed dose rate and the annual effective dose must be determined.

Radiation emitted by a radioactive material is absorbed by any material it encounters. The dose conversion factors for converting the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K into nGy h^{-1} per Bq Kg^{-1} as 0.427, 0.662 and 0.043 respectively (UNSCEAR, 1988, UNSCEAR, 2000). Using these factors, absorbed dose, D and annual effctive Dose, AED are calculated from the equations

$$\mathrm{D} = (0.427\mathrm{C}_{Ra} + 0.662\mathrm{C}_{Th} + 0.043\mathrm{C}_{K})\mathrm{nGyh}^{-1}, \tag{2.27}$$

To estimate the annual effctive dose rate (AED), the conversion coefficient, (0.7 SvGy^{-1}) from the absorbed dose to effective dose and the out door occupancy factor, (0.4) must be taken into account. The world average indoor and outdoor occupancy factors are 0.8 and 0.2 respectively. It's estimated that the indoor and outdoor occupancy factors for Uganda are 0.6 and 0.4 respectively (UNSCEAR, 1998). Using these factors, the Annual Effective Dose rate (AED) is given by equation (Aguko et al., 2013)

$$\mathrm{AED} = \mathrm{D} \times 24\mathrm{h} \times 365\mathrm{days} \times 0.4 \times 0.7\mathrm{SvGy}^{-1} \times 10^{-6} \tag{2.28}$$

In other countries, studies on radiological levels in mines have been done and published, such as Nigeria, Ghana, Kenya and Saudi Arabia (e.g Ademola et al., 2014; Girigisu et al., 2013; Abdulkarim & Umar, 2013; Osoro et al., 2011; Aguko et al., 2013). Girigisu et al., (2013) carried out assesment of radiological levels in soils from Bagega artisanal gold mining exrcises in Bagega Zamfara State, Nigeria. They found the mean values of the mean annual effective dose rate was 0.033 mSv y $^{-1}$, which is lower compared to the 0.07 mSv y $^{-1}$ UNSCEAR baseline. This means the area is safe for human activity. Abdulkarim & Umar also investigated Natural Radioactivity around Gold mining sites in Birin, Gwari North Western Nigeria. They concluded

that, since the radium equivalent activity and hazard indices were less than the world average, the mining activities in the area pose no radiological hazard to the general public.

In Ghana, Faanu et al., (2011) did research on determination of Hazard in Soil and Rock Samples in a Mining Area in Ghana. They found the average annual effective dose was 0.17 ± 0.09 mSv y $^{-1}$. The average radium equivalent activity concentration in the sample was 61.00 Bq kg $^{-1}$. The results obtained show that soil, rock and waste materials that may be used for construction of buildings may not pose any significant radiological hazards to the inhabitants in the study area. In Kenya, Osoro et al., (2011) did research on Surface soils around the proposed sites for Titinium mining project in Kenya. They found that the mean absorbed dose rate was below the world recommended average value and recommended that the values should be considered when planning appropriate monitoring programmes during the the mining operations. Aguko et al., (2013) carried out an assesment of radiation exposure levels associated with gold mining in Sakwa Wagusu, Bondo District, Kenya. They found that the radium equivivalent activity is less than the world average and they recommended that proper ventilation be put in the buildings in this area.

Chapter 3

Research Methodology

3.1 Introduction

The focus of this study was to determine the radiation exposure levels due to gamma ray emitting radionuclides. The steps to achieve the aim of the study such as design of the study, sampling and sampling techniques, measurement of activity levels, determination of radiological values, presentation of results and analysis of data are discussed in detail in the following sections.

3.2 Design of the Study

The research was concerned about determining the activity levels of radionuclides and their associated indices and there after relate it with results done by other people in Uganda and other countries. The results were compared with the world tolerable values as by UNSCEAR, (2000). The entire research was therefore descriptive, exploratory and relational. The major gold mines chosen in this study were based on population and security of the area. Three gold mines were chosen fronm Nakapiripirit, two from Mororto and one from Abim. All these gold mines are found in the southern part of Karamoja. Since the correction coeficient for each radionulide is the same in all soil samples, the major variable was the mass of the soil sample. This is because soils from different gold mines have different masses, and even the marinelli beakers in the laboratory do no have the same masses. All the samples were run for 6000s.

3.3 Exploration of the Area of Study

A survey was done on all the selected gold mines. This was done to establish the relationship between the soils that had stayed and those which were directly fresh from deep the mines, subsurface soils from this mines were also considered in the initial survey. There was no significant difference in their concentrations. In this reasearch therefore, the soils fresh from deep in the mines and subsurface soils were all considered. However in some gold mines like Nakabaat in Moroto district and Nabulatuk in Nakapiripirit district, mining is done along the river bank, and the activity concentration of ^{40}K in soils near the bank of the river was found to be higher than those soils outside the river bank, therefore in this research, soils from along the river bank were considered.

3.4 Sampling and sampling techniques

The sampling was done in Karamoja region. The mining areas were selected based on population of the area. In this research, the mines from southern part of Karamoja were chosen. These were majorly chosen from Nakapiripirit and Moroto districts.

3.4.1 Sample Collection

The soil sampling was done in accordance with California standard operating procedure for surface and subsurface soil sampling (1999). The sampling was done in a zig-zag pattern comprising six sampling areas (Masitah et al., 2008) and the position and elevation of each sampling location was determined using global positioning system (GPS). The soil samples were taken using a hand Auger (Figure 3.1). At each sampling location, 10 representative samples were collected at equal distances. The distance between a sampling point to another was about 30 metres. This was to ensure homogeneity of the samples collected from each sampling area (Ademola et al., 2014). In this way, sixty soil samples were collected from all the six chosen areas. The samples were transfered into polythene bags, labelled and double-bagged to avoid cross contamination (Girigisu et al., 2013). After removing unwanted materials such as roots small sticks etc, the samples were transported to the labarotory.

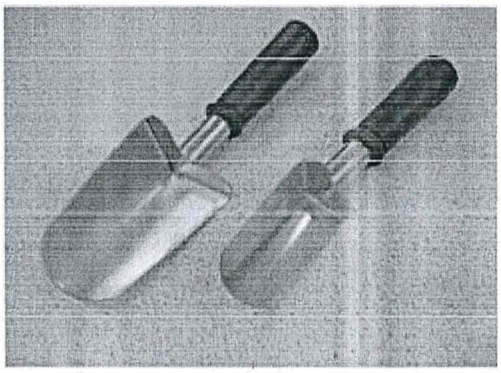

FIGURE 3.1: A Hand Auger for collecting samples

3.4.2 Sample Preparation

These samples were air dried in an oven for 12 hours to remove any moisture, because moisture is also an impurity (Kinyua et al., 2011). The samples were then passed through a 2 mm mesh sieve to remove stones and other materials such as sticks. This was done to get homogeneous samples, so as to increase the efficiency of dectection by GDM 20 (Mestiah et al, 2008 & Umar et al, 2012). Each dry sample was put into a 500 ml marinelli beaker. The containers was sealed to avoid any possiblity of of Radon escaping from the samples (Alaamer, 2008). The sealed containers were kept for about 720 hours. This was to allow for Radon and its short-lived progenies to reach secular equilibrium prior to gamma spectroscopy (Alaamer., 2008).

3.5 Instrumentation

A GDM20 Model gamma ray spectrometer (NaI (TI) detector) (Fig 3.2) was used in this study. GDM20 consists of a 7.6 cm by 7.6 cm NaI detector crystal optically coupled to a Photomultiplier Tube (PmT) and its energy resolution is less than 7% full width at half maximum. The assembly has a pre-amplifier inco-orperated in it (Mustafa et al, 2012; Said et al., 2010). The detector is enclosed in a 100 mm thick lead shield line with cadmium and copper (0.3 mm thick) sheets with a fixed bottom and movable cover. This arrangement is aimed at minimizing the effect of background and scattered Radiation. The detector is connected to an IBM compatible computer with Autodas software installed for data acquisition.

FIGURE 3.2: Spectrometer system for Nuclear Radiation (www.gammadata.net).

3.5.1 Energy Calibration of the gamma ray Detector

One of the the essential requirements in nuclear spectroscopy is the ability to identify the photo peaks present in a spectrum produced by the detector. This is achieved by carrying out energy calibration of the detector system.

In this study, the energy calibration of the GDM20 was done using ^{152}Eu source which was available. This source was placed in the detector and a spectrum obtained had several peaks but peaks whose energies ranged from 0.344 to 1.41 MeV were chosen (Mattetnik, 1995). This is because all the radionuclides of interest have energies in this range. The channel position coresponding to 0.344 MeV peak was determined using the "cen" command, then followed by the "cal" command. This designated the peak position to an energy value in MeV. The procedure was repeated for the 1.41 MeV photo peak. With this two commands, the spectrum was energy calibrated and the channel scale was replaced with an energy scale (Mattetnik, 1995).

3.5.2 Energy resolution and Effeciety of the Detector

The energy resolution of NaI (TI) detector is normally between $7 - 9\%$ for gamma ray energy of about 1 MeV and Full Width at Half Maximum (FWHM) is about

46 keV (Faanu, 2011). FWHM is the width of the gamma ray peak at half of the highest point on the peak distribution. The energy resolution of a NaI (TI) detector is related to FWHM by the equation (Akkurt et al., 2014)

$$R = \frac{FWHM}{E_0} \times 100\% \,, \tag{3.1}$$

where R is the energy resolution and E_0 is the related gamma ray energy. Equation 3.1 shows that energy resolution is proportional to the FWHM and decreases with with increasing gamma ray energy. The smaller the FWHM, the smaller is the energy resolution. Therefore the NaI (TI) detector does not give a good resolution than other detectors like HPGe (High purity Germanium) detector (Hossain et al., 2012; Glenn, 2000).

Detector effeciency (ε_t) is the ratio of the total number of counts per unit time over the whole spectrum to the number of gamma rays emmitted by the source per unit time. It is given by the equation (Hossain et al., 2012)

$$\varepsilon_t = \frac{c_t}{N_\gamma} \times 100\% \,, \tag{3.2}$$

where c_t is the total number of counts per unit time (minus the background rate) and N_γ is the number of gamma rays emmitted by the source per unit time. NaI (TI) detector is more efficient in detecting radionuclides than HPGe (High purity Germanium) detector which detects only those nuclides with low energy efficiently than nuclides with higher energy. This is NaI (TI) detector has a large area, therefore it's probability of detecting gamma rays is high (Hossain et al., 2012).

3.6 Aquisition of Primary Data

The exact masses of the samples in the marinelli beaker were obtained using beam balance and were then run in the GDM20 spectometer to obtain the spectrum. Each soil sample was counted for 6000 seconds to observe the gamma-ray spectrum. The background radiation was measured for the same time so as to minimise the uncertainity in the net counts. The background was subtracted from each spectrum of interest using autodas command. From the spectrum obtained, peaks were identified. Autodas software analysis of the spectrum gave the information needed to calculate the specific activities of the elements present in the sample. This information include

the Centroid, standard deviation (S.D), Full Width at Half Maximum (FWHM), Sum (S) and the Rate (R). The radionuclides in the chosen peaks were identified using the centroid energy of the peaks and using the correction coefficiencies in Table 3.1, the Specific Activities of the radionuclides were calculated.

3.7 Analysis of Data

The data was analysed using microsoft excel 2010 package and Python programming language for calculation of mean specific activities, standard deviation and radiological indices. Matlab programme was used to draw the required graphs.

3.8 Calculation of Specific activities

The gamma background level at the laboratory site was detetermined using an empty plastic container washed with dilute Hydrochloric acid and distiled water. The background radiation was measured under the same conditions of measurements of the samples. It was then subtracted from the measured gamma ray spectra of each sample (Alaamer, 2012). The samples were measured for 6000 s, this is because efficiency of GDM 20 increases with time. The activities of the ^{226}Ra and ^{232}Th were measured on assumption that they are in equilibrium with their daugther products, because they are not gamma emitters. Potassium is measured directly from the gamma ray photon emitted by by ^{40}K. A spectrum used to identify and determine concentrations was obtained (Said et al., 2010). The radionuclides in the chosen peaks were identified using the centroid energy of the peaks, and using the correction coefficiencies in table (3.1) the Specific Activities of the radionuclides were calculated from equation

$$\text{S.A} = \frac{\text{S}}{\text{tmC}}\,, \tag{3.3}$$

and the associated error was calculated using the equation

$$\text{Error} = \frac{\sqrt{S}}{\text{tmC}}\,, \tag{3.4}$$

where S.A is the activity concentration of the radionulide in the soil sample in Bq kg^{-1}, t is the live time of the sample, m is the mass of the soil sample and C is the

correction coefficiency of the System. The correction coefficiencies are presented in table (3.1)

Energy (Kev)	Decay Series	Coefficient
84	Th(Th-228)	0.0286
184	U(Ra-226)	0.0043
205-238	Th(Pb-212)	0.068
242	U(Pb-214)	0.0104
295	U(Pb-214)	0.0237
309-352	U(Pb-214)	0.03
538-580	Th(TI-208)	0.0101
610	U(Bi-214)	0.021
780	Eu-152	0.0296
860.56	Th(TI-208)	0.001254
1170	Co-60	0.02
1460	K-40	0.00234

TABLE 3.1: Correction Coeficiencies of the radionulides

3.9 Determination of Radiological quantities

To determine how much of these radionuclides are inhaled and ingested, radiological assessment in terms of Radium equivalent activity, Absorbed dose rate, and Hazard indices were determined. Radium equivalent Activity is calculated using the equation

$$\mathrm{Ra}_{eq} = \mathrm{C}_{Ra} + 1.43\mathrm{C}_{Th} + 0.07\mathrm{C}_{K} \tag{3.5}$$

where C_{Ra}, C_{Th} and C_{K} are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Bq kg^{-1} respectively (Harb et al., 2008; Laith et al., 2013; Alaamer., 2008).
Absorbed Dose Rate is calculated from the equation

$$\mathrm{D} = (0.427\mathrm{C}_{Ra} + 0.662\mathrm{C}_{Th} + 0.043\mathrm{C}_{K})\mathrm{nGyh}^{-1}, \tag{3.6}$$

where D is the dose rate (UNSCEAR, 2000, Fatima et al., 2008).
The annual effctive Dose is calculated using the equation

$$\mathrm{AED} = \mathrm{D} \times 24\mathrm{h} \times 365\mathrm{days} \times 0.4 \times 0.7\mathrm{SvGy}^{-1} \times 10^{-6} \tag{3.7}$$

where AED is the annual effctive Dose (Kinyua et al., 2011).

The external hazards due to natural radionuclides of ^{226}Ra, ^{232}Th and ^{40}K are defined iterms of external or out door radiation hazard index denoted by H_{ex} (Said et al., 2010, Tufail et al., 1992, Alaamer, 2008, UNSCEAR, 2000). It will be calculated using equation

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \tag{3.8}$$

The Internal Hazard Index is calculated using equation

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810}, \tag{3.9}$$

where H_{in} is the Internal Hazard Index (Girigisu et al., 2013, UNSCEAR, 2000, Kinyua et al., 2011, Said et al., 2010).

Chapter 4

Results

4.1 Introduction

This chapter presents results obtained from the study. Data from the experiment, Specific activities and Radiological indices are all handled in the following sections.

4.2 Data from the experiment

Using GDM20, the gamma-ray spectrum for the radionuclides present in the each soil sample collected from the gold mining areas of interest in the Karamoja region was obtained. The samples were labelled according to the name of the gold mine and the position from where it was collected. For example RPA means soil sample from Rupa gold mine collected from sampled position A. The first two letters represent the name of the gold mine and the last letter represent the position from where the sample was collected. For all the samples, the same criteria was followed. This was applied to all the sample spectra obtained. For Rupa gold mine, the spectrum from sample point RPA is shown in Fig 4.1 below.

From the spectrum obtained, five prominent peaks were identified. Autodas software analysis of the spectrum gave the information needed to calculate the specific activities of the elements present in the sample. This information include the Centroid, standard deviation (S.D), Full Width at Half Maximum (FWHM), Sum (S) and the Rate (R). The radionuclides in the chosen peaks were identified using the

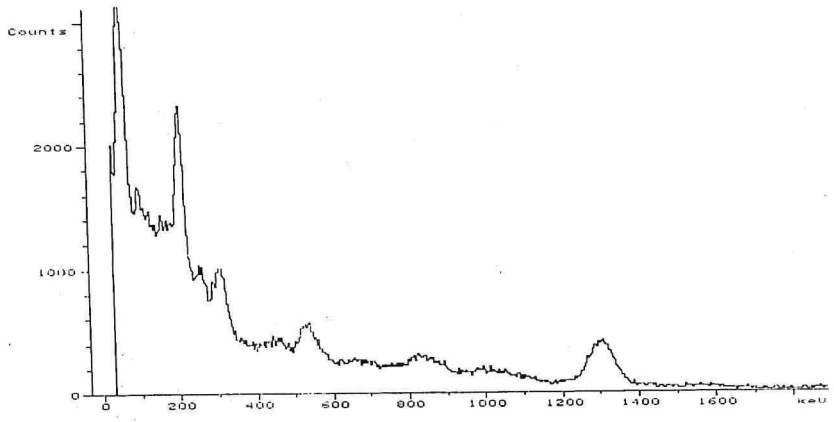

FIGURE 4.1: Sample spectrum for Rupa gold mine

centroid energy of the peaks and using the correction coefficiencies in Table 3.1, the Specific Activities of the radionuclides were calculated. The exact masses of the samples were obtained using beam balance and were then run in the GDM20 spectometer to obtain the spectrum. The information for the spectrum in the Figure 4.1 and the respective Radionuclides is as in Table 4.1 below.

Sample I.D: RPA , Sample Mass = 0.689kg, Live Time = 6004s

Radionuclides	photo peak	Centroid (Kev)	S.D (Kev)	FWHM (Kev)	Sum	Rate (s^{-1})	S.A($Bqkg^{-1}$)
U(Ra-226)	01	125.498	25.899	60.862	962	0.16	54.081
Th(Pb-212)	02	198.861	14.537	34.162	2169	0.36	8.623
U(Pb-214)	03	307.952	18.130	42.605	1393	0.23	11.224
Th(Tl-208)	04	529.642	22.253	52.294	1175	0.20	28.122
^{40}K	05	1301.939	22.327	52.468	813	0.14	83.987

TABLE 4.1: Radionuclides coresponding to each peak for the Soil Sample from Rupa Gold mine

The Radionuclides coresponding to each peak for Morulem, Nabulatuk, Morita, Acerer, and Nakabaat gold mines are shown in Appendix A.

4.3 Specific Activity of the Soil Samples

Using the information given in Table 4.1, Table 3.1 and applying Equations 3.3 and 3.4 to soil from each sampled location, the Specific activities and associated errors for Rupa gold mine were calculated and are presented in the Table 4.2.

Sample ID	Mass (Kg)	Specific Activity ($Bqkg^{-1}$)			
		^{226}Ra	^{232}Th	^{238}U	^{40}K
RPA	0.689	54.08±1.74	18.37±0.50	11.26±0.30	83.99±2.95
RPB	0.759	70.99±1.89	15.20±0.44	6.40±0.21	73.64±2.61
RPC	0.670	52.37±1.74	16.35±0.48	6.69±0.24	95.81±3.19
RPD	0.693	77.54±2.08	25.66±0.59	9.89±0.28	130.27±3.66
RPE	0.688	57.07±1.79	25.80±0.60	8.44±0.26	242.28±5.00
RPF	0.691	68.80±1.96	24.20±0.58	10.31±0.28	144.31±3.85
RPG	0.761	39.68±1.42	23.83±0.55	10.68±0.28	118.63±3.30
RPH	0.697	48.51±1.64	20.55±0.53	7.86±0.25	172.58±4.20
RPI	0.727	94.29±2.24	20.36±0.52	7.91±0.25	125.89±3.51
RPJ	0.724	57.02±1.75	21.23±0.53	7.67±0.24	100.16±3.14

TABLE 4.2: Specific Activities for Soil samples from Rupa gold mine

The specific activities of ^{226}Ra ranged from 39.68 ± 1.42 to 94.29 ± 2.24 $Bqkg^{-1}$ with mean of 62.03 ± 1.83 $Bqkg^{-1}$ where as that of ^{232}Th ranged from 15.20 ± 0.44 to 25.80 ± 0.60 $Bqkg^{-1}$ with mean of 21.16 ± 0.53, that of ^{238}U ranged from 6.40 ± 0.21 to 11.26 ± 0.30 with mean of 8.19 ± 0.51 and that of ^{40}K ranged from 73.64 ± 2.61 to 242.28 ± 5.00 $Bqkg^{-1}$ with mean of 128.76 ± 3.54 $Bqkg^{-1}$.The specific activities in Table 4.2 for each radionuclide in each of the ten sample points in Rupa gave the graph illustrated by Fig 4.2. The graph shows that, the activity concentration of ^{40}K is higher than those of ^{226}Ra, ^{232}Th and ^{238}U at all the sampled locations. The tables showing specific activities for Morulem, Nabulatuk, Morita, Acerer, and Nakabaat gold mines and their respective graphs are shown in appendix B

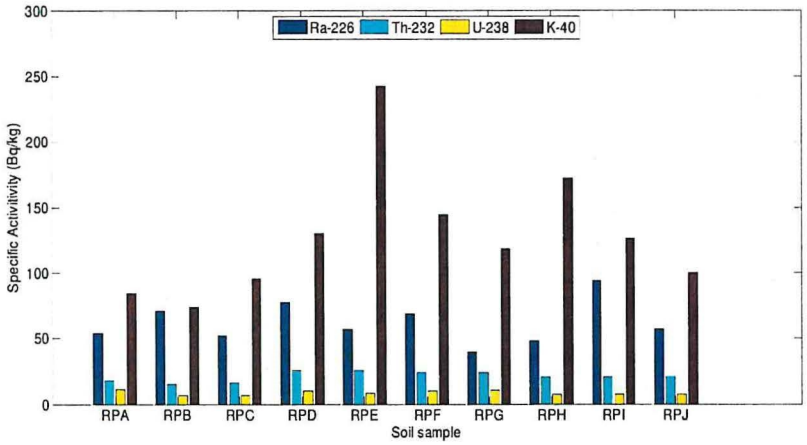

FIGURE 4.2: Specific activities for Rupa gold mine

4.3.1 Mean activities of Radionuclides for each gold mine in Karamoja region

Mining area	Specific Activity ($Bqkg^{-1}$)			
	^{226}Ra	^{232}Th	^{238}U	^{40}K
Rupa	62.03±1.83	21.16±0.53	8.19±0.50	128.76±3.54
Morulem	72.63±1.90	39.12±0.69	12.68±0.30	342.71±5.60
Nabulatuk	64.50±1.90	79.79±1.07	27.71±0.49	975.99±10.38
Morita	31.09±1.24	47.85±0.77	19.52±0.37	912.40±9.23
Acerer	31.93±1.27	44.88±0.74	17.03±0.35	808.23±8.68
Nakabaat	33.37±1.34	32.97±0.66	15.09±0.34	429.79±6.53

TABLE 4.3: Mean activities for radionuclides in Soil samples from each gold mine

The mean activities of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K for all the sampled gold mines ranged from 31.09 ± 1.24 to 72.63 ± 1.90 $Bqkg^{-1}$, 21.16 ± 0.53 to 79.79 ± 1.07 $Bqkg^{-1}$, 8.19 ± 0.50 to 27.7 ± 0.37 $Bqkg^{-1}$ and 113.39 ± 2.03 to 975.99 ± 10.38 $Bqkg^{-1}$ respectively. The over all mean and standard deviation for all the selected gold mines was calculated and is presented in the table 4.4

Radionuclides	^{226}Ra	^{232}Th	^{238}U	^{40}K
Total mean	49.26±1.58	44.29±0.74	16.57±0.40	599.64±7.33
Standard deviation	24.65±2.57	26.66±27.66	7.6±0.32	28.66±2.97

TABLE 4.4: Total mean and standard deviation of the activities for all the selected gold mines in Karamoja

A graph of mean activity of the radionuclides for all the selected gold mines is presented in (Fig 4.3) below. The graph shows that Nabulatuk and Morita have higher

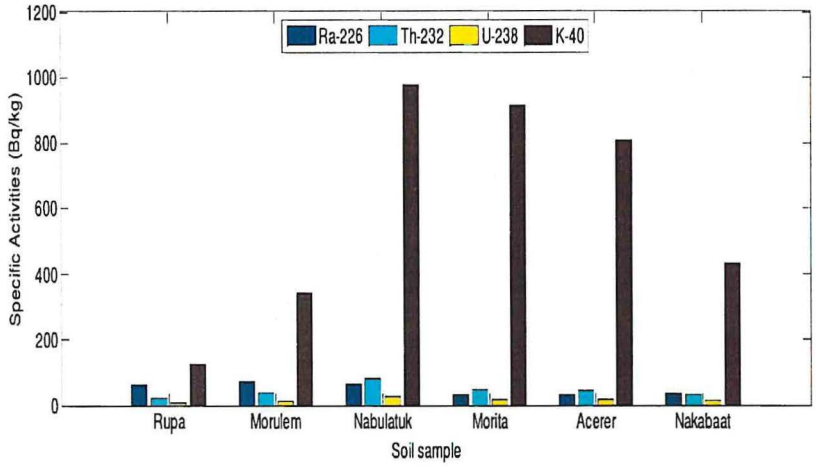

FIGURE 4.3: Mean activities for the sampled gold mines

concentrations that all the other gold mines. In all gold mines, ^{40}K is abundant.

4.4 Radiological indices

The radiological indices were calculated. Radium equivalent dose rate, Ra_{eq}, Absorbed dose rate, D, Annual effective dose, AED, and Hazard indices for all the selected gold mines all presented in the table 4.5 below. The radium equivalent activity for each mining area was calculated using equation 3.5. The absorbed dose rate and Annual effective dose rate were calculated using equations 3.6 and 3.7 respectively. The hazard indices were calculated using equations 3.8 and 3.9.

	Ra_{eq} ($Bqkg^{-1}$)	D ($nGhr^{-1}$)	AED ($mSvy^{-1}$)	H_{ex} ($Bqkg^{-1}$)	H_{in} ($Bqkg^{-1}$)
Rupa	93.28±2.61	35.31±1.31	0.14±0.00	0.28±0.01	0.44±0.01
Morulem	131.21±2.93	50.21±1.53	0.21±0.00	0.42±0.01	0.61±0.01
Nabulatuk	186.12±3.52	75.31±1.96	0.34±0.01	0.69±0.01	0.86±0.01
Morita	106.53±2.40	55.30±1.42	0.23±0.00	0.46±0.01	0.54±0.01
Acerer	102.33±2.39	51.16±1.39	0.21±0.00	0.42±0.01	0.51±0.01
Nakabaat	83.83±2.33	35.33±1.29	0.15±0.00	0.31±0.01	0.39±0.01

TABLE 4.5: Radiological indices for the sampled gold mines in Karamoja

The graph to show how hazardous the soils from the selected gold mines of Karamoja was plotted and is shown in Fig 4.4

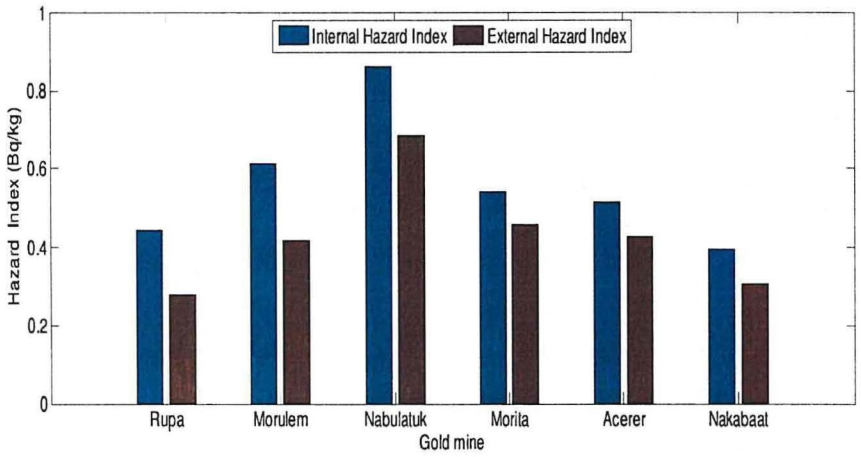

FIGURE 4.4: Hazard indices in soils from selected gold mines in Karamoja

The graph shows that, in all sampled gold mines, the internal hazard index exceeds the external hazard index though both are below unity.

4.5 Comparison of activity concentrations with similar studies

The activity concentrations of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K from this study were compared with similar studies from other countries and are presented in Table 4.6

Country	Specific Activity ($Bqkg^{-1}$)				References
	^{226}Ra	^{232}Th	^{238}U	^{40}K	
Kenya	44.20	40.30	-	639.60	Aguko et al., 2013
Nigeria	-	26.40	55.30	505.10	Ademola., 2014
Nigeria	-	62.69	37.36	997.52	Nasiru et al., 2013
Ghana	13.61	24.22	-	162.08	Faanu et al., 2011
Kenya	20.90	27.60	-	69.50	Osoro et al., 2011
Nigeria	18.30	16.30	-	370.79	Girigisu et al., 2013
Nigeria	2.39	51.98	-	390.95	Abdulkarim& Umar, 2013
World Average	35	30	35	400	UNSEAR, 2000
Uganda	49.26	44.29	16.57	599.7.33	Current study

TABLE 4.6: Comparison of activity concentrations with similar studies

Table 4.6 shows results on similar studies carried out in other countries. From the table, it can be seen that the results are above the world recommended averages except for ^{238}U.

Chapter 5

Discussions, Conclusions and Recommendations

5.1 Introduction

This chapter describes the discussion of results obtained, conclusions and recommendations. These were based on the objectives of the study. The breakdown of the chapter is described in the subsequent sections.

5.2 Discussion of results

The specific activities of the radionuclides and the radiological indices in soils from gold mines of Karamoja are all discussed in this section.

5.2.1 Specific activities

The specific activities and mean activities of the radionuclides of interest per mining area were calculated. In Rupa gold mine, the specific activities of ^{226}Ra ranged from 39.68 ± 1.42 to 94.29 ± 2.24 Bqkg^{-1} with mean of 62.03 ± 1.83 Bqkg^{-1} where as that of ^{232}Th ranged from 15.20 ± 0.44 to 25.80 ± 0.60 Bqkg^{-1} with mean of 21.16 ± 0.53, that of ^{238}U ranged from 6.40 ± 0.21 to 11.26 ± 0.30 with mean of 8.19 ± 0.51 and that of ^{40}K ranged from 73.64 ± 2.61 to 242.28 ± 5.00 Bqkg^{-1} with mean of 128.76 ± 3.54

$Bqkg^{-1}$. These values are generally lower than the world average values published by UNSCEAR, (2000) which are 35, 30, 35 and 400 $Bqkg^{-1}$ for ^{226}Ra ^{232}Th ^{238}U and ^{40}K respectively except for ^{226}Ra which is higher than this figures. The mean specific activity for all the sampled locations in Rupa gold mine are lower than those obtained by Aguko et al., (2013) and Ademola et al., (2014), (Table 4.5) except for ^{226}Ra which is higher than the values obtained by Aguko et al., (2013) and UNCEAR, (2000). The results of study compare well with results obtained by Bede et al., (2015). The difference in results may be attributed to difference in geological and geographical conditions. This therefore means that the radiation risk from the soil is negilgible and the soils may not be so dangerous to the health of the people in the mine.

In Morulem, the specific activities of ^{226}Ra ranged from 47.58 ± 1.48 to 95.68 ± 2.19 $Bqkg^{-1}$ with mean of 72.63 ± 1.90, that of ^{232}Th ranged from 30.15 ± 0.63 to 49.10 ± 0.78 $Bqkg^{-1}$ with mean of 39.12 ± 0.69 $Bqkg^{-1}$, that of ^{238}U ranged from 8.35 ± 0.26 to 16.61 ± 0.34 $Bqkg^{-1}$ with mean 12.68 ± 0.30 $Bqkg^{-1}$ and that of ^{40}K ranged from 200.05 ± 4.52 to 483.95 ± 6.76 $Bqkg^{-1}$ with mean of 342.71 ± 5.60 $Bqkg^{-1}$. The distribution of these radionuclides is not generally uniform in all sampled locations. In all locations ^{40}K is the most abundant and ^{238}U had the least concentration. According to the world averages of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, the mean activity of ^{226}Ra is twice the world average value of 35 $Bqkg^{-1}$ wheres as that of ^{232}Th is also above the world average value of 30 $Bqkg^{-1}$ and ^{40}K are below the world avarage of 400 $Bqkg^{-1}$ (UNSCEAR, 2000). In comparison with other similar studies in other countries (Table 4.5), the mean values obtained in this gold mine are lower than those obtained by Nasiru et al., (2013) and Aguko et al., (2013) except for ^{226}Ra whose mean value is higher than the results obtained by these people. The difference in mean values may be as a result of difference in geological formations of these mines and partly due to other economic activities taking place in this area such as farming. Although the concentrations of ^{232}Th and ^{40}K are not very high, the soils from this gold mine may be dangerous to the health of the people, given the poor culture of not putting on protective gear such as masks given the fact that the concentration of ^{226}Ra is very high .

In Nabulatuk gold mine, the specific activities of ^{226}Ra ranged from 25.41 ± 1.22 to 130.18 ± 2.82 $Bqkg^{-1}$, that of ^{232}Th ranged from 43.23 ± 0.77 to 103.58 ± 1.31 $Bqkg^{-1}$, that of ^{238}U ranged from 16.97 ± 0.36 to 35.28 ± 0.56 $Bqkg^{-1}$ and that of ^{40}K

ranged from 854.89 ± 10.06 to 1113.78 ± 11.90 Bqkg^{-1}. The istribution of radionuclides in sampled locations is not uniform. In all the sampled locations, ^{40}K was the highest and ^{238}U was the least abundant. The mean activities for ^{226}Ra, ^{232}Th and ^{40}K were 64.50 ± 1.90,79.79 ± 1.07, 27.7 ± 0.49 and 975.99 ± 10.38 Bqkg^{-1} respectively. According to the recommended world activity levels, the mean activities of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K in nabulatuk gold mine are all above the world permissible average of 35, 30, 35 and 400 Bqkg^{-1} for ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K respectively (UNSCEAR, 2000). In comparison with other similar studies from other countries (Table 4.5), the results obtained from this gold mine are higher than those obtained by Ademola et al., (2014), Aguko et al., (2013) and those obtained by Girigisu et al., (2013). Gold mining in Nabulatuk is done along the river bank, therefore these very high figures and difference in results from those done by other people may be due to the fact that during rainy season, the river floods and soils brought about by floods from different places are left along the the river bank therefore the some radionuclides can be transported along with this soils. This gold mine should be classified as high Background Radiation Area (HBRA). This therefore mean that, the people at this gold mine risk acquiring radiation related sicknesses, given the given the poor culture of not putting on protective gear such as masks.

In Morita gold mine, The specific activities of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K for each sampled location ranged from 13.89 ± 0.86 to 54.91 ± 1.71 Bqkg^{-1}, 29.98 ± 0.60 to 67.31 ± 0.95 Bqkg^{-1}, 11.03 ± 0.29 to 26.91 ± 0.42 and 694.68 ± 7.95 to 1532.72 ± 12.44 Bqkg^{-1} respectively. The distribution of radionuclides is not uniform in all the sampled locations though ^{40}K is very high in location MRJ as compared to other locations sampled. In all sampled locations, ^{40}K is highest and ^{238}U is the lowest. The mean activities for ^{226}Ra, ^{232}Th and ^{40}K were 31.09 ± 1.24, 47.85 ± 0.77, 19.53 ± 0.39 and 912.40 ± 9.23 Bqkg^{-1} respectively. The mean activities of ^{226}Ra is below the world average value of 35 Bqkg^{-1}, that of ^{232}Th is above the world average of 30 Bqkg^{-1} (UNSCEAR, 2000) where as that of ^{40}K is twice the world average values published by UNSCEAR, (2000). The values obtained in this study compare well with those obtained by Nasiru et al., (2013) (Table 4.5). Since specific activites are high, the soils from this gold mine may be dangerous to the health of the people, given the poor culture of not putting on protective gear such as masks and very long time of stay in the mining holes.

In Acerer gold mine, The specific activities of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K for each

sampled location ranged from 22.47 ± 1.07 to 41.79 ± 1.45 Bqkg^{-1}, 29.75 ± 0.61 to 66.51±0.91 Bqkg^{-1},9.79±0.27 to 28.60±0.46 Bqkg^{-1} and 701.58±8.26 to 920.37±9.11 Bqkg^{-1}. The radionuclides are not uniformly distributed in all the sampled locations of Acerer though for ^{40}K locations like ACJ and ACH have higher activity concentrations than the other locations. In all the sampled locations, ^{40}K was the highest and ^{238}U was the lowest. The mean activities for ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K were 31.93 ± 1.27, 44.88 ± 0.74, 15.01 ± 0.34 and 808.23 ± 8.68 Bqkg^{-1} respectively. The mean activity of ^{226}Ra is below world average where as that of ^{232}Th ^{40}K are higher than the world average values published by UNSCEAR, (2000). The values obtained from this gold mine compare well with those obtained by Nasiru et al., (2013) (Table 4.5). Since specific activites are high, the soils from this gold mine may be dangerous to the health of the people, given the poor culture of not putting on protective gear such as masks and very long time of stay in the mining holes.

In Nakabaat gold mine, the specific activities of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K for each sampled location ranged from18.42 ± 0.94 to 69.85 ± 2.11 Bqkg^{-1}, 19.15 ± 0.51 to 41.48 ± 0.70 Bqkg^{-1}, 10.84 ± 0.27 to 18.39 ± 0.40 and 281.36 ± 5.75 to 575.65 ± 7.85 Bqkg^{-1} respectively. The radionuclides are not uniformly distributed in all the sampled locations of Nakabaat. In all the sampled locations, ^{40}K was the highest and ^{238}U was the lowest.. The mean activities for ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K were 33.37±1.34, 32.97±0.66, 15.09±0.34 and 429.79±6.53 respectively. The mean specific activities of the radionuclides are generally lower than the world average values, except for ^{40}K which is just slightly above the world average figure. All these values obtained are lower than those obtained by Nasiru et al., (2013) and Girigisu et al., (2013) (Table 4.5). The difference may be attributed to difference in geological formation of the mine. Athough ^{40}K above the world average figure, the radiation risk from the soil is negilgible.

The mean activities of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K for all the sampled gold mines ranged from 31.09±1.24 to 72.63±1.90 Bqkg^{-1}, 21.16±0.53 to 79.79±1.07 Bqkg^{-1}, 8.19±0.50 to 27.7±0.37 Bqkg^{-1} and 113.39±2.03 to 975.99±10.38 Bqkg^{-1} respectively. The overall mean activities of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K were 49.26 ± 1.58, 44.29±0.74, 16.57±0.40 and 599.64±7.33 Bqkg^{-1} respectively. This shows that the activity concentrations of the radionuclides in soils from the sampled gold mines of Karamoja are generally above the world average values of 35, 30, 35 and 400 Bqkg^{-1} for ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K respectively for soils as published by UNSEAR, (2000).

The results from this study compare well with published data from other countries around the world (Table 4.5). Nasiru et al., (2013) got higher values than those obtained in this study. Lower values were found by Girigisu et al., (2013) in Nigeria, Osoro et al., (2011) in Kenya and Faanu et al., (2011) in Ghana. The variation of natural radioactivity levels at different mines in different countries may be attributed to variation of concentrations of radionuclides in the geological formations and the economic activities taking place in the mining area, such as farming with use of fertilizers which may increase the concentration of potassium in the soils.

5.2.2 Radiological indices

Radium equivalent dose rate, Ra_{eq}, Absorbed dose rate, D, Annual effective dose, AED, and Hazard indices for all the gold mines were calculated. Morita gold mine had a higher equivalent activity than all the others. The equivalent activity for the gold mines were 93.28 ± 2.61, 131.21 ± 2.93, 186.12 ± 3.52, 106.53 ± 2.40, 102.33 ± 2.39 and 83.83 ± 2.33 Bqkg^{-1} for Rupa, Morulem, Nabulatuk, Morita, Acerer and Nakabaat respectively. The mean Radium equivalent activity for all the sampled mines was found to be 117.22 ± 2.30 Bqkg^{-1} which is below the world average of 370 Bqkg^{-1} (ICRP, 2000; UNSCEAR, 2000). This means the soils from these gold mines pose no much radiation risk to the people working in the gold mines.

The absorbed dose rate was calculated for all the gold mines using equation 3.6. Only Nabulatuk with a dose rate of 75.31 ± 1.96 had a higher rate than the world average dose of 55 nGhr^{-1} (ICRP, 2000; UNSCEAR, 2000). The dose rates for Rupa, Morulem, Morita, Acerer and Nakabaat were 35.31 ± 1.31, 50.21 ± 1.53, 55.30 ± 1.42, 51.16 ± 1.39 and 35.33 ± 1.29 nGhr^{-1} respectively. The mean Absorbed dose rate for all the gold mines was 50.44 ± 1.48 nGhr^{-1} which is below the world average dose rate (ICRP, 2000; UNSCEAR, 2000). This means the soils pose no significant health risk to the people working in these mining areas except for Morita and Nabulatuk which have high absorbed dose rates than the whole average of 55 nGhr^{-1}.

The annual effective dose rate, AED, was calculated from equation 3.7. All selected gold mines were found to have annual effective dose rates below unity. The effective dose rates for Rupa, Morulem, Nabulatuk, Morita, Acerer and Nakabaat, 0.14 ± 0.00, 0.21 ± 0.00, 0.34 ± 0.01, 0.23 ± 0.00, 0.21 ± 0.00 and 0.15 ± 0.00 nGyr^{-1} respectively. The mean annual effective dose rate was 0.21 ± 0.00 nGyr^{-1} which is less than unity

as recommended by UNSCEAR, (2000) and ICRP, (2000). Therefore the soils are safe for construction purposes in this area.

The external hazard index for each gold mine was calculated. All mines were found to have external hazard indices less than unity. The external hazard indices for Rupa, Morulem, Nabulatuk, Morita, Acerer and Nakabaat 0.28 ± 0.01, 0.42 ± 0.01, 0.69 ± 0.01, 0.46 ± 0.01, 0.42 ± 0.01 and 0.31 ± 0.01 Bqkg^{-1} respectively. The mean external hazard index for all the gold mines was found to be 0.43 ± 0.01 Bqkg^{-1} which also less than unity as per UNSCEAR, (2000). The soils therefore do not pose any significant radiological hazard to the people working these gold mines.

The internal hazard index for each gold mine was calculated using equation 3.6. The internal hazard indices for all the sampled mines were found to be less than unity except for some sampled points like NBC in Nabulatuk which were above unity. Nabulatuk generally has high internal hazard index and given the poor practice of not putting on masks and any other protective gears while mining, the people in this area are at a risk of acquiring radiation diseases. Therefore the mining activities in this gold mine should be regulated by the government through the Atomic Energy Council. The indices for Rupa, Morulem, Nabulatuk, Morita, Acerer and Nakabaat were 0.44 ± 0.01, 0.61 ± 0.01, 0.86 ± 0.01, 0.54 ± 0.01, 0.51 ± 0.01 and 0.39 ± 0.01 respectively. The mean internal hazard index for all the gold mines was found to be 0.53 ± 0.01. This figure is less than unity as required by UNSCEAR, (2000) and ICRP, (2000). Therefore the mining activities in the sampled gold mines pose no significant radiological hazard to the population.

5.3 Conclusion

The mean concentrations of ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K were 49.26 ± 1.58, 44.29 ± 0.74, 16.57 ± 0.40 and 599.64 ± 7.33 Bqkg^{-1} respectively. These values were higher than world average values of 35, 30 and 400 Bqkg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively (UNSCEAR, 2000) except for ^{238}U which was lower than the published value by UNSEAR, (2000). In all samples ^{40}K had the highest concentrations. This area should therefore be classified as a High Background Radiation Area (HBRA) especially Nabulatuk, Acerer and Morita gold mines which have very high activity concentrations and high absorbed dose rates.

The mean Absorbed dose rate was 50.44 ± 1.48 nGhr^{-1} which is below the world average dose rate of 55 nGhr^{-1} (UNSCEAR, 2000; ICRP, 2000). Radium equivalent values for the studied area ranged from 83.83 ± 2.33 to 186.12 ± 3.52 with mean of 117.22 ± 2.30 Bqkg^{-1} which is below the world average of 370 Bqkg^{-1} (UNSCEAR, 2000; ICRP, 2000). The values of external and internal hazard indices were both below unity. Therefore the mining activities in the sampled gold mines pose no significant radiological hazard to the population except Nabulatuk and Morita gold mines with very absorbed dose rates.

Though the results in the study indicate higher levels of natural radionuclides in selected gold mines in Karamoja region than the world average values, the mining activities pose no significant radiological hazard to the population and the soils and rocks area can be safely used for construction purposes. However, the observed unprofessional practices such as lack of use of gas masks while working in the dust-filled mine caves could expose workers to possible risks from inhalation of respirable crystalline silica and radon gas, therefore miners should be educated and safely culture incalcated in the mining practice of the area. A decline in radiosensitivity takes place with age, making young children more susceptible to radiation-induced malignancies. Although the malignancies risk for the population as a whole is 5% (Goodman, 2010), young workers below the age of 18 are at a higher risk of suffering radiation realated illneses such as Cancer.

5.4 Recommendations

1. Mining activies must be supervised and regulated by appropriate authorities especially the Atomic Energy Council (Uganda).

2. People from Nabulatuk and Acerer in Nakapiripirit district where the concentrations of this radionuclides are twice the world average must be advised to reduce on time of exposure. This can be done through sensitisation of the people on the effects of excessive exposure to radiation by the radiation protection authorities.

3. More research should be done in this area especially in other parts of Karamoja like Kotido, Kaabong and Amudat where gold minining is also taking place to get information regarding the activity concentrations and absorbed dose rates.

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APPENDIX A

SPECIFIC ACTIVITIES FOR SOIL SAMPLES FROM GOLD MINES IN KARAMOJA SUB-REGION

ID	PEAK	N	TIME	MASS	C	S.A	Error
RPA	1	962	6004	0.689	0.0043	54.0812	1.7436
	2	2169	6004	0.689	0.0608	8.6237	0.1852
	3	1398	6004	0.689	0.0300	11.2649	0.3013
	4	1175	6004	0.689	0.0101	28.1227	0.8204
	5	813	6004	0.689	0.0023	83.9875	2.9456
RPB	1	1410	6086	0.759	0.0043	70.9867	1.8905
	2	1400	6086	0.759	0.0608	4.9848	0.1332
	3	887	6086	0.759	0.0300	6.4007	0.2149
	4	1186	6086	0.759	0.0101	25.4208	0.7382
	5	796	6086	0.759	0.0023	73.6416	2.6102
RPC	1	906	6005	0.670	0.0043	52.3687	1.7398
	2	2059	6005	0.670	0.0608	8.4171	0.1855
	3	807	6005	0.670	0.0300	6.6860	0.2354
	4	987	6005	0.670	0.0101	24.2889	0.7731
	5	902	6005	0.670	0.0023	95.8082	3.1901
RPD	1	1388	6007	0.693	0.0043	77.5408	2.0813
	2	2444	6007	0.693	0.0608	9.6562	0.1953
	3	1235	6007	0.693	0.0300	9.8891	0.2814
	4	1752	6007	0.693	0.0101	41.6698	0.9955
	5	1269	6007	0.693	0.0023	130.2731	3.6570
RPE	1	1015	6012	0.688	0.0043	57.0677	1.7913
	2	2640	6012	0.688	0.0608	10.4977	0.2043
	3	1048	6012	0.688	0.0300	8.4456	0.2609

	4	1717	6012	0.688	0.0101	41.1000	0.9919
	5	2345	6012	0.688	0.0023	242.2811	5.0032
RPF	1	1230	6017	0.691	0.0043	68.7984	1.9617
	2	2231	6017	0.691	0.0608	8.8255	0.1868
	3	1286	6017	0.691	0.0300	10.3101	0.2875
	4	1662	6017	0.691	0.0101	39.5778	0.9708
	5	1404	6017	0.691	0.0023	144.3089	3.8513
RPG	1	780	6007	0.761	0.0043	39.6811	1.4208
	2	2035	6007	0.761	0.0608	7.3218	0.1623
	3	1464	6007	0.761	0.0300	10.6752	0.2790
	4	1862	6007	0.761	0.0101	40.3289	0.9346
	5	1269	6007	0.761	0.0023	118.6324	3.3302
RPH	1	873	6004	0.697	0.0043	48.5146	1.6420
	2	2231	6004	0.697	0.0608	8.7684	0.1856
	3	987	6004	0.697	0.0300	7.8618	0.2502
	4	1367	6004	0.697	0.0101	32.3425	0.8748
	5	1690	6004	0.697	0.0023	172.5828	4.1981
RPI	1	1770	6005	0.727	0.0043	94.2882	2.2411
	2	1609	6005	0.727	0.0608	6.0618	0.1511
	3	1036	6005	0.727	0.0300	7.9103	0.2458
	4	1528	6005	0.727	0.0101	34.6541	0.8865
	5	1286	6005	0.727	0.0023	125.8861	3.5104
RPJ	1	1066	6005	0.724	0.0043	57.0213	1.7465
	2	2018	6005	0.724	0.0608	7.6342	0.1699
	3	1001	6005	0.724	0.0300	7.6747	0.2426
	4	1529	6005	0.724	0.0101	34.8205	0.8905

	5	1019	6005	0.724	0.0023	100.1629	3.1378
MLA	1	1015	6236	0.764	0.0043	49.5448	1.5551
	2	5787	6236	0.764	0.0608	19.9779	0.2626
	3	2092	6236	0.764	0.0300	14.6366	0.3200
	4	2428	6236	0.764	0.0101	50.4577	1.0240
	5	3968	6236	0.764	0.0023	355.9232	5.6503
MLB	1	1354	6004	0.782	0.0043	67.0661	1.8226
	2	8505	6004	0.782	0.0608	29.7936	0.3231
	3	2339	6004	0.782	0.0300	16.6059	0.3434
	4	2789	6004	0.782	0.0101	58.8139	1.1137
	5	3590	6004	0.782	0.0023	326.7617	5.4536
MLC	1	1035	6023	0.840	0.0043	47.5751	1.4788
	2	9159	6023	0.840	0.0608	29.7750	0.3111
	3	1935	6023	0.840	0.0300	12.7487	0.2898
	4	2404	6023	0.840	0.0101	47.0458	0.9595
	5	3688	6023	0.840	0.0023	311.5178	5.1296
MLD	1	1548	6003	0.753	0.0043	79.6415	2.0242
	2	6929	6003	0.753	0.0608	25.2118	0.3029
	3	1317	6003	0.753	0.0300	9.7118	0.2676
	4	3332	6003	0.753	0.0101	72.9828	1.2644
	5	5119	6003	0.753	0.0023	483.9561	6.7642
MLE	1	2150	6035	0.830	0.0043	99.8193	2.1528
	2	7639	6035	0.830	0.0608	25.0829	0.2870
	3	1925	6035	0.830	0.0300	12.8101	0.2920
	4	2722	6035	0.830	0.0101	53.8036	1.0313

	5	4861	6035	0.830	0.0023	414.7194	5.9483
MLF	1	1917	6012	0.775	0.0043	95.6826	2.1854
	2	6910	6012	0.775	0.0608	24.3924	0.2934
	3	1826	6012	0.775	0.0300	13.0635	0.3057
	4	2504	6012	0.775	0.0101	53.2099	1.0633
	5	3598	6012	0.775	0.0023	330.0081	5.5017
MLG	1	1553	6091	0.692	0.0043	85.6857	2.1743
	2	5208	6091	0.692	0.0608	20.3223	0.2816
	3	1056	6091	0.692	0.0300	8.3512	0.2570
	4	1702	6091	0.692	0.0101	39.9801	0.9691
	5	3081	6091	0.692	0.0023	312.3785	5.6278
MLH	1	1035	6100	0.786	0.0043	50.2018	1.5604
	2	7624	6100	0.786	0.0608	26.1533	0.2995
	3	2188	6100	0.786	0.0300	15.2116	0.3252
	4	2244	6100	0.786	0.0101	46.3393	0.9782
	5	4373	6100	0.786	0.0023	389.7725	5.8942
MLI	1	1202	6083	0.692	0.0043	66.4067	1.9154
	2	5379	6083	0.692	0.0608	21.0172	0.2866
	3	1686	6083	0.692	0.0300	13.3510	0.3251
	4	2376	6083	0.692	0.0101	55.8858	1.1465
	5	2975	6083	0.692	0.0023	302.0280	5.5374
MLJ	1	1520	6009	0.695	0.0043	84.6424	2.1710
	2	4289	6009	0.695	0.0608	16.8914	0.2579
	3	1295	6009	0.695	0.0300	10.3362	0.2872
	4	2755	6009	0.695	0.0101	65.3150	1.2444

	3	2401	6006	0.722	0.0300	18.4565	0.3767
	4	4376	6006	0.722	0.0101	99.9156	1.5104
	5	10693	6006	0.722	0.0023	1053.8073	10.1909
NBF	1	2125	6348	0.598	0.0043	130.1824	2.8241
	2	14984	6348	0.598	0.0608	64.9211	0.5304
	3	4018	6348	0.598	0.0300	35.2818	0.5566
	4	5295	6348	0.598	0.0101	138.1041	1.8979
	5	7678	6348	0.598	0.0023	864.3590	9.8644
NBG	1	753	6215	0.541	0.0043	52.0821	1.8980
	2	12196	6215	0.541	0.0608	59.6589	0.5402
	3	2988	6215	0.541	0.0300	29.6224	0.5419
	5	5009	6215	0.541	0.0101	147.4997	2.0841
	5	8763	6215	0.541	0.0023	1113.7778	11.8980
NBH	1	761	6005	0.583	0.0043	50.5516	1.8325
	2	11322	6005	0.583	0.0608	53.1910	0.4999
	3	3255	6005	0.583	0.0300	30.9919	0.5432
	4	4185	6005	0.583	0.0101	118.3566	1.8296
	5	8850	6005	0.583	0.0023	1080.3037	11.4835
NBI	1	432	6021	0.656	0.0043	25.4356	1.2238
	2	11784	6021	0.656	0.0608	49.0701	0.4520
	3	3412	6021	0.656	0.0300	28.7949	0.4930
	4	4536	6021	0.656	0.0101	113.7049	1.6883
	5	9366	6021	0.656	0.0023	1013.3648	10.4710
NBJ	1	977	6007	0.586	0.0043	64.5462	2.0650

	2	9357	6007	0.586	0.0608	43.7198	0.4520
	3	2615	6007	0.586	0.0300	24.7625	0.4842
	4	3996	6007	0.586	0.0101	112.3955	1.7780
	5	8501	6007	0.586	0.0023	1032.0457	11.1934
MRA	1	319	6010	0.722	0.0043	17.0966	0.9572
	2	8950	6010	0.722	0.0608	33.9241	0.3586
	3	2440	6010	0.722	0.0300	18.7438	0.3795
	4	3315	6010	0.722	0.0101	75.6398	1.3137
	5	9327	6010	0.722	0.0023	918.5746	9.5114
MRB	1	993	6022	0.782	0.0043	49.0381	1.5562
	2	5393	6022	0.782	0.0608	18.8356	0.2565
	3	4696	6022	0.782	0.0300	33.2399	0.4851
	4	4056	6022	0.782	0.0101	85.2764	1.3390
	5	8565	6022	0.782	0.0023	777.2559	8.3985
MRC	1	1034	6007	0.729	0.0043	54.9120	1.7077
	2	5959	6007	0.729	0.0608	22.3813	0.2899
	3	1915	6007	0.729	0.0300	14.5768	0.3331
	4	2766	6007	0.729	0.0101	62.5382	1.1891
	5	7756	6007	0.729	0.0023	756.8970	8.5944
MRD	1	618	6007	0.782	0.0043	30.5954	1.2307
	2	8837	6007	0.782	0.0608	30.9412	0.3291
	3	3502	6007	0.782	0.0300	24.8502	0.4199
	4	3887	6007	0.782	0.0101	81.9273	1.3141
	5	7636	6007	0.782	0.0023	694.6814	7.9497

MRE	1	525	6011	0.786	0.0043	25.8417	1.1278
	2	4561	6011	0.786	0.0608	15.8777	0.2351
	3	1720	6011	0.786	0.0300	12.1349	0.2926
	4	2104	6011	0.786	0.0101	44.0915	0.9612
	5	9973	6011	0.786	0.0023	902.0709	9.0329
MRF	1	368	6129	0.717	0.0043	19.4747	1.0152
	2	5519	6129	0.717	0.0608	20.6561	0.2780
	3	1454	6129	0.717	0.0300	11.0290	0.2892
	4	2356	6129	0.717	0.0101	53.0817	1.0936
	5	8446	6129	0.717	0.0023	821.3466	8.9372
MRG	1	491	6049	0.797	0.0043	23.6849	1.0689
	2	6053	6049	0.797	0.0608	20.6502	0.2654
	3	1915	6049	0.797	0.0300	13.2405	0.3026
	4	2437	6049	0.797	0.0101	50.0486	1.0138
	5	9584	6049	0.797	0.0023	849.5502	8.6779
MRH	1	260	6004	0.725	0.0043	13.8908	0.8615
	2	6360	6004	0.725	0.0608	24.0312	0.3013
	3	1842	6004	0.725	0.0300	14.1055	0.3287
	4	2949	6004	0.725	0.0101	67.0772	1.2352
	5	7961	6004	0.725	0.0023	781.5793	8.7597
MRI	1	638	6680	0.692	0.0043	32.0974	1.2707
	2	8786	6680	0.692	0.0608	31.2612	0.3335
	3	3669	6680	0.692	0.0300	26.4572	0.4368
	4	3924	6680	0.692	0.0101	84.0476	1.3417
	5	11783	6680	0.692	0.0023	1089.3250	10.0353

MRJ	1	805	6171	0.686	0.0043	44.2230	1.5587
	2	9290	6171	0.686	0.0608	36.0938	0.3745
	3	3418	6171	0.686	0.0300	26.9136	0.4603
	4	4213	6171	0.686	0.0101	98.5350	1.5181
	5	15183	6171	0.686	0.0023	1532.7173	12.4389
ACA	1	598	6098	0.721	0.0043	31.6308	1.2935
	2	4131	6098	0.721	0.0608	15.4536	0.2404
	3	1977	6098	0.721	0.0300	14.9887	0.3371
	4	3065	6098	0.721	0.0101	69.0218	1.2467
	5	7218	6098	0.721	0.0023	701.5818	8.2579
ACB	1	832	6108	0.758	0.0043	41.7914	1.4489
	2	4487	6108	0.758	0.0608	15.9399	0.2380
	3	1863	6108	0.758	0.0300	13.4129	0.3108
	4	2320	6108	0.758	0.0101	49.6133	1.0300
	5	8251	6108	0.758	0.0023	761.5922	8.3843
ACC	1	483	6142	0.728	0.0043	25.1210	1.1430
	2	8093	6142	0.728	0.0608	29.7690	0.3309
	3	3836	6142	0.728	0.0300	28.5967	0.4617
	4	3559	6142	0.728	0.0101	78.8071	1.3210
	5	7529	6142	0.728	0.0023	719.5819	8.2930
ACD	1	458	6059	0.728	0.0043	24.1471	1.1283
	2	3857	6059	0.728	0.0608	14.3818	0.2316
	3	1974	6059	0.728	0.0300	14.9174	0.3358
	4	2075	6059	0.728	0.0101	46.5762	1.0225
	5	8388	6059	0.728	0.0023	812.6625	8.8732

ACE	1	704	6131	0.773	0.0043	34.5457	1.3020
	2	8539	6131	0.773	0.0608	29.6342	0.3207
	3	3272	6131	0.773	0.0300	23.0134	0.4023
	4	5600	6131	0.773	0.0101	116.9919	1.5634
	5	9072	6131	0.773	0.0023	818.0435	8.5886
ACF	1	438	6005	0.755	0.0043	22.4670	1.0735
	2	3003	6005	0.755	0.0608	10.8941	0.1988
	3	1332	6005	0.755	0.0300	9.7932	0.2683
	4	2226	6005	0.755	0.0101	48.6120	1.0303
	5	9124	6005	0.755	0.0023	860.0218	9.0036
ACG	1	676	6037	0.783	0.0043	33.2579	1.2792
	2	4890	6037	0.783	0.0608	17.0146	0.2433
	3	2134	6037	0.783	0.0300	15.0484	0.3258
	4	3454	6037	0.783	0.0101	72.3466	1.2310
	5	8739	6037	0.783	0.0023	790.0652	8.4515
ACH	1	557	6008	0.789	0.0043	27.3262	1.1578
	2	4125	6008	0.789	0.0608	14.3124	0.2228
	3	1892	6008	0.789	0.0300	13.3043	0.3059
	4	2663	6008	0.789	0.0101	55.6215	1.0778
	5	10209	6008	0.789	0.0023	920.3657	9.1090
ACI	1	758	6030	0.765	0.0043	38.2140	1.3880
	2	4909	6030	0.765	0.0608	17.5029	0.2498
	3	2230	6030	0.765	0.0300	16.1141	0.3412
	4	2893	6030	0.765	0.0101	62.0938	1.1544

	5	8471	6030	0.765	0.0023	784.7658	8.5265
ACJ	1	797	6006	0.757	0.0043	40.7670	1.4440
	2	9359	6006	0.757	0.0608	33.8567	0.3500
	3	2885	6006	0.757	0.0300	21.1516	0.3938
	4	4554	6006	0.757	0.0101	99.1723	1.4696
	5	9720	6006	0.757	0.0023	913.6276	9.2669
NKA	1	539	6007	0.684	0.0043	30.5075	1.3141
	2	3264	6007	0.684	0.0608	13.0657	0.2287
	3	1879	6007	0.684	0.0300	15.2437	0.3517
	4	2884	6007	0.684	0.0101	69.4961	1.2941
	5	4639	6007	0.684	0.0023	482.4972	7.0841
NKB	1	644	6019	0.673	0.0043	36.9724	1.4569
	2	2528	6019	0.673	0.0608	10.2644	0.2041
	3	2235	6019	0.673	0.0300	18.3915	0.3890
	4	2554	6019	0.673	0.0101	62.4252	1.2352
	5	3958	6019	0.673	0.0023	417.5616	6.6372
NKC	1	506	6005	0.779	0.0043	25.1554	1.1183
	2	4171	6005	0.779	0.0608	14.6651	0.2271
	3	2382	6005	0.779	0.0300	16.9734	0.3478
	4	2330	6005	0.779	0.0101	49.3156	1.0217
	5	5072	6005	0.779	0.0023	463.3540	6.5061
NKD	1	566	6035	0.773	0.0043	28.2157	1.1860
	2	6831	6035	0.773	0.0608	24.0837	0.2914
	3	1870	6035	0.773	0.0300	13.3618	0.3090

	4	2774	6035	0.773	0.0101	58.8746	1.1178
	5	5311	6035	0.773	0.0023	486.5233	6.6760
NKE	1	381	6005	0.801	0.0043	18.4209	0.9437
	2	5028	6005	0.801	0.0608	17.1928	0.2425
	3	1565	6005	0.801	0.0300	10.8454	0.2742
	4	2105	6005	0.801	0.0101	43.3297	0.9444
	5	5289	6005	0.801	0.0023	469.9073	6.4614
NKF	1	474	6005	0.664	0.0043	27.6458	1.2698
	2	3744	6005	0.664	0.0608	15.4437	0.2524
	3	1861	6005	0.664	0.0300	15.5577	0.3606
	4	1916	6005	0.664	0.0101	47.5766	1.0869
	5	5371	6005	0.664	0.0023	575.6496	7.8547
NKG	1	518	6016	0.697	0.0043	28.7290	1.2623
	2	4205	6016	0.697	0.0608	16.4938	0.2544
	3	1646	6016	0.697	0.0300	13.0848	0.3225
	4	2297	6016	0.697	0.0101	54.2374	1.1317
	5	3939	6016	0.697	0.0023	401.4482	6.3964
NKH	1	521	6015	0.686	0.0043	29.3636	1.2864
	2	2281	6015	0.686	0.0608	9.0921	0.1904
	3	1938	6015	0.686	0.0300	15.6557	0.3556
	4	1217	6015	0.686	0.0101	29.2018	0.8371
	5	3819	6015	0.686	0.0023	395.5251	6.4003
NKI	1	1093	6106	0.596	0.0043	69.8471	2.1127
	2	1856	6106	0.596	0.0608	8.3882	0.1947

Appendix B

Specific Activities and Graphs

Sample ID	Mass (Kg)	Specific Activity ($Bqkg^{-1}$)			
		^{226}Ra	^{232}Th	^{238}U	^{40}K
MLA	0.830	49.54±1.56	35.22±0.64	14.64±0.32	355.92±5.65
MLB	0.786	67.07±1.82	44.30±0.72	16.61±0.34	326.76±5.45
MLC	0.840	47.58±1.48	38.41±0.64	12.75±0.29	311.52±5.13
MLD	0.692	79.64±2.02	49.10±0.78	9.71±0.27	483.95±6.76
MLE	0.695	99.82±2.15	39.44±0.66	12.81±0.29	414,72±5.94
MLF	0.764	95.68±2.19	38.80±0.68	13.06±0.06	330.01±5.50
MLG	0.782	85.69±2.17	30.15±0.63	8.35±0.26	312.37±5.67
MLH	0.753	50.20±1.56	36.25±0.64	15.21±0.33	389.77±5.89
MLI	0.775	66.40±1.92	38.45±0.72	13.35±0.33	302.03±5.54
MLJ	0.692	84.64±2.17	41.10±0.75	10.33±0.29	200.05±4.52

TABLE B.1: Specific Activities for Soil samples from Morulem gold mine

When a graph of activity concentration of the radionuclides per sample location was plotted, the following graph (Fig B.1) was obtained.

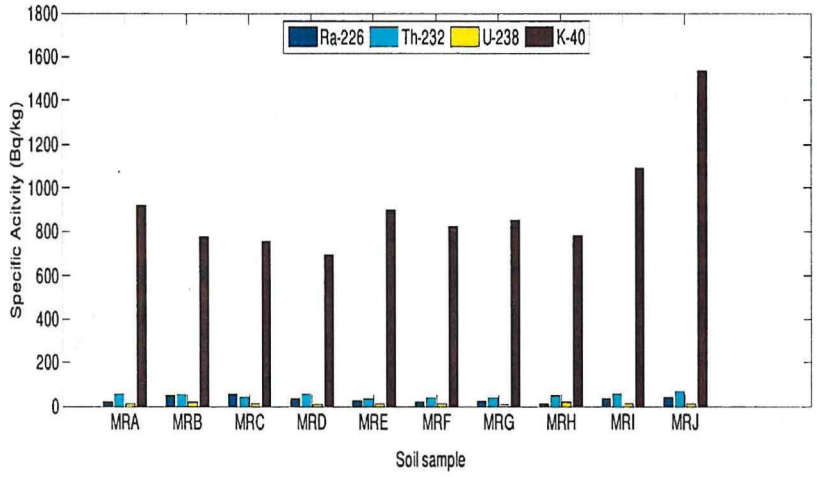

FIGURE B.1: Specific activities for Morulem gold mine

B.0.1 Nabulatuk gold mine

Sample ID	Mass (Kg)	Specific Activity ($Bqkg^{-1}$)			
		^{226}Ra	^{232}Th	^{238}U	^{40}K
NBA	0.743	26.84±1.18	43.23±0.77	16.97±0.36	967.14±9.62
NBB	0.723	35.63±1.38	66.74±0.93	27.52±0.46	882.09±9.32
NBC	0.585	121.64±2.80	101.91±2.03	33.44±0.56	854.89±10.06
NBD	0.661	97.16±2.35	68.37±0.98	31.23±0.50	898.16±9.69
NBE	0.722	40.92±1.48	67.38±0.94	18.46±0.38	1053.81±10.19
NBF	0.598	130.18±2.82	101.51±1.24	35.28±0.56	864.36±9.86
NBG	0.541	52.08±1.90	103.58±1.31	29.62±0.54	1113.78±11.90
NBH	0.583	50.55±1.83	85.77±1.16	30.99±0.54	1080.30±11.48
NBI	0.656	25.41±1.22	81.39±1.07	28.79±0.49	1013.36±10.47
NBJ	0.586	64.54±2.07	78.06±1.11	24.76±0.49	1032.04±11.19

TABLE B.2: Specific Activities for Soil samples from Nabulatuk gold mine

A graph of activity concentration of radionuclide for each sampled location gave the graph (Fig B.2) below.

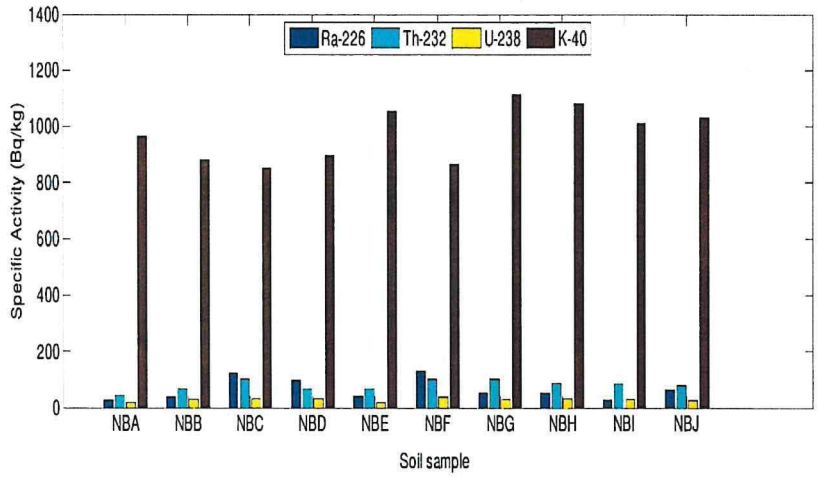

FIGURE B.2: Specific activities for Nabulatuk gold mine

B.0.2 Morita gold mine

Sample ID	Mass (Kg)	Specific Activity ($Bqkg^{-1}$)			
		^{226}Ra	^{232}Th	^{238}U	^{40}K
MRA	0.772	17.10±0.96	54.78±0.84	18.74±0.40	918.57±9.51
MRB	0.782	49.04±1.56	52.06±0.80	33.23±0.49	777.26±8.40
MRC	0.729	54.91±1.71	42.46±0.74	14.58±0.33	756.90±8.60
MRD	0.782	30.59±1.23	56.43±0.82	24.85±0.41	694.68±7.95
MRDE	0.786	25.84±1.13	29.98±0.60	12.13±0.29	902.07±9.03
MRF	0.717	19.47±1.02	36.87±0.69	11.03±0.29	821.35±8.94
MRG	0.797	23.68±1.07	35.35±0.64	13.24±0.30	849.55±8.68
MRH	0.725	13.89±0.86	45.55±0.77	14.10±0.33	781.58±8.76
MRI	0.692	32.10±1.27	57.65±0.84	26.46±0.44	1089.32±10.03
MRJ	0.686	44.22±1.56	67.31±0.95	26.91±0.46	1532.72±12.44

TABLE B.3: Specific Activities for Soil samples from Morita gold mine

A graph of activity concentration of this radionuclides per sampled location gave the result (Fig B.3) below.

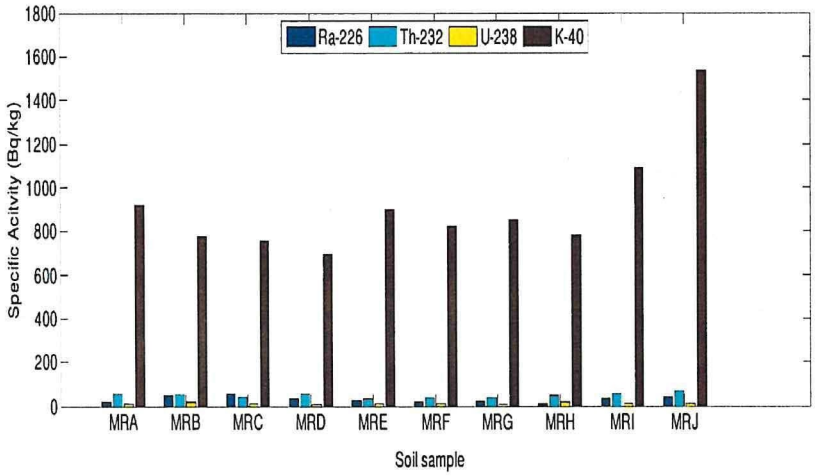

FIGURE B.3: Specific activities for Morita gold mine

B.0.3 Acerer gold mine

Sample ID	Mass (Kg)	Specific Activity ($Bqkg^{-1}$)			
		^{226}Ra	^{232}Th	^{238}U	^{40}K
ACA	0.721	31.63±1.29	42.24±0.74	14.99±0.34	701.58±8.26
ACB	0.758	41.79±1.45	32.78±0.63	13.41±0.31	761.59±8.38
ACC	0.728	25.12±1.14	54.30±0.83	28.60±0.46	719.58±8.29
ACD	0.728	24.14±1.13	30.48±0.63	14.92±0.34	812.66±8.87
ACE	0.773	34.55±1.30	73.31±0.94	23.01±0.40	818.04±8.59
ACF	0.755	22.47±1.07	29.75±0.61	9.79±0.27	860.02±9.00
ACG	0.783	33.26±1.28	44.68±0.74	15.05±0.33	790.06±8.45
ACH	0.789	27.32±1.16	34.97±0.65	13.30±0.31	920.37±9.11
ACI	0.765	38.21±1.39	39.80±0.70	16.11±0.34	784.77±8.53
ACJ	0.757	40.77±1.44	66.51±0.91	21.15±0.39	913.63±9.27

TABLE B.4: Specific Activities for Soil samples from Acerer gold mine

A graph of specific activities of the radionuclides per each sampled location is shown (Fig B.4) below.

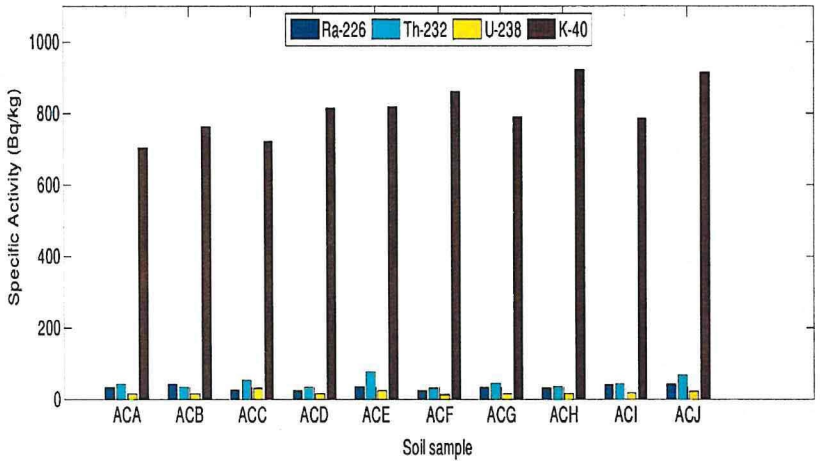

FIGURE B.4: Specific activities for Acerer gold mine

B.0.4 Nakabaat gold mine

Sample ID	Mass (Kg)	Specific Activity ($Bqkg^{-1}$)			
		^{226}Ra	^{232}Th	^{238}U	^{40}K
NKA	0.684	30.51±1.39	41.28±0.76	15.24±0.35	482.50±7.08
NKB	0.673	36.97±1.46	36.34±0.72	18.39±0.39	417.56±6.64
NKC	0.779	25.16±1.12	31.99±0.63	16.97±0.35	463.56±6.51
NKD	0.773	28.22±1.19	41.48±0.70	13.36±0.31	486.52±6.68
NKE	0.801	18.42±0.94	30.26±0.59	10.84±0.27	469.90±6.46
NKF	0.664	27.65±1.27	31.51±0.67	15.56±0.36	575.65±7.85
NKG	0.697	28.73±1.26	35.37±0.69	13.08±0.32	401.45±6.40
NKH	0.686	29.36±1.29	19.15±0.51	15.66±0.36	395.53±6.40
NKI	0.596	69.85±2.11	30.91±0.70	17.18±0.40	281.36±5.75
NKJ	0.745	38.89±1.42	31.41±0.64	14.61±0.33	324.07±5.56

TABLE B.5: Specific Activities for Soil samples from Nakabaat gold mine

The graph of specific activities for each radionuclide per sampled location gave the result (Fig B.5) below.

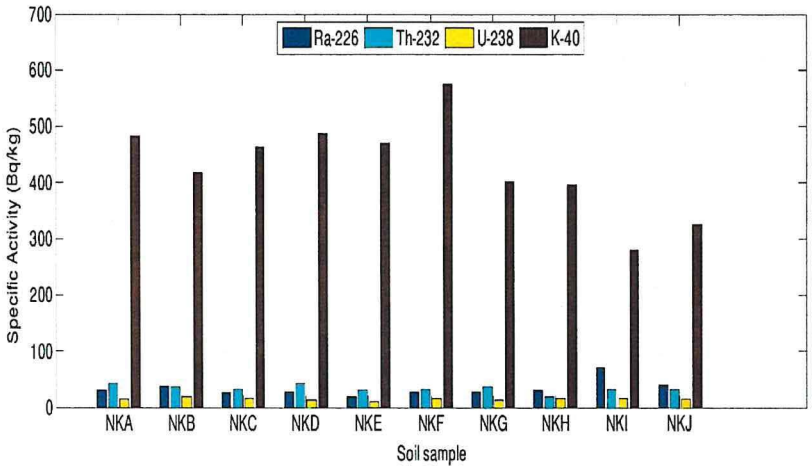

FIGURE B.5: Specific activities for Nakabaat gold mine

This graph shows that concentarion of ^{40}K is highest in each sampled location

Appendix C

Pictures of People from Karamoja gold mines

FIGURE C.1: Miners digging the holes to find gold

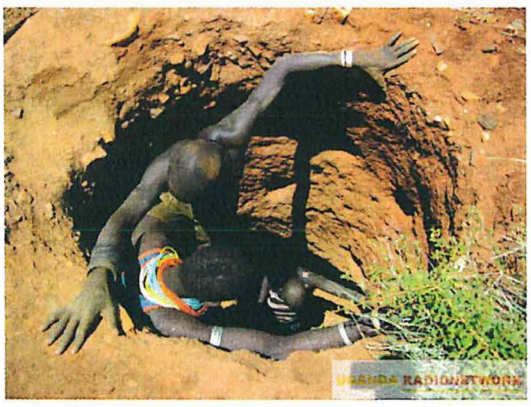

FIGURE C.2: Miners entering the dug hole

FIGURE C.3: A miner getting gold out of the soil

FIGURE C.4: A Child washing out soil to get gold

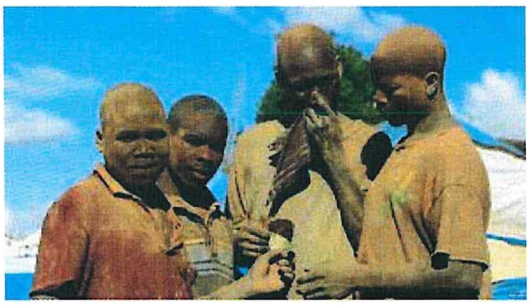

FIGURE C.5: Miners after digging the hole