Analysis of Radiation Levels in Nairobi's Central Business District and the Industrial Area, Kenya

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A Thesis Submitted In Partial Fulfilment for the Degree of Master of Science in Chemistry in the Jomo Kenyatta University of Agriculture and Technology

2015

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Signature ……..... Date……

Benardatte Wairimu Chege

This thesis has been submitted for examination with our approval as the University supervisors.

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Prof. Charles Mundia,
DeKUT, Kenya.

DEDICATION

To my parents, late sister Eunice, my siblings and all my friends. Their unwavering support has given me the strength and hope to press on to the conclusion of my studies.

ACKNOWLEDGEMENT

My sincere gratitude to my supervisors Prof. Erastus Gatebe and Prof. Charles Mundia for the effort, time and energy they put in making this research project a success. I wish to thank Chemistry Department (JKUAT), Institute of nuclear Science and Energy (University of Nairobi-UoN) and the Yamagata University for their endless support during my study period. This research project would not have been complete today were it not for your great support. I would also wish to thank my dear friends in the Chemistry Laboratory, JKUAT who were always there for me. Above all I thank the Almighty God for His mercies, strength and loving kindness which is better than life.

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ACRONYMS AND ABBREVIATIONS

CBD	Central Business District
CME	Coronal Mass Ejections
ELF	Extremely low frequency
EURATOMEC	European Atomic Energy Community
eV	Electron volts
GPS	Global Positioning System
HPGe	Hyper Pure Germanium
IAEA	International Atomic Energy Agency
ICRP	International Commission on Radiological Protection
IFALPA	International Federation of Air Line Pilots' Associations
IR	Infrared
KMC	Kenya Meat Commission
MW	Microwave
NIR	Non-ionizing radiation
NORE	Naturally Occurring Radioactive Elements
RF	Radio frequency
UNSCEAR	United Nations Scientific Committee on the Effects of Atomic Radiation
UV	Ultraviolet
$Bqkg^{-1}$	Becquerel per kilogram
$SvGy^{-1}$	Sieverts per gray
$mSvy^{-1}$	Milli sievert per year
$nGyh^{-1}$	Nano gray per hour
μSvy^{-1}	Micro sievert per year
H_{ex}	External hazard index
H_{in}	Internal hazard index
AED	Annual effective dose

ABSTRACT

Radiation is energy travelling through space. Exposure to radiation is a hazard to human health and in some situations it is known to be carcinogenic. In Kenya there is scanty information on radiation levels at various workplaces. The objective of the study was to analyse the radiation levels within Nairobi Central Business District (CBD) and the industrial areas. This was based on the fact that the study area has a huge population and the mining, quarrying and constructions taking place around this area can result to enhanced human exposure to radiation. Environmental radiation monitor model Horiba PA- 1100 was used to measure the air absorbed dose rates 1m above the ground. Soil samples were collected across the study area and were analysed qualitatively and quantitatively using gamma spectrometry to determine and quantify the activity of the radionuclides in the environment. Using energies of the spectral lines obtained from the gamma spectrometry, the radionuclides were identified and their respective activity concentrations were calculated from their respective intensities. The mean activity concentrations values for soil in ^{232}Th, ^{226}Ra and ^{40}K were 117.14, 75.91 and 928.55 Bqkg^{-1} respectively as compared to 30, 35 and 400 Bqkg^{-1} which are the accepted values for ^{232}Th, ^{226}Ra and ^{40}K respectively as reported (UNSCEAR 2008). The average for air absorbed dose rate was 1064.92 nGyh^{-1}. Average calculated absorbed dose rate 263.05 nGyh^{-1} was 6 times higher than the world acceptable effective radiation dose 43 nGyh^{-1} according to UNSCEAR, 2000. The averages for both the external and internal hazard indices were 0.88 and 1.09 respectively. The external and internal hazard indices for the areas around Mwiki dumpsite and Tetrapak industries exceeded 1 which is the world acceptable value. This means that the residents of these areas are at high risks of both internal and external radiation exposure. The mean annual effective dose 0.96 mSvy^{-1} is less than the acceptable limit 1mSv/y for members of public though residents of Mwiki and Tetrapak areas are experiencing higher values of 1.33 and 1.89 mSvy^{-1}. The study concludes that of the various sampled site, residents of Mwiki and people working around Tetrapak Industries are exposed to huge doses of radiation and could be at higher risks of radiation related health problems.

CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

1.1 Background of the study

Radiation is energy given off by matter in the form of rays or high-speed particles. The space environment contains two major biologically significant influences; space radiations and microgravity (Takahashi *et al*., 2010). Human beings are exposed to radiation from sources outside their bodies; mainly cosmic rays and gamma ray emitters in soils, building materials, water, food, and air. Radiation exposure originates from both extra-terrestrial sources and radioactive elements in the earth's crust (Alaamer, 2008). The main contribution to external exposure comes from gamma-emitting radionuclides present in trace elements in the soil, mainly ^{40}K ^{238}U and ^{232}Th families (UNSCEAR, 2008b). Natural background radiation mainly comes from the external terrestrial radiation, principally due to uranium and thorium decay chains, and by ^{40}K, which is present in the Earth's crust (Atambo, 2011; Xhixha *et al*., 2013).

Exposure to natural radioactivity is the most significant part of total radiation exposure to human beings (Figure 1.1). Radon is usually the largest natural source of radiation contributing to the exposure of the members of public at times accounting for half the total exposure from all sources. Naturally occurring radioactive elements (NORE) including U and Th are found in traces in almost all types of rocks, soil, sands and waters (Kebwaro *et al*., 2011; El-taher, 2012). Radioactive materials (radioisotopes or radionuclides) and the radiation they produce are everywhere in the soil, in our food and water, and in our bodies (NSC, 2005). Radioactive residues are deposited on the Earth's surface as a result of a variety of activities such as residues from nuclear weapon testing, accidents at nuclear facilities and past practices such as uranium mining that were subject to less stringent regulatory control than that required by present-day safety standards (IAEA, 2009). Exposure to radon can also result from building materials during construction and demolition of buildings with high radioactive materials.

The current study has evaluated the health hazard as a result of exposure to radiation due to constructions and mining industries. The study area hosts many industries including most of the cement industries and is experiencing a huge population increase. Human activities like crushing of stones in the cement industries, mining industries and radioactivity from the high-rise buildings contribute to increased environmental radiation hence are prone to the health effects associated with radiation exposure. This could lead to external exposures outdoors which arises from terrestrial radionuclides present at trace levels in all soils (UNSCEAR, 2000).

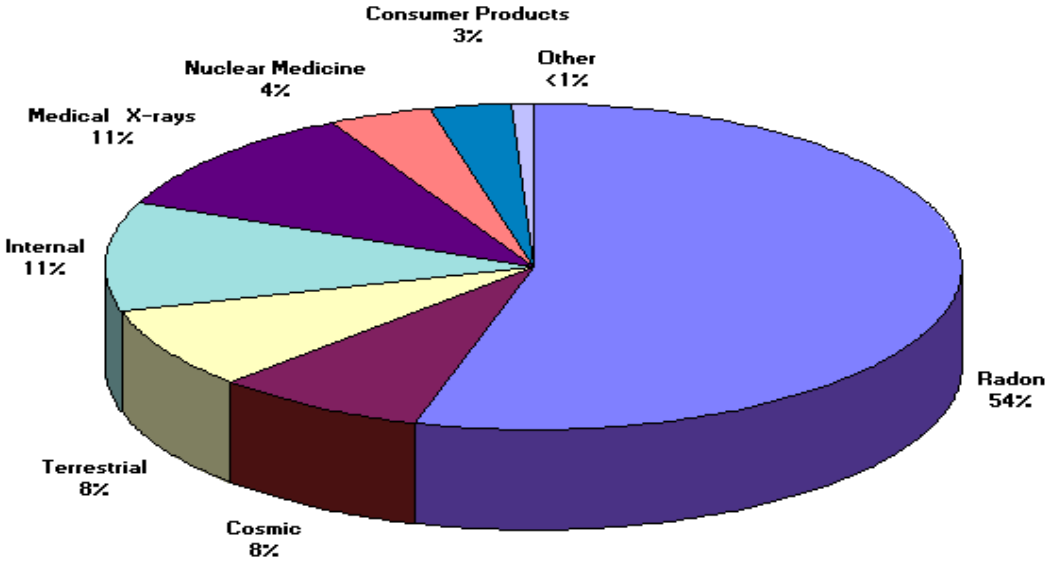

Figure 1.1:

According to Kenya population data sheet 2011, Kenya's population is growing rapidly and has more than tripled from 10.9 million people in 1969 to 38.6 million people in 2009. The rapid growth in population has contributed to a reduced amount of arable land per capita available to rural farmers and their children. This in turn has led many of the youths moving to and residing in the rural areas in search of employment and this leads to the huge population growth in the city.

Over the last one hundred years, the population of Nairobi has been steadily increasing. Currently Nairobi has a population of over 3.1 million people with 1.5 and 1.6 million women and men respectively. 56 .5 percent of Nairobi's population is young, below the age of 24 years. The youthful structure of the population causes

high dependency ratios and is responsible for high unemployment rates. The overall population density for Nairobi is 4515 people per square kilometre (Table 1.1) which is the most densely populated area according to census 2009 with a population density of over 22164 people per square kilometre at the Central Business District.

Table 1.1: Kenya population distribution

	Population						
	Population 2009 (millions)	Women	Men	Population Under Age 15 (%)	Population Density per square Kilometre		Total Fertility rate
Province	Total				1999	2009	
Total	38.6	19.4	19.2	42.9	49.4	66.4	4.6
Rural	26.1	13.2	12.9	-	-	46.3	5.2
Rural	12.5	6.2	6.3	-	-	729.5	2.9
Nairobi	3.1	1.5	1.6	30.3	3079.4	4515.0	2.8
Central	4.4	2.2	2.2	36.0	281.7	333.0	3.4
Coast	3.3	1.7	1.7	42.3	30.0	40.1	4.8
Eastern	5.7	2.9	2.8	41.8	30.2	37.0	4.4
North Eastern	2.3	1.1	1.3	51.7	7.5	18.2	5.9
Nyanza	5.4	2.8	2.6	45.9	350.1	431.5	5.4
Rift Valley	10.0	5.0	5.0	45.3	38.3	54.6	4.7
Western	4.3	2.2	2.1	47.1	406.4	521.6	5.6

Source: Kenya Population Datasheet, 2011.

There have been many incidences of stillbirths as well as cancer cases which are some of the health effects associated to high radiation dosages. Cancer is the 3rd highest cause of morbidity in Kenya [7% of deaths per year], after infectious diseases and cardiovascular diseases. About 39,000 new cases of Cancer are reported each year in Kenya with more than 27,000 deaths per year with majority of the cases reported being in Nairobi. This creates an urgent need for the search of the possible causes of the disease and the possible ways of reducing or eliminating it. In this

study terrestrial gamma dose rate for outdoor occupation was evaluated by estimation of the natural radioactivity levels in various soil samples. Natural radioactivity was determined from ^{226}Ra, ^{232}Th and ^{40}K contents according to (NCRP, 2004). Exposure to radiation has several effects to human health such as burns, premature aging, stillbirths or miscarriages, mutations, cancer and even death in cases of exposure to fatal doses. The symptoms of radiation sickness include: nausea, weakness, hair loss, skin burns or diminished organ function. This creates the need for the current study so as to assess the level of exposure to radiation and consequently the possible effects.

1.2 Radiation sources

Radiation is naturally present in our environment since the formation of the earth but can also be produced artificially. The most important sources of X-rays and gamma rays are natural sources, medical uses, atmospheric nuclear weapons tests, nuclear accidents, and nuclear power generation. Natural radioactivity from extra-terrestrial sources and radioactive elements in the earth's crust is a source of continuous radiation exposure to human beings (Garba *et al*., 2013). The amount of radioactivity in soil varies widely (Alaamer, 2008) depending on the geological processes involved in the formation of the soil and rocks. Human activities like mining and milling of mineral ores, processing and enrichment, nuclear fuel fabrications, and handling of the fuel cycle tail end products cause release of additional amounts of natural radionuclides into the environment (Saleh *et al*., 2007). Natural sources contribute almost 80% of the collective radiation exposure of the world's population (Alaamer, 2008; Faweya and Babalola, 2010).

There are two pathways through which radiation dose is imparted to the human beings from the building materials (Hewamanna *et al*., 2001; El-taher, 2012) namely external and internal exposures. Internal exposures arise from intake of terrestrial radionuclides by inhalation of dust particles containing radon and its progeny and ingestion due to water intake as well as agricultural products. Indoor exposures depend on radionuclide concentration in outdoor soil and in building materials. External exposure arises due to the gamma irradiation (Popic *et al*., 2012) with radionuclides originating from decay chains of thorium (^{232} Th) and uranium (^{238}U,

^{235} U), as well as potassium (^{40}K). Radon gas is a major source of natural radiation contributing more than 50% of the total radiation exposure. As a result great interest has been expressed worldwide for the study of naturally occurring radiation and environmental radioactivity. This has led to extensive surveys and information being gathered worldwide regarding activity concentrations in building materials (UNSCEAR, 2008b ; Alaamer, 2008).

Ionizing radiation is present naturally in the environment from cosmic and terrestrial sources. Artificial sources of ionizing radiation are also a significant source of radiation exposure to human body. Over the last 100 years, ionizing radiation has been increasingly applied in medicine and medical radiology due to the overwhelming benefits to patients from properly conducted procedures (Alaamer, 2008; IAEA, 2009). As a result medical radiation exposures have become an important component of the total radiation exposure of populations.

Non-Ionizing Radiation

Non-ionizing radiation (NIR) is radiation with energy levels below that required for effects at the atomic level (Zamanian & Hardiman, 2005). The NIR spectrum is divided into two main regions, optical radiations and electromagnetic fields. The optical can be further sub-divided into Ultraviolet (UV), visible, and Infra-red (IR). The electromagnetic fields are further divided into radiofrequency microwave (MW), very high frequency and low frequency radio wave (Kwan-hoong, 2003). The NIR originates from natural origin (such as sunlight or lightning discharges) and manmade (seen in wireless communications, industrial, scientific and medical applications).

The sun is the Earth's biggest source of radiation. It emits all wavelengths in the electromagnetic spectrum majority being in the form of visible, IR and UV radiation. Occasionally, giant explosions called solar flares and Coronal Mass Ejections (CME) occur on the surface of the Sun and release massive amounts of energy out into space in the form of x-rays, gamma rays and streams of protons and electrons. UV exposure depends on environmental as well as individual factors related to activity (Antoine *et al*., 2007). Sources of UV radiation are the sun, arc welding, oxy-gas welding, sun lamps, lasers (UV), sterilization (germicidal) lamps, low pressure gas discharge lamps, high pressure discharge lamps. Electromagnetic fields such

as microwaves are used in telecommunications, radar/satellite links, mobile phones, microwave ovens, Television transmitters. Radiofrequency is used in radio communications, visual display units, television sets. Extremely low frequency (ELF) electric and magnetic fields (EMFs) surround electrical machinery, home appliances, electric wiring, high-voltage electrical transmission lines and transformers. (Kwan-hoong, 2003).

1.3 Ionizing Radiation

According to (UNSCEAR 2008 ; IAEA, 2010 ; Surdu *et al*., 2013) about 22.8 million workers are exposed to ionizing radiation with about 13 million being exposed to natural sources and about 9.8 million to artificial sources. However due to the rapid increase in human activities this number is tremendously increasing. The exposure of human beings to ionizing radiation from natural sources is a continuous and inescapable feature of life on earth (Primal & Narayana, 2012). Ionizing radiation is emitted as the unstable atoms of radioactive materials constantly emit alpha, beta, gamma, or other forms of radiation as they "decay" to a stable state. This process can take from a fraction of a second to billions of years, depending on the material (NSC, 2005). Ionizing radiation contains sufficient electromagnetic energy to strip atoms and molecules from the tissue and alter chemical reactions in the body (Zamanian & Hardiman, 2005**)**.

Ionizing radiation falls into two broad groups; particulate radiations such as high energy electrons, neutrons, protons or alpha particles that ionize matter by direct atomic collisions and electromagnetic radiations or photons such as X-rays or gamma rays which ionize matter by other types of atomic interactions (Busby & Fucic, 2006; Thakur *et al.*, 2013). The main natural contributors to external exposure from gamma-radiation are the uranium and thorium series, together with potassium 40 (^{40}K) wherever present in small quantities in the earth and in the building materials. When the nucleus of a radioactive isotope decays, emitting ionizing radiation, the nucleus is transformed into a different isotope, called a decay product. The new isotope may be stable or unstable. If it is unstable, it will continue to decay (Figure 1.2), changing its nucleus and emitting more ionizing radiation. Several decays occur before a stable isotope is produced (NSC, 2005). Radioactivity is due to alpha (α),

beta (β) and gamma (γ) radiation from the unstable isotopes in the composition (Aguko *et al.*, 2013).

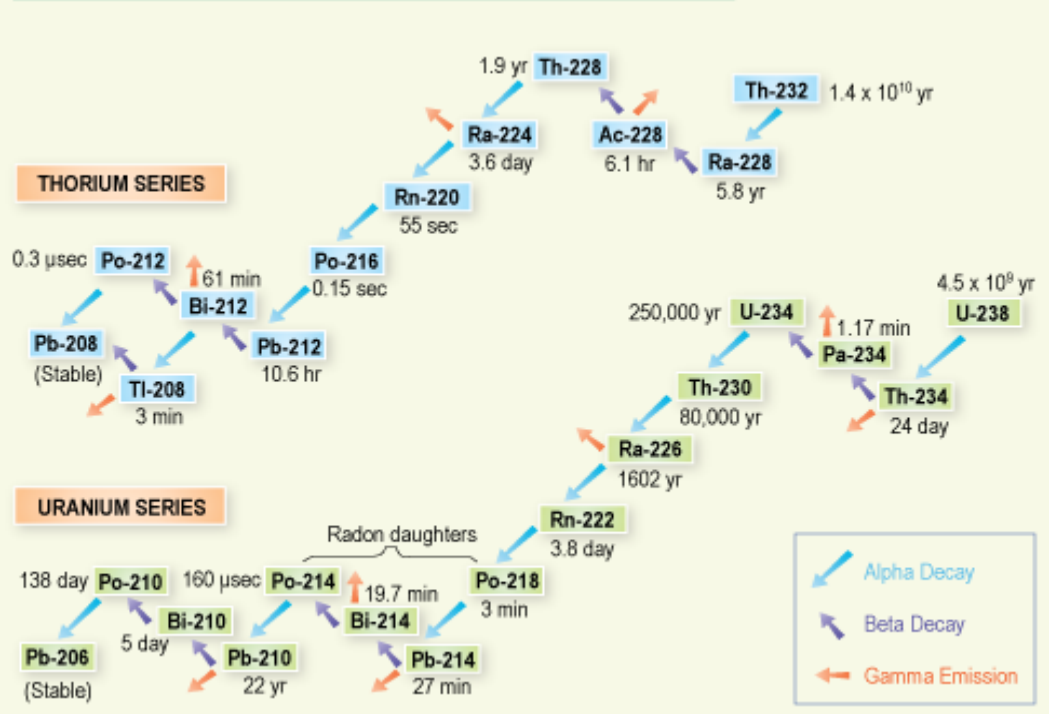

Figure 1.2: Radioactive decay in Th and U series

Ionization radiation is found in a wide range of occupational settings, health care facilities, processing industries, storage facilities (ware houses), research and education institutions, mining sites, nuclear reactors and their support facilities, nuclear weapon production facilities, and various manufacturing settings. People may be exposed to ionizing radiation from natural background, medical and manmade sources. Natural background radiation comes from cosmic rays and radioactive elements present in the soil. There is sufficient evidence in humans for the carcinogenicity of solar radiation. Solar radiation causes cutaneous malignant melanoma and non melanocytic skin cancer (Parkin *et al.*, 2011).

Radiation therapy is currently used to treat some types of cancer and involves dosages many thousand times higher than those used in diagnostic x-rays. Certain types of diagnostic radiographic procedures have been postulated to be linked with increased risk of breast cancer, although epidemiological studies examining this relationship have been inconclusive (Bhatti *et al.*, 2008).

1.4 Latitude and altitude effects

Doses from cosmic radiation increase with altitude and geomagnetic latitude (UNSCEAR, 2013). This is due to the shielding effect of the atmosphere and the earth's geomagnetic fields which interfere with the intensity of cosmic radiation reaching the upper atmosphere. The shape of the earth's magnetic field is such that only particles of higher energies can penetrate at lower geomagnetic latitudes. This produces the 'geomagnetic latitude effect' with intensities and dose rates minimal at the equator and maximal near the geomagnetic poles. The dose rate resulting from cosmic radiation depends on the latitude, altitude, and solar cycle (IFALPA, 2012). Near the earth, the geomagnetic field acts as a separator of the incident cosmic particles according to their energy. Equatorial latitudes are the most protected regions. On the other hand, high energy particles incident on the atmosphere interact with molecules in the air and generate a complex set of secondary charged and uncharged particles. The secondary nucleons in turn generate more nucleons, producing a nucleonic cascade in the atmosphere. The changing dose rate is caused by changing atmospheric components which arise from secondary nucleons' interactions in the atmosphere thus the increasing radiation dose rates with altitude. Astronauts venturing beyond the Earth's protective atmosphere and magnetic field may be exposed to galactic cosmic rays, solar particle events, and secondary protons and neutrons encompassing a broad range of energies (Takahashi *et al*., 2010) .

1.5 Effects of radiations to human health

The term "radiation" has some negative associations such as mutation and death from nuclear weapons. Radiation exposures are quantified in terms of energy. The historical concept is of 'absorbed dose' now measured in Grays (Gy). One Gray is an average absorbed energy density of 1 joule per kg of tissue. Also employed are units of 'dose equivalent', Sieverts (Sv), where the absorbed dose is multiplied by a weighting factor to account for the type of radiation involved (Busby & Fucic, 2006). In the recent years the level of radiations in the environment has been found to be rapidly increasing with increasing Technology. Knowledge of cancer risks in humans has also advanced tremendously in the last half century. Much of this knowledge has come from studies of bomb survivors in Hiroshima and Nagasaki, who have been

followed for more than 50 years (Chambers & Harley, 2008) . Leukemia was the first type of cancer found to be in excess among the Japanese survivors of atomic bombings of Hiroshima and Nagasaki in 1945 (Wakeford *et al.*, 2009). In addition, there is now a wealth of data from studies of people who have been exposed for medical, occupational or environmental reasons (Gilbert, 2009).

Biological effects of radiation can be classified as stochastic such as radiation-induced cancer and deterministic such as erythema (Chida *et al*., 2009). Diagnostic and experimental radiation exposures in the early 1900s revealed the deterministic effects of radiation such as skin erythema and radiation burns (Korir *et al.*, 2011). The health effects of radiation depend on the type of radiation, the dose of radiation absorbed (Table 1.2), the time over which the exposure occurs, the exposure pathway (i.e. ingestion, inhalation, external), and the specific parts and percentage of the body exposed. Certain tissues are especially sensitive to the effects of radiation for example bone marrow and gastrointestinal tract tissue (Adalja *et al.*, 2011). The most sensitive are blood and blood related organs and the most insensitive is the nervous system.

Many studies have included extensive efforts to estimate doses for individual subjects making it possible to quantify risk as a function of dose, to evaluate how age at exposure and gender might modify the dose-response relationship, to examine how the risk changes as subjects are followed over time, and to investigate interactions of radiation and other exposures. Epidemiologic studies thus provide information that is needed for risk assessment and setting radiation protection standards, and also increase our understanding of the carcinogenic process (Gilbert, 2009**)**.

Table 1.2: Radiation Dose and Acute illness

Estimated whole body radiation dose	Effect
1 Sievert	Threshold for acute radiation symptoms
3-4 Sievert	Threshold for possible death without treatment
5-6 Sievert	Threshold for possible death with treatment
>8 Sievert	Death likely, even with treatment

Source: Adalja *et al.*, 2011

Ionizing radiation is a proven human carcinogen, its carcinogenic potential was shown when skin cancers developed in early X-ray workers who developed leukaemia after working with radioactive isotopes (Williams, 2009; Shuryak *et al*.,2011). Different types of ionizing radiation produce different dependences of cancer risk on radiation dose rate. High doses of ionizing radiation (HDR) induce a wide variety of harmful effects, from acute death to late carcinogenesis (Ohyama *et al*., 2004). The evidence for carcinogenicity of ionizing radiation comes from different sources including studies of atomic bomb survivors in Japan, people exposed during the Chernobyl nuclear accident, people treated with high doses of radiation for cancer and other conditions, and people exposed to high levels of radiation at work, such as uranium miners. Evidence of harm associated with over exposure to UV has been demonstrated in many studies (WHO, 2003).

Solar UV radiation is one of the most powerful natural physical carcinogens, able to disrupt integrity of the skin. UV radiation penetrates the epidermis and induces a variety of biological effects in nervous system components of the skin. Chronic UV exposure is a major environmental factor that promotes skin ageing (Rodriguez *et al*., 2009). UV radiations originate from a great number of biological and chemical

processes which in majority of cases are hazardous for animal and plant systems (Chadysiene & Girgzdys, 2009).

Other types of cancer related to radiation exposure are lung cancer, skin cancer, thyroid cancer, multiple myeloma, breast cancer, stomach cancer and leukemia. Leukemia arises in the bone marrow and is the most common radiation-induced cancer. Effects of radiation to human health depends on the amount of radiation the person was exposed to, the length of exposure, type of radiation, age, and health of the person and also the part of the body that was exposed. High energy charged particles travel through living cells (Figure 1.3), depositing energy (Ohnishi *et al*., 2009) which causes structural damage to DNA and alters many cellular processes.

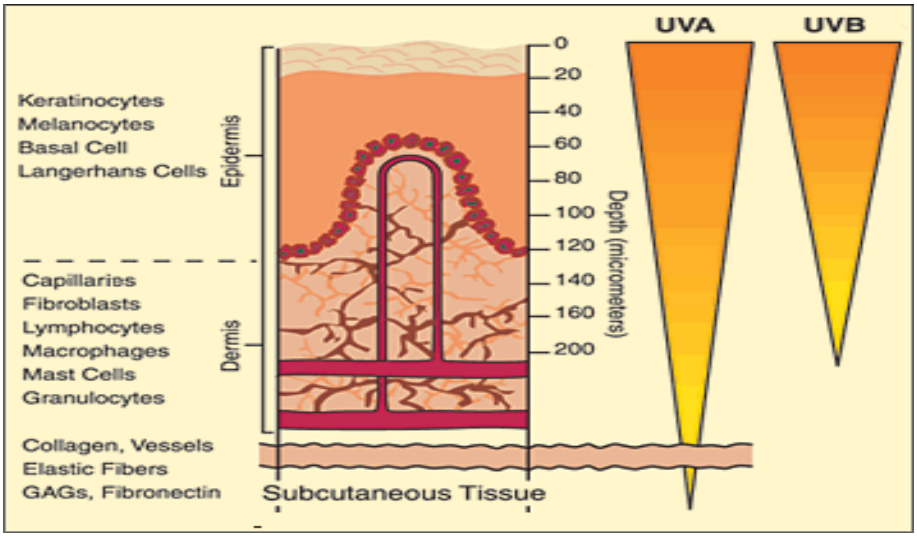

Figure 1.3: Depth of penetration of UV into the skin

(Source: Ohnishi et al., 2009).

The major sources of external radiation exposure originate from radioactive pollutants from atomic weapons tests, nuclear fuel cycle discharges and medical exposures (Busby & Fucic, 2006). Medical imaging has been identified as one of the major causes of environmental exposure to carcinogens (Carpeggiani *et al*., 2012). Increasing use of wireless equipment has also increased the amount of radiation exposure.

1.6 Radiation exposure parameters calculated from activity concentrations.

From the activity concentration of the soil samples various radiation exposure parameters can be calculated. These include Radium equivalents, absorbed dose rates, annual effective dose rates, external and internal hazard indices.

1.6.1 Radium equivalent activity (Ra_{eq})

Ra_{eq} is a weighted sum of activities of ^{226}Ra, ^{232}Th, and ^{40}K; and 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. To avoid radiation hazards, materials whose Ra_{eq} is greater than 370 Bq kg^{-1} should not be used. Ra_{eq} is defined by the following equation:

$$Ra_{eq} = A_{Ra} + 1.429A_{Th} + 0.077A_{K} \quad \text{..... Eq 1}$$

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

1.6.2 Absorbed Dose Rates

Radiation emitted by a radioactive substance is absorbed by any material it encounters.

UNSCEAR 2000 has given the dose conversion factors for converting the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K into dose ($nGyh^{-1}$ per $Bqkg^{-1}$) as 0.427, 0.662 and 0.043, respectively.

$$D = (0.427C_{Ra} + 0.662C_{Th} + 0.043C_{K})\ nGyh^{-1} \quad \text{..... Eq 2}$$

where: C_{Ra}, C_{Th} and C_K are the activity concentrations ($Bqkg^{-1}$) of radium, thorium and potassium in soil respectively.

1.6.3 Annual Effective Dose (AED)

Effective dose is a dosimetric quantity that accounts for the health effects of radiation to human body. To estimate the annual effective dose (AED), the conversion coefficient, (0.7 $SvGy^{-1}$) is taken into account from the absorbed dose in air to effective dose. The indoor and outdoor occupancy factors (average fraction of time spent indoor and outdoor) in Kenya which are 0.6 and 0.4 respectively were also taken into account in the calculation of AED.

$$\text{Effective dose rate} = \eta\Phi s(\ 8.76\times 10^{-}6) \quad \text{..... Eq 3}$$

s = 0.7 $SvGy^{-1}$ is the conversion coefficient, Ŋ is absorbed dose rate in $nGyh^{-1}$ and Φ= 0.4 is the outdoor occupancy factor in Kenya.

1.6.4 External Hazard Index (H_{ex})

Radiation exposure due to ^{226}Ra, ^{232}Th and ^{40}K may be external. This hazard is referred to as the external hazard index or outdoor radiation hazard index and is denoted by H_{ex}, The external hazard index mainly occurs due to the body contact with the radioactive elements or skin contact with radiation and is usually calculated as shown in the equation 4 below.

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_k}{4810} \quad \text{..... Eq 4}$$

C_{Ra}, C_{Th} and C_K are activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K respectively in $Bqkg^{-1}$. The value of this index should be less than 1 in order for the radiation hazard to be considered acceptable to the public (Beretka and Mathew, 1985).

1.6.5 Internal Hazard Index (H_{in})

Internal exposures arise from the intake of terrestrial radionuclides by ingestion and inhalation. Doses by ingestion are mainly due to ^{40}K and to the ^{238}U and ^{232}Th series radionuclides present in food and drinking water other than in soil (Tsai *et al*., 2008). Besides, no crop was produced in the studied area. Therefore, the contribution of ingestion is not taken into consideration. The internal hazard index (H_{in}) gives the internal exposure to carcinogenic radon and is given by equation 5 as given by Beretkab & Mathew, 1985.

$$H_{ex} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_k}{4810} \quad \text{..... Eq 5}$$

C_{Ra}, C_{Th} and C_K are activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K respectively, in $Bqkg^{-1}$. The value of this index should be less than unit in order for the radiation hazard to have negligible hazardous effects of radon to human respiratory organs.

1.7 Radioactivity measurements/studies

Over the past twenty years, there has also been a great deal of interest in the risks arising from exposure to radiation. Thus, great interest has been expressed worldwide

for the study of naturally occurring radiation and environmental radioactivity. This has been achieved through the measurement of the activity concentration of the radionuclides in soil samples using their respective spectroscopic parameter indicated in Table 1.3 below.

Table 1.3: Spectroscopic parameters employed for the quantification of activity

Element	Emitter	Half-life of nuclide	Gamma-ray energy (keV)	Absolute emission probability of gamma decay (%)
^{226}Ra	^{214}Bi	19.90 min	609.31	46.30
	^{214}Pb	26.80 min	351.92	37.20
^{232}Th	^{212}Bi	60.55 min	727.17	11.80
	^{212}Pb	10.64h	238.63	44.60
	^{228}Ac	6.25h	911.60	27.70
^{40}K		1.3 x 10^^{9}y	1460.81	10.67

Source: Tsai *et al.*, 2008

Natural environmental radioactivity and the associated external exposure due to gamma radiation depend primarily on the geological and geographical conditions, and appear at different levels in the soils of each region in the world (Alaamer, 2008). Around the world though, there are some areas with sizable populations that have high background radiation levels. The highest are found primarily in Brazil, India and China (Gnoni *et al.,* 2008). The higher radiation levels are due to high concentrations of radioactive minerals in soil. This has led to extensive surveys on radiation levels and radionuclide distribution in the environment in many countries. These surveys provide vital radiological baseline information which is essential in understanding human exposure from natural and man-made sources of radiation and necessary in establishing rules and regulations relating to radiation protection (Saleh *et al*., 2007).

It is clear from studies of miners that exposure to radon (^{222}Rn) and radium decay (^{226}Ra) products when inhaled during breathing enters the human lungs and causes

lung cancer (Chambers & Harley, 2008). 98.5% of the radiological effects of the uranium series are produced by radium and its daughter products. Many surveys have been carried out to determine the radium equivalent activity of soil samples in many countries (Atambo, 2011). The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in collected soil samples have been estimated mainly by gamma ray spectrometry, although the fission track registration technique has also been used for the analysis of uranium concentration in these samples.

International guidelines and directives for dealing with exposure due to naturally occurring radioactive elements exist. However only a few countries have adopted them and made regulations for the acceptable limits of exposure for workers and the general public (ICRP, 2000). The European Atomic Energy Community (EURATOMEC, 2002) and International Atomic Energy Agency (IAEA, 2004) also recommended exemption levels in activity concentrations for substances containing NORE. Based on the risk factors the ICRP has published recommendations for dose limits for the general public. The acceptable annual effective dose limit is 1mSv per year (ICRP, 2000 ; NCRP, 2004) for the general public. Safety standards are only effective, however, if they are properly applied in practice (IAEA, 2009).

In Baoji China, soil samples collected around the Baoji coal-fired power plant (Wang and Lu, 2007) and analysed using gamma ray spectrometric system indicated activity concentrations with mean values of 27.35, 52.66 and 764.72Bqkg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K, respectively. The radium equivalent activity in all the soil samples was (370Bqkg^{-1}). Similar work by Al-Trabulsy *et al.* (2011) at Saudi coast of the Gulf of Aqaba found that the average activities for ^{226}Ra, ^{232}Th, and ^{40}K were 11.471, 22.573 and 641.1761 Bqkg^{-1}, respectively. The area is subjected to several sources of pollution especially due to industries at the coastal area. Celik *et al.* (2010) in Ordu which is in the Eastern Black Sea region of Turkey for ^{226}Ra, ^{232}Th and ^{40}K in selected building materials were 34.5, 26.9 and 378.4 Bq kg^{-1}, respectively. Radium equivalent activity, terrestrial absorbed dose, annual effective dose rate, external hazard indices and internal hazard indices were calculated, and were found to be within the acceptable limits. Shousha (2006) analysed various cement samples in Egypt which showed average concentrations values of 72.21±6.39, 24.98±2.24 and 134.49±10.45Bqkg^{-1} for ^{226}Ra, ^{232}Th and ^{40}K respectively and radium equivalent

(Ra_{eq}) activity was 311.91±31.10Bqkg^{-1}. Another study carried out in 3 Egyptian sand samples by Abel-ghany, *et al*. (2009) showed that activity concentrations were 94.93, 80.22 and 700.79 BqKg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively. The Ra_{eq} was 263 BqKg^{-1}). The hazard index (H_{in}) was 0.96.

In Western Haryana India, Mehra (2009) established that average concentration for ^{238}U, ^{232}Th and ^{40}K in the soil samples were 18.78, 47.35 and 361.57 Bqkg^{-1} respectively. A similar study by Kumar and Singh (2003) showed Ra_{eq} activities lower than the limit set in the Organization for Economic Cooperation and Development (OECD) report (370 Bqkg^{-1}), equivalent to external gamma dose of 1.5 mSv yr^{-1}.

In Kenya, Mulwa *et al.* (2013) established that radium equivalent activity for Limestone rock samples collected in Kitui South, was below the recommended limit of 370Bqkg^{-1} hazard indices also were below a unit. Kinyua *et al*. (2011) in the soapstone quarries of Tabaka region of Kisii district established that the activity concentrations of ^{232}Th, ^{226}Ra and ^{40}K ranged from 38.6-271.7, 43.1-360, and 245-1780 Bqkg^{-1} respectively. The average absorbed dose rate was found to be 541.4 nGyh^{-1} 1m above the ground level while the calculated total absorbed dose rates were found to average 177.6 nGyh^{-1} below the surface. This is about 4 times higher than the world average of 43nGyh^{-1}. Internal and external hazard indices (1.03 and 1.27, respectively) were more than unity. Annual effective dose rate in the quarries was 0.44mSvy^{-1}. Achola (2009) established that in south western Kenya, the mean estimated annual external effective dose rate due to radionuclides in the rocks and soil was 5704.78μSvy^{-1}. Average activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th were found to be 508.67 BqKg^{-1}, 178.69 BqKg^{-1} and 1396.85 BqKg^{-1} respectively. Based on the higher levels of gamma-absorbed dose rates in air (5.705mSvy^{-1}) this region was considered as high natural background radiation area (HBRA). Similar results were reported in other parts of Kenya such as Mrima hill, Ruri hills, Rangwa ring complex, Homa Mountain, Soklo point and Kuge (Tuinge), in Gwasi, Suba district. The current study intends to compare the radionuclide concentrations obtained with the world standards and results that have been obtained in several other countries.

1.8 Instrumentation: Gamma-Ray Spectrometry.

High-resolution gamma-ray spectrometer with a high-purity germanium (HPGe) detector is one of the most widely used procedures during the identification and quantification of the radionuclides (Gültekin, 2006) in collected soil samples. The HPGe detectors are accurately shielded with 10 cm thick lead (Figure 1.4) which reduces environmental background radiation. The main advantage of this technique, with respect to the traditional methods employing magnetic spectrometers, is its high resolution and the good precision in measuring energy of the gamma-rays coming from nuclear cascades, transitions and decays (Szymanska *et al*., 2008).

Figure 1.4: The shielded HPGe detector.

The detector is then connected to a preamplifier, amplifier then to a Multi Channel Analyzer (MCA) as shown in Figure 1.5 below.

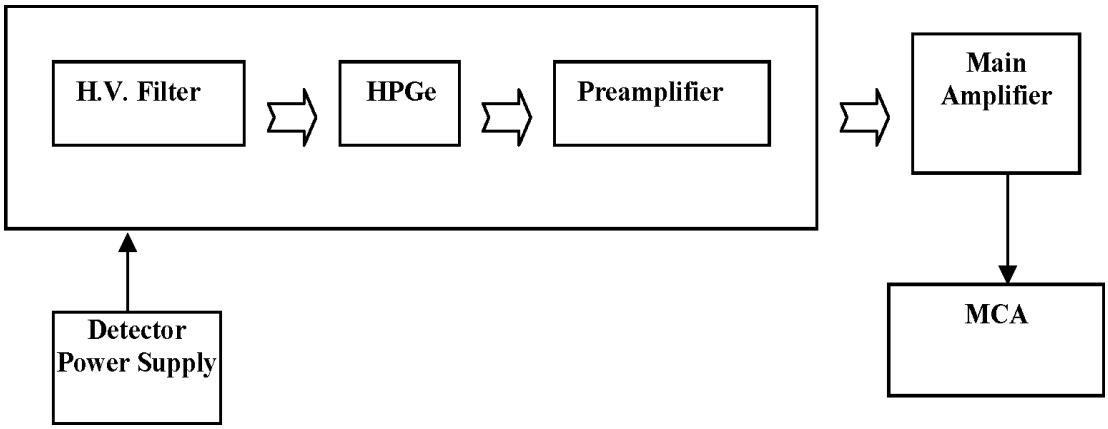

Figure 1.5: Typical gamma spectroscopy system

(Source: Abelghany *et al.*, 2009).

1.9 Statement of the problem

In recent times, there has been increase in incidences of diseases attributed to environmental exposure. Some might have been biological and others radiological. Radiological exposure is not well understood and its contribution to these incidences. This research set out to analyze the radiation exposure in Nairobi CBD and the industrial areas. This was because most of the industrial activities are located in the industrial area and their activities leads to increased radiation to the environment. The CBD has a high concentration of high-rise buildings which can be a source of radiation from the building materials. Most residents and workers in the study area are not aware of radiation exposure and the possible health effects that are associated with exposure to the radiations.

1.10 Justification

There isn't a conclusive research that has been done in determining the radioactivity levels in Kenya besides the increasing numbers of industries, quarries, high-rise buildings and infrastructures. Actual data is required in construction and manufacturing industries to determine their environmental pollution in form of radiation. The building and construction materials that are used are not tested on the radioactivity; this could pose danger to human health and can even result to death due to cancer. Radiation exposure must be maintained as low as possible since even the lowest doses may cause cancer over a prolonged period of exposure. This study was carried out to determine the level of radiation exposure from natural sources in mining areas, quarries and along highways. As the country aspires to attain vision 2030 on medium economic growth, there is an increase in technology and infrastructures which can result to an increase in the risks associated with radiation exposure. This provides a need to generate data to inform and guide the process of workplace safety as well as the residential places.

1.11 Hypothesis

The radiation levels in the study area do not contribute to the environmentally attributed health issues.

1.12 Objectives

1.12.1 General objective

Analyze for radiation in Nairobi Central Business District (CBD) and the Industrial area.

1.12.2 Specific objectives

1. To measure radiation levels in Nairobi Central business District and the industrial areas.
2. To carry out elemental analysis on soil samples from the study area and determine the main source of radiation from the soil samples.
3. To compare air absorbed dose rate with calculated absorbed dose rates from the soil samples.

CHAPTER TWO

MATERIALS AND METHODS

2.1 Study area

The study was carried in Nairobi's CBD and the industrial areas (Figure 2.1). Nairobi CBD extends between 36° 4′ and 37° 10′ east and approximately between 1° 9′ and 1° 28′ south, covering an area of 689 square kilometres. The altitude is approximately 1,700 meters above sea level which means that the climate is temperate.

Figure 2.1: Map of the study area

2.2 Apparatus and Instrumentation

The apparatus used in this research project included polythene bags, mortar and pestle, 0.6 micron sieve, weighing balance, plastic beakers, oven, horiba radiation monitor. The beakers, sieve motor and the pestle were thoroughly cleaned by first

soaking in detergent and rinsing with tap water before being rinsed thoroughly with distilled water. The beakers were dried completely before the packaging and storage of the samples. The radiation monitor was calibrated at the Radiation Protection Board (RPB) before it was used for measuring the air absorbed dose rates.

2.3 Sample collection

Soil samples were collected from Kenya Meat Commission (KMC), Athi River Mining Industry (A.R. mining), Mlolongo, Industrial area-Tetra Pak (Indu. Area -T.P) Mwiki dumpsite and Njiru Quarry. The sample collection was done on the basis of the levels of effective dose rates obtained using the handheld meter and also the economic activity of the area. Soil was scooped using a spoon at a depth of about 15 centimeters at every sample collection site. The samples were packed separately in polythene bags for transportation to the laboratory at the Institute of Nuclear Science and Technology (University Of Nairobi) for sample preparation and analysis.

2.4 Determination of radiation exposure

Two approaches were used to estimate the absorbed doses that is direct measurements using pocket radiometer and calculations based on radionuclide deposition densities. The study was carried out as summarised in the flow diagram shown in Figure 2.2.

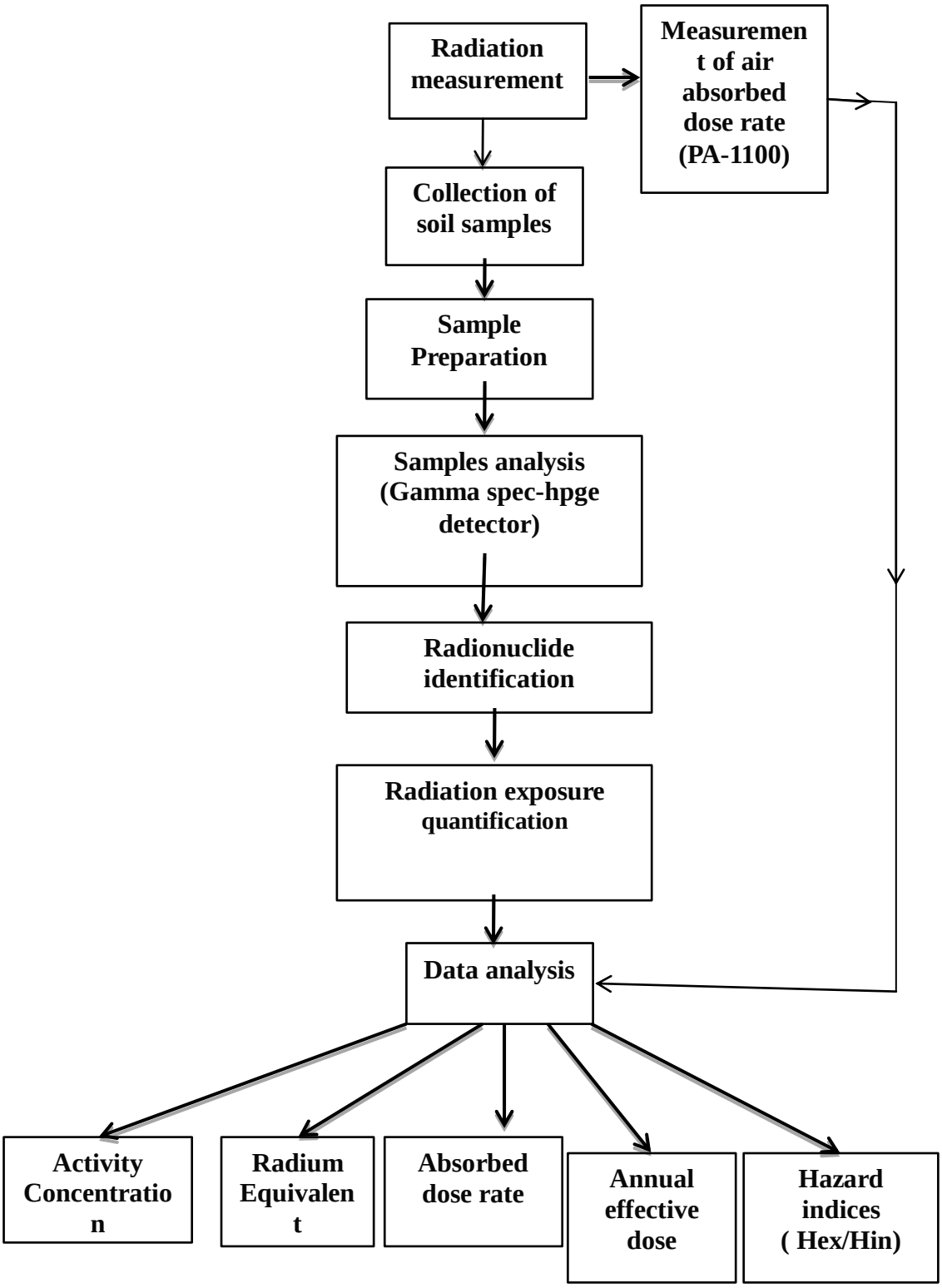

Figure 2.2: Flow diagram showing a summary of the methodology.

2.5 Direct measurement of air absorbed dose rate.

A pocket radiometer (model horiba PA 1100) with a reading of upto 35 μSvh^{-1} (Plate 2.1) was used to measure the air absorbed doses rate. The radiation monitor was held one meter above the ground. Absorbed dose rates in air ($nGyh^{-1}$) were computed from the dose rates (in μSvh^{-1}- Table 3.1) measured in the field using the conversion coefficient factor of 0.7 $SvGy^{-1}$ as recommended by UNSCEAR 2000.

Plate 2.1: Environmental Radiation monitor (Model PA-1100).

The sampling device comprised of a GPS enabled android pad and a radiation detector. The reading obtained using the environmental monitor was sent to the android pad via Bluetooth (Plate 2.2).

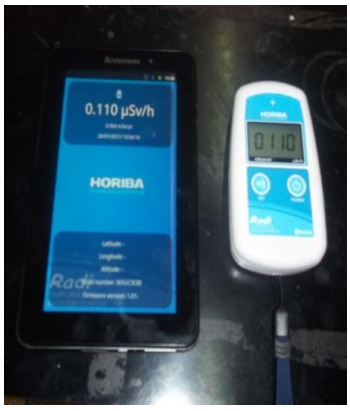

Plate 2.2: Bluetooth Connection of the radiation monitor to the GPS enabled Ipad.

Mapping of the sampled area was achieved by using the GPS enabled ideo pad. The mapping involved the Latitude, longitude and also the altitude readings (Table 3.1). The Ipad was connected to a laptop using a USB cable (Figure 2.3), for data storage and analysis.

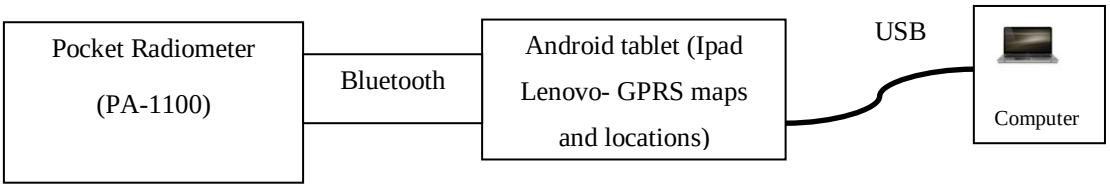

Figure 2.3: Layout of the instruments used to measure air absorbed radiation.

2.6 Calculation based measurement

The radiation released from radioactive elements in the soil was determined from the radiation intensities obtained using the gamma spectrometry method. The various radiation exposure parameters that were computed from the radiation intensities include: Activity concentration, radium equivalent, absorbed dose rate, annual effective dose, external hazard index and the internal hazard index.

2.7 Sample preparation

In the lab soil samples were then dried in an oven at 80°C for 24 hours, completely removing moisture from the samples. The soil samples were separately crushed into powder form and sieved through a 0.6 mm mesh sieve. 200 g of each sample was weighed and packed in special gas tight plastic containers according to IAEA (2000). The samples containers with each sample were closed and tightly sealed. The containers were labeled appropriately and then stored in a cool dry place for 30 days to attain secular equilibrium i.e. the decay products of ^{232}Th series and ^{226}Ra subseries were in radioactive equilibrium with their daughter nuclides.

2.8 Sample analysis

Gamma spectrometric method was used in the identification and quantification of the NORMS present in each soil sample. The gamma ray spectrometer used during the study consisted of a p-type coaxial intrinsic high purity germanium (HPGe) detector (ORTEC model CPVDS 30-30185) mounted vertically. The system was calibrated using a standard reference material (**SRM**) (International Atomic Energy Agency,

IAEA RGTh-**1**, IAEA RGU-1 and IAEA RGK-1). After calibration each of the plastic containers holding the sample was placed in the sample compartment one at a time that is on the detector of the instrument and the sample compartment was sealed. The detector was connected to a power supply (model –Tenellec TC-950), an amplifier (Tenellec TC-244) and a Canberra multichannel analyzer model PCA-8000 with apex software, that allowed data acquisition, display of gamma-spectra and storage of the results in memory counters called channels. The MCA was interfaced with a computer and a printer. To ensure that all nuclides due to ^{238}U and ^{232}Th were visible in the gamma spectrum, spectral data acquisition time for the each sample was 12 hours. The detector had a relative efficiency of 31.6% and full width at half maximum (FWHM) of 1.83 keV energy resolution, diameter of 57.4mm, 56.9mm length and active volume of 144 ml. The detector was housed inside a 10 cm thick lead shield internally lined with 2 mm Cu foils. This provided an efficient suppression of background gamma radiation present within the laboratory. From the gamma spectra several radionuclides were identified and the radioactivity parameters were calculated.

2.8.1 Determination of activity concentration

Identification of the radionuclides was done through the method of comparison and activities of the soil samples were calculated by comparing the intensities of the sample with those of the standard. The ^{226}Ra activities for samples assumed to be in radioactive equilibrium were estimated from ^{214}Pb (351.92 keV) and ^{214}Bi (609.31 keV). The gamma-ray energies of ^{212}Pb (238.63 keV) and ^{228}Ac (911.60 keV) were used to estimate activity of ^{232}Th (Table 3.2). The activity concentrations of ^{40}K were measured directly by its own gamma rays (1460.81 keV).

The activity concentration for each radionuclide (^{226}Ra, ^{232}Th and ^{40}K) in each sample was determined by the net intensity of respective peaks. Equation 6 below was used to calculate activity concentration of the radionuclides.

$$\frac{M_s A_s}{I_s} = \frac{M_r A_r}{I_r} \quad \text{.....Eq 6}$$

M_s= Mass of the sample M_r = Mass of the standard

A_s = Activity of the sample A_s = Activity of the standard

I_s = Intensity of the sample I_s =Intensity of the standard

2.8.2 Determination of radium equivalents

The radiation hazards associated with the radionuclides (Ra_{eq}) were estimated. This was done by calculating the Ra_{eq} value from the activity concentration of thorium radium and potassium (equation 1) above and the values obtained were reported in Table 3.3.

2.8.3 Determination of Absorbed dose rate (D)

Using these factors of 0.427, 0.662 and 0.043 for ^{226}Ra, ^{232}Th and ^{40}K, respectively, the total absorbed dose rate in air was calculated from the activity concentration of these radionuclides as given in equation 2. The results obtained were as displayed in Table 3.4. The absorbed dose-rates were used in further computations to obtain the annual effective dose.

2.8.4 Determination of Annual Effective Dose (AED)

The effective dose rate in units of $mSvy^{-1}$ was estimated using a conversion coefficient of 0.7 $SvGy^{-1}$ (Equation 3) according to UNSCEAR (1998). The indoor and outdoor occupancy factors 0.6 and 0.4 respectively were also used in the calculations and the results obtained were tabulated as in Table 3.4.

2.8.5 Determination of External Hazard Index (H_{ex})

The external hazard index H_{ex}, was calculated from the activity concentrations of thorium radium and potassium (Equation 4) according to Beretka and Mathew 1985. The H_{ex} values obtained were as tabulated in Table 3.5.

2.8.6 Determination of Internal Hazard Index (H_{in})

The internal hazard index was also calculated from the activity concentrations of thorium, radium, and potassium according to Beretka and Mathew 1985 (Equation 5) and the results were tabulated (Table 3.5).

CHAPTER THREE

RESULTS AND DISCUSSION

3.1 Air absorbed dose rates

The air absorbed dose rates measured 1 m above the surface at each sampled site were obtained and presented in Table 3.1. The values for the sampled sites varied from 334.86-1604.18 $nGyh^{-1}$ Table 3.6 the lowest dose being experienced at Athi River Mining and the Njiru quarry. The average measured absorbed dose rate for the six sampled sites was 1064.92 $nGyh^{-1}$, which is 17 times higher than the world average value of 60 $nGyh^{-1}$ (UNSCEAR, 2000). According to table 1.1 the radiation dose rates were found to change significantly with the change in altitude and latitude. The geomagnetic field effect was evident since as one moves away from the equator towards the poles the radiation dose was found to be increasing. However the difference noted in radiation readings was not so huge since the changes in altitude and latitude were not also large.

Table 3.1: Measured absorbed dose rates- using the radiation monitor

AREA CODE	LONGITUDE	LATITUDE	ALTITUDE	mSv/yr	$nGyh^{-1}$
1	36.91	-1.26	1586.95	0.90	901.74
2	36.91	-1.27	1591.24	1.14	1139.58
3	36.91	-1.27	1584.57	0.72	719.06
4	36.91	-1.26	1576.28	0.80	796.73
5	36.91	-1.24	1579.00	0.76	757.11
6	36.91	-1.24	1573.35	0.82	820.69
7	36.91	-1.25	1564.35	0.66	660.80
8	36.92	-1.26	1581.49	0.85	846.19
9	36.94	-1.24	1518.48	0.84	837.59
10	36.92	-1.23	1535.32	0.87	867.58
11	36.94	-1.40	1600.42	0.96	964.50
12	36.96	-1.43	1510.11	0.93	927.94
13	36.96	-1.43	1506.60	1.27	1265.31
14	36.97	-1.44	1500.46	0.59	587.32
15	36.98	-1.45	1482.14	0.34	335.03
16	36.99	-1.45	1501.23	1.04	1035.74
17	36.99	-1.45	1506.37	1.04	1039.24
18	36.99	-1.45	1522.86	1.04	1035.98
19	37.00	-1.45	1507.57	0.89	894.62
20	36.99	-1.45	1529.20	0.95	948.22
21	36.99	-1.46	1529.69	0.84	838.88
22	36.98	-1.46	1523.43	0.68	681.71
23	36.99	-1.46	1526.00	0.98	982.01
23	36.87	-1.32	1620.60	0.98	980.16
25	36.87	-1.32	1624.89	1.10	1104.25
26	36.86	-1.32	1621.37	1.11	1108.27
27	36.86	-1.32	1613.80	1.04	1035.31

28	36.86	-1.32	1621.40	0.77	773.91
29	36.86	-1.32	1618.06	0.76	755.92
30	36.86	-1.32	1611.63	1.10	1098.61
31	36.86	-1.32	1611.91	0.89	886.12
32	36.86	-1.31	1625.23	1.15	1150.81
33	36.86	-1.31	1626.71	1.38	1383.02
34	36.85	-1.31	1627.14	1.12	1116.11
35	36.84	-1.30	1627.20	0.99	994.00
36	36.83	-1.29	1628.00	1.19	1191.14
37	36.83	-1.29	1629.77	0.90	901.40
38	36.83	-1.29	1639.69	1.07	1074.99
39	36.83	-1.29	1644.17	0.83	834.43
40	36.83	-1.29	1665.91	1.08	1082.09
41	36.82	-1.29	1661.97	1.24	1237.04
42	36.82	-1.29	1669.74	1.07	1071.30
43	36.82	-1.29	1656.89	1.10	1102.76
44	36.82	-1.29	1656.89	0.99	987.27
45	36.82	-1.29	1654.71	0.98	976.19
46	36.82	-1.28	1649.09	1.01	1014.66
47	36.82	-1.28	1645.37	1.18	1182.08
48	36.82	-1.28	1725.80	1.01	1012.73
49	36.82	-1.28	1713.91	1.02	1022.21
50	36.82	-1.28	1662.91	1.06	1062.71
51	36.82	-1.28	1657.29	0.83	830.40
52	36.82	-1.28	1673.71	1.09	1088.40
53	36.82	-1.28	1687.34	0.94	935.04
54	36.80	-1.26	1687.74	0.95	951.37
55	36.80	-1.26	1688.29	1.08	1080.46
56	36.80	-1.27	1727.15	1.03	1030.34
57	36.94	-1.25	1568.21	1.47	1465.50

58	36.94	-1.25	1534.28	1.22	1223.61
59	36.94	-1.25	1539.13	0.85	848.26
60	36.94	-1.25	1530.77	1.04	1040.61
61	36.94	-1.25	1525.77	1.60	1604.18
62	36.94	-1.24	1529.33	1.08	1076.89
63	36.94	-1.24	1535.95	1.35	1353.92
64	36.98	-1.18	1526.10	1.14	1144.90
65	37.08	-1.03	1468.31	1.39	1387.75
66	37.08	-1.03	1456.21	1.21	1207.58
67	37.07	-1.04	1500.51	1.51	1514.92
68	37.07	-1.04	1481.56	0.97	969.45
69	37.08	-1.04	1492.74	1.16	1160.21
70	37.08	-1.04	1493.85	0.82	818.16
71	37.07	-1.05	1492.87	1.18	1182.61
72	37.04	-1.08	1493.82	1.31	1305.77
73	36.96	-1.15	1519.00	1.14	1140.58
74	36.96	-1.15	1518.21	1.15	1154.77
75	36.96	-1.15	1525.36	1.22	1216.35
76	36.95	-1.16	1544.10	1.00	999.32
77	36.89	-1.23	1603.15	1.24	1243.23
78	36.84	-1.32	1620.23	1.23	1234.80
79	36.84	-1.32	1621.62	1.07	1065.56
80	36.83	-1.32	1628.21	1.16	1160.62
81	36.83	-1.32	1633.64	1.07	1075.00
82	36.83	-1.33	1635.41	1.13	1129.84
83	36.83	-1.33	1635.23	0.78	775.21
84	36.83	-1.32	1637.85	1.10	1096.35
85	36.84	-1.30	1638.77	1.22	1224.32
86	36.84	-1.30	1645.69	0.94	944.13
87	36.84	-1.30	1642.95	0.93	934.46

88	36.84	-1.29	1641.82	1.04	1035.40
89	36.84	-1.29	1642.92	1.14	1143.54
90	36.83	-1.29	1648.36	0.62	620.47
91	36.83	-1.29	1656.62	1.20	1200.15
92	36.83	-1.28	1673.49	1.02	1019.36
93	36.88	-1.23	1621.82	1.14	1142.08
94	37.01	-1.10	1502.59	1.13	1127.02
95	37.01	-1.09	1520.05	1.05	1049.95

3.2 Activity concentrations of radionuclides in the samples

Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K radionuclides in soil collected from different sample sites in the study area were calculated from their intensities (equation 6) and values were reported in $Bqkg^{-1}$ as indicated in Table 3.2 below.

Table 3.2: Activity concentrations of radionuclides in the samples.

	ACTIVITY CONCENTRATION		
WORLD AVERAGE.	^{232}Th	^{226}Ra	^{40}K
SAMPLE SITE	**30**	**35**	**400**
KMC	85.12±0.36	65.53 ±0.24	823.174± 0.10
MWIKI	198.47 ±0.14	96.41± 0.18	1029.11± 0.09
MLOLONGO	75.79 ±0.01	21.19± 0.22	579.787± 0.10
NJIRU QUARRY	80.10 ±0.22	63.77± 0.23	860.87± 0.08
A. RIVER MINING	34.55± 0.03	49.12±0.48	1113.86± 0.09
INDU. AREA-Tetra pak (T.P)	228.80± 0.32	159.52± 0.14	1164.51± 0.1

The activity concentration for ^{232}Th and ^{226}Ra were in the range of 34.55± 0.03-228.80± 0.32 and 21.19± 0.22- 159.52± 0.14 $Bqkg^{-1}$ respectively with the highest activity values for ^{232}Th and ^{226}Ra being Tetrapak followed by Mwiki dumpsite respectively. The high values obtained at Tetrapak could be due to the heavy machinery in the industry whereas mwiki dumpsite is located in a place was once an open mining area. In all the soil samples ^{40}K had the highest activity concentration which ranged from 579.79±0.10- 1164.51±0.1 $Bqkg^{-1}$ with the highest activity value being at Tetrapak and the lowest at Mlolongo. The high values observed for ^{40}K is due to the fact that ^{40}K is a common element in the soil and its concentration is relatively high due to its long halflife compared to ^{232}Th and ^{226}Ra. The variation of natural radioactivity levels at different sampling sites was due to the variation of concentrations of radionuclides in the geological formations and can partly be attributed to the economic activities of the different areas.

The activity concentrations values for ^{232}Th ^{226}Ra and ^{40}K obtained from soil samples collected at Tetrapak were relatively higher than from the rest of the sampled sites. This can be attributed to the location of the industry which is at the core of the Nairobi Industrial area. This implies that people living or working around Tetrapak are at a higher risk of experiencing the effect due to exposure to the radiation as compared to the occupants of the rest of the sampled sites. Residents of Mwiki are at a higher risk of radiation exposure too especially those living near the Mwiki dumpsite. The Mwiki dumpsite is close to the Njiru quarry which means that some rock deposits from the quarry could be contributing to the high activity concentrations obtained for thorium.

Comparison of average activity concentrations of radionuclides obtained in each sample site and the world acceptable activity concentrations (Table 4.1) indicated that all the soil samples had higher activity values than the acceptable values. This partly explains the high incidences of cancer cases that are reported annually in the study area which could be resulting from radiation exposure due radioactivity from constructions, the quarries, buildings and open mines.

The mean activity concentrations values for ^{232}Th, ^{226}Ra and ^{40}K were 117.14, 75.91 and 928.55 Bqkg^{-1} respectively. The calculated activity values were higher than the world acceptable activity concentrations which are 30, 35 and 400 Bqkg^{-1} respectively as reported by UNSCEAR (2000).

3.3 Radium equivalent (Ra_{eq}) obtained from the samples

Ra_{eq} (weighted sum of activities) owing to activity concentration of 3 natural radionuclides (^{226}Ra, ^{232}Th, and ^{40}K) from all sites were computed according to Equation 1. The values obtained (Table 3.3) varied from 174.21-643.99 Bq kg^{-1}.The mean value of Ra_{eq} was 326.18 Bq kg^{-1}, which is less than the threshold value of 370 Bq kg^{-1}.

Table 3.2 Computed Radium equivalent values.

PLACE	RADIUM EQUIVALENT ($Bqkg^{-1}$)
KMC	250.64
MWIKI	459.36
MLOLONGO	174.21
NJIRU QUARRY	244.60
A. RIVER MINING	184.29
INDU. AREA (T.P)	643.99

Highest radium equivalent values were obtained from the soil samples collected at Tetra pak industry and the Mwiki dumpsite which were 643.99 and 459.36 Bq kg^{-1} respectively. These values were greater than the threshold value of 370 Bq kg^{-1}. This could mean that stones mined too close to the Mwiki dumpsite are not be suitable for building or there could be some radioactive materials that are disposed at the site with other garbage . Scavengers at the dumpsite could be taking in the radiations that are emitted at this site.

3.4 Absorbed Dose Rates from soil

The absorbed dose rates due to terrestrial gamma rays above the ground were calculated using equation 2 and were expressed in $nGyh^{-1}$. Using the conversion factors (equation 3) the annual effective dose rates in $mSvy^{-1}$ were computed and were tabulated (Table 3.4). These values varied from 149.46 – 514.28 $nGyh^{-1}$.The mean value for absorbed gamma radiation dose rate (D) was 263.05 $nGyh^{-1}$, which is approximately 6 times higher than the world acceptable value of 43 $nGyh^{-1}$ (UNSCEAR, 2000).

Table 3.3: Absorbed Dose Rates and Annual effective dose rates from soil.

SAMPLE SITE	ABSORBED DOSE RATE ($nGyh^{-1}$)	ANNUAL EFFECTIVE DOSE RATE (mSv/y)
KMC	198.77	0.73
MWIKI	371.79	1.33
MLOLONGO	149.49	0.52
NJIRU QUARRY	194.48	0.72
A.RIVER MINING	149.46	0.56
INDU. AREA (T.P)	514.28	1.89

.

The mean annual effective dose (E) was 0.96 $mSvy^{-1}$. Residents of Tetrapak area and around the Mwiki dumpsite experience higher annual effective dose rates 1.89 and 1.33 $mSvy^{-1}$. These values were higher than the recommended value of 1 $mSvy^{-1}$ and this means that these residents could be experiencing the health effects that are associated with the outdoor occupancy factor.

3.5 External and internal hazard indices

The external and internal hazard indices which are due to external exposure and inhalation of radon gas were computed according to equations 4 and 5 respectively. The H_{ex} and H_{in} values obtained were as recorded (Table 3.5). The values ranged from 0.47 to 1.74 and 0.53 to 2.17. The mean values were 0.88 and 1.09 respectively. The acceptable unity value for H_{ex} and H_{in} was exceeded both at Mwiki and Tetrapak sample sites. This meant that the residents of these two areas are at a higher risk of external exposure as well as in inhalation. The results indicate that the major source of exposure at Tetrapak was due to inhalation though the external exposure was also higher than in soil sample collected at Mwiki. The exposure levels due to inhalation were also relatively high at KMC and Njiru quarry. In all the samples internal hazard indices were higher than the external ones. This means that a greater exposure in the

studied sites is due to inhalation of radon gas and less on external contact with the solid materials.

Table 3.4: External and Internal hazard indices.

PLACE	EXTERNAL HAZARD INDEX (H_{ex})	INTERNAL HAZARD INDEX (H_{in})
KMC	0.68	0.85
MWIKI	1.24	1.50
MLOLONGO	0.47	0.53
NJIRU QUARRY	0.66	0.83
A.RIVER MINING	0.50	0.63
INDU. AREA(T.P)	1.74	2.17

3.6 Comparison of the calculated and measured absorbed dose rates.

Calculated dose and measured absorbed were tabulated and compared. The results indicated that the highest value for calculated dose rate was Tetrapak (514.28 $nGyh^{-1}$). Njiru quarry had the highest measured dose rate (1604.18). In all the sampled sites measured absorbed doserates were far much higher than the calculated values (Table 3.6) for all the sample sites. The difference is that the measured absorbed dose rates included the dose due to cosmic rays as well as latitude and longitude effects which were not accounted for in the calculated absorbed dose rates.

Table 3.5: Calculated and measured absorbed dose rates (nGyh-1).

SAMPLE SITE	CALCULATED DOSE RATE ($nGyh^{-1}$)	MEASURED ABSORBED DOSE RATE ($nGyh^{-1}$)
KMC	198.77	1036.14
Mwiki	371.79	1102.76
Mlolongo	149.49	928.32
Njiru Quarry	194.48	1604.18
Athi River mining	149.46	335.03
Industrial area (T.P)	514.28	1383.02

3.7 Conclusions and Recommendations

3.7.1 Conclusions

Radiation exposure is one of the causes of cancer. Majority of the people in Nairobi are unaware of radiation exposure and the health effects associated to the exposure. The aim of the study was to analyse the radiation levels in Nairobi city and the industrial areas where currently scanty information has been provided. The air absorbed radiation dose rates were measured using a hand held radiation monitor and some soil samples were collected from the study area. The measured average absorbed dose rate in air at the sampled sites was (1064.92 $nGyh^{-1}$). Elemental and radioactivity analysis of the soil samples was done using Gamma-ray spectrometry method using the High purity germanium detectors. From the soil samples mean activity concentrations values of ^{232}Th, ^{226}Ra and ^{40}K were 117.14, 75.91 and 928.55 $Bqkg^{-1}$ respectively. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were all found to be above the world's average values which are 30, 35 and 400 $Bqkg^{-1}$ respectively. In all sampled sites, ^{40}K had the highest activity concentration. The activity concentrations for the various sample sites varied from one samples site to the other. This variance results due to the soil type and the soil composition due to geological processes involved in soil formation and also human activities like mining and quarrying.

The mean Ra_{eq} value was 326.18 Bq kg^{-1}, which is less than the threshold value of 370 Bq kg^{-1}. Highest Ra_{eq} values obtained from the soil samples collected at Tetra pak industry and the Mwiki dumpsite 643.99 and 459.36 Bq kg^{-1} respectively indicate that stones mined too close to the Mwiki dumpsite may not be suitable for building.

The calculated average absorbed dose rate in air (263.05 $nGyh^{-1}$) due to gamma-ray emitters was at least 6 times higher than the world average value (43 $nGyh^{-1}$) according UNSCEAR, 2000. The mean annual effective dose was 0.96 $mSvy^{-1}$. Values for Tetrapak and mwiki areas (1.89 and 1.33 $mSvy^{-1}$) were higher than the recommended value of 1$mSvy^{-1}$. This means that these residents could be experiencing the health effects that are associated with the outdoor occupancy factor.

The mean values were 0.88 and 1.09 respectively. The mean H_{in} exceeded unity value, the limit acceptable by ICRP 2000. Soil samples collected around Tetrapak industy indicated the highest H_{ex} and H_{in} values of 1.74 and 2.17 respectively.

The measured absorbed dose rate values were higher than the calculated values. The high measured absorbed dose rate values were due to cosmic rays and the latitude-longitude effect.

The study generally concludes that materials mined close to the Mwiki dumpsite are not suitable for building. People living around Mwiki and Tetrapak industries are at a higher risk of radiation exposure hence the effects associated with such exposure especially cancer which is expensive disease to treat and in most cases it leads to death.

3.7.2 Recommendations

From the current study the radiation levels in most sampled sites were found to be higher than the world limits. Since this area is one of the most densely populated areas in Kenya and is the area with the highest cancer incidences reported annually, safety measures should be taken.

1. Workers in the open mining industry (quarries) should be advised to use protective clothing so as to reduce the radiation exposure and the health risks accrued to the radiations. The activity concentrations in building blocks and other building materials like cement should be tested before use to verify their suitability. This will ensure that exposure due to inhalation is minimised and is within the acceptable limits. Further studies should be done in the study area to investigate the other possible sources of radiation exposure and other carcinogenic substances to curb the high rate of death due to cancer in Nairobi region.

2. More research should be done in Kenya to get more representative results of human radiation exposure. Soil sampling should also be done at different times of the year since climatic changes in the year could affect dispersion of radionuclides.

3. The government should enhance awareness on radiation exposure and the effects to the general public and also radiation workers so as to reduce effects that could be arising due to ignorance by the public. It should also take precaution on how waste materials are deposited to reduce effect to people leaving around and those working at the dumpsites.

4. Machinery for quarrying can be provided to the miners so as to reduce the time they spend in the quarries (occupancy factor) hence reducing the annual effective dose rate they receive. Such people should also be encouraged to use protective gears while at work. Clear policies that pay attention to the effects of exposure to the environment radiation should be put in place and the government should ensure that the policies are implemented or observed by all workers.
5. Similarly the government and the directorate of occupational safety and health services (DOSHS) should introduce a policy guideline on workplace radiation levels as well as risk exposure limit as a result of radiation even under the occupation safety and health act 2007. Proper data or mapping of radiation hot spot in the country can be made available which can be used for understanding the problem of radiation.

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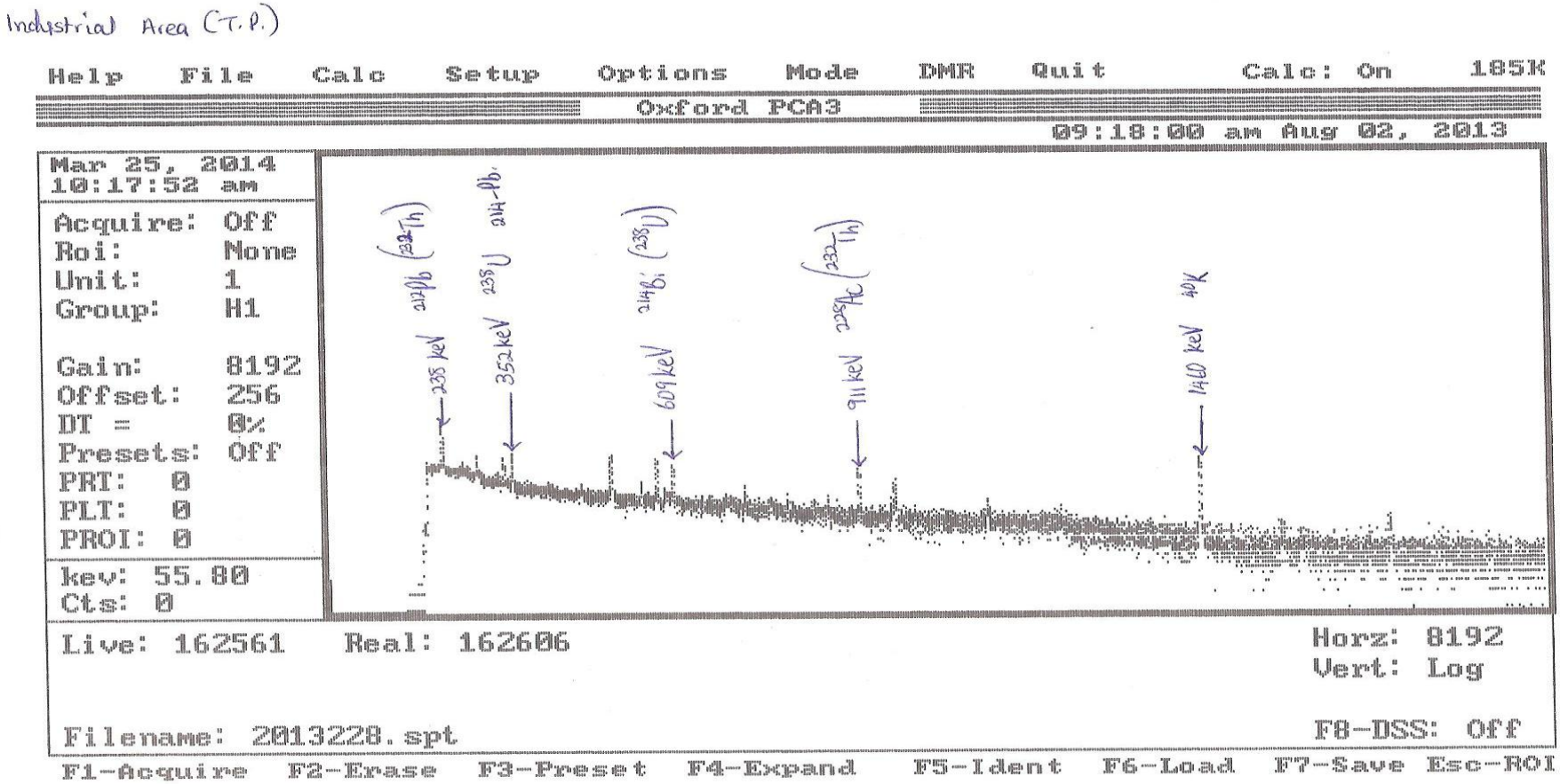
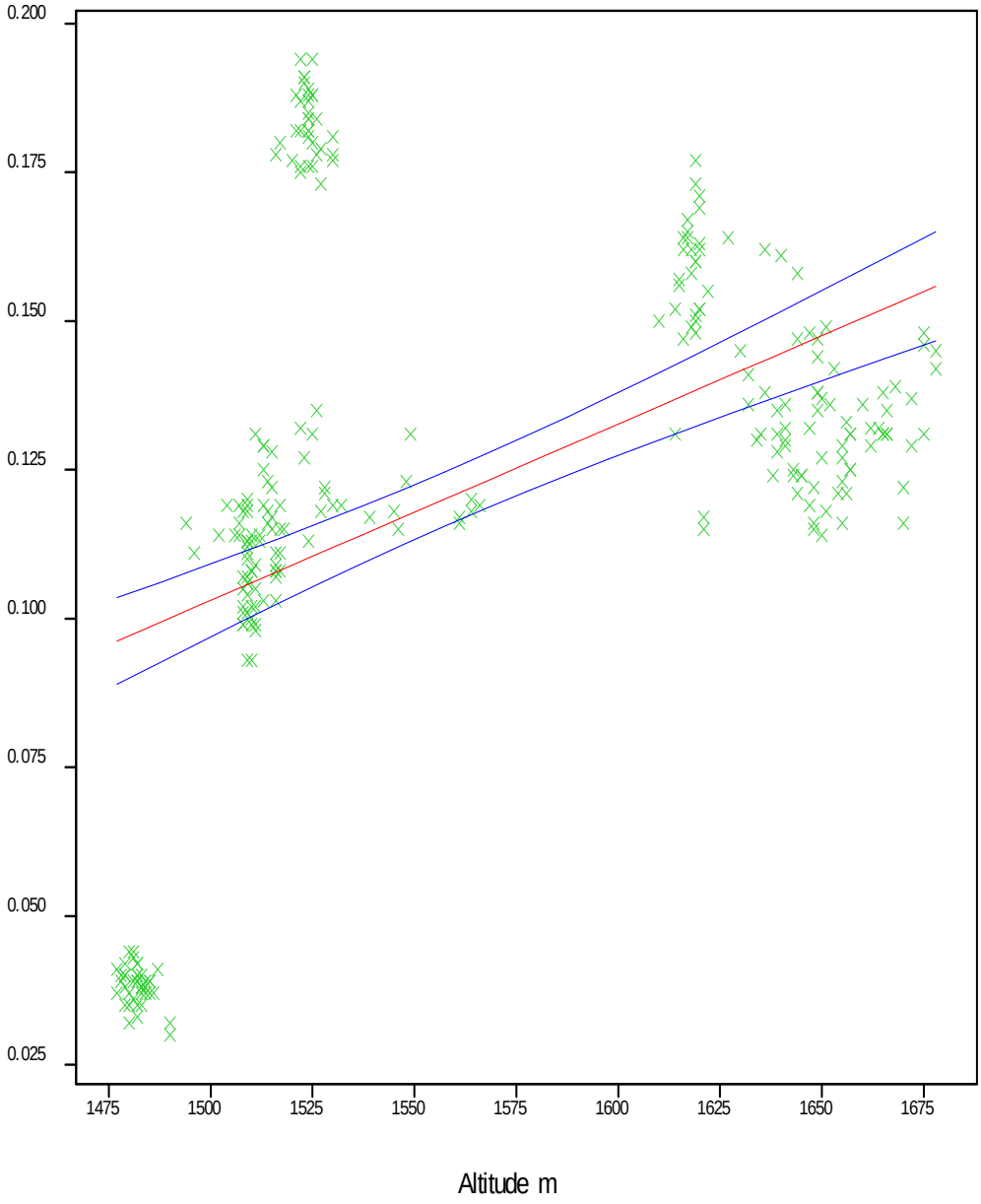
APPENDICES.

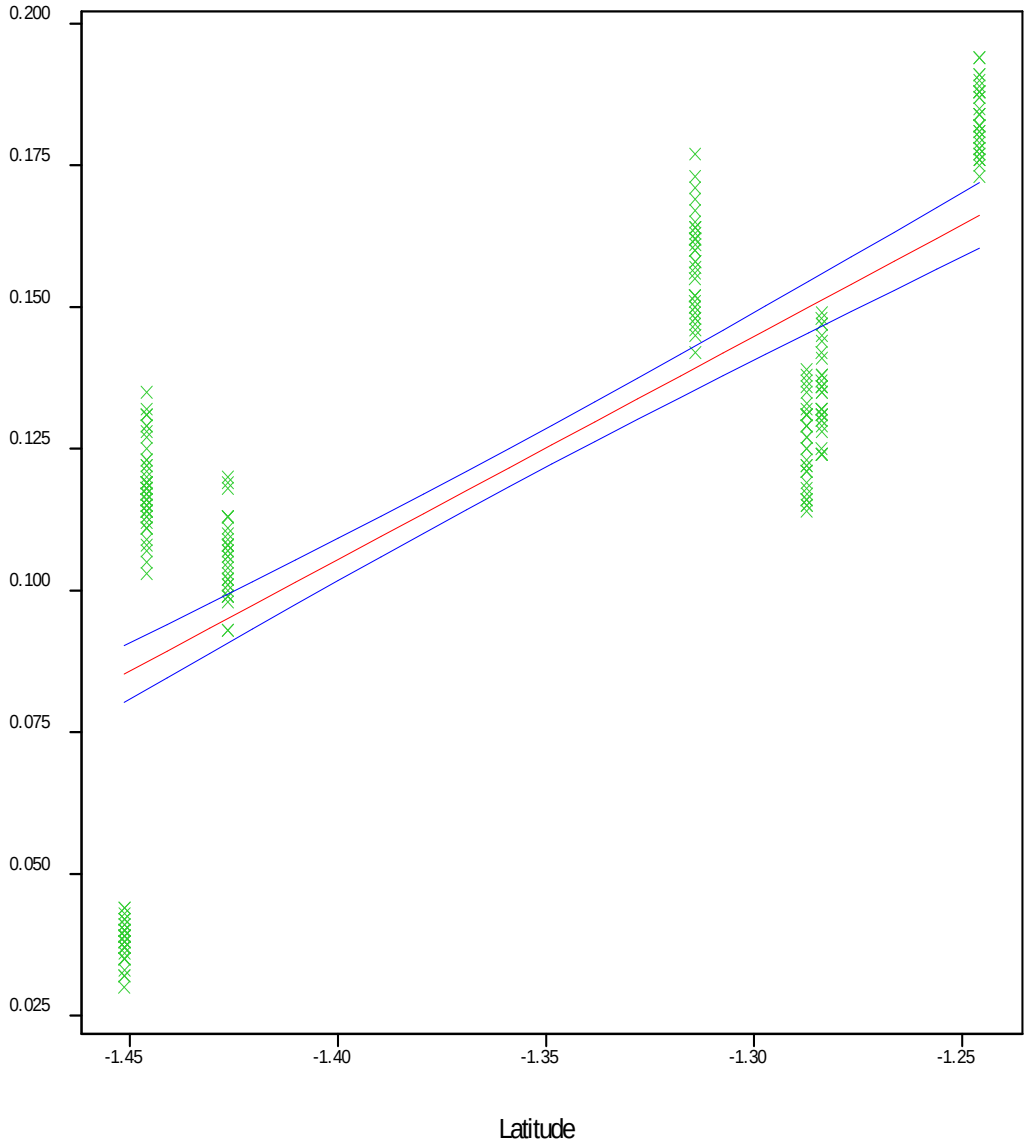
Appendix I: Spectrum for Industrial area.



Appendix II: Profile diagram for Radiation (µSv/h) versus Altitude.



Appendix III: Profile diagram for Radiation (µSv/h) versus Latitude.



Appendix IV: Profile diagram for Radiation (µSv/h) versus longitude.