CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND TO THE RESEACH

The human environment is the basis for any economic, social and cultural development. It is therefore important that its quality be maintained in a good state to ensure a high level of social performance, which can be achieved by closer monitoring of pollution factors (Avwiri and Ebeniro, 1998).

Radiation is everywhere in our environment. It is present in the soil, air, water, food and in the construction materials used to build houses. Natural radiation from outer space (cosmic radiation), the ground (terrestrial radiation) and even from within our body has always been an integral part of our environment. Radioactive emissions could contribute to the deleterious health effects among people living in areas of high level of radiation. Naturally occurring radionuclides contribute a major portion to the effective dose of the world wide population. Natural radionuclides in the soil generate a significant component of the background radiation exposure of the population (Merdanoglu and Altinsoy, 2006).

The increasing awareness on the harmful effects of nuclear radiation demands that all the sources of nuclear radiation must be monitored. Cosmic rays originate from the sun and the outer space. The gamma rays are emitted by naturally occurring radioactive elements in the earth's crust. The main radioactive elements in the earth's crust are isotope of ^{40}K, ^{238}U and ^{232}Th radioactive series. The half-lives of the above radioactive elements in the earth are very long and the magnitude of the dose received by an individual from these sources depends on the types of rocks and surrounding soil. The natural radioactivity in soils mainly comes from Uranium, Thorium decay series and Potassium (UNSCEAR, 2000).

Natural environmental radioactivity and the associated external exposure due to gamma radiation depend mainly on geological conditions and appear at different levels in the soil of each region in the world (UNSCEAR, 2000). Obviously, the actual level of radiation exposure due to the radionuclide contents of rocks and soil varies widely from place to place and the actual background contribution to the external gamma dose rate at a given location can be determined only by measurements. Thus, the dose rate depends on the geological location (Martino and Harbinson, 1972). The specific levels of terrestrial environmental activity concentrations are related to the composition of each lithologically separated area, and to the content of the rock from which the soil originate (Habshi, 1980). A number of human activities contribute to our natural radiation environment (Scholten and Timmermans, 2005).

Measurement of natural background radiation and radioactivity in soil has been carried out in many countries to establish the baseline data of natural radiation level (Mireles *et al*., 2003). Exposures to natural sources are in most cases not a matter for regulatory concern. However, there are situations where exposures to natural sources may warrant consideration as to whether controls should be applied or not. One such situation is where the conditions are conducive to the build-up of elevated concentrations of radon in air. Another situation is the mining and/or processing of material where the activity concentrations of radionuclides of natural origin in the material itself, or in any material arising from the process, are significantly elevated — such material has come to be referred to as **N**aturally **O**ccurring **R**adioactive **M**aterial (NORM) (IAEA, 2005).

A majority of people live in houses built with soil. Soil is an important environmental material used for making bricks and building houses. Naturally occurring radionuclides in building raw materials add to the indoor exposure (Shanthil *et al*., 2010). The noble gas ^{222}Rn is present in the soil and building materials. There has been an increasing interest in indoor radioactivity measurements motivated by the concern about the possible consequences of long-term exposure to higher concentration of ^{222}Rn and its progeny. Normally, indoor radon concentrations are considerably higher than outdoor radon concentrations. The radiation from radon and its daughter produces a risk of lung cancer by inhalation of air with high concentration of radon and those of its daughters over a long period of time (Jonsson, 1987).

It was considered imperative to develop a strategy to educate the general public on the health hazards due to high concentration of indoor radon. For this purpose, data were required about the present level of radon awareness of the population so as to introduce a comprehensive strategy for public education.

1.2 RESEARCH PROBLEMS

The principal adverse health effect from the inhalation of radon and mainly its progenies is lung cancer (ICRP, 1993). The problem of indoor radon has lead to the increase in radon investigations in dwellings all over the world.

In Nigeria, interest on environmental radiation started in the 1960's after nuclear weapon test were reported in the Sahara desert. In 1964, the Federal Radiation Protection Service (FRPS) was set up in the Physics Department of the University of Ibadan. Since the establishment, considerable researches have been carried out on the distribution and movement of radioisotopes in soils and other environmental samples (Farai and Jibiri, 2000; Farai and Jibiri, 2013; Farai and Sanni, 1992; Jibiri and Emelue, 2008; Obed *et al*., 2005; Obed *et al*., 2010; Obed *et al*., 2011a; Obed *et al*., 2011b).

Such research activities have contributed immensely to the knowledge on radiation level in our environment. However, research activities on radon concentrations are few and data on radon concentrations in houses are very sparse. This has led to little or no awareness of the populace of the area about the radon and its health hazards. Thus, there is need for further research activities on indoor radon to determine the factors that influence the level of indoor radon and the effects of such factors on the indoor radon concentration. A survey of background radiation in Iwo community predominantly underlain by basement complex rocks which could be high in radionuclide content, to yield data that may be used to assess the health effects on the population is very important.

1.3 JUSTIFICATION OF THE RESEARCH

Radon is a colourless, odourless and chemically inert radioactive gas existing in various concentrations throughout the world. Amongst the decay series products, radon is an important source of the natural radiation. It is estimated that 50-55 % of the average annual dose from natural background radiation is contributed by ^{222}Rn alone (Matiullah *et al*., 1993b). The majority of developed countries have carried out radon surveys over the

last two decades (UNSCEAR, 2000). All such survey programmes have been motivated by workers that confirmed a relationship between the exposure of dwellers of high indoor radon concentration and health hazards such as lung cancer risk (Khokhar, 2006).

According to the National Academy of Science and the National Cancer Institute (USA), radon is the second most common cause of lung cancer after cigarette smoking, accounting to 15,000 to 22,000 cancer deaths per year in the USA alone (http://en.wikipedia.org/wiki/gammaspectroscopy.htm). It is known that radon exhaled from building materials and soil can accumulate indoors to a concentration of up to thousands of Becquerel per cubic metre. This means that some members of the population may be exposed to radon concentrations comparable to those found in mines (BEIR VI, 1999).

It has recently been clearly recognised that the elevated levels of ^{222}Rn could be present in certain types of human dwellings. Under specific conditions such as houses existing in the uranium mining environment, the lung dose arising from the inhalation of ^{222}Rn daughters can be sufficiently high as to cause an increase in lung cancer occurrence. An average person spends more than 80 % of time indoors (UNSCEAR, 1993). Due to this, the control of the levels of ^{222}Rn concentration in the different geographic areas where human activities are developed is important.

Keeping in view the possible health hazards for the dwellers owing to indoor radon concentration, it is essential to bring awareness to the general public to avoid its harmful effects. This purpose can be achieved by carrying out radon awareness surveys and measurements in urban and rural areas. Such surveys had been conducted in many parts of the world (Ford *et al*., 1996; Wang *et al*., 2000 and Farid, 1992). The results of this survey can be taken to represent base line information for future reference and research for the purpose of introduction of safety regulations to avoid indoor radon associated health hazards in Iwo.

1.4 AIM AND OBJECTIVES OF THE STUDY

The aim of this work is to carry out radon awareness survey, measurements of indoor radon concentrations and terrestrial gamma dose rates for estimating cancer risk in Iwo, Osun State, Nigeria.

The main objectives of this study are to:

i. conduct a radon survey, in order to assess the degree of radon awareness in the general public.
ii. determine the indoor radon concentrations.
iii. determine outdoor activity concentrations of ^{226}Ra,^{232}Th and ^{40}K in surface soil and rock samples.
iv. evaluate the radiological hazards indices.
v. estimate the excess lifetime cancer risk, morbidity and mortality due to cancer risk.

CHAPTER TWO

LITERATURE REVIEW

2.1 THEORETICAL BACKGROUND

The level of natural background radiation varies depending on location. In background radiation, naturally occurring sources are responsible for the vast majority of radiation exposure. The main natural sources of radiation are radon, cosmic rays, gamma radiation from rocks and soil, radioactive nuclides in food and drinks. Natural background of ionizing radiation, which constitute 80 % of the sources of ionizing radiation come from four primary sources – cosmic radiation, solar radiation, external terrestrial sources and radon. Natural radiation involves the entire population of the world and has been experienced at relatively constant rate for a long time. Natural radiation and radioactivity in the environment provides the major source of collective human exposure to all sources of ionizing radiation (NCRP 45, 1975).

Terrestrial radiation is the radiation emitted by elements that occur naturally in the earth's crust. The dose rate resulting from terrestrial radiation depends on the geological formations of the subsoil and therefore varies from one location to another. Sources of terrestrial radiation include water, rocks, and elements such as: Thorium, Radium, Uranium. Terrestrial radiation is of two main types: Primordial radionuclide and cosmogenic radionuclide (e.g ^{14}C, ^{2}H, ^{22}Na and ^{7}Be).

Cosmic ray is the term given to high energy radiation which strikes the Earth from space. Primary cosmic radiations are galactic cosmic rays generated outside the solar system and solar cosmic rays produced by the sun. The radiation originating from outer space and the sun is called cosmic radiation and contributes about 15 % of the background radiation level on earth and a greater part is due to radon.

Cosmic radiation is a complex mixture of charged and neutral particles, some of them generated when primary particles from space interact with the earth's atmosphere. This radiation primarily consist of positively charged ions and larger nuclei sources outside our solar system. This radiation interact with atoms in the atmosphere to create secondary radiation, including X-rays, muons, protons, alpha particles, pions, electrons and neutrons. Solar particle events are rare occurrences that can result in higher exposures for short periods of time. The earth and all living things in it are constantly bombarded by radiation from outer space. Cosmic rays interact with the upper atmosphere of the earth and produce showers of lower energy particles most of which are absorbed by the earth's atmosphere. The Earth's atmosphere offers considerable protection from cosmic radiation, such that at ground level only small exposures occur.

The intensity of cosmic radiation increases with altitude, indicating that it comes from outer space. The amount of cosmic radiation of an area increases as the elevation increases. Cosmic radiation is much more intense in the upper troposphere and varies in different parts of the world based largely on the geomagnetic field and altitude. Cities located at high altitudes receive more dose of cosmic radiation. The actual radiation level is influenced by a number of factors, most importantly through the shielding provided by the earth's atmosphere (UNSCEAR, 1988).

As altitude increases during flight, there is an initial lowering of the exposure to cosmic radiation due to the reduction of the terrestrial component of background radiation. As altitude increases further, the cosmic radiation component increases and can exceed the initial radiation exposure at ground level. Exposures increase further as the flight path is away from the equator. It changes with latitude, indicating that it consists at least partly of charged particles which are affected by the earth's magnetic field. Individually the cosmic ray ions are much faster and more energetic than those trapped in the Earth's field. The world average background dose for a human being is about 2.4 mSv yr^{-1} from cosmic radiation and natural radionuclide in the environment (ICRP, 2007).

Primordial radionuclides are radionuclides that originated with other (stable) nuclei in the course of cosmic nucleogenesis by thermonuclear reactions in the core of a star, which then exploded as a supernova and enriched the nucleus cloud from which the sun and the solar system was formed about 4-5 billion years ago. The primordial radionuclide

include ^{40}K, ^{232}Th, ^{238}U, ^{235}U, ^{226}Ra and ^{222}Rn. These are radionuclides that contribute a lot to environmental radiation and are the members of natural radioactive series ^{238}U, ^{232}Th and ^{40}K. This is part of the natural radiation that originates from radioactive rocks and radioactive isotopes occurring in the soil (Szabo, 1993). The primordial radionuclides are present in rocks and minerals in concentration that can vary by several magnitudes depending on the geochemical processes to which the material they come from have been subjected**.**

Human activities such as mining and mineral ore processing result to an enhanced radioactivity in the environment. Inadequate disposal of the tailings further enhances the spread of radiation. (Jwanbot and Ike, 1999). Agents like erosion, weathering and leaching affect the spread and migration of the radioactivity of the environment. The major radionuclides of concern for terrestrial radiation are common elements with low abundance radioactive isotope e.g. potassium and carbon or rare but intensely radioactive elements e.g. Uranium, Thorium, Radium and Radon. Most of these sources have been decreasing, due to radioactive decay since the formation of the earth. People living in granite areas or on mineralized sands receive more terrestrial radiation than others (Solomon *et al*., 2002; Khademi *et al*., 1980).

In addition to the cosmic and terrestrial sources, all people also have radioactive ^{40}K, ^{14}C, ^{210}Pb and other isotopes inside their bodies from birth. The variation in dose from one person to another is not as great as the variation in dose from cosmic and terrestrial sources as shown in Table 2.1.

2.2 RADON

Radon cannot be detected with human senses. It is moderately soluble in water and can be absorbed by water flowing through rock and sand containing radon. Its solubility depends on the water temperature, the colder the temperature of water the greater the radon's solubility (EPA, 1987). Radon has the highest gas density of about 9.96 kg m^{-3} and is about seven times heavier than air. Being a noble gas, it has greater ability to migrate freely through soil, air, etc. (Matiullah *et al*., 1993a).

Table 2.1: Average radiation dose from natural sources

Source	Worldwide average annual effective dose (mSv)	Typical range (mSv)
EXTERNAL EXPOSURES		
Cosmic rays	0.4	0.3 – 1.0
Terrestrial gamma rays	0.5	0.3 – 0.6
INTERNAL EXPOSURES		
Inhalation (mainly radon)	1.2	0.2 - 10
Ingestion (food, drinking-water)	0.3	0.2 - 0.8
Total	2.4	1 - 10

(Source: UNSCEAR, 2000)

Radon has three important isotopes. These are: (1) ^{222}Rn (called radon, belongs to ^{238}U decay series); (2) ^{220}Rn (called thoron, belongs to ^{232}Th decay series); (3) ^{219}Rn (called actinon, belongs to ^{235}U decay series). Scientifically, radon is known to be ^{222}Rn, the most abundant isotope of the element radon. Radon-219 has a relatively low abundance in the earth's crust, only about 0.7 %, and has the shortest half-life of about 4 seconds. Because of its very short half-life, ^{219}Rn usually disappears soon after its production. Radon-220 is also not able to travel far (i.e. decays before reaching the earth's surface due to its-short half-life of 55.5 seconds), and can often be eliminated from the monitoring system by introducing filters or other delaying techniques. The most important isotope of radon is ^{222}Rn. Its half-life is 3.82 days and can move substantial distances from its point of origin (Obed *at el.*, 2011b). Hence ^{222}Rn is generally considered as a health hazard when estimating risk factors from exposure to radon.

2.2.1 RADON DAUGHTERS

Generally, radon is considered to have no immediate health effects. Its short- lived daughter products are responsible for the main health risk. The immediate, promptly decaying daughter of ^{222}Rn (^{218}Po, ^{214}Pb, ^{214}Bi, ^{214}Po), being chemically more reactive, may get attached to surfaces (attached fraction), typically of aerosols, which can be inhaled and deposited in the nose or the pharynx (3 % chance of adhering to the lung lining); the unattached fraction (free ions) have a high probability (50 %) of settling on the surface of bronchi (Connell, 2005). Since the longest lived, ^{214}Pb, has a half-life of less than 27 minutes, the whole sequence of decays is completed before the normal clearance processes of the lung can sweep them away. As a result, the sensitive surfaces of the bronchi are irradiated by these decays, the most energetic destructive of which are the heaviest ionizing short-range alpha particles from the polonium isotopes ^{214}Po and ^{218}Po. A third alpha-active polonium isotope ^{210}Po contributes relatively little because its decay requires the prior decay of ^{210}Pb having 22-years half-life (Metters, 1992). The radon decay chart is shown in Fig. 2.1.

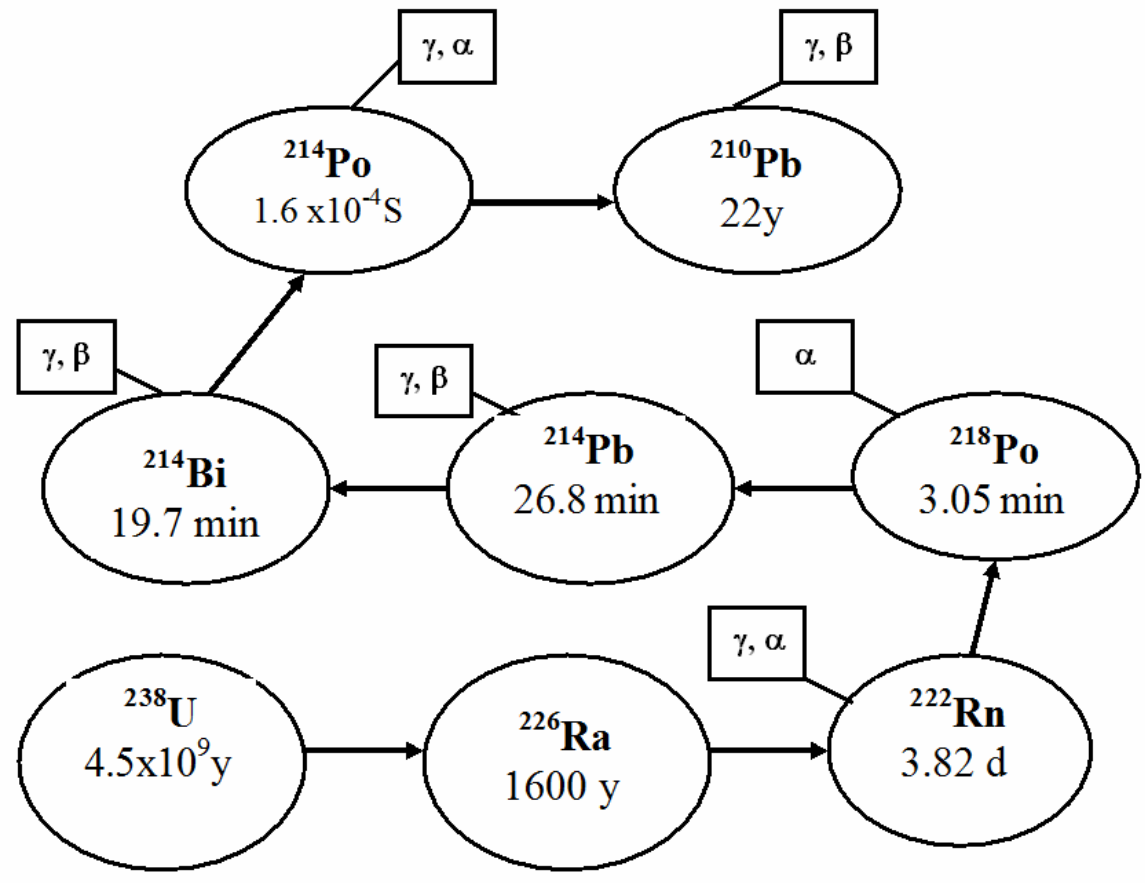

Figure 2.1: Radon decay chart

(Source: EPA, 1994)

2.3 INDOOR RADON PATHWAYS

Radon is directly produced from radium in the ^{238}U decay series which is found everywhere in varying trace amounts in the earth's crust, therefore the major contributor to the indoor radon concentration is the soil beneath the house (Kerry, 1982). This phenomenon provides a partial explanation for the observed higher radon levels in basements and on ground floors as compared to upper stories. The other key factor may be normal air circulation patterns. Building materials generally contribute fairly little to the total indoor radon concentration, except when the radium content in it is above the normal values. All building materials are derived from soil and rocks that contain trace amount of radioactive nuclides occurring in the earth's crust.

Radon in outdoor air may also enter a structure as the air is exchanged. This input is usually more than balanced by the loss of radon of the outdoors (since indoor air concentrations are usually higher than those outside the structure). The other source of radon entry into a building is natural gas usage. However, this source is usually very small in comparison with the others. Characterization of the indoor source of radon requires consideration of the rate at which radon is generated in the source materials and its modes of transport through various materials.

Many of the building materials such as bricks, wallboard or concrete are sufficiently porous and allow the radon to enter into the indoor air. Consequently radon concentrations in dwellings partly depend on construction practices and materials used. Where water is in direct contact with mineral particles that contain radium, radon can be implanted in water by alpha recoil (Akerblom, 1994). When ground water passes through soil and rocks containing significant amount of radon gas, it can be dissolved and then transported by the water. When radon-containing water is heated or aerated, a large part of the dissolved radon is released. The risk associated with radon in drinking water is usually not considered to be great despite the high concentration sometimes found. The most significant dose arising from radon in potable water is a result of inhalation of radon released from the water (Suomela and Kahlos, 1972), as opposed to doses to the stomach from drinking water. Fortunately, not all the radon produced from radium in the soil and building materials can migrate and enter in to the home. Some of the radon atoms are trapped within the grains of soil and are not able to escape (Semkow, 1990). From the un-

trapped radon atoms, some are absorbed in ground water and some diffuse through the soil. Besides some other parameters, the radon concentration in soil gases and dwellings mainly depend on the emanation and exhalation rate of radon, respectively.

2.4 MECHANISM OF LUNG CANCER INDUCTION

The radioactive daughters disintegrate, emitting alpha particles, beta particles and gamma rays. For internal radiation dosimetry, only alpha particles are important, because of the longer range and lower biological effectiveness of gamma rays and beta particles, as compared to those of alpha particles, their dose equivalent to the lung tissue is negligible. Most dust particles that deposit in the bronchi are eventually cleared (removed) by mucus, but not quickly enough to keep the bronchial epithelium from being exposed to alpha particles from the decay of ^{218}Po and ^{214}Po. Although they cannot travel far, alpha particles produced in the lungs can damage sensitive cells. This highly ionizing radiation passes through and delivers radiation doses to several types of lung cells. An alpha particle that penetrates the epithelial cells can deposit enough energy in a cell to kill or to transform it. The transformed cell, alone or through interaction with some other agent, has the potential to develop eventually into a lung cancer (EPA, 1987; Khan, 1991).

2.5 RADON MEASUREMENTS

Radon can be measured over different time periods ranging from two days to a year. Tests are categorized as either short-term or long-term depending upon the number of days the devices are used. A short-term test is the quickest way to test for radon. In this test, the device remains in an area (e.g., school's room) for a period of 2 to 90 days depending on devices, such as: activated charcoal devices, alpha track detectors, electric-ion chamber, continuous monitors or charcoal liquid scintillation detectors (Obed *at el.*, 2011b). The detection of radon can thus be performed directly on radon itself or indirectly on radon and its daughters. Radon and several of its daughters decay by emitting α−particles. ^{214}Pb, ^{214}Bi, ^{210}Pb and ^{210}Bi are also β-emitters and γ−rays accompany their β−emissions. Accordingly, radon detection can be performed through α, β or γ radiation detection (Obed *at el.*, 2011b).

There are several techniques for the measurement of radon concentrations and its progenies which can be broadly divided into two major classes:

a. Active method

b. Passive method

Radon monitoring devices can be classified into four categories

i. Envelope or bare detector samplers

ii. Diffusion samplers

iii. Permeation samplers

iv. Radon collector samplers

2.5.1 ACTIVE METHOD

This method requires active devices to determine the level of radon concentrations. These active devices need to power the electronics instruments for signal processing. They have the capability to integrate and record a new result hourly.

Examples of active devices use to measure indoor radon concentrations are:

a. Continuous radon monitor devices

b. Grab radon sampling

c. Pump/collapsible bag devices (PB)

d. Three-day integrating evacuated scintillation cells (Sc)

A. CONTINUOUS RADON MONITOR

The First Type: - This type operates on ambient air which is sampled for radon in a scintillation cell after passing through a filter that removes radon decay products and dust. As the radon in the cell decays, the radon decay products plate out on the interior surface of the scintillation cell. Alpha particles produced by subsequent decays or initial radon decay, strike the Zinc sulphide coating on the inside of the scintillation cell, thereby

producing scintillations. The scintillations are detected by a photomultiplier tube in the detector which generates electrical pulses. These pulses are processed by the detector electronics and the data are usually stored in the memory of the monitor where results are available for recall or transmission to a data logger or printer.

This type uses either in flow –through cell in which air is drawn continuously through the cell by small pump, and in periodic-full all in which air is drawn into the cell once during each pre-selected time interval, then the scintillations are counted and the cycle is repeated.

The Second Type: - This type operates on ionization chamber. Radon in the ambient air diffuses into the chamber through a filtered area so that the radon concentration in the chamber follows the radon concentration in the ambient air with some small time lag. Within the chamber, alpha particles emitted during the decay of radon atoms produces burst of ions which are recorded as individual electrical pulses each disintegration. These pulses are processed by the monitor electronics the number of pulses counted is displaced usually on the monitor and the data are available usually for processing by an optional data logger/printer.

The Third Type: - This type functions by allowing ambient air to diffuse through a filter into a detection chamber. As the radon decays, the alpha particles are counted using a solid-state silicon detector. The measured radon concentration in the chamber follows the radon concentration in the ambient air by a small time lag.

B. GRAB RADON SAMPLING (GB, GC, GS)

There are three grab radon sampling methods, with three different types of device. The devices are:

i. Grab radon/Scintillation cell (GS)

ii. Grab/activated charcoal (GC)

iii. Grab radon pump/collapsible Bag (GB)

Grab radon/Scintillation Cell (GS):- This uses a sample of air which is drawn into and sealed in a flask or cell that has a zinc sulphide phosphorous coating on its interior surfaces. One surface of the cell is fitted with a clear window that is put in contact with a photomultiplier tube to count light pulses (scintillations) resulting from alpha disintegration from the air sample interacting with the zinc sulphide coating. The number of pulses is proportional to the radon concentration in the cell. The cell is counted about four hours after filling to allow the short lived radon decay products to reach equilibrium with radon. After the cells are placed in the counters the counting system would be allowed to dark–adapt for two minutes. Correction factors are applied to the counting results to compensate for decay during the time between collection and counting and for decay during counting, if the counting time is long, greater than one hour. Air is pumped continuously through a flow-through-type scintillation cell for just a few minutes. Alpha particles resulting from the decay of radon gas and decay products are counted as the gas is swept through.

Grab/activated Charcoal (GC):- This uses air pumped through activated charcoal to collect the sample. A charcoal –filled cartridge is placed into a sampler and air is pumped through the carbon cartridge. The pump with a charcoal cartridge is not flow dependent but must remain operational at the sampling location until the charcoal collects enough radon to be in equilibrium with the radon at the sampling location. The cartridge must be weighted prior and after sampling, in order to collect for the reduced sensitivity of the charcoal due to adsorbed water. The cartridges are analysed by placing them on sodium iodide gamma scintillation system or a germanium gamma detector.

Grab radon pump/collapsible Bag (GB):- This uses of Pump/collapsible Bag (GB) is the older and simpler methods of marking an integrated measurement of the concentration of radon over a period of time is to collect a sample of ambient air in a radon proof container over the desired sampling time period and measure the resulting radon concentration in the container.

One practical method is to use a small pump with a very low and uniform flow rate to pump ambient air into an inflatable and collapsible radon-proof bag. After the desired sampling period (typically 24 hours), the concentration of radon in the bag can be analysed by any of the standard methods using appropriate radon decay correction factors. For this

method the counting system should be allowed to dark-adapt for two minutes after the cells are placed in the counters.

The main purpose of the collapsible bag is to avoid variation in pump flow rate due to build up of back pressure in a container. Bags that have been measured to have a very low loss of radon by diffusion through the bag have been made of laminated mylar, aluminized laminated mylar, and Tedlar. The pump flow rate is not critical as long as it is suitable for the size of the bag and the sample duration, but variation of the flow rate over the collection time period of the sample will affect the accuracy of the measurement. A number of suitable battery and/or charger operated pumps with controlled flow rates are available commercially.

Although, this method accumulates radon over period of time for subsequent analysis, it should not be considered a true integrating method. Radon peaks occurring early in the sampling period will leave less radon for analysis than the same size peak-occurring towards the end of the sampling period.

C. PUMP/COLLAPSIBLE BAG DEVICES (PB)

This method uses the same technology for pump/collapsible bay (GB). The only different is that, the bag is filled over a much shorter collection period in GB than in the PB method.

D. THREE-DAY INTEGRATING EVACUATED SCINTILLATION CELLS (SC)

This method typically uses Lucas-type scintillation cells that have been out fitted with a restricted valve attached to the main valve, samples are collected by opening the value on an evacuated cell. The restricted valve is set so that the cell fills from mercury (Hg) vacuum to above 80 % of its capacity over a three-day period. At the end of the measurement period, the value is closed and returned to the analysis laboratory. Since the volume of the cell is known, the exact volume of the filtered air collected over the three day measurement period can be calculated from the vacuum gauge reading at the end of the sampling period.

The sample is analysed on an alpha scintillation counter. Prior to counting, the pressure in the cell is brought to one atmosphere by adding radon-free (aged) air so that the sample is analysed under the same conditions that prevailed during calibration of the cell. In order to allow radon and radon decay products to grow into equilibrium and to allow any radon decay products that may have been collected to decay, the sample should be counted no sooner than four hours after the end of the measurement period. After the cells are placed in the counters, the counting system should be allowed to dark-adapt for two minutes.

During the three-day sampling period, some of the radon that has been collected decays. The mid-point of the sampling period cannot be used for the decay correction factor because the air flows into the cells greater during the initial time of sampling. The fraction of radon that decays must therefore be calculated from the shape of a plot of percent fill versus time. This must be measured for each cell. This factor should be applied as a correction during data reduction. Since this method accumulates radon over a period of time for subsequent analysis, it is not a true integrating method. Radon peaks occurring early in sampling period will leave less radon for analysis them the same size peak occurring towards the end of the sampling period.

2.5.2 PASSIVE METHOD

This method requires passive devices to measure indoor radon concentrations. These passive devices do not need any bulk electronics; for signal processing or any power source to function. They are integrating detectors and can be used to determine the average radon concentration in the working environment where the device is located during the measurement period. Examples of passive devices in measuring indoor radon concentration are:

a. Activated Charcoal Adsorption Devices

b. Electrets – Passive Environment Radon Monitor (E-PERM)

c. Solid State Nuclear Track Detector (SSNTD)

A. ACTIVATED CHARCOAL ADSORPTION DEVICES (ACS)

These are passive devices requiring no power to function. The passive nature of the activated charcoal allows continual adsorption and desorption of radon. During the measurement period (typically two to seven day) the adsorbed radon undergoes radioactive decay. The technique does not integrate uniformly radon concentrations during the exposure period.

As with all devices that store radon, the average concentration calculated using the mid-exposure time is subjected to error if the ambient radon concentration varies substantially during the measurement period.

A device used commonly by several groups consists of a circular, 6 -10 m diameter container that is approximately 2.5 cm deep and filled with 25 g to 100 g of activated charcoal. One side of the container is fitted with a screen that keeps the charcoal in, but allows air to diffuse into the charcoal. In some cases, charcoal container has a diffusion barrier over the opening. For longer exposure, this barrier improves the uniformity of response to variations of radon concentration with time. Desiccant is also incorporated in some containers to reduce interference from moisture adsorption during longer exposures.

Another variation of the charcoal container has charcoal package inside a sealed bag allowing the radon to diffuse through the bag. All ACs are sealed with a radon-proof cover or outer container after preparation.

The measurement is initiated by removing the cover to allow radon-laden air to diffuse into the charcoal bed where the radon is adsorbed onto the charcoal. At the end of a measurement period, the device is resealed securely and returned to a laboratory for analysis. The detector should be analysed at least 3 hours after the end of sampling to allow for in growth of decay product.

In the laboratory, the ACs are analysed for radon decay products by placing the charcoal, still in its container directly on a gamma detector. The exposed devices are performed using a sodium iodide gamma scintillation detector to count the gamma rays emitted by the radon decay products on the charcoal. The detector may be used in conjunction with a multi-channel gamma spectrometer or with a single-channel analyzer with the window set to include the appropriate gamma energy window. The detector

system and detector geometry must be the same used to derive the calibration factors for the device.

B. ELECTRETS-PASSIVE ENVIRONMENT RADON MONITOR (E-PERM)

E-PERMs are passive devices requiring no power to function. They are integrating detectors and can be used to determine the average radon concentration in the working environment where the device is located during the measurement period. The E-Perm electrets radon chamber consists of a plastic shell which has a spring-loaded plastic cap and a replaceable holder at the bottom which holds the electrets.

The electrets is removable plastic disc has a Teflon surface which has fixed voltage induced on it. When the E-perm sampler is open radon gas will diffuse into the shell through small holes at the top and particulate, radon progeny will be trapped by the filter. The negative ions released during the nuclear decay of radon gas will move to the surface of the electret causing a reduction in its surface voltage. The amount of voltage reduction is directly related to the time integrated average concentration to which the electrets were exposed.

Sampling Procedure

The measurement should not be made if the occupant is planning re-modelIing, making changes in the heating, ventilation, air conditioning system; or performing either modification that may influence the radon concentration during the measurement period. The E-PERM should not be deployed if the occupant's schedule prohibits terminating the measurement at the time selected for returning it to the laboratory. The building should be closed, with all windows and external doors shut (except for normal entrance and exist) for at least 12 hours prior to and during the sampling period.

E-PERMS should be deployed unto workplaces as soon as possible after their initial voltage is measured. Until an E-PERM is deployed its electrets cover should remain in place over the electrets to minimize back ground effects. During the measurement period, the E-PERM must not be disturbed. It should not be placed near draft caused by high volume air conditioning vents windows and doors. Avoid location near excessive heat such as direct strong sunlight. The E-PERM should be placed flat on a shelf or table at least 50 cm above floor level and with the detector's top face at least 10 cm from objects.

Nothing should impede air flow around the E-PERM. The E-PERM should not be placed close to the outside walls of the building. After sampling is completed, E-PERM should be wrapped from top to bottom with a sample seal.

Before using an E-PERM in the field, the initial voltage must be taken. If an initial voltage is less than 200 volts, the E-PERM must be discarded. Place the Closed E-PERM should be placed into the circular electrets receptacle on the read out instrument and rotate the E-perm in the electrets reader to assure that it is well seated in the receptacle. The shutter should be open and close repeatedly until the same voltage reading appears twice in sequence. The twice repeated voltage observed in this sequence is the true electrets blank voltage. The voltage must be between -001 and +001 volts before reading is taken. If not, re-seat the E-PERM and re-read the voltage.

C. SOLID STATE NUCLEAR TRACK DETECTOR (SSNTD)

Solid State Nuclear Track Detectors (SSNTDs), which are also known as etched track detectors, Alpha Track Detector (ATD) or Dielectric Track Detectors (DTD), are a sample of solid materials (photographic emulsion, crystal, glass or plastic) exposed to nuclear radiation, in which the damage can be created in the solid along the path of a heavily ionizing particle such as an alpha particle or a fission fragment. The damage along the path, called a track, may become visible under an ordinary optical microscope after etching. Etching is usually performed in solutions of caustic alkalis such as sodium hydroxide, often at elevated temperatures for several hours. The visible tracks are counted either by direct observation using an optical microscope or with the help of automated counter. If the particles enter the detector's surface at normal incidence, the pits are circular; otherwise elliptical.

Material commonly used to measure radon concentration in SSNTD that register alpha tracks are:

i. Cellulose Nitrate
ii. Poly-Allyl Diglycol Carbonate (PADC) - CR-39

i. UNFILTERED TRACK (UT) DETECTOR

This a piece of cellulose nitrate film package in a shielded container. Alpha particles emitted by radon and its decay products in air strike the detector and produce sub microscopic damage tracks. Cellulose nitrate is sensitive to alpha energies between 1.5 MeV and 4.8 MeV. It is not sensitive to radon decay products that plate out on the detector since their energies are above 5 MeV. Detectors are placed in a caustic solution that accentuates the damage tracks so they can be counted using a microscope or an automatic spark counter.

ii. POLY-ALLYL DIGLYCOL CARBONATE (PADC)

This is also known as Tastrak, which is commercially marketed as Columbia Resin 39 (CR-39). It is clear colourless, rigid plastic of density 1.3 g cm^{-3} with the chemical formula $C_{12}H_{18}O_7$. This material is commonly used in SSNTDS to measure radon concentration.

The CR-39 plastic detector is sensitive to alpha energy up to 40 MeV, which in quite large compared to the other detector commonly used for radon measurement, because charged particles come to the detector with large energy and their tracks have different diameters. CR-39 can register alpha particle tracks from the decays of radon and its daughter products. CR-39 detectors function as true integrators and measure the average concentration over the exposed period. The main advantages of SSNTD over other radiation detectors are the detailed information available on individual particles, the persistence of the tracks a allowing measurements to be made over a long periods of time, and the simple, cheap, small size, easy to use and robust construction of the detectors. They are widely used in different scientific disciplines.

2.5.3 CHEMICAL ETCHING

This is the most common method used for enlarging the size of the latent tracks produced by heavily ionizing particles. Chemical etching is usually carried out in a thermostatically controlled bath at temperatures ranging from 30 ^{0}C to 90 ^{0}C. The etching time is 2-16 h. Different etchants are used for different detectors. The etchants which have been most commonly used are aqueous alkaline solution of NaOH and KOH with concentrations of 1 to 12 M. The size of track depends upon the concentration of etching

solution, etching time and temperature. In order to etch the detectors, an elastic spring (holding many detectors) is attached to a wire and immersed into the etching solution within a beaker. The top of the beaker is covered with a glass lid to avoid evaporation. The beaker is then placed in a temperature controlled water bath. At the end of etching, the detectors are removed and washed under running tap water, to remove the etching residue from the etch pits. After drying, the detectors are counted under an optical microscope. The etched track diameter is typically a few μm in size and grows larger in size after prolonged etching. Chemical etching works on the principle that once a material is placed in a suitable etchant solution, the solution preferentially attacks the damaged core of the track and penetrates along its length with a velocity V_T while, the surrounding undamaged material is attacked at a lower rate of V_G, the bulk etching Velocity. V_G is generally constant for given etching conditions, where V_T depends on the amount of damage present in the region of the core (i.e. on the nature of the ionizing particle), and will usually vary along an individual track. The detectors track registration efficiency largely depends on the: (a) composition and concentration of the chemical etchant (b) temperature and (c) etching time. The efficiency of CR-39 detector etched at 40 - 70 ^{0}C in conventionally used 6 M aqueous solution of NaOH is 64 % (for α-particle from ^{252} Cf in 2π geometry).

2.6 REVIEW OF EXISTING KNOWLEDGE

Indoor radon activity concentrations have been measured all over the world since 1970s. Surveys have been carried out in almost every European country. The recommended action level set by some countries such as Australia, China, Ireland, Norway, U.K and USSR, for ^{222}Rn levels in dwellings is 200 Bq m^{-3}, while some agencies like the World Health Organisation (WHO), the International Commission for Radiation Protection (ICRP) and US Environmental Protection Agency (EPA) have recommended the action level as 150, 200 and 150 Bqm^{-3}, respectively. The average indoor concentration published for dwelling of different cities around the world vary between 8.7 Bq m^{-3} (Australia) and 190 Bqm^{-3} (German states of Saxony Turingia), with a weighted arithmetic mean of 40 Bqm^{-3} for all the cities considered in 1993. (EPA, 1993; Farid, 1997).

In Nigeria, Indoor radon concentration level was measured in twelve selected phosphate fertilizer warehouses in Nigeria in order to establish potential hazards to persons using such warehouses as offices. The fertilizer warehouses were selected based on the

brand of fertilizers stored, size, ventilation pattern and the number of workers in the warehouses during working hours. Electret Ion Chamber Technology (EIC) with the trade name E-PERM^{TM} was employed for the measurement of radon concentration in the warehouses. Average radon concentration in the warehouses range between 33.6 Bq m^{-3} and 117 Bq m^{-3} with an arithmetic mean of 91.62 ± 5.9 Bq m^{-3} (Okeji and Agwu, 2012).

Indoor radon levels were measured in some offices in the Faculty of Science, University of Ibadan, using Electret Passive Environmental Radon Monitor (E-PERM). Measurements were made at 54 locations in five departments of the faculty. Indoor radon concentrations in these departments were found to vary from 39.70 to 126.77 Bq m^{-3} with an average mean of 65 ± 20 Bq m^{-3}. The results obtained showed variation with ventilation and type of building materials. The average indoor radon concentration obtained was below the indoor radon concentration action level (148 Bq m^{-3}) recommended by Environmental Protection Agency (EPA), hence no remedial action was required. The work however established the applicability of the technique for a much wider scope of indoor radon survey in Nigeria (Farai and Jibiri, 2013).

Radon-222 was measured continuously in a groundwater system in Nigeria for one year by γ-spectroscopy. The mean radon concentrations for a particular month was 15,1 Bq l^{-1} with a standard deviation of 1.0 Bq l^{-1} while the mean for the whole year is 14.8 Bq/l with a standard deviation of 1.4 Bq l^{-1}. All the values for the year lied essentially within ±δ of the mean. Rainfall appeared to be the only major factor causing variations (Farai and Sanni, 1992).

In Nigeria's oldest university campus, CR-39 track etch detectors were used for the measurement of ^{222}Rn concentration in 24 offices in order to estimate the effective dose to the occupants from ^{222}Rn and its progeny. The dosimetric measurements were made over a period of 3 months. The radon concentration ranged from 157 to 495 Bq m^{-3}, with an arithmetic mean and standard deviation of 293.3 and 79.6 Bq m^{-3}, respectively. The effective dose to the workers was estimated and this varied from 0.99 to 3.12 mSv y^{-1}, with a mean of 1.85 mSv y^{-1} (Obed *et al.*, 2010).

Radon measurements were performed in secondary schools in Oke-Ogun area, South-west, Nigeria, using Solid State Nuclear Track Detectors (SSNTDs). About seventy

CR-39 detectors were distributed in 35 high schools of the Oke-Ogun area. The overall average radon concentration in the surveyed area was 45 $\pm$ 27 Bq m^{-3} (Obed *et al*., 2011b).

Indoor radon survey was also carried out in 77 dwellings in Oke-Ogun area, South-western Nigeria, average radon concentration in living rooms and bedrooms were 255 $\pm$ 47 Bq m^{-3} and 259 $\pm$ 67 Bq m^{-3} with annual effective dose of 6.4 and 6.5 mSv y^{-1}, respectively, (Obed *et al*., 2011a).

In Slovenia, indoor radon concentration measurements were carried out in 24 old houses (older than 30 years), in an area with high natural radiation (Poljanska valley) and in 44 houses, in the vicinity of coal-fired power plant (Saleska valley). The median value and arithmetic mean were found to be 69 and 133 Bq m^{-3}, respectively. The median value in dwellings in Saleska valley was 54 Bq m^{-3}. The median value and arithmetic mean in Poljanska were found to be 230 and 360 Bq m^{-3}, respectively. An increased radon concentration was found to be due to the construction of the houses, which were built without concrete slabs. Outdoor radon concentration was also monitored in the villages around uranium mine Zirovskki (close to Poljanska valley) in 1985 till uranium mine stopped with operation in 1990 (Farid, 1992). CR-39 detectors were changed quarterly. The annual outdoor average radon concentrations were found to be 20 Bq m^{-3} and in other regions inside Slovenia were found to be between 5 and 20 Bq m^{-3} depending on microclimate and geological conditions. It was found that radon concentration in the village continuously increased with time (=30 % in 5 years) and decreased with distance from the mine, which had no significant effect beyond 3 km from the mine.

2.7 MITIGATION TECHNIQUES

Radon in the soil can enter the home through two gas transport mechanisms: molecular diffusion (movement from an area of high concentration to low concentration at constant pressure) and pressure driven flow (movement from a high to a low pressure area) (EPA, 1987). Radon control depends on the following:

A- Changes in pressure prevent radon entry. Examples for strategies that depend on this principle are:

i. Soil depressurization, where a suction fan is used to produce a low pressure field under the slab. This low pressure field prevents radon entry and the air will be drawn from the building interior into the sub - slab area.

ii. Building pressurization through Heating, Ventilating, and Air– Conditioning (HVAC) system, which involves bringing in more air to the building than is exhausted, by the HVAC system, causing a slightly positive pressure inside the building relative to the sub - slab area. The positive pressure in the building causes air to flow from inside the building to the outdoors through openings in the substructure and building shell.

B- Diluting the radon after it enters the building. By increasing building ventilation (without HVAC system control), by opening lower-level windows, doors, and vents or by blowing outdoor air into the building with a fan, reduces radon levels by diluting indoor air with outdoor air and by minimizing the pressure differentials that draw radon into the building.

C- An approach that combines all the principles, such as: sealing. This involves sealing major radon entry routes to block or minimize radon entry. Strategies that prevent radon entry have been applied successfully in buildings with a wide range of radon concentrations. Strategies that use outdoor air to dilute radon after it has entered the building are most practical if the pre-mitigation radon concentration is only slightly elevated (EPA, 1994).

CHAPTER THREE

MATERIALS AND METHODS

3.1 THE STUDY AREA

Iwo is a town in Osun State, South -Western Nigeria. It is the seat of Iwo kingdom, a traditional state. The expanse of land occupied by the study area lies between Latitude 7 º 37′N and 7 º 40′ N, and Longitude 4 º 9′ E and 4 º 13′E. The land area occupied is 245 km^2 and a population of 191,348 at the 2006 Nigeria National Census (http://en.wikipedia.org/wiki/Iwo, Nigeria-Wikipedia, the freeencyclopedia.mht). Iwo town is situated at a distance of 43.5 km from Ibadan, 35.4 km and 49.9 km from Oyo and Oshogbo, respectively. The location of Iwo town is shown in Figure 3.1

3.2 GEOLOGY OF THE STUDY AREA

Geologically, the altitude is generally between 700 and 900 feet above the sea level. The highest point in the town is the granite rock, which is about 900 feet above the mean sea level. There are also five isolated hills, three on the western section of the town and two in the Eastern section. Quarrying is carried out at three rock outcrops. The granite stones are used locally. Apart from quarrying, no mining operations are witnessed in the region.

Geographically, the South-West trade (warm and moist) and the North-East trade (hot and dry) wind currents give rise to the major seasons - the wet and dry seasons, respectively. The wet season starts in April and ends in early October. The dry season starts in November and ends in March. A cool dust-laden wind (Harmattan) blows during December and January. Iwo is geographically located at Northern part of Osun State, of relative humidity, 79.90 %, and maximum temperature at 32.5 ^{0}C (Aiyelola and Ajewole, 2006; Lamidi, 2013). The town and its immediate environs fall within the dry forest of the savannah vegetation zone with annual rainfall of 2.0 m - 2.5 m (Lamidi, 2013). Iwo is situated in the midst of a rich agricultural area.

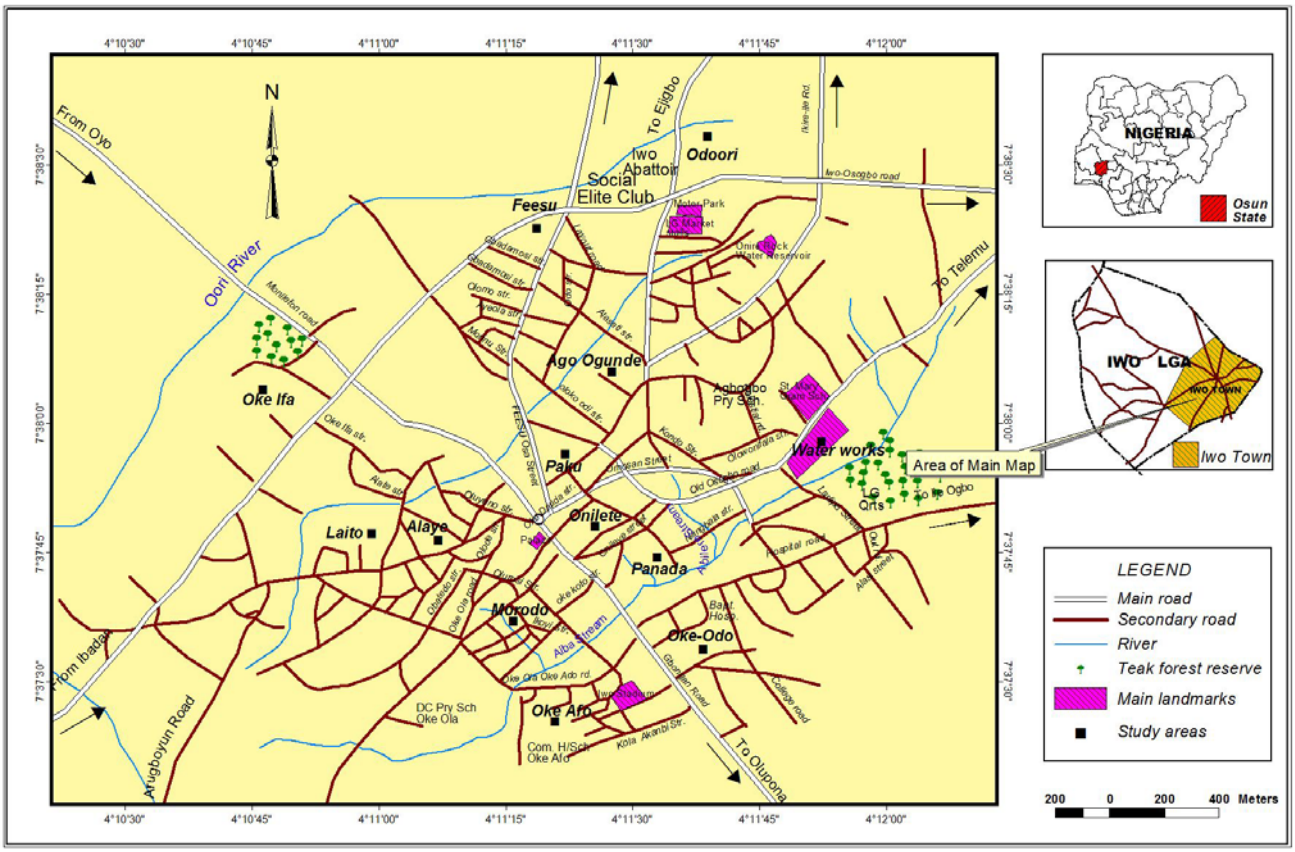

Figure 3.1: Map of Iwo showing sampling points

Iwo town, divided into 4 zones (Molete, Isale-Oba, Gidigbo and Oke- Adan) consists of wards which comprise of many areas. The town primary economic activity is agriculture with the primary crops being cocoa, maize, corns, cassava and palm oil. The occupation of the people ranges from farming, trading and processing of Agricultural products (Lamidi, 2013).

3.3 RADON AWARENESS

Radon awareness survey was conducted by collecting data, so as to create awareness on radon gas and its health hazards. A total of 313 adult persons randomly selected from all walks of life were interviewed from July, 2009 to April, 2010. Adult (age > 18 years) educated and uneducated persons were contacted and their responses were properly recorded on the questionnaires. A copy of this questionnaire is shown in Appendix B.

Another questionnaire on indoor radon measurements were designed and given to the occupants of the house. Each was given to the occupant, where CR-39 detector was placed. Measurements were taken in multifamily and multistorey buildings. The houses selected from the present study were of different styles of construction, falling in a typical range from traditional houses made up of mud with plastered walls and flooring, to the houses made up of bricks and cement, flats made of concrete with plastered and painted walls and carpeted flooring. A copy of this questionnaire is shown in Appendix C.

3.4 MEASUREMENT OF INDOOR RADON CONCENTRATIONS

Forty-seven CR-39 detectors, with forty-seven questionnaires on indoor radon measurements, were deployed to 29 houses in 6 different areas – Paku, Oweyo, Oke-Odo, Oke–Afo, Araromi (Isale-Oba zone) and Ago-Ogunde (Oke-Adan zone) in Iwo, Osun State, Nigeria. Indoor radon measurements were carried out in 14 houses at 4 areas and in 15 houses at 4 areas in dry season and rainy season, respectively.

3.4.1 PREPARATION OF CR-39 DETECTORS

The technique used in this survey is based on passive Nuclear Track Detectors (NTDs), which is commercially marketed as CR-39 (Columbia Resin), Poly-Allyl Diglycol Carbonate (PADC) with the chemical formula $C_{12}H_{18}O_7$, also known as Tastrak. These detectors are manufactured by TASL (Track Analysis Systems Ltd, Bristol, UK). The CR-39 is a small piece of transparent plastic that is sensitive to tracks of highly ionizing particles such as alpha particles. It has been found to be the most sensitive and efficient detector among all the plastics, to detect all ions including low energy protons and high energy charged particles (Dwivedi, 1991). In addition to this, it can discriminate the different energies of alpha particles (Hadler *et al*., 1991).

CR-39 detectors are very sensitive to alpha energy up to 40 MeV, which in quite large compared to the other detectors commonly used for radon measurements. They are very useful in the detection of alpha particles from the decays of radon and its daughter products in dwellings under different conditions. CR-39 detectors function as true integrators and measure the average concentration over the exposed period; and they are portable and can be easily placed at measurement locations. Charged particles come to the detector with large energy and register tracks, which have different diameters. The rectangle (3.7 × 1.3 cm^2, 1.0 mm thick) and square (1 ×1 cm^2, 1.0 mm thick) in shape, of density of 1.30 g cm^{-3} were used. Radon concentration measurements were performed using CR-39 detectors enclosed in small cylindrical diffusion chambers. The passive radon dosimeter is a closed chamber into which radon diffuse in order to provide a discriminative measurement of radon.

In the dry season, indoor radon measurements were carried out in 14 houses at 4 areas. Twenty two detectors were deployed to 14 houses. The rectangular piece of the NTD of 3.7 × 1.3 cm in size, 1.0 mm thick and have a density of 1.30 g cm^{-3} was used. The detectors were stored in a refrigerator, in order to minimise chances of high background exposure. Each detector was fixed by plasticine at the bottom of the cover of the dosimeter (5.8 cm height and 5 cm diameter). Each dosimeter (diffusion chamber) was sealed with sellotape paper, in order to prevent air from entering into the container, so as to minimise the background level before deployment. The Calibration factor of the 22 detectors was estimated using Monte Carlo simulation.

In the rainy season, indoor radon measurements were also carried out in 15 houses at 4 areas. Twenty-five detectors were deployed to 15 houses. The square piece of the NTD of 1.0 × 1.0 cm, in size, 1.0 mm thick and of a density of 1.30 g cm^{-3} was used, as shown in plate 3.1. Each detector was placed and fixed inside a small Radosys plastic container, an exposure pot for radon measurement of diameter 2 cm and height 5.5 cm, as shown in plate 3.2. Each detector was packed with PVC and sealed, from the company, to prevent extraneous exposure before deployment. Small dosimeters were used, so that the range of an alpha particle in air, R would be greater than the distance between the position of emission of alpha particle and the centre of the track detector, r, in the dosimeter, then the alpha particle would reach the detector and deposit some energy. The angle of incidence θ of the particle would be smaller than certain critical angle of etching θ and CR-39 would be able to record the track. Each dosimeter was sealed, in order to prevent air into the diffusion chamber, so as to minimise the background level before deployment. The calibration factor of these 25 detectors was supplied by the company.

3.4.2 DEPLOYMENT AND RETRIEVAL OF CR-39 DETECTORS

The twenty-two detectors were deployed and placed in the 14 studied houses randomly selected and based on accessibility. One detector was placed in a room and one or two detectors were placed and exposed in a house. Each detector was placed at 1.5 metre from the floor (breathing height zone for a sitting person). The detectors were exposed in each house for a period of 3 months, in dry season, from 26th July, 2009 to 29th October, 2009.

In rainy season, twenty-five detectors were also deployed to 15 houses. Twelve detectors were replaced with new ones in 6 houses while 13 detectors were relocated to another 9 randomly selected houses. Each detector was exposed in a room 1.5 metre from the floor for a period of 3 months (from 3rd April, 2010 to 9th July, 2010). The samples were not placed near drafts, ventilation, air conditioners, doors, fans, and windows.

Each detector was retrieved and re-sealed to avoid continued exposure of the detector beyond their deployment period. These detectors were taken to Radiation and Health Physics Laboratory in the University of Ibadan, Nigeria; for etching and analysis.

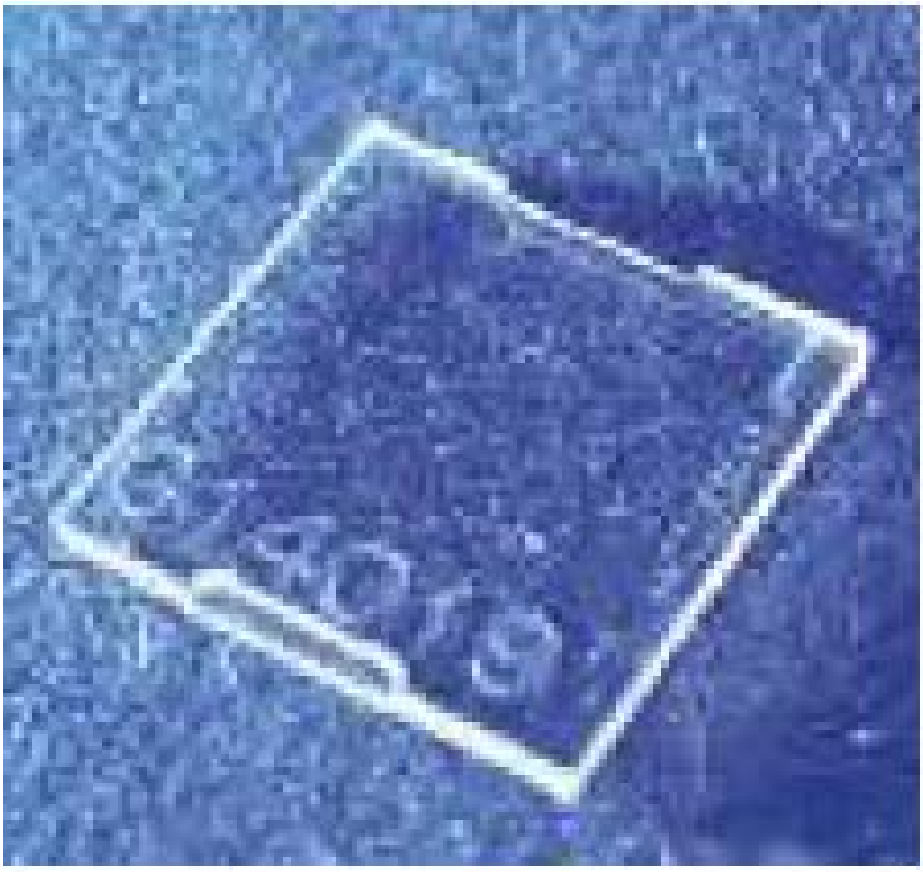

Plate 3.1: CR-39 detector of size 1 × 1 cm^2, 1.0 mm thick square in shape

Plate 3.2: Cylindrical exposure chamber (Radopot), 23 mm × 40 mm in dimension

3.4.3 ETCHING OF CR-39 DETECTORS

CR-39 detectors were removed from the dosimeters and etched using 6.25 M NaOH solution, which was prepared by dissolving 60 g of NaOH pellets in 240 cm^3 of water. The detectors were etched at 90 ^{O}C for 2 hours in the etching bath, as shown in plate 3.3; and then, the detectors were immediately removed and washed in running tap water and then in distilled water for about 15 minutes, to interrupt the chemical process, before allowed to dry on a filter paper. After etching, the CR-39 detectors were taken to the Radiation Laboratory, Department of Physics, University of Trieste, Trieste, Italy, for further analysis.

3.4.4 COUNTING OF NUMBER OF TRACKS

Tracks were viewed through the optical microscope as dark holes. The combination of optical microscope shown in Plate 3.4 (with a magnification of 40 X) and a USB camera shown in Plate 3.5, were coupled with a personal computer to scan 10 regions of interest on each CR-39 detector of size 1.0 ×1.0 cm, and 25 regions of interest on CR-39 detectors of size 3.7 × 1.3 cm. The regions of interest were scanned from each detector. The numbers of tracks in each scanned region of interest were counted with the Image Plu software. Some regions were not free from artefacts (e.g. internal flaws in the plastic or dust particle). In order to exclude such artefacts, the perfect sphere dark holes were considered and counted. One of such regions is shown in Plate 3.6.

3.4.5 CALCULATIONS OF ^{222}Rn CONCENTRATIONS, WORKING LEVEL, WORKING LEVEL PER MONTH, ANNUAL EFFECTIVE DOSE AND EXCESS LIFETIME CANCER RISK

The total tracks were determined by summing the number of holes in all the regions for each detector. The average track and track density were determined. Conversion of track density to radon concentration was determined, using equation (3.1)

$$A_{Rn}\ (\text{Bq m}^{-3}) = \frac{D_o}{T} K \qquad (3.1)$$

Plate 3.3: The Etching Bath

Plate 3.4: Microscope - Konus Academy 1000x (Mod. 5304) 40x

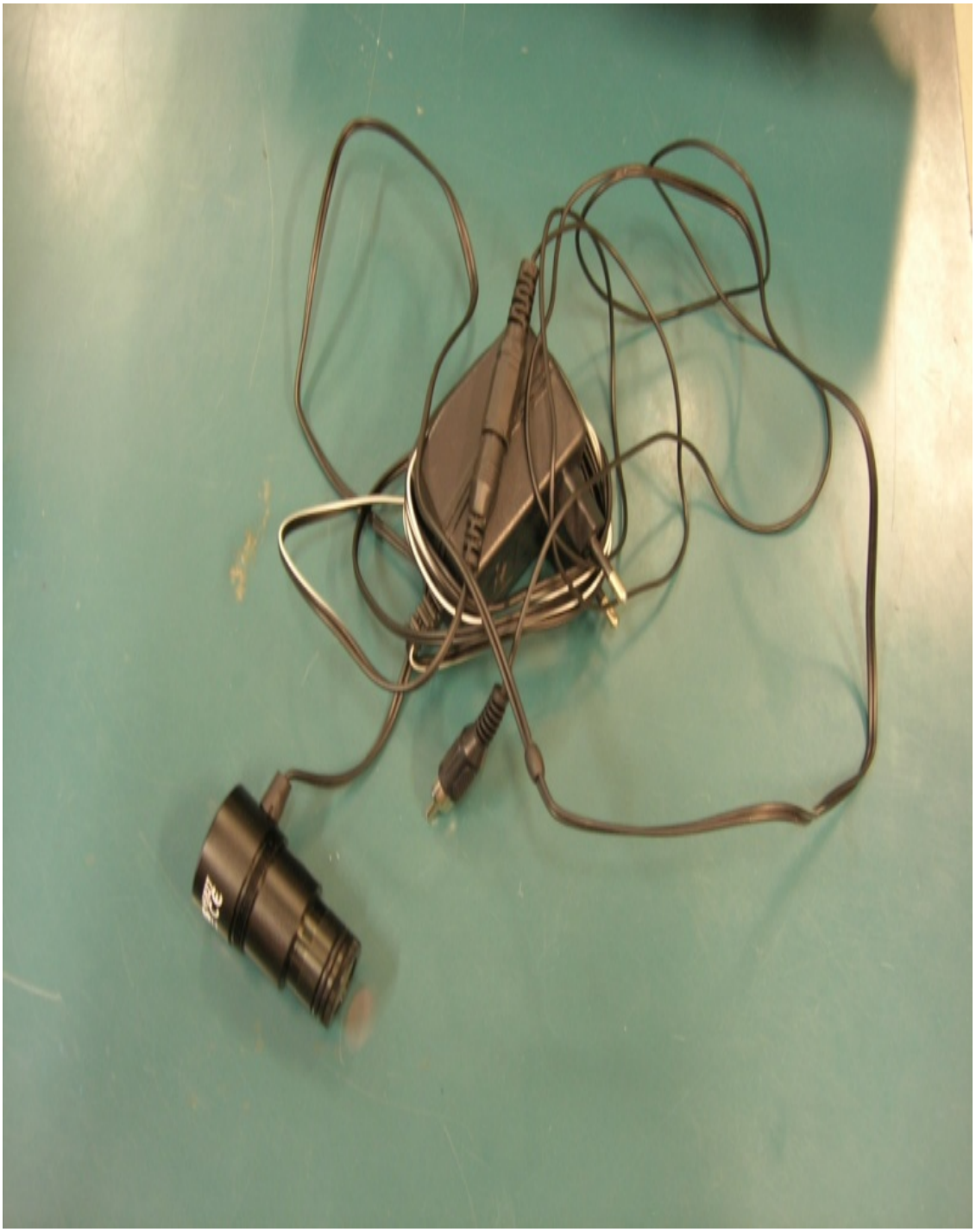

Plate 3.5: Micro camera - Konus CMOS Camera USB PLUG (Mod. 5829) [~10x]

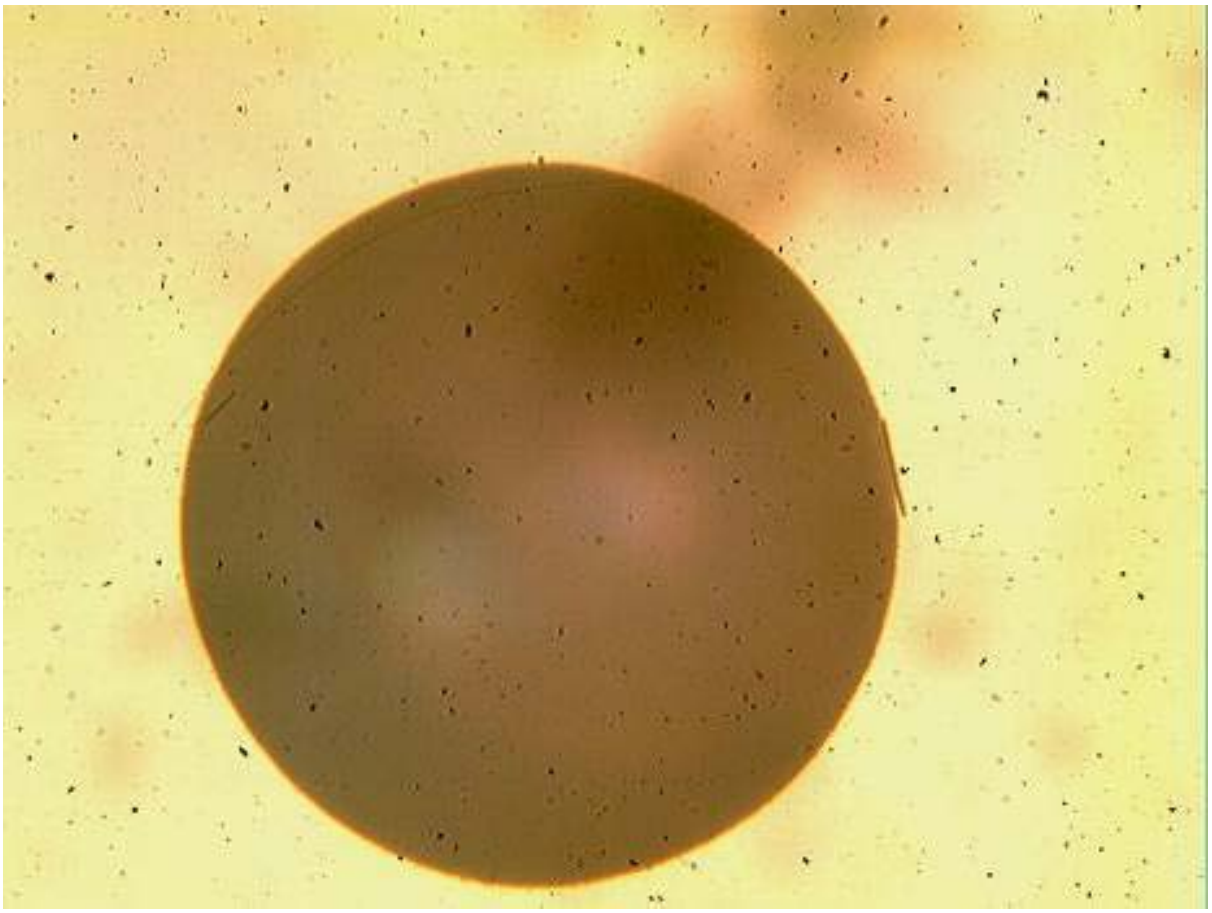

Plate 3.6: Track in CR-39 detector (0.5 μm px^{-1}, 40 X and A = 0.085 mm^2)

where, A_{Rn} is the radon concentration, D_o is the track density ,T is the time of exposure and K is the calibration factor.

The Calibration Factors used for square and rectangular piece of NTD used are 1843 Bq $m^{-3.}$ (Tracks /mm^2) day and 1455 Bq $m^{-3.}$ (Tracks /mm^2) day, respectively.

Working level (WL) is a measure of atmospheric concentration of radon and its progeny. One working level is defined as any combination of short lived radon daughters in I litre of air that will result in the ultimate emission of $1.3x10^5$ MeV of alpha energy. This corresponds to an atmospheric concentration of 100 pCi of ^{222}Rn per litre (3700 Bq m^{-3} in equilibrium with its daughters) (Herman, 1996).

The Potential Alpha Energy Concentration (PAEC) and the Working Level per Month (WLM) can be estimated from the radon concentration levels using these formulae (UNSCEAR, 2006):

$$\text{PAEC (WL)} = A_{Rn} \times \frac{F}{3700} \quad (3.2)$$

and

$$\text{WLM} = \text{WL} \times \frac{T}{170\ \text{h}} \quad (3.3)$$

where, A_{Rn} is radon concentration, F is the equilibrium factor (0.4) and WL is the working level, T is time exposure in hours and 170 h is working hours per month.

The annual effective dose to the population of Iwo town due to exposure to radon decay products was determined using the following expression given by (UNSCEAR, 2006):

$$H\ (\text{mSv}) = A_{Rn} \times F \times O \times DCF \quad (3.4)$$

where, H is the annual effective dose (mSv), A_{Rn} is the ^{222}Rn concentration (Bq m^{-3}), F is an equilibrium factor (0.4), O is the occupancy factor (7000 h) and DCF is the dose conversion factor (9.0 nSv Bq m^{-3} h^{-1}).

Excess lifetime cancer risk (ELCR) was estimated from effective dose (H in mSv) using the following formula:

$$ELCR = H \times DL \times RF \quad (3.5)$$

where, DL is the life expectancy (70 years) and RF is the risk factor (0.055 Sv^{-1}) recommended by the ICRP (ICRP, 2007).

3.5. MEASUREMENT OF OUTDOOR RADIOACTIVITY CONCENTRATIONS

This study was carried out to determine the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in surface soil samples from 19 areas in Iwo, Osun State, Nigeria.

3.5.1 SAMPLE COLLECTION

Sixty soil samples randomly extracted, as representative of the soil at a depth of 20 -30 cm and 20 rock samples were randomly collected in the vicinity of the houses in Iwo, Osun State, in January, 2010. The ground was manually dug and soil samples were collected. The stones, pepples and organic materials were removed from the soil samples. The rock samples were collected from the parent rocks. The samples collected were transferred to labelled polythene bags, closed and transferred to the laboratory for preparation and measurements.

3.5.2 SAMPLE PREPARATION

The samples were transported to the Radiation and Health Physics Research Laboratory of the University of Ibadan, where they were air-dried, to remove the moisture content and then pulverized by crushing all samples into fine powder by using mortar and pestle, in order to pass through a fine mesh sieve. Each sample was sieved with a fine mesh sieve of 0.2 mm, in order to homogenize the particles. Each sample was weighed and recorded. The net weight of each sample was 200 g. Each sample was packed and hermetically sealed in a plastic container of diameter of 6 cm and height 7 cm which had been verified to be non- radioactive. The samples were then kept for 2 months to ensure secular equilibrium between ^{226}Ra (^{238}U series) and ^{228}Ra (^{232}Th series) and their respective short-lived gaseous gamma emitting progenies (USDOE, 1992), prior to gamma counting.

3.5.3 CALIBRATION OF EQUIPMENT

The spectrometer used for the measurement of radioactivity in the samples consists of a 76 mm × 76 mm NaI (TI) (Model No. 802 series) by Canberra Inc., which was coupled to a Canberra series 10 plus Multichannel Analyser (MCA) through a pre-amplifier base. The detector was maintained in a vertical position in a Canberra cylindrical lead shield with a thickness of 10 cm as shown in Plate 3.7. The detector has a resolution of about 8 % at 662 keV of ^{137}Cs. This is capable of distinguishing the gamma ray energies considered for measurements of natural radionuclides. The 1460 keV was used for the measurement of ^{40}K, while 1760 keV peak from ^{214}Bi and 2615 keV peak from ^{208}Ti were used for the measurements ^{238}U and ^{232}Th, respectively. The channel numbers of the photo peaks corresponding to the different gamma energies were recorded, as presented in Table 3.1. The energy in MeV of the photo peak was plotted against the corresponding channel number to get the energy-channel linear relationship as shown in Figure 3.2. The linear equation is given as:

$$E\ (MeV) = 0.0202C + 0.3255 \qquad (3.6)$$

where, E is the energy of the photo peak in MeV and C is the channel number corresponding to the photo peak.

With this equation stored in the memory of the MCA, it was easy to identify the radionuclide present in the samples.

The absolute efficiency calibration was performed using mixed standard gamma source. A reference pulverized soil sample, prepared from Rocketdyne laboratory, California, USA, which is traceable to a mixed standard gamma source (No. 48722-356) by Analysis Inc. Atlanta Georgia, was counted for 10 hours to determine the detector efficiency, ϵ_p of the system, which at a constant matrix and geometry is defined as:

$$\epsilon_p = \frac{A}{tC_rYm} \qquad (3.7)$$

where, A is the net count above the background after counting, C_r is the activity concentration of a reference sample Bq kg^{-1}, m is the mass in kg, t is the time in s, and Y is the gamma ray emission probability.

Plate 3.7: The NaI (Tl) measuring assembly used for soil and rock measurements

Table 3.1: The standard radionuclides with their corresponding Energy (MeV) and Channel Number

Nuclide	Energy / MeV	Channel Number
^{27}Na	0.511	11
^{137}Cs	0.662	17
^{60}Co	1.173	40
^{22}Na	1.275	46
^{60}Co	1.332	48
^{40}K	1.460	56
^{238}U	1.750	74
^{232}Th	2.615	113

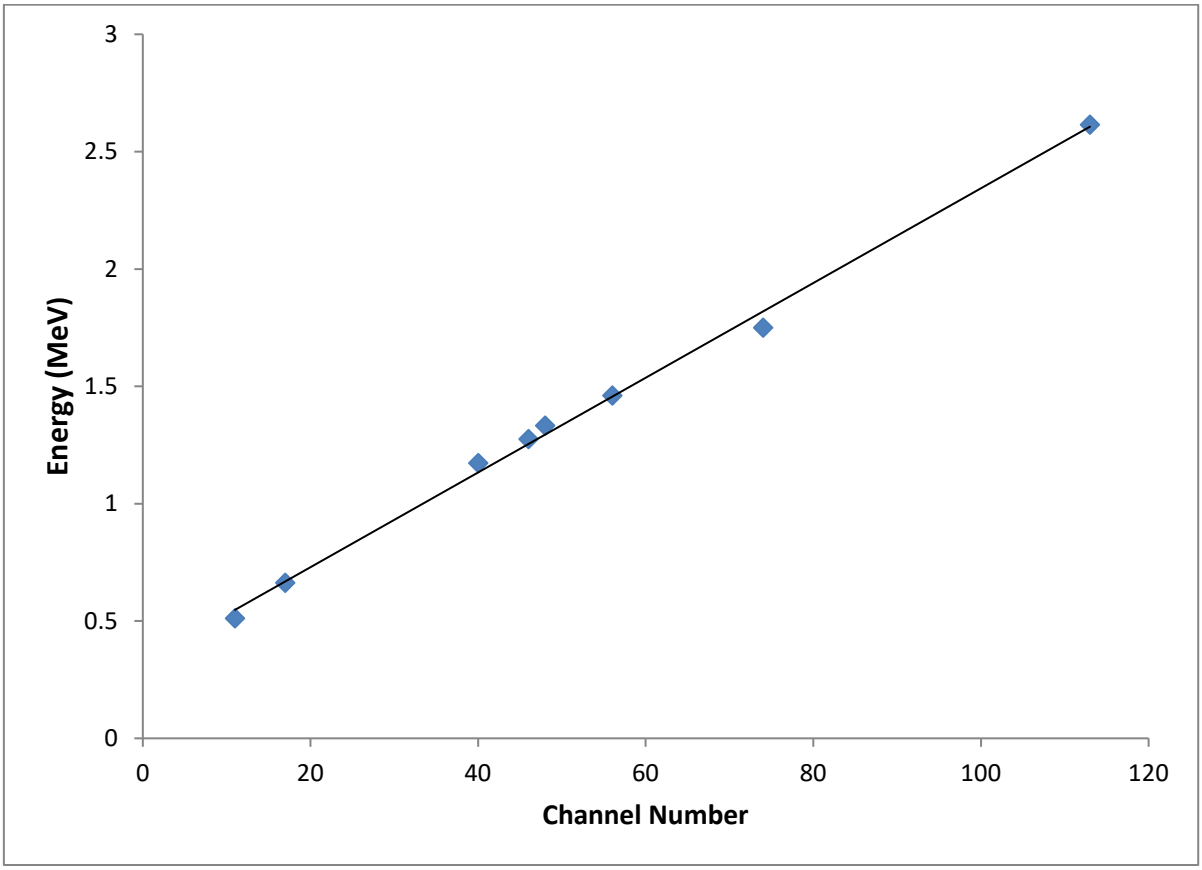

Figure 3.2: Graph of Energy - Channel Number dependence

A reference pulverized soil sample of a known activity concentration was used, as presented in the Table 3.2.

The calibration or conversion factor, K, is:

$$K = \frac{1}{\epsilon_p t Y m} \quad (3.8)$$

The efficiency was determined for the energy range 0.66 to 2.62 MeV. The reference sample has a similar matrix as the pulverized soil samples.

Activity concentration of the gamma ray emitting radionuclides in each soil sample was obtained by relating the detection efficiency obtained from calibration, to the net count under each full-energy peak at the end of each 10 hours long.

3.5.4 RADIOACTIVITY COUNTING

The samples were placed in the detector and measured for a period of 36,000 s. The net area under the corresponding peaks in the energy spectrum was computed by subtracting counts due to Compton scattering of higher peaks and other background sources from the total area of the peak.

The counting rate, A, counting per 10 hours, under each photo peak due to natural radionuclides was obtained after pre-set counting time of 10 hours. This counting time was considered long enough for the NaI (TI) crystal to collect a spectrum showing distinctly the peaks of interest.

The activity concentration of each radionuclide was calculated using the following equation (Noorddin, 1999):

$$C_n = \frac{A}{\epsilon_p t Y m} = K A \quad (3.9)$$

where, C_n is the specific activity concentration of each radionuclide in the samples, (Bq kg^{-1}), m is the mass of the samples (kg), Y is the absolute transition probability of the specific gamma ray.

Table 3.2: The activity concentration, gamma energy, gamma yield, net area, conversion factor and efficiency of the standard source

Radionuclide	Activity Concentration Bq kg^{-1}	Energy /MeV	Yield	Net Area (count per 10 hrs)	Conversion factor	Efficiency (x 10^{-1})
^{40}K	479.15 ± 23.43	1.460	0.107	8343± 9.773 %	0.0288	4.40
^{238}U	566.47 ± 8.33	1.760	0.159	8659 ± 7.109 %	0.0322	2.71
^{232}Th	11.60 ± 0.77	2.615	0.358	785 ± 26.87 %	0.0275	1.41

3.6 MINIMUM DETECTION LIMIT

The detection limit of a measuring system describes its operating capability without the influence of the sample under certain conditions. It is an estimation of the lowest amount of activity of a specific gamma- emitting radionuclide that can be detected at the time of measurement. The Environmental measurement Laboratory procedure (USDOE, 1992) has been adopted in this study to determine the Lower Limit of Detection (LLD) and this is defined as:

$$\text{LLD (Bq kg}^{-1}) = 4.65 \cdot \left[\frac{R_b}{t_b}\right]^{1/2} \cdot K \qquad (3.10)$$

where, R_b is the net background count in the corresponding peak, t_b is the background time (s), K is the conversion factor that converts count per seconds (cps) to activity concentration (Bq kg^{-1}) and

$$\left[\frac{R_b}{t_b}\right]^{1/2} = \text{Standard deviation of the instrument background counting rate}$$

The LLD values of ^{40}K, ^{232}Th and ^{238}U were determined after counting for 36000 s. The LLD values for ^{40}K, ^{226}Ra and ^{232}Th determined were 11.46, 5.15 and 2.23 Bq kg^{-1}, respectively. The values of activity concentrations of the radionuclides lower than LLD are considered Below Detection Limit (BDL) of the detector system.

CHAPTER FOUR

RESULTS AND DISCUSION

4.1 ANALYSIS OF QUESTIONNAIRES ON RADON AWARENESS

Most of the respondents in the survey, (59 %), were at Tertiary level while, 30 %, 2 %, and 9 % were at Secondary level, Primary and Others levels of education, respectively. The percentage of modal age class, (30 - 39), of the respondents was 33 %, which was followed by 25 % in 20 – 29 age class. Details of the age distribution and the education at level of the respondents are shown in Table 4.1.

The highest percentage, 26 %, of the respondents spent 5 - 8 hours during working days while during weekends the highest, 23 %, of respondents spent 9 - 12 hours in dwellings. Most respondents, 25 % and 23 %, at Tertiary level spent 9 - 12 hours indoor during working days and weekends, respectively, as shown in Figures 4.1 and 4.2.

High percentage (71 %) of respondents at Tertiary level gave positive response to most of the questions, Q1 - Q17. Comparing this with the respondents in other level of education, the percentage of the respondents that gave positive response is greater than the other levels (Secondary, Primary and Others levels). This information respond was positively related to educational level, with more at Tertiary level. This indicates that they had heard of radon than those at secondary, primary and Others levels, as presented in Tables 4.2 and 4.3.

The overall comparison of radon awareness level of all 313 respondents from Iwo town, with regards to questions Q1 to Q17 at different levels of education, about half of the respondents, 54 %, had heard of radon and only 45 % recognized that radon is colourless, odourless and a radioactive noble gas. Many survey respondents, 61 %, were unaware that radon gas is present everywhere while 64 % of the respondents were not aware we cannot completely avoid breathing in radon gas. Also, some respondents, 53 % did not know that radon causes health hazards while 51 % of the respondents did not know that it causes lung

Table 4.1. Number of respondents with different levels of education with age

Age	Number of Respondents with Tertiary Education	Number of Respondents with Secondary Education	Number of Respondents with Primary Education	Number of Respondents with Others Education	Total Number of Respondents
20-29	48	30	0	1	79
30-39	54	43	2	3	102
40-49	45	12	2	5	64
50-59	28	8	1	8	45
60-69	7	0	1	12	20
70-79	1	0	0	1	2
≥80	1	0	0	0	1

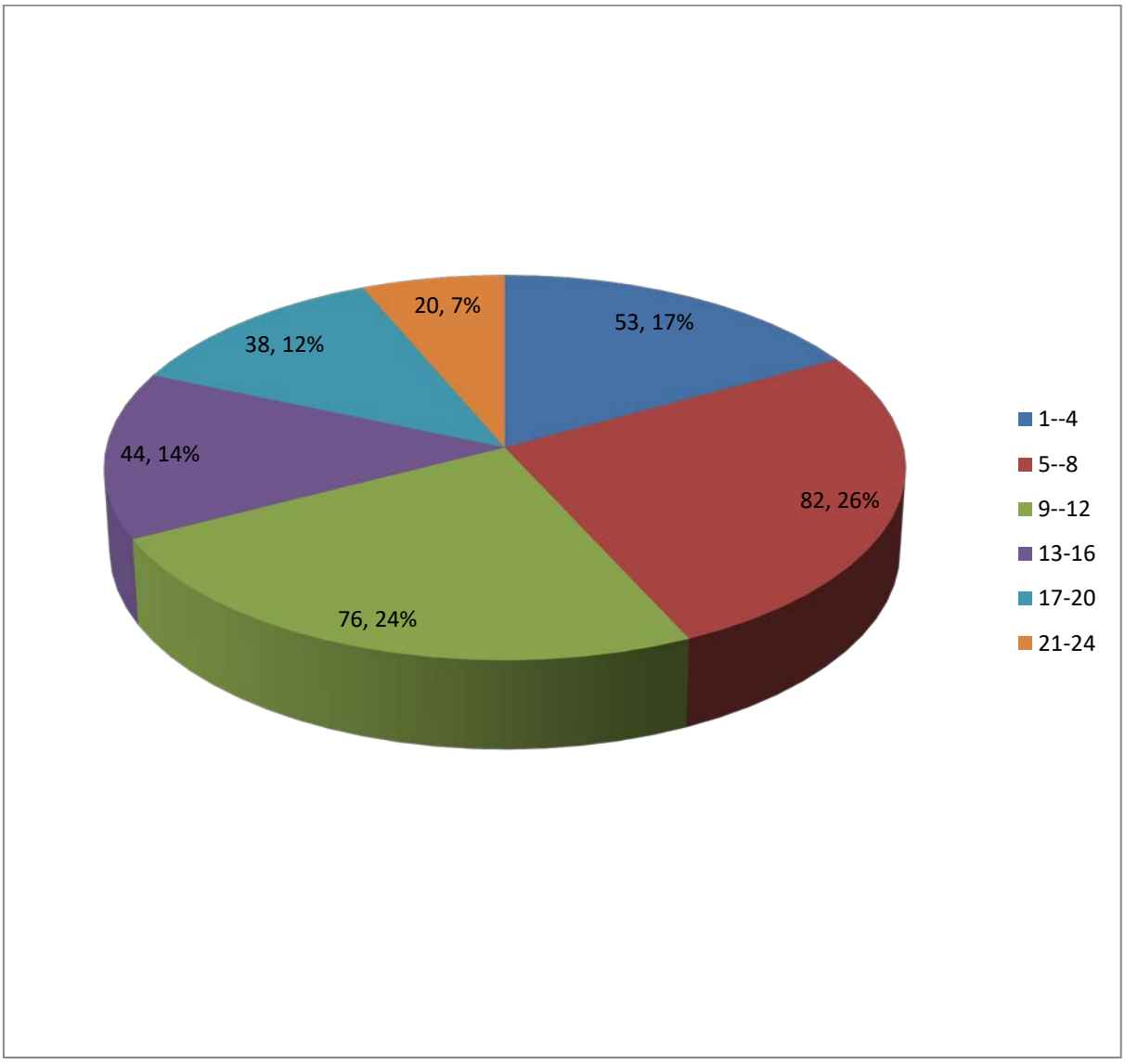

Figure 4.1: A Pie Chart of total number of respondents with number of hours spent in houses during working days

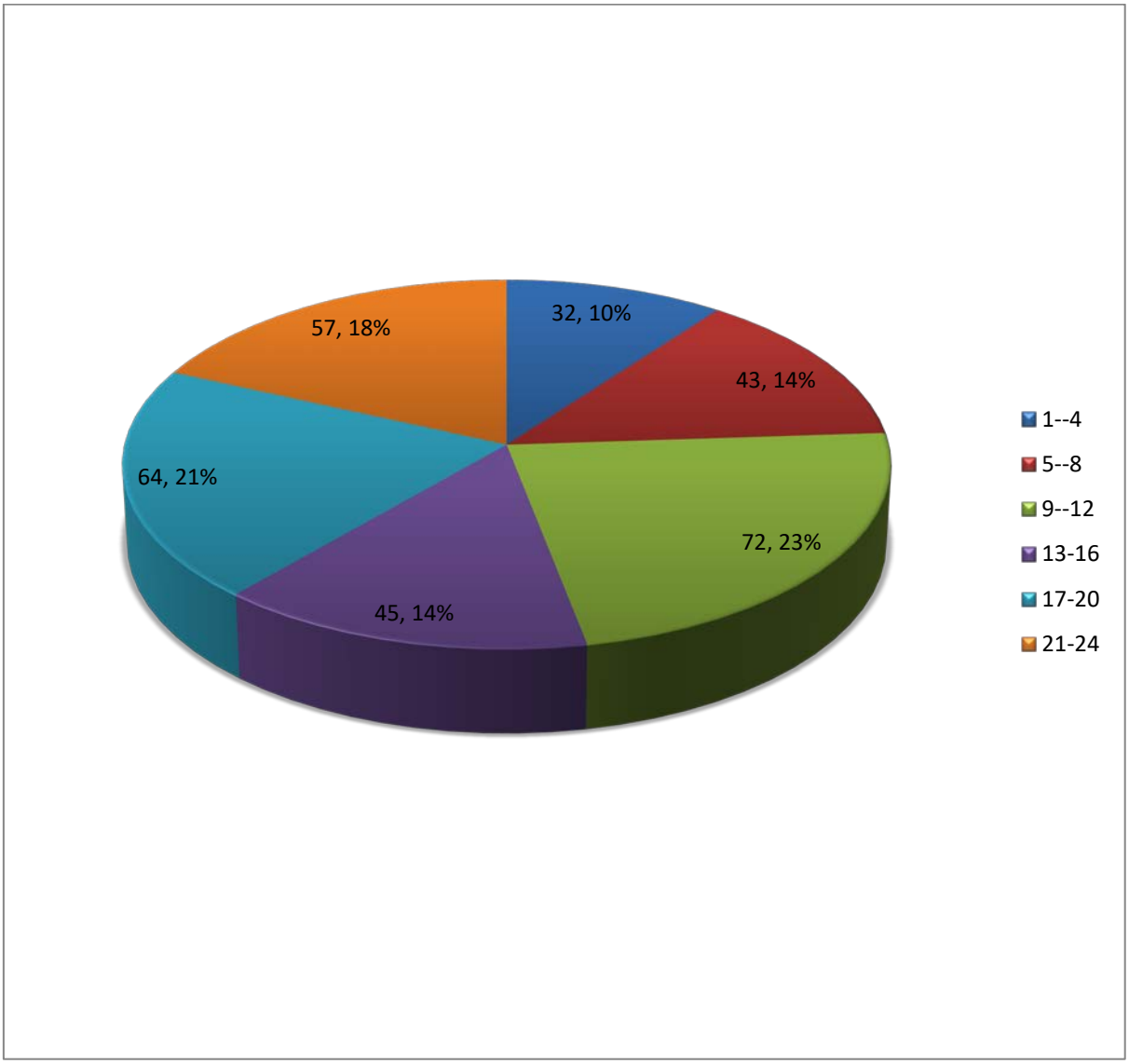

Figure 4.2: A Pie Chart of total number of respondents with number of hours spent in houses during weekends

Table 4.2: Number of respondents that gave positive response to the questions

Question	Number of Respondents with Tertiary Education	Number of Respondents with Secondary Education	Number of Respondents with Primary Education	Number of Respondents with Others Education	Total Number of Respondents	
	184	93	6	30	313	100 %
Q1	126	40	1	1	168	54
Q2	106	34	1	0	141	45
Q3	93	27	1	0	121	39
Q4	84	28	1	1	114	36
Q5	114	33	0	1	148	47
Q6	108	43	1	1	153	49
Q7	67	9	0	1	77	25
Q8	85	36	0	1	122	39
Q9	91	32	1	0	124	40
Q10	89	33	1	1	124	40
Q11	109	41	1	1	152	49
Q12	105	41	2	2	150	48
Q15	116	55	3	13	187	60
Q16	48	27	2	1	78	25
Q17	139	71	4	5	219	70

Table 4.3: Number of respondents that gave negative response the questions

Question	Number of Respondents with Tertiary Education	Number of Respondents with Secondary Education	Number of Respondents with Primary Education	Number of Respondents with Others Education	Total Number of Respondents	
	184	93	6	30	313	100 %
Q1	58	53	5	29	145	46
Q2	78	59	5	30	172	55
Q3	91	66	5	30	192	61
Q4	100	65	5	29	199	64
Q5	70	60	6	29	165	53
Q6	76	50	5	29	160	51
Q7	117	84	6	29	236	75
Q8	99	57	6	29	191	61
Q9	93	61	5	30	189	60
Q10	95	60	5	29	189	60
Q11	75	52	5	29	161	51
Q12	79	52	4	28	163	52
Q15	68	38	3	17	126	40
Q16	136	66	4	29	235	75
Q17	45	22	2	25	94	30

cancer. A large percentage of respondents, 61 %, were unaware that smokers are at higher risk from radon exposure and only 25 % of respondents were smoking cigarette.

The knowledge of radon comes from natural radioactive decay of radium and uranium from the soil beneath the house and underground well water that can transport the radon from the soil into the house was noted by 40 % of the survey respondents. Some survey respondents, 49 %, believed that radon level can be measured in a house while 48 % of the respondents hoped that radon can be reduced in a house. In all, 70 % of the respondents were interested and needed more information on radon while 60 % of the respondents were interested in carrying out radon measurement in their dwellings in future.

The result of this survey implies that on average, only 44 % respondents were scientifically aware of radon. This above discussed radon survey results conclude that level of radon awareness in Iwo town is low. In developed countries, such as U.S.A, about two third of the population on the average have radon awareness regarding its health hazards (Tahir, 2008). In Iwo town, only a small segment of population especially those who have acquired scientific education at Tertiary Level are aware of the fact that indoor radon concentration may cause health problems. Generally, low level of radon awareness in Iwo may be associated with low literacy rate and lack of scientific education.

4.2 ANALYSIS OF QUESTIONNAIRES ON RADON MEASUREMENTS IN HOUSES

Questionnaires were analyzed based on information given by the occupants of the house and the direct measurements of some parameters in the various houses were examined. Most of buildings surveyed, (68.1 %), were greater than 20 years. A situation, where only one individual occupied a room, had the highest percentage of 46.8 % and the number of the years spent (1 - 5 years) by the occupant (s) in a room had highest percentage of 48.9 %. The summary is presented in Tables 4.4 and 4.5, respectively.

Most of the houses (87.23 %) were above the ground, the underlying soil type of houses (Loamy soil) had the highest percentage of 46.81 % and 72.72 % of the houses surveyed were not fenced. The percentage of bungalow is 68.09 % which is more than that of storey buildings (31.91 %); and 65.96 % of the rooms had electric fan for circulating air.

Table 4.4: Frequency distribution of number of people in houses

Number of People	Frequency	Percentage (%)
1	22	46.8
2	3	6.4
3	1	2.1
4	8	17.0
5	4	8.5
6	7	14.9
7	0	0.0
8	2	4.3

Table 4.5: Frequency distribution of number of years spent in a building

Number of year Spent	Frequency	Percentage (%)
1 – 5	23	48.9
6 – 10	12	25.5
11 – 15	5	10.6
16 – 20	5	10.6
21 - 25	2	4.3

Almost, in all the houses (97.87 %), well were used as a source of domestic water. The summary is presented in Table 4.6.

The commonest materials for construction, 89.4 % of walls, 85.1 % of floors and 76.6 % of ceilings, were block with cement, concrete and asbestos, respectively; while 48.9 % of windows and 87.2 % of doors were made from glass (louvers) and wood, respectively. Most of the walls (65.96 %) and ceilings (59.57 %) of the houses were painted while 70.23 % of the rooms were covered with mosquito nets but 70.21 % of the doors were not covered with net. All the houses surveyed were plastered with cement and rectangular in shape. The summary is presented in Table 4.7.

4.3 RADON CONCENTRATIONS IN HOUSES

The minimum detectable radon concentration (MDC) was found to be 14 Bq m^{-3} for an exposure of 90 days (Ibrahim and Milles, 2009). The radon concentration in houses surveyed in Iwo town ranged from 111 ± 22 to 299 ± 60 Bq m^{-3}. The arithmetic mean, Geometric mean (GM) and Geometric Standard Deviation (GSD) of radon concentrations were 196.3 Bq m^{-3}, 190.3 Bq m^{-3} and 49.6, respectively. The highest radon concentration (299 ± 60 Bq m^{-3}) was found in Ago-Ogunde and Oke-Odo with average of 249 ± 54 and 182 ± 49 Bq m^{-3} respectively, while the lowest concentration (111 ± 22 Bq m^{-3}) was found in Oke-Afo with an average of 197 ± 57 Bq m^{-3}. The summary is presented in Table 4.8.

It was found that 19.2 % of the dwellings monitored showed radon concentration between 100 and 150 Bq m^{-3}, 40.4 % showed concentration between 150 and 200 Bq m^{-3}, 21.3 % showed concentration between 200 and 250 Bq m^{-3} and 19.2 % showed concentration between 250 and 300 Bq m^{-3}. The data distribution is skewed (skewness = 0.45) as shown in Figure 4.3 and it is well described by log-normal model (R= 0.986) which is shown in Figure 4.4. The GM and GSD of the data can be used to describe the distribution and their knowledge is useful to evaluate the fraction of rooms that exceed the reference values (Venoso et. al., 2009). The estimated parameters m' and σ' are related to the GM and the GSD by equations: $m' = \ln$ (GM) and $\sigma' = \ln$ (GSD). The estimated parameters of the distribution are $m' = 5.25$ and $\sigma' = 0.25$.

Table 4.6: Frequency distribution of types of rooms, shape of buildings, position of buildings, device of circulating air, water installation and the topology of the ground

General Parameter	Specific Parameter	Frequency	Percentage (%)
Types of Room	1. Bedroom	32	68.1
	2. Sitting Room	15	31.9
Shape of the Building	1. Bungalow	32	68.1
	2. Flat	6	12.8
	3. Storey	15	31.9
	4. Flat storey	4	8.5
Devices for Circulating Air	1. Air conditioner	0	0.0
	2. Electric Fan	31	66.0
	3. Nil	16	34.0
Water Installation	1.Well water	46	97.9
	2.Tap/Water Works	1	2.1
Position of Building	1. Above the ground	41	87.2
	2.Semi-Underground	2	4.3
	3. Above column	4	8.5
	4. Inner wall contact the ground	34	72.3
	5.Inner wall not contact the ground	13	27.7
	6.Fenced Building	10	21.3
	7.Un-fenced Building	37	78.7
Typology of the Ground	1.Loamy Soil	22	46.8
	2.Sandy Soil	19	40.4
	3. Clay Soil	6	12.8

Table 4.7: Frequency distribution of materials used for construction and covering the walls, floors, ceilings, doors and windows

General Parameter	Specific Parameter	Frequency	Percentage (%)
Materials for Construction of Wall	1. Block with cement	42	89.4
	2. Brick with mud	5	10.6
	3. Plaster with cement	47	100.0
Materials for Construction of Floor	1. Concrete	40	85.1
	2. wood	3	8.5
	3. Tiles	4	6.4
Materials for Construction of Ceiling	1. Abestor	36	76.6
	2. Fibre	4	8.5
	3. Wood	3	6.4
	4. Concrete	4	5.5
Materials for Construction of Window	1. Louvers	23	48.9
	2. Wood	24	51.1
Materials for Construction of Door	1. Wood	41	87.2
	2. Iron	4	8.5
	3. Curtain	2	4.3
Materials for Wall Covering	1. Paint	31	66.0
	2. Paint and Paper	2	4.3
	3. Nil	14	29.8
Materials of Ceiling Covering	1. Paint	28	59.6
	2. Nil	19	40.4
Materials of Window Covering	1. Mosquito Net	41	87.2
	2. Nil	6	12.8
Materials of Door Covering	1. Mosquito Net	14	29.8
	2. Nil	33	70.2

Table 4.8: Statistical distribution of radon concentrations in Iwo

Area	Site	Average ($Bq\ m^{-3}$)	SD ($Bq\ m^{-3}$)	Minimum ($Bq\ m^{-3}$)	Maximum ($Bq\ m^{-3}$)	GM ($Bq\ m^{-3}$)	GSD
Oke Afo	13	197	57	111	277	190	1.36
Oke Odo	23	198	49	125	299	192	1.28
Araromi	3	171	22	149	192	170	1.14
Ago Ogunde	3	249	54	192	299	245	1.25
Paku	2	153	10	146	160	153	1.07
Oweyo	3	180	21	160	201	180	1.12

SD- standard deviation among dwellings; GM – geometric mean, GSD – geometric standard deviation

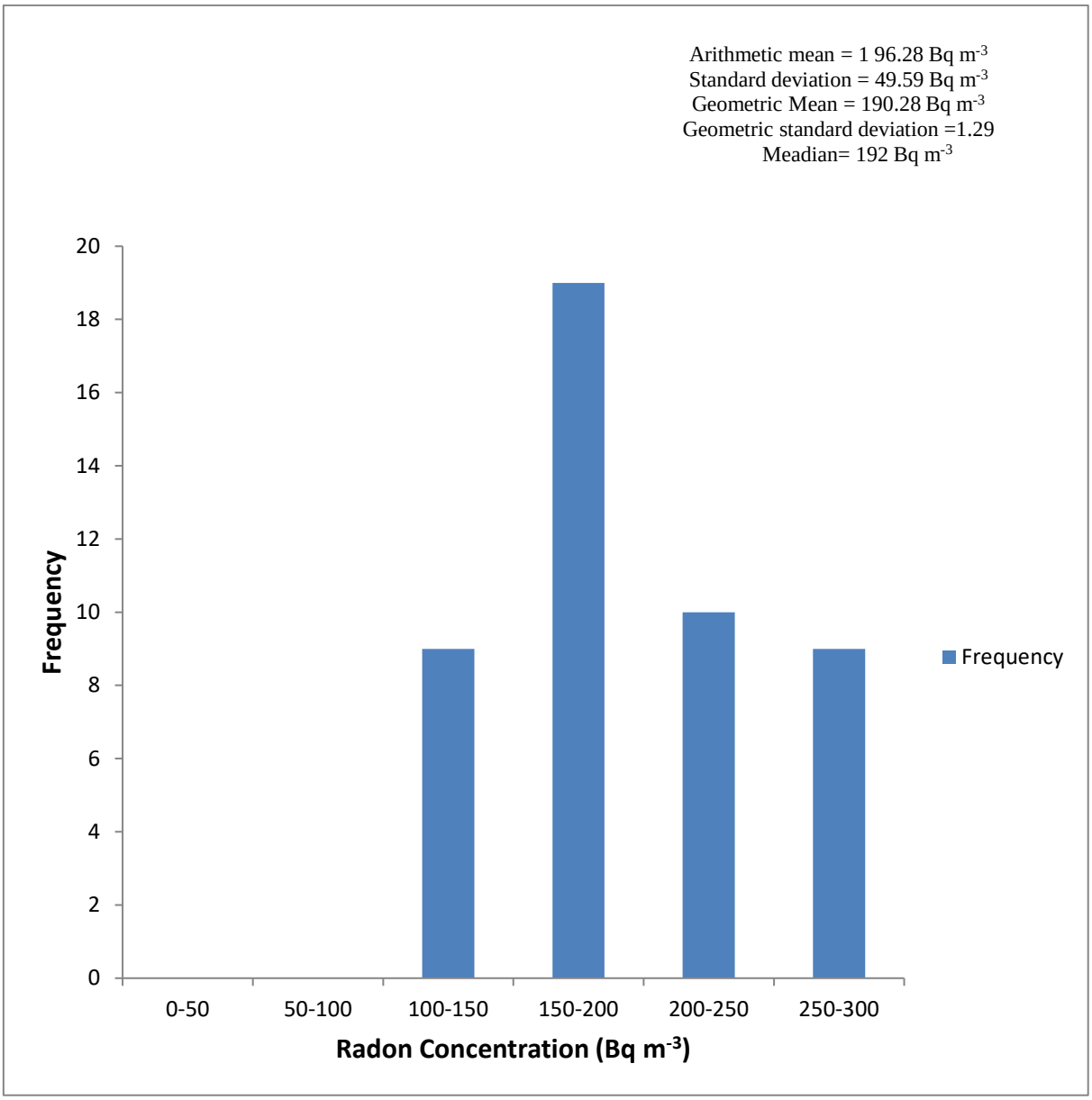

Figure 4.3 : Frequency distribution of radon concentrations in dwellings in Iwo

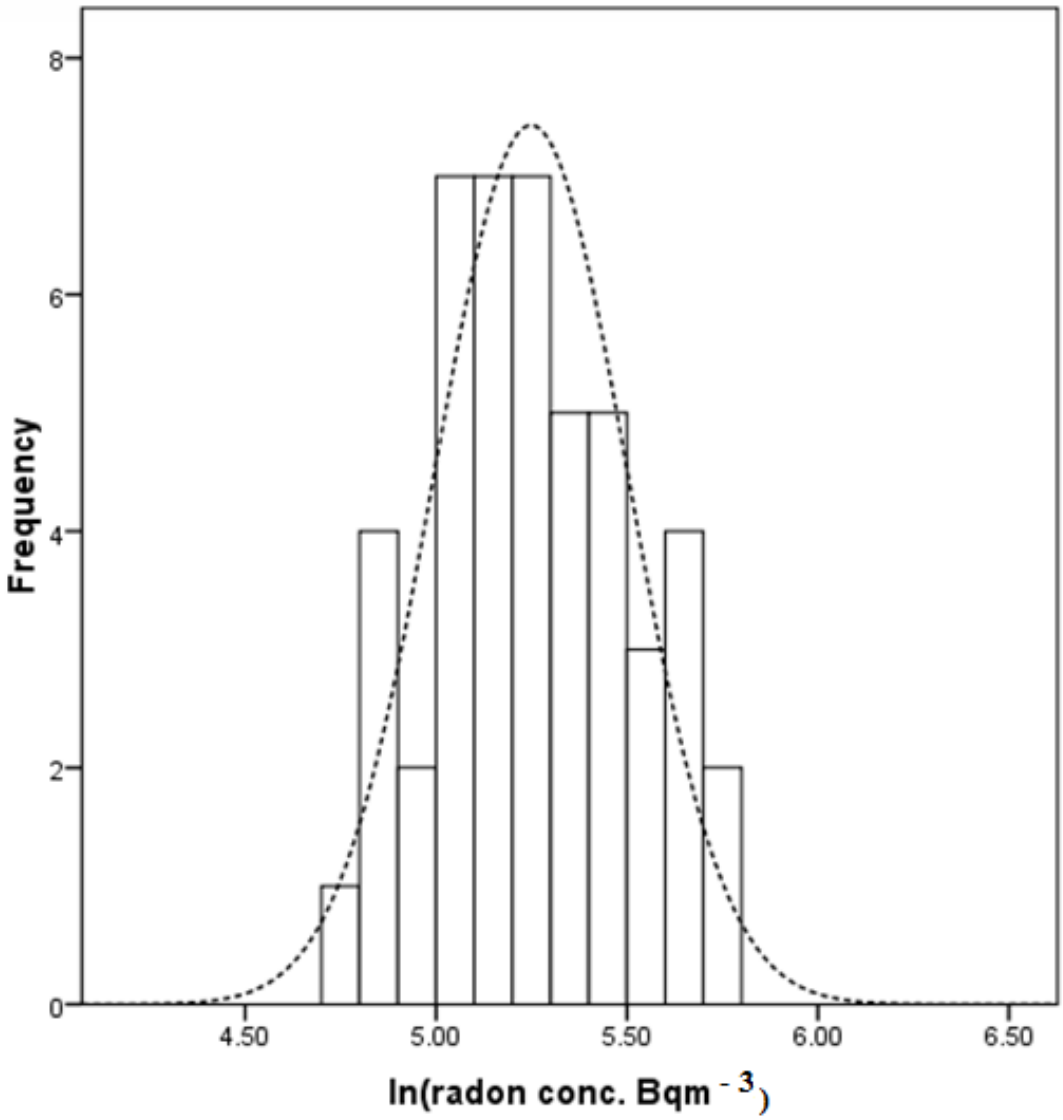

Figure 4.4: The distribution of logarithm of radon concentrations

In 12 houses, indoor radon was carried out in both living rooms and bedrooms in which CR-39 detectors were replaced in each location, during the rainy and dry seasons. In 83.33 % of living rooms, it was observed that, indoor radon concentrations were higher in rainy season than in dry season. Also, it was found that in 83.33 % of the bedroom, the level of radon concentrations were higher in rainy season than in dry season, as shown in Figures 4.5 and 4.6.

There is a positive correlation between indoor radon in dry season and rainy season as shown in Figure 4.7. The variation of radon concentration levels between the rainy season and the dry season is considered statistically significant at 95 % confidence level (paired t test, two-tailed p value = 0.0015). The decrease of indoor radon levels in hot weather could be explained by the increase in the frequency of opening of the window by the residents (Doi *et al*., 1994).

In rainy season, indoor radon levels varied from 128 to 299 Bq m^{-3} with arithmetic mean of 219.3 ± 52.1 Bq m^{-3}. In living rooms, it ranged from 128 to 277 Bq m^{-3} with average of 200.0 ± 56.8 Bq m^{-3}; while in bedrooms it ranged from 128 to 299 Bq m^{-3} with average of 228.4 ± 48.8 Bq m^{-3}. The frequency distribution in rainy season is shown in Figure 4.8.

In dry season, the variation in indoor radon levels was found to be ranged from 111 to 236 Bq m^{-3} with mean of 170.1 ± 30.7 Bq m^{-3} and it ranged from 111 to 236 Bq m^{-3} and 125 to 222 Bq m^{-3} with averages of 176.6 ± 36.9 Bq m^{-3} and 167.1 ± 28.3 Bq m^{-3} in living rooms and bedrooms, respectively. The frequency distribution in dry season is shown in Figure 4.9.

The average indoor radon concentration found in bedrooms (199.7 ± 50.5 Bq m^{-3}) was higher than that of living rooms (189.1 ± 48.4 Bq m^{-3}). The variation of radon concentration levels between the bedrooms and the living rooms is considered not statistically significant at 95 % confidence level (unpaired t test, two-tailed p value = 0.4963).

Indoor radon levels in Iwo town showed more variation in different seasons. The variation in indoor radon levels in the same season may be due to the ventilation as well as the building characteristics (Faheem *et al*., 2007). The range variation of the indoor radon

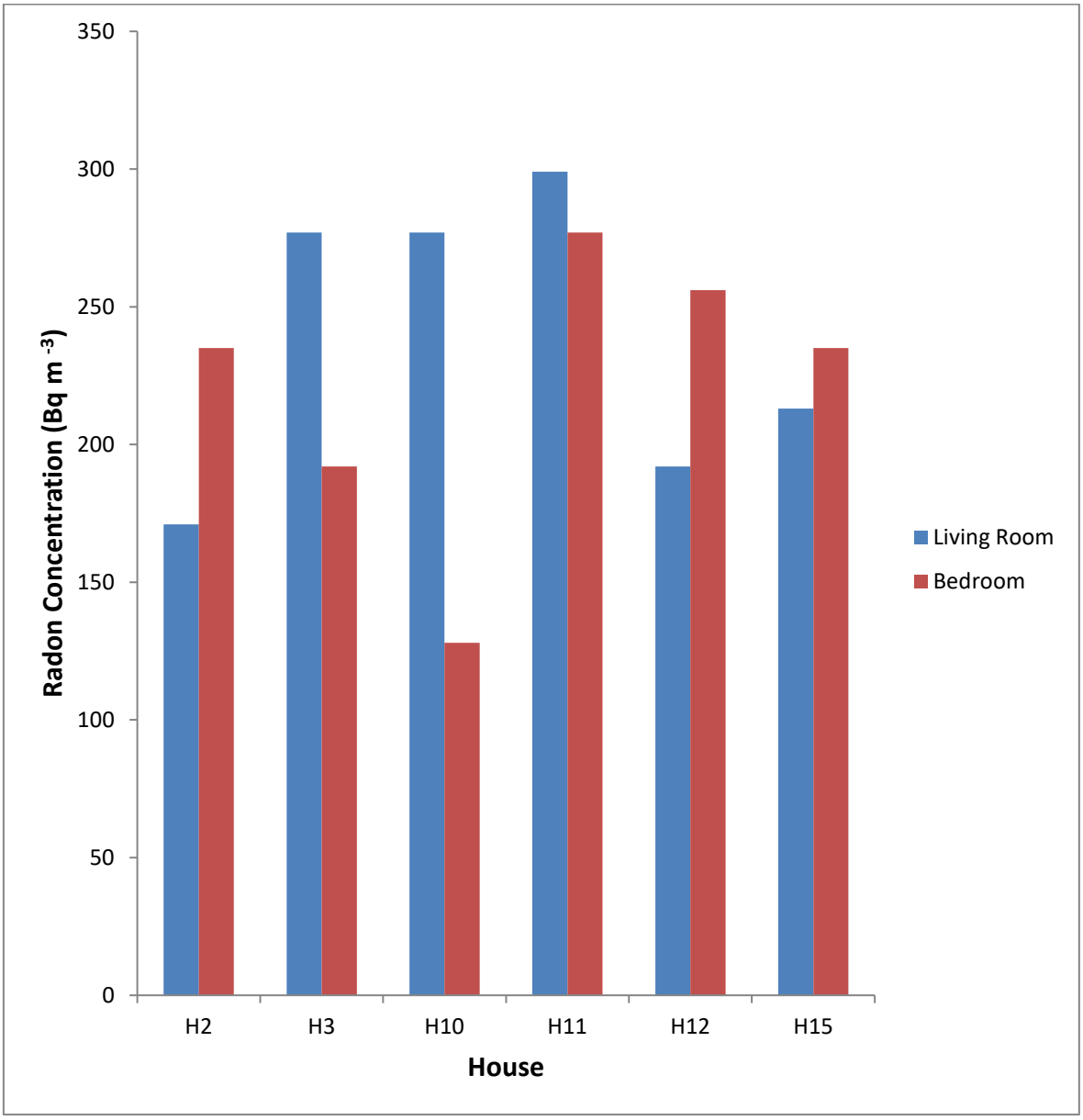

Figure 4.5: Comparison of radon concentrations during rainy season between living rooms and bedrooms

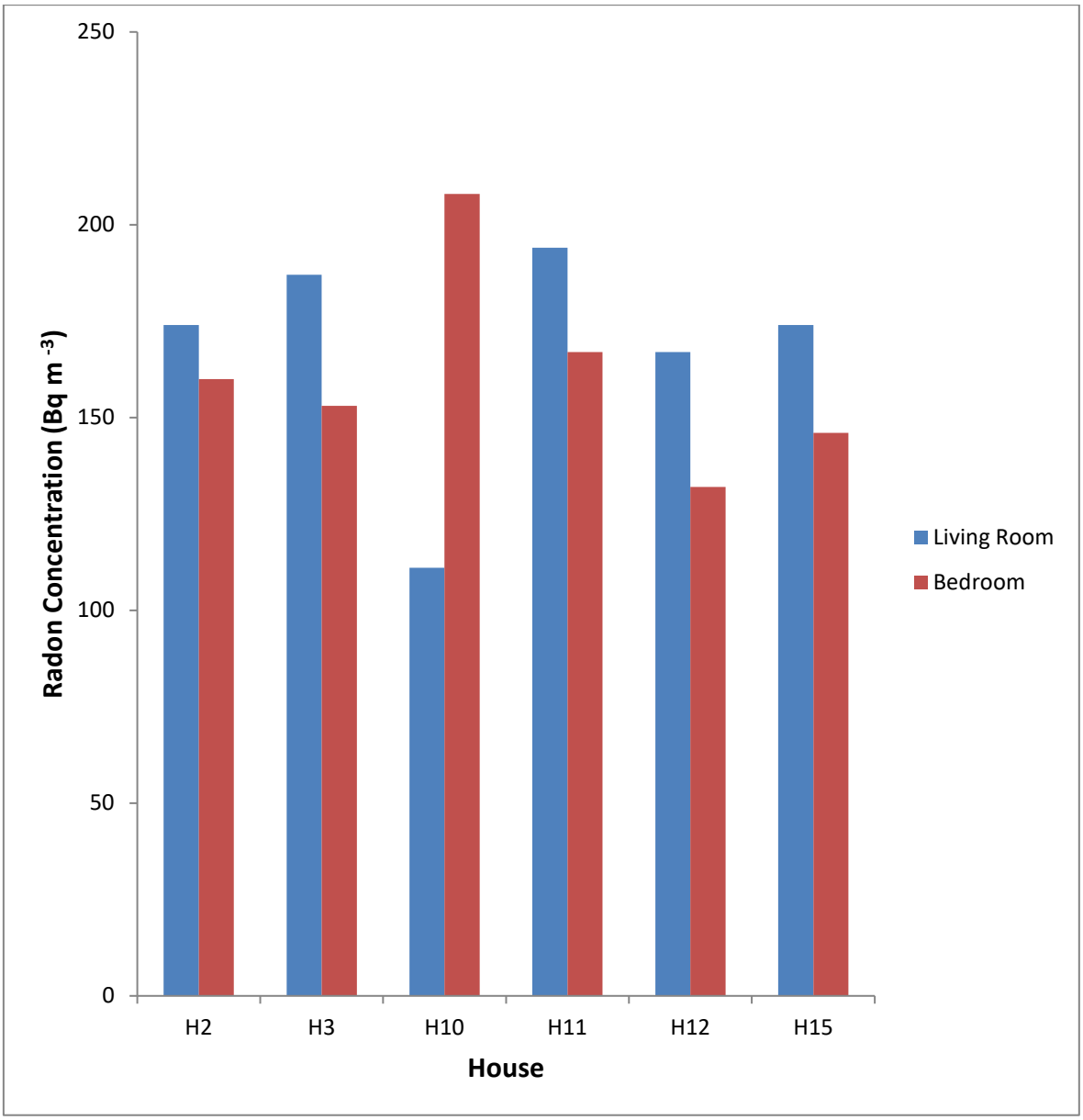

Figure 4.6: Comparison of radon concentrations during dry season between living rooms and bedrooms

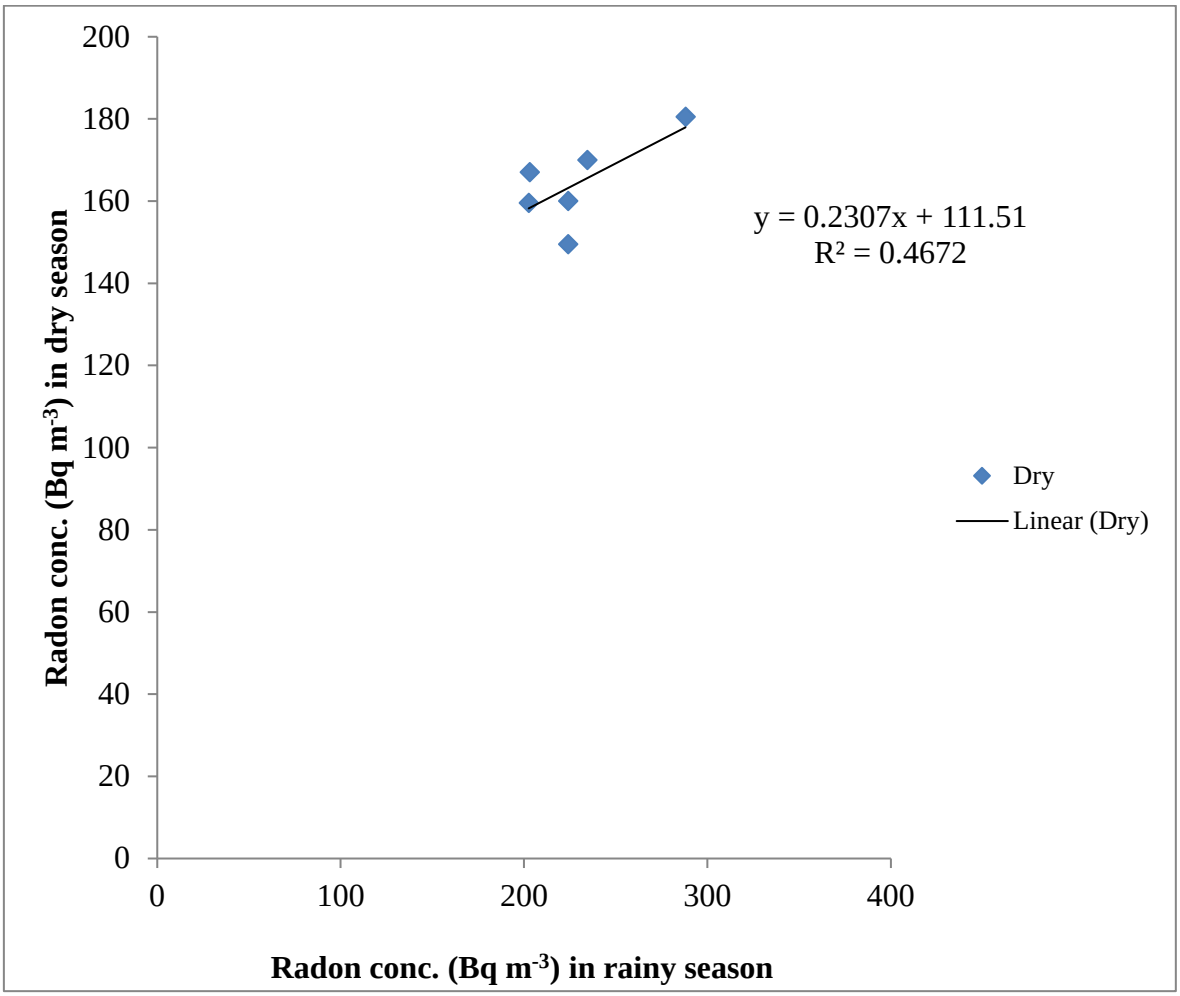

Figure 4.7: Correlation of radon concentration in rainy season and in dry season

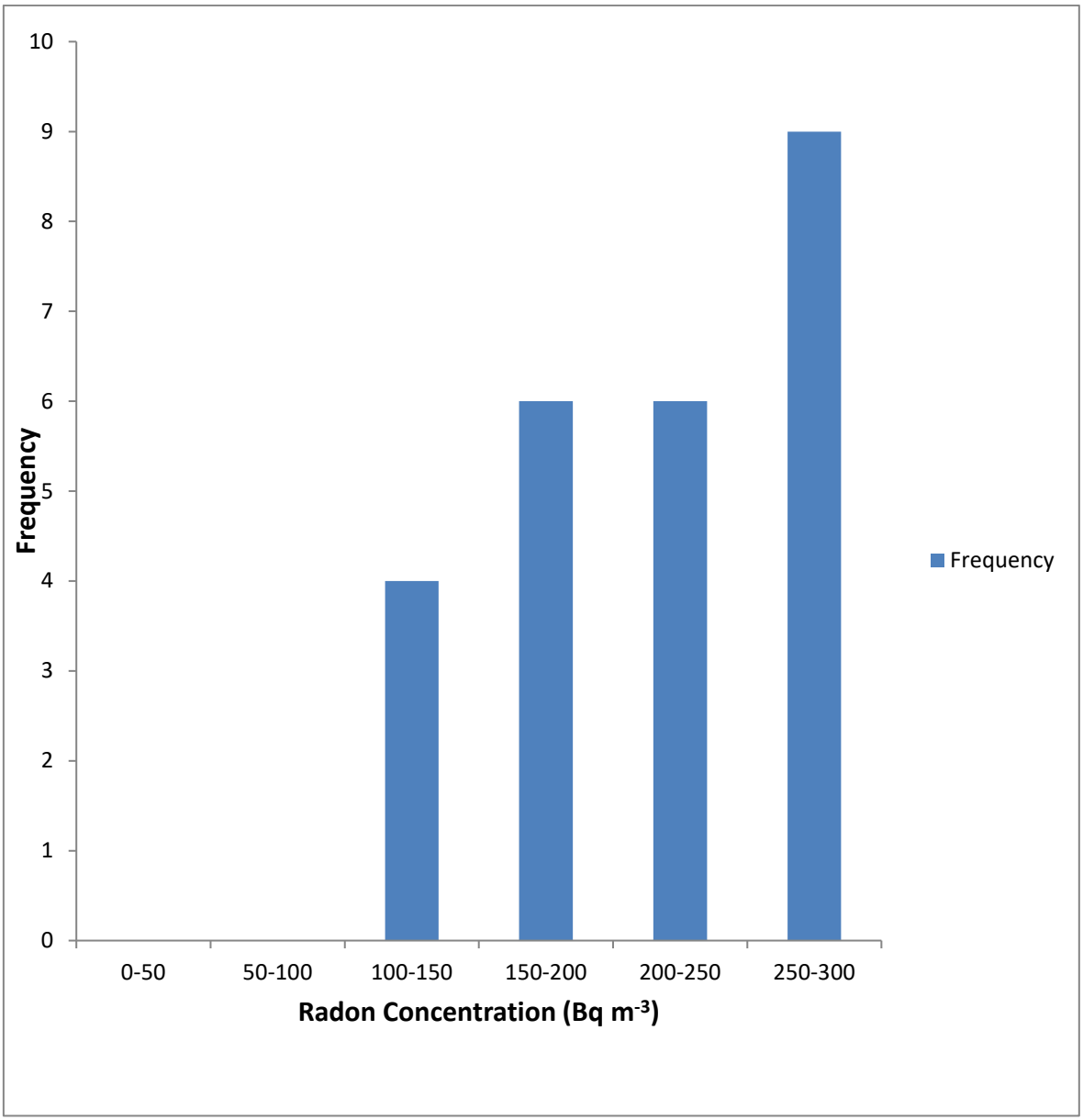

Figure 4.8: Frequency distribution of radon concentrations in houses during the rainy season

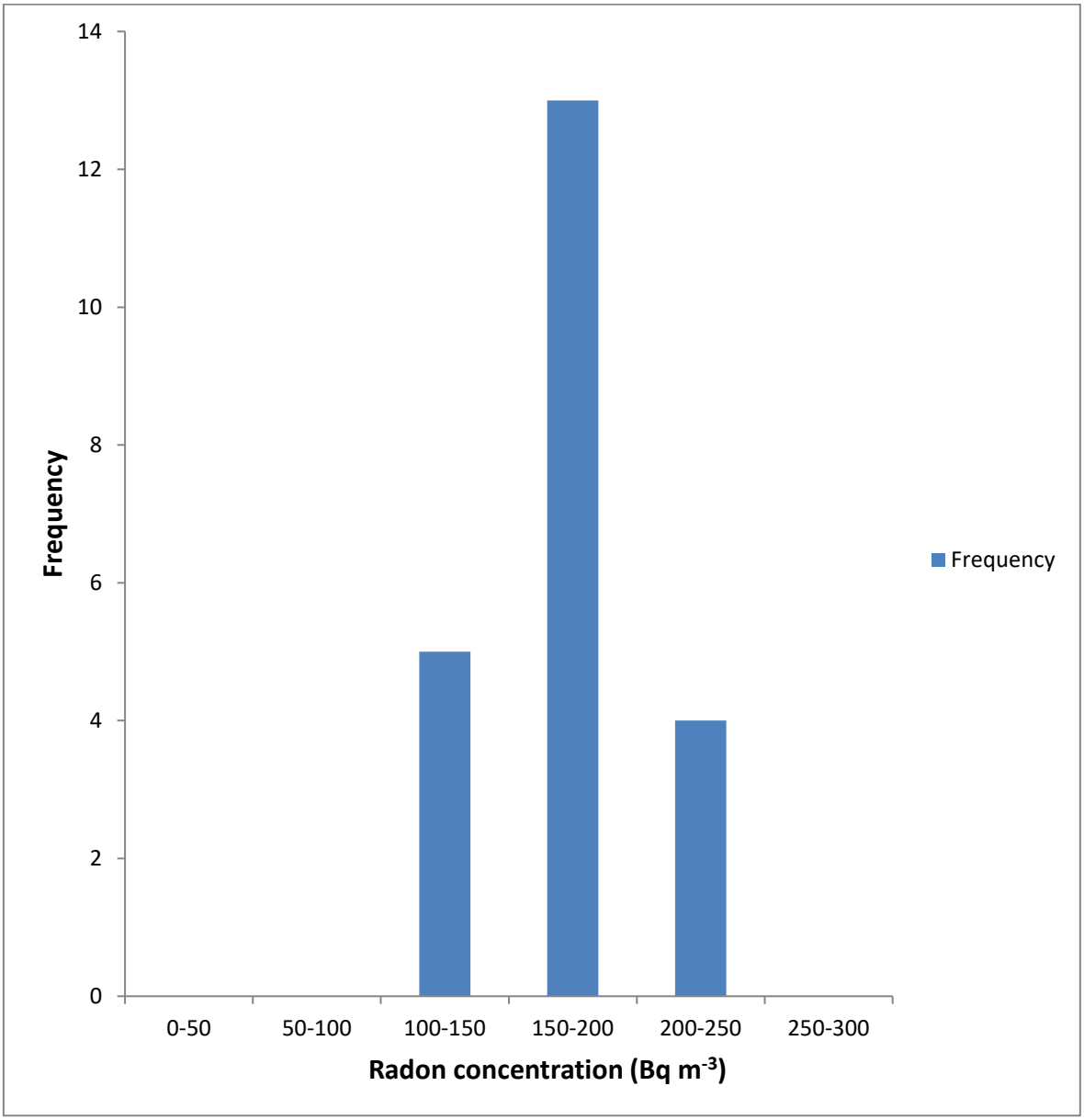

Figure 4.9: Frequency distribution of radon concentrations in houses during the dry season

activities between different dwellings in these areas can be explained by the different ventilation rates, nature of the soil underneath and particularly the geological considerations. The results vary because different factors determine indoor radon concentrations and one important factor is the geology.

During the rainy season, radon tends to be higher because it is confined underground by a layer of water saturated surface soil which has much reduced gas permeability so for a site that has a relatively low permeability, the wet layer becomes thinner than the monitoring depth and capping effect causes higher radon value during the rainy season. The period between May and July is characterized with heavy rainfall in south- western, Nigeria. And during this period, windows and doors are usually closed and the radon readings are expected to be at their highest. It is normal to have more open windows summer time (dry season) and consequently a lower indoor radon level than in the wet season (Obed *at el*., 2011b).

In this present indoor radon survey, 40.4 % of the dwellings were above the lower limit (200 Bq m^{-3}) of International Commission on Radiological Protection (ICRP) reference level as shown in Figures 4.10 and 4.11. The mean values of radon levels are considered safe while comparing with the safe limit in dwellings between 200 and 600 Bq m^{-3}, the action level recommended by International Commission on Radiological Protection (ICRP, 1993).

4.3.1 RADON CONCENTRATIONS IN DIFFERENT FLOORS

The average indoor radon concentration in dwellings on the ground floor (212.1 ± 54.0 Bq m^{-3}) was slightly higher than that of first floor (208.0 ± 32.0 Bq m^{-3}), as shown in Figure 4.12. Normally, radon levels tend to be higher at ground floors than upstairs because it is where radon enters the house and also this might be due to poor ventilation at the ground floors. The first floors might have higher exchange rates with outdoor air. The variation of radon concentration levels between ground and first floors is considered not statistically significant at 95 % confidence level (unpaired t-test, two-tailed p value = 0.205).

In general, it was observed that the radon concentrations are high on the ground floor and decrease with higher floors, although with exceptional variation in the trend

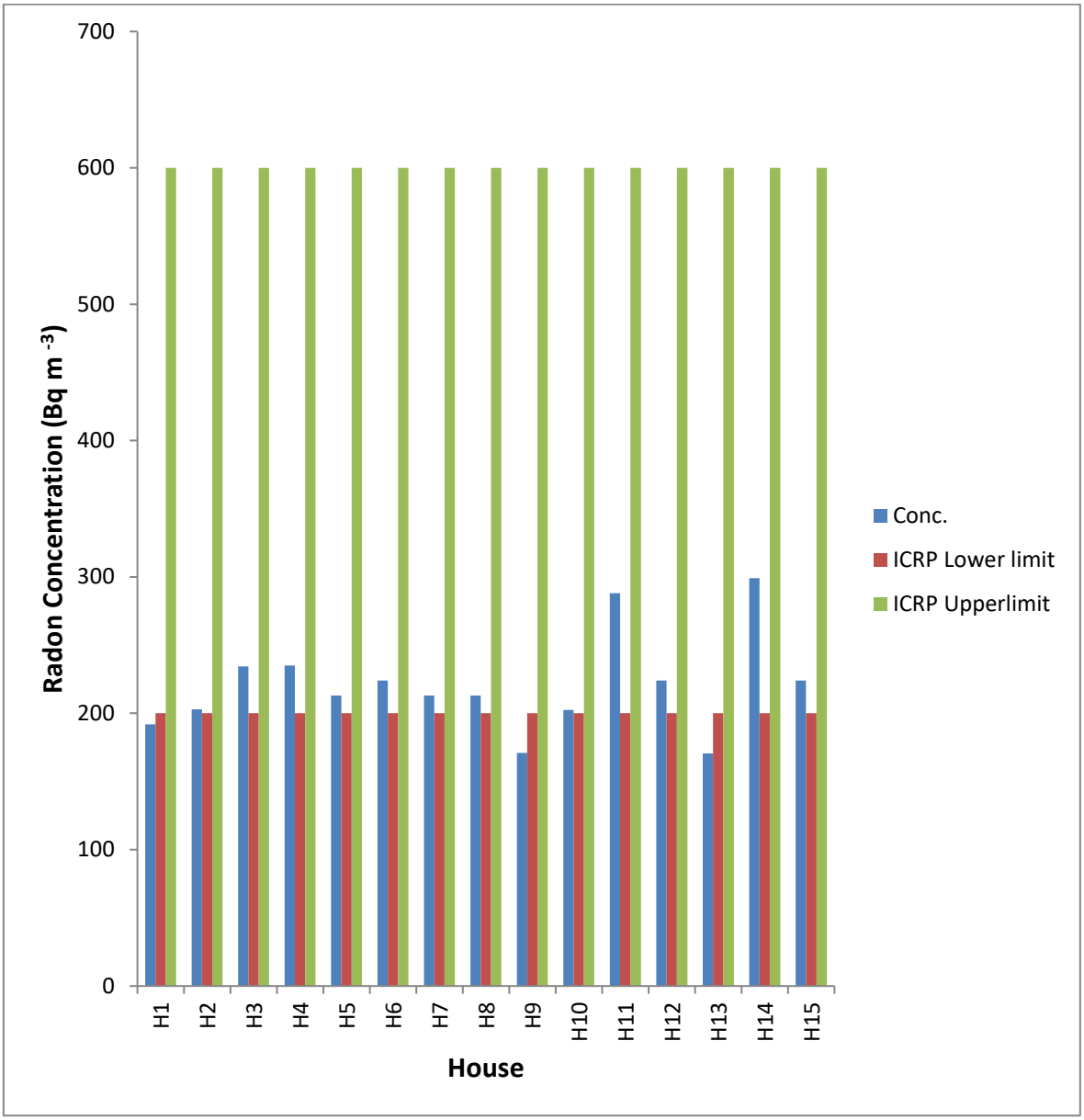

Figure 4.10: Comparison of average radon concentrations in houses during rainy season with reference levels from ICRP 65, 1993

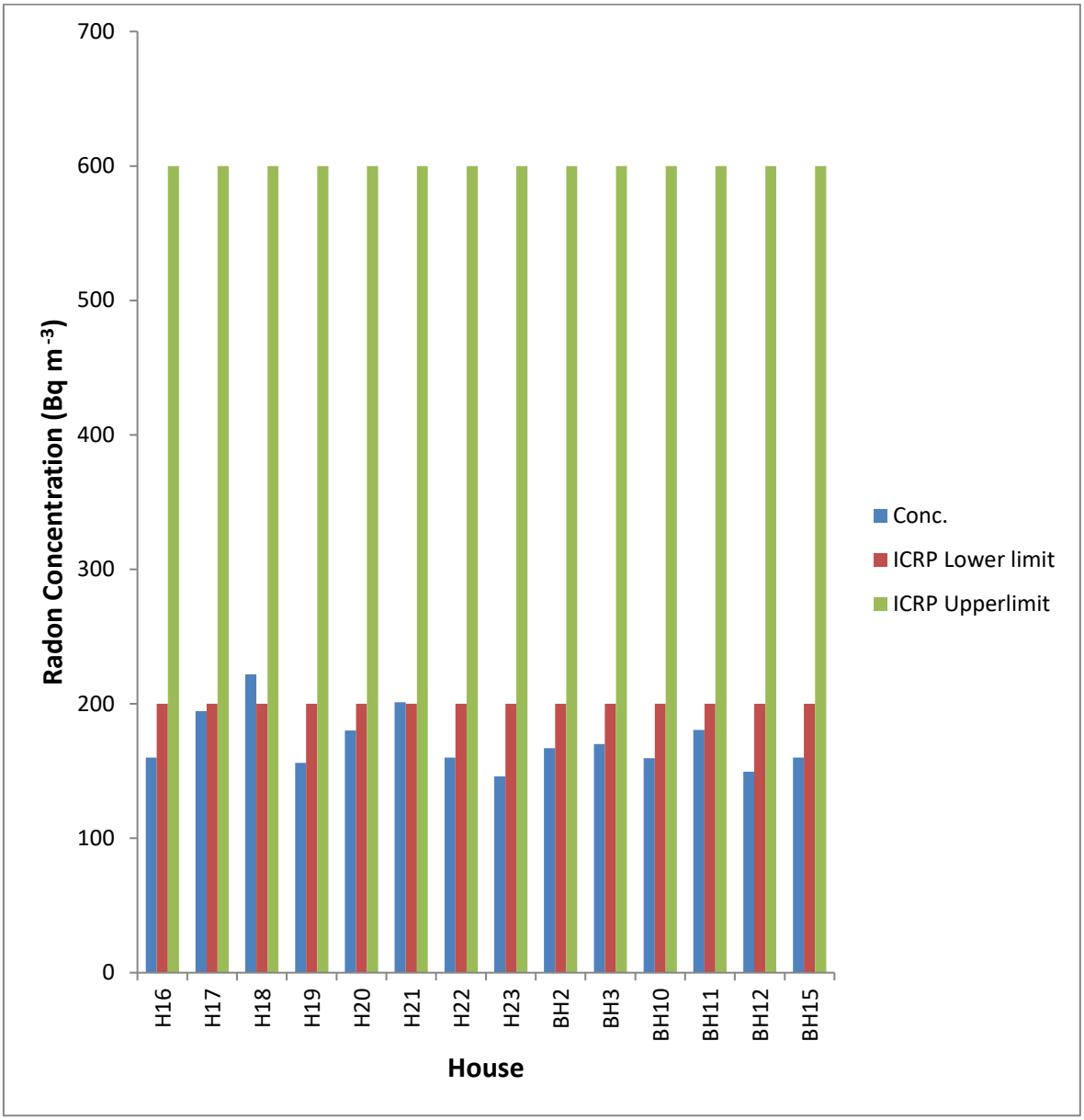

Figure 4.11: Comparison of average radon concentrations in houses during dry season with reference levels from ICRP 65, 1993

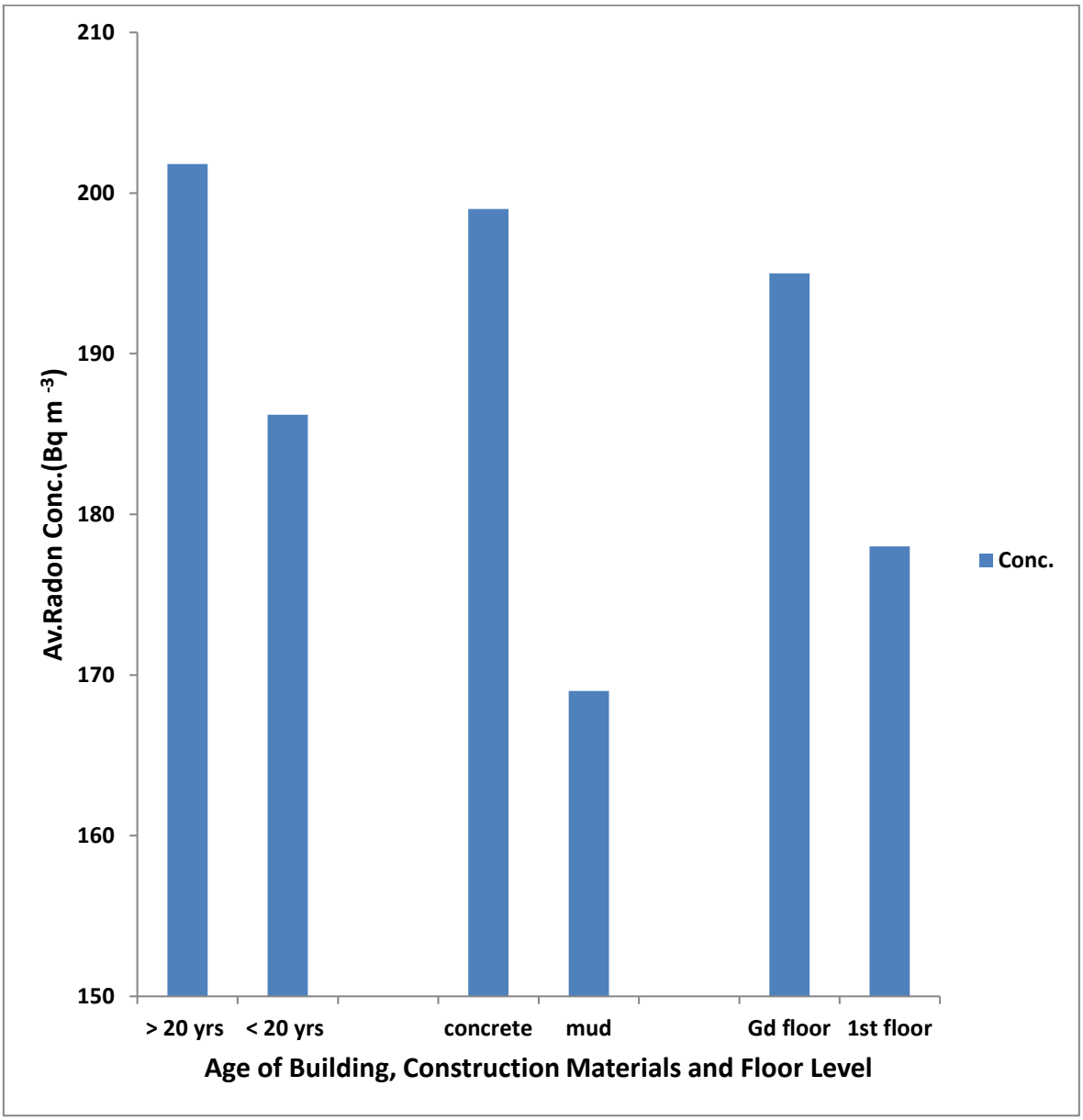

Figure 4.12: Variation of radon concentrations with age of building, construction materials and floor levels

between two floors (Malik and Atari, 1989; Ayotte *et al*., 1998). The mass balance equation was employed for indoor radon modeling. The model predicts a decreasing trend of indoor radon with height, whereas in reality the indoor radon concentrations are highly dependent on the ventilation rate and the change in ventilation rate over the sampling period, which is difficult to model (Shaikh *et al*., 2003). In two high-rise buildings and a series of similar room up to the seventeenth floors, it was found that there was no systematic reduction of radon activity with floor height above the ground levels (Abu-Jarad and Fremlin, 1982).

The indoor radon concentration depends on the relationship between the volume of air contained in the indoor space, the rate of production or released of the radionuclide, the rate of removal of the radionuclides from the air via decay or setting, the rate of air exchange with the outside atmosphere and the outdoor concentration (Jones, 1999). The radon emanation from building materials and ventilation rate are more important parameters in estimating indoor radon level (Shaikh *et al*., 2003).

4.3.2 EFFECT OF BUILDING AGES, CONSTRUCTION MATERIALS AND BUILDING STRUCTURES

The indoor radon data obtained from the houses surveyed in this study area was analysed depending upon the age of the house, ventilation conditions and the type of building materials. The probable effects of the age of the house and the construction materials were studied in randomly selected houses, which were based on accessibility, from Iwo town. For this purpose, the houses were classified into three groups: less than 20 years old (After 1991), greater than 20 years old (1997 - 1991) and less than 30 years old (1946 - 1976). Two groups (< 20) and (> 20) years old were considered because the sample size of the third group were not large enough to give good statistics.

About 29.79 % were < 20 years old with an average radon concentration of 186.2 $\pm$ 50.8 Bq m^{-3} while 68.09 % were found to be > 20 years old with an average radon concentration of 201.8 $\pm$ 49.5 Bq m^{-3}. The average radon concentration is higher in the old houses than the new ones, as shown in Figure 4.12. This is because ventilation rates in the old houses are less than the new houses. The presence of cracks in the floors and walls in the old houses allows radon gas to emanate easily from soil. The differences in radon

concentration levels between old and new houses were not statistically significant (unpaired t-test, two tailed p value = 0.3438) at 95 % confidence level.

The two types of building materials used for the construction of the buildings were also identified: brick with mud and block with cement. The average radon concentration measured for the buildings constructed of brick with mud was 169.4 $\pm$ 21.4 Bq m^{-3} while the building constructed of block with cement have an average of 199.45 $\pm$ 51.15 Bq m^{-3}. The radon concentration from the use of block with cement is higher than that of brick with mud, as shown in Figure 4.12. This might be due to the effects of the building materials. Radon emanation increases with increase of thickness of building materials made from granite but not with ones made of clay (Abu- Jarad et al., 1980).

4.3.3 THE EFFECT OF VENTILATOR

Only 69.96 % of the houses surveyed had electric fan to exchange indoor air. In rainy season, the average indoor radon levels of the dwellings using electric fan (220 $\pm$ 50 Bq m^{-3}) was slightly greater than where there was no fan (218 $\pm$ 59 Bq m^{-3}); while in dry season, the difference is higher. The arithmetic mean of the houses surveyed using fan in rainy and dry seasons are 220 $\pm$ 50 Bq m^{-3} and 168 $\pm$ 24 Bq m^{-3}.

Indoor radon is higher in rainy season than in dry season, as shown in Figure 4.13. The variation might be due to the usage of fan more frequently in dry season than in rainy season for the exchange of indoor air.

4.3.4 EFFECTS OF COVERING MATERIALS ON INDOOR CONCENTRATIONS

The commonest combination (65.96 %), the second (23.40 %) and the third (4.26 %) of covering materials for walls, ceilings and floors were (Carpet Paint Paint), (Concrete Asbestos Plaster) and (Carpet Asbestos Plaster) with average of 197 ± 50, 195 ± 52 and 222 ± 78 Bq m^{-3}, respectively, as presented in Table 4.9.

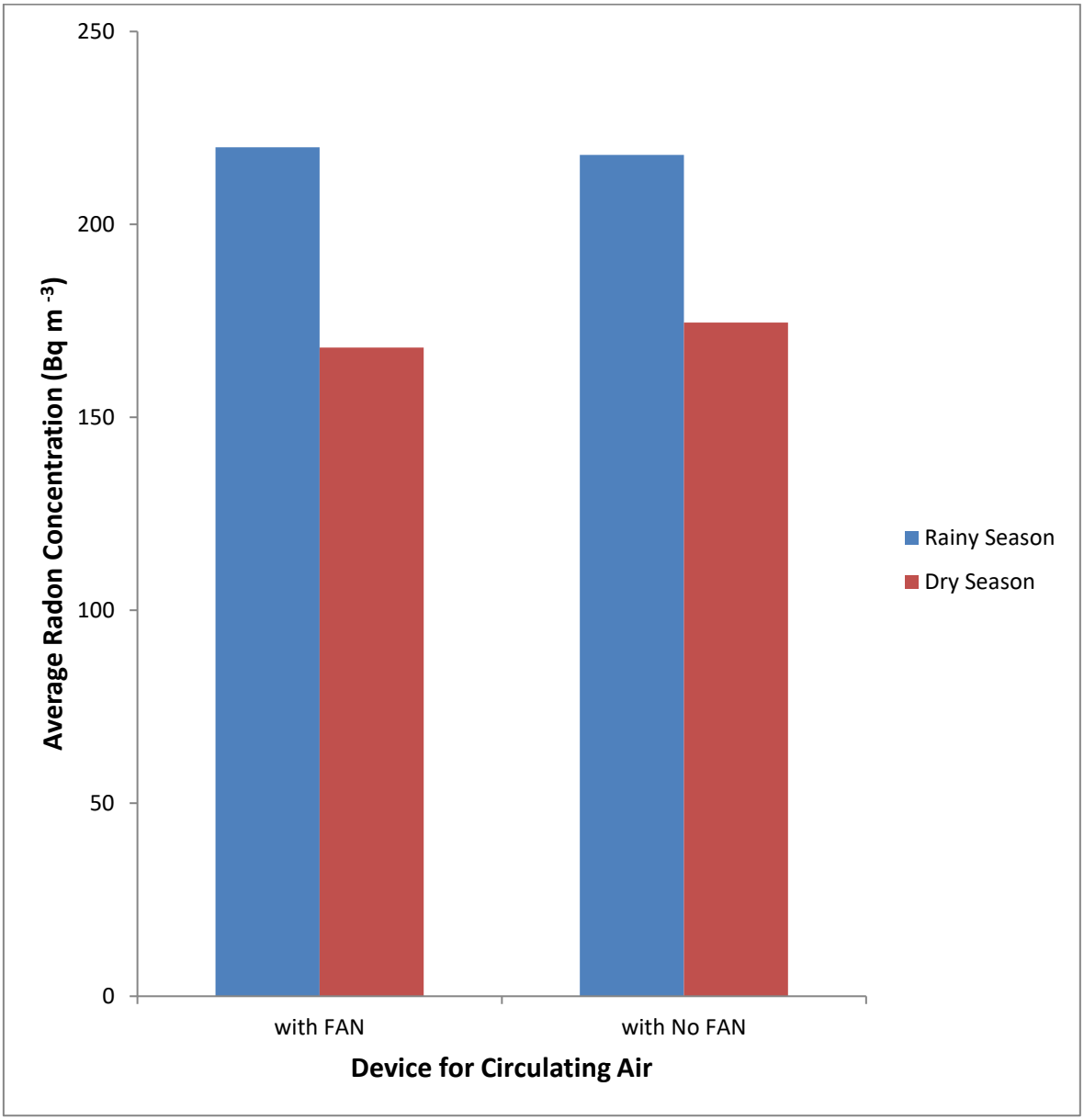

Figure 4.13: Comparison of average radon concentrations between the rooms with fan and the rooms with no fan

Table 4.9: Statistical distribution of radon concentration among the 3 combinations of construction coverings for walls, floors and ceilings in the dwellings surveyed

	Combination A: carpet, paint and paint	Combination B: Concrete, abestor and plaster	Combination C: Capert, abestor and plaster
Number of dwellings	31	11	2
Arithmetic Mean (Bq m^{-3})	197	195	222
Min (Bq m^{-3})	125	111	167
Max (Bq m^{-3})	299	277	277
SD (Bq m^{-3})	50	52	78
GM (Bq m^{-3})	191	188	215
GSD	1.28	1.33	1.43

SD- standard deviation among dwellings; GM – geometric mean, GSD – geometric standard deviation

4.4 EFFECTIVE DOSE, WORKING LEVEL AND EXCESS LIFETIME CANCER RISK TO THE OCCUPANTS

The range of Working Level of different houses varied from 12.0 to 32.3 mWL. The arithmetic mean, Geometric mean and Geometric standard deviation of working level were 21.2 ± 5.4 mWL, 20.6 mWL and 5.6, respectively. The average of working level in living rooms and bedrooms obtained were 20.44 ± 5.53 mWL and 21.58 ± 5.46 mWL, respectively. The estimation of Working Level per Month (WLM) was determined with average of 0.84 ± 0.22 y^{-1} and 0.89 ± 0.22 y^{-1} in living rooms and bedrooms, respectively. The summary is presented in Table 4.10 – 4.12.

The effective dose to the occupants for radon inhalation was estimated using conversion factor of 9×10^{-6} mSv y^{-1}, which varied from 2.80 to 7.53 mSv y^{-1} with arithmetic mean of 4.95 mSv y^{-1}. The annual effective doses thus calculated for radon inhalation by the inhabitants in living rooms and bedrooms were found to vary in the range of 2.80 to 6.98 mSv y^{-1} and 3.15 to 7.53 mSv y^{-1}, with mean of 4.76 ± 1.22 mSvy^{-1} and 5.03 ± 1.27 mSv y^{-1}, respectively. The highest effective dose (7.53 mSv y^{-1}) was observed in Ago-Ogunde and Oke-Odo with average of 6.27 ± 1.36 mSv y^{-1} and 5.07 ± 1.30 mSv y^{-1}, respectively, as in Tables 4.13 – 4.15.

In Nigeria, and other African countries have not yet formulated national directives to enforce radon limits in dwellings and workplaces. In its publication 65, the ICRP recommends that action levels for the annual effective dose should be set between 3 and 10 mSv y^{-1} (ICRP, 1993). The doses received by the population investigated in Iwo town, Osun State, South-western Nigeria lie below the upper limit (10 mSv y^{-1}).

The Excess Lifetime Cancer Risk (ELCR) obtained range from 10.8×10^{-3} to 29.0×10^{-3} $(MPY)^{-1}$ with an average of $(19.0 \pm 4.8) \times 10^{-3}$ $(MPY)^{-1}$. The mean excess lifetime cancer risk obtained for living rooms and bedrooms in Iwo town were 18.3×10^{-3} and 19.3×10^{-3} $(MPY)^{-1}$, respectively, as presented in Tables 4.13 – 4.15. The ELCR obtained was higher than the world average 0.29×10^{-3} $(MPY)^{-1}$ (UNSCEAR, 2000).

Table 4.10 : Average radon concentrations, WL, and WLM in bedrooms in different areas in Iwo

Area	Average Radon Concentration ($Bq\ m^{-3}$)	Working Level (mWL)	Working Level Month (y^{-1})
Oke-Afo	205.1 ± 56.9	22.18 ± 6.15	0.91 ± 0.25
Oke-Odo	201.2 ± 51.7	21.75 ± 5.59	0.90 ± 0.23
Araromi	170.1 ± 53.84	18.43 ± 3.29	0.76 ± 0.14
Ago-Ogunde	249 ± 53.84	26.92 ± 5.82	1.11 ± 0.24
Paku	153 ± 9.90	16.54 ± 1.07	0.68 ± 0.04
Oweyo	180.33 ± 20.50	19.50 ± 2.22	0.80 ± 0.09
Mean ± SD	199.7 ± 50.5	21.58 ± 5.46	0.89 ± 0.22

Table 4.11: Average radon concentrations, WL, and WLM in living rooms in different areas in Iwo

Areas	Average Radon Concentration (Bq m^{-3})	Working Level (mWL)	Working Level Month (y^{-1})
Oke-Afo	188.5 ± 60.1	20.38 ± 6.49	0.84 ± 0.27
Oke-Odo	191.8 ± 45.4	20.73 ± 4.90	0.85 ± 0.20
Araromi	171.0 ± 34	18.49 ± 3.68	0.76 ± 0.15
Mean $\pm$ $\boldsymbol{SD}$	189.1 ± 48.4	20.44 ± 5.23	0.84 ± 0.22

Table 4.12: Average radon concentration, WL, and WLM in different areas in Iwo

Area	Average Radon Concentration ($Bq\ m^{-3}$)	Working Level (mWL)	Working Level Month (y^{-1})
Oke-Afo	197.5± 56.5	21.4 ± 6.1	0.88 ± 0.25
Oke-Odo	197.9 ± 48.7	21.4 ± 5.3	0.88 ± 0.22
Araromi	170.7 ± 21.5	18.5 ± 2.3	0.76 ± 0.10
Ago-Ogunde	249.0 ± 53.8	26.9 ± 5.8	1.11 ± 0.24
Paku	153.0 ± 9.9	16.5 ± 1.1	0.68 ± 0.04
Oweyo	180.3 ± 20.5	19.5 ± 2.2	0.80 ± 0.09
Mean $\pm$ *SD*	196.3 ± 49.6	21.2 ± 5.4	0.87 ± 0.22

Table 4.13: Effective dose and excess lifetime cancer risk estimated in bedrooms in different areas in Iwo

Areas	Effective dose ($mSv\ yr^{-1}$)	Excess Lifetime Cancer Risk x 10^{-3} $(MPY)^{-1}$
Oke-Afo	5.2 ± 1.4	19.9
Oke-Odo	5.1 ± 1.3	19.5
Araromi	4.3 ± 0.8	16.5
Ago-Ogunde	6.3 ± 1.4	24.2
Paku	3.9 ± 0.3	14.8
Oweyo	4.5 ± 0.5	17.5
Average	5.03 ± 1.27	19.4

Table 4.14: Effective dose and excess lifetime cancer risk estimated in living rooms in different areas in Iwo

Area	Effective dose ($mSv\ yr^{-1}$)	Excess Lifetime Cancer Risk x 10^{-3} $(MPY)^{-1}$
Oke-Afo	4.75 ± 1.51	18.3
Oke-Odo	4.84 ± 1.14	18.6
Araromi	4.31 ± 0.86	16.6
Average	4.76 ± 1.22	18.3

Table 4.15: Effective dose and excess lifetime cancer risk estimated in different areas in Iwo

Area	Effective dose ($mSv\ yr^{-1}$)	Excess Lifetime Cancer Risk $x\ 10^{-3}$ $(MPY)^{-1}$
Oke-Afo	5.0 ± 1.4	19.2
Oke-Odo	5.0 ± 1.2	19.2
Araromi	4.3 ± 0.5	16.6
Ago-Ogunde	6.3 ± 1.4	24.2
Paku	3.9 ± 0.3	14.8
Oweyo	4.5 ± 0.5	17.5
Average	5.0 ± 1.2	19.0

4.5 ACTIVITY CONCENTRATIONS OF ^{40}K, ^{226}Ra AND ^{232}Th IN SOIL AND ROCK SAMPLES

The BDL values for ^{40}K, ^{226}Ra and ^{232}Th determined were 11.47, 5.15 and 2.23 Bq kg^{-1}, respectively. The activity concentrations of the samples ranged between 11.1 to 1449.7 Bq kg^{-1}, < 5.15 to 99.10 Bq kg^{-1} and < 2.23 to 106.48 Bq kg^{-1} for ^{40} K, ^{226} Ra and ^{232}Th, respectively. The frequency distribution of ^{40}K, ^{226}Ra and ^{232}Th are shown in Figures 4.14- 4.16.

The average activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th were 497.4 ± 312.4 Bq kg^{-1}, 16.53 ± 15.92 Bq kg^{-1} and 22.19 ± 15.33 Bq kg^{-1}, respectively, as presented in Table 4.16. The mean concentrations are in decreasing order, $C_{Th} < C_{Ra} < C_{K,}$. The activity concentrations of soil samples varied between 11.08 -1105.03 Bq kg^{-1}, < 5.15 – 35.37 Bq kg^{-1} and < 2.23 - 106.48 Bq kg^{-1} for ^{40}K, ^{226}Ra and ^{232}Th, respectively. The means activity concentrations of soil samples for ^{40}K, ^{226}Ra and ^{232}Th were 447.4 ± 216.6, 13.02 ± 7.83 and 25.17 ± 15.37 Bq kg^{-1} , respectively. The mean activity concentrations of rock samples for ^{40}K, ^{226}Ra and ^{232}Th were 647.4 ± 478.0, 27.05 ± 26.60 and 13.25 ± 11.47 Bq kg^{-1}, respectively.

The activity concentrations of ^{40}K and ^{226}Ra of the rock samples were higher than that of sandy soil, loamy soil and the clay soil samples, as shown in Figure 4.17. The average activity concentrations of metamorphic rocks for ^{40}K (1182.5 ± 231.8 Bq kg^{-1}), ^{226}Ra (37.36 ± 43.97 Bq kg^{-1}) and ^{232}Th (22.15 ± 17.37 Bq kg^{-1}) are higher than that of Igneous and Sedimentary rocks, as shown in Figure 4.18. Among the compositions of rock samples observed, the highest activity concentration was found in pragmatic for ^{40}K while the Talc has the least, as shown in Figure 4.19.

The average concentrations of soil samples for ^{40}K, was higher than the world average value but ^{226}Ra and ^{232}Th were below the world average values (420 Bq kg^{-1} for ^{40}K, 33 Bq kg^{-1} for ^{226}Ra and 45 Bq kg^{-1} for ^{232}Th) (UNSCEAR, 2000). The mean activity concentrations of rock samples for ^{40}K (647.4 ± 478.0 Bq kg^{-1}) was found to be higher than the world average value (420 Bq kg^{-1}).

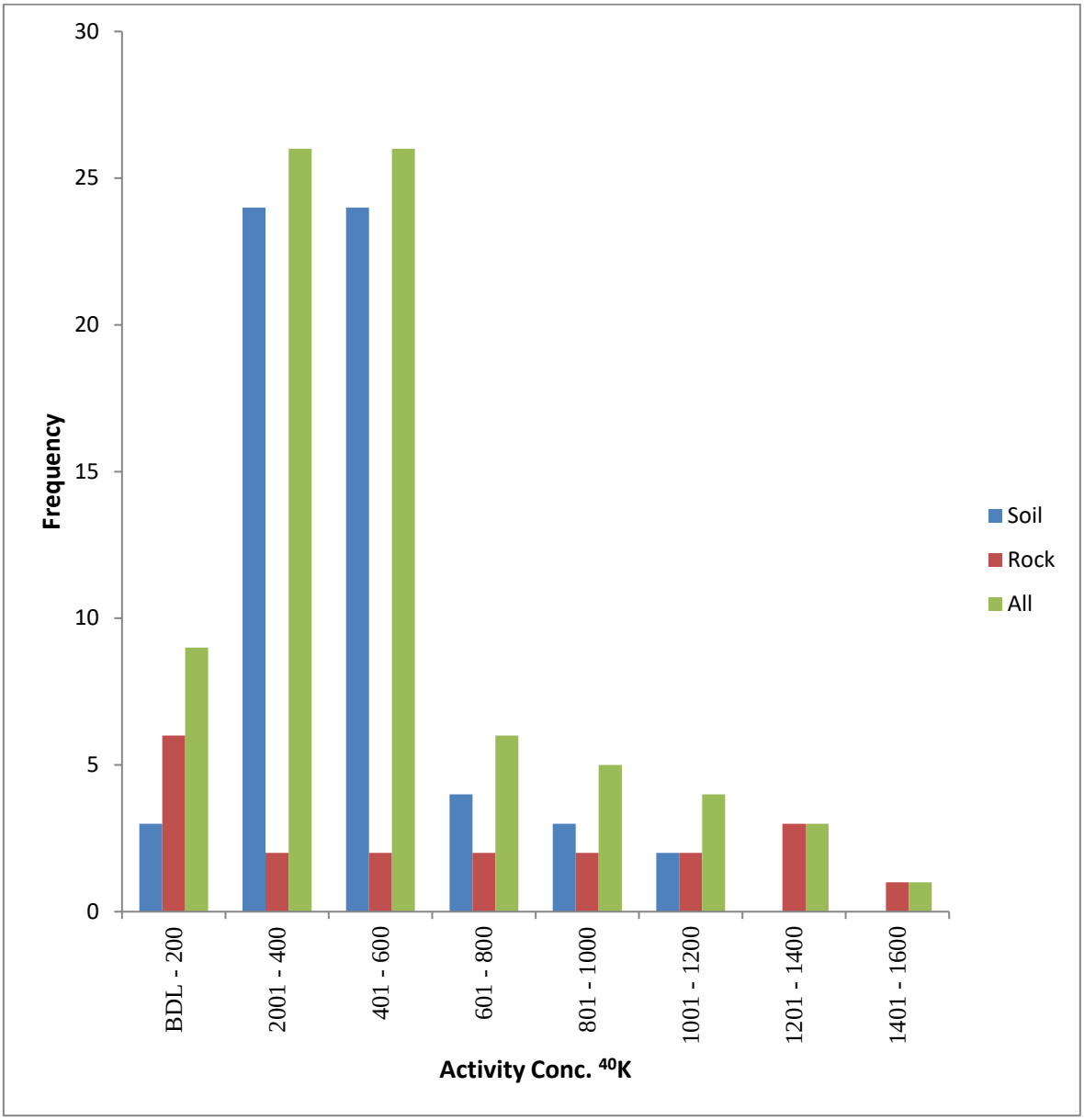

Figure 4.14: Frequency distribution of the activity concentrations of ^{40}k in soil, rocks and in all samples

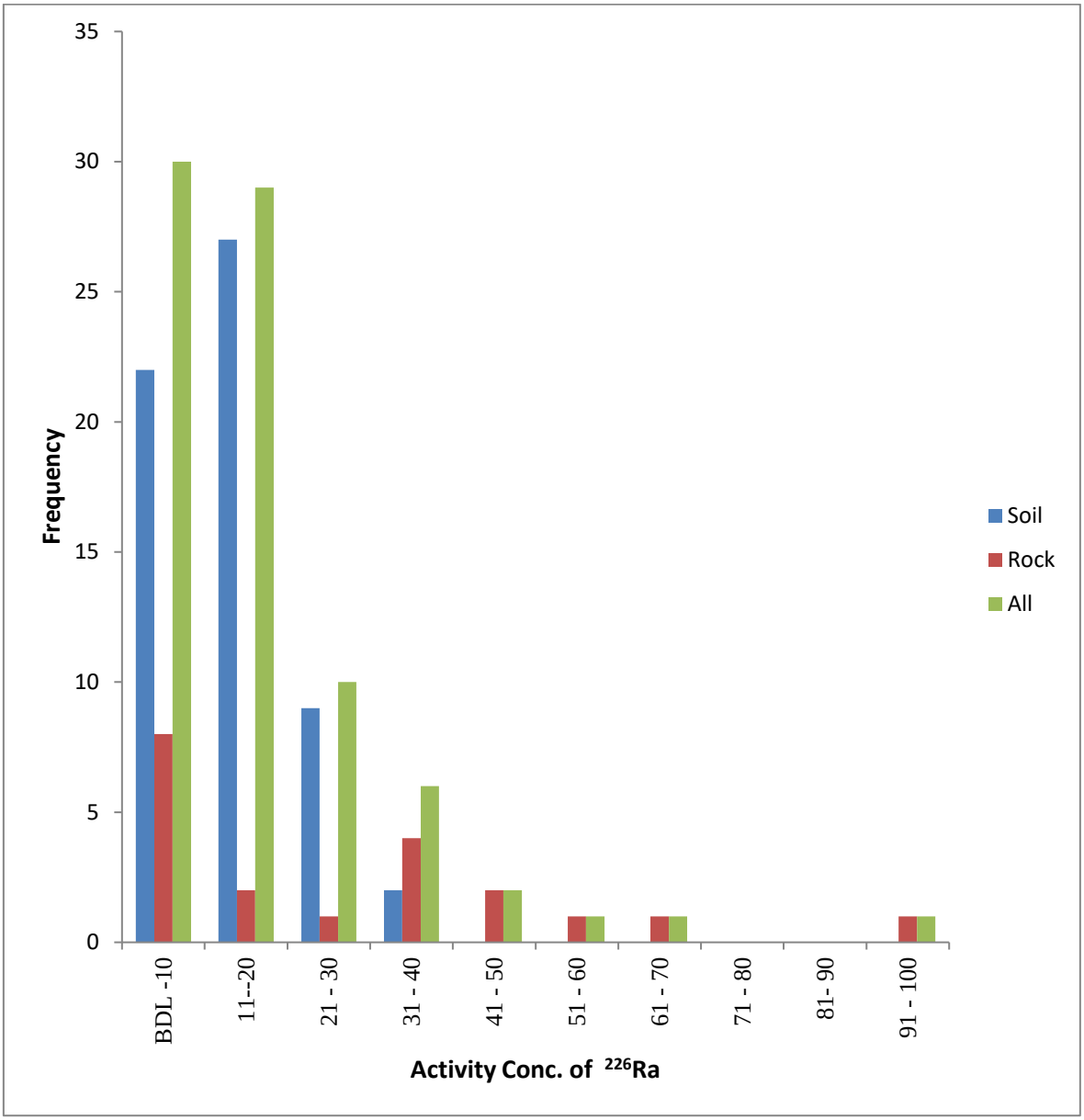

Figure 4.15: Frequency distribution of the activity concentrations of ^{226}Ra in soil, rocks and in all samples

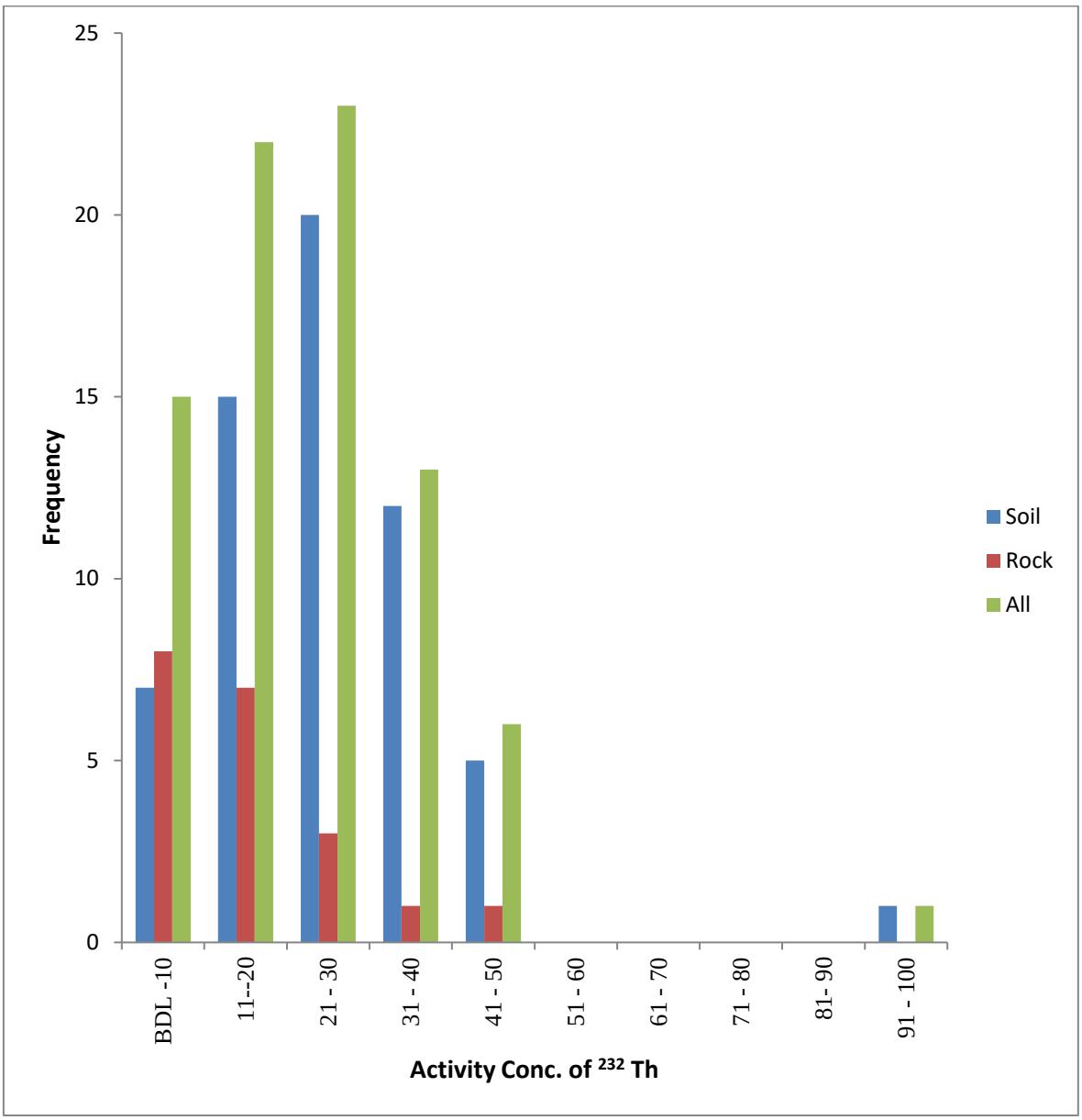

Figure 4.16: Frequency distribution of the activity concentrations of ^{232}Th in soil, rocks and in all samples

Table 4.16: Average radionuclide concentrations in soil around the dwellings surveyed in Iwo

Area	Activity Concentration of ^{40}K ($Bq\ kg^{-1}$)	Activity Concentration of ^{238}U (^{226}Ra) ($Bq\ kg^{-1}$)	Activity Concentration of ^{232}Th ($Bq\ kg^{-1}$)
Oke-Bode	394.0 ± 79.7	9.2 ± 6.8	23.1 ± 9.7
Laito	236.5 ± 124.9	9.9 ± 9.4	15.5 ± 12.6
Alaye	265.8 ± 98.5	11.3 ± 12.2	29.0 ± 8.6
Kajola	264.7 ± 103.5	6.2 ± 5.2	22.8 ± 2.6
Oke-Ifa	211.6 ± 40.4	12.7 ± 0.9	34.1 ± 3.9
Oweyo	415.6 ± 268.7	18.5 ± 15.2	19.0 ± 5.7
Paku	486.2 ± 375.3	15.7 ± 13.9	35.4 ± 31.8
Morodo	487.1 ± 49.5	23.7 ± 21.6	10.6 ± 1.4
Oke-Odo	653.9 ± 388.6	24.2 ± 26.0	24.7 ± 13.8
Oke-Afo	529.2 ± 346.3	15.7 ± 11.9	26.3 ± 12.9
Yafoye	235.1 ± 134.9	11.8 ± 4.8	12.1 ± 10.6
Water-Works	812.8 ± 677.1	11.4 ± 2.3	3.1 ± 4.2
Ogunajo	628.5 ± 90.1	8.1 ± 10.7	9.0 ± 13.4
Onilete	509.4 ± 231.1	17.7 ± 10.5	14.2 ± 8.6
Araromi	476.7 ± 72.2	21.4 ± 15.5	0.7 ± 1.0
Panada	805.0 ± 493.2	20.2 ± 19.7	12.5 ± 9.8
Odoori	607.5 ± 228.6	10.3 ± 2.4	33.8 ± 3.1
Feesu	573.2 ± 282.4	23.0 ± 3.0	34.3 ± 4.9
Ago-Ogunde	232.3 ± 185.1	11.0 ± 1.4	11.5 ± 0.6
Mean ± SD	497.4 ± 312.4	16.5 ± 15.9	22.2 ± 15.3

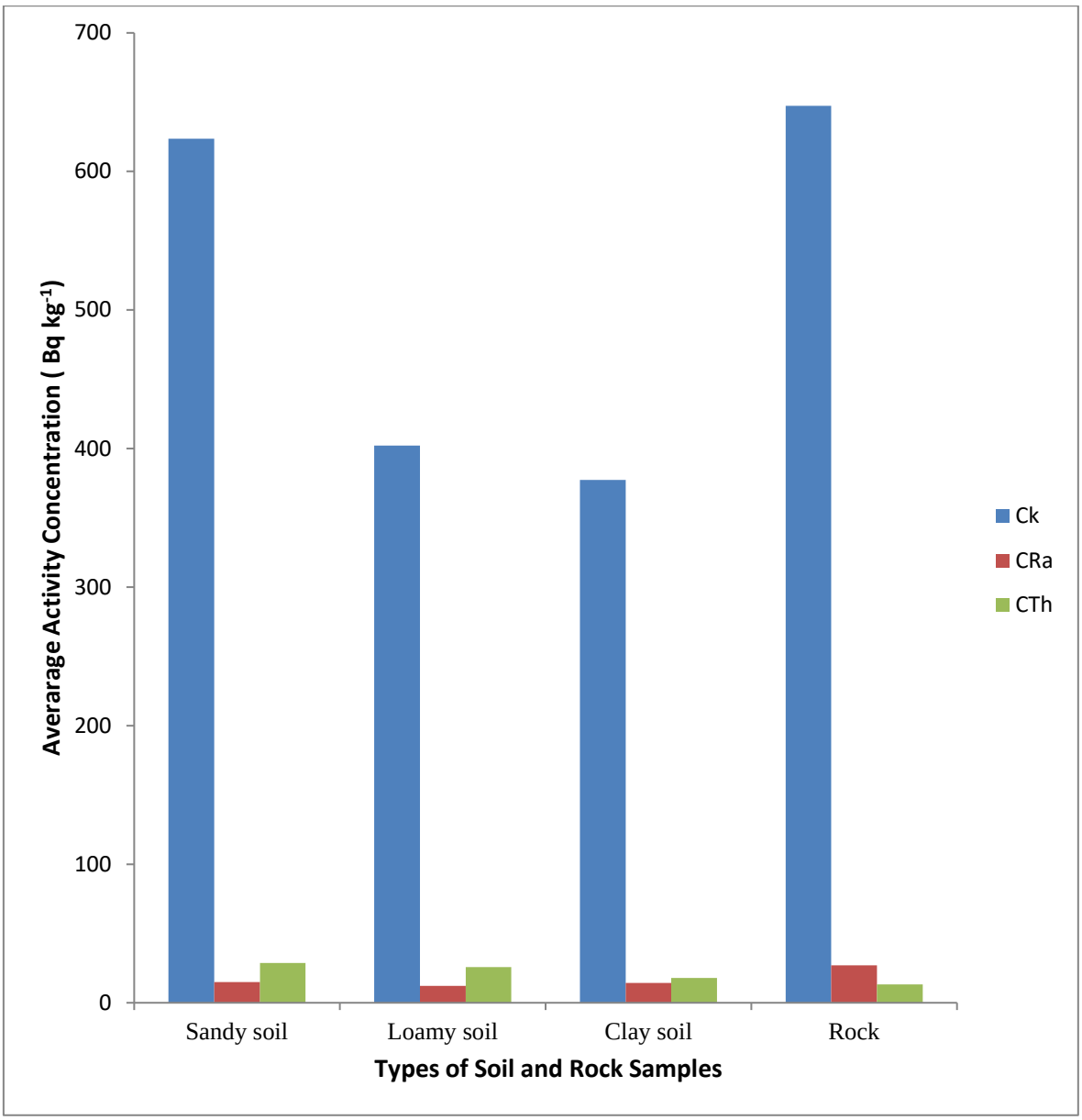

Figure 4.17 : Comparison of activity concentrations of ^{40}K, ^{238}U (^{226}Ra) and ^{232}Th of soil types and rock samples

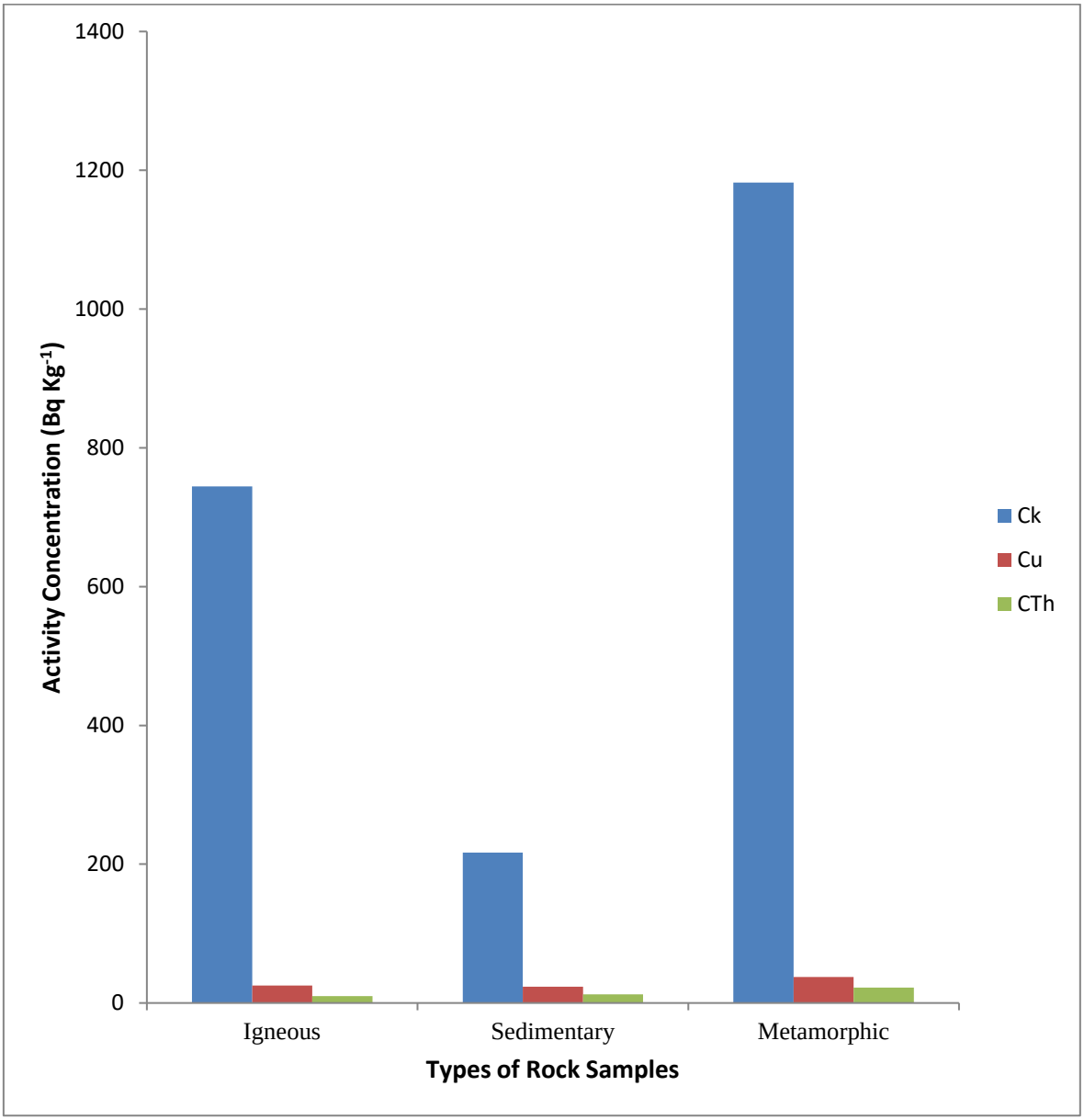

Figure 4.18: Comparison of activity concentrations of ^{40}K, ^{238}U (^{226}Ra) and ^{232}Th of types of rock samples

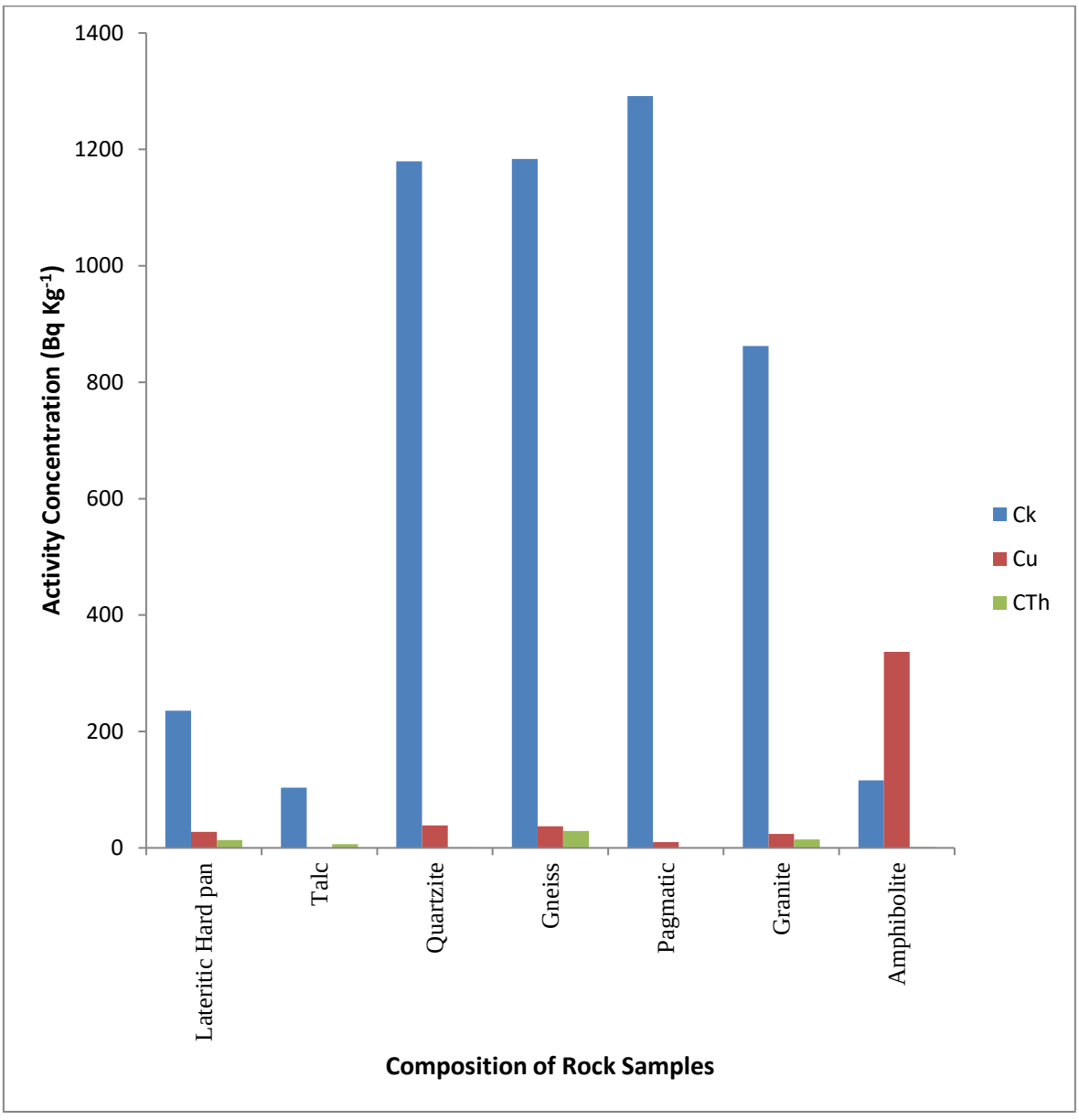

Figure 4.19: Comparison of activity concentrations of ^{40}K, ^{238}U (^{226}Ra) and ^{232}Th of different compositions of rock samples

4.6 ABSORBED DOSE RATE IN AIR

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K measured are only an indication of the levels of the radionuclides present and do not relate the effect of such level on bio-system. The external absorbed dose rate, D (nGy h^{-1}) in air at 1 m above the ground due to the concentrations of ^{238}U, ^{232}Th and ^{40}K in the samples was calculated using the equation (UNSCEAR,1988):

$$D = a \cdot C_u + b \cdot C_{Th} + c \cdot C_k + d \cdot C_{cs} \qquad (4.1)$$

where, a is the dose rate per unit ^{238}U activity concentration (4.27×10^{-1} Gy h^{-1}/Bq kg^{-1}), C_u is the concentration of ^{238}U in the sample (Bq kg^{-1}), b is the dose rate per unit ^{232}Th activity concentration (6.62×10^{-1} Gy h^{-1}/ Bq kg^{-1}). c is the dose rate per unit ^{40}K activity concentration (0.43×10^{-1} Gy h^{-1}/ Bq kg^{-1}), d is dose rate per unit ^{137}Cs activity concentration (0.3×10^{-1} Gy h^{-1}/ Bq kg^{-1}) and C_{cs} is the concentration of ^{137}Cs in the sample (Bq kg^{-1}). Since cesium-137 was not detected in any of the samples, the last term in equation (4.1) was taken as zero. The absorbed doses calculated according to the equation (4.1).

The mean absorbed dose rates was 43.14 ± 19.48 nGy h^{-1}, which ranged between 8.84 - 131.6 nGy h^{-1} as presented in Table 4.17. The mean absorbed dose rates for soil and rock samples were found to be 41.46 ± 14.36 nGy h^{-1} and 48.16 ± 30.03 nGy h^{-1}, respectively. The average absorbed dose rate for all the samples, (43.14 ± 19.48 nGy h^{-1}), is lower than the world average value 57 nGy h^{-1}, (UNSCEAR, 2000).

Generally, the activity concentrations of the radionuclides in the samples indicate only the presence of natural radioactive element since no artificial radioactive elements such as ^{137}Cs was detected.

Table 4.17: The mean absorbed dose rate (nGy h^{-1}) in soil and rock samples around the dwellings surveyed in Iwo

Zone	Area	Locations	Absorbed Dose Rate in Air (nGy h^{-1})	Range
Gidigbo	Oke-Bode	5	36.19 ± 10.82	(13.2 - 34.4)
	Laito	2	24.68 ± 17.75	(5.1 - 35.4)
	Alaye	4	35.43 ± 11.87	(19.8 - 36.9)
	Kajola	4	29.16 ± 2.26	(33.9 - 41.4)
Isale-Oba	Oke-Ifa	2	37.12 ± 2.05	(25.7 - 28.4)
	Oweyo	4	38.35 ± 5.72	(28.9 - 37.0)
	Paku	7	51.07 ± 15.84	(27.0 - 67.3)
	Morodo	3	38.09 ± 6.42	(21.9 - 40.7)
	Oke-Odo	18	54.84 ± 28.13	(1.0 - 140.2)
	Oke-Afo	6	46.82 ± 12.62	(24.3 - 70.0)
	Yafoye	3	23.14 ± 11.46	(8.1 - 16.2)
	Water-Works	2	41.85 ± 25.32	(17.1 - 60.8)
Molete	Ogunajo	3	36.48 ± 12.04	(19.9 - 40.5)
	Onilete	5	38.88 ± 10.22	(26.7 - 70.6)
	Araromi	2	30.10 ± 2.84	(24.8 - 31.0)
Oke-Adan	Panada	2	51.53 ± 36.10	(19.4 - 70.6)
	Odoori	3	52.91 ± 10.58	(33.9 - 56.1)
	Feesu	3	57.14 ± 16.04	(36.5 - 68.8)
	Ago-Ogunde	2	22.28 ± 8.97	(6.2 - 30.5)
	Mean $\pm$ *SD*		43.1 ± 19.5	

4.7.1 RADIUM EQUIVALENT ACTIVITIES (Ra_{eq})

In order to represent the activity levels of ^{226} Ra, ^{232}Th and ^{40}K by a single quantity, radiation hazards associated with them must be taken into consideration. A common radiological index has been introduced, this index is called radium equivalent (Ra_{eq}) activity and mathematically defined by:

$$Ra_{eq}\ (Bq\ kg^{-1}) = C_{Ra} + 1.43\ C_{Th} + 0.077\ C_k \qquad (4.2)$$

where, C_{Ra}, C_{Th} and C_k are the activity concentrations in Bq kg^{-1} of ^{226}Ra,^{232}Th and ^{40}K, respectively. It may be noted that ^{238}U has been replaced with the product ^{226} Ra because there may be a dis-equilibrium between ^{238}U and ^{226}Ra. It has been assumed that 10 Bq of ^{226}Ra, 7 Bq of ^{232} Th and 130 Bq of ^{40}K produce the same gamma doses (El-Arabi, 2007), while defining Ra_{eq} activity according to the equation (4.2).

The activity index provides the guideline in regulating the safety standards on radiation protection for the general public residing in common dwellings (Shanthil *et al*., 2010). The Ra_{eq} is related to the external gamma dose and internal dose due to radon and its daughters (Berekta and Matthew, 1985).

Radium equivalent activities ranged from 17.5 Bq kg^{-1} to 269.0 Bq kg^{-1} with average of 86.6 $\pm$ 38.8 Bq kg^{-1} and median of 80.6 Bq kg^{-1}. The highest radium equivalent activities (116.1 ± 30.4 Bq kg^{-1}) was observed in Feesu and followed by 110.0 ± 56.1 Bq kg^{-1} in Oke-Odo, as presented in Table 4.18.

4.7.2 EXTERNAL AND INTERNAL HAZARD INDICES

In order to determine External Hazard Index, it was assumed that 370 Bq kg^{-1} of ^{226} Ra, 259 Bq kg^{-1} of ^{232}Th and 4810 Bq kg^{-1} of ^{40}K produce the same gamma dose rate (Stranden, 1998). In order to represent the activity levels of ^{226}Ra,^{232}Th and ^{40}K as a single quantity, the external hazard index, H_{ex}, was calculated by the following equation (Berekta and Matthew,1985)

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \qquad (4.3)$$

Table 4.18: Radium equivalent activity (Ra_{eq}), external hazard index (H_{ex}), internal hazard index (H_{in}) and gamma index ($I\gamma_r$) in soil of Iwo

Zone	Area	Radium Equivalent (Ra_{eq}) (Bq kg^{-1})	External Hazard Index (H_{ex})	Internal Hazard Index (H_{in})	Gamma Index ($I\gamma_r$)
Gidigbo	Oke-Bode	72.64 ± 23.01	0.20	0.22	0.56
	Laito	50.33 ± 37.09	0.14	0.16	0.38
	Alaye	73.20 ± 25.36	0.20	0.23	0.54
	Kajola	59.26 ± 3.53	0.16	0.18	0.45
	Oke-Ifa	77.80 ± 4.44	0.21	0.24	0.57
Isale-Oba	Oweyo	77.68 ± 7.05	0.21	0.26	0.59
	Paku	103.82 ± 35.79	0.28	0.32	0.78
	Morodo	76.39 ± 16.33	0.21	0.27	0.59
	Oke-Odo	109.95 ± 56.13	0.30	0.36	0.85
	Oke-Afo	93.94 ± 22.74	0.25	0.30	0.72
	Yafoye	47.17 ± 22.40	0.13	0.16	0.36
	Water-Works	78.37 ± 43.76	0.21	0.24	0.65
	Ogunajo	69.45 ± 24.67	0.19	0.21	0.56
Molete	Onilete	77.28 ± 18.51	0.21	0.26	0.60
	Araromi	59.10 ± 8.49	0.16	0.22	0.47
	Panada	100.09 ± 71.67	0.27	0.33	0.80
Oke-Adan	Odoori	105.43 ± 19.21	0.29	0.31	0.81
	Feesu	116.11 ± 30.37	0.31	0.38	0.88
	Ago-Ogunde	45.28 ± 16.54	0.12	0.15	0.34
	Mean	78.59 ± 21.41	0.21	0.25	0.60

The value of this index must be less than unity for the radiation risk to be negligible (Abel-Ghany *et al*., 2009). The maximum value of Ra_{eq} must be < 370 Bq kg^{-1}, in order to keep external dose < 1.5 mSv y^{-1} (NEA-OECD, 1979). The materials whose Ra_{eq} exceeds 370 Bq kg^{-1} is discouraged, so as to avoid radiation hazards.

In addition to the external hazard, radon and its short-lived products are also hazardous to the respiratory organs. The internal exposure to radon and its daughter products is quantified by internal hazard index (H_{in}) (Berekta and Matthew, 1985). The internal exposure to ^{222}Rn and its radioactive progeny is controlled by internal hazard index (H_{in}), which is given by (Abel-Ghany *et al*, 2009).

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \leq 1 \qquad (4.4)$$

If the maximum concentration of radium is half that of the normal acceptable limit, H_{in} will be less than 1.0 (Berekta and Matthew, 1985), for the safe use of a material in construction of dwellings, index, H_{in} should be less than unity (Iqbal *et al*., 2000).

The internal hazard index and external hazard indices of soil samples ranged from 0.118 - 0.49 and 0.09 - 0.45 with average of 0.26 ± 0.08 and 0.23 ± 0.08, respectively; while the internal hazard index and external hazard indices of rock samples ranged between 0.05 – 0.99 and 0.05 – 0.73 with average of 0.33 ± 0.22 and 0.26 ± 0.16 , respectively. The summary is presented in Table 4.18.

4.7.3 GAMMA INDEX

The gamma index, $I\gamma_r$, of the soil is used to estimate the level of gamma radiation hazard associated with natural gamma emitters in the soil. It was evaluated using the relation given by (NEA-OECD, 1979) and (Higgy *et al*., 2000).

$$I_{\gamma r} = \frac{C_{Ra}}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \qquad (4.5)$$

The values of the gamma index calculated according to equation (4.9) are presented in Table 4.18. The gamma index must be lower than unity, in order to keep the radiation hazard insignificant (Huy and Luyen, 2006). The index, $I\gamma_r$, is correlated with the annual dose due to the excess external gamma radiation caused by superficial material values of

index I ≤ 1 correspond to 0.3 mSv y^{-1}, while I ≤ 3 correspond to 1 mSv y^{-1}. Thus, activity concentration index should be used only as a screening tool for identifying materials which might be of concern to be used as covering material. According to this dose criterion, materials with I ≤ 3 should be avoided, since these values correspond to dose rates than 1 mSv y^{-1} (EC, 1999), which is the highest value of dose rate in air recommended for population (UNSEAR, 1993; UNSEAR, 2000).

Gamma index of soil samples ranged from 0.25 - 1.27 with average of 0.64 ± 0.22. The average gamma index of rock samples was 0.74 ± 0.46. The summary is presented in Table 4.18.

The gamma index of sand soil samples was higher than that of rock samples. Clay soil samples had the least internal, external and gamma hazard indices, as shown in Figure 4.20. Hence, radiation might be low in buildings made of clay soil. Radon emanation increases with increase of thickness of building materials made from granite but not with ones made of clay (Abu- Jarad et al., 1980). Among the compositions of rock samples, gnesis has the highest internal, external and gamma hazard indices while talc has the least, as shown in Figure 4.21.

4.8 ANNUAL OUTDOOR EFFECTIVE DOSE RATES

In order to determine the biological hazard to which an individual is exposed, gray is converted to Sievert taking into account a value of 0.7 Sv Gy^{-1} was used for conversion factor for the biological effectiveness of the dose in causing damage in human tissue recommended by the UNSCEAR and the outdoor occupancy factor of 0.4, calculated from the data on radon awareness surveyed, that specifies the proportion of the total time spent outdoors and indoors and this factor may vary. The annual outdoor effective dose rate (mSv y h^{-1}) was calculated by the following formula (UNSCEAR, 2000).

$$E = D \times DCF \times O_f \times T \qquad (4.6)$$

where, E (mSv y^{-1}) is the annual effective dose, D is the absorbed dose rate in air (nGy h^{-1}), DCF is the dose conversion factor (0.7 Sv Gy^{-1}), O_f is the outdoor occupancy factor (0.4) and T is the time in hours in a year (8760 h y^{-1}).

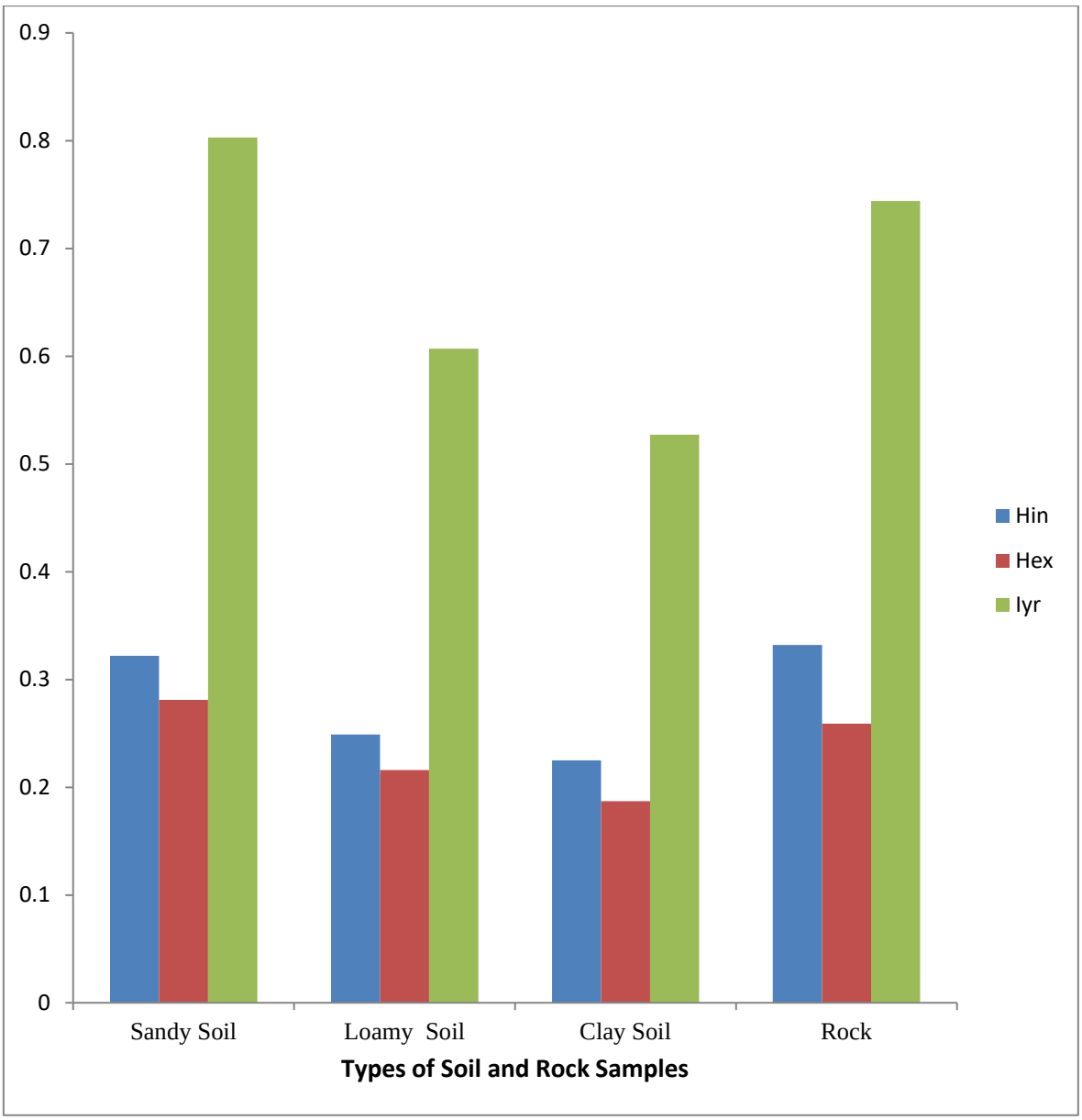

Figure 4.20 : The comparison of average internal hazard index, external hazard index and gamma index of sandy soil, loamy soil, clay soil and rock samples

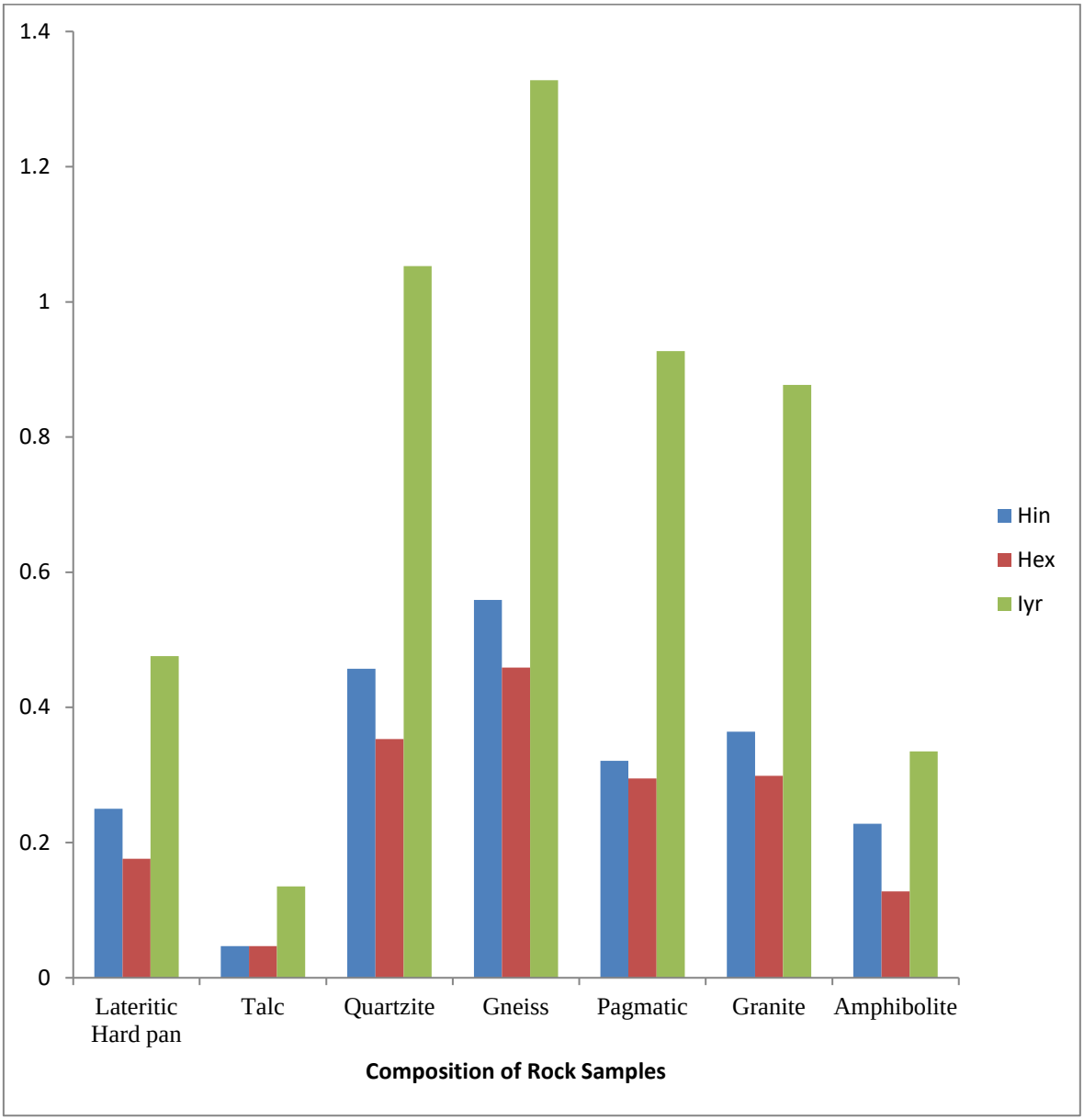

Figure 4.21: Comparison of average internal hazard index, external hazard index and gamma index of compositions of rock samples

The average outdoor gamma effective dose rates obtained was 96.31 ± 25.71 μSvy^{-1} which ranged between 54.65 μSv y^{-1} - 140.15 μSv y^{-1}. The average outdoor gamma effective dose rates for soil and rock samples were 101.8 ± 35.2 μSv y^{-1} and 118.2 ± 73.8 μSv y^{-1}, respectively. The mean value obtained is higher than world average value of outdoor exposure of 70 μSv y^{-1} but less than 1 mSv annual dose limit for members of the public prescribed by UNSCEAR, (2000).

4.9 CANCER MORTALITY AND MORBIDITY RISKS ASSESSMENT

The cancer risk associated with radionuclide external exposure was calculated as the product of the appropriate cancer risk coefficient and the corresponding radionuclide exposure. In other words, radiation risk follows a linear no threshold (LNT) model. The risk coefficients were obtained from the EPA Report (EPA, 1999) on cancer risk coefficients for environmental exposures to radionuclides. The risk coefficients are expressed as risk of cancer mortality or morbidity per unit integrated exposure to radionuclide for soil contaminated to an infinite depth (Kg Bq s^{-1}).The lifetime cancer risk R for exposure to a given radionuclide can be calculated using

$$R = r \times X \tag{4.7}$$

where r is the risk coefficient of a particular radionuclide and X is the time integrated activity concentration of the radionuclide in the exposure scenario.

The time integrated activity concentrations were calculated using 51.41 years life expectancy at birth in Nigeria (Mundi, 2010), 3.15 × 10^{7} s in a year and the activity concentration of each radionuclide. The risk coefficients for the radionuclides are presented in Table 4.19.

As observed, the lowest value of mean of cumulative cancer morbidity and mortality risks, 2.3×10^{-4} and 1.6×10^{-4} , were observed in Kajola and Oke-Ifa while the highest values, 9.95×10^{-4} and 6.14×10^{-4}, were observed in Ogunajo and Water-Works, respectively, as presented in the Table 4.20.

The cumulative cancer morbidity and mortality risks found in rock samples were greater than that of sandy soil, loamy soil and clay soil, as shown in Figure 4.22. Among the types of rock samples observed, the highest cumulative cancer morbidity and mortality risks

Table 4.19: Mortality and morbidity risk coefficients (r) for external exposure from soil at infinite depth

Radionuclide	Mortality (kg Bq s^{-1})	Morbidity (kg Bq s^{-1})
^{40}K	4.66×10^{-16}	6.83×10^{-16}
^{232}Th	1.97×10^{-19}	2.93×10^{-19}
^{226}Ra	1.33×10^{-17}	1.96×10^{-17}

(Source: EPA, 1999)

Table 4.20: Mean effective dose, cumulative cancer morbidity risks and cumulative mortality risks in soil of Iwo

Zone	Area	Mean Effective dose rates (μSv y^{-1})	Cumulative Cancer Morbidity Risks $x10^{-4}$	Cumulative Cancer Mortality Risks $x\ 10^{-4}$
Gidigbo	Oke-Bode	88.77 ± 26.56	4.36	2.98
	Laito	60.54 ± 43.58	2.62	1.79
	Alaye	86.90 ± 29.14	2.94	2.01
	Kajola	71.52 ± 5.54	2.93	2.00
Isale-Oba	Oke-Ifa	91.01 ± 5.04	2.34	1.62
	Oweyo	94.06 ± 14.04	4.06	3.14
	Paku	125.26 ± 42.00	5.38	3.67
	Morodo	93.43 ± 15.76	5.40	3.68
	Oke-Odo	134.51 ± 69.04	7.24	4.94
	Oke-Afo	114.84 ± 30.92	5.86	4.00
	Yafoye	56.76 ± 28.12	2.60	1.78
	Water-Works	102.65 ± 62.14	8.99	6.14
Molete	Ogunajo	89.48 ± 29.54	9.95	4.74
	Onilete	95.36 ± 25.10	5.64	3.85
	Araromi	73.83 ± 6.98	5.28	3.60
Oke-Adan	Panada	126.39 ± 88.6	8.91	6.08
	Odoori	129.78 ± 25.96	6.72	4.59
	Feesu	140.15 ± 39.36	6.35	4.33
	Ago-Ogunde	54.65 ± 22.00	2.57	1.76
	Mean	91.31 ± 25.71	5.51	3.76

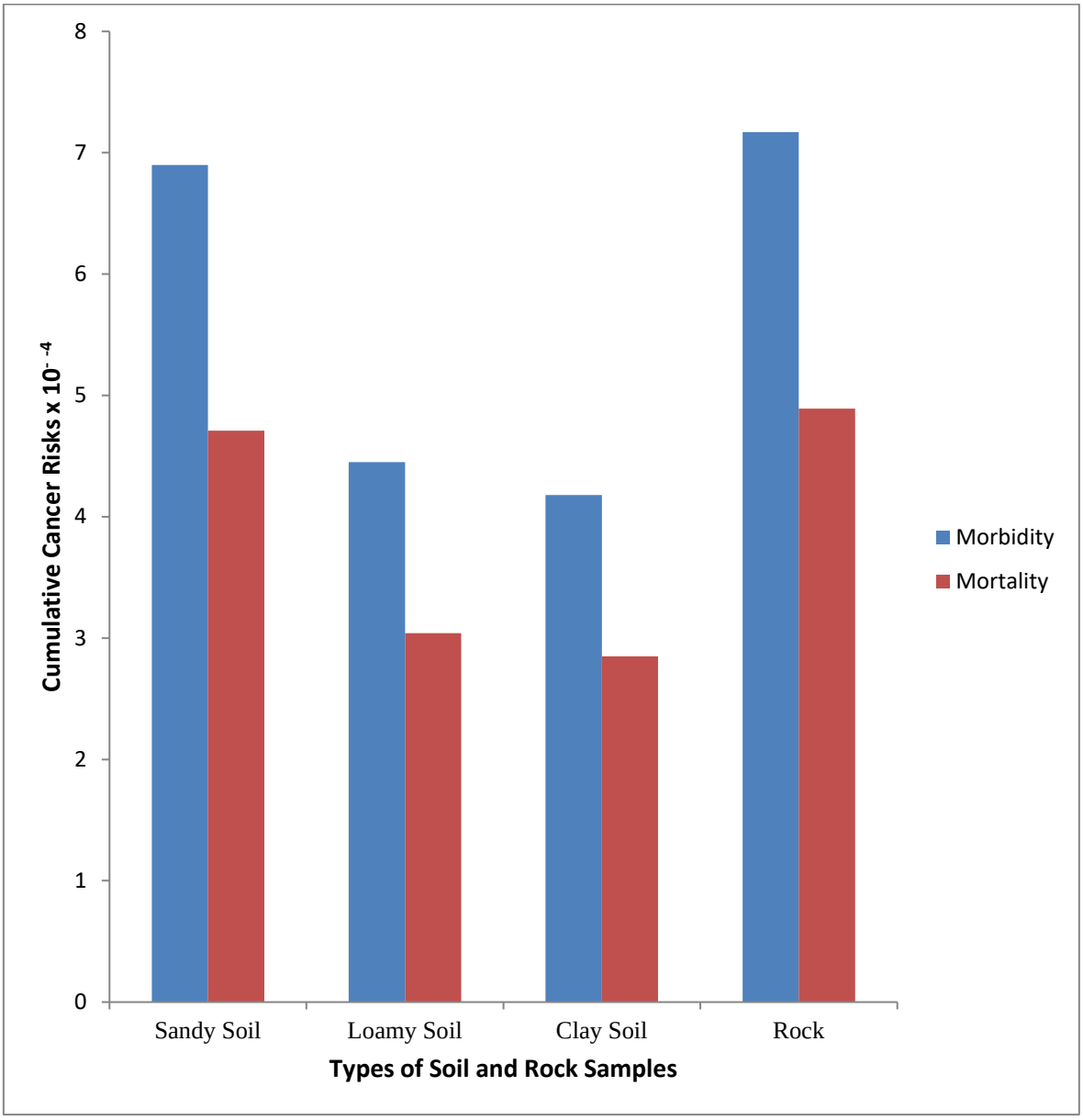

Figure 4.22: Comparison between the cumulative of cancer mortality and morbidity risks of sandy, loamy, clay and rock samples

were observed in metamorphic rock samples, as in Figure 4.23. The summary of overall means of cumulative cancer morbidity and mortality risks in all samples were calculated to be 5.5×10^{-4} and 3.8×10^{-4}, respectively, is presented in Table 4.21.

From radiological point of view these values are low, and do not imply any significant concerns about the health effects on the population.

Only activity concentrations greater than the detection limit value of the detector were used for analysis. The reported uncertainty is the standard deviation which gives information on the spread of activity in the region. The results can be taken to represent base line information for future reference and research in Iwo town, Osun State, South-Western, Nigeria.

4.10 CORRELATION BETWEEN ^{238}U IN SOIL AND INDOOR ^{222}Rn IN DWELLINGS IN THE STUDY AREA

A correlation analysis was performed with the results obtained, between specific ^{238}U (^{226}Ra) content in soil and measured indoor radon concentration in order to generate a model for expected indoor radon concentration (D) from ^{238}U concentration (X) in soil (Figure 4.24).

The model with correlation of 0.7832 generated the equation (4.8)

$$D = 4.2989X + 130.2 \qquad (4.8)$$

If this model is applied to Iwo town, the value for average indoor radon concentration will be 201.3 Bq m^{-3} as opposed to 196.3 Bq m^{-3} that was actually measured. Since the value (201.3) falls within the confidential limit ($186 \leq 196 \leq 206$). Therefore, the correlation between ^{238}U in soil and ^{222}Rn in indoor air is significant at 95 % level of significant. There is a correlation between indoor radon concentration and ^{238}U natural radionuclide in the soil around the houses surveyed.

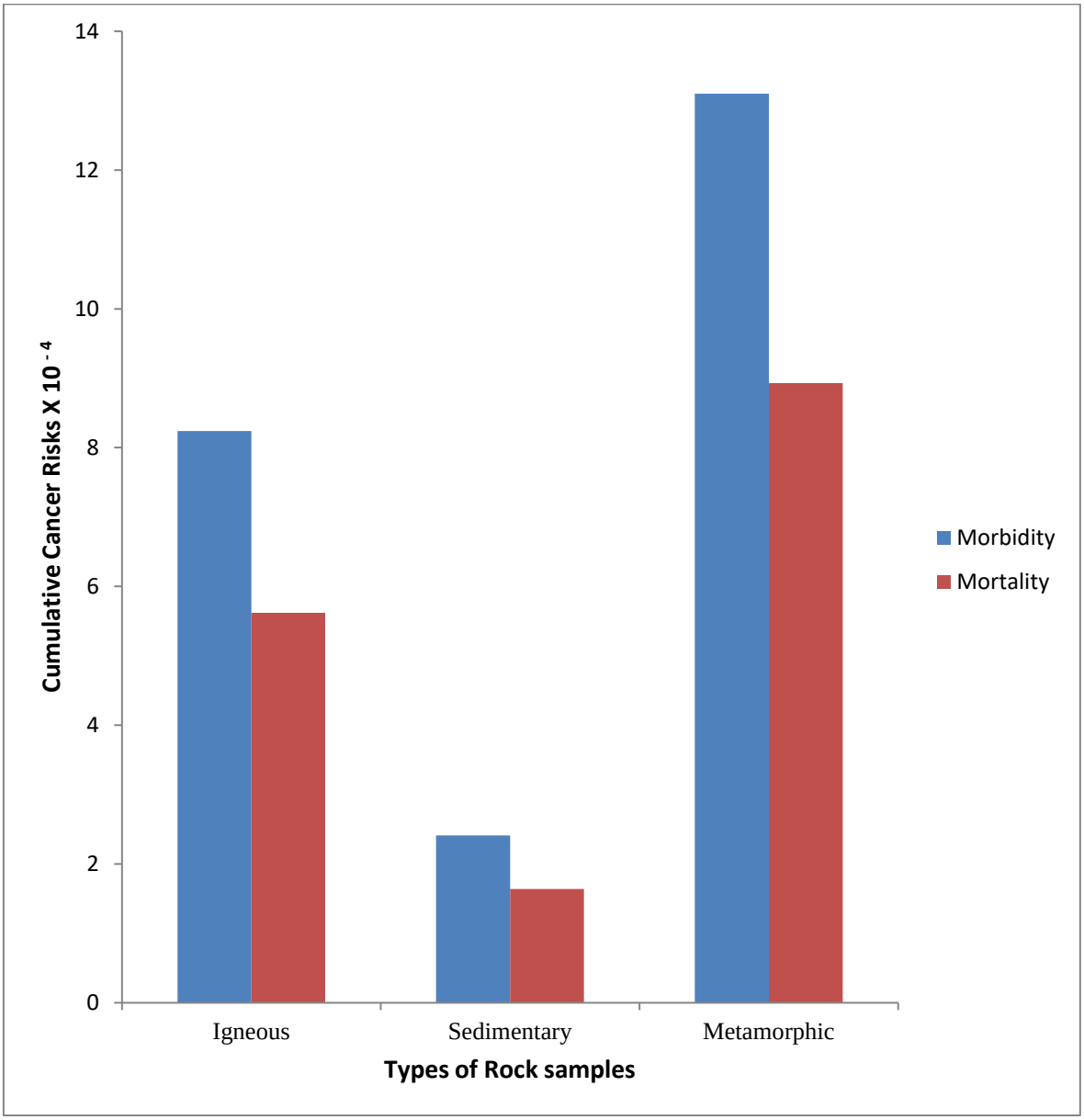

Figure 4.23: Comparison between the cumulative of cancer morbidity and mortality risks in different types of rock samples

Table 4.21: The average lifetime cancer morbidity and mortality risks due to radionuclide in all samples

	Soil Samples		Rock Samples		All Samples	
Radionuclides	Morbidity Risk	Mortality Risk	Morbidity Risk	Mortality Risk	Morbidity Risk	Mortality Risk
^{40}K	5.0×10^{-4}	3.4×10^{-4}	7.2×10^{-4}	4.9×10^{-4}	5.5×10^{-4}	3.8×10^{-4}
^{226}Ra	4.1×10^{-7}	2.8×10^{-7}	8.6×10^{-7}	5.8×10^{-7}	5.3×10^{-7}	3.6×10^{-7}
^{232}Th	11.9×10^{-9}	8.0×10^{-9}	6.3×10^{-9}	4.2×10^{-9}	10.5×10^{-9}	7.1×10^{-9}
Cumulative Risk	5.0×10^{-4}	3.4×10^{-4}	7.2×10^{-4}	4.9×10^{-4}	5.5×10^{-4}	3.8×10^{-4}

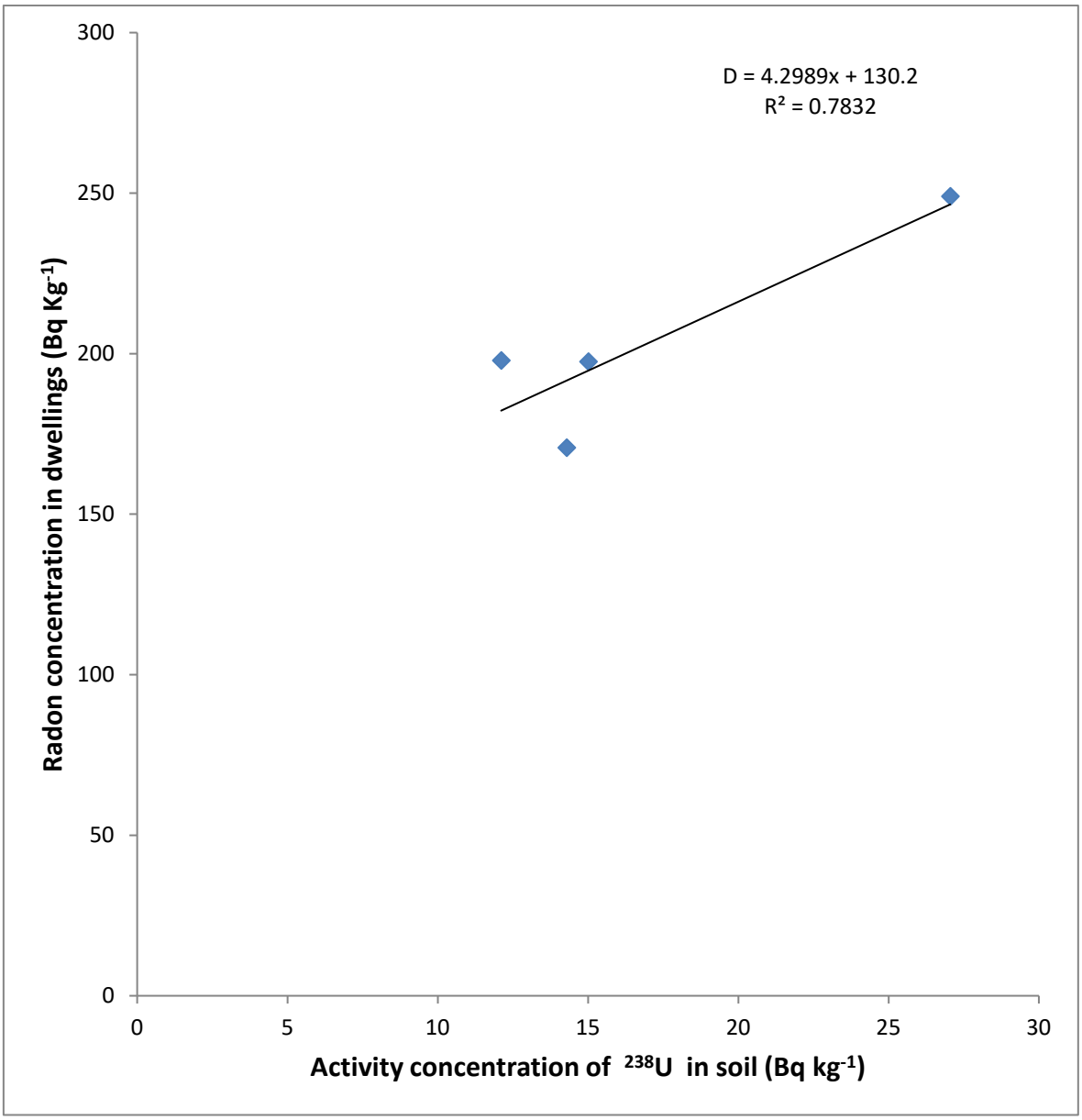

Figure 4.24: Correlation of activity concentration of ^{238}U and ^{222}Rn concentration in the study area

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This survey, carried out in Iwo leads to the conclusion that the general public has poor radon awareness level as compare to the advanced countries. The indoor radon concentrations in dwellings were found to be within the reference levels of ICRP. In view of the worldwide concern about the radionuclide contents in soil and rock, radiological assessment of the activity concentrations at different areas in Iwo, the total absorbed dose rate in air due to soil and rock samples and other radiological indices estimated were found to below the prescribed safe limits. The annual effective dose due to ^{40}K, ^{226}Ra and ^{232}Th, obtained is lower than the average worldwide reported value. The doses received by the population investigated in Iwo town, Osun State, South-western Nigeria lie below the upper limit (10 mSv y^{-1}).

5.2 RECOMMENDATIONS

There is a need to improve on level of radon awareness. This can be done if the relevant Authorities should design and implement a policy for public education in this direction. A nationwide mass media campaign may be launched by the Federal Ministry of Environment, Environment Protection Agency and Community Development Department to educate the general public in this respect at the union council level about hazards of radon and other radionuclides to avoid its harmful effects.

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APPENDIX A

Table A 1. Activity Concentrations of ^{40}K, ^{238}U and ^{234}Th in count per 10 hours

Sample code	Potassium-40	Uranium -238	Thorium-232
Background	1843 ± 8.965 %	269 ± 45.79 %	1056 ± 9.834 %
KAL	3609 ± 7.607 %	417 ± 39.18 %	1803 ± 9.910 %
MK5	17254 ± 2.03 %	378 ± 47.16 %	2151 ± 9.004 %
IK10	27091 ± 1.718 %	1737 ± 13.55 %	3811 ± 6.213 %
IP2	23023 ± 1.84 %	334 ± 59.94 %	3138 ± 6.810 %
IK15	4448 ± 6.583 %	1119 ± 18.86 %	1214 ± 11.097 %
IG1	12528 ± 2.949 %	569 ± 34.39 %	1069 ± 14.30 %
ME1	21936 ± 1.937 %	775 ± 30.02 %	2370 ± 7.511 %
IK4	17644 ± 2.458 %	1285 ± 19.12 %	1898 ± 10.07 %
IW1	24336 ± 1.820 %	413 ± 55.86 %	1063 ± 13.90 %
GL2	4424 ± 6.436 %	317 ± 79.02 %	1503 ± 10.43 %
IY1	32488 ± 8.751 %	510 ± 49.11 %	1053 ± 15.12 %
IG3	11367 ± 3.482 %	228 ± 92.79 %	122 ± 414.64 %
MK2	6588 ± 4.781 %	793 ± 26.22 %	1448 ± 11.19 %
MK1	9235 ± 3.623 %	488 ± 42.21 %	1448 ± 10.94 %
I05	9573 ± 3.510 %	612 ± 35.56 %	2151 ± 7.760 %
I06	4740 ± 6.363 %	846 ± 25.46 %	1915 ± 8.522 %
IP1	6306 ± 5.185 %	910 ± 25.21 %	2151 ± 7.856 %
IT2	9478 ± 3.544 %	904 ± 24.22 %	1757 ± 9.325 %
MK4	11339 ± 3.155 %	485 ± 48.50 %	2823 ± 6.587 %
M01	8169 ± 3.982 %	447 ± 48.59 %	1860 ± 8.876 %
IW2	7660 ± 4.034 %	462 ± 42.15 %	1467 ± 9.975 %
IK3	13109 ± 2.882 %	672 ± 34.10 %	1990 ± 9.223 %
IK8	9491 ± 3.394 %	660 ± 41.54 %	2040 ± 7.726 %
IK1	23233 ± 1.865 %	510 ± 61.60 %	2872 ± 6.512 %
IA6	22381 ± 2.143 %	841 ± 34.77 %	1119 ± 15.33 %
MD1	9255 ± 4.635 %	748 ± 41.47 %	615 ± 31.89 %
MY1	9788 ± 3.471 %	362 ± 74.74 %	1435 ± 10.84 %
I07	2036 ± 9.006 %	477 ± 64.64 %	8260 ± 4.184 %

Table A 1. Activity Concentrations of ^{40}K, ^{238}U and ^{234Th} in count per 10 hours

Sample code	Sample code	Sample code	Sample code
IM1	11203 ± 2.949 %	274 ± 95.18 %	1875 ± 7.895 %
IK19	20890 ± 2.113 %	319 ± 85.61 %	3990 ± 5.134 %
IK7	6382 ± 4.851 %	790 ± 34.05 %	2016 ± 7.510 %
IT2	10298 ± 3.20 %	683 ± 38.58 %	1688 ± 9.000%
IK20	11538 ± 3.893 %	385 ± 33.74 %	4199 ± 5.576 %
GB5	8598 ± 4.099%	503 ± 28.36 %	3106 ± 6.734 %
MA1	11034 ± 3.169 %	423 ± 35.17 %	1154 ± 16.50 %
GB3	9561 ± 3.578%	269 ± 50.25 %	2087 ± 9.423 %
IK9	10372 ± 3.431%	413 ± 34.44 %	2631 ± 7.787 %
IK2	12149 ± 3.031%	373 ± 37.89 %	3150 ± 6.465 %
IK11	11706 ± 3.053%	443 ± 30.67 %	2298 ± 8.489 %
MK3	9160 ± 3.685%	514 ± 25.94 %	2218 ± 8.271 %
GA1	6189 ± 5.679%	522 ± 28.72 %	3850 ± 5.864 %
MD2	16955 ± 2.352%	386 ± 37.03 %	3461 ± 5.845 %
IE1	6758 ± 4.828%	368 ± 38.87 %	2185 ± 8.948 %
GA4	4367 ± 7.162%	288 ± 49.99 %	2514 ± 7.925 %
GB1	7367 ± 4.434%	328 ± 40.05 %	1886 ± 9.980 %
IK6	6407 ± 4.974%	386 ± 33.91 %	2289 ± 8.208 %
I09	5841 ± 5.655%	579 ± 24.39 %	2757 ± 7.255 %
I07	10901 ± 3.312%	390 ± 36.17 %	2558 ± 7.835 %
GO1	5582 ± 5.972%	466 ± 30.45 %	3177 ± 6.460 %
G02	5474 ± 6.279%	448 ± 32.90 %	3554 ± 6.161 %
OC1	17469 ± 2.330%	657 ± 22.68 %	3669 ± 6.022 %
GL1	7501 ± 4.679%	514 ± 27.52 %	2712 ± 7.620 %
GB2	10581 ± 3.489%	464 ± 32.22 %	3424 ± 6.460 %
IG2	14472 ± 2.857%	330 ± 42.58 %	2710 ± 7.449 %
IK14	9623 ± 3.654%	483 ± 29.33 %	3022 ± 6.602 %
IA2	8659 ± 4.294%	367 ± 39.36 %	2999 ± 7.154 %
IP3	8132 ± 4.279%	390 ± 36.38 %	2867 ± 7.107 %

Table A 1. Activity Concentrations of ^{40}K, ^{238}U and ^{234Th} in count per 10 hours

Sample code	Sample code	Sample code	Sample code
GB4	7416 ± 4.695%	464 ± 30.23 %	2602 ± 7.883 %
GA2	6813 ± 4.941%	286 ± 48.82 %	2852 ± 7.120 %
GK1	4773 ± 6.671%	406 ± 33.09 %	2568 ± 7.576 %
IK5	10278 ± 3.401%	472 ± 28.57 %	2324 ± 8.170 %
IA3	8126 ± 4.325%	445 ± 31.51 %	3054 ± 6.876 %
IK13	21088 ± 2.033%	478 ± 32.15 %	4031 ± 5.820 %
IP5	12511 ± 2.966%	322 ± 43.78 %	2848 ± 7.002 %
IK21	19060 ± 2.198%	504 ± 29.83 %	3863 ± 5.871 %
IP4	10596 ± 3.439%	467 ± 30.40 %	2757 ± 7.451 %
IA5	13283 ± 2.853%	386 ± 37.98 %	3523 ± 6.163 %
IA4	6361 ± 5.283%	432 ± 32.47 %	2933 ± 6.816 %
IY2	7767 ± 4.385%	451 ± 30.67 %	2385 ± 8.564 %
IA1	7547 ± 4.742%	534 ± 27.56 %	3366 ± 6.054 %
OD1	10830 ± 3.454%	457 ± 32.96 %	3471 ± 6.491 %
GJ1	5612 ± 5.783%	440 ± 31.04 %	2577 ± 7.591 %
I01	14827 ± 2.525%	356 ± 38.69 %	2144 ± 9.200 %
GA3	8522 ± 4.044%	650 ± 21.63 %	2847 ± 7.159 %
GJ2	8948 ± 3.816%	269 ± 50.07 %	2420 ± 8.005 %
GJ3	6478 ± 5.192%	331 ± 42.35 %	2835 ± 7.157 %
IK13	3648 ± 7.973%	151 ± 80.38 %	1504 ± 11.61 %
OD2	9485 ± 4.657 %	421 ± 25.42 %	3101 ± 5.421 %
OC2	8455 ± 3.856 %	601 ± 20.55 %	3012 ± 5.025 %
OC3	9555 ± 4.756 %	569 ± 22.65 %	3445 ± 7.856 %