

**ASSESSMENT OF RADIOACTIVITY CONCENTRATION AND RADIATION
HAZARDS INDEX FOR BUILDING MATERIALS USED IN BABADOGO
ESTATE, NAIROBI CITY COUNTY, KENYA**

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DECLARATION

This thesis is my original work and has never been presented for the award of a degree or any other award in any institution of higher learning.

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DEDICATION

I dedicate the Thesis to my Parents; Henry Oborah, Rael Oborah, my wife Belinder Adhiambo, daughter Natalie Amukah, sons Carl Amukah, Heinrich Amukah.

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LIST OF ABBREVIATIONS AND ACRONYMS

AEDR	Annual effective dose rate
ADC	Analogue to digital converter
A_s	Specific activity of the sample
D	Absorbed dose in air
H_E	Annual Effective dose
H_{ex}	External Hazard Index
I_s	Intensity of the sample
IAEA	International Atomic Energy Agency
MCA	Multichannel analyzer
MCB	Multichannel Buffer
M_s	Mass of the sample
NaI(Tl)	Thallium activated sodium iodide
NORM	Naturally Occurring Radioactive Materials
OECD	Organization for Economic Cooperation and Development
PMT	Photomultiplier tube
$R_{a_{eq}}$	Radium equivalent activity
RPB	Radiation Protection Board
TENORM	Technological Enhanced Natural Occurring Radionuclide
UNSCEAR	United Nations Scientific Committee on Effects of Atomic Radiations
UV	Ultraviolet
E_y	Photon Energy
Z	Number of Electron

ABSTRACT

Natural radioactive materials in certain conditions can get to hazardous radiological level. Some of these hazards are not prone to control as well as, they are usually referred to as the background radiation. The aim of my research work is to evaluate natural radioactivity concentration and radiological impacts on representative sampled building materials collected from different locations in Babadogo estate within Nairobi City County. The selected samples were crushed, sieved dried and store for four weeks after which, analysis done using gamma ray spectrometer was put into action for spectral data acquisition then analysis. The activity concentration levels of ^{238}U , ^{232}Th and ^{40}K for the selected samples of building materials was measured by the use of gamma- ray spectrometry method. Radiological parameters were evaluated based on the prerequisite activity concentration obtained. The analyzed data compared with the standard acceptable values. The activity concentration in ^{40}K varied from 55 ± 3 to 2647 ± 132 Bq/kg giving average value of 831 ± 42 Bq/kg, ^{238}U varied from 39 ± 2 to 3602 ± 180 Bq/kg giving average figures of 378 ± 19 Bqkg $^{-1}$ and ^{232}Th ranged from 5.000 ± 0.300 to 4213 ± 211 Bqkg $^{-1}$ giving mean figure of 290 ± 15 Bq/kg . Calculated mean figures for activity concentration surpassed the world mean figures of 420Bq/kg, 33Bq/kg, 45Bq/kg in ^{40}K , ^{238}U and ^{232}Th respectively. Absorbed dose rate calculated ranges between 73 ± 4 and 4777 ± 239 nGyh $^{-1}$ having average value of 540 ± 27 nGyh $^{-1}$.The mean number for the absorbed dose rate was above the world acceptable mean value of 54 nGyh $^{-1}$. The calculated annual effective dose rate varied from 0.040 ± 0.002 mSvy $^{-1}$ to 2.340 ± 0.117 mSvy $^{-1}$ having average figure of 0.260 ± 0.013 mSvy $^{-1}$,which was above the world average of 0.070 mSvy $^{-1}$ but below the maximum dose constraint of 1 mSvy $^{-1}$. These results show that building materials in Babadogo estate are safe and can be used for construction of buildings and thus can be continued using as further research is done on other building materials not covered in my research work.

CHAPTER ONE

INTRODUCTION

1.1 Background to the study

Human populations are always exposed to natural background radiation, other than artificial radiation. The prime roots for background radiation are natural radioactivity (*Mavi and Akkurt, 2010*). Natural radioactivity has been in existence since the onset of the universe owing to long half-life in the natural radioactive elements found in the earth's lithosphere. The radionuclides in ^{238}U , ^{232}Th and ^{40}K is native to in all types of gravels, granites, sand and gypsum where from building materials are composed (*Mavi and Akkurt, 2010*). The largest contributor to the external dose of the general populace is natural radiation. It is significant to determine the gamma radiation dosage in distinction to natural sources (*UNSCEAR, 1988*).

Building is an essential part in human life, owing to the fact most of lifetime is spent at our homes or in offices. Indoor gamma radiation mostly is as a result of building materials likewise terrestrial and cosmic radiation (*Huang et al., 2015*). Any radiological hazard can be determined by measuring activity concentration in the building materials. The activities concentration of ^{238}U , ^{232}Th and ^{40}K in the construction materials, that primarily builds upon on geological and geographical situations, in addition to the geochemical distinctive principle of the building materials (*Turhan et al., 2008*). Igneous rocks such as granite are correlated with higher radiation levels while lower radiation levels are associated with sedimentary rocks. In some

instants however, it is reported that some shales and phosphate rocks have relatively high content of radionuclide (*UNSCEAR, 1988*). Harmful effects from radiation found in building materials are imminent, although information on activity concentration levels in building materials from Kenya is hardly accessible. This therefore called for a need to do a research study on building materials used in Babadogo estate as it might be regarded to be having superior activity concentration of naturally occurring radioactive materials (NORM). Through this the aimed of estimating the actual risks is achieved. In this study, sample of building materials; sand, bricks, and concrete block was used. Natural radioactivity level data in building materials is thusly imperative in the evaluation of the desirable radiological hazards which affects human health and in order to develop standards and guidelines which can be for use and management of sand, bricks, and concrete block as used in building materials.

1.2 Study Area

Babadogo is one of the many estates in the capital city of Nairobi, located in north- east of Nairobi County in Kasarani Sub-County in Kenya with an approximate area of 1.95 km². The area of study is at an altitude 1684 meters, it transverses latitudes 1.17 South, longitude 36.49 East. It is located about 11.1 kilometers east of City centre of Nairobi on the main Thika super highway. The estate has since grown over years and has become one of the most densely populated estates in the County of Nairobi. It is also home to many industries; about ten companies are located in this estate thus influencing the population density for many residents who work in these companies.

The building materials (sand, clay brick and concrete block) used in construction in this estate is mainly from the neighboring counties of Nairobi namely; Kiambu, Machakos and Kajiado. The sand is mainly brought from Machakos County (UN-HABITAT, 2009). Presence of phosphate and granite rocks in Machakos County and Nairobi areas neighboring Machakos County have contributed to the elevated levels of radioactivity concentration. According to Achola (2009), naturally occurring radioactive materials (NORM) in the environment is enhanced from these rocks. Heavy rains in these regions causes the weathering of ignite rocks that forms traces of radionuclide to be deposited in river banks which acts as sand mines fields and later collected with the sand for building purposes in the these counties including in Nairobi(Okalebo *et al.*,2009).

Fact remains that clay cubes along with rocks are likely to be more dangerous than wood Shikala (2013). This inasmuch as clay cubes and rocks have more naturally occurring radioactive material like uranium, potassium and thorium (Simin *et al.*,2011). Building materials devote about 0.008 microsievert (μSv) per hour (UNSCEAR, 2000). The results from this study provide valuable information and statistics on radioactivity concentration of radionuclides and radiation hazards index from the area of study and can avail the baseline information for the future.

1.3 Statement of the Research Problem

Materials used in buildings are assumed to be the cause of high radioactivity concentration, with the potential of contributing significantly to an increased radiation dose taken in by human beings. By cause of increased social concern, research needs to be done, in the assessment of natural radioactivity concentration. From the research

work therefore, statistics and information about the radioactivity concentration in sand, in clay bricks and in concrete blocks used for building in Babadogo estate will be produced. This will help scientific committees, International Institutions like; United Nation Scientific Committee on Effect of Atomic Radiation, Radiation protection Board and others mandated to manage the environment.

1.4 Hypothesis

The Presumption of the study is that the radioactivity concentrations from naturally occurring radionuclide materials (NORM) as well as effective gamma radiation are off the suggested figures from building materials used in Babadogo estate (*Amrani and Tahtat,2000*) . This is because the building materials are obtained from areas believed to be having granite rocks and sand from rivers in the neighboring counties of Nairobi, which are located near farms, which over the years, introduced technologically enhanced naturally occurring radionuclide (TENORM), and therefore are above the limits recommended by ICRP (2000):

1.5 Objectives of the Study

1.5.1 General Objective

The main purpose of the research work obliged to the determination of radioactivity concentration levels for radionuclide ^{238}U , ^{232}Th and ^{40}K in clay bricks, sand and concrete blocks used for building in Babadogo estate in Nairobi County, Kenya for the purpose of evaluating the radiological hazards for the human exposure.

1.5.2 The Specific Objectives

- i. To assess the radioactivity concentration for naturally occurring radionuclide in sand, in clay bricks as well as in concrete blocks used for building in Babadogo estate, Nairobi County, Kenya.
- ii. To calculate the radiological criteria: the absorbed dose rate, annual effective dose, radium equivalent activities as well as hazard index due to clay bricks, sand and concrete blocks.
- iii. To assess the radiological hazards due to human exposure to gamma radiation from clay bricks, sand, as well as concrete blocks used as building materials.

1.6 Rationale of the study

Environmental impact due to naturally occurring radioactive materials from construction materials is difficult to assess due to the limited data available. The study provides measured data as well as insight concerning the radioactivity concentration for radionuclide in selected building materials from Babadogo estate, Nairobi, Kenya. The outcome of the study is envisaged to be crucial to the known correspondent scientific committees, government of Kenya as well as Non-governmental organizations (NGOs) and the County government of Nairobi in making important decisions about sand, bricks and blocks as building materials to give to the public and planners.

CHAPTER TWO

LITERATURE REVIEW

2.1 Radiation Measurement

Because of the presence of the three categories of radionuclides like Primordial radionuclides, cosmogenic radionuclides and human-produced radionuclides environmental radioactivity always occurs (*International Atomic Energy Agency, 1987*). Naturally these radionuclides are originated from in air, water as well as from soil. The human body too has these radionuclides, which human being ingested daily with water and with food and is made up of chemicals. There has been concern about the effect of gamma radiation exposure to people especially in dwelling, schools and working places in Kenya Mustapha, (1999). As a result of insufficient information about the concentrations and hazards of gamma ray, many people have continued to live in dwellings unaware of the dangers posed by these rays. In this study radioactivity level of NORM in randomly selected building materials has been measured (*Stojanovska et al., 2010*). The assessment of naturally radioactivity concentration levels as well as radiation hazards due to building materials used in Babadogo estate, Nairobi City County, Kenya is important because the industrialization and construction taking place in the region might have resulted in enhancement, Technologically Enhanced Naturally Occurring Radionuclide Materials (TENORM) that have elevated levels for NORM in the environment (*Faheem et al., 2008*).

2.2 Related studies on assessment of activity levels as well as gamma index

Measurement as regards natural radioactivity has been done although a few have done on levels of radioactivity in building materials in Africa. Hashim (2000) measured the magnitude of radionuclide ^{238}U , ^{232}Th as well as ^{40}K from sediments samples in Mombasa, Kenya. From the results of that research work it was discovered that the levels for the radionuclide were within the acceptable standards. The radioactivity for surface soil in the proposed titanium mines in Kenya has been reported (Osoro, 2007). The assessment showed that the surface soils in the area around the proposed mines contain low level of natural radionuclide.

The mean value for absorbed dose rate, analyzed from soil samples collected in Mrima hills, Kenya (Osoro, 2007) was found to be 440nGyh^{-1} about seven times the world safety ceiling figures of 60nGyh^{-1} . Viresh *et al.* (1999) measured the natural radioactivity from Indian building materials as well as the byproducts. The results indicated that the research work values were less than the ceiling estimated. From the values of radium equivalent activity the criterion formula for gamma index, suggested acceptable radiation dose attributed from building materials. The figures were from Organization for Economic Cooperation and Development (OECD) countries. Melission *et al.* (1966) from Punjab-Pakistan did assess the radiological hazards as well as natural radioactivity in soil samples and building materials samples, the data obtained showed that the statistics were acceptable. Stoulos *et al.* (2003) researched on natural radiation from building materials in Greece, from the results obtained in that work, the level of natural radiation were in the acceptable range. However, ^{232}Th and ^{40}K

concentration from sample clay bricks were more than those from concrete blocks. The mean figure for annual effective dose absorbed by the residents from a typical building material was determined at 0.5mSv.

The activity concentrations in building materials available in Turkey (*Mavi and Akkurt, 2010*) after having analyzed the samples from building products, the values for radium equivalent ranges from 158.8Bqkg⁻¹ to 188.8Bqkg⁻¹. In Turkey, gamma ray spectroscopy was employed to measure the level of natural radioactivity and the finding showed that specific concentration of ²³⁸U, ²³²Th and ⁴⁰K for randomly selected building materials range from 3.5Bqkg⁻¹ to 114.1Bqkg⁻¹, 1.6Bqkg⁻¹ to 20.7Bqkg⁻¹ and 201.4Bqkg⁻¹ to 49228.8Bqkg⁻¹ in that order (*Mavi and Akkurt, 2010*). From Cyprus, Stoulos *et al.* (2003) investigated the gamma radiation at the same time dose rate from commercially-used natural tiling rocks and the result showed that the activity for ²³²Th ranges from 1-906Bq/kg, ²³⁸U from 1-588Bq/kg and ⁴⁰K from 50-1606Bq/kg. Having applied the dose criterion by the WHO, (2012) as superficial materials, it was reported that 25 samples meet exception figure of 0.3mSv/y, while some two meet upper dose of 1mSv/y lastly only one exceeds the limit.

In Algeria, Amrani and Tahtat (2000) researched on the natural as well as the manufactured building materials collected. The radioactivity concentration for radionuclides ²²⁶Ra, ²³²Th and ⁴⁰K were measured using a high-resolution HPGe gamma spectrometry system. The research determined that the ranges were 12Bqkg⁻¹ to 65Bqkg⁻¹, 7Bqkg⁻¹ to 51Bqkg⁻¹ and 36Bqkg⁻¹ to 675Bqkg⁻¹ in that order. In Cuba province, Flores *et al.* (2008) assessed activity concentration for 40 samples commonly

used as raw materials and building products. Gamma ray spectrometry was employed for the research work and the average figures for concentration were within ranges of 9Bqkg^{-1} to 857Bqkg^{-1} in ^{40}K , 6Bqkg^{-1} to 57Bqkg^{-1} in ^{226}Ra and 1.2Bqkg^{-1} to 22Bqkg^{-1} in ^{232}Th . From Iran, employing gamma ray spectroscopy, Simin *et al.* (2011) assessed natural radioactivity in building materials. The results of the study showed that cement had maximum value of ^{232}Th concentration at 28.9Bq/kg and lowest value in gypsum at 2.2Bq/kg . The study showed that the cement samples had maximum values of 39.6Bq/kg for ^{226}Ra while that of ^{232}Th concentrations was 28.9Bq/kg . While the lowest values were 8.1Bq/kg for ^{226}Ra and 2.2Bq/kg for ^{232}Th in gypsum samples. In the same work dose rate value was 53.7nGy^{-1} while hazard index value was below the recommended levels.

2.3 Radiation and Human Health

Risks of radiation-induced health effects are either nonexistent or too small to be observed for the dose rates up to 1mSv/y and above the annual effective, Podgorsak, (2015) discovered while he was studying gamma radiation from Uranium gamma radiation. Electromagnetic radiation such as gamma rays is known to have high frequency and very short wavelength. Electromagnetic radiation results after interactions of sub-atomic particles; such as electron-positron annihilation, neutral pion decay, radioactivity decay, fusion, fission, or inverse Compton scattering through a processes called astrophysical, Quiter,(1972). Effects of radiation on human health must be deliberated taking into account the ever present natural background.

Since the formation of the earth, there are two forms of background radiation; cosmic rays from space and radiation present in the earth. From naturally occurring radioisotopes of potassium as well as of rubidium and decay products of uranium together with that of thorium, terrestrial radiation are produced, Melissian,(1966). The dose people receive on average two thirds comes from terrestrial sources. On average, (UNSCEAR, 2000) calculate the world's people receive an effective dose equivalent of about $350\mu\text{Sv/y}$ from external radiation. There are limits set by International Commission on Radiological Protection due to exposure to ionizing radiation. The Commission expect public not to be exposed to a value of 1mSv per annum and above, with the occupational exposure not exceeding 20mSv per annum, excluding exposure due to background and medical radiation (UNSCEAR ,2000). There are two classifications of radiation effects; somatic effect and genetic effect. In somatic effect the damage appears in the irradiated person at the same time genetic effect, the damage appears on the offspring of the irradiated person Dunalp, (1988). Since radiation damage to the cells is passed to the offspring through the germ cells in the gonads. Consequences of lengthy exposure to radiation result to somatic effects such as leukemia and cancer Baykara *et al.*(2000). These radiation effects can further be categorized as prompt effects and delayed effects, where prompt effects includes radiation sickness as well as radiation burns, witnessed immediately large doses of radiation are delivered over short periods, International Digital Organization for Science Information, (2012). Delayed effects, includes effects such as cataract formation as well as cancer induction that may appear months or years after radiation exposure.

CHAPTER THREE

THEORETICAL BACKGROUND OF GAMMA-RAY SPECTROSCOPY

3.1 Introduction

In phase three, the approach is outlined as ; the theoretical concepts in the natural radioactivity, production of high-energy photons, radioactive equilibrium, interaction between ionizing radiation and matter, radiation as well as human health and lastly principle mechanism of NaI (T1) detector.

3.2 Gamma-ray Spectroscopy

Determination of energy distribution by gamma rays discharged by the nuclei is called gamma spectroscopy. When the energies of the gamma ray photons are discharged from the nuclei, gamma ray spectrometer determines it as well as the count rate. The detailed analysis of the spectrum obtained from the Multichannel Analyser (MCA) determines the character as well as the quantity in the gamma ray emitters present in the headstream.

3.3 Gamma ray production

Radioactive elements decay to emit different radiations which include; alpha particles radiation, beta particles radiation as well as gamma rays. Gamma ray decay is where nucleus goes from an excited state to a state of lower energy. In this processes the difference in energies between the two states is what liberates to form a photon. Stable Nickel-60 isotope is obtained when Cobalt-60 undergoes the process of beta decay. As the end result, excited nickel releases two gamma rays with energies of values 1.173MeV and 1.332MeV.

3.4 Secular Equilibrium

When the decay rates for parent radionuclide are the same as for the daughter radionuclide then that process is called secular equilibrium. It is only possible when the half-life for the parent radionuclide is longer than the daughter radionuclide.

By considering decay for parent radionuclide as A, while decay into daughter radionuclide as B, then the decay law given by equation (3.1) can be used to bring up the concept of radioactive equilibrium.

$$\frac{dN_B}{dt} = \lambda_A N_A - \lambda_B N_B \quad (3.1)$$

Parent (A) atoms number is N_A , while daughter (B) atoms number is N_B at a given time, at the same time λ_A and λ_B are the decay constants for the radionuclides A and B in that order. The half-lives ($t_{1/2}$) are given by

$$\lambda = \frac{\ln(2)}{t_{1/2}} \quad (3.2)$$

When equilibrium state is attained, the activity for daughter radionuclide is gotten from the activity of parent radionuclide by the secular equilibrium equation (3.3)

$$N_B = \frac{\lambda_A}{\lambda_B} N_A \quad (3.3)$$

3.5 Interaction of gamma rays with matter

Charged particles dissipate their energy continuously in a series of many ionizations and excitations. However, gamma rays are photons and have neither charge nor mass.

Single-event process whereby there is interaction between gamma ray alongside matter hence leading to complete absorption or scattering.

There are three ways in which gamma rays interaction with matter occurs, these three key interaction mechanism are; the photoelectric effect, the Compton scattering as well as the pair production. These modes of interaction of matter and radiation are significant in radiation detection as well as in measurement. Probability of any of the three process or mechanism occurring depends on two factors; energy ($h\nu$) from the gamma-ray as well as the atomic number (Z) for the materials. The Figure 3.1 shows relative preponderance for the three mechanisms.

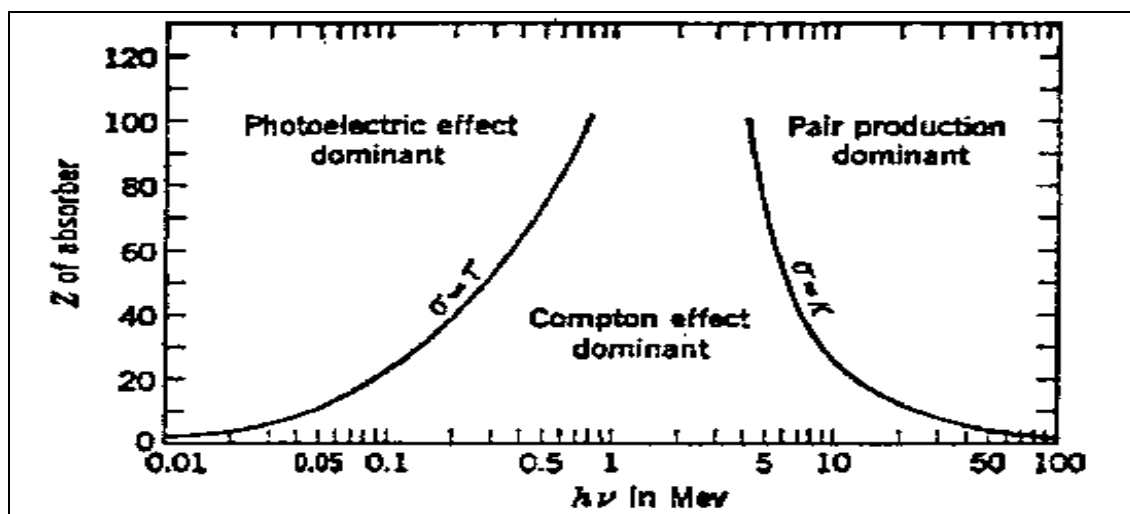


Figure 3.1: Predominance of photon interaction process (IAEA, 2005)

Free electrons are generated when photons interact with matter and these electrons are slowed down by matter, resulting to a charged pairs, then in getting photon energy,

photon detectors use the charge pairs generated by measuring the quantity of the charge produced in these pairs (Barekta and Mathew, 1985).

3.5.1 Photoelectric effect

Photoelectric effect is a mechanism through which gamma ray interacts with matter. From the process, an electron emitted from an atom has the same energy equal to that of gamma ray. Photoelectron is produced during the incident gamma ray photon interaction with tightly bound electron in matter, the electron then absorbs the incident photon energy. During this process a vacancy is created, making the atom excited (Podgorsak, 2005). The atom can then recover energy in its equilibrium state. Excitation energy bounded by the remaining electrons in the atom is then redistributed, resulting in discharge of further electrons. This condition is known as Auger cascade and is responsible for transfer to a hole left by an already ejected photoelectron so that higher electron may fall into this hole. The equation (3.4) shows the kinetic photon energy.

$$E = h\nu - h\nu' \quad (3.4)$$

Incident photon energy is $h\nu$ while the binding energy is $h\nu'$.

Equation (3.5) shows the probability of having photoelectric effect mechanism

$$T \propto \frac{Z^4}{(h\nu)^2} \quad (3.5)$$

Where T being expectation of a photon causing photoelectric effect while Z is the atomic number. It is therefore observed that heavier atoms absorb more energy from the incident photon compared to lighter ones.

3.5.2 Compton Effect

Scattering of a gamma-ray off a free electron is called the Compton scattering interaction. The process involves, direct interaction of a photon with a free and orbital electron. Therefore creating scattered gamma-ray photons as well as recoil electron, this is then transferred as the kinetic energy of the recoil electron. The scattered photon absorbs the incoming photon energy and the energy of the ejected electron from the atom is therefore define by the equation (3.6)

$$E_e = h\nu - h\nu', \quad (3.6)$$

The equation is dictated by two conditions; when $\theta = 0$, the scattered photon reserve entire energy while the recoil electron acquire no energy, at the same time when $\theta = \pi$, incident gamma-ray is backscattered while the recoil electron moves along the direction of incidence, therefore resulting in maximum energy transfer between the incoming gamma ray and the electron.

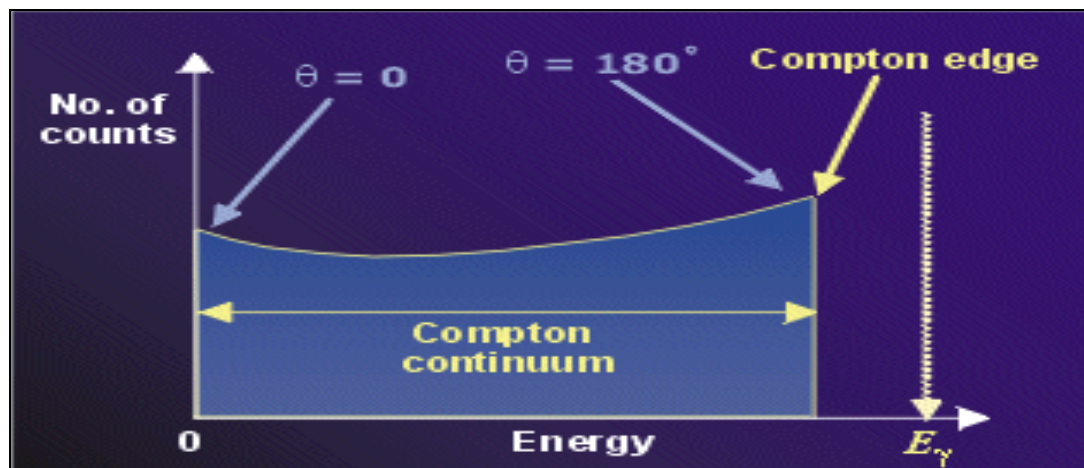


Figure 3.2: Compton continuum (Glean, 2005)

There is deflection of gamma photon through angle theta with respect to the initial direction during collision as in figure 3.2

Scattering angles between 0 and π occurs in the detector. The continuum of energies is then transferred to the electron as a result of the scattering. The energy ranges from 0⁰ as the minimum to the maximum of 180⁰.The photon energy of the incident, after backscattering is given by equation 3.7

$$hv' = \frac{hv}{1 + \frac{2hv}{mc^2}} \quad (3.7)$$

The difference in value between the actual energy of the incident photon and maximum recoil electron energy is given by equation 3.8

$$Ec = hv - Ee^- = \frac{hv}{1+2hv/mc^2} \quad (3.8)$$

The shape of the Compton continuum is altered by the binding energy of electrons in radiation detector. At the lower energy end of the spectrum Compton continuum is observed. The probability for Compton scattering is approximately proportional to Z, below~100keV.

3.5.3 Pair production

When gamma photon is transformed into an electron-positron pair, the mechanism is called pair production. As a result of high electric field, the process happens close to the

nuclei of the absorbing material. Photons are converted into an electron-positron pair when there is sufficient energy. The sum of the rested-energies for the electron as well as positron is the same as the minimum photon energy.

$$2mc^2 = 2 \times 0.511\text{MeV} = 1.02\text{MeV} \quad (3.9)$$

Photon energy beyond minimum goes into kinetic energy of electron-positron production. The chances for pair production must be below 1.022MeV, since pair production is more likely to occur than Compton scattering for only photon energies above and several in 1 MeV. From figure (3.1) there is a summary of how different interactions change their chances of occurring depending on the energy of the gamma-ray as well as the atomic number of the material.

3.6 Radiation and human health

Risks from radiation exposure cannot be eradicated absolutely but can be confined. Deterministic and stochastic are the two side effects from the exposure of radiation to human health. The dose rate, 100 mrem/y and above the annual natural radiation background are acceptable. Since dose rate or risks of radiation-induced health hazard are neither nonexistent nor too small to be observed (Gang *et al* 2012).

Electromagnetic radiation such as gamma rays has high frequency and very short wavelength. Gamma rays are produced when sub-atomic particles interact such as the following process: electron-positron annihilation, neutral pion decay, radioactivity decay, fusion, fission, or inverse Compton scattering in astrophysical processes. The

effect of radiation on human health is discussed in this chapter within the context of the natural background.

Cosmic rays from space as well as radiation present in the earth forms the background radiation. The terrestrial radiation originates from naturally occurring radioisotopes of potassium as well as rubidium and from decaying products of uranium and thorium. Dose rate people take in on average, two third comes from terrestrial sources; most of the dose rate comes from the radon gas. On average, (UNSCEAR, 1988) calculate the world's people receive an effective dose equivalent of about $350\mu\text{Sv/y}$ from external radiation.

CHAPTER FOUR

MATERIALS AND METHODS

4.1 Study area, Sampling as well as Sample Preparation

Random samples of building materials for sand, clay bricks, as well as concrete blocks were collected from construction site, in Babadogo estate (Appendix 2). The sampling method employed here was random sampling, to enhance statistical sensitivity of the sampling (IAEA, 2005). Thirty three samples of clay bricks, concrete blocks and some sand of approximately between 1.5kg and 2kg were collected first from each site then placed in carton boxes. Hand held Global Positioning System (GPS, Garmin Monterra model) was employed to locate each sampling site. These samples were then taken to secure central point within the Babadogo estate for the grinding of the blocks and bricks.

All the samples were then ground, crushed into powder form, sieved then lastly dried in an oven at 110⁰C as long as 24 hours. In order to obtain uniform particle sizes, a 1×1 mm meshed sieve was used. Standard plastic marinelli beakers accurately weighed and labeled was used to pack the dry samples; the beaker together with the samples was about 450±1g. The hermetically sealed samples were stored for a period of four weeks prior to counting to secure radioactive stability among 226-Ra and its short-lived progeny (Ramasamy et al., 2011). Again storing for four weeks was to enhanced secular equilibrium between ²³⁸U as well as ²³²Th and their respective daughters.

4.2 NaI(Tl) gamma-ray spectrometer

The radioactivity detector operates on the principle of emission of photon energy. For the measurement of gamma radiation a 76mm × 76mm NaI (Tl) detector was used for the study. Oxford multichannel analyzer (MCA) card was used for data acquisition. In the PCAP there is high voltage supply, a charge sensitive pre-amplifier, a shaping amplifier, 80MHZ Wilkinson analogue to digital converter (ADC) with Multichannel Analyzer. While in the MCA; it comprises of 4K channels, Multichannel Buffer (MCB) card and ACE emulation software package. Lastly the MCB card collects data independently of the other operations of the computer.

Placing a gamma ray source in front of the detector, the gamma ray interacted with the NaI (Tl) crystal therefore releasing radiations, predominantly in the Ultraviolet (UV) region. Photoelectric effect then occurs when radiation produced strikes the cathode of the photomultiplier tube hence produces low energy electrons. The application of high voltage to photomultiplier tube enhances acceleration of the photoelectrons down the series of electrodes. Output voltage Pulse is formed when the electron in the dynode is integrated then recorded and stored by MCA according to their energy value. The data collected was then displayed as a spectrum on a computer screen.

The radionuclide for all samples was measured using gamma ray spectrometer. Radioactivity measurement was done by the shielded 76×76 mm NaI(Tl) detector connected to a high voltage operating photomultiplier tube (PMT) which is also connected to a computer based, the Oxford PCAP Multichannel Analyzer (MCA) card with software application for the spectral data acquisition and analysis. From the PMT

there exists photocathode where electrons are discharged through photoelectric effect by the scintillation photons and a series of dynodes. The dynode is biased to high voltage with respect to the preceding dynode in order to multiply the number of electrons in the pulse of charge. Detector was used to determine the radioactivity concentration for ^{238}U , ^{232}Th as well as ^{40}K in the building materials samples randomly collected.

Samples placed in a sealed marinelli beakers were put in the detector one at each time then counted for about 30,000 seconds. Before these counts, background counts were recorded first under similar factors of those of the samples measured later on the figures (background). These were subtracted at the end of the counts of all the thirty three samples in order to find net counts for the samples.

Spectrum recorded is displayed on the screen of the MCA where the horizontal axis representing the photon energy or channel number at the same time the vertical axis representing the photons recorded per channel (intensity) at the end of each counting session. In order to determine the peak area by minimizing uncertainties due to measurements same sample and reference geometry was employed (Turham *et al.*, 2008). From Fig 4.1 is an electronic diagram of the NaI(Tl) gamma-ray spectrometer for the research work.

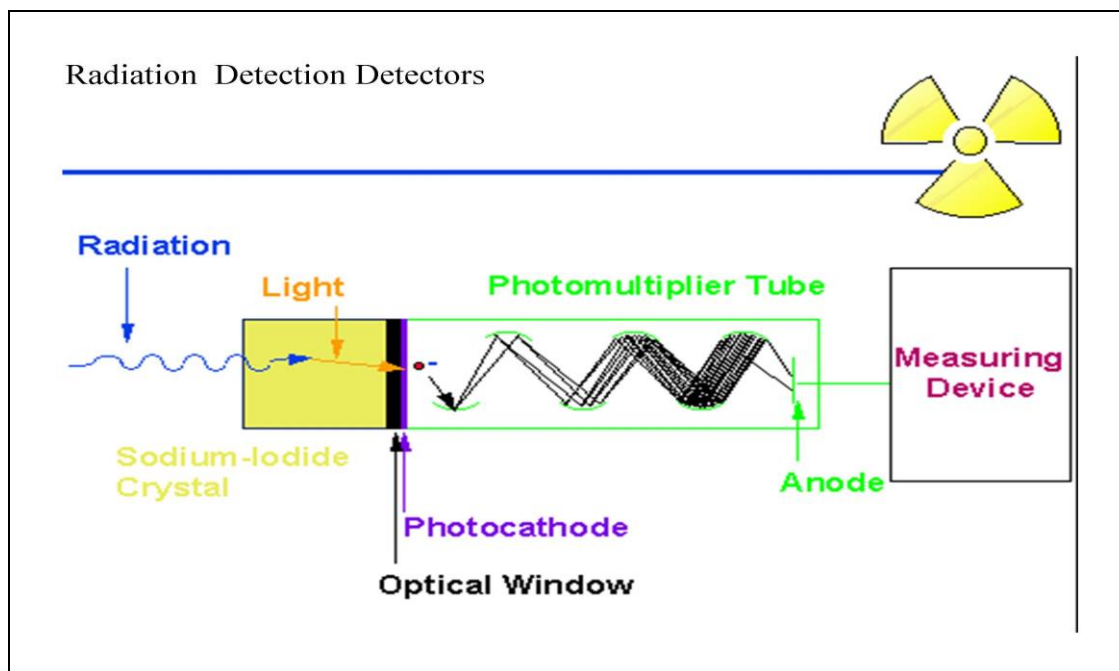


Figure.4.1: Thallium activated sodium Iodide detector for radiation (Glean, 2005)

4.2.1 Energy Calibration in NaI(Tl) Spectrometry

The three standard materials acquired from International Atomic Energy Agency (IAEA) were used for system calibration. This was done at Kenyatta University Physics laboratory prior to spectral data acquisition from the samples. At the start of every measurement session energy calibration was carried out to cater for the weather condition variation, vibrations as well as heating up of the detector. RGK-1, RGU-1, and RGTH-1 for potassium, uranium, and thorium respectively are the standard samples (IAEA, 1987). Calibration is done so that the channels are provided with relevant energy values. The peak positions were used to deduce the Energy-Channel relationship. By the use of a second order polynomial in the form of Equation (4.1), the

photon energy is represented as a function of channel number (Ibrahim and Awadallah, 2009)

$$E=Y_0+C_1B+C_2B^2 \quad (4.1)$$

Where B represents channel number, while Y_0 , C_1 as well as C_2 are constants and the fitted values are 13.867 ± 0.693 , 3.513 ± 0.176 and 0.001 ± 0.00005 . From figure 4.2 the energy calibration curve as well as the fit parameters is tabulated from Table 4.1. Hence polynomial is generated by least square fit of the calibration. E is photon energy and B is the channel number.

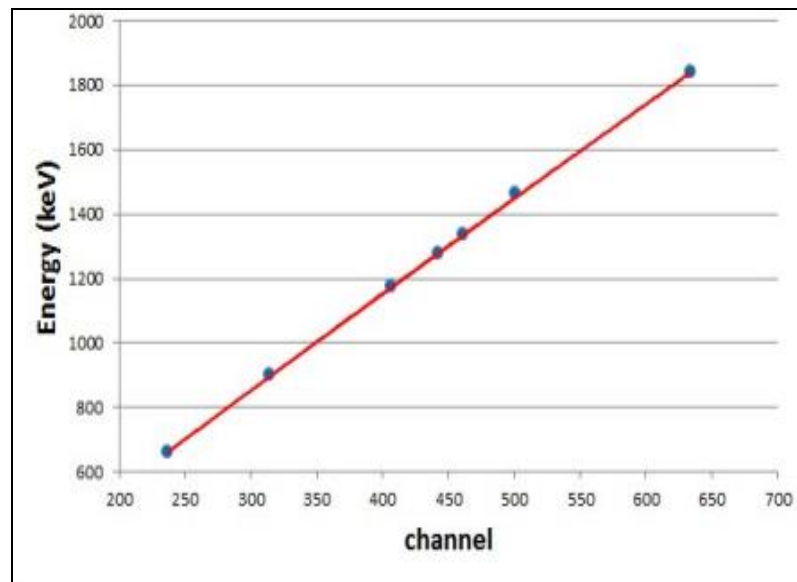


Figure 4.2: Second order polynomial fit to calibration energy for the NaI(Tl) detector

Table 4.1: The fit parameters of the polynomial regression for the energy calibration of Na(Tl) detector used in the research.

Constant	Fitted value
C ₂	0.00109±0.00005
C ₁	3.51288±0.176
Y ₀	13.86667±0.693

4.2.2 Background measurement

For the background radiation levels estimation, a randomized controlled trail was done using plastic container with distilled water of about 300±10g. The measuring of background radiation was done for a period of 30,000 seconds then the result deducted from each of the recorded spectrum for all the samples of building materials that were analyzed in the research.

4.2.3 Energy resolution of the NaI(Tl) detector

The ability of a detector to distinguish two close lying photo peaks is termed as the energy resolution. The determination was done by Gaussian fitting of photo peak of Cs-137 as shown in Figure 4.4. Energy resolution can be expressed in terms of the full

width at half maximum (FWHM). From equation (4.2), energy resolution can be determined for the NaI(Tl) detector (Khandoker, 2015).

$$\text{Energy resolution} = \frac{\text{FWHM}}{E} \times 100\% \quad (4.2)$$

Equation (4.3) was used for the Gaussian curve

$$y = y_0 + \frac{A}{w\sqrt{\frac{\pi}{2}}} e^{-\frac{[x-x_c]^2}{w^2}} \quad (4.3)$$

Figure 4.3 Gaussian fit has energy resolution value of value 7.4% as was obtained from the NaI(Tl) detector

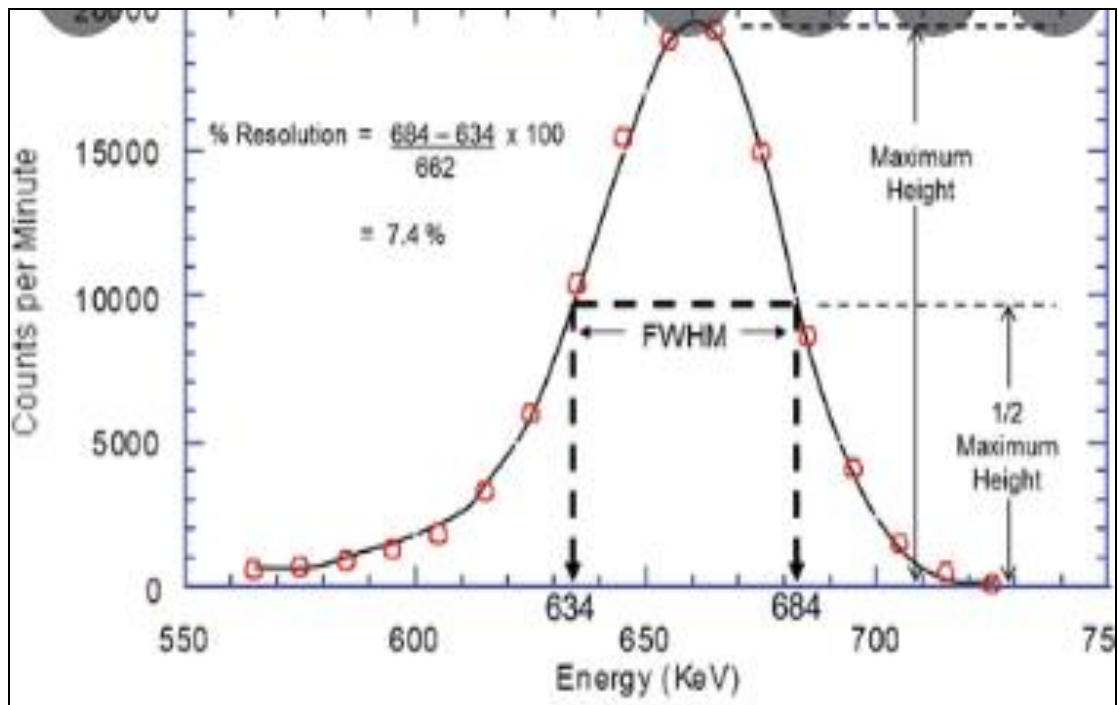


Figure 4.3: Full energy peak for ¹³⁷Cs measured in my research work.

All spectra for the thirty three samples were recorded and stored. Figure 4.4 shows a sample spectrum curve for building materials; sand sample collected from site S3 from Babadogo estate.

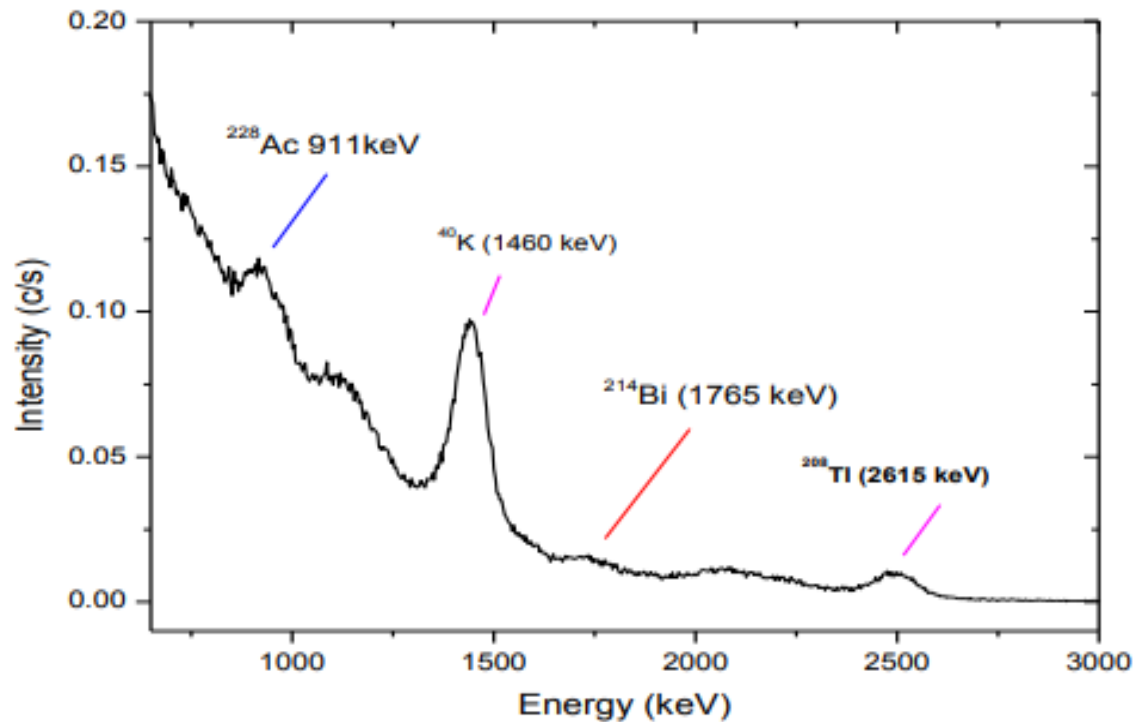


Figure 4.4: Gamma ray spectrum for sand sample analyzed

4.3 Analysis of Samples

The processes of determination of the gamma ray concentration activities for the NORM in the samples, was focused on the identification of five regions of interest (RIO) from the spectrum as in Figure 4.6. And were centered about the characteristics of photo-peaks, which were approximated to be: 1460KeV (^{40}K), 1765KeV (^{214}Bi) and 2615KeV (^{208}Tl). The gamma ray spectrometer cannot directly determine the activities of radionuclides ^{238}U and ^{232}Th since they are alpha emitters, enhance the use of 214-Bi

and 208-Tl was deployed. From the two the activities levels of ^{40}K , ^{226}Ra as well as ^{232}Th series, respectively were able to be evaluated (Ravisanka *et al.*, 2016).

Procedure for sample analysis was as follows;

- a.) Every sample was counted for 30,000 seconds on the calibrated Na(Tl) spectrometer and its spectrum recorded and stored in the text files of a PC based MCA.
- b.) Background count was subtracted from all the sample counts in order to get net count.
- c.) Radioactivity concentration for all samples were then calculated as described in section 4.5



Figure.4.5: The regions of interest in the spectrum taken for Sample 1(sand)

The regions in the spectrum occupied by a peak, the optimal width of the peak region in region-of-interest analysis depends on the measured spectrum. Again region-of-interest (ROI) spectral region are used for calculating numbers of counts in the peak region-of-interest analysis. If a peak has been located, it is safe to assume that a region about 5 times the FWHM of the peak covers all counts belonging to the peak (Arafa, 2004).

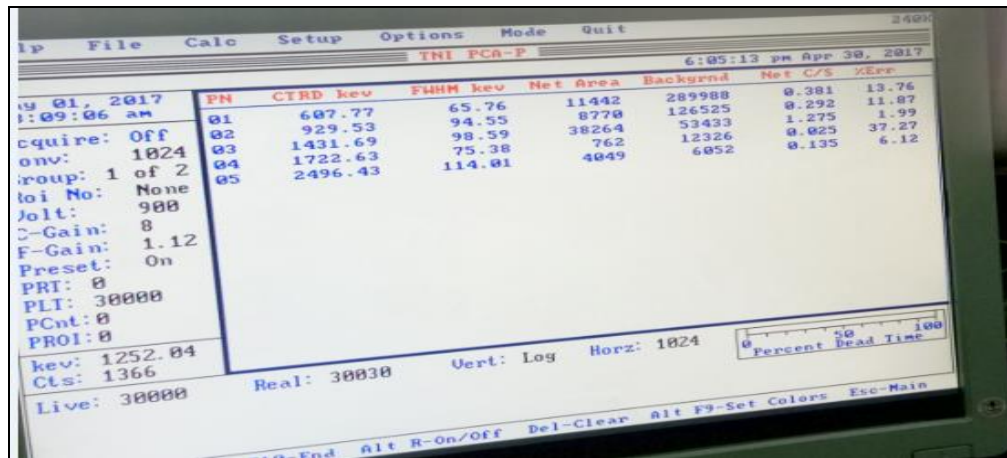


Figure 4.6: Analysis of photo peaks in the spectrum taken for sample 1 (sand)

4.4 Calculation of radioactivity concentration levels

Comparison method was used for the calculation of activity concentration of the radionuclides in all the thirty three samples, as in the equation (4.4)

$$A = \frac{I}{\sum M} \quad (4.4)$$

A, represent the activity concentration of the actual sample, while M represents the mass and I represent the intensity.

4.5 Calculations of the radiological parameters

4.5.1 Dose rate calculation

Calculation of absorbed dose rate in air was done using the equations (4.5) and (4.6) (UNSCEAR, 1988) for clay bricks and sand respectively

$$D=0.92C_U+1.1C_{Th}+0.08C_K \quad (4.5)$$

$$D=0.43C_U+.0.666C_{Th} +0.042C_K \quad (4.6)$$

D represent absorbed dose in $nGyh^{-1}$, C_U is activity concentration for ^{238}U in $Bqkg^{-1}$, C_{Th} is activity concentration for ^{232}Th in $Bqkg^{-1}$ while C_K is activity concentration for ^{40}K in Bq/kg present in all the samples.

4.5.2 Annual effective dose rate (AEDR)

For the calculation of annual effective dose rate in air due to the building materials, conversion coefficient for absorbed dose in air from effective dose received by an adult was put into consideration. The value $0.7SvGy^{-1}$ (UNSCEAR, 2000) for environmental exposure to gamma rays of specific energy range was used. Therefore for the annual effective dose rate equivalence for the research the calculation was done by equation (4.7).

$$AEDR=D \times T \times F \quad (4.7)$$

D is the calculated prerequisite dose rate ($nGyh^{-1}$), while T is represent the indoor occupancy time ($D \times 8760 \times 0.2 \times 0.7 \times 10^{-6} = 701hy^{-1}$) lastly F is the conversion factor with the value $0.7 \times 10^{-6}SvGy^{-1}$

4.5.3 Radium equivalent activity

Using radium equivalent activity (Ra_{eq}) as the prerequisite to assess whether building materials are associated with radiological hazards since it was found to have ^{238}U , ^{232}Th as well as ^{40}K measured in Bqkg^{-1} . The index represents radioactivity concentrations for natural radionuclides ^{238}U , ^{232}Th as well as ^{40}K and is an estimate base that one Bqkg^{-1} for ^{238}U , one Bqkg^{-1} for ^{232}Th lastly 13 Bqkg^{-1} for ^{40}K released by the same radiation dose rates (Kilic, 2009). The evaluation of parameter was by equation (4.8)

$$Ra_{eq}=C_U + 1.43C_{Th} + 0.077C_K \quad (4.8)$$

Activity concentrations in the building materials are represented by C_U , C_{Th} and C_K in Bq/kg for ^{238}U , ^{232}Th as well as ^{40}K in that order. The measured maximum and minimum radium equivalent activity were $6170 \pm 308 \text{Bq/kg}$ and $82 \pm 4 \text{Bq/kg}$ respectively.

4.5.4 Hazard index H_{ex}

Assessment for the suitability of building materials is fulfilled, by the calculation of a gamma index after which the value is used as a screening tool to assess appropriateness of the building materials. The annual contribution of the natural radionuclides to the gamma dose is defined as the hazard index. The values of 300Bq/kg , 200Bq/kg and 3000Bq/kg are the bulk restrictions for the radionuclides ^{238}U , ^{232}Th and ^{40}K respectively for their radioactivity concentration when the excess gamma radiation originating from increasing annual effective dose member to the public figure of 0.3msv/y at most (Mann and Gartinkil, 1966) . Equation (4.9) was used to calculate the index.

$$I = \frac{A_U}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \leq 2 \quad (4.9)$$

The value of index $I \leq 2$ here correspond to a dose rate criterion of 0.3mSv/y, where A_U, A_{Th} , as well as A_K are the activity concentration (Bq/kg) in building materials of $^{238}\text{U}, ^{232}\text{Th}$ and ^{40}K respectively.

4.6 Quality assurance and control

In order to accomplish systematic, reliable as well as valid research outcome, succeeding procedures were taken.

- i) Building materials from a particular site were labeled properly to avoid disorderly of the samples during sampling period which was 33 days.
- ii) Samples were stored well in sealed containers to steer clear of contamination while on transit to the Kenyatta University laboratory.
- iii) To enhance statistical representation of the sampling, the area covered was evenly distributed.
- iv) Tools used in collection and storage of samples were treated with care to steer clear of impurity for samples by the same tools hence compromising the results.
- v) Consistent selection of the region of interest (RIO) Figure 4.6 for all spectra was done during determination of the intensity.

- vi) NaI(Tl) detector was Calibrated every time before a sample was placed inside, standard samples provided by IAEA was used as well as during the activity calculation of these samples.

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Radioactivity concentration

The study intended to assess the radioactivity concentration levels for the naturally occurring radionuclide and radiological hazards due for building materials used in Babadogo estate, Nairobi City County. The use of NaI(Tl) detector came in handy for the research work. Radioactivity concentrations for the selected building materials samples were measured thereafter radiological parameters were evaluated from pre-requisite radioactivity concentration; the evaluated radiological parameters were; the absorbed dose rate, the annual effective dose rate, the radium equivalent as well as the hazard index. These radiological parameters were computed then the results presented in tables and graphs. The calculated values of these parameters are presented in this chapter.

5.2 Measured Radioactivity Concentration of Building Materials from Babadogo estate.

These building materials used for construction in Babadogo estate are known to come from various regions or Counties surrounding Nairobi County. The sand used is mainly from Machakos County (UN-HABITAT, 2009). The presence of phosphate and granite rocks which undergo the process of weathering as a result of change of weather pattern in Machakos County enhances the formation of sand in this region with elevated levels of radioactive materials, the (NORM) in the environment (Rotich ,2015). Heavy rain

falls in these regions neighboring Nairobi County, such as Kiambu, Machakos and Kajiado causes the weathering of rocks that forms traces of radionuclides to be deposited in river banks and later collected with the sand for building. In addition the weathered particles form surface soil which is used in the manufacturing of clay bricks.

The measured values of the radioactivity concentrations in radionuclides for ^{40}K , ^{238}U , and ^{232}Th are presented on Table 5.1. Mean value of radioactivity concentration in radionuclides ^{40}K was higher than that for ^{238}U and ^{232}Th , as a result of potassium being the major contributor of the naturally occurring radionuclide. The measured radioactivity concentration for ^{40}K varied from $55\pm 3\text{Bqkg}^{-1}$ to $2647\pm 132\text{Bqkg}^{-1}$ translating to a mean value of $831\pm 42\text{Bqkg}^{-1}$. Radioactivity concentration for ^{238}U varied from $39\pm 2\text{Bqkg}^{-1}$ to $3602\pm 180\text{Bqkg}^{-1}$ giving the mean value of $378\pm 19\text{Bqkg}^{-1}$ and that of ^{232}Th had minimum of value of $5\pm 0.03\text{Bq/kg}$ while the maximum value was $4213\pm 211\text{Bq/kg}$ and the mean value was $290\pm 15\text{Bq/kg}$.

Table 5.1: Radioactivity concentrations values for the natural radionuclides ^{40}K , ^{238}U and ^{232}Th measured for the research work in Babadogo estate building materials, units in Bq/kg.

Sample site	K40Bqkg ⁻¹	U238 Bqkg ⁻¹	Th232Bqkg ⁻¹	Building material	County of origin of the materials
A ₁	1556±78	100±5	230±12	Sand	Machakos
A ₂	57±3	187±9	29±1	Sand	Machakos
A ₃	1744±87	671±34	29±1	Sand	Kiambu
A ₄	1063±53	180±9	17±1	Sand	Kajiado
A ₅	637±32	108±5	12±1	Sand	Kajiado
A ₆	1248±62	108±5	151±8	Sand	Makueni
A ₇	350±18	210±11	243±12	Sand	Makueni
A ₈	398±20	360±18	95±5	Sand	Makueni
A ₉	2648±132	1019±51	45±11	Sand	Kiambu
A ₁₀	612±31	174±9	24±1	Sand	Kiambu
A ₁₁	1050±53	123±6	23±1	Sand	Narok
A ₁₂	1626±81	3603±180	11±1	Sand	Narok
A ₁₃	670±34	1243±62	3081±154	Sand	Narok
A ₁₄	485±24	110±6	10±1	Sand	Narok
A ₁₅	1056±53	63±3	4214±210	Brick	Kiambu
A ₁₆	1181±59	144±7	20±1	Brick	Kiambu
A ₁₇	56±3	163±8	155±8	Brick	Kiambu
A ₁₈	1045±53	40±2	6±1	Brick	Kiambu

Sample site	K40 Bqkg ⁻¹	U238 Bqkg ⁻¹	Th232 Bqkg ⁻¹	Building material	County of origin of the materials
A ₁₉	55±3	61±3	11±1	Brick	Kiambu
A ₂₀	699±35	59±3	11±1	Brick	Kiambu
A ₂₁	466±23	181±9	11±1	Brick	Kiambu
A ₂₂	992±50	408±20	29±1	Brick	Kiambu
A ₂₃	849±42	168±8	90±5	Brick	Kiambu
A ₂₄	202±10	140±7	78±4	Block	Nairobi
A ₂₅	906±45	179±9	125±6	Block	Nairobi
A ₂₆	331±17	421±21	124±6	Block	Nairobi
A ₂₇	153±8	523±26	111±6	Block	Nairobi
A ₂₈	59±3	130±7	24±1	Block	Nairobi
A ₂₉	77±4	284±14	25±1	Block	Nairobi
A ₃₀	358±18	273±14	64±3	Block	Nairobi
A ₃₁	1724±86	511±26	218±11	Block	Nairobi
A ₃₂	1653±83	439±22	172±9	Block	Nairobi
A ₃₃	1427±71	98±5	99±5	Block	Nairobi
Max	2648±132	3603±180	4214±210		
Min	55±3	40±2	6±1		
Mean	831±42	378±19	290±15		

The maximum radioactivity concentration for ⁴⁰K, ²³⁸U and ²³²Th in the selected building material samples used in Babadogo estate were: 2648±132 Bqkg⁻¹, 3603±180

Bqkg⁻¹ as well as 4214 Bqkg⁻¹ at the same time the minimum radioactivity concentration for radionuclides are :55±3Bqkg⁻¹ ,40±2 Bqkg⁻¹ and 6±1Bqkg⁻¹.

Table 5.2: Average activity concentration of radionuclide in building materials from Babadogo estate compared to the world average. It is an extract from table 5.1

Radionuclide	Study(Bqkg⁻¹) Average values	Acceptable Safety Limit (Bqkg⁻¹) (UNSCEAR,2000)
⁴⁰K	831±42	420
²³⁸U	378±19	33
²³²Th	290±15	45

The average radioactivity concentrations for the radionuclide of the recommended average values are; 420Bqkg⁻¹, 33Bqkg⁻¹and 45Bqkg⁻¹ for ⁴⁰K, ²³⁸U and²³²Th respectively (UNSCEAR, 2000).

Figure 5.1 shows the specific activity distribution for ²³⁸U, ²³²Th as well as ⁴⁰K for the selected sample sites in Babadogo estate for the study area. From Table 5.1 and Figure 5.1 the highest radioactivity concentration values for ²³⁸U,²³²Th as well as ⁴⁰K were in sites ;which were labeled A's A₁₂,A₁₅, and A₉ respectively. Radioactivity concentration values in ⁴⁰K were more advance in all samples collected from Babadogo estate except for samples A₂, A₇, A₈ and A₁₉ which were less than world weighted mean of 420Bq/kg. The activity concentration values for ²³⁸U were greater than the acceptable safety limit value of 33Bq/kg for all samples collected from study area. The radioactivity concentration values in ²³²Th were only higher from these seven samples; A₁, A₆, A₇,

A₈, A₁₃, A₁₅ and A₁₇ which were above the world weighted mean of 45Bq/kg (UNSCEAR, 2000). The high level of activity concentration from almost all the sample collected from Babadogo estate can be attributed to the origin of the source of building materials as indicated in Table 5.1.

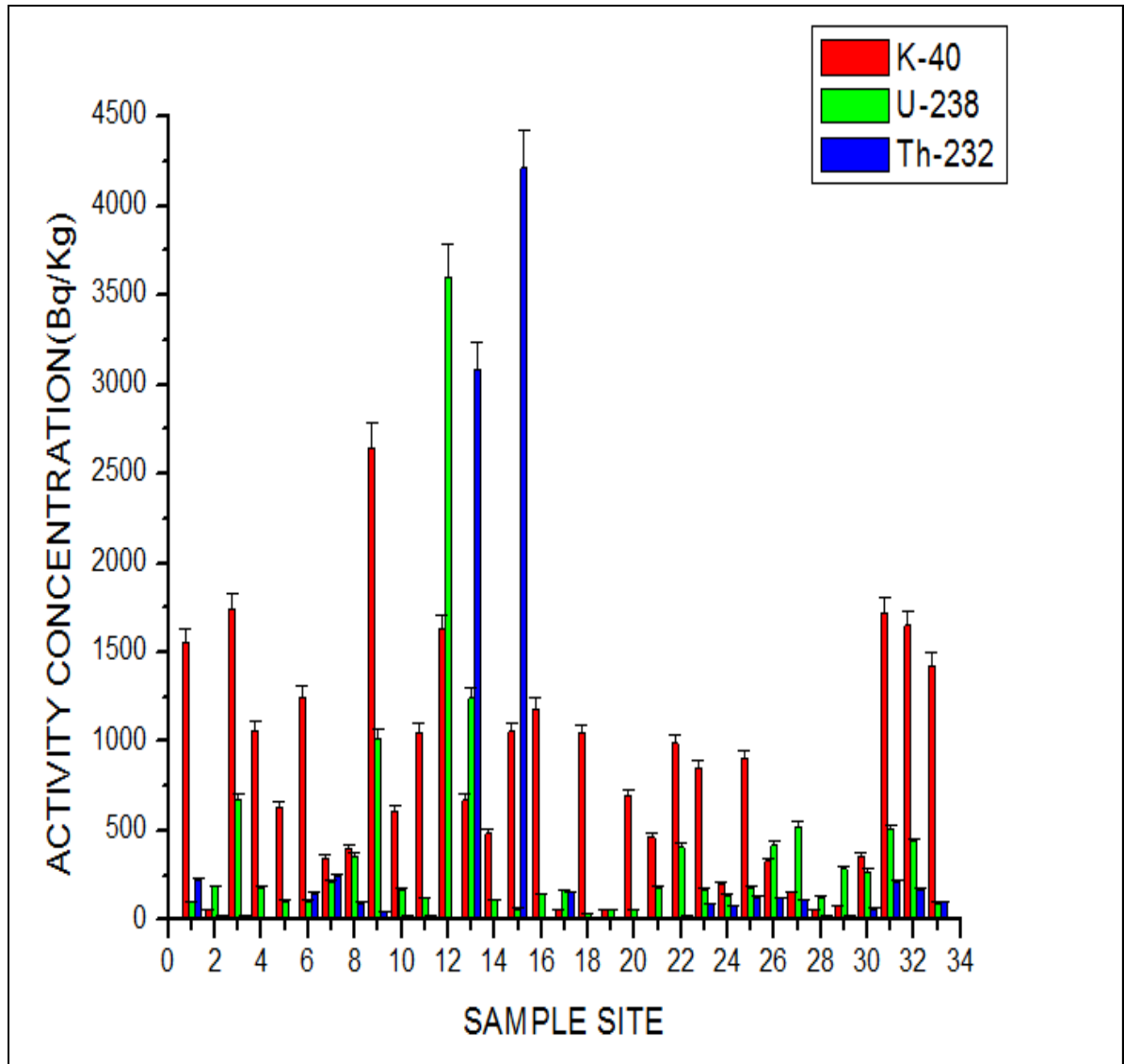


Figure 5.1: Radioactivity concentration in natural radionuclides; ^{238}U , ^{232}Th and ^{40}K measured from the 33 samples collected.

5.3 Measured radium equivalent of building materials from Babadogo estate.

Radium equivalent for all the randomly selected thirty three samples collected in Babadogo estate was determined by the use of equation 4.7. The results are also analyzed, tabularized and lastly presented. The radium equivalent value of $866\pm 43\text{Bq/kg}$ was more than 370 Bq kg^{-1} the World's recommended limit for building materials.

Table 5.3: Measured Radium equivalent of Building Materials from Babadogo estate.

Sample Site	Radium Equivalent(Bq/kg)	Building material
A ₁	548±27	Sand
A ₂	233±12	Sand
A ₃	847±42	Sand
A ₄	286±14	Sand
A ₅	174±9	Sand
A ₆	420±21	Sand
A ₇	584±29	Sand
A ₈	526±26	Sand
A ₉	1286±64	Sand
A ₁₀	256±13	Sand
A ₁₁	237±12	Sand
A ₁₂	3744±187	Sand
A ₁₃	5700±285	Sand
A ₁₄	556±28	Sand

Sample site	Radium equivalent(Bq/kg)	Building material
A ₁₅	6170±308	Brick
A ₁₆	263±13	Brick
A ₁₇	389±19	Brick
A ₁₈	129±6	Brick
A ₁₉	82±4	Brick
A ₂₀	128±6	Brick
A ₂₁	233±12	Brick
A ₂₂	526±26	Brick
A ₂₃	362±18	Brick
A ₂₄	267±13	Block
A ₂₅	427±21	Block
A ₂₆	624±31	Block
A ₂₇	693±31	Block
A ₂₈	169±8	Block
A ₂₉	325±16	Block
A ₃₀	392±20	Block
A ₃₁	956±48	Block
A ₃₂	812±40	Block
A ₃₃	250±13	Block
Mean	866±43	
Max	6170±308	
Min	82±4	

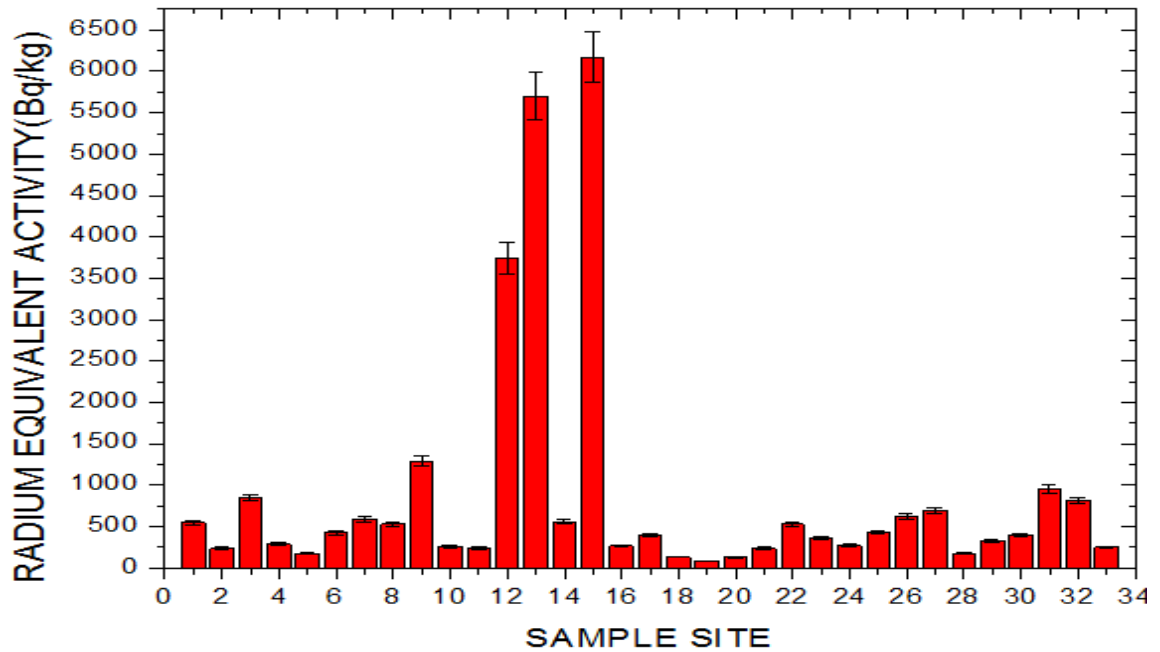


Figure.5.2: Radium equivalent for the building materials measured in this research

work

The samples from site 15 have the highest radium equivalent because the activity concentration for the sample was also more.

5.4 Dose rate

Total dose rate from the randomly selected sample sites was then calculated using equations 4.4 as well as 4.5 for sand and clay brick/block respectively. The average dose rate values of natural radionuclides for building materials randomly sampled from Babadogo estate was $540 \pm 27 \text{ nGy h}^{-1}$. The maximum and minimum values for the samples were 4777 nGy h^{-1} and 73 nGy h^{-1} respectively. Also evident in the research work, the calculated dose rate was above the acceptable safety limit value of 54 nGy h^{-1} but within the world satisfactory limit of 1500 nGy h^{-1} (UNSCEAR, 2000). Table 5.4 and

figure 5.3 are the tabulation and graphical analysis for the dose rate in the research work. From Table 5.4, the report showed that sample 12, 13 and 15 had the highest values which were also above the world acceptable safety limits.

Table 5.4: The dose rate for sample collected from Babadogo estate

Site No.	Dose rate(nGy/kg)	Building material
A ₁	261±13	Sand
A ₂	102±5	Sand
A ₃	381±19	Sand
A ₄	133±7	Sand
A ₅	81±4	Sand
A ₆	199±10	Sand
A ₇	267±13	Sand
A ₈	235±12	Sand
A ₉	579±29	Sand
A ₁₀	117±6	Sand
A ₁₁	112±6	Sand
A ₁₂	1625±81	Sand
A ₁₃	2614±131	Sand
A ₁₄	75±4	Sand
A ₁₅	4777±239	Brick
A ₁₆	249±12	Brick
A ₁₇	325±16	Brick

Site No.	Dose rate(nGy/kg)	Building material
A ₁₈	127±6	Brick
A ₁₉	73±4	Brick
A ₂₀	122±6	Brick
A ₂₁	216±11	Brick
A ₂₂	486±24	Brick
A ₂₃	319±16	Brick
A ₂₄	231±12	Block
A ₂₅	374±19	Block
A ₂₆	550±27	Block
A ₂₇	615±31	Block
A ₂₈	151±8	Block
A ₂₉	295±15	Block
A ₃₀	350±17	Block
A ₃₁	848±42	Block
A ₃₂	725±36	Block
A ₃₃	210±10	Block
Mean	540±27	
Max	4777±239	
Min	73±4	

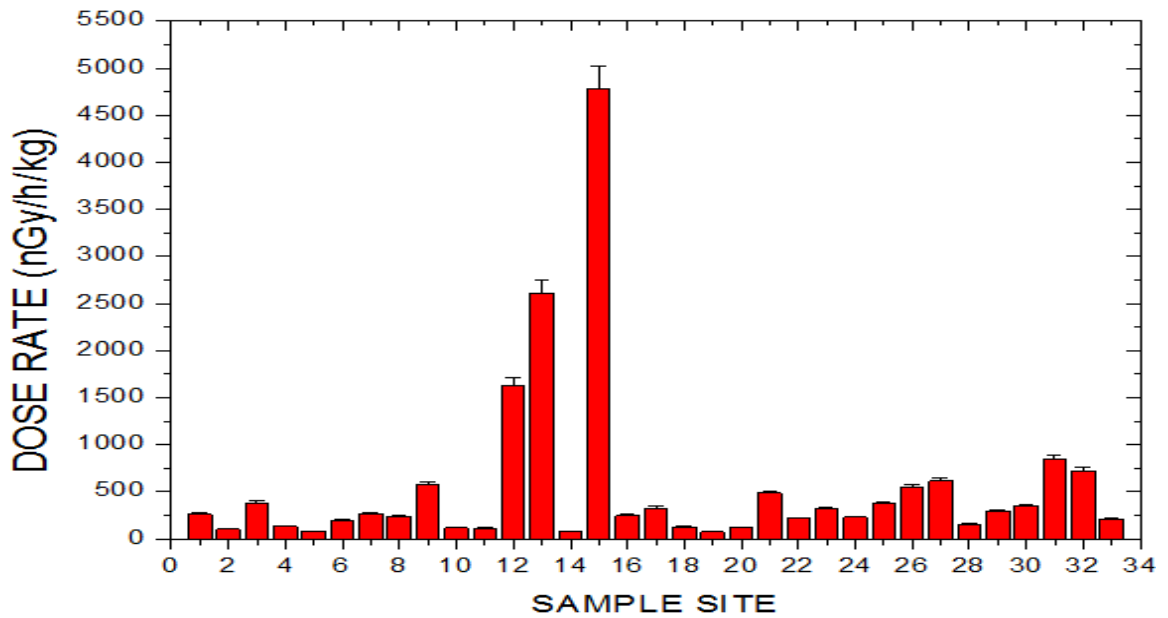


Figure 5.3: Dose rate from the selected building materials measured in the research work.

5.5 Annual effective dose rate

Calculated annual effective dose rate ranges between a minimum of $0.04 \pm 0.002 \text{ mSv} \cdot \text{y}^{-1}$ to a maximum of $2.34 \pm 0.117 \text{ mSv} \cdot \text{y}^{-1}$ giving a mean figure of $0.26 \text{ mSv} \cdot \text{y}^{-1}$, given in Table 5.4. Exposure to gamma rays from randomly selected building materials in Babadogo estate is minimal compared to the dose limit of $1 \text{ mSv} \cdot \text{y}^{-1}$. Only samples 13 and 15 were reported to have annual effective dose rate above the dose rate limit of $1 \text{ mSv} \cdot \text{y}^{-1}$ (UNSCEAR, 2000). As from Figure 5.4 it shows the bar graph for annual effective dose rate.

Table 5.5: Annual effective dose rate for samples of building materials collected from Babadogo estate for this work.

Site No.	Effective dose rate(mSv/y)	Building material
A ₁	0.13±0.007	Sand
A ₂	0.05±0.002	Sand
A ₃	0.19±0.010	Sand
A ₄	0.07±0.004	Sand
A ₅	0.04±0.002	Sand
A ₆	0.10±0.005	Sand
A ₇	0.13±0.007	Sand
A ₈	0.12±0.006	Sand
A ₉	0.28±0.014	Sand
A ₁₀	0.06±0.03	Sand
A ₁₁	0.06±0.03	Sand
A ₁₂	0.80±0.04	Sand
A ₁₃	1.28±0.064	Sand
A ₁₄	0.04±0.002	Sand
A ₁₅	2.34±0.1170	Brick
A ₁₆	0.12±0.006	Brick
A ₁₇	0.16±0.008	Brick
A ₁₈	0.06±0.003	Brick
A ₁₉	0.04±0.002	Brick
A ₂₀	0.06±0.003	Brick

Site No.	Annual effective dose rate(mSv/y)	Building material
A ₂₁	0.24±0.012	Brick
A ₂₂	0.11±0.006	Brick
A ₂₃	0.16±0.008	Brick
A ₂₄	0.11±0.006	Block
A ₂₅	0.18±0.009	Block
A ₂₆	0.27±0.014	Block
A ₂₇	0.30±0.015	Block
A ₂₈	0.07±0.004	Block
A ₂₉	0.14±0.007	Block
A ₃₀	0.17±0.009	Block
A ₃₁	0.42±0.021	Block
A ₃₂	0.36±0.018	Block
A ₃₃	0.10±0.005	Block
Mean	0.26±0.13	
Max	2.34±0.12	
Min	0.04±0.002	

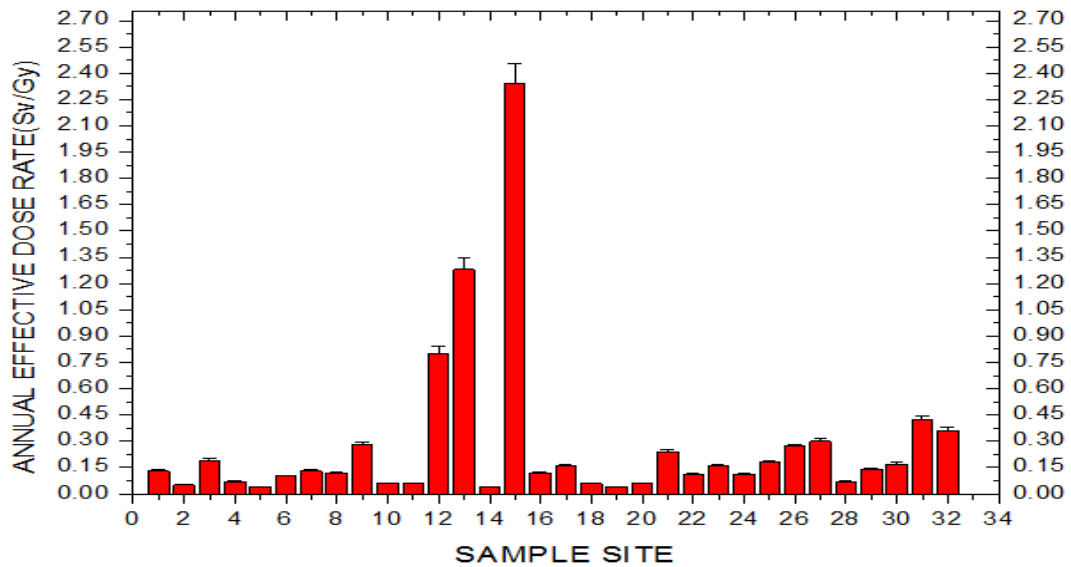


Figure 5.4: Measured annual effective dose rate for the selected samples of building materials of the research work

5.6 Gamma Index

Calculated values for the gamma index in these selected building materials ranges between a maximum value of $21.63 \pm 1.08 \text{mSvy}^{-1}$ to the minimum value of $0.28 \pm 0.014 \text{mSvy}^{-1}$. Using equation 4.8 for the calculation of Gamma index, the mean value observed in the research work was above world average figure of 1mSvy^{-1} , but below the acceptable safety value of 20mSvy^{-1} (UNSCEAR, 2000). Gamma index values from the building materials analyzed in the research work was presented. From table 5.6, the building materials from sample site number 15, only was reported to have a figure of $21.63 \pm 1.08 \text{mSvy}^{-1}$ which was more than the acceptable safety figures of 20mSvy^{-1} . Therefore building materials from Babadogo estate are safe, hence recommended as suitable building materials without posing any significant radiological risks to the general public.

Table 5.6: Gamma index for selected sample of building materials collected in Babadogo estate for the research work

Sample no.	Gamma Index(mSv/y)	Building materials
A ₁	2.00±0.10	Sand
A ₂	0.79±0.04	Sand
A ₃	2.96±0.15	Sand
A ₄	1.04±0.05	Sand
A ₅	0.63±0.03	Sand
A ₆	1.53±0.08	Sand
A ₇	2.03±0.10	Sand
A ₈	2.56±0.13	Sand
A ₉	3.75±0.18	Sand
A ₁₀	0.91±0.04	Sand
A ₁₁	0.88±0.44	Sand
A ₁₂	12.61±0.63	Sand
A ₁₃	19.77±0.99	Sand
A ₁₄	0.58±0.03	Sand
A ₁₅	21.63±1.08	Brick
A ₁₆	0.97±0.05	Brick
A ₁₇	1.34±0.07	Brick
A ₁₈	0.51±0.03	Brick

Sample no.	Gamma Index(mSv/y)	Building materials
A ₁₉	0.28±0.01	Brick
A ₂₀	0.48±0.02	Brick
A ₂₁	0.82±0.04	Brick
A ₂₂	1.83±0.09	Brick
A ₂₃	1.29±0.06	Brick
A ₂₄	0.92±0.05	Block
A ₂₅	1.52±0.08	Block
A ₂₆	2.13±0.11	Block
A ₂₇	2.35±0.12	Block
A ₂₈	0.57±0.03	Block
A ₂₉	1.10±0.06	Block
A ₃₀	1.35±0.07	Block
A ₃₁	3.37±0.17	Block
A ₃₂	2.87±0.14	Block
A ₃₃	0.87±0.04	Block
Min	2.98±0.15	
Max	21.63±1.08	
Mean	0.28±0.014	

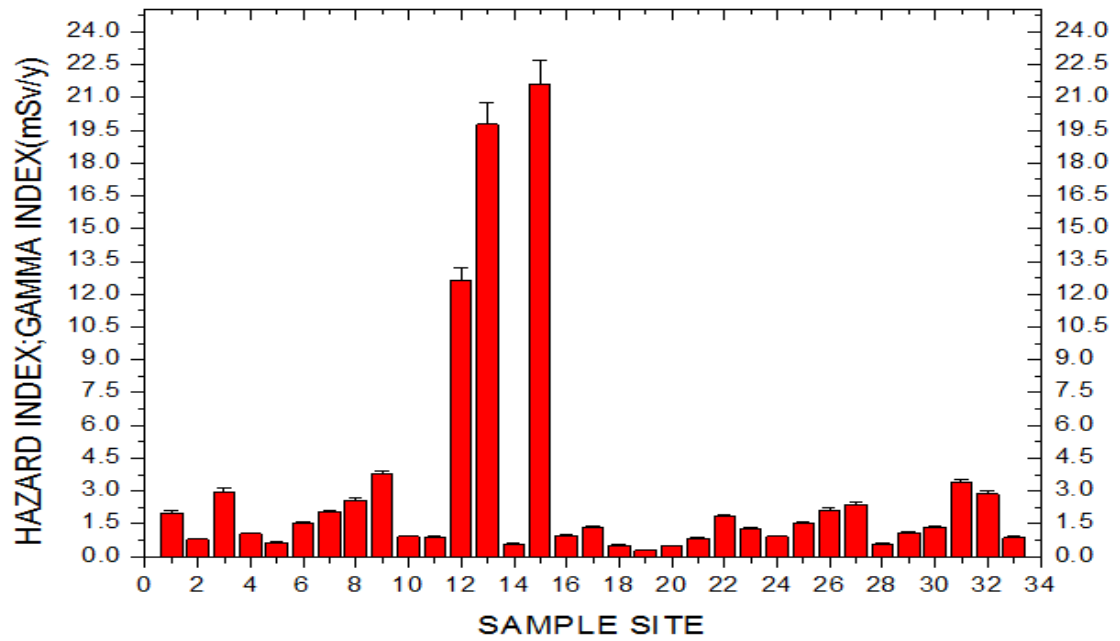


Figure 5.5: Gamma index for the building materials measured in this research work

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study aimed at measuring natural radioactivity levels for the naturally occurring radionuclides in building materials; sand, clay bricks, and concrete blocks used in Babadogo estate in Nairobi City County, Kenya using NaI(Tl) detector. Their corresponding gamma radiological parameters like ;the absorbed dose rate in air, annual effective dose, radium equivalent activities and hazard index(external) due to clay bricks, the sand and the concrete blocks have been calculated from activities and reported. The dominance of assessing the natural radioactivity levels as a prerequisite to estimate the radiological parameters for the purpose of evaluating the ionizing radiation health effects of human exposure to gamma radiation as a result of randomly sampled building materials. The gamma spectrometry technique was employed in measuring the radioactivity concentration of 33 samples collected randomly arising out of Babadogo estate in Nairobi City County, Kenya. Out of the study, the calculated range and the corresponding average values of the activity concentration for the potassium-40, uranium-238 and thorium-232 in building materials were found ;(55±3-2647±13) and 831±42(40±2-3602±80) and 378±19 and (6±1- 4213±210) and 290±15 Beckquerel/kilogram respectively. The study revealed that the average determined values for the samples; ^{40}K , ^{238}U and ^{232}Th were above and beyond the World average figures. The range as well as mean values of radium equivalent were calculated as (82±4-6170±308) and 866±43 Bq/kg .The range together with average values for

absorbed dose rate were found to be $(73 \pm 4 - 4777 \pm 239)$, $540 \pm 27 \text{ nGy.h}^{-1}$. The world average values of radium equivalent as well as absorbed dose are 370 Bq.kg^{-1} and 54 nGy.h^{-1} . From this study annual effective doses rate was ranging as $(0.04 \pm 0.002 - 2.34 \pm 0.117) \text{ mSvy}^{-1}$ and the mean value was $0.26 \pm 0.13 \text{ mSvy}^{-1}$ which was above and beyond the world's average value of 0.07 mSvy^{-1} but below the maximum dose constraint of 1 mSvy^{-1} to the public. The mean external hazard index value of $2.98 \pm 0.15 \text{ mSv/y}$ was calculated for these samples of building materials turned up to be less than the World safe limits of figure 20 mSv/y .

The study area is in the industrial areas (many industries) as well as residential estate. These calculated radiological parameter's data dispense a general background level for the area studied and may serve as a guideline for future measurements and assessments of viable radiological threat to human health in this estate.

6.2 Recommendations

The study was conducted using few building materials sampled randomly from construction sites in Bababadogo estate, Nairobi City County .It is therefore recommended that assessment of radioactivity concentration for, the samples with high values like A_{15} be done in regions where the building materials were originally collected. It is essential to evaluate the benefaction of each of these construction materials in order to ascertain the safety of the buildings in this study area. An epidemiological study on the effects of radiation on the workers in these construction sites is also recommended. This will help to ascertain who are likely to suffer from cancer related diseases.

It is recommended for a similar research to be extended to other counties with to ascertain the level of activity concentration and other radiological parameters.

The helpfulness of these radiological parameters that have been achieved during the study will be of great value to both the County Government of Nairobi as well as the National Government.

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APPENDIX I

Table A1:1 the probabilities of gamma rays emission for IAEA reference sample (IAEA, 2005)

Reference sample	Gamma-ray energy(keV)	Emission probability	Source nuclide
RGU-1	186	0.033	²²⁶ Ra
	242	0.074	²¹⁴ Bi
	295	0.187	²¹⁴ Pb
	352	0.358	²¹⁴ Pb
	609	0.446	²¹⁴ Bi
	1120	0.149	²¹⁴ Bi
	1765	0.123	²¹⁴ Bi
RGTH-1	238	0.450	²¹² Pb
	338	0.123	²²⁸ Ac
	583	0.307	²⁰⁸ Tl
	2615	0.360	²⁰⁸ Tl
RGMIX	1460	0.110	⁴⁰ K
	1765	0.161	²¹⁴ Bi
	2615	0.360	²⁰⁸ Tl

APPENDIX II Babadogo Estate

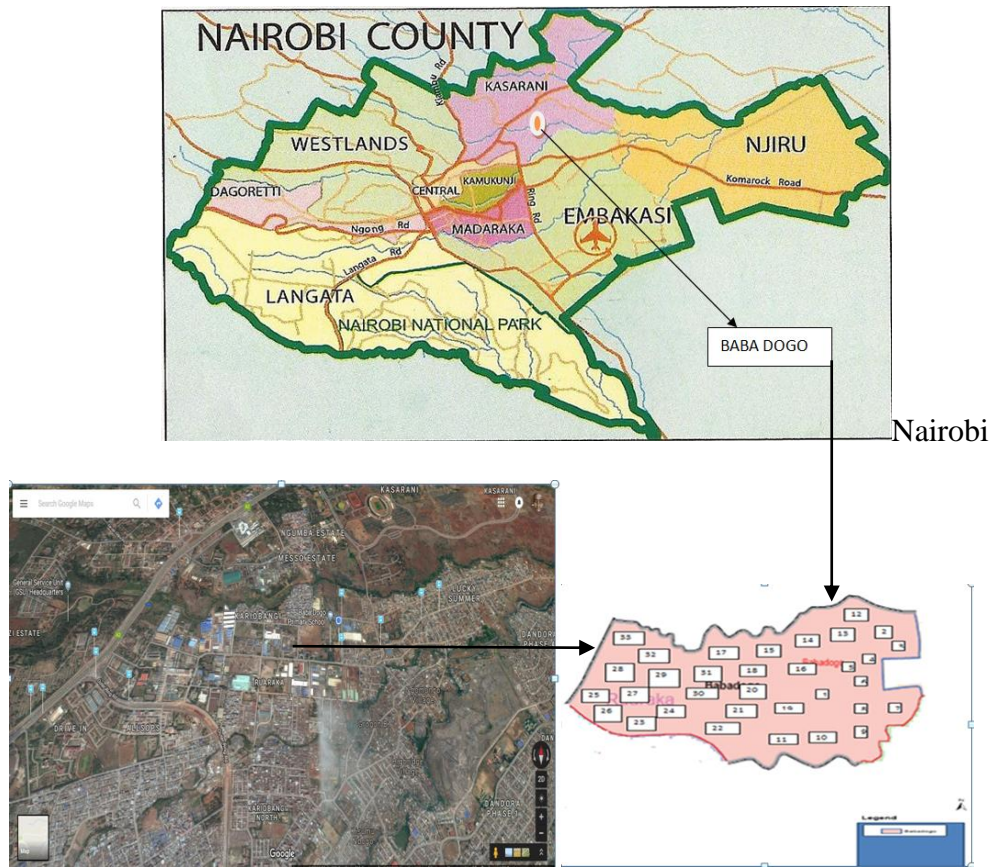


Figure A1: Map of Babadogo Estate in Ruaraka Area ,Nairobi County.

APPENDIX III: Building materials



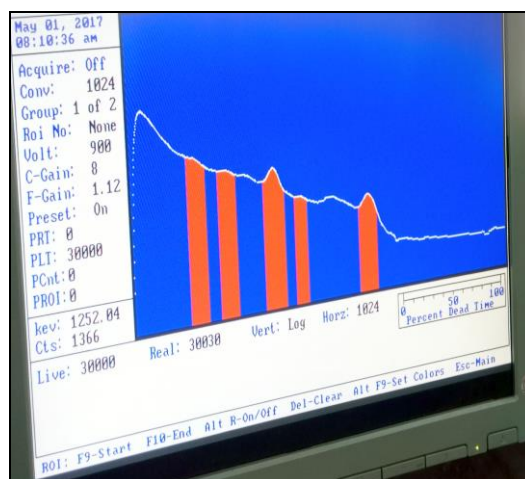
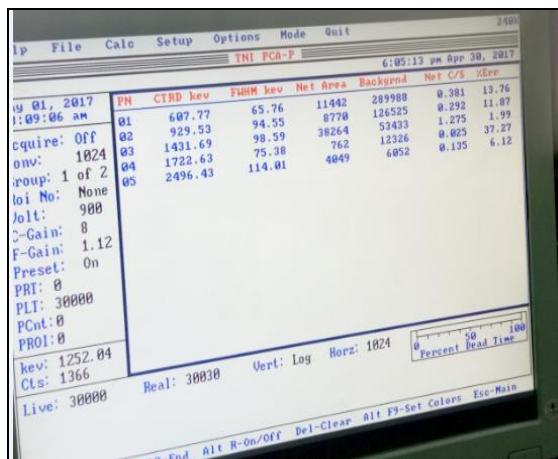
Figure A2: A photo of Sampling Building Materials in the Field

APPENDIX IV: Sample ready for Analysis



Figure A3. A photo of Sampled Building materials in Lab.2

APPENDIX V: Analyzed Data and Region of Interest.



Figurer A4 .A photo of Analyzed Data in Lab .2

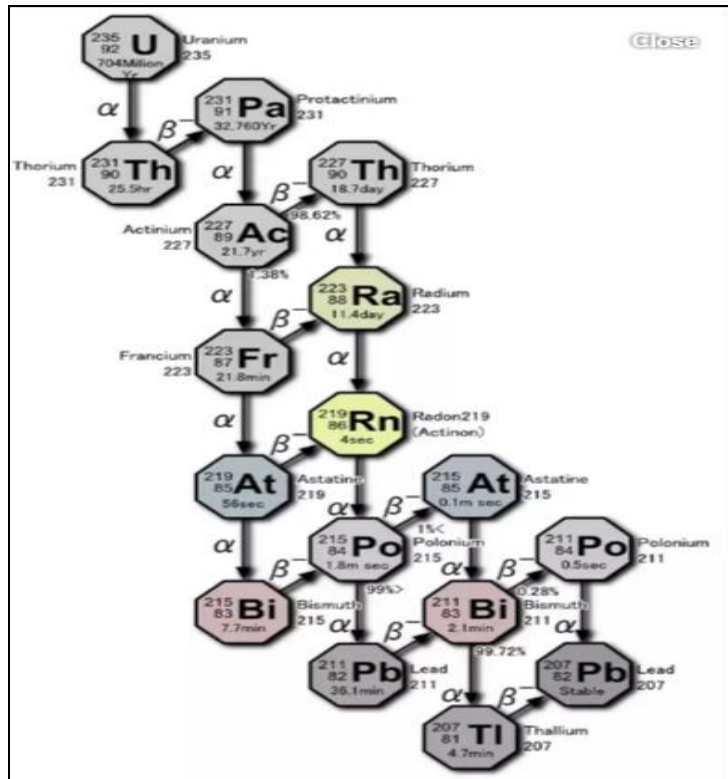
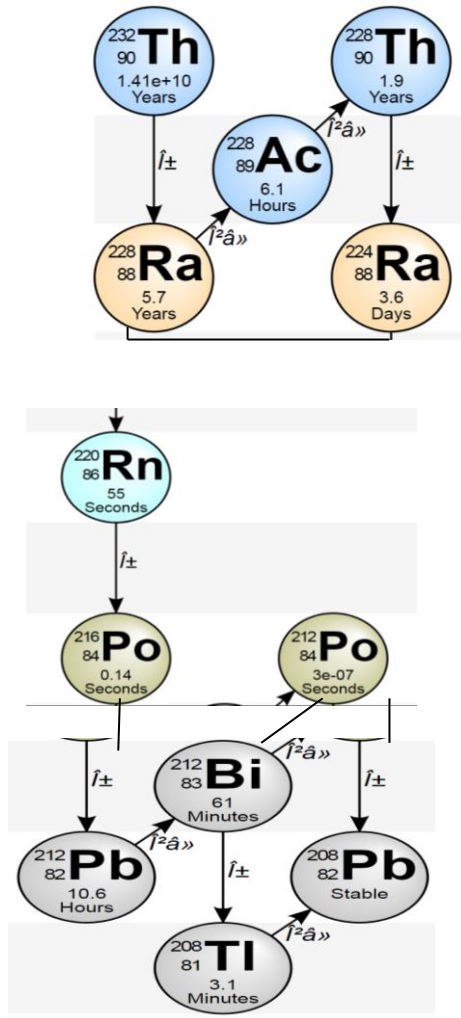
APPENDIX VI: ^{235}U Disintegration succession

Figure A5. ^{235}U disintegration succession (Glean, 2005)

APPENDIX VI: ^{232}Th Disintegration successionFigure A6. ^{232}Th disintegration succession (Glean, 2005)

APPENDIX VII: Endorsed radiation weighting factor, W_R **Table A2:** Radiation weighting factors (ICRP, 2000)

Radiation type	Radiation weighting factor W_R
Photons	1
Electrons	1
Protons	2
Alpha particles	20