DETERMINATION OF BACKGROUND IONIZING RADIATION IN QUARRIES AND PREMISES AROUND NAIROBI COUNTY

OGOLA PHILLIP EINSTEIN OTIENO (BSc)

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JUNE, 2016
DECLARATION

I, Phillip Einstein Ogola, declare that the work presented in this thesis is original work and has not been presented for the award of a degree in any other university or any other award.

OGOLA PHILLIP EINSTEIN OTIENO

I56/20183/2012

Signature .................................. Date ........................................

SUPERVISORS

We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

Dr. Richard O. Oduor
Department of Biochemistry and Biotechnology
Kenyatta University

Signature .................................. Date ........................................

Dr. Mathew Piero Ngugi
Department of Biochemistry and Biotechnology
Kenyatta University

Signature .................................. Date ........................................

Dr. Siphila W. Mumenya
College of Architecture and Engineering
University of Nairobi

Signature .................................. Date ........................................
DEDICATION

This thesis is dedicated to my father Dr. Henry Aloo Ogola and my late mother Mrs. Elizabeth Anyango Ogola from whom I derive my inspiration.
ACKNOWLEDGEMENT

I am grateful to the Almighty God for giving me the courage and strength since I began this academic journey. Despite the many challenges I faced, He made me lie down in green pastures and surely goodness and mercies followed me all the time.

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I dearly thank and recognize my father Dr. Henry Aloo Ogola for the sacrifices he made to stand with me while doing this work. You endured it all just to see to it that this work was done to completion. You have been a source of inspiration and encouragement for me especially during our most painful period. I am grateful to my late mum Mrs. Elizabeth Anyango Ogola for her constant calls of encouragement and prayer. May her soul Rest in Peace. To my siblings: Alice Valerie Ogola, Anthony Collins Ogola and John Edwin Ogola, I cannot thank you enough for your support, prayers and encouragement. I would not have made it without you guys thus will be forever grateful to you.

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<tr>
<td>COPD</td>
<td>Chronic Obstructive Pulmonary Disease</td>
</tr>
<tr>
<td>CT</td>
<td>Computerized Tomography</td>
</tr>
<tr>
<td>DNA</td>
<td>Deoxyribonucleic Acid</td>
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<tr>
<td>ICRP</td>
<td>International Commission on Radiological Protection</td>
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<td>IARC</td>
<td>International Agency for Research on Cancer</td>
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<tr>
<td>MRI</td>
<td>Magnetic Resonance Imaging</td>
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<tr>
<td>mRNA</td>
<td>Messenger Ribonucleic Acid</td>
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<tr>
<td>NCD</td>
<td>Non Communicable Diseases</td>
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<td>NEMA</td>
<td>National Environmental Management Authority</td>
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<td>NORMs</td>
<td>Naturally Occurring Radioactive Materials</td>
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<td>PET</td>
<td>Positron Emission Tomography</td>
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<td>TLD</td>
<td>Thermoluminescent Dosimeter</td>
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<tr>
<td>UNSCEAR</td>
<td>United Nations Scientific Committee on the Effects of Atomic Radiation</td>
</tr>
<tr>
<td>UV</td>
<td>Ultraviolet</td>
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<tr>
<td>WHO</td>
<td>World Health Organization</td>
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More recently, exposure to background ionizing radiations by the public is increasingly becoming a concern especially their contribution to the rising cancer incidences in Kenya. Such background ionizing radiations occur naturally from the sun, in rocks and soil and can cause changes in human cell including genetic mutation thus leading to cancer. Unfortunately, majority of the buildings in Kenya are usually constructed using stones and sand mined from underground rocks and river beds yet Kenya is not adequately radio-profiled to determine the levels of embedded radio-nuclides capable of emitting ionizing radiations. Conventionally, the World Health Organization (WHO) recommends that the annual exposure to the ionizing radiation to the general public should not exceed 1 mSv. This project therefore, sought to determine the levels of indoor background radiation in selected human premises and quarries around Nairobi County. Calibrated Radiation Alert® (Digilert 200) handheld radiation detectors were used to capture the reading. The meters were held at the abdominal level (about 1 m above ground level) and readings were recorded in mR/h for all quarry sites and premises. Numerical data was subjected to analysis of variance using Minitab version 17.0 to determine the statistical differences of exposure levels within various areas. A total of 38 quarries were designated Q 01 to Q 38 and 400 premises were sampled. The results showed that in Ndarugo area, Q09 had the highest annual dose threshold of 1.32 mSv while Q07 had the lowest annual dose threshold of 0.91 mSv. For quarries in other parts of Nairobi County, Q23 had the highest annual dose threshold of 1.68 mSv while Q34 had the lowest annual dose threshold of 1.06 mSv. Of the 38 quarries sampled in this study, only 5 quarries had annual exposure levels below the recommended WHO standard representing a dismal 13% compliance. There were significant differences in annual dose levels between the quarries sampled in the study (p<0.05 was statistically significant). The annual indoor readings were highest in Eastleigh (4.070 mSv) and relatively lowest in Nairobi Central Business District (CBD) at 2.763 mSv, representing a deviation from WHO recommended standard of 307.0% and 176.3%, respectively. None of the premises sampled had exposure levels below the WHO recommended standard of 1 mSv. Overall, these results indicate presence of higher levels of ionizing radiations in quarries and premises beyond the acceptable annual threshold thereby posing significant health risk to the public. Consequently, these results could find great application in guiding the formulation of the national building code to include routine surveillance of the background ionizing radiation levels in quarries and in various buildings to assess the health risk of quarry workers and general public as well as exploring appropriate mitigation approaches.
CHAPTER ONE
INTRODUCTION

1.1 Background information

Cancer is the uncontrolled growth of abnormal cells in the body. Cancerous cells are also called malignant cells and invade nearby body parts. The spread to more distant body parts can be facilitated by the lymphatic system and the bloodstream. Benign tumors do not grow uncontrollably and do not spread to nearby cells. The risk factors for cancer include tobacco use, exposure to ionizing radiation, lack of exercise, environmental pollutants and obesity (Anand et al., 2008). These risk factors damage genes and combine with genetic faults causing disease (Burt et al., 2002). Cancer ranks as the leading cause of death in developing countries, and it kills more people globally per year than AIDS, tuberculosis or malaria (Garcia et al., 2007). Over 60% of the deaths occur in the poor regions of the world. It is expected that by 2020, there will be 15 million new cases of cancer globally, and 70% will be in developing countries (Lopez-Gomez et al., 2013).

In the next 20 years, it is anticipated that there will be significant increases in morbidity, mortality and economic cost due to cancer (Swerdlow et al., 2008). With proper awareness programmes and primary prevention measures, up to one third of cancer cases in developing countries can be prevented. In addition, the survival rates of these cases could be increased in cases of early detection of
cancer (Boyle et al., 2008). In developing countries, there are minimal facilities for the diagnosis and treatment of cancer. There are also almost no national cancer control programmes in place in the developing countries (Sitas et al., 2008). Most Africans have no access to cancer screening, diagnosis, treatment and palliative care due to lack of resources and the basic infrastructure despite African countries accounting for over a million new cases annually (Jemal et al., 2010).

Due to the increase of cancer burden in developing countries, there is need for more professionals (doctors, nurses, and the relevant staff), hospitals and treatment facilities. These factors pose a major financial and logistical problem (Boyle, 2008). In Africa, it is believed that lack of healthcare workers is the major setback in implementation of many health programmes and has resulted in a hindrance in delivering health interventions to patients (Crisp et al., 2008). Doctors, nurses and other medical personnel are scarce in number in developing countries (Boyle, 2008) and as a result limited specialized skills in oncology.

A case study in Ethiopia revealed that there is only one oncologist for a population of 60 million (Axios International, 2009). In addition due to the low cancer awareness in developing countries, it is estimated that 80% of cancer patients have advanced stage disease at initial presentation. Even if it is detected
early, there is inadequate access to cancer treatment and management (Sitas et al.,
2008). Developing countries need radiotherapy due to the late stage presentations
and the cancer types that predominate. In Africa there is less than 2% of all
radiotherapy centers globally (IAEA, Directory of Radiotherapy Centers) and has
15% of the world’s population (World Population Data Sheet, 2009). This
demonstrates the dire need of radiotherapy improvement.

In Kenya, cancer ranks third among the cause of death after infectious and
cardiovascular diseases. It was reported that in 2005 it accounted for
approximately 18,000 deaths, most involving patients under the age of 70 (Noor
et al., 2009). In women, the leading types of cancer are cervical and breast while
in men they are esophagus, head, neck and prostate. In children the commonest
are blood cancers and lymphomas (WHO, 2010). As such, several studies are
currently focusing on mitigating risk factors that are often associated with cancer.

1.2 Problem statement and justification

One of the main causes of cancer is exposure to ionizing radiations like x rays and
gamma rays. Ionizing radiations comprises subatomic particles, ions or atoms and
electromagnetic waves on the short wavelength end of the electromagnetic
spectrum. They are highly energetic and when they pass through a material, they
deposit enough energy that will lead to breakage of molecular bonds and
displacement of electrons from atoms. The electron displacement results in ions that cause changes in human cells (Environmental Protection Agency, 2009). This leads to DNA mutations that cause cancer or cell death.

World Health Organization recommends that the annual exposure to background ionizing for the general public should not exceed 1 mSv because the risk of cancer increases with the increase in the duration of radiation exposure. The extent of cell damage is directly related to the dose of radiation it receives (Environmental Protection Agency, 2007). The five major types of ionizing radiation are gamma rays, neutrons, alpha particles, beta particles and X rays. Alpha particles and beta particles are emitted from naturally occurring radioactive materials present in the soil and rocks.

In Kenya, unfortunately, there is no data on profiles. As a result, there is a knowledge gap on the levels of radiation exposure from the stones used in construction. Furthermore, there is no awareness on the early detection system of radionuclides present in soil and rocks. Most buildings in Kenya are usually constructed using sand and stones mined from rocks and river beds. Hence, the amount of radionuclides present in these stones and sand that are used in construction of buildings lack radio-certification measures in the country. The World Health Organization (WHO) recommends that the annual dose exposure to ionizing radiation for the general public should not exceed 1 mSv. The Radiation
Protection Act, Chapter 243 stipulates that to prevent occurrence of stochastic effects, the dose equivalent limits for radiation workers in uniform exposure to ionizing radiation shall be 50mSv per year and 0.5Sv per year in any tissue with the exception of the eye lens to prevent non stochastic effects. This study sought to determine the levels of indoor background radiation in selected human premises and quarries around Nairobi County (Radiation Protection Act, 2013).

1.3 Hypotheses

i. There are no higher levels of background ionizing radiation in quarries around Nairobi County compared to the recommended threshold.

ii. There are no higher levels of background ionizing radiation from human premises in Nairobi County compared to the recommended threshold.

1.4 Objectives

1.4.1 General objective

To determine the levels of background ionizing radiation exposure in selected quarries and human premises around Nairobi County and its environs relative to WHO recommended exposure standard.
1.4.2 Specific objectives

i. To determine the levels of background ionizing radiation in selected quarries around Nairobi County and its environs relative to WHO recommended exposure standard.

ii. To determine the levels of background ionizing radiation in selected human premises built with quarry stones from Nairobi County and its environs relative to WHO recommended exposure standard.

1.5 Research output

i. Levels of background ionizing radiation from selected quarries in Nairobi was generated.

ii. Level of indoor exposure to background ionizing background radiation from human premises in Nairobi was developed.

1.6 Significance of the study

i. The relevant stakeholders will use these results to explore various mitigation measures so as to reduce exposure levels.
CHAPTER TWO

LITERATURE REVIEW

2.1 Non communicable diseases burden

According to WHO (2008), non-communicable diseases (NCDs) accounted for up to 36 million deaths and 80% of the deaths occurred in low and middle income countries. WHO projections show that 28 million people in the WHO African region will die from a chronic disease over the next 10 years. Projections indicate that by 2020 there will be a large increase in NCD deaths in Africa. NCDs are projected to exceed the combined deaths occurring as a result of communicable and nutritional diseases and maternal and prenatal deaths by 2030 (WHO, 2008). Up to 9 million deaths caused by NCDs occur before the age of 60 (WHO, 2008).

The four major types of NCDs are cardiovascular diseases, cancer, chronic respiratory diseases and diabetes. Cardiovascular diseases account for 17.3 million people annually followed by cancers (7.6 million), respiratory diseases (4.2 million) and diabetes (1.3 million) (WHO, 2008). Without effective prevention and control measures, it is estimated that up to 41 million people in low-and middle-income countries will die from NCDs by 2015 (Abegunde et al., 2007) and will be a burden to the economy over the next two decades (Bloom et al., 2011).
The increasing trends in the burden of NCDs in low and middle income countries has been attributed to the increasing levels of risk factors such as smoking/tobacco use, physical inactivity, exposure to ionizing radiation, unhealthy diet and increased alcohol consumption (WHO, 2011). The leading risk factor for NCD globally is high blood pressure which accounts for 16.5% of global death followed by tobacco use (9%), high blood glucose levels (6%), physical inactivity (6%) and obesity (5%) (WHO, 2011). Cases of unhealthy diets may show in a population as increased blood glucose, high blood pressure, elevated blood lipids, overweight and obesity. The mean salt intake in most low and middle income countries exceeds the recommended maximum intake (Brown et al., 2009).

Reducing salt intake could prevent annually death cases by 2.5 million globally (Macgregor, 2004). Low levels of fruit and vegetable intake accounts for up to 2.7 million NCD related deaths annually (Hall et al., 2009). Approximately 3.2 million deaths annually are as a result of physical inactivity (Beaglehole, 2011). Majority of Africa health care systems have inadequate funding and personnel to cope with the cumulative burden of infectious and chronic diseases. Many of the African health ministry’s acknowledge the impact of NCDs but few have in place policies and measures to combat them (Alwan, 2001).
According to WHO (2011), low and lower middle income countries have the highest proportion of deaths caused by NCDs under the age of 60 years. Premature deaths under the age of 60 years for high income countries accounted for 13% and 25% for upper middle income countries. In lower middle income countries, the death proportion under 60 years rose to 28% while in low income countries the proportion of premature NCDs deaths accounted for 41%. The 2011 WHO projections reveal that Non Communicable Diseases (NCDs) will be responsible for a significantly increased total number of deaths in the next decade. NCD deaths are projected to increase by 15% globally between 2010 and 2020 (to 44 million deaths).

The greatest increases will be in the WHO regions of Africa, South-East Asia and the Eastern Mediterranean, where they will increase by over 20%. In the African Region, NCDs will cause around 3.9 million deaths by 2020 (WHO, 2011). The regions that are projected to have the greatest total number of NCD deaths in 2020 are South-East Asia (10.4 million deaths) and the Western Pacific (12.3 million deaths) (WHO, 2008). A previous study conducted in 2008 by WHO highlight the following NCDs as the leading causes of deaths: cardiovascular diseases (17 million deaths, or 48% of NCD deaths); cancers (7.6 million, or 21% of NCD deaths); and respiratory diseases, including asthma and chronic obstructive pulmonary disease (COPD), (4.2 million). Diabetes caused an additional 1.3
million deaths. Population growth and improved longevity are leading to increasing numbers and proportions of older people, with population ageing emerging as a significant trend in many parts of the world. As populations age, annual NCD deaths are projected to rise substantially, to 52 million in 2030.

Whereas annual infectious disease deaths are projected to decline by around 7 million over the next 20 years, annual cardiovascular disease mortality is projected to increase by 6 million, and annual cancer deaths by 4 million. In low and middle-income countries, NCDs will be responsible for three times as many disability adjusted life years and nearly five times as many deaths as communicable diseases, maternal, perinatal and nutritional conditions combined, by 2030 (WHO, 2008). The proportion of global NCD deaths under the age of 70, by cause of death, is demonstrated in Figure 2.1.
Figure 2.1: Proportion of global NCD deaths under the age of 70, by cause of death in 2008 (WHO, 2011).

2.1.1 Socioeconomic impact of NCDs

The increased incidence of NCDs is an impediment to poverty alleviation initiatives in low income countries. Economically disadvantaged individuals get sick and die sooner compared to those individuals of higher social class. This is because the former are at a greater risk of exposure to the risk factors such as tobacco and also have limited access to proper health care. Due to exorbitant costs for NCDs treatment, low resource households can be quickly drained off their resources leading to poverty (WHO, 2011).
2.2 Global cancer burden

The global cancer burden is on the rise and this is largely attributed to population aging and growth, besides adoption of behavioral risk factors such as smoking in the economically developing world. WHO estimates that 7.6 million deaths occurred in 2005 and if action is not taken, there will be 84 million deaths in the next decade. According to estimates by GLOBOCAN in 2008, 12.7 million new cancer cases and 7.6 million cancer deaths occurred and 56% of the new cases and 64% of the deaths occurred in the developing countries. In the low and middle income countries, breast, lung and colorectal cancers occur in high frequencies among the females. Global cancer burden can be prevented and managed through the wide application of prevention, early detection, diagnosis and treatment and palliative care (Boyle and Levin, 2008).

Cancer is predicted to be an increasingly important cause of morbidity and mortality in the next few decades, in all regions of the world. The challenges of tackling cancer are enormous and – when combined with population ageing – increases in cancer prevalence are inevitable, regardless of current or future actions or levels of investment. The projected changes in population demographics in the next two decades mean that even if current global cancer rates remain unchanged, the estimated incidence of 12.7 million new cancer cases in 2008 (Ferlay et al., 2010) will rise to 21.4 million by 2030, with nearly two thirds of all cancer diagnoses occurring in low- and middle-income countries.
Large variations in both cancer frequency and case fatality are observed, even in relation to the major forms of cancer, in different regions of the world. Figure 2.2 presents the most frequent types of cancer diagnosis (based on age-standardized rates) in each country, for men and women (WHO, 2011).

Figure 2.2: Most frequently diagnosed cancers worldwide, by country and sex in 2008 (WHO 2011).
Within upper-middle-income and high-income countries, prostate and breast cancers are the most commonly diagnosed in males and females respectively, with lung and colorectal cancers representing the next most common types in both sexes. These cancers also represent the most frequent types of cancer-related deaths in these countries although lung cancer is the most common cause of cancer death in both sexes (WHO, 2011).

Within low-income countries, the absolute burden of cancer is much lower, and while lung and breast cancers remain among the most common diagnoses and types of cancer-related deaths, cancers of the cervix, stomach and liver are also among the leading types – all of which are cancers with infection-related etiology (WHO, 2011). Middle-income countries are intermediate with respect to their patterns of cancer burden. Within the lower-middle-income countries, the three most common types of cancer are lung, stomach and liver cancers in males, and breast, cervix and lung cancer in females, thereby revealing a similar pattern to the low-income countries (although liver, colorectal and esophageal cancers are also of importance) (WHO, 2011).

The lower middle-income group contains some of the most populous countries in the world, including China and India, hence the absolute numbers of cancers and cancer-related deaths are notably high in this group. Future planning of service provision is an integral part of cancer control programmes. Considering the
projected growth in cancer morbidity, important differences can be observed in relation to World Bank income groups. The estimated percentage increase in cancer incidence by 2030 (compared with 2008) will be greater in low- (82%) and lower-middle-income countries (70%) compared with the upper-middle- (58%) and high-income countries (40%). Without any changes in underlying risk factors (based only on anticipated demographic changes), between 10 and 11 million cancers will globally be diagnosed annually in 2030 in the low- and lower-middle-income countries (Figure 2.3).

According to WHO (2011), there were 10.9 million new cancer cases, 6.7 million cancer deaths and 24.6 million people living with cancer. The main cancer in the world today is lung cancer accounting for 1.35 million cases and 1.18 million
deaths. This is followed by breast cancer accounting for up to 1.15 million new cases. Breast cancer accounts for 17%, colorectal 11.5% and prostate 9.6%. In men, lung cancer is second behind prostate cancer in the developed world. For the case of women, cervical cancer is second in the developing world but is seventh in the developed world.

Breast cancer in females and lung cancer in males are the most frequently diagnosed cancers and the leading cause of cancer death for each sex in both economically developed and developing countries, except lung cancer is preceded by prostate cancer as the most frequent cancer among males in economically developed countries. These cancers were followed, without specific rank order, by stomach and liver cancers in males and cervix and lung cancers in females in economically developing countries and by colorectal and lung cancers in females and colorectal and lung or prostate cancers in males in the economically developed world (WHO, 2011).

2.2.1 Emerging trends in cancer diagnosis and management

Medical imaging technologies have become increasingly important in the clinical management of cancer, and now play key roles in cancer screening, diagnosis, staging, and monitoring response to treatment. Technological and scientific innovations over the last decade have greatly contributed to improved diagnostics,
predictive modeling, and prognosis among cancers affecting both men and women (Eun and Mandi, 2011). Standard imaging modalities such as Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET) and Computerized Tomography (CT) require significant financial resources and infrastructure, which limits access to these modalities to those patients in high-resource settings (Richards-Kortum, 2011). The new nuclear medicine imaging techniques provide a visual representation of the biological processes at the molecular level (Richard-Kortum, 2011).

These techniques can improve the precision of cancer diagnosis and management by being able to characterize early response to treatment and predict and identify which patient will respond best to specific therapies. In addition, optical imaging strategies, with the potential for reduced cost and enhanced portability, are emerging as additional tools to facilitate the early detection and diagnosis of cancer (Eun and Mandi, 2011). Optical imaging is a new technology which may provide a potential solution to the global need for affordable imaging tools to aid in the early detection and management of cancer. Mammography is still the most valuable tool available for reducing breast cancer mortality by early detection through screening programs. New technologies in this field include the introduction of digital mammography, which is advantageous in women with
dense breast providing improved accuracy in breast cancer detection (Richards-Kortum, 2011).

While healthcare providers have traditionally used optical tools such as endoscopes, colposcopes, and surgical microscopes in cancer management, a new generation of instruments is being developed which can detect not just reflected white light, but additional signals arising from cancer biomarkers, carried in the fluorescence, polarization, and narrowband reflectance of light (Sherris, 2011). These systems are capable of examining tissue over a wide range of spatial scales, with wide field macroscopic imaging typically spanning several square-centimeters, and high-resolution in vivo microscopy techniques enabling cellular and subcellular features to be visualized. Optical instrumentation is relatively inexpensive, using mass-fabricated components developed by the telecommunications and consumer electronics industries. Another key factor is the recent emergence of multimodal optical imaging systems, simultaneously providing wide-field and high-resolution optical imaging, within cost-effective, portable, and even battery-powered formats (Sherris, 2011).

Lelièvre et al. (2011) revealed technological advances that focus on the development of nonlinear optical imaging detection of early alterations of the breast epithelium. Using chemical treatment as well as nutrients that can influence breast cancer development, Raman spectroscopy can exquisitely measure changes...
in epithelial polarity by measuring lipid ordering, label-free, in live tissue structures. This technology opens the path to high-throughput screening of epithelial cancer risk and protective factors (Lelievre et al., 2011).

Other advancements focus on the delivery of paramagnetic submicron particles via the breast ducts to detect and treat abnormal cells. The development of the first breast-on-chip system to test nanotechnology-based multiplex targeting approaches for improved early diagnosis of neoplasia is ongoing (Richards-Kortum, 2011). Assessing epigenetic of marks at specific gene loci using fluorescence lifetime microscopy-based single molecule analyses reveals great results with the technology capable of measuring cellular heterogeneity in tissues, thus bringing new possibilities for better diagnostic procedures (Richards-Kortum, 2011). Although radiotherapy and chemotherapy have widely been used, additional comprehensive approaches that involve deep engagements with key stakeholders healthcare providers, health systems, laboratory networks and commercial interests are quickly being embraced (Sherris, 2011).

Diagnostic techniques that focus on DNA reaction networks are also being developed to detect cancer-specific mRNAs in human blood, amplify the signal, analyze the amplified signal, and generate an observable output for diagnosis. This tool offers flexibility and scalability (Graugnard et al., 2011).
2.3 Radiation exposure

Ionizing radiation exposure is measured as "absorbed dose" in gray (Gy). The "effective dose" measured in sievert (Sv) takes account of the amount of ionizing radiation energy absorbed, the type of radiation and the susceptibility of various organs and tissues to radiation damage. As human beings we are continually exposed to natural background radiation from many natural sources, such as cosmic rays, and naturally occurring radioactive materials in all the foods, fluids and air.

According to United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) Report (2000) the average natural background radiation dose to human beings worldwide is about 2.8 mSv each year, but this varies typically over the range 1-10 mSv. However, for a limited number of people living in known high background radiation areas of the world, doses can exceed 20 mSv per year. There is no evidence to indicate this poses a health risk. For most people more than half of their natural background radiation dose comes from radon, a radioactive gas that can accumulate in homes, schools and workplaces. When inhaled, the radiation exposure from radon may lead to lung cancer. Radiation doses to humans may be characterized as low-level if they are comparable to natural background levels (UNSCEAR Report, 2000).
Human exposure to natural radiation sources has been in existence. The earth has always been bombarded by high energy particles originating in outer space that generate secondary particle showers in the lower atmosphere. Additionally, the earth’s crust contains radio nuclides. For most individuals, exposure to natural background radiation is the most significant part of their total exposure to radiation.

2.3.1 Cosmic radiation

There are three sources of cosmic radiation: galactic cosmic radiation, solar cosmic radiation and radiation from the earth’s radiation belts also known as Van Allen belts (Spurny and Danchev, 2001). At sea level, cosmic radiation contributes about 10% of the total dose rate from natural radiation to which human beings have always been exposed. At higher altitudes in the atmosphere or in space, cosmic rays constitute the dominant radiation fields (Heinrich, 1999). Cosmic ray interactions produce a number of radioactive nuclei known as cosmogenic radio nuclides. The cosmogenic radionuclide most relevant to public exposure is $^{14}$C (Heinrich, 1999).
Van Allen radiation belts are formed through the capture of protons and electrons by the earth’s magnetic field. There are two van Allen radiation belts, an internal one centered at about 3000km and an external one centered at about 22000 km from the earth’s surface. The daily equivalent dose to the skin in the internal belts could reach several tens of sieverts for protons and several thousands of sieverts for electrons (Spurny and Danchev, 2001). The internal radiation belt descends rather close to the earth’s surface in the region called the South Atlantic Anomaly which is centered at about 800km east of Alegre, Brazil (Spurny and Danchev, 2001).

2.3.2 Terrestrial radiation

Naturally occurring radio nuclides of terrestrial origin, also termed as primordial radio nuclides are present in various degrees in all environmental media, including the human body. Only those radio nuclides with half-lives comparable to the age of the earth, and their decay products, exist in sufficient quantity to contribute significantly to population exposure (UNSCEAR Report, 2008). The main contribution to external exposure comes from gamma emitting radio nuclides present in trace amounts in the soil, mainly $^{40}\text{K}$ and the $^{238}\text{U}$ and $^{232}\text{Th}$ families. Information on outdoor exposure comes from direct measurements of dose rate or from evaluations based on measurements of radionuclide concentrations in soil.
UNSCEAR Report (2004) on Global Survey on Public Radiation Exposures provides information on distribution of doses according to specified ranges and on the average and the range of radionuclide concentrations in soil. Indoor exposures depend on radionuclide concentrations in outdoor soil and in building materials. The relative contribution from each source is highly dependent on the type of house and building material. Information on distribution of indoor exposures derived from direct measurements is not extensive, but these can be accessed on the basis of information on soil, shielding and building material, and then linked with the number of people exposed in order to estimate population exposures (UNSCEAR Report, 2004).

2.4 Occurrence of ionizing radiation

Radiation has always been a natural part of our environment. Natural radioactive sources in soil, water and air contribute to our exposure to ionizing radiation, as well as man-made sources resulting from mining and use of naturally radioactive materials in power generation, nuclear medicine and consumer products, military and industrial applications. Naturally Occurring Radioactive Materials (NORM) consist of materials, usually industrial wastes or by-products enriched with radioactive elements found in the environment, such as uranium, thorium and
potassium and any of their decay products, such as radium and radon (James et al., 2010).

These natural radioactive elements are present in very low concentrations in earth's crust and are brought to the surface through human activities such as oil and gas exploration or mining and through natural processes like leakage of radon gas to the atmosphere or through dissolution in ground water (James et al., 2010). Naturally occurring radioactive elements such as uranium, radium, and radon are dissolved in very low concentrations during normal reactions between water and rock or soil. Ground water that coexists with deposits of oil can have unusually high concentrations of dissolved constituents that build up during prolonged periods of water/rock contact. Many oil-field waters are particularly rich in chloride, and this enhances the solubility of other elements including the radioactive element radium (Fisher, 1998).

NORM can also be present in consumer products, including common building products (like brick and cement blocks), granite counter tops, glazed tiles, phosphate fertilizers and tobacco products. Naturally-occurring radioactive elements including primordial radionuclides have been present in the rocks and
minerals of the earth's crust since it was formed. Examples of naturally-occurring radio nuclides are uranium, radon gas, and carbon-14 (Mast et al., 1998).

According to the UNSCEAR Report in 2000, the annual dose averaged over the population of the world, is about 2.8 mSv in total. Over 85% of this total is from natural sources with about half coming from radon decay products in homes. Exposure to environmental radiations is mainly dependent on geological and geographical conditions (Florou and Kritidis, 1992). Higher levels of radiation are usually associated with igneous rocks, while lower levels are associated with sedimentary rocks. There are some exceptions as some phosphate rocks have high radionuclides content (UNSCEAR Report, 1993).

Investigations on terrestrial natural radiation have received particular attention worldwide leading to extensive surveys in many countries including India, Brazil, China, Iran, (UNSCEAR Report, 2000). The inhalation of natural radionuclides other than radon and its decay products makes only a minor contribution to internal exposure. These radionuclides are present in air because of the re-suspension of soil particles. The decay products of radon are present because of radon gas in air.
2.4.1 Biological effects of ionizing radiation

Ionizing radiation can have health benefits in radiation therapy for the treatment of cancer and thyrotoxicosis. It is used to sterilize many products including some types of food, and it is used in many common items such as smoke detector sensors. It induces cancer with a latent period of years or decades after exposure (Valentin, 2006). High doses can result in radiation burns and rapid fatality through acute radiation syndrome. Normally controlled doses are used for medical imaging using x-rays and CT (computerized tomography) scans and radiotherapy (Lehnert, 2007). At high enough doses, ionizing radiation can damage molecules such as DNA in cells (Lehnert, 2007). Damage to DNA and other important cellular components can result in cell damage or cell death. This can lead to health effects like an increase in cancer risk and, at extremely high doses, death (Valentin, 2006).

2.4.2 Ionizing radiations cause cancer

Ionization is the process by which an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions, and this is often in conjunction with other chemical changes (IUPAC, 2009). Ionization can result from the loss of an electron after collisions with sub atomic particles, collisions with other atoms, molecules and ions, or through the interaction with light resulting in producing three types of ionizing radiation; alpha particles, beta
particles and gamma rays (Glenn, 2000). Heterolytic bond cleavage and heterolytic substitution reactions can result in the formation of ion pairs (Michael et al., 2009). Ionization can also occur through radioactive decay by the internal conversion process, in which an excited nucleus transfers its energy to one of the inner-shell electrons causing it to be ejected. During ionization, an atom or a molecule acquires a negative or positive charge by gaining or losing electrons to form ions often in conjunction with other chemical changes (Glenn, 2000).

Ionizing radiation is composed of particles that individually carry enough kinetic energy to liberate an electron from an atom or molecule ionizing it. Such an event can alter chemical bonds and produce ions that are chemically reactive. This greatly magnifies the chemical and biological damage per unit energy of radiation because chemical bonds will be broken in the process. Ionizing radiation is ubiquitous in the environment and comes from naturally occurring radioactive materials and cosmic rays. It is not directly detectable by human senses and so instruments like the Geiger counters are used to detect its presence. Ionizing radiations are known to modulate the expression of genes associated with genotoxic and physiological stress responses including DNA damage sensing and repair, and immune response (Coleman et al., 2005).
Genetic mutation often leads to uncontrolled growth if four key types of gene responsible for the cell division process are damaged. These include oncogenes which signal cells on when to divide, tumor suppressor genes which alert cells on when not to divide, suicide genes which control apoptosis (programmed cell death) and DNA-repair genes which instruct cells to repair damaged DNA (Wilson and Roberts, 2011). Genetic mutation makes the cell unable to correct DNA damage, unable to control the function of oncogenes and tumor suppressor genes thus leading to uncontrollable cell growth. Exposure to ionization radiation can lead to damage to living tissue, causing mutation, radiation sickness, cancer and death (Wilson and Roberts, 2011).

2.5 Detection of Naturally Occurring Radioactive Materials (NORM)

Natural background radiation comes from the ground, building materials, air, food and cosmic rays. Depending on where you live, levels of this type of radiation vary. Radiation readings above typical background radiation levels may indicate the presence of NORM. Determining the type of material present is essential to assess what, if any, precautions need to be taken with the material. This process is called characterization. Radiation surveys used for characterization should be conducted by personnel trained in radiation safety or by external consultants to determine if the suspect material is NORM or man-made radioactive material (Smith et al., 1996).
2.5.1 Radiation Alert Digilert200

Of the many radiation monitors used in the surveillance of radiation, Digilert200 is increasingly becoming desirable. The Digilert200 is a health and safety instrument that is optimized to detect low levels of radiation. It measures alpha, beta, gamma, and x-ray radiation (ionizing radiation only). Its applications include detecting and measuring surface contamination, monitoring possible radiation exposure while working with radionuclides and screening for environmental contamination. It uses a Geiger-Mueller tube to detect radiation. The Geiger tube generates a pulse of electrical current each time radiation passes through the halogen quenched tube and causes ionization. Each pulse is electronically detected and registers as a count. The Digilert200 displays the counts in various modes including mR/h.

2.5.2 Handling of Naturally Occurring Radioactive Materials (NORM)

Although concentrations of NORM are usually quite low and the risk is minimal, safe handling of the material is important, since higher concentrations of NORM can result when the material is processed. This is often referred to as technologically enhanced NORM. Because specific safety measures may be required to protect workers who handle NORM-contaminated equipment or NORM waste, NORM should only be handled by a person with appropriate
Some of the best practices for individuals and facilities encountering NORM include providing training and procedures to staff where there is the possibility of encountering NORM, not eating/drinking/smoking in areas where the presence of NORM is a possibility, storing NORM and any contaminated materials (including clothing) and waste in a designated area with access limited to authorized personnel, minimizing operations that may generate dust containing NORM, minimizing the time spent in NORM-contaminated work areas and storage areas, maximizing the distance from the source when handling or storing NORM, using appropriate shielding to minimize dose rates from the material if warranted and disposing of NORM-contaminated materials efficiently, to avoid stockpiling the material (Wascom, 1994).
CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Area

The study area involved various quarry sites and premises located around Nairobi County (Figure 3.1). Nairobi was selected because it is the capital city of Kenya and is surrounded by several expanding suburbs. The city is governed by the County Government of Nairobi. The city lies on the Nairobi River basin in the southern part of country, and has an elevation of 1,795 metres (5,889 ft) above sea level. Nairobi is the 14th-largest city in Africa, including the population of its suburbs. Nairobi County was founded in 2013 on the same boundaries as Nairobi Province. According to 2009 census, the city of Nairobi (1°17’S 36°49’E) has an estimated population of about 3.13 million people.

In addition, Nairobi’s industrial activities have been acknowledged as the basis of modern development due to their important contribution to the economic growth and wellbeing of its inhabitants and general citizenry. These incentives have attracted a large number of industries whose domains of operation are mostly manufacturing, quarrying, chemicals production, bottling, pharmaceuticals, and auto-workshops.
Figure 3.1: Map of Nairobi showing the study area.
3.2 Study Design

3.2.1 Quarries

For this study, quarries were clustered as Ndarugo on Thika road and other parts of Nairobi. In each of the clustered areas, 19 quarries were sampled. A total of 38 quarries were sampled based on their accessibility. Measurements of the background radiation level were carried out using calibrated portable radiation monitor (Digilert 200) containing a Geiger Muller tube capable of detecting alpha, beta, gamma and X-rays following the manufacturer's instructions.

3.2.2 Premises

Nairobi was divided randomly into eight sampling estates. These estates included Kasarani, Buruburu, Kahawa, Kinoo, CBD, Mlolongo, Eastleigh and Ruaka. The indoor radiation levels of 400 units were measured. The measurements were captured with the radiation meter held away from sampled surfaces in all the areas. In every premise/unit, eight indoor measurements were recorded. A total of four readings were recorded for each unit. Global Positioning System (GPS) was used to measure the precise location of sampling. Analysis of spatial distribution of data was performed using ArcGIS software version 10.
3.3 Determination of radiation levels in quarries

Measurements of the activity and exposure rate were carried out in units of milli Roentgen per hour (mR/h). A total of fifteen different points were selected for measurement per quarry and the same procedure repeated in other quarries. Since the normal background radiation levels often vary at different locations within and among quarries a timed count was taken so as to establish the normal background radiation count rate for each point. An *in-situ* approach of background radiation measurement was preferred and adopted to enable sample maintain their original environmental characteristics. A 10-minute average was chosen as moderately accurate following the manufacturer’s manual. At each point, a sample of three measurements were taken and the mean value calculated.

3.4 Determination of radiation levels in premises

Measurements of indoor radiation were taken in eight different points per premise and the same procedure repeated in other premises. The readings were captured in milli Roentgen per hour (mR/h). At each point, a sample of four measurements were taken and the mean value calculated.

3.5 Data management and statistical analysis

The readings were then recorded in a work sheet and entered in Microsoft excel spreadsheet for analysis. UNSCEAR (1988) recommends an indoor occupancy factor of 0.8. The occupancy factor (OF) represents the proportion of the total
time during which an individual is exposed to a radiation field. For both quarries and premises, the readings were converted from hours to years under the assumption that humans live in their premises for 24h a day and that most of the quarry workers live around the quarries. When converting the indoor readings to annual equivalent doses in mSv/y for the premises, the following equation was used.

\[ E_1 = X \times 8760 \times 0.8 \times 0.01 \times 1.7 \]

- **\( E_1 \)** is the annual equivalent dose rate in mSv/y.
- **\( X \)** is the indoor meter reading in mR/h.
- **8760** is the annual conversion factor in hours/year.
- **0.8** is the indoor occupancy factor.
- **0.01** is the conversion of mR to mSv.
- **1.7** is the calibration factor.

However, assuming that some quarry workers live away from the quarries and that they only work for 8h per day for 6 days a week as required by the labor laws, the following equation was used.

\[ E_1 = X \times 2504 \times 0.8 \times 0.01 \times 1.7 \]

- **\( E_1 \)** is the annual equivalent dose rate in mSv/y.
- **\( X \)** is the meter reading in mR/hr.
- **2504** is the annual conversion factor in hours/year.
0.8 is the indoor occupancy factor

0.01 is the conversion of mR to mSv.

1.7 is the calibration factor.

The data was subjected to descriptive statistics and were expressed as Mean±SEM. One way ANOVA was used to test the significance within the quarry clusters and premise clusters at 95% confidence level. The data was further subjected to Tukey’s post hoc for pairwise comparison and separation of means. Minitab version 17.0 was used to determine the significant relationships between the radiations from different quarries and premises. Spatial distribution of data was done using ArcGIS software version 10.3. The findings were presented through tables that showed levels of mean radiation levels between the various quarries and premises and their differences in statistical significance.

The results were further computed relative to the recommended WHO annual dose reference of 1mSv. The percentage deviations was calculated by getting the percentage of the difference of the annual reading from the WHO standard. The results were presented in tables and spatial distribution of data was presented in maps.
CHAPTER FOUR

RESULTS

4.1 Profile for levels of ionizing radiation in quarries around Nairobi County.

The quarries were clustered in two groups—those from Ndarugo and other parts of Nairobi County. In Ndarugo, out of the 19 quarries sampled, and assuming that quarry workers only work for 8h a day for 6 days a week, only 5 of the quarries had annual ionizing radiation readings below the acceptable levels (Table 4.1). These quarries included Q01 (0.96 mSv), Q07 (0.91 mSv), Q11 (0.98 mSv), Q12 (0.95 mSv) and Q13 (0.95 mSv). Of the five quarries that had acceptable levels, analysis of variance revealed that Q01 and Q11 were not significantly different ($p>0.05$; Table 4.1). In addition, analysis of variance showed that Q12 and Q13 were not significantly different while Q07 was significantly different from Q01, Q11, Q12 and Q13 ($p<0.05$; Table 4.1). Noticeably, Q15 had the highest annual dose equivalent of 1.38 mSv while Q07 had the lowest annual dose equivalent of 0.91 mSv.

Analysis of variance showed that ionizing radiation in quarries Q02, Q10, Q14 and Q19 were significantly different and Q05, Q08 and Q16 were not significantly different ($p>0.05$; Table 4.1). When ionizing radiation data was adjusted to 24 h daily working period, ionizing radiation in Q07 showed the least reading of 3.18 mSv whereas Q15 had the highest reading of 4.84 mSv. None of
the ionizing radiation readings computed was below the WHO acceptable limit of 1mSv (Table 4.1).

Table 4.1: Annual exposure to ionizing radiation in quarries in Ndarugo computed using 8h and 24h daily working period.

<table>
<thead>
<tr>
<th>Quarry ID</th>
<th>Annual exposure (mSv) (8h daily working period)</th>
<th>Annual exposure (mSv) (24h daily working period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q01</td>
<td>0.96±0.031^{hij}</td>
<td>3.37±1.804^{hij}</td>
</tr>
<tr>
<td>Q02</td>
<td>1.11±0.037^{efghij}</td>
<td>3.88±2.149^{efghij}</td>
</tr>
<tr>
<td>Q03</td>
<td>1.15±0.040^{efghij}</td>
<td>4.00±2.374^{efghij}</td>
</tr>
<tr>
<td>Q04</td>
<td>1.21±0.034^{cdefghij}</td>
<td>4.23±1.966^{cdefghij}</td>
</tr>
<tr>
<td>Q05</td>
<td>1.14±0.027^{efghij}</td>
<td>3.98±1.571^{efghij}</td>
</tr>
<tr>
<td>Q06</td>
<td>1.13±0.023^{ghij}</td>
<td>3.95±1.331^{ghij}</td>
</tr>
<tr>
<td>Q07</td>
<td>0.91±0.021^{j}</td>
<td>3.18±1.224^{j}</td>
</tr>
<tr>
<td>Q08</td>
<td>1.13±0.035^{efghij}</td>
<td>3.95±2.051^{efghij}</td>
</tr>
<tr>
<td>Q09</td>
<td>1.32±0.045^{bcdefg}</td>
<td>4.63±2.646^{bcdefg}</td>
</tr>
<tr>
<td>Q10</td>
<td>1.08±0.030^{fghij}</td>
<td>3.78±1.744^{fghij}</td>
</tr>
<tr>
<td>Q11</td>
<td>0.98±0.029^{ghij}</td>
<td>3.44±1.633^{ghij}</td>
</tr>
<tr>
<td>Q12</td>
<td>0.95±0.020^{lij}</td>
<td>3.32±1.185^{lij}</td>
</tr>
<tr>
<td>Q13</td>
<td>0.95±0.035^{lij}</td>
<td>3.32±2.024^{lij}</td>
</tr>
<tr>
<td>Q14</td>
<td>1.12±0.038^{fghij}</td>
<td>3.92±2.247^{fghij}</td>
</tr>
<tr>
<td>Q15</td>
<td>1.38±0.038^{abcdef}</td>
<td>4.84±2.241^{abcdef}</td>
</tr>
<tr>
<td>Q16</td>
<td>1.14±0.027^{efghij}</td>
<td>3.98±1.562^{efghij}</td>
</tr>
<tr>
<td>Q17</td>
<td>1.16±0.029^{defghij}</td>
<td>4.06±1.678^{defghij}</td>
</tr>
<tr>
<td>Q18</td>
<td>1.01±0.024^{lij}</td>
<td>3.54±1.413^{lij}</td>
</tr>
<tr>
<td>Q19</td>
<td>1.06±0.031^{fghij}</td>
<td>3.69±1.811^{fghij}</td>
</tr>
</tbody>
</table>

The results are expressed as Mean ± SEM for 30 readings per quarry. Values followed by the same superscript are not significantly different ($p<0.05$; one way ANOVA followed by Tukey’s post hoc test).

The percentage deviation from the recommended standard of annual exposure to ionizing radiation in quarries in Ndarugo showed that only five quarries sampled...
had exposure levels below the recommended threshold (Table 4.2). This was calculated assuming that the quarry workers worked for eight hours in a day, for six days in a week. In addition, 42% of the quarries were between deviations clusters of 11%-20% while 5% of the quarries had deviation clusters of between 21%-30%. Furthermore, 16% was observed in cluster of 1%-10% while 11% was recorded in the cluster of greater than 31%. Computing for a 24 h period, 14% of the quarries in Ndarugo fell in the cluster of 151%-300% while 5% were within 301%-450% cluster (Table 4.2).

### Table 4.2: Percentage deviation from the recommended WHO standard of annual exposure to ionizing radiation in quarries in Ndarugo

<table>
<thead>
<tr>
<th>Deviation cluster (%)</th>
<th>Number of quarries (%) (Annual 8h)</th>
<th>Deviation cluster (%)</th>
<th>Number of quarries (%) (Annual 24h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0&lt;</td>
<td>26</td>
<td>0&lt;</td>
<td>0</td>
</tr>
<tr>
<td>1-10</td>
<td>16</td>
<td>1-150</td>
<td>0</td>
</tr>
<tr>
<td>11-20</td>
<td>42</td>
<td>151-300</td>
<td>14</td>
</tr>
<tr>
<td>21-30</td>
<td>5</td>
<td>301-450</td>
<td>5</td>
</tr>
<tr>
<td>31&gt;</td>
<td>11</td>
<td>451-600</td>
<td>0</td>
</tr>
</tbody>
</table>

For the quarries in other parts of Nairobi County and its environs, none of the quarries showed ionizing radiation readings below the acceptable standard for both 8h and 24h daily working period (Table 4.3). Calculations using 8 h daily working period revealed that Q23 had the highest ionizing radiation annual dose equivalent of 1.68 mSv while Q34 had the lowest annual dose equivalent of 1.06 mSv. Computation using 24 h daily working period showed that Q23 had the
The highest ionizing radiation level was 5.87 mSv while Q34 had the least ionizing radiation reading of 3.69 mSv. Analysis of variance showed that Q25 (1.58 mSv), Q26 (1.57 mSv), Q29 (1.57 mSv) and Q35 (1.58 mSv) were not significantly different (p > 0.05; Table 4.3).

Table 4.3: Annual exposure to ionizing radiation in quarries around Nairobi County and its environs computed using 8 h and 24 h daily working period.

<table>
<thead>
<tr>
<th>Quarry ID</th>
<th>Annual exposure (mSv) (8h daily working period)</th>
<th>Annual extreme (mSv) (24h daily working period)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Q20</td>
<td>1.49±0.031abcd</td>
<td>5.21±1.789abcd</td>
</tr>
<tr>
<td>Q21</td>
<td>1.26±0.036bcdefgh</td>
<td>4.42±1.735bcdefgh</td>
</tr>
<tr>
<td>Q22</td>
<td>1.30±0.032bcdefgh</td>
<td>4.55±1.871bcdefgh</td>
</tr>
<tr>
<td>Q23</td>
<td>1.68±0.103</td>
<td>5.87±6.067</td>
</tr>
<tr>
<td>Q24</td>
<td>1.36±0.026abbcdef</td>
<td>4.76±1.532abbcdef</td>
</tr>
<tr>
<td>Q25</td>
<td>1.58±0.028ab</td>
<td>5.52±1.647ab</td>
</tr>
<tr>
<td>Q26</td>
<td>1.57±0.047ab</td>
<td>5.48±2.767ab</td>
</tr>
<tr>
<td>Q27</td>
<td>1.30±0.047bcdefgh</td>
<td>4.54±2.738bcdefgh</td>
</tr>
<tr>
<td>Q28</td>
<td>1.36±0.038bcdef</td>
<td>4.76±2.113bcdef</td>
</tr>
<tr>
<td>Q29</td>
<td>1.57±0.045ab</td>
<td>5.49±2.626ab</td>
</tr>
<tr>
<td>Q30</td>
<td>1.35±0.027abbcdef</td>
<td>4.71±1.586abcdef</td>
</tr>
<tr>
<td>Q31</td>
<td>1.35±0.023abbcdef</td>
<td>4.73±1.467abbcdef</td>
</tr>
<tr>
<td>Q32</td>
<td>1.25±0.028bcdefgh</td>
<td>4.37±1.619abcdefgh</td>
</tr>
<tr>
<td>Q33</td>
<td>1.53±0.052abc</td>
<td>5.34±3.047abc</td>
</tr>
<tr>
<td>Q34</td>
<td>1.06±0.026ghij</td>
<td>3.69±1.549ghij</td>
</tr>
<tr>
<td>Q35</td>
<td>1.58±0.041ab</td>
<td>5.54±2.428ab</td>
</tr>
<tr>
<td>Q36</td>
<td>1.20±0.028bcdefgh</td>
<td>4.21±1.636bcdefgh</td>
</tr>
<tr>
<td>Q37</td>
<td>1.33±0.046bcdef</td>
<td>4.67±2.725bcdef</td>
</tr>
<tr>
<td>Q38</td>
<td>1.46±0.045abcde</td>
<td>5.11±2.634abcdef</td>
</tr>
</tbody>
</table>

The results are expressed as Mean ± SEM for thirty readings per quarry. Values followed by the same superscript are not significantly different (p ≤ 0.05; one way ANOVA followed by Turkey’s post hoc test).
The percentage deviation from the recommended standard of annual exposure to ionizing radiation in other quarries in Nairobi County and its environs showed that assuming the workers were exposed for 8 h per week for 6 days, the exposure levels were distributed across the deviation clusters (Table 4.4). None of the quarries sampled had ionizing radiation exposure levels below the WHO recommended standard. Additionally, 7% of the quarries were in the ionizing radiation deviation cluster of 46%-60% while 1% was observed in 1%-15% and 61%-75% deviation clusters. Furthermore, 5% of the premises were in the clusters of 16%-30% and 31%-45%, respectively. Computing for 24 h working period, 14% of the quarries were in 201%-300% deviation cluster while only 5% were in 301%-400% clusters (Table 4.4). Overall, of the 38 quarries sampled, only five were below the recommended ionizing radiation threshold, representing a dismal 13% compliance.

Table 4.4: Percentage deviation from the recommended WHO standard of annual exposure to ionizing radiation in other quarries in Nairobi County and its environs.

<table>
<thead>
<tr>
<th>Deviation (%)</th>
<th>Number of quarries (%)</th>
<th>Deviation cluster (%)</th>
<th>Number of quarries (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(Annual 8h)</td>
<td>(Annual 24h)</td>
<td></td>
</tr>
<tr>
<td>0&lt;</td>
<td>0</td>
<td>0&lt;</td>
<td>0</td>
</tr>
<tr>
<td>1-15</td>
<td>1</td>
<td>1-100</td>
<td>0</td>
</tr>
<tr>
<td>16-30</td>
<td>5</td>
<td>101-200</td>
<td>0</td>
</tr>
<tr>
<td>31-45</td>
<td>5</td>
<td>201-300</td>
<td>14</td>
</tr>
<tr>
<td>46-60</td>
<td>7</td>
<td>301-400</td>
<td>5</td>
</tr>
<tr>
<td>61-75</td>
<td>1</td>
<td>401-500</td>
<td>0</td>
</tr>
</tbody>
</table>
4.2 Profile for levels of ionizing radiation in premises around Nairobi County.

A total of eight randomly selected buildings were sampled for this study (Appendix 1). In all the 400 units sampled, none of the premises had ionizing radiations below the recommended annual standard of 1 mSv. In Mlolongo, 40 units were sampled (Appendix 2; Table 4.5). None of the 40 premises had readings below the recommended threshold (Table 4.5). It was observed that 58% of the units fell between the clusters of 101%-200% followed by 25%, which fell in the cluster of 201%-300%. In CBD, 100 premises were sampled (Appendix 3; Table 4.5). A similar trend was observed whereby 67% of the sampled units fell in the clusters of 101%-200% while 21% of the units were in the clusters of 201%-300% (Table 4.5).

In eastern side of Nairobi, a total of 50 units were sampled in Kasarani (Appendix 4; Table 4.5). A high number of units 48% was observed in 201%-300% cluster followed by 30% in the clusters of 101%-200%. In Eastleigh, out of the 60 units sampled, 38% of them fell in the clusters of 301%-400% followed by 34% that was in 201%-300% clusters (Appendix 6; Table 4.5). In Ruaka (Appendix 6), Kinoo (Appendix 7) and Buruburu (Appendix 8), 31, 29 and 59 units were sampled, respectively. A high number of premises were captured in the cluster of 201%-300% in the three estates with Ruaka having 55%, Kinoo 45% and Buruburu 47%. In the clusters of 101%-200%, 7% of the premise units was
observed in both Ruaka and Kinoo. Kahawa estate (Figure 4.9) had 31 premises sampled out of which 45% fell in the 301%-400% followed by 36% in 201%-300% and 19% in 101%-200% (Table 4.5).

Table 4.5: Percentage of premises (%) and percentage annual deviation from WHO recommended exposure standard of ionizing radiation in selected estates around Nairobi County.

<table>
<thead>
<tr>
<th>Deviation cluster (%)</th>
<th>Mlolongo (%)</th>
<th>CBD (%)</th>
<th>Kasarani (%)</th>
<th>Eastleigh (%)</th>
<th>Ruaka (%)</th>
<th>Kinoo (%)</th>
<th>Buruburu (%)</th>
<th>Kahawa (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>2</td>
<td>6</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>101-200</td>
<td>58</td>
<td>67</td>
<td>30</td>
<td>15</td>
<td>7</td>
<td>7</td>
<td>14</td>
<td>19</td>
</tr>
<tr>
<td>201-300</td>
<td>25</td>
<td>21</td>
<td>48</td>
<td>34</td>
<td>55</td>
<td>45</td>
<td>47</td>
<td>36</td>
</tr>
<tr>
<td>301-400</td>
<td>15</td>
<td>6</td>
<td>16</td>
<td>38</td>
<td>32</td>
<td>31</td>
<td>32</td>
<td>45</td>
</tr>
<tr>
<td>&gt;400</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>13</td>
<td>6</td>
<td>17</td>
<td>5</td>
<td>0</td>
</tr>
</tbody>
</table>

A summary of the percentage annual deviation from WHO recommended standard of ionizing radiation in Nairobi County and its environs showed that majority of the premises (36%) were in the deviation cluster of 201%-300% while 2% were in 1%-100% deviation cluster (Table 4.6). None of the premises sampled had their deviation cluster below the acceptable threshold. In addition, 5% of the premises had their annual deviations above 400%, 24% were in the cluster of 301%-400% and 33% were between 101%-200% (Table 4.6).
Table 4.6: Percentage annual deviation from WHO recommended standard of ionizing radiation in Nairobi County and its environs

<table>
<thead>
<tr>
<th>Deviation cluster (%)</th>
<th>Number of units (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-100</td>
<td>0</td>
</tr>
<tr>
<td>101-200</td>
<td>2</td>
</tr>
<tr>
<td>201-300</td>
<td>33</td>
</tr>
<tr>
<td>301-400</td>
<td>36</td>
</tr>
<tr>
<td>&gt;400</td>
<td>24</td>
</tr>
</tbody>
</table>

From the annual exposure to ionizing radiation in premises around Nairobi County and its environs it was observed that Ruaka, Kinoo and Eastleigh showed ionizing radiation levels that were not significantly different from each other \((p>0.05;\text{Table 4.7})\). In addition, Kahawa and Buruburu ionizing radiation levels were not significantly different from each other, \((p>0.05)\) while Kasarani, Mlolongo and CBD had ionizing radiation levels that were significantly different from each other \((p<0.05)\). Eastleigh had the largest ionizing radiation deviation from WHO with 307% while CBD had the lowest deviation with 176.3% (Table 4.7).
Table 4.7: Annual exposure to ionizing radiation in premises around Nairobi County and its environs.

<table>
<thead>
<tr>
<th>Estates</th>
<th>Annual Indoor Average (mSv)</th>
<th>Percentage deviation from WHO recommended standard</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buruburu</td>
<td>3.752±0.096&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>275.2%</td>
</tr>
<tr>
<td>CBD</td>
<td>2.763±0.060&lt;sup&gt;d&lt;/sup&gt;</td>
<td>176.3%</td>
</tr>
<tr>
<td>Eastleigh</td>
<td>4.070±0.118&lt;sup&gt;a&lt;/sup&gt;</td>
<td>307%</td>
</tr>
<tr>
<td>Kahawa</td>
<td>3.713±0.129&lt;sup&gt;ab&lt;/sup&gt;</td>
<td>271.3%</td>
</tr>
<tr>
<td>Kasarani</td>
<td>3.407±0.105&lt;sup&gt;bc&lt;/sup&gt;</td>
<td>240.7%</td>
</tr>
<tr>
<td>Kinoo</td>
<td>4.032±0.146&lt;sup&gt;a&lt;/sup&gt;</td>
<td>303.2%</td>
</tr>
<tr>
<td>Mlolongo</td>
<td>3.105±0.121&lt;sup&gt;cd&lt;/sup&gt;</td>
<td>210.5%</td>
</tr>
<tr>
<td>Ruaka</td>
<td>3.976±0.121&lt;sup&gt;a&lt;/sup&gt;</td>
<td>297.6%</td>
</tr>
</tbody>
</table>

Values are expressed as Mean±SEM. Values followed by the same superscript are not significantly different (p≤0.05; One way ANOVA followed by Tukey’s post hoc test)
CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATIONS

5.1 Discussion

Residents are exposed to radiation in their environment with or without their consent; and the exposure to natural background radiation is an unpreventable event on earth. The levels of radiation in various quarries varied among themselves. This may be attributed to the difference in concentrations of naturally occurring radionuclides among the various quarries. Previous studies have shown that naturally occurring radionuclides become trapped in the earth’s crust during the formation of the parent rocks (Gessel and Prichard, 1975; Florou and Kritidis, 1992) and end up in soils as part of rock cycle through weathering (USEPA, 2007).

Previous studies reveal that the radionuclides may show a distinct variation in the radiation level in any environment based on many factors such as geographical and local geology of the area studied (Gbadebo, 2011). The relatively high levels of ionizing radiations may be attributed to the quarrying activities which can enhance the natural background radiation levels by bringing out large amount of otherwise buried materials containing natural occurring radioactive materials onto the surface of the environment (Saleh et al., 2008). From the results obtained in this study, after computing the values with 8h daily working period as per the
International Labour Standards, the lowest dose of annual ionizing radiation exposure levels in Ndarugo cluster was recorded in Q07 (0.91 mSv) while the highest ionizing radiation levels was reported in Q09 with a reading of 1.32 mSv. Most of the quarry sites selected for this study had their annual radiation exposure above the normal acceptable annual limits of 1 mSv for the general public set up by the International Commission for Radiological Protection (ICRP), while other quarries had their exposure levels below the standard. Only five quarries in Ndarugo had exposure levels below the acceptable standards, representing a dismal 13% compliance. All the quarries sampled in other parts of Nairobi County had exposure levels above the acceptable standards. This means that the quarry workers and the general citizenry residing around the quarries are exposed to high levels of ionizing radiations. This might result into health effects following long term exposure.

The high radiation profiles recorded in quarry sites in other parts of Nairobi County could be ascribed to the radionuclides that occur naturally in the earth’s crust (potassium-40, uranium-238 and thorium-232) that could be exposed to the environment due to quarrying activities. These radionuclides decay and emit ionizing radiations hence the high radiation levels. The significant difference in the radiation profiles between the quarries may be attributed to the differences in concentration of the naturally occurring radionuclides per quarry. More specifically, natural environment radioactivity and the associated external
exposure due to ionizing radiation depend on the geological and geographical conditions and appear at different levels in the soils of each region in the world (UNSCEAR, 2000).

The results of this study are in agreement with a number of radiological studies. For instance, according to a study by Onwuka (2014), elevated levels of natural background radiation was reported in a quarry site in Ishiagu, Ebonyi State, Nigeria. A number of ionizing radiation surveys previously carried out in the Niger delta also show that there is a strong correlation between high industrial activities and elevated background ionizing radiation (BIR) levels for parts of the region (Avwiri and Ebeniro, 1998; Chad-Umoren and Briggs-Kamara, 2010). In a study of the external environmental radiation status of some industrial locations in Port Harcourt, which included oil and gas facilities, an average value of 0.014 mR/h was reported for the background radiation, showing an elevation from the standard background radiation level of 0.013 mR/h (Avwiri and Ebeniro, 1998).

A study by Ononugbo et al. (2011) showed that the equivalent dose had an annual average range of 1.056 mSv to 2.871 mSv, which is much lower than the International Commission on Radiological Protection recommended 20 mSv dose limit for radiological workers, but above the permissible level of 1 mSv/y recommended for the general public (ICRP, 1990). Further analysis showed that
72% of the sampling sites exceeded the normal background radiation level thus indicating considerable radiation risk for the communities around the sites. Ebong and Alagoa (1992) showed that the nature of input raw materials, effluents from the production process and the output production determine the effect of an industrial operation on the radiation levels of its host environment.

A number of variables that contribute to the impact the industry makes on the ionizing radiation profile of its areas of operation include the use of radiation generators, sealed and unsealed sources of radioactive materials, naturally occurring radioactive materials (NORMs) originating from reservoir rocks, scales, sludge, oil spillage and gas flaring (Sigalo and Briggs-Kamara, 2004; OGP, 2008; Chad-Umoren, 2012; Meindinyo and Agbalagba, 2012). A survey of the ionizing radiation patterns in Rivers State by Chad-Umoren and Briggs-Kamara (2010) indicated that activities of the hydrocarbon industry contributed to elevating the ionizing radiation levels of the environment.

Quarrying activities also enhance the natural background levels by bringing out large amounts of otherwise buried materials containing natural occurring radioactive materials onto the surface of the environment (Saleh et al., 2009). In addition, the formation of carbon monoxide due to incomplete combustion of fuel
from vehicular sources, generators and heavy duty machines used in the study area and poor drainage systems that cause erosion may expose buried radioactive ores to the immediate environment (Sohrabi, 1990). Apart from the geology, a given environment may experience seasonal dose rate variations due to precipitation, humus decay and vegetation growth (Holmes-Siodle and Adams, 1993).

According to international recommendations, the public should not be exposed to more than an annual average of 1 mSv (IAEA 2004; UNSCEAR 2008; ICRP, 2013). Consequently, my study which results has showed that only 13% of the quarries had exposure rates below the recommended threshold. The International Commission on Radiological Protection (ICRP) stipulates that dose limits are intended to serve as a boundary condition that will prevent deterministic effects and limit the probability of stochastic effects. Stochastic effects are cancer inducing or heritable effects involving the development of cancer and may occur in either mature somatic cells or through the mutation of germ (reproductive) cells. Deterministic effects which are often of an acute nature, are mostly the result of death or malformation of somatic cells following radiation exposure, and only appear if the radiation dose exceeds a threshold value (Strom, 2003).
Therefore, the implication is that the quarry workers are exposed to high levels of ionizing radiations. The baseline risk of cancer occurrence in the quarries that were sampled could result from long term exposure to ionizing radiation or a stochastic process for both occupational workers and the general public. This may in turn signify some health problems to the people around the quarry. The environmental impacts of radiation depend on the type and amount of particular radiation. All forms of ionizing radiation constitute danger to biological tissues with the health effects varying with level of exposure. At 70 rem, it can lead to hair loss and vomiting. At 100 rem it can cause hemorrhage while doses between 400-2000 rem can constitute to death.

The results of this study show that none of the estates sampled had annual indoor ionizing radiation exposure levels below the acceptable standards set by WHO. It was observed that the readings varied between the estates. Eastleigh, Kinoo and Ruaka were not statistically significant from each other. In addition, Buruburu and Kahawa were also not significantly different. CBD, Kasarani and Mlolongo were significantly different. High levels of indoor radiation can be attributed to the high levels of ionizing radiations that was seen in quarries. It may be possible that the building stones used in construction were sourced from the quarries in Nairobi.
A survey taken by the World Health Organization (WHO) and the International Commission on Radiological Protection (ICRP) shows that residents of temperate climates spend about 80% indoor (Chad-Umoren et al., 2007). The annual mean indoor levels of ionizing radiation exposure was high in Eastleigh with a reading of 4.070 mSv while Nairobi CBD had the lowest annual mean indoor reading of 2.763 mSv. These values are, however, above the 1.0 mSv acceptable limits for public exposure. Kahawa and Kasarani had high readings of 3.713 mSv and 3.407 mSv respectively. Probably the buildings in these two estates were constructed using stones mined from quarries in Ndarugo due to the proximity. Therefore, the inhabitants are exposed to high levels of ionizing radiation.

According to Kamara and Dunn (2014), any exposure to ionizing radiation has the tendency to change the biological make-up of the human body which may result in radiation induced sicknesses. Furthermore, the high radiation values may also be due to the sand and soil used for the building construction that might contain traces of Uranium and Thorium that contributes to background radiation (Ibeanu, 2004; Jwanbot et al., 2010).

Moreover, this may imply that the building stones used for the foundation of the buildings originated from mostly igneous rocks which are believed to be rich in minerals like zircon, Monazite, Uranite, Potassium, Feldspars and Biotite (Wertz,
1998; Solomon et al., 2002) which release ionizing radiation. Furthermore, elevated radiation levels may be due to the way some of the buildings were constructed as part of the roof is made up of concrete.

The results of this study are in agreement with Masok et al. (2015) whereby an assessment of indoor background radiation levels in Plateau State University, Nigeria showed that the mean indoor annual equivalent dose rates were high. The results obtained were higher than those obtained by Masok et al. (2015), which recorded an equivalent dose of 2μSv per scan (0.73mSv) received by people in those surroundings during an X-ray scanning of a container. This value is small compared to mean of indoor annual effective dose of 4.07 mSv that was obtained in this work in Eastleigh. This discrepancy may be due to compliance with safety procedures by the personnel.

In addition, the results are higher compared with previous work at radio diagnostic center, Plateau State specialist hospital (Jwanbot et al., 2012) and Braithwaite Memorial Specialist Hospital Port Harcourt, Rivers State (Okoye and Avwiri, 2013). Since the mean effective dose equivalent in all the areas is higher than the 1.0mSv annual effective dose for general public in the study area, long term exposure of the public to these radiations may lead to radiation induced health hazard such as erythema, skin cancer, genetic mutation and sterility (Avwiri et al, 2011).
Some of the places that receive high levels of background natural radiations in the world include Kerala in India, Ramsar in Iran and Guarapari in Brazil (Ghiassi-Nejad et al., 2012). Sohrabi (2013) classified radiation areas as low (less than 5 mSv), medium (5-10 mSv), high (20-50 mSv) and very high (greater than 50 mSv). In China, Yangjiang is a high natural background radiation area. The primary source of this radiation is high levels of $^{40}$K and $^{238}$Th (Tao et al., 2000). Its annual effective dose rate equivalent is 4.27 mSv (Zou, 2005). A health survey conducted showed that the children in the high background radiation areas had chromosomal translocation at low frequencies.

Another study by Zakeri et al. (2011) showed that there was a positive correlation between dicentrics and ring chromosomes (Dic+Rc) and age in high background radiation areas. The frequency of Dic+Rc linearly increased over lifetime due to chronic low dose exposure. A biological and epidemiological study in Ramsar showed increased chromosomal aberrations (Zakeri et al., 2011). A study by Fazeli (1993) showed a significant positive response in cytogenetic results of the study group compared with the control group particularly in the house with the highest level of exposure.

A more recent study by Taeb (2014) investigated the alterations in 8 tumor markers in blood samples from residents of Ramsar. From the study, there was a significant difference correlation between chronic exposure and concentration of
3 of the 8 investigated tumor markers. Cytogenetic studies by Ghiassinejad (2002) revealed adaptive response and chromosomal aberrations in residents of Ramsar. Adaptive response is a phenomenon whereby the body is resistant to high radiation doses. Ghiassinejad (2002) reported that there was an increased level of IgE and high incidence of chromosome aberrations in high background radiation areas (HBRA).

A research by Mosavi-jarrahi (2005) showed a correlation between exposure to high levels of background natural radiation and incidence of cancer mortality. The high mortality rate was especially seen in females from high background radiation areas than normal background radiation areas. This was attributed to the high levels of indoor radon dose because most female residents remain indoors. Darby et al. (2005) showed a positive relationship between high indoor radon levels and elevated lung cancer risk.

Many human malignant tumors exhibit abnormal chromosomal segregation at cell division. It is believed that these anomalies play a role in tumorigenesis by increasing the rate of chromosome mutations, including deletion and amplification of genes involved in cellular proliferation and/or survival (Gisselson, 2001). *In vitro* experiments have also shown that mitotic instability may be a mechanism for developing resistance to cytotoxic drugs. Abnormal mitotic mechanisms may result in numerical or structural aberrations in the
daughter cells. Numerical aberrations can be caused either by the loss of chromosomes at metaphase/anaphase or by multipolar divisions associated with abnormal number or structure of centrosomes (Gisselson, 2001).

Structural rearrangements have been associated with chromosomal breakage-fusion-bridge (BFB) cycles that can be initiated by telomeric dysfunction, giving rise to unstable dicentric or ring chromosomes. In most tumors exhibiting chromosomal instability, including high-grade malignant pancreatic, ovarian, and head and neck carcinomas. All malignant tumor types have been shown to contain chromosomal aberrations. The pattern of abnormalities varies greatly between malignancies, ranging from simple balanced rearrangements to complex abnormalities affecting both chromosome structure and number (Mitelman Database of Chromosome Aberration in Cancer, 2001).

In hematological neoplasms, certain abnormalities are often strongly associated with specific diagnostic entities. Typically, these changes are reciprocal translocations such as the t (9; 22) in chronic myelogenous leukaemia (Heim and Mitelman, 1995). Similar genetic abnormalities are seen in some solid tumors, for example the 11; 22 translocation in Ewing sarcomas and the inversion of proximal 10q in papillary thyroid carcinomas (Vecchio and Santoro, 2000).
Studies on the Chernobyl accident show that workers had severe radiation effects. Doses to the thyroid received in the first few months after the accident were particularly high in those who were children and adolescents who drank milk with high levels of radioactive iodine. By 2005, more than 6,000 thyroid cancer cases had been diagnosed in this group, and it is most likely that a large fraction of these thyroid cancers is attributable to radioiodine intake. There is also increased incidence of leukemia and opacities of the eye lens might be caused by relatively low radiation doses (Chenobyl Forum Report, 2005).

Radiation acts primarily by inducing DNA damage in somatic cells. A range of DNA lesions will form through direct energy deposition in DNA or through the indirect action of free radicals; however, double-strand breaks and complex lesions in DNA are likely to be most important in causing mutations. Systems exist to repair damage in nuclear DNA. However no repair is completely error free, although some repair systems tend to be more error-prone than others. Consequently, even the lowest doses of radiation may induce DNA damage that may be converted into DNA sequence mutations. Cancer development originates from single cells that have sustained mutations through DNA damage. Such cells gain growth advantages and progress to a proliferative and ultimately malignant tumor (UNSCEAR report, 2008).
Radiation can also induce apoptosis and influence cell-cycle checkpoints, which together can affect the outcome of a radiation exposure. Most evidence suggests that DNA deletions are the major contributors to the mutations driving radiation carcinogenesis. In somatic carcinogenesis, radiation-induced initiating events are but one of many steps required for tumor formation. By contrast, direct induction of mutations in the germ line, where compatible with viability, will directly contribute to the burden of heritable mutations and possible heritable disease. (UNSCEAR report, 2008).

Some of the mitigation measures that have been used to reduce exposure to ionizing radiation include building of walls with material that absorbs radiation, such as 230 mm baked solid clay bricks, lead sheet of 2 mm be sandwiched between other bricks, use of lead sheets between building blocks to prevent radiation passing unhindered through the open areas and barium plastering of at least 6mm of thickness to cover the walls. Barium has a relatively high atomic number (56) thereby absorbing some radiation.

5.2 Conclusion

From the study, it can be concluded that the quarries sampled for this study recorded significantly high levels of ionizing radiations. Of the 38 quarries sampled, only 5 had ionizing radiation levels below the acceptable standard set by WHO for exposure to the general public. In addition, none of the premises
sampled had their annual indoor ionizing radiation below the safe levels. The null hypotheses were rejected in this study.

5.3 Recommendations

From this study, the following recommendations can be made:

1. Regular and periodic monitoring of the background ionizing radiation level should be carried out in quarries and in various buildings to assess the health risk of quarry workers and general public and also ensure that areas of potential risks are identified early enough and the risk mitigated.

2. Results for the study can be used as a guide in formulation of the national building code to include radiation surveillance during construction.

5.4 Suggestions for further research

1. This study can be extended to other cities and counties so as to determine the national trend.

2. Barium plastering and anti-radiation coating as mitigation measures should be explored.
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Appendix 1: Distribution of indoor ionizing radiation data from 8 different estates in Nairobi County and its environs
Appendix 2: Percentage annual deviation from WHO recommended exposure standard of ionizing radiation in Mlolongo

Legend
Mlolongo Premises Radiation Deviation
Cluster from WHO Standard
- >0
- 0.1 - 100.0
- 100.1 - 200.0
- 200.1 - 300.0
- 300.1 - 400.0
- <400

36°56'24"E 36°56'27"E 36°56'30"E 36°56'33"E
1°23'36"S 1°23'33"S

36°56'24"E 36°56'27"E 36°56'30"E 36°56'33"E
1°23'36"S 1°23'33"S

MapmyIndia. © OpenStreetMap contributors and the GIS User Community
Appendix 3: Percentage annual deviation from WHO recommended exposure standard of ionizing radiation in CBD
Appendix 4: Percentage annual deviation from WHO recommended exposure standard of ionizing radiation in Kasarani
Appendix S: Percentage annual deviation from WHO recommended exposure standard of ionizing radiation in Eastleigh
Appendix 6: Percentage annual deviation from WHO recommended exposure standard of ionizing radiation in Ruaka

Legend
Ruaka Premises Radiation Deviation
Cluster from WHO Standard
- >0
- 0.1 - 100.0
- 100.1 - 200.0
- 200.1 - 300.0
- 300.1 - 400.0
- <400

Legend
Ruaka Premises Radiation Deviation
Cluster from WHO Standard
- >0
- 0.1 - 100.0
- 100.1 - 200.0
- 200.1 - 300.0
- 300.1 - 400.0
- <400

Legend
Ruaka Premises Radiation Deviation
Cluster from WHO Standard
- >0
- 0.1 - 100.0
- 100.1 - 200.0
- 200.1 - 300.0
- 300.1 - 400.0
- <400
Appendix 7: Percentage annual deviation from WHO recommended exposure standard of ionizing radiation in Kinoo
Appendix 8: Percentage annual deviation from WHO recommended exposure standard of ionizing radiation in Buruburu

Legend
Buruburu Premises Radiation Deviation Cluster from WHO Standard
- >0
- 0.1 - 100.0
- 100.1 - 200.0
- 200.1 - 300.0
- 300.1 - 400.0
- <400
Appendix 9: Percentage annual deviation from WHO recommended exposure standard of ionizing radiation in Kahawa
Appendix 10: Research authorization letter

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Date: 25th September, 2015

NACOSTI/P/15/7987/7340

Phillip Einstein Ogola
Kenyatta University
P.O. Box 43844-00100
NAIROBI.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on "Determination of levels of background ionizing radiations from human premises and selected quarries around Nairobi County," I am pleased to inform you that you have been authorized to undertake research in Nairobi County for a period ending 23rd September, 2016.

You are advised to report to the County Commissioner and the County Director of Education, Nairobi County before embarking on the research project.

On completion of the research, you are expected to submit two hard copies and one soft copy in pdf of the research report/thesis to our office.

DR. S. K. LANGAT, OGW
FOR: DIRECTOR GENERAL/CEO

Copy to:

The County Commissioner
Nairobi County.

The County Director of Education
Nairobi County.