MEASUREMENT OF NATURAL RADIOACTIVITY OF SOILS FROM SELECTED CITIES IN OYO STATE, SOUTHWESTERN NIGERIA

BY

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CERTIFICATION

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DEDICATION

This work is dedicated to the Glory of God and all my loved ones.

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ABSTRACT

The concentrations of some of the natural radionuclides in the uranium, actinium and thorium series and of ^{40}K in soil samples collected from 9 major towns of Oyo State, Southwestern Nigeria have been determined by gamma ray spectrometry (using high purity germanium detector). Spectral analyses were performed with the Genie2k spectrometry software, version 2.1 (Canberra Industries Inc.). A library of radionuclides, which contained the energy of the characteristic gamma peaks for each nuclide analysed and their corresponding emission probabilities were built from the data supplied in the software. The natural radionuclides that were discovered in the soil samples includes, ^{40}K, ^{208}Tl,. ^{210}Pb, ^{212}Bi, ^{212}Pb, ^{214}Bi, ^{214}Pb, ^{224}Ra, ^{226}Ra, ^{228}Ac, ^{228}Th, ^{234M}Pa, ^{234Th} and ^{235}U. ^{137}Cs was the only artificial radionuclide found in trace form in some of the samples analysed. The specific activities ranged from –0.102 ± 0.29 for ^{137}Cs to 1,850.60 ± 36.83 for ^{40}K. The outdoor gamma radiation absorbed dose rate in air due to each of the primordial radionuclides was calculated from the mean values of the activity concentration in each sample.

The estimated annual outdoor effective dose equivalent for the urban areas in the state is 50.25 μSvy^{-1} while that of rural area is 108.57 μSvy^{-1}. Average value for the state is 79.41 μSvy^{-1}. Using the estimated population of 6,617,720 for the year 2005, the estimated collective effective dose equivalent for the state is 5.26×10^2 man-Svy^{-1}. The expected number of people in the state at risk of incurring radiation-induced cancer per year was found to be 10(i.e. risk G = 2 from the urban areas, and 8 from rural areas).

CHAPTER ONE

1.0 INTRODUCTION

Man lives in an environment in which he is continuously being bombarded with ionizing radiations from both natural and man-made sources. Starting from the realization of the deleterious effects of an unbridled exposure to ionizing radiation, there has been a tremendous effort to locate and control these sources. Apart from the natural sources, there are other known technically enhanced sources such as coal-fired and nuclear electric generating plants, gas and oil production as well as mining of solid minerals. Also known to concentrate naturally occurring radionuclides are phosphate rocks which are basic raw materials for all inorganic fertilizers used in agriculture. The continuous application of fertilizers used in a given field could enhance the radioactivity level of that field (Balogun et al. 1998).

In the last decade, the demand for and the use of chemical fertilizer has continued to increase in Southern Nigeria, particularly in the South West where there is a resurgence of interest in dry season farming and the increasing loss of fertility in the over-used soils of this region. The dry season agricultural practices are concentrated around a few non-seasonal river basins found around this region (Balogun et al. 1998).

Mineral phosphates such as rock phosphate and phosphogypsum are known to be radioactive. Hence, the various phosphate-based fertilizers derived

from them are expected to show an enhanced level of radioactivity when compared to the background. For this reason, measurements of radioactivity levels in these products and the mineral phosphates have been made by various research groups (Balogun et al. 1998). In various parts of the world, radioactivity is being measured in diverse media ranging from food to soil and sediments. In Louisiana, USA, studies have shown the presence of not only naturally occurring radionuclides but also fallout ^{137}Cs, (Rao et al. 1996), while measurements from Bangladesh showed a high contribution from ^{40}K, ^{238}U and ^{232}Th with ^{238}U being most abundant (Balogun et al. 1998). More recently, the study by (Kuo et al. in press) showed the presence of naturally occurring radionuclides in drinking water and food of a Taiwan population, while (Benamar et al. 1997) measured the level of natural and man-made radionuclide in some sediments from Algiers (Voutilainen et al. 1998).

In Nigeria, (Olomo, 1990) has studied the occurrence of radionuclide in a number of cereals and cassava food products. He found that the levels of radioactivity in foods and food products are very low in Nigeria with the single largest contributor being the radioactive isotope ^{40}K. In a further study of soil samples from the Obafemi Awolowo University campus, a neighbourhood of the area under study in the present work, low level of radioactivity was recorded for ^{238}U, and ^{232}Th while the largest contributor is ^{40}K (Olomo, 1990). This finding is not surprising in this area, with solid rock outcrops known to be potassium rich as hills in several places on the University campus. (Akinloye, 1998) went

further to study the radioactivity in a number of media which include meat, fish, water and soil as part of a pre-operational study of the nuclear facilities sited on the University campus. Her findings are comparable with those earlier mentioned. In all these studies, no man-made radionuclide has been detected. In a later measurement, however, the presence of ^{137}Cs in some soil samples obtained within the Ile-Ife metropolis has been shown with an average occurrence of 0.28 ± 0.15 Bq/kg (Balogun et al. 1998).

Knowledge of the distribution pattern of both anthropogenic and natural radionuclides is essential in maintaining some sense of control of prevailing radiation levels. Measurement of natural and fallout radioactivities in soils gives information on natural sources, cumulative deposition from nuclear device testing and nuclear accidents (Siotis and Wrixon, 1984). The reported radio toxicity of the radionuclides varies from moderate (^{222}Rn) through high (^{234}Th, ^{228}Ac, ^{137}Cs) to very high (^{226}Ra, ^{228}Th) (IAEA, 1973). The deposition of radioactive fallout including ^{137}Cs at any given site is related to factors such as latitude, precipitation and local topography (Cox and Frankhauser, 1984, Dejong et al. 1982, Whicker and Schultz, 1982). The fission product ^{137}Cs is strongly absorbed and retained by soil particles, as are the natural radionuclides, which are found randomly distributed at different depths of the soil.

The objective of this work is to measure the activity concentration of some members of the uranium and thorium series, and of the primordial

radionuclide ^{40}K in soil samples taken at depths 0-5, 10-15 and 20-25cm at different locations in selected cities of Oyo State, Southwestern Nigeria. Oyo state is one of the largest states in Nigeria, and Ibadan, which is the state capital, is the largest city in West Africa and second largest in Africa after Cairo in Egypt. The baseline data of this type will almost certainly be of importance in making estimations of population exposure.

1.1 Radioactivity in Nature

The solid earth of our world is radioactive and has been since it was created. Over 60 radionuclides can be found in nature, and they can be placed in three general categories: (Merril and Gesell, 2004)

1. Primordial - been around since the creation of the Earth
2. Cosmogenic - formed as a result of cosmic ray interactions
3. Human produced - enhanced or formed due to human actions

Radionuclides are found in air, water and soil, and additionally in human body, being the product of the environment. Every day, humans ingest/inhale radionuclides in the air, in food and water. Radioactivity is common in the rocks and soils that make up the planet, in the water and oceans, and even in building materials and homes (Merril and Gesell, 2004). It is just everywhere. There is no where on earth that is free of natural radioactivity.

1.1.1 Primordial radionuclides

Primordial radionuclides are left over from when the earth and the universe was created. They are typically long lived, with half-lives often on the order of hundreds of millions of years. Radionuclides that exist for more than 30 half-lives are not measurable. The progeny or decay products of the long lived radionuclides are also in this heading. A few of them are listed in Table 1.1.

Table 1.1: Primordial Radionuclides

Nuclide	Symbol	Half-life	Natural Activity
Uranium 235	^{235}U	7.04×10^{8} yr	0.72% of all natural uranium
Uranium 238	^{238}U	4.47×10^{9} yr	99.27% of all natural uranium; 0.5 to 4.7 ppm total uranium in the common rock types
Thorium 232	^{232}Th	1.41×10^{10} yr	1.6 to 20 ppm in the common rock types with a crustal average of 10.7 ppm
Radium 226	^{226}Ra	1.60×10^{3} yr	0.42 pCi/g (16 Bq/kg) in limestone and 1.3 pCi/g (48 Bq/kg) in igneous rock
Radon 222	^{222}Rn	3.82 days	Noble Gas; annual average air concentrations range in the US from 0.016 pCi/L (0.6 Bq/m^3) to 0.75 pCi/L (28 Bq/m^3)
Potassium 40	^{40}K	1.28×10^{9} yr	Soil - 1-30 pCi/g (0.037-1.1 Bq/g)

1.1.2 Cosmogenic radionuclides

Cosmic radiation permeates all of space, the source being primarily outside of our solar system. The radiation is in many forms, from high speed heavy particles to high energy photons and muons. The upper atmosphere interacts with many of the cosmic radiations, and produces radioactive nuclides. They can have long half-lives, but the majority have shorter half-lives than the primordial nuclides. Table 1.2 shows some common cosmogenic nuclides:

Table 1.2: Cosmogenic Radionuclides

Nuclide	Symbol	Half-life	Source	Natural Activity
Carbon 14	^{14}C	5730 yr	Cosmic-ray interactions, $^{14}N(n,p)^{14}C$;	6 pCi/g (0.22 Bq/g)
Tritium 3	^{3}H	12.3 yr	Cosmic-ray interactions with N and O; spallation from cosmic-rays, $^{6}Li(n,alpha)^{3}H$	0.032 pCi/kg (1.2 x 10^{-3} Bq/kg)
Beryllium 7	^{7}Be	53.28 days	Cosmic-ray interactions with N and O;	0.27 pCi/kg (0.01 Bq/kg)

Cosmic radiation as discussed above, upon interaction with the atmosphere, produces cosmogenic radionuclides. It is also responsible for whole body doses.

Cosmic radiation is really divided into two types: primary and secondary. Primary cosmic radiation is made up of extremely high energy particles (up to 10^{12} MeV), and are mostly protons, with some larger particles. A large percentage of it comes from outside of our solar system and is found throughout space. Some of the primary cosmic radiation is from our sun, produced during solar flares.

Little of the primary cosmic radiation penetrates to the earth's surface, the vast majority of it interacts with the atmosphere. When it does interact, it produces the secondary cosmic radiation, or what we actually see here on earth. These reactions produce other lower energy radiations in the form of photons, electrons, neutrons and muons that make it to the surface.

The atmosphere and the earth's magnetic fields also act as shields against cosmic radiation, reducing the amount that reaches the earth's surface. With that in mind, it is easy to see that the annual dose one gets from cosmic radiation depends on what altitude he is at. From cosmic radiation, flying at high altitude can add a few extra millirem to the annual dose, depending on how often one flies, how high the plane flies, and how long the flight lasts in the air.

1.1.3 Human-Produced radionuclides

Humans have used radioactivity for about one hundred years, and through its use, added to the natural inventories. The amounts are small compared to the natural amounts discussed above, and due to the shorter half-lives of many of the

nuclides, have seen a marked decrease since the halting of above ground testing of nuclear weapons. A few of such nuclides are listed in Table 1.3.

Table 1.3: Human-Produced Radionuclides

Nuclide	Symbol	Half-life	Source
Tritium	^{3}H	12.3 yr	Produced from weapons testing and fission reactors; reprocessing facilities, nuclear weapons manufacturing
Iodine 131	^{131}I	8.04 days	Fission product produced from weapons testing and fission reactors, used in medical treatment of thyroid problems
Iodine 129	^{129}I	1.57×10^{7} yr	Fission product produced from weapons testing and fission reactors
Cesium 137	^{137}Cs	30.17 yr	Fission product produced from weapons testing and fission reactors
Strontium 90	^{90}Sr	28.78 yr	Fission product produced from weapons testing and fission reactors
Technetium 99m	^{99m}Tc	6.03 hr	Decay product of ^{99}Mo, used in medical diagnosis
Technetium 99	^{99}Tc	2.11×10^{5} yr	Decay product of ^{99m}Tc
Plutonium 239	^{239}Pu	2.41×10^{4} yr	Produced by neutron bombardment of ^{238}U ($^{238}U + n \rightarrow {}^{239}U \rightarrow {}^{239}Np + \beta \rightarrow {}^{239}Pu + \beta$)

1.2 Measuring Radiation

1.2.1 The Roentgen (R) and Rem (Roentgen Equivalent Man)

Radiation exposure is measured in units of roentgen and rem. One roentgen is equal to one rem. Because one roentgen or one rem of radiation is a fairly large amount of radiation, the prefix milli is often used. A typical radiation dose from a medical x-ray is about 40 mrem. According to the National Council on Radiation Protection and Measurements (NCRPM), the average person in the United States is exposed to a dose of approximately 360 mrem per year from both man-made and natural sources (NCRP Report No. 93, 1987). The SI unit for radiation exposure is the Sievert (Sv). One sievert is equal to 100 rem.

1.3 Measuring Radioactivity

Radioactivity is measured in the number of nuclear transformations or disintegrations that occur in a sample during a specific time. This is known as the activity of the sample. The SI unit for activity is the becquerel (Bq), which equals 1 disintegration per second (dps). The conventional unit of activity is the curie (Ci), which is 3.7×10^{10} or 37 billion (37,000,000,000) disintegrations per second. Both the curie and becquerel measure the same thing (activity). One curie is considered to be a large amount of activity, whereas one Becquerel is a very small amount of activity. To account for this, prefixes are often used to change the size of the unit.

1.4 Compositions of Soil:

Soil is made up of inorganic rock particles, minerals, water, gases, dead organic matter, living animals and microorganisms. It takes hundreds to hundreds of thousands of years to build soil. Soil represents one of a nation's most important assets.

Soil absorbs precipitation and gradually metes it out to plant roots and into subterranean aquifers and surface streams. Soil shelters seeds and provides the physical support and nourishment for plants. It consumes wastes and the physical remains of dead plants and animals, rendering their potential toxins and human pathogens harmless, while recycling their constituent materials into forms usable by plants (Gretchen et al. 1997).

1.4.1 Soil Formation:

Soil formation starts with the physical and chemical breakdown of rock (weathering). This releases essential plant nutrients. This process is speeded up by the presence of oxygen, water and acids released by the atmosphere and microorganisms.

Plants and animals add organic material to the surface of soil as they decay and breakdown. Generally, mature soil consists of a surface layer of mostly organic matter in all stages of decomposition, underlain by a mixture of smaller amounts of organic matter with inorganic material like sand, silts and clays, all of which rests on progressively less weathered layers of subsoil.

The 5 main factors that determine the character of soil are climate, living soil organisms and plants, topography, the nature of parent material and the soil age. Soil texture is important and depends on the size of its constituent particles. It influences the rate of water movement, its capacity to store water and its susceptibility to erosion and water logging (Gretchen et al. 1997).

1.5 Gamma Ray Spectrometry.

A gamma ray spectrometer can be used as a laboratory device where samples are counted and also as a field device for performing in-situ analysis. The key factors in the choice of instrumentation are efficiency, resolution, background, energy range, sample capability, and cost. Since environmental measurements must be made of species that are many times at very low concentrations, there is a premium on sensitivity. High resolution is required to distinguish a minor activity in the presence of larger activities. Scintillation counters employing a sodium iodide crystal with a thallium activator have been a mainstay of gamma ray spectrometry. Of main consideration in the choice of NaI (Tl) system are the crystal size, geometry, and the type of electronic instrumentation. The type of sample and level of contamination dictate these parameters. Semiconductor detectors are stable, reliable, and have good energy resolution. The most commonly used semiconductor detectors are germanium detectors. Silicon detectors are used for gamma spectrometry at low energies. The germanium detectors must be operated at liquid nitrogen temperatures (77^0K); however, the silicon detectors can be operated at room temperatures but are inferior in

resolution. The germanium detector is not as efficient as the NaI detector but is capable of distinguishing between very closely spaced energies. It is recommended that NaI (TI) detectors be used to measure one (or a few) radionuclides at very low concentrations and germanium detectors be used to characterize a sample with a large number of radionuclides present. Germanium detectors are much more expensive than NaI (TI) systems.

1.6 Low Level Radiation Dose And Radiobiological Studies

There are widespread sources of ionizing radiations in any environment that are essential to radiation and health physicist at any given time. Ionizing radiation from natural sources include those from terrestrial radionuclides in the soil, outdoor and indoor air, water and food that can lead to public exposure externally and internally below or equal to two times the average global annual effective dose of 2.4 $mSvy^{-1}$ (UNSCEAR, 1993). The detrimental health effects to man resulting from such exposure have been assumed to have a linear relationship with the dose received by an individual. This assumption and the idea of whether or not radiation standard should be proposed for a low-level radiation area has been a subject of radiological controversy (Jaworowski, 1999; Smith and Kemball, 1998; Landua, 1974; Richard and Evelyn, 1981; Ujeno, 1983; Martinelli et al. 1983 and Gonazalel, 1994). Some authors (Lucky, 1982; Jaworonwski, 1999) believe that the linear no threshold (LNT) theory is contradicted by the phenomenon of hormesis i.e. the stimulating and protective effect of low doses of radiation otherwise known as the adaptive response. However, Smith and Kemball (1998) believe that chronic exposure to low

activity sources will result in significant harmful effects. In this work the linear no threshold theory in which the probability of a stochastic effect is proportional to the absorbed dose is assumed. That is, the risk of incurring deleterious health effects exist no matter how small the dose received. The ultimate aim of measuring radiation level in an environment such as where this work was carried out is to assess the risk of adverse health effects on the inhabitants. Some cities were selected in Oyo State, Southwestern Nigeria, most especially in the rocky or industrialized areas where radioactivity may be very high. These health effects depend on the total energy deposited by the radiation, the time and spatial distribution of the energy deposited and the tissues involved. This dependence is quantified in terms of a hierarchy of concepts and units which have all been defined by ICRU (IAEA, 1994). These are described below:

1.7 Radiation Quantities And Their Units

1.7.1 Absorbed Dose

Radiation effects depend on the amount of the energy of the radiation deposited in the human tissue. A measure of this amount of energy is called the absorbed dose D, which is used in dosimetry to assess the risk of any health effects. This dosimetric quantity is defined as:

$$D = \frac{d_\varepsilon}{d_m} \qquad \text{(Gy)} \qquad 1.1$$

where d_E is the mean energy imparted on a volume element by an ionizing radiation and d_m is the mass of the volume element. The average dose is the total energy over the volume divided by the mass in the volume. The SI unit is

the grey (Gy) defined as 1joule/kilogram. The older unit is the rad (100 ergs/gram) and 1Gy = 100rad.

1.7.2 Dose Equivalent

Since the same dose of different types of radiation will cause different biological effects, each radiation type is weighed on a reference scale. The radiation-weighing factor W_R expresses the ability of the radiation type to cause biological damage. Once the radiation type is weighed, the dose equivalent H_T to a tissue T due to an absorbed dose D_T is given by

$$H_T = D_T W_T \qquad 1.2$$

the unit of H_T is rem or sievert (Sv) (1Sv = 100 rem).

1.7.3 Effective Dose

The radiation quantity that takes into account the radiosensitivity of individual organ is called the effective dose. A measure of the radiosensitivity for the different tissues is called the tissue-weighing factor W_T given in Table 1.4 below.

Table 1.4: The weighing and risk factors for different tissues (ICRP, 1990)

Organ	Weighting factor (W_T)	Risk factor x (10^{-3})Sv^{-1}
Gonad	0.25	4.00
Breast	0.15	2.50
Red bone marrow	0.12	2.00
Lung	0.12	2.00
Thyroid	0.03	0.50
Bone	0.03	0.50
Remainder	0.30	5.0
Total	1.00	16.5

It is defined as the proportion of the detriment to the tissue from stochastic effects to the total detriment when the whole body is uniformly irradiated. The effective dose H_E to the whole body is the sum total of the weighed equivalent doses for all the exposed tissues in an individual given as:

$$H_E = \sum_T W_t H_T \qquad 1.3$$

The unit is also Sievert (Sv)

1.7.4 Collective Effective Dose

The total impact of the radiation exposure due to a given practice or source depends on the number of individuals that is exposed as well as the dose received.

The collective effective dose S_E to any group is the summation of the products of the mean effective dose H_E in the various sub-groups of the exposed people and the number N_i of individual given as:

$$S_E = \sum_i N_i H_{E_i} \qquad \text{(Man-Sv)} \qquad 1.4$$

The linear no threshold relationship between dose equivalent and health effects has been assumed in this work and this implies that there is a risk associated with the exposure of an individual member of the sub-group to ionizing radiation. This risk of having different health effects on an individual within a given population is given as:

$$R = \sum_i P_i \qquad 1.5$$

where P_i is the probability that the individual will have an effect i.

For a homogenous population of N individuals, the collective health detriment G is given as:

$$G = N \sum_i P_i g_i \qquad 1.6$$

where g_i is the severity factor of the effect i.

These effects vary in nature and severity depending on the type of organ and its radiosensitivity and the type and quantity of radiation.

The collective health detriment G on a population of N people can be written in term of the collective effective dose S_E given as:

$$G = R_T S_E \qquad \text{(Man)} \qquad 1.7$$

where R_T is a constant of proportionality called the total risk factor. The risk factor for different tissues is given in Table 1.4 above.

1.8 The Aim and Objectives of The Study

The aim of this work is to determine the radioactivity levels of the various radionuclides in selected cities in Oyo State, The deposition of industrial wastes, application of fertilizer and the presence of rock phosphate, which are radiation sources pose a finite risk of radiation exposure which can cause extensive environmental contamination. The base line data will be useful for epidemiological studies to access the risk of incurring health effect due to the radiation. This risk has been stated in section 1.6 to be a function of radiation dose absorbed. This risk is significant and should be of concern when a large population is involved.

The objective of this work therefore is to collect data on the radioactivity levels of soil of the different environments in the state and then use the data to determine:

(1) the baseline concentration value of naturally occurring radioactive elements.

(2) possible areas of high level of radioactivity

(3) the relative absorbed dose to people living in the study area due to exposure to the radiation.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Natural Radioactivity in soil

Soils are made during the process of weathering of rocks and therefore have the same composition as rocks. Activity levels vary greatly depending on soil type, mineral make-up and density (~1.58 g/cm^3). Natural sources of radiation in the environment include those due to terrestrial and extra terrestrial sources. Natural radiation from terrestrial sources include those from primordial radionuclides whose half-lives are comparable to the age of the earth. Such radionuclides include ^{40}K, ^{238}U and ^{232}Th with members of their decay series. Rock and soils have been known to contain these primordial radionuclides in varying concentrations (Ibrahim et al., 1993; Delaine et al., 1986; Ajayi, 2000). Rocks like igneous, pegmatite, granites and gneisses have been known to be rich in these radionuclides (Eisenbud, 1987). It has been noted that phosphate rocks, and important raw material in the production of fertilizer contain relatively high concentration of uranium (Delaine et al., 1986; Ibrahim et al., 1993; Klement, 1982). Table 2.1 shows the average radionuclide contents of major rocks in the ground. Since weathering of rocks contributes to the formation of soil, those formed from igneous rock will be rich in their radioactive content than those formed from the softer sedimentary rocks. Sands, which contain mineral like monazite are rich in primordial radionuclides and thus contribute to the spatial variations reported in many countries (Mollah et al., 1987). Spatial variations

can be made more pronounced in locations where soil erosion had taken place. According to Wollenberg and Smith (1990), environmental radiation from the soil is due to top soil up to a depth of about 30cm. Therefore, determinations of radionuclides activities in locations with thick topsoil will exclude studies of the underlying rocks.

Apart from the above three primordial radionuclides in rocks and soil, there is also radioactivity in air due to radionuclides like ^{222}Rn and ^{220}Rn, which are gaseous members of ^{238}U and ^{232}Th series, respectively. Many houses have been known to contain ^{222}Rn and its daughter products in varying concentrations and this has been a subject of study by many researchers (Beretka and Mathew, 1985; Richard and Bernard, 1987; Chung Keung et al. 1989; Khan, 1991; Langoro et al. 1991; Farai and Sanni, 1992; 1992b). These radionuclides emanate from the soil, ground water, and through diffusion from building materials to build up in the air. Radon concentrations in air depend on many factors including ground cover (e.g paving, building, and vegetation), altitude, soil porosity and grain size, temperature, atmospheric pressure, soil moisture, rainfall and snow cover, atmospheric conditions and seasons (Ronald, 1998).

Natural radiation of extra terrestrial origin is produced when high-energy particles of cosmic origin interact with atoms and molecules in the atmosphere resulting in the production of two prominent radionuclides ^{7}Be and ^{3}H.

Table 2.1: Average radionuclide contents of major rock types (Eisenbud, 1987)

Type of rock	^{226}Ra (pCi/g)	^{238}U (pCi/g)	^{232}Th (pCi/g)	^{40}K (pCi/g)
Igneous	1.30	1.30	1.30	1.30
Sedimentary				
Sandstones	0.71	0.40	0.65	8.80
Shales	1.08	0.40	1.10	22.00
Limestone	0.42	0.40	0.14	2.20

2.2 High Background Radiation Areas

Around the world though, there are some areas with sizable populations that have high background radiation levels, the highest are found primarily in Brazil, India and China (Merril and Gesell, 2004). The higher radiation levels are due to high concentrations of radioactive minerals in soil. One such mineral, monazite, is a highly insoluble rare earth mineral that occurs in beach sand together with the mineral ilmenite, which gives the sands a characteristic black color. The principal radionuclides in monazite are from the ^{232}Th series, but there is also some uranium and its progeny, ^{226}Ra(Merril and Gesell, 2004).

In Brazil, the monazite sand deposits are found along certain beaches. The external radiation levels on these black sands range up to 5 mrad/hr (50 μGy/hr), which is almost 400 times normal background in the US. Some of the major streets of the cities have radiation levels as high as 0.13 mrad/hr (1.3 μGy/hr), which is more than 10 times the normal background. Apart from the beaches,

another high background area in Brazil is the result of large rare earth ore deposits that form a hill that rises about 250 meters above the surrounding area. An ore body near the top of the hill is very near the surface, and contains an estimated 30,000 tons of thorium and 100,000 tons of rare earth elements. The radiation levels near the top of the hill are 1 to 2 mrad/hr (0.01 to 0.02 mGy/hr) over an area of about 30,000 m^2. The plants found there have absorbed so much ^{228}Ra, that they can produce a self "x-ray" if placed on a sheet of photographic paper (an autoradiograph) (Merril and Gesell, 2004).

On the Southwest coast of India, the monazite deposits are larger than those in Brazil. The dose from external radiation is, on average, similar to the doses reported in Brazil, 500-600 mrad/yr (5 - 6 mGy/yr), but individual doses up to 3260 mrad/yr (32.6 mGy/yr) have been reported (Merril and Gesell, 2004).

An area in China, has dose rate that is about 300-400 mrad/yr (3-4 mGy/yr). This is also from monazite that contains thorium, uranium and radium Biological Effect of Ionizing Radiation (BEIR V, 1990).

In areas of high natural background radiation, an increased frequency of chromosome aberrations has been noted repeatedly (Merril and Gesell, 2004). The increases are consistent with those seen in radiation workers and in persons exposed at high dose levels, although the magnitudes of the increases are somewhat higher than predicted. No increase in the frequency of cancer documented in populations residing in areas of high natural background radiation (Merril and Gesell, 2004).

2.3 Human Epidemiology

2.3.1. Occupationally-exposed populations

a. Nuclear facility workers

Early nuclear weapons facility radiation workers have negligible indications of excess cancers or other adverse effects, and have substantial indications of lower cancer rates and all cause effects than the general population. These reduced health effect results are generally rationalized by ascribing the effect to undefined and unanalyzed "healthy worker effects" that reflect the fact that the workers do not include general population members that are not able to work.

Much higher doses than UK workers were experienced by USSR nuclear weapons facility workers. This includes the ingestion and internal exposure from plutonium, a long-lived alpha-emitting radioactive element, which is specifically relevant to EPA proposal. Excess cancers were found in workers only at very high doses, with substantial indication of lower than expected cancers in low to moderate doses. (Hohryakov and Romanov, 1994). The frequency of lung cancer was investigated among 2,346 workers in the radiochemical plant 'Mayak' who were exposed to radiation, both externally and internally from incorporation of plutonium.

The result shows that the subgroups with the lower cumulative doses have fewer observed cases of lung cancer deaths than expected, while the cohort with

dose equivalent in excess of 4 Sv exhibits an observed number of lung cancer deaths that is 2.7 times larger than the expected number." Other USSR data shows a reduction in lung cancer for workers with low to moderate body-burdens of Pu, while lung cancer is increased at high doses. (Tokarskaya et al., 1997).

b. Radiology workers

Radiation exposure of radiology workers (radiologists, radiological technicians, and others) has occurred for more than 100 years (Smith and Doll, 1981).Practitioners in radiology have received significant doses compared to natural background or nuclear workers. Radiologists in practice before 1925 had very high doses, including many with World War I experience with wounded military personnel in which case loads, x-ray equipment, and "hands-on" x-ray practices led to very high doses. Marie Curie practiced at the front lines in France with her "radiologic cars", and trained hundreds of radiologists, receiving very high doses in the process (Smith and Doll, 1981).

2.3.2 Medical Patient Health Effects

Medical patients receive significant radiation doses from both external sources, e.g., x-rays, and the ingestion and injection of radionuclides in nuclear medicine as internal sources of radiation exposure. Both types of exposure are used for both diagnostic and therapeutic applications, at low to moderate, and high to very high doses, generally at low to moderate dose rates. These

exposures are generally well-controlled, with potentially good to excellent dosimetry. Moderate medical treatment doses are not found to cause adverse health effects in dozens of studies that carefully consider significant potential confounding factors from health conditions. (Yalow, 1994).

Yalow reports that before 1968 (before the lower dose by radioimmunoassay), 1 to 3 million U.S. patients received internal doses for I-131 thyroid diagnosis. She reports that a Swedish study finds no excess thyroid cancer from diagnostic I-131 use (mean thyroid doses estimated to be 50 centiGray) for patients that were not suspected of having thyroid cancer, and that these patients have a 62%, statistically significant, reduction in thyroid cancer. (Yalow, 1994)

Biological Effect of Ionizing Radiation (BEIR V, 1990) reports the same result for patients given I-131 for diagnostic purposes stating that these results "do not support the conclusion that diagnostic doses of I-131 significantly increases the risk of thyroid cancer." BEIR V (1990). Studies of significant x-ray exposures and leukemia incidence are also negative. (Boice et al. 1991). Yalow also reports on one such study of leukemia from radiation exposures up to 300 centiSievert from normal x-ray practices over many years,. (Yalow, 1994)

2.3.3. Medical Applications for Health Benefits

Low-dose radiation (LDR), stimulates the immune system, enzymatic repair, and physiological functions, contrary to the LNT premise. Such

capabilities are successfully applied to treat cancer, and other diseases and debilities. Kiyohiko Sakamoto documented successful applications of the stimulation of immune response and successful treatment of cancer, conducted confirmatory studies of immunological responses to LDR in mice that succeeded in preventing, and reducing, cancers in mice. (Sakamoto and Myojin,, 1996).

2.4 Effect of Exposure to Radiation

Chronic exposure to low activity sources will result in significant harmful effects. This is the linear no threshold theory in which the probability of a stochastic effect is proportional to the absorbed dose is assumed. That is, the risk of incurring deleterious health effects exist no matter how small the dose received. (Smith and Kemball, 1998)

2.4.1 Assessment of Radiation Level

The data needed for the assessment of the radiation level of most parts of Nigeria are scanty. Agu (1965) carried out one of the pioneering radiation monitoring exercises in Nigeria in 1965. Since then, work had progressed slowly in this area. The work done so far includes, atmospheric radioactivity of Tin mining by-product in Jos (Babalola, 1984; Oresegun and Babalola, 1990), ^{222}Rn in Groundwater of Nigeria (Farai and Sanni, 1992; 1992b), natural radionuclide contents of some foodstuffs in Nigeria (Olomo, 1990; Arogunjo, 2003), natural radionuclide concentrations in aquatic species (Farai and Oni, 2002), and the determination of natural radionuclide contents of soil and rocks in some parts of Nigeria (Ajayi, 2000; Olomo et al. 1994; Jibiri and Farai, 1998; Arogunjo and

Farai, 1999). Most of the works carried out in Nigeria are without particular focus on areas as done in this study.

2.5 Soil Ingestion

Various studies have evaluated the unintentional and intentional ingestion of soil by children and adults. In 1984, the Centers for Disease Control estimate age-specific soil ingestion at about $10gd^{-1}$ based on observations of behaviors of children of 1 to 4 years of age (Kimbrough et al., 1984). In 1986, one of the first quantitative assessments of human soil ingestion was carried out using tracer elements in the soil like aluminum, silicon, titanium (Binder et al. 1990; Calabrese et al., 1990). The scenarios applicable to this current soil action level study are for a rural lifestyle with homes in a sparsely vegetated area, similar to the Rocky Flat areas. Soil ingestion is difficult to verify and quantify, and some studies do not differentiate between inadvertent or intentional intake. Many soil ingestion studies have focused primarily on children, leading to a general view that geophasia is more common in young children than other segments of the population. The reason for this conclusion may be that it has been easier to document geophasic children in the more controlled study environments with children. However, there are several studies (e.g., Binder et al., 1986) that cite cases of geophasia in several segments of the population, including adolescents and pregnant women. While this may be more common in indigenous or rural populations, geophasia has been documented in various population subgroups in the United States. The incidence of geophasia in the population is quite small,

estimated at less than 1%; however, quantitative evaluation of this phenomenon is sparse.

Most studies, even the more recent mass-balance soil ingestion studies (Stanek and Calabrese, 1995) are conducted under fairly idealized conditions or during more mild seasons of the year, and authors tend to point this out in their reports (Calabrese et al., 1990; Binder et al., 1986). This timing factor provides conditions where children may have more ready access to open play areas and outdoor activities and adults are more involved in gardening activities. While values derived from studies conducted from a few days to a few weeks are quite valid in estimating daily soil ingestion rates, there is a need to carefully consider the implications of translating this daily soil ingestion rate to an annual soil ingestion rate.

The daily soil ingestion rates are based on a few days or weeks of measurements during times when the soil ingestion may be more likely because of weather conditions or available surface soil.

2.6 Fruits, Vegetables, and Grain Consumption

Annual consumption of major food groups as a function of age for the United States have been estimated and reported by various agencies NCRP (1999). This information was necessary in assessment in order to calculate an average dose from ingestion of produce and grains grown in the contaminated soil, or of meat and milk ingested from animals that ate vegetation grown on the site. In a recent publication, NCRP (1999) compiled values from a number of sources for consumption of major food groups. Recommendation was made for

an annual consumption rate for fruits, non-leafy vegetables, and grains of $190kgy^{-1}$ for the infant scenario (Table 5, NCRP 1999).

2.7 Gamma Ray Spectrometry – General

Among the different techniques available for detection of natural and man-made radionuclides, gamma ray spectrometry is probably the most widely applied. A wide choice of detectors with different characteristics, together with advanced electronics and software is available for qualitative and quantitative analysis.

In the following paragraphs high resolution gamma spectrometry with Germanium (Hyperpure or Lithium drifted) detectors will be described, with special regard to applications in the analysis of natural radionuclides (Typically Uranium and Thorium).

2.7.1 Basic Detection Principle

In semiconductor detectors, the energy lost by photons in the sensitive volume of the detector, results in ionization processes. These phenomena generally occur through a series of events in which energy of a primary electron is spent in creating new ionizations. These processes produce free charges (electrons and holes) which are collected at detector electrodes. The volume in which the collection of free charge carriers is effectively accomplished is defined as "Sensitive volume" of the detector.

The measurement of the total charge set free by incoming photon permits the measurement of the energy delivered by the photon inside the detector. The number of free charge carriers (created per unit of energy dissipated by the

radiation in the detector) depends on the type of semiconductor material used for the detectors, which characteristics are of great importance for the energy resolution of the system.

While silicon is normally used for the manufacturing of x-rays and soft gamma rays detectors (below 50 keV), germanium is chosen when high energy radiation is to be detected, because of its higher absorption coefficient and density, which increase the efficiency of the system.

Generally, the semiconductor material is of "p-type" because of the presence of defects and impurities with the predominance of acceptor impurities that could affect the charge collection in the detector. These limitations could be overcome by "doping" the semiconductor with donor ions. An alkali metal, lithium, is typically used, diffusing it inside the semiconductor lattice. Thanks to advanced material technologies, it is now possible to obtain large detectors of Hyperpure Germanium, which closely approach the characteristics of an intrinsic semiconductor.

The complexity of gamma ray spectra of natural radionuclides in environmental samples can be exemplified through the analysis of the spectrum of a single monoenergetic gamma emitter, which is illustrated in Fig. 2.1.

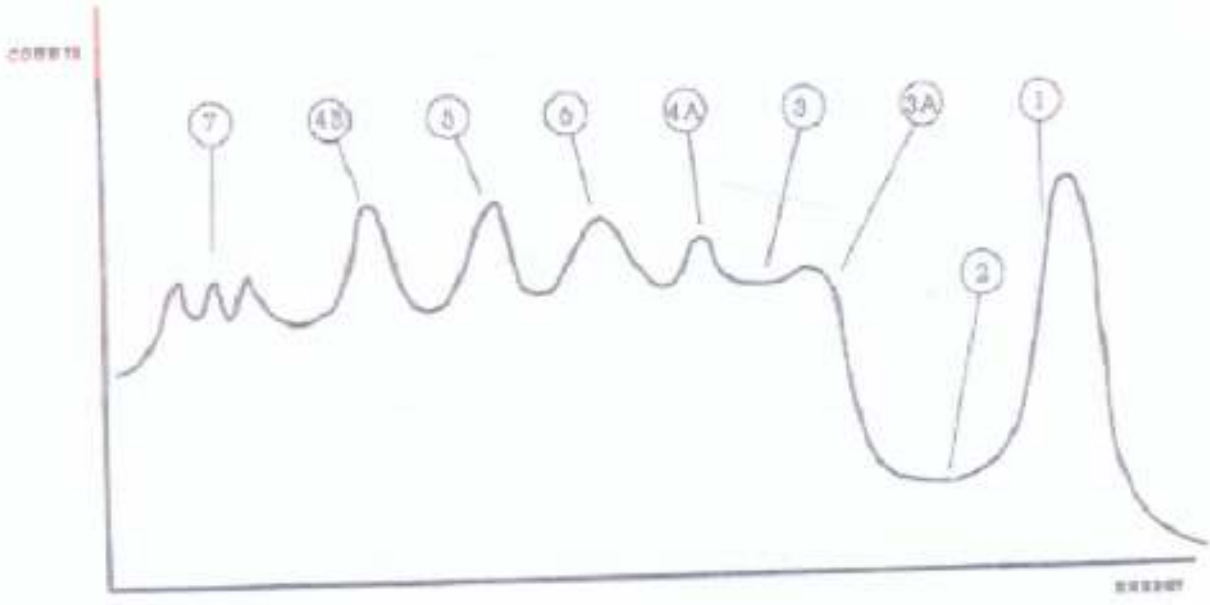

Figure 2.1: Spectrum simulation of a monoenergetic gamma emitter

A single monoenergetic gamma ray emitting radionuclide produces a spectrum in which several different peaks appear, that can be described as in the following:

(1) ***Photoelectric Peak***: characterized by asymmetry of the peak, due to limitations in charge collection process in the detector (caused by the presence of charge traps or uneven distribution of the collecting field in the crystal) and to the escape from the detector of bremstrahlung radiation emitted by electrons inside the detector lattice (which phenomena determine the broadening of the photoelectric peak toward the low energy end).

(2) ***Short-term Compton continuum***: due to the escape of photons emerging from a multiple Compton scattering event.

(3) ***Compton continuum***: (starting at Compton edge (3A) and extending toward lower energies) caused by a Compton scattering event followed by the escape of the emerging photon from the sensitive volume of the detector, where the Compton continuum shape is related to the energy distribution of the electron emerging from Compton scattering.

(4) ***Single escape peak (4A), double escape peak (4B)***: produced when the energy of incoming photon exceeds 1022 keV (double of energy associated with the rest mass of electron), and consequently primary interaction event may be the production of an electron – positron pair.

(5) ***Annihilation peak***: produced by 511 keV photons resulting from pair annihilation events occurring outside the detector.

(6) ***Back scattering peak***: induced when a photon emitted by the sample toward the space surrounding the detector is scattered in the direction of the detector.

(7) ***X-rays peak***: (characteristic of detector atoms) produced by the ionization of inner shells of detector atoms which results in the emission (following the rearrangements of electronic shells) of characteristic x radiation.

General Set up of the Spectrometric System

The acquisition and analysis of gamma emission spectra from environmental samples requires a general set up for the evaluation of the specific activities of the radionuclides. For this analysis the energy and efficiency calibration plus the background of the system must be accurately known.

2.7.2 Calibration of the System

Efficiency calibration of the system was accomplished through the use of commercially available and calibrated multipeak gamma sources that contain Cadmium-109, Cobalt-57, Cerium-139, Tin-113, Strontium-85, Caesium-137, Cobalt-60 and Yttrium-88. These radionuclides cover the energy range of interest for calibration and make it possible to evaluate respectively the efficiency curve, the relation between channel number and energy, and other parameters of interest such as the resolution, the symmetry of peaks, etc.

Reference source of natural Uranium and Thorium are also commercially available, and the use of this type of calibration sources permits direct comparative analysis.

The calibrations have to be made in the same geometric conditions that will be used for analysis, by diluting or dispersing the calibration source in a material which has similar self-absorption characteristic of samples to be analyzed. The comparisons among different detectors are often based on the following detector characteristics: efficiency, resolution and peak-to-Compton ratio. All of these parameters are referred to measurements made in 1330 keV photons emitted from a Cobalt 60 point source located at 20 centimeters from front face of the detector. The efficiency is expressed as percentage ratio of the efficiency of the detector to that of a 3" x 3" NaI (T1) detector.

2.7.3 Evaluation and control of Background

Radioactive elements contained in the environment near the detector lead to a background spectrum, which interfere with the sample emission spectrum and decrease the sensitivity of the system. Detectors are generally enclosed in a shield with high atomic number material (typically lead). Internal liners of cadmium, copper, plexiglass are used to reduce the x-fluorescence of the internal walls. Quality of the material used for the detector and the shield must be checked both for the presence of artificial (Cobalt-60, Caesium-137 and 134) and natural radionuclides.

Cause for instability of background may be the variation in the air contents of Radon-222 and its daughters. This problem can be overcome by sealing the internal part of the shield and filling it with nitrogen. For the data

evaluation, a library of background spectra must be available, containing spectra recorded with suitable sample container.

2.8 Determination by Gamma Spectrometry of Radionuclides of Uranium-238 and Thorium-232 Series

Since only a few radionuclides from the Uranium-238 and Thorium-232 series emit gamma rays useful for gamma spectrometry, the assessment of the radionuclides content through the gamma spectrometry can only be obtained when the equilibrium conditions are achieved.

Fractioning of the chains (due to geological or physical reasons) may occur. Furthermore, for a correct quantitative evaluation of radioactive elements equilibrium with Radon can be achieved only with containers with no leakage. Typical gamma emitters and spectral lines adopted for the analysis of uranium and thorium contents in environmental samples are listed in the following paragraphs.

The emission of thorium-234 at 63.3 keV can be conveniently used for evaluation of the Uranium-238 content not only because the equilibrium between these radionuclides is guaranteed by a relatively short half life of thorium-234 but also because this energy is located in an undisturbed zone of the spectrum. Radium-226 may be measured by its direct emission at 185.99 keV, but account should be made for the presence of 185.55 keV gamma emission from uranium-235, normally present in geological samples.

Several gamma spectral lines with high yield of Lead-214 and Bismuth-214 are present; emissions from Lead-214 at 295 keV and 352 keV and from Bismuth-214 at 609 keV, 1120 keV and 1764 keV may be easily used. Polonium-210 may also be measured using its 46.5 keV gamma ray.

Concentration of uranium-235 may be evaluated by using the 185.99 keV line, if subtraction of the contribution of 185.99 keV gamma emission from Radium-226 is made.

Spectral lines of lower intensities useful for evaluation of uranium-235 are located at 144, 163, 205 keV.

With regard to thorium-232 series, the most useful spectral lines for examination of this chain are respectively 583 keV (Thallium-208) and 911, 969 keV (Actinium-228).

2.9 Sample Treatment for Gamma Ray Spectrometry

The treatment of the sample prior to the gamma spectrometric analysis is required respectively:

- To obtain a sample geometry identical to that used for the calibration
- To avoid the loss of gas (typically radon) and to reach equilibrium condition with daughters.

Example of these treatments are described in the following section for two important types of environmental samples made respectively of fresh water and solid materials derived from earth crust (rocks, soil, cement, etc.)

2.9.1 Water

If determination of Radon-222 dissolved in water is required, gamma spectrometry of short-lived daughters as Lead-214 and Polonium-214 can be easily made with good sensitivity (= 0.2 Bq/1 with a commercial 25% efficiency, 1.90 keV resolution detector, 1 liter Marinelli Beaker, 10000 sec. acquisition time).

The leakage of radon gas from the sample container and from Marinelli beaker must be carefully checked, because of its high escape rate and/or high diffusion through several different materials. A Radon-proof sealing is very difficult to achieve and plastic materials, which can be heat-sealed, or solvent sealed are the most appropriate.

For the evaluation of non-gaseous elements with long half-life, sample treatment may be required to concentrate the radionuclides to be analysed thus increasing the sensitivity of the measure. Among various radiochemical available procedures, direct ion exchange resin enrichment plus alumina appears to be the less expensive and the most sensitive available.

2.9.2 Soil, Cement, Rocks, Sands etc.

For the analysis of Radium-226 content, the gamma emission of Lead-214 and Bismuth-214 may be used, if equilibrium all along this segment of decay chain is guaranteed. To this end, the sample is enclosed in the container used for analysis, and sufficient time should elapse to allow growth of Radon-222 and gamma emitting daughters. The Thorium analysis, when the same precautions taken for Uranium series were taken, can be effectively made using spectral lines emitted by Actinium-228 and Thallium-208.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

The research work is aimed at studying the concentration and distribution of some radionuclides in soils of Oyo State, Southwestern Nigeria. The purpose of the research is to detect the possible human exposure and to compare it to the maximum permissible level (MPL) so as to disclose the possible effect on human being and suggest the preventive measure. It will also compare the concentration and distribution in different locations and the factors responsible for the trend.

3.2 Choice of Sites

Nine cities were selected in Oyo State where soil samples were collected at different locations and depths (0-5, 10-15, 20-25cm). These cities of choice are widely spread out to ensure that every region of the state was covered. The cities include Ibadan, Egbeda and Eruwa in the southern part of the state, Oyo, Ogbomoso, Fiditi and Iseyin at the central part and finally Shaki and Igbeti at the Northern part.

3.3 Geographical Settings of Oyo State

Apart from the fact that the locations are spread out to have a wide coverage for the measurement of the level of radionuclide contaminations of the soils in the state, the locations are characterized by different geology and topography. Ibadan is a very large city, densely populated with about 2 million inhabitants and averagely industrialized. It is the largest city in West Africa and

the second largest in Africa after Cairo in Egypt. Ibadan is generally a low land area with few hills and rocks. Oyo and Ogbomoso are ancient cities of averagely low land. They are fairly large with average population density. Eruwa and Igbeti are rocky cities, not large and of low population density. Other cities like Egbeda, Fiditi, Iseyin and Shaki are low lands with low population density. Oyo State lies within longitudes 3^0 8' and 4^0 33' E and latitudes 7^0 22' and 9^0 32' N, with averagely high rainfall of about 1200-1350mm annually, Relative humidity is between 70% and 90% and temperature between 27^0C and 32^0C.

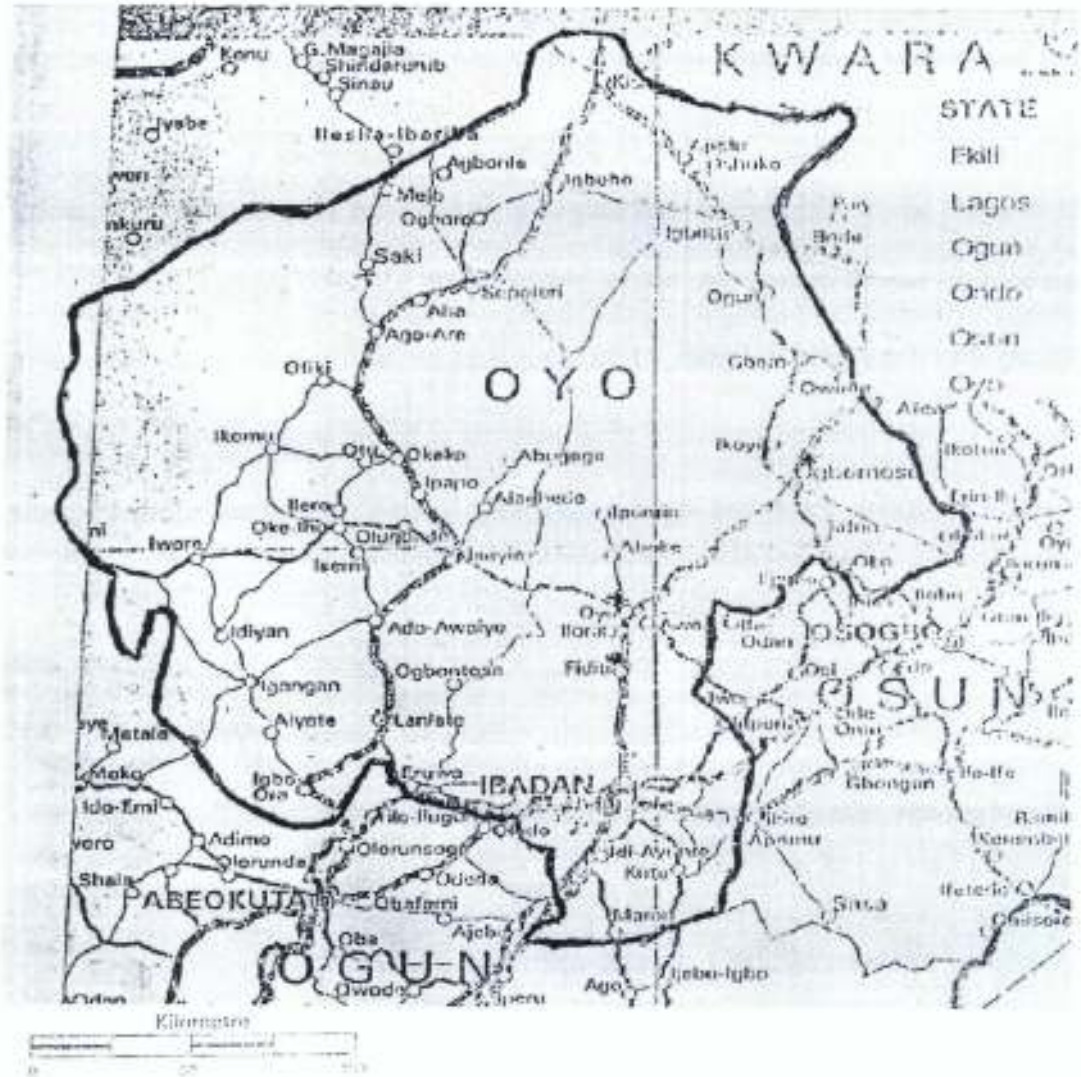

Fig 3.1: MAP OF OYO STATE

3.4 Sample Collection

117 Soil samples were collected from the 9 cities. In most of these cities, 5 locations were selected and at each location, five spots were selected by marking out a 1 m^2 area. Samples were collected from the 4 vertices of the square and the intersection of its diagonals at depths 0-5cm, 10-15cm and 20-25cm. The soil samples from the same depth were thoroughly mixed together to form a single sample of about 400g making a total of 3 samples from each of the five locations in each city to make a total of 15 samples from each city except Iseyin and Igbeti where 3 and 9 samples were collected respectively. This soil samples were packed in labeled cellophane bags and were taken to Physics Department of the Federal University of Technology, Akure for preparation for analysis.

3.5 Sample Processing

The soil samples were processed according to the recommended procedure by the IAEA (1989).

The samples were first sun dried, then oven-dried at 110^0C to constant weight.

3.5.1 Grinding and Sieving

The soil samples were pulverized and sieved using a 2mm mesh screen to obtain a fine texture of soil samples. Some of the soil samples most especially the one collected at the rocky area are very coarse in nature and hence it is difficult to obtain enough fine samples sieved. Therefore, the use of a mole

grinding machine was employed to grind the coarse sample to fine ones so as to obtain sufficient mass of sieved fine soil samples for analysis.

3.5.2 Weighing

The sieved soil samples were each poured into already weighed plastic container and weighed using a beam balance.

3.5.3 Packaging and Labeling

The weighed soil samples were each packed in thick cellophane bag and labeled. The labeling was done to indicate the city where the soil sample was taken, the location and the depth of the soil.

3.6 Sample Analysis and Activity Determination

The well-prepared and packed soil samples were taken to Germany for analysis using Gamma Ray Spectrometry Machine. The sieved soil samples were sealed in a $76cm^3$ Petri dish container and subjected to gamma spectroscopy to determine the activity.

3.7 Test – Measurement by High Resolution Gamma-Ray Spectrometry

Soil samples are weighed into a container of known geometry for counting by high-resolution gamma-ray spectrometry. Samples that require measurement of Radium-226 are mixed with resin before being placed into the measurement container. This mixture is allowed to stand for a minimum of 28 days (to allow for Radon ingrowth) before being counted by the high-resolution gamma-ray spectrometer. Some radionuclides (gamma emitters) can be identified and quantified using a gamma-ray spectrometer. Some radionuclides,

which do not emit any useful gamma rays may still be quantified by measuring their short-lived daughter products and assuming them to be in secular equilibrium.

Naturally occurring radionuclides include Beryllium-7 (formed in the atmosphere by the actions of cosmic rays), Potassium-40 and those radionuclides originating from the decay of uranium or thorium series

Gamma spectrometry measurements were carried out with coaxial-type Ge detectors (Canberra Industries Inc.,) of 50% relative efficiency and having a resolution of 2.4 keV at 1.33 MeV. The system was set up to cover about 2 MeV photon energy ranges over 4k channels. The detectors are properly shielded in lead castles. Calibrations of the measuring systems had been carried out using certified reference standards for various radionuclides. Spectral analyses were performed with the Genie2k spectrometry software, version 2.1 (Canberra Industries Inc.). A library of radionuclides, which contained the energy of the characteristic gamma peaks for each nuclide analysed and their corresponding emission probabilities was built from the data supplied in the software. Each sample was counted for 24hours to achieve minimum counting error. Specific activity of each radionuclide in soil were expressed in $Bqkg^{-1}$ of dry mass of soil and corrected for the time elapsed since the samples were collected in the field.

3.8 Constraints

The research work altogether, beginning from the collection of samples to analysis are not without some constraints. First, the traditional belief and

superstition which placed a suspicious view on soil collection made it difficult to penetrate some communities to collect the soil samples. Another is the issue of time and availability of gamma spectrometer to analyse the large number of samples that were prepared for analysis. Most of this constraints were properly handled like those communities that resisted the collection of soil samples in them were left for nearby areas in the same community for the collection of soil samples and also the time and space available for the use of the spectrometer were judiciously utilized.

CHAPTER FOUR

4.0 RESULT AND DISCUSSION

4.1 General Radioactivity Level of Soil Samples

The result of the analysis is shown in Table 4.1. The table shows that ^{40}K has the highest concentration in almost all of the samples with the exceptions of Fiditi, Egbeda, Igbeti top soil, Ogbomosho top soil (0-5cm) and deep soil (20-25cm). Samples like Igbeti middle soil (10-15cm) and deep soil (20-25cm) are characterized by extremely high concentration of ^{40}K, the concentration in Eruwa top soil is equally very high. Other radionuclides with fairly high concentration in some areas includes, ^{210}Pb, ^{212}Bi, ^{212}Pb, ^{228}Ac and ^{228}Th. ^{137}Cs, ^{210}Pb, ^{224}Ra, ^{228}Th and ^{234M}Pa are not present in some of the samples, ^{238}U is not detected in any of the samples while ^{235}U, though detected in all the samples, is in a very low concentration. ^{137}Cs, has extremely low concentration even to the point of having negative concentration in some samples i.e Shaki and Eruwa middle soil (10-15cm). The comprehensive details of the result of analysis of the soil samples are given in Tables 4.1 to 4.4 and figures 4.1 to 4.11.

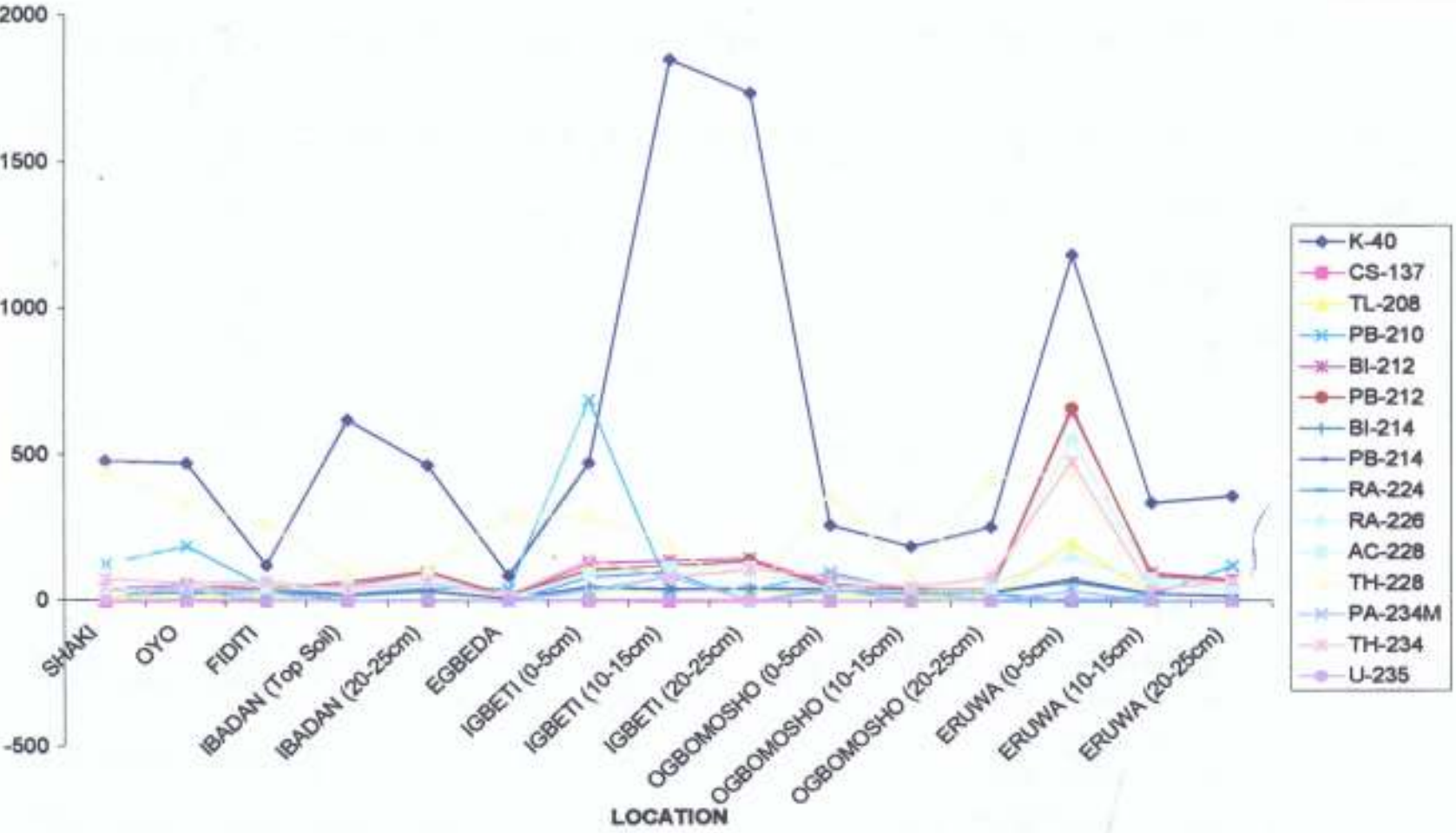

FIG 4.1: GRAPH OF RADIONUCLIDE CONCENTRATION OF THE SOIL OF VARIOUS CITIES COVERED IN OYO STATE

TABLE 4.1: RADIONUCLIDES CONCENTRATION OF THE SOIL OF SOME SELECTED CITIES IN OYO STATE, SOUTHWESTERN NIGERIA($Bq Kg^{-1}$)

RADIO NUCLIDES / LOCATION	^{40}K	^{137}Cs	^{208}Tl	^{210}Pb	^{212}Bi	^{212}Pb	^{214}Bi	^{214}Pb	^{224}Ra	^{226}Ra	^{228}Ac	^{228}Th	^{234M}Pa	^{234}Th	^{235}U
SHAKI 0 – 10cm 86g	480.07 ±19.12	-0.102 ±0.29	13.23 ±0.86	127.44 ±39.35	43.92 ±6.15	40.63 ±2.09	35.00 ±1.65	38.72 ±2.19	21.33 ±7.58	21.81 ±28.13	37.53 ±1.50	445.95 ±94.71	48.14 ±30.43	76.31 ±6.07	3.46 ±1.68
OYO 0 – 5cm 117g	470.90 ±19.07	0.88 ±0.29	12.25 ±0.89	187.10 ±52.17	54.26 ±6.40	38.00 ±2.12	25.66 ±1.46	27.12 ±1.20	28.69 ±6.76	51.43 ±6.94	34.97 ±1.73	328.80 ±27.61	39.88 ±25.18	62.49 ±4.77	3.16 ±0.42
FIDITI 121-8g	121.26 ±5.78	–	14.40 ±0.80	46.73 ±30.58	41.55 ±4.65	39.78 ±1.79	32.64 ±1.44	35.83 ±1.61	31.83 ±6.94	59.10 ±5.26	37.39 ±1.78	263.34 ±20.80	–	66.55 ±4.40	3.63 ±0.32
IBADAN 110g Top Soil	618.96 ±16.05	–	16.57 ±0.76	22.69 ±5.75	51.57 ±6.93	63.57 ±1.87	18.30 ±0.93	19.67 ±0.85	–	26.32 ±7.40	48.34 ±1.73	91.62 ±11.29	–	42.63 ±2.86	1.62 ±0.45
IBADAN 20 – 25cm	463.76 ±13.38	–	28.06 ±0.94	44.24 ±3.80	97.27 ±6.67	100.30 ±4.94	32.78 ±1.04	35.29 ±1.96	–	60.61 ±7.91	81.29 ±3.70	116.81 ±18.98	–	62.73 ±4.99	3.72 ±0.48
EGBEDA 99g	85.83 ±4.04	0.89 ±0.25	5.23 ±0.34	40.77 ±16.29	14.62 ±2.76	18.38 ±0.76	7.82 ±0.48	7.84 ±0.42	–	16.77 ±4.54	13.54 ±0.94	289.35 ±18.60	–	22.24 ±1.86	1.03 ±0.28
IGBETI 0 – 5cm	473.08 ±17.80	1.16 ±0.29	36.08 ±1.64	689.23 ±62.21	129.25 ±9.93	106.57 ±3.25	46.54 ±1.81	48.89 ±1.78	81.98 ±7.92	16.04 ±22.22	97.67 ±3.42	293.82 ±17.85	37.41 ±17.28	142.63 ±5.87	5.16 ±1.31
IGBETI 10 – 15cm	1,850.60 ±36.83	–	39.17 ±1.10	41.09 ±7.08	138.79 ±7.78	120.10 ±2.95	38.39 ±0.97	41.17 ±1.36	99.19 ±7.50	93.70 ±7.98	117.53 ±3.88	199.41 ±16.55	83.06 ±52.15	78.91 ±5.20	5.75 ±0.48
IGBETI 20 – 25cm	1,735.91 ±42.15	–	41.03 ±1.27	36.71 ±7.94	146.04 ±9.51	137.44 ±6.71	39.69 ±1.40	43.95 ±2.42	–	96.02 ±10.06	117.15 ±5.13	2.85 ±9.90	–	110.87 ±7.67	5.89 ±0.61
OGBOMOSHO 0 – 5cm 118g	260.25 ±10.75	–	16.52 ±0.94	97.56 ±35.85	58.48 ±5.58	48.28 ±2.07	39.43 ±1.80	41.10 ±1.56	35.93 ±7.28	43.02 ±35.99	44.01 ±1.57	366.00 ±23.20	43.14 ±23.06	82.48 ±4.32	1.70 ±2.17
OGBOMOSHO 10 – 15cm 109.3g	186.63 ±7.35	–	11.94 ±0.58	35.02 ±6.62	40.80 ±5.69	36.74 ±1.63	25.61 ±0.99	27.14 ±1.41	24.63 ±5.96	59.87 ±6.52	33.04 ±1.44	87.03 ±10.01	–	45.53 ±3.52	3.67 ±0.40
OGBOMOSHO 20 – 25cm 111g	254.23 ±12.51	0.74 ±0.39	12.25 ±0.97	–	32.36 ±7.09	38.03 ±2.64	29.52 ±1.80	30.15 ±1.38	27.00 ±8.75	59.52 ±8.29	34.39 ±1.81	419.99 ±39.97	–	81.83 ±6.93	3.65 ±0.51
ERUWA 0 – 5cm 95.4g	1,188.14 ±25.87	1.17 ±0.68	198.31 ±4.10	–	653.30 ±20.95	661.81 ±12.91	64.65 ±2.00	76.16 ±2.08	–	153.73 ±16.28	556.09 ±13.62	442.52 ±30.65	35.22 ±38.90	480.12 ±18.43	9.43 ±0.99
ERUWA 10 – 15cm	338.05 ±10.18	-0.09 ±0.22	26.26 ±0.86	21.37 ±2.84	98.03 ±6.51	89.12 ±4.42	24.96 ±0.97	26.95 ±1.49	–	63.60 ±7.09	79.38 ±3.51	–	–	39.17 ±2.72	3.90 ±0.43
ERUWA 20 – 25cm 114.5g	361.12 ±14.07	–	22.02 ±1.07	122.83 ±43.00	74.78 ±6.50	72.83 ±2.37	20.51 ±1.14	19.26 ±0.87	–	40.12 ±5.37	60.86 ±2.07	–	–	71.25 ±4.44	2.46 ±0.33

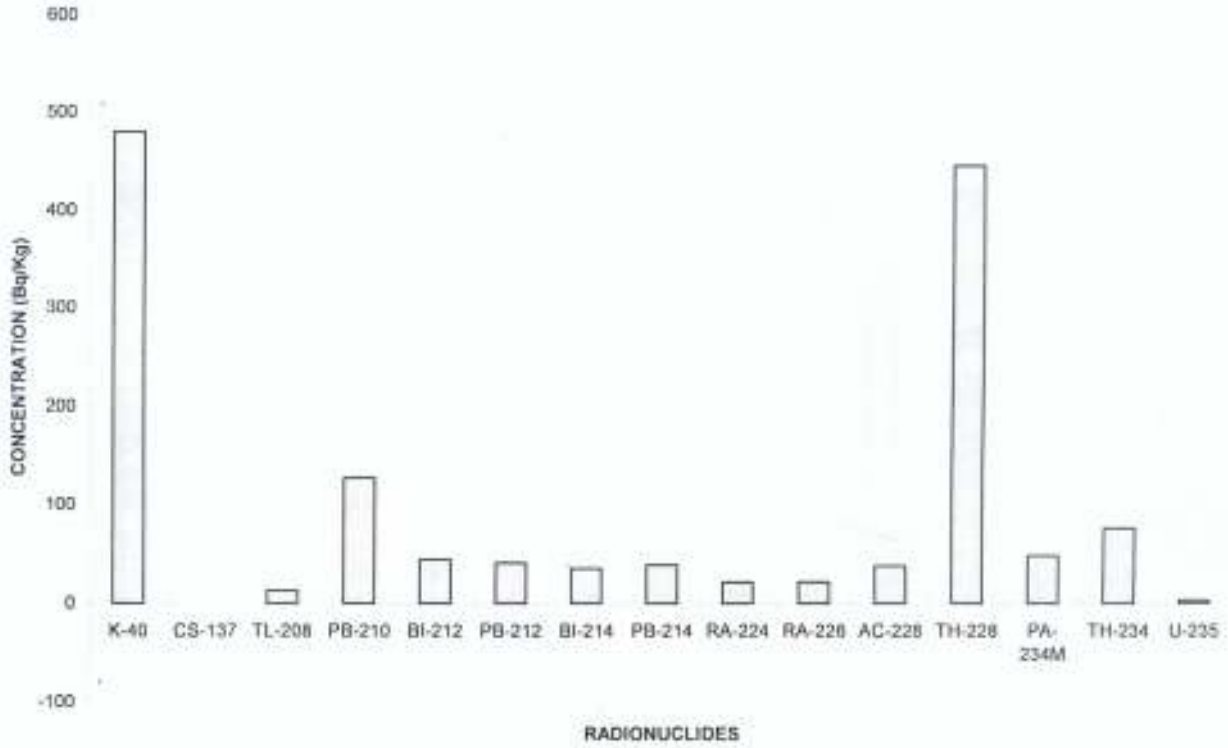

Fig 4.2: RADIONUCLIDE CONCENTRATION OF SHAKI SOIL

4.1.1 Radioactivity Level in Shaki Soil

In Shaki, the concentration of ^{40}K (480.07 ± 19.12 Bq/kg) and ^{228}Th (445.95 ± 94.71 Bq/kg) in the soil is responsible for over 65.58 % of the total radionuclide concentration in the soil. The concentration of ^{235}U (3.46 ± 1.68 Bq/kg) is low. This can be accounted for by the fairly rocky nature of the soil. The possible source of the high concentration of ^{40}K is the use of fertilizer for Agricultural purpose. Table 4.1 and figure 4.2 above show the activity of the various radionuclides in Shaki soil.

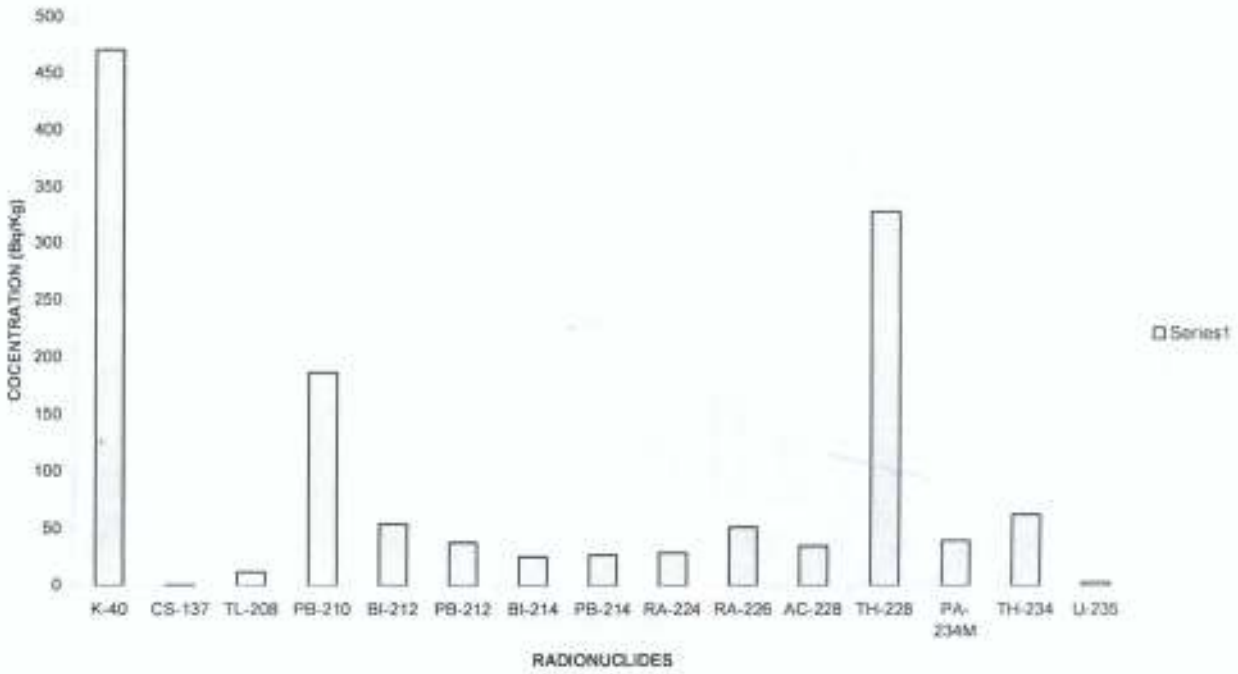

Fig 4.3: RADIONUCLIDE CONCENTRATION OF OYO SOIL

4.1.2: Radioactivity Level in Oyo Soil

There are close similarities in the radioactivity of Oyo and Shaki soil. From ^{40}K (470.90 ± 19.07 Bq/kg) that has the highest activity to ^{137}Cs (0.88 ± 0.29 Bq/kg) that has the least activity in the soil, the generality of the radioactivity in Oyo soil shows almost the same trend with that of Shaki soil. This is not far-fetched from the fact that both cities have closely related topography. Though Oyo is more populous than Shaki and the industrial activity there is higher, Shaki soil is slightly rocky than Oyo soil. The result is shown in Table 4.1 and figure 4.3 above.

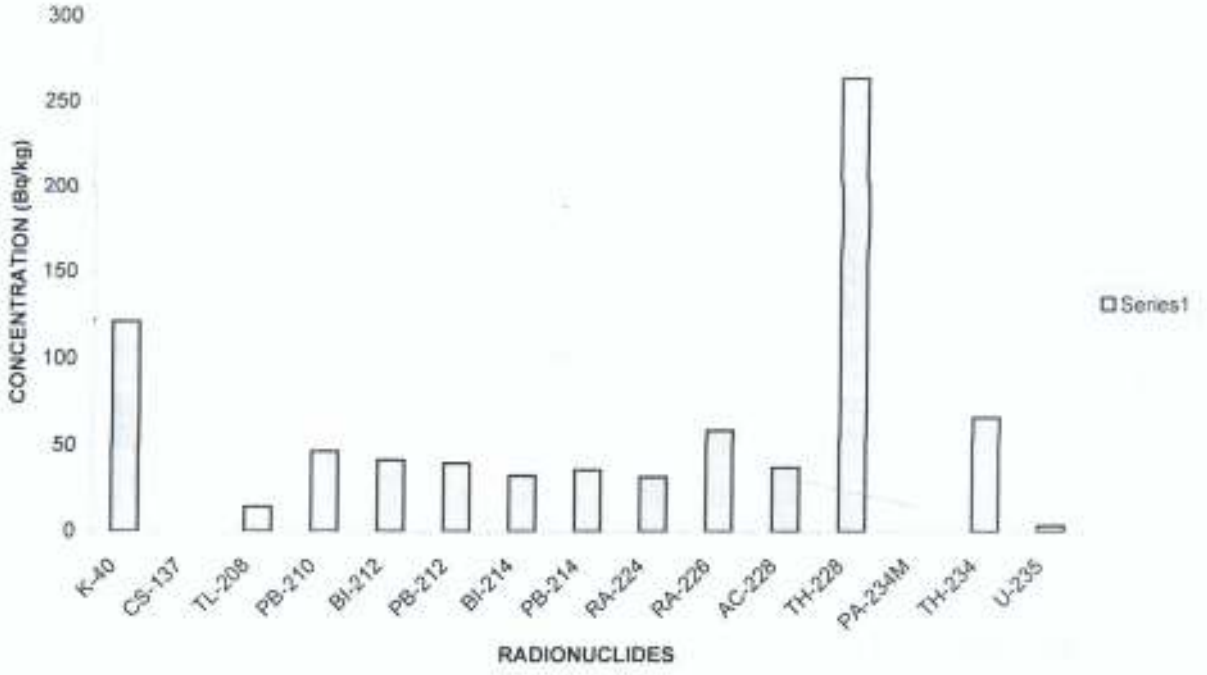

Fig 4.4: RADIONUCLIDE CONCENTRATION OF FIDITI SOIL

4.1.3: Radioactivity Level in Fiditi Soil

Fiditi is a small town and the radioactivity concentration in its soil is low. Most especially for ^{40}K which is (121.26 ± 5.78 Bq/kg) compared to other locations which have higher concentration except for Egbeda that has the least. The concentration of ^{228}Th is the highest of the range (263.34 ± 20.80). ^{137}Cs and ^{234M}Pa were not detected in the soil making the total number of radionuclides detected to be 13 with ^{228}Th and ^{40}K taking total percentage of 48.44 %. ^{235}U concentration (3.63 ± 0.32 Bq/kg) is slightly higher in Fiditi than Oyo and Shaki. The result is shown in Table 4.1 and figure 4.4 above.

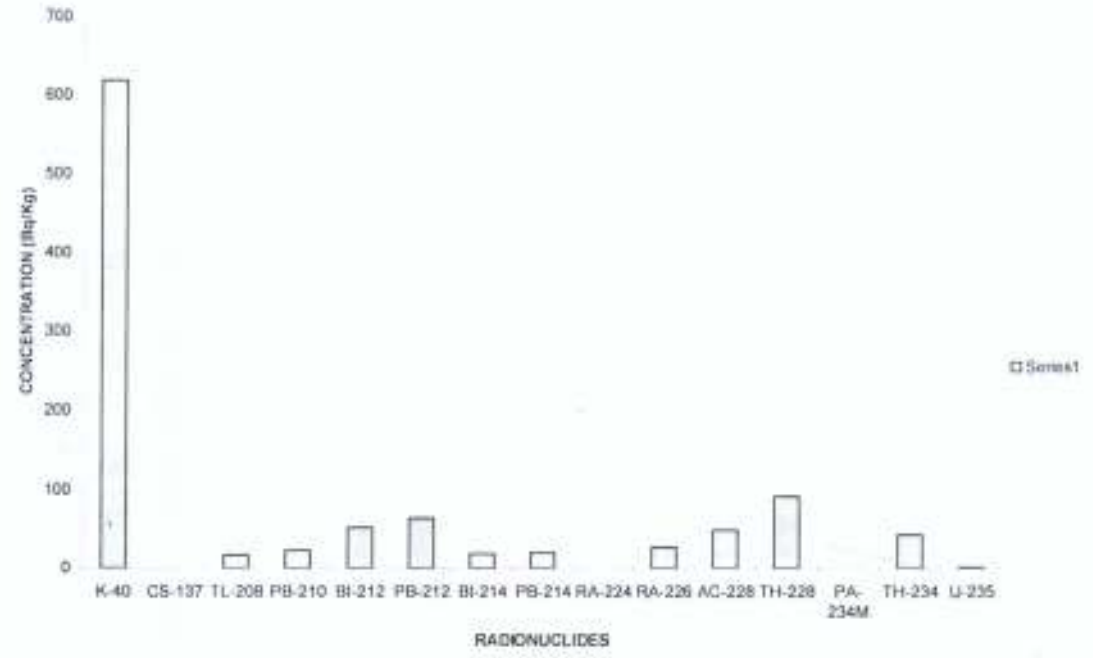

FIG 4.5a: RADIONUCLIDE CONCENTRATION OF IBADAN TOP SOIL

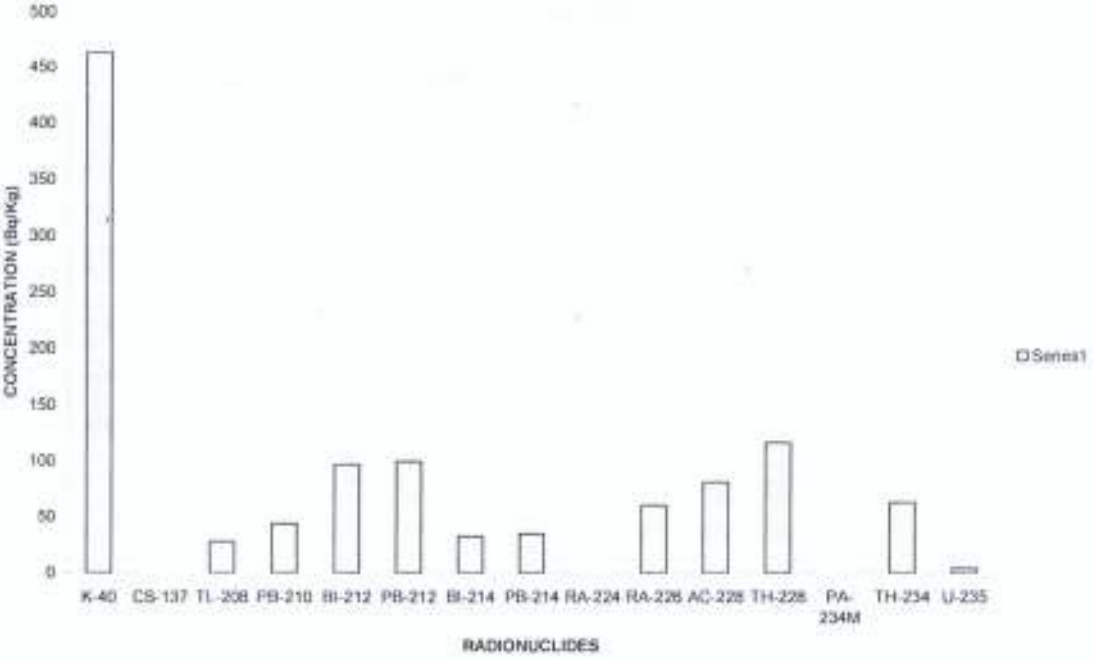

FIG 4.5b: RADIONUCLIDE CONCENTRATION OF IBADAN SOIL (20-25cm)

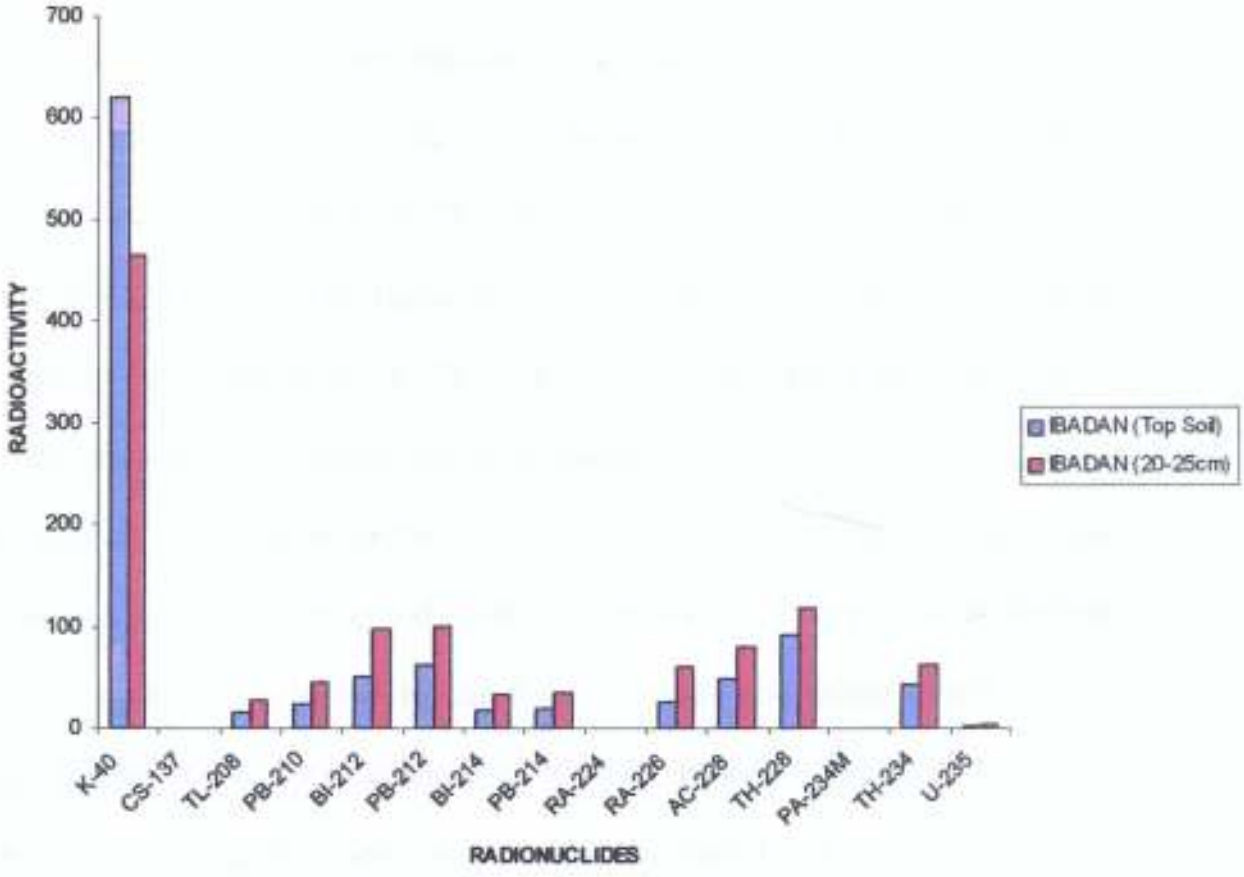

FIG 4.5c: VARATION IN RADIOACTIVITY OF IBADAN SOIL WITH DEPTH

4.1.4: Radioactivity Level in Ibadan Soil

In Ibadan, ^{40}K is the only radionuclide that has significantly higher activity when compared with others. The 2 soil samples analysed from Ibadan show averagely high concentration of ^{40}K. The top soil sample has higher activity concentration (618.96 ± 16,05 Bq/kg) than the soil sample taken at 20-25cm depth with activity concentration of 463.76 ± 13.38 Bq/kg and this is the only case in which the top soil shows higher activity in Ibadan soil. Other radionuclides show higher activity concentration in the 20-25 cm depth of the soil than the top. This could be as a result of leaching and erosion which has little effect on the activity of ^{40}K which could be replicated by the fertilizer usage and other organic decay. Though Ibadan cannot be categorized as rocky, it exhibits the highest industrial activity in all the locations where samples were collected and it is also the most populous city. This contributed to the average high activity of radionuclides in its soil. In Ibadan ^{137}Cs, ^{224}Ra and ^{234M}Pa were not detected making the total number of radionuclides in Ibadan soil to be 12. Table 4.1 and figures 4.5a - 4.5c give the detail.

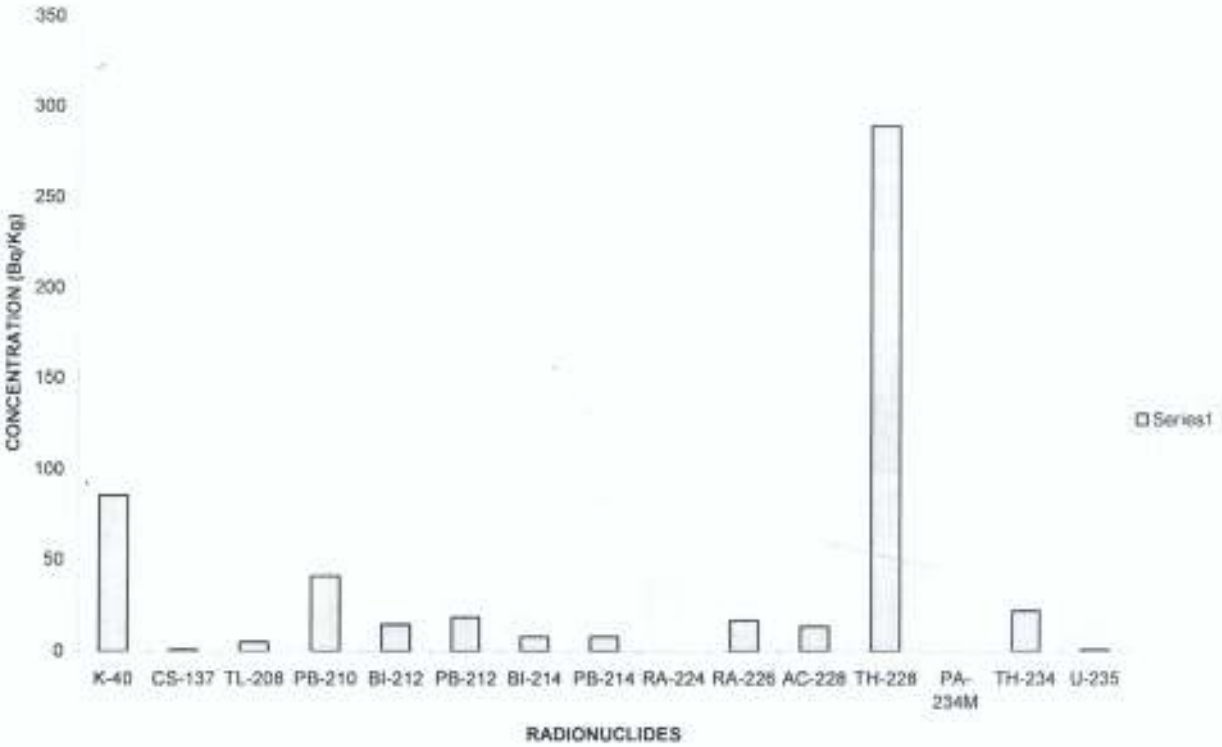

FIG 4.6: RADIONUCLIDE CONCENTRATION OF EGBEDA SOIL

4.1.5: Radioactivity Level in Egbeda

Egbeda's result shows the least radionuclide activity in the soil, it shows the lowest concentration in many of the radionuclides except in some few ones like ^{228}Th, which constituted the highest activity in the area. This Thorium-228 that has the concentration of 289.35 ± 18.60 Bq/kg constitutes 55.19 % of the entire radioactivity in Egbeda soil. Egbeda is a small settlement and therefore there is no industrial activity in the area. Also, the topography is of a low land and not rocky, all these accounted for the low activity of radionuclides in the soil. The activity distribution of various radionuclides in Egbeda soil is presented in Table 4.1 and figure 4.6 above.

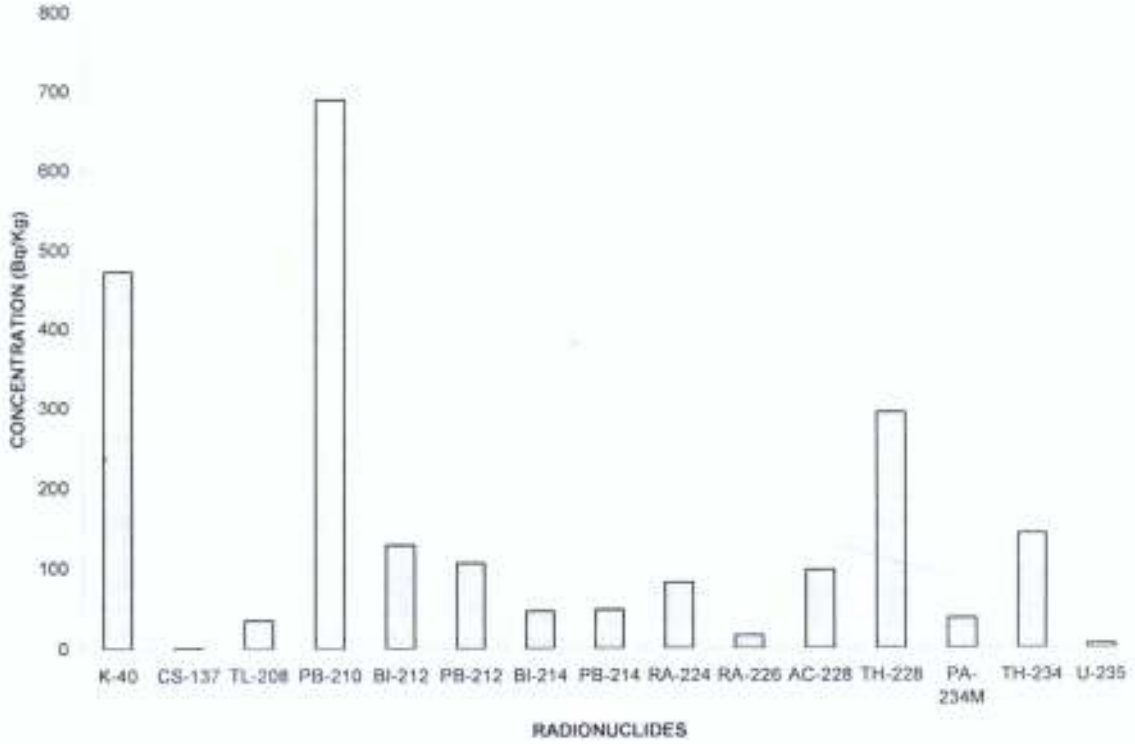

FIG 4.7a: RADIONUCLIDE CONCENTRATION OF IGBETI SOIL (0-5cm)

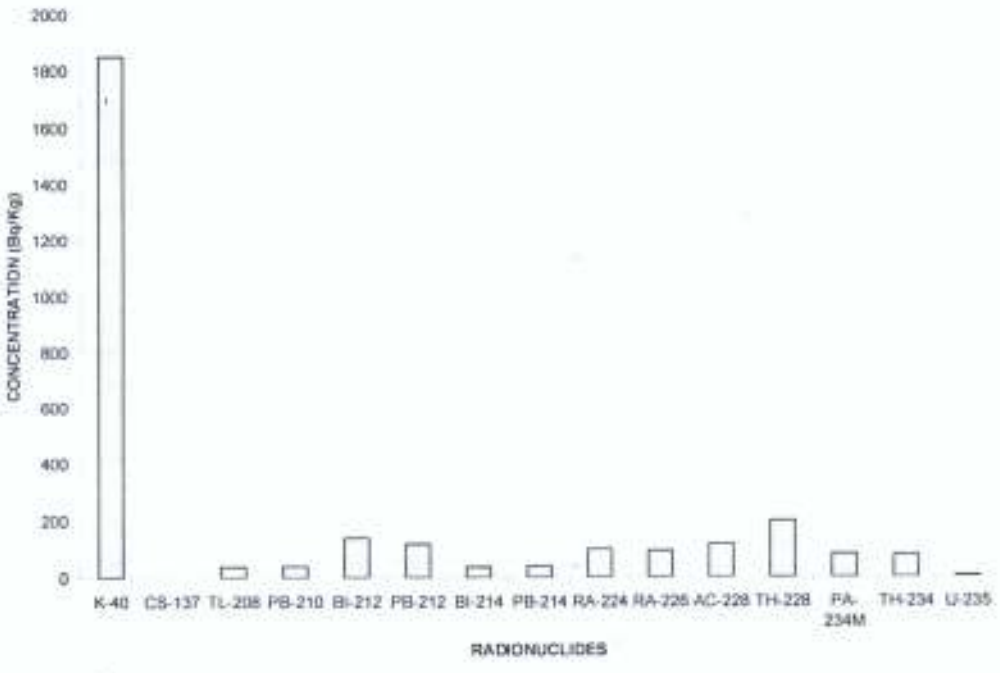

FIG 4.7b: RADIONUCLIDE CONCENTRATION OF IGBETI SOIL (10-15cm)

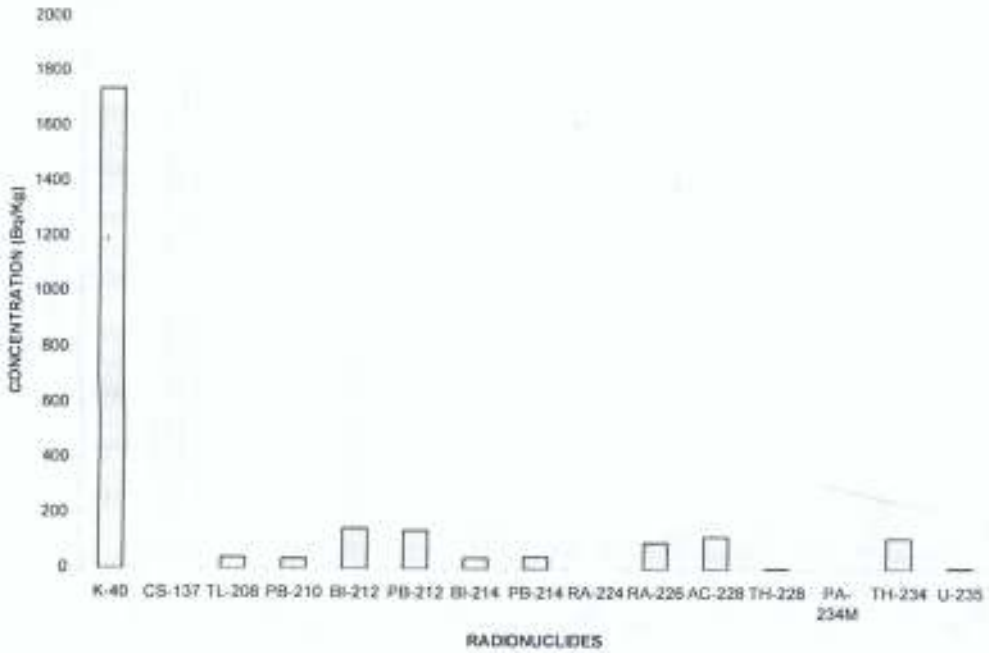

FIG 4.7c: RADIONUCLIDE CONCENTRATION OF IGBETI SOIL (20-25cm)

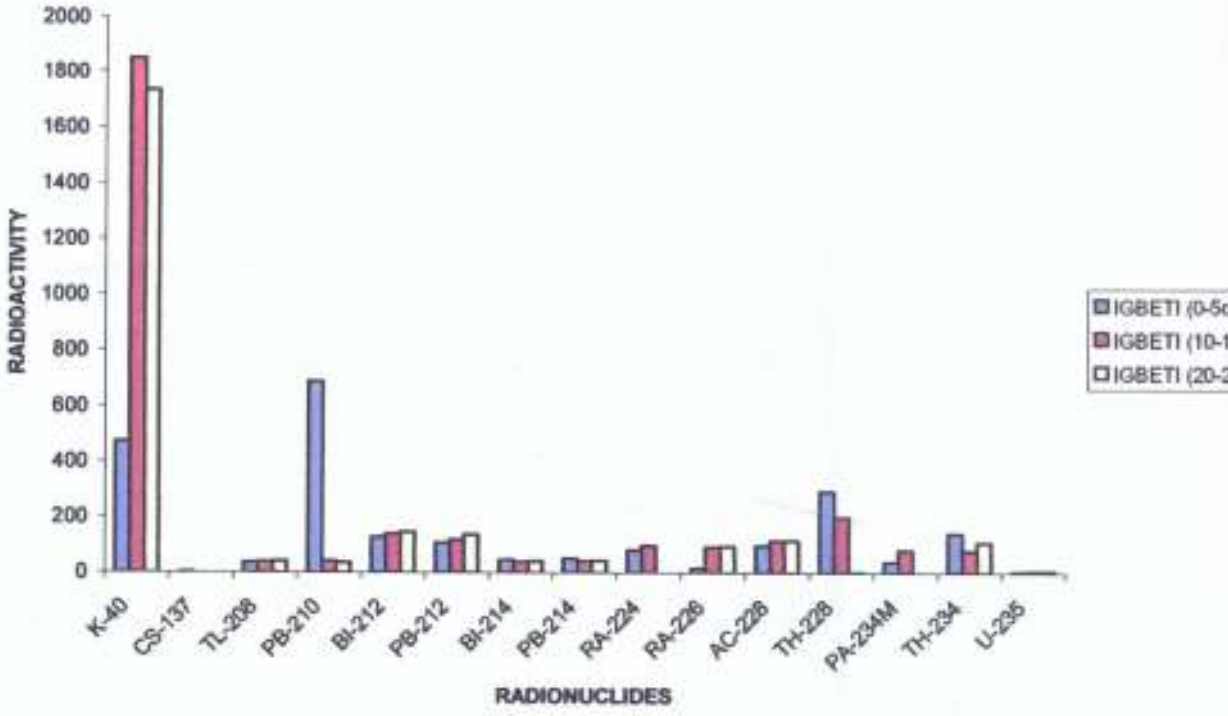

FIG 4.7d: VARIATION IN RADIOACTIVITY OF IGBETI SOIL WITH DEPTH

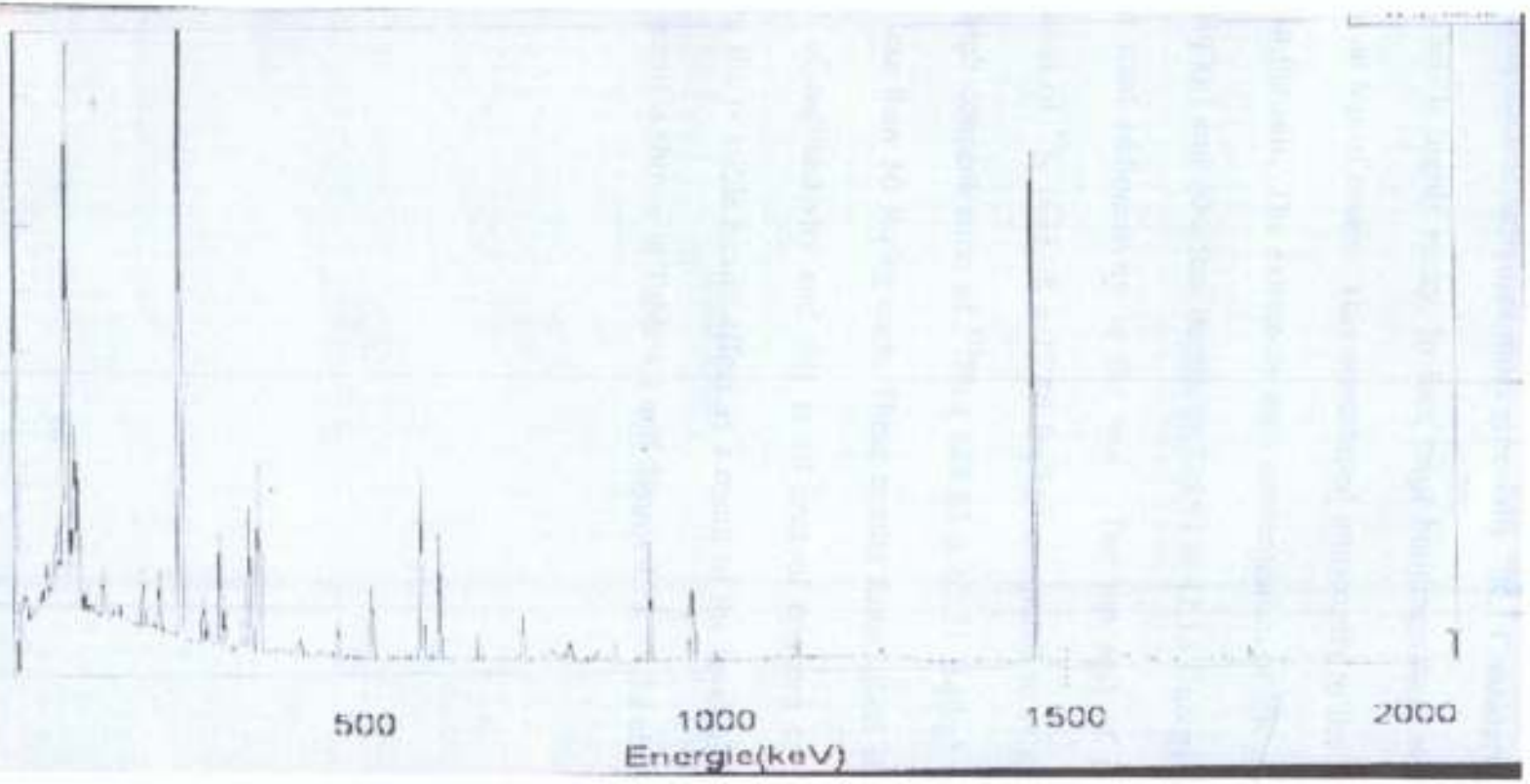

FIG. 4.7e: Typical Soil Spectrum Obtained from Igbeti-Oyo Soil

4.1.6: Radioactivity Level in Igbeti Soil

Igbeti soil happened to exhibit the highest detected radionuclides activities of all the sites where samples were collected. Three soil samples from depths 0-5, 10-15 and 20-25 cm were analyzed from Igbeti and all were highly concentrated with various radionuclide activities most especially ^{40}K. Considering the topography of Igbeti, Igbeti is highly rocky. In fact, most buildings there were built in-between, beside or on top of rocks. This contributed immensely to the level of radioactivity detected in the soil. The extremely high concentration of ^{40}K in 10-15cm (1,850.60 ± 36.83 Bq/kg) and 20-25cm depths (1,735.91 ± 42.15 Bq/kg) represented over 70 % of the total radioactivity in the soil. The top soil of Igbeti that has low concentration of ^{40}K (473.08 ± 17.80 Bq/kg) compared to other samples from the area has high concentration of ^{210}Pb (689.23 ± 62.21 Bq/kg) compared to others that have less than 50 Bq/kg each. These results from Igbeti show a considerably high level of radioactivity and this is an area of concern to a health physicist, considering the possible health effect as a result of the level of radioactivity in the area. The result is shown in Table 4.1 and figures 4.7a – 4.7d above.

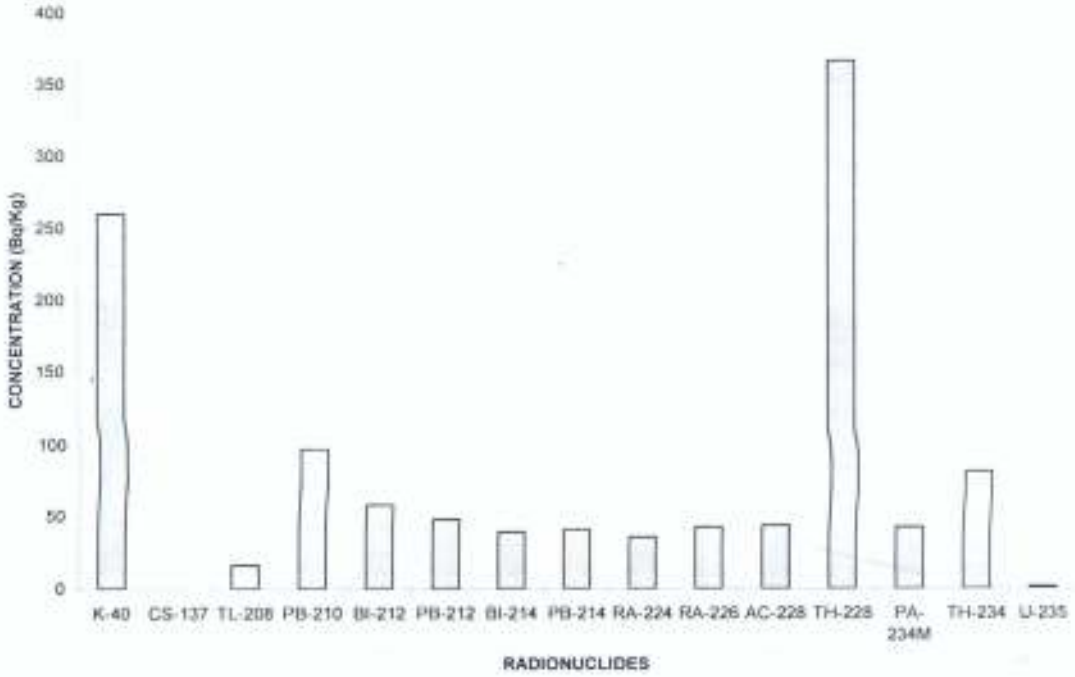

FIG 4.8a: RADIONUCLIDE CONCENTRATION OF OGBOMOSO SOIL (0-5cm)

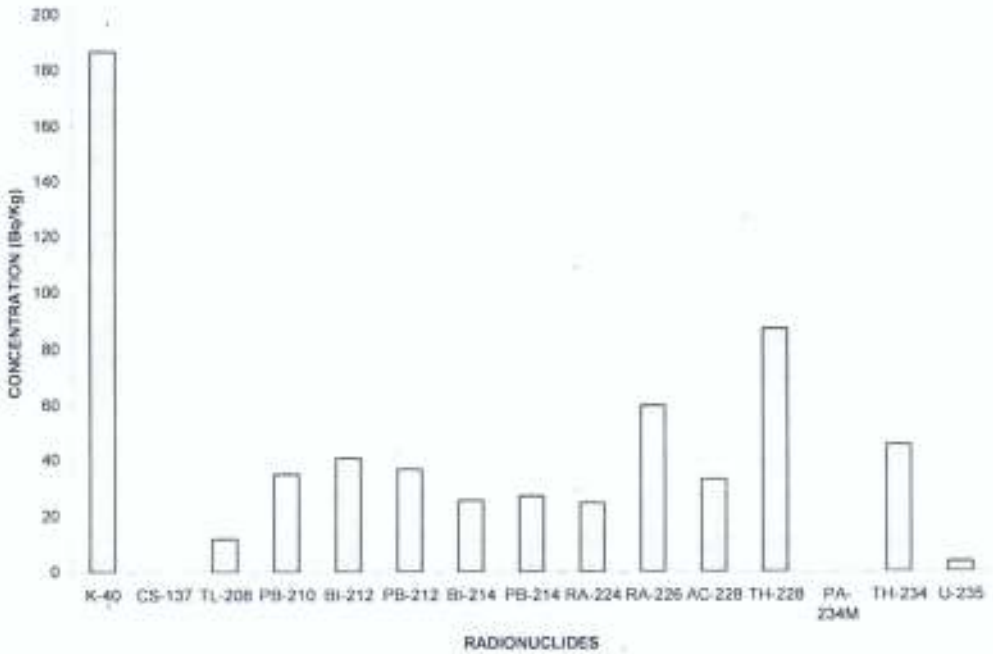

FIG 4.8b: RADIONUCLIDE CONCENTRATION OF OGBOMOSO SOIL (10-15cm)

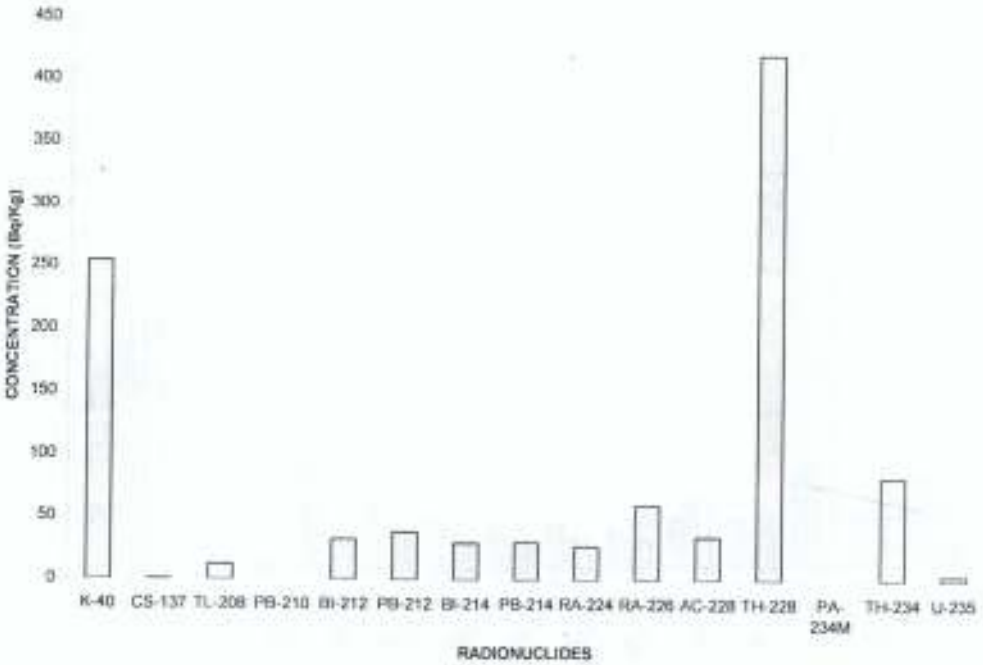

FIG 4.8c: RADIONUCLIDE CONCENTRATION OF OGBOMOSO SOIL (20-25cm)

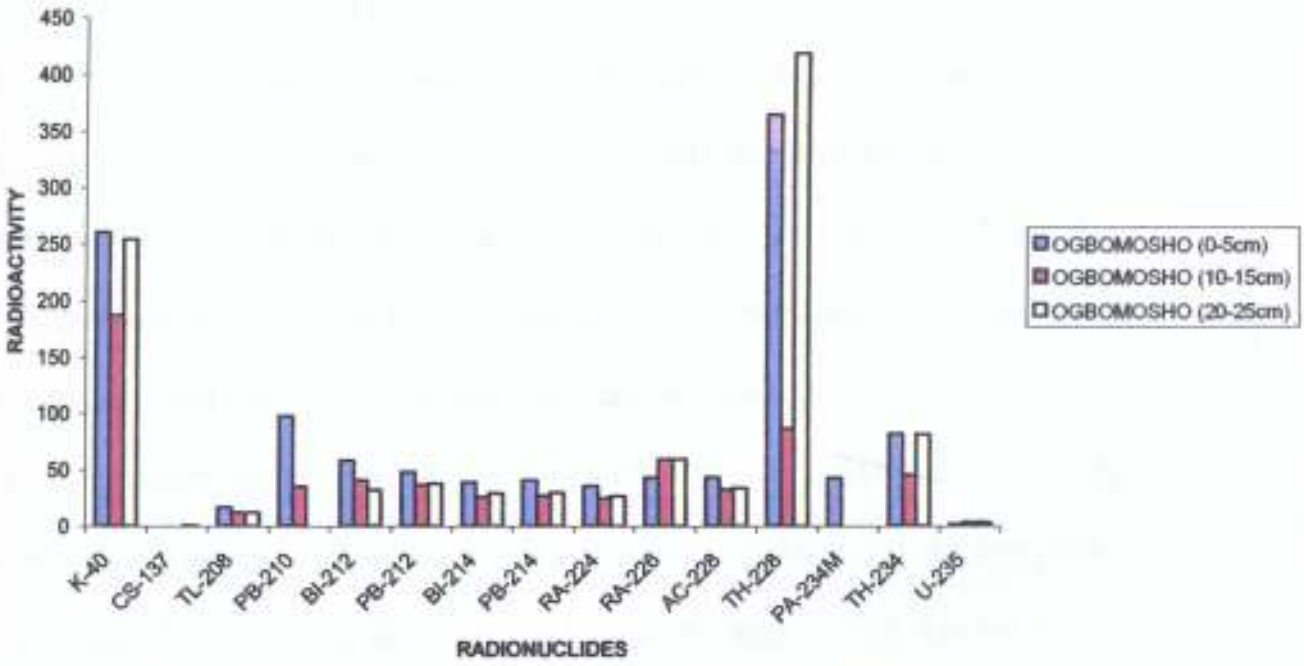

FIG 4.8d: VARIATION IN RADIOACTIVITY OF OGBOMOSHO SOIL WITH DEPTH

4.1.7: Radioactivity Level in Ogbomosho Soil

Ogbomosho soil samples show a low radioactivity concentration. From the three soil samples that were analysed from Ogbomosho, the result shows a generally low but fairly close activity most especially between the top soil (0-5cm depth) and 20-25cm depth; except for some radionuclides like ^{137}Cs, ^{210}Pb And ^{234M}Pa that are not present in both together. The 10-15cm depth sample shows a lower concentration of most of the radionuclides, compared to other samples in the area. Ogbomosho, though a fairly large town and averagely populated, is not rocky but the soils are stony and there are no serious industrial activities in the area, hence the averagely low radioactivity in the soil from the area. ^{228}Th has the largest concentration in the top soil with 366.00 ± 23.20 $Bqkg^{-1}$ and 20-25cm depth with 419.99 ± 39.97 $Bqkg^{-1}$, unlike most other samples in which ^{40}K dominated the radionuclide activities. This high ^{228}Th concentration comes as a result of the nature of the soil. Most of the soils are sandstone and according to Ragland and Rogers (1961), most of the thorium in sedimentary rocks like sandstones is carried by quartz and feldspar, hence the high concentration in Ogbomosho soil. The relationship between the various radionuclide activity in Ogbomosho soils are shown in Tables 4.1 and figures 4.8a – 4.8d above.

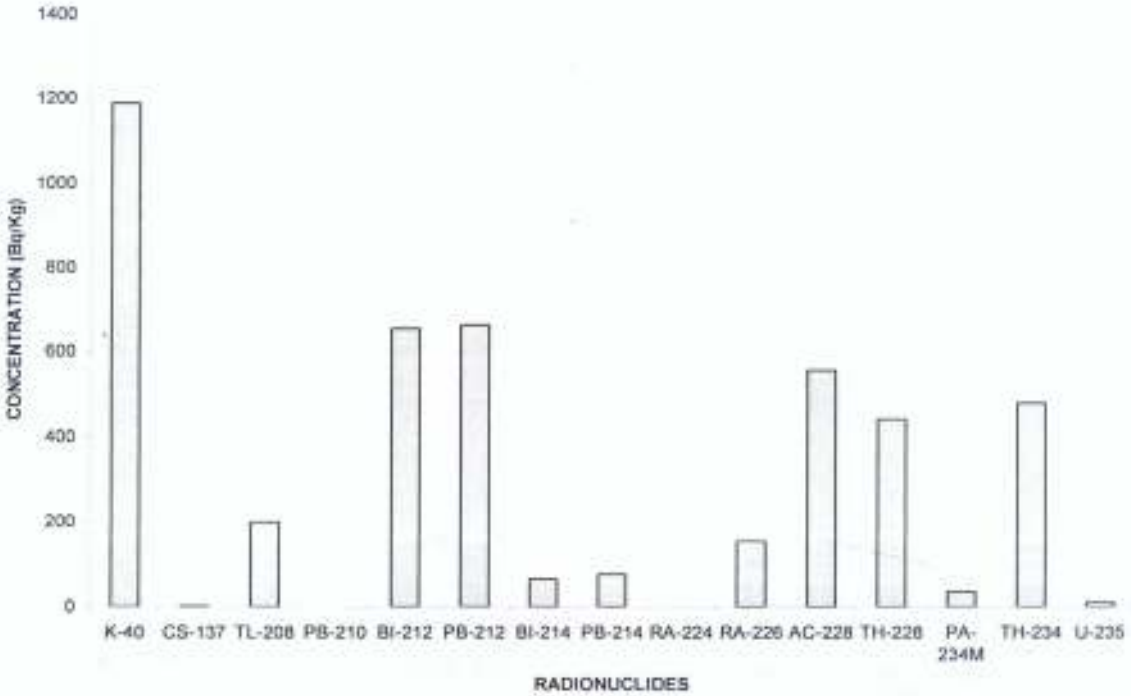

FIG 4.9a: RADIONUCLIDE CONCENTRATION OF ERUWA SOIL (0-5cm)

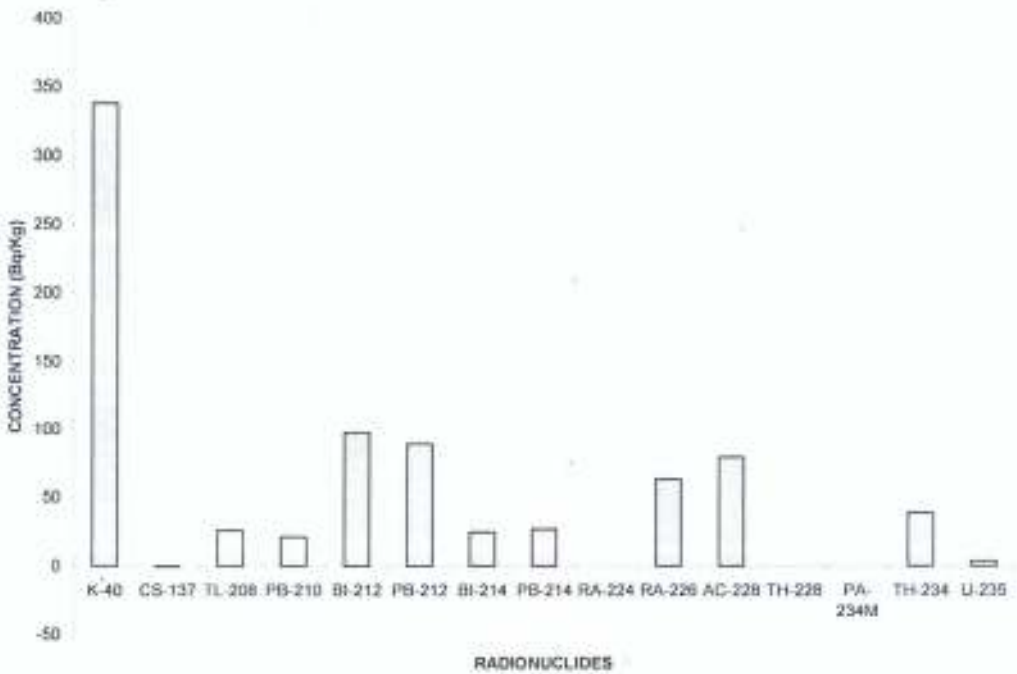

FIG 4.9b: RADIONUCLIDE CONCENTRATION OF ERUWA SOIL (10-15cm)

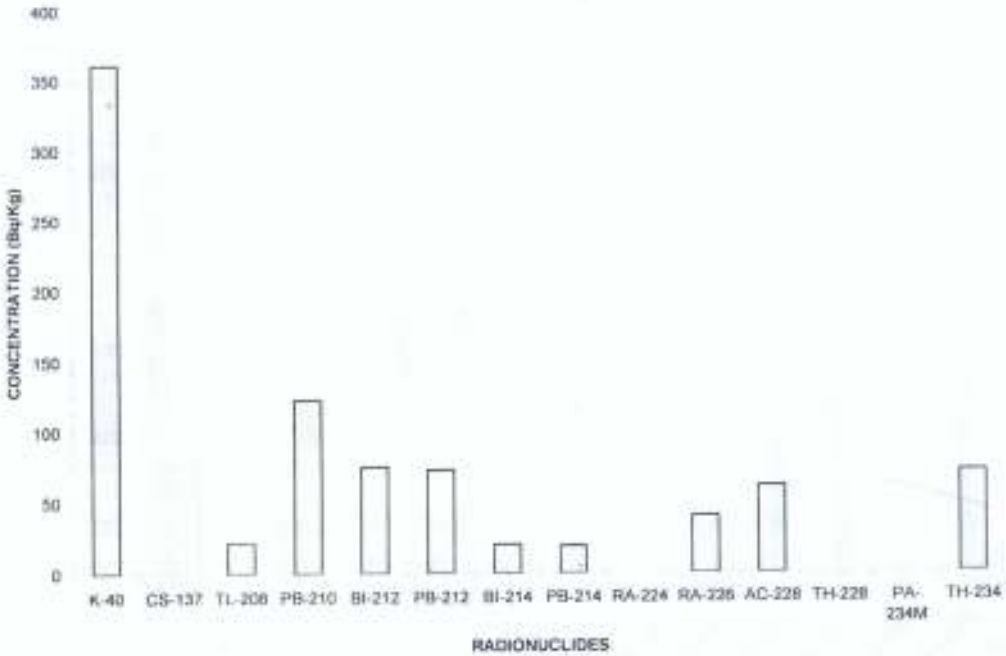

FIG 4.9c: RADIONUCLIDE CONCENTRATION OF ERUWA SOIL (20-25cm)

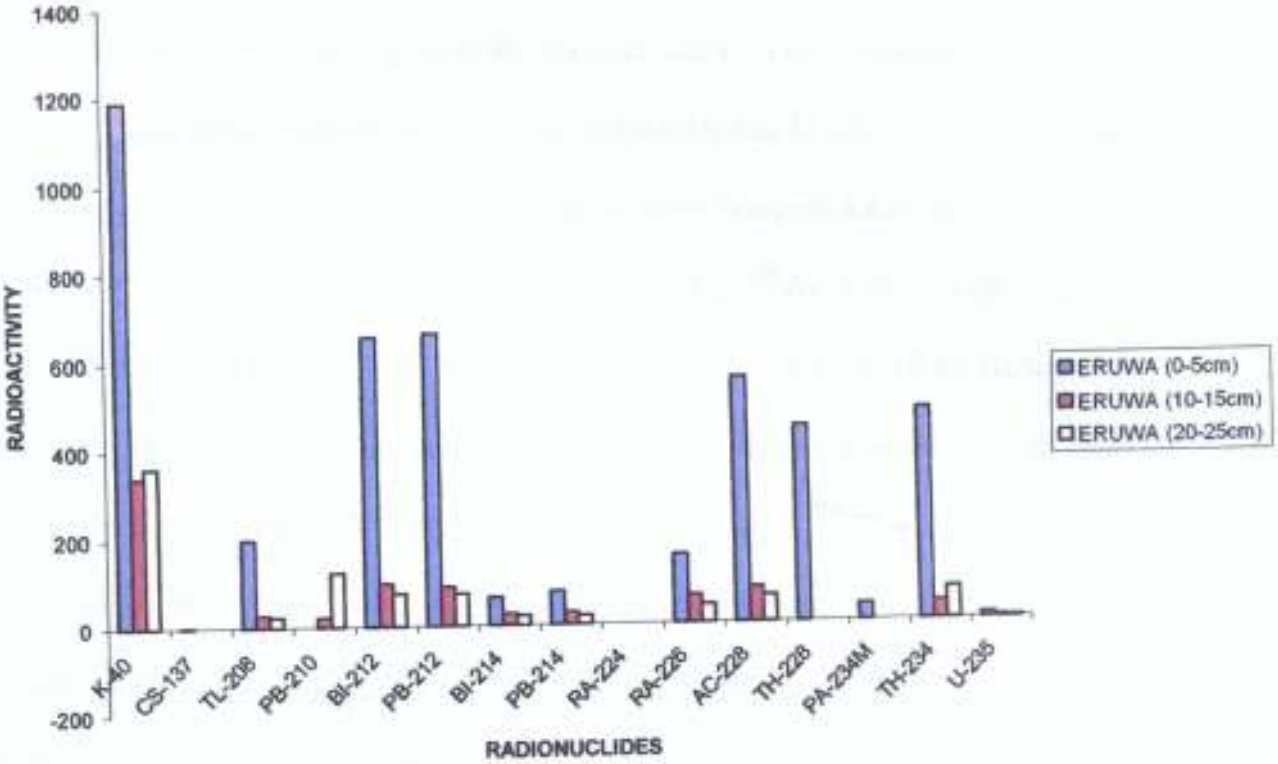

FIG 4.9d: VARIATION IN RADIOACTIVITY OF ERUWA SOIL WITH DEPTH

4.1.8: Radioactivity Level in Eruwa Soil

Eruwa. is another rocky area in the research work. The high concentration of ^{40}K in the soil is much prominent in the top soil which has 1,188.14 ± 25.87 Bq/kg Some other radionuclides that exhibited high activity concentration are ^{212}Bi with 653.30 ±20.95 Bq/kg, ^{212}Pb with 661.81 ± 12.91 Bq/kg, ^{228}Ac with 556.09 ± 13.62 Bq/kg, ^{228}Th with 442.52 ± 30.65 Bq/kg and ^{234}Th with 480.12 ± 18.43 Bq/kg. Of all the soil samples that were analysed, Eruwa top soil exhibited the highest radionuclide concentration of ^{235}U with 9.43 ± 0.99 Bq/kg, ^{137}Cs with 1.17 ± 0.68 Bq/kg, ^{212}Bi, ^{212}Pb, ^{228}Ac, ^{234}Th stated above, in ^{208}Tl with 198.31 ± 4.10 Bq/kg, ^{214}Bi with 64.65 ± 2.00 Bq/kg, ^{214}Pb with 76.16 ± 2.08 Bq/kg and ^{226}Ra with 153.73 ± 16.28 Bq/kg. Invariably, Eruwa top soil has the highest activity concentration of most of the radionuclides except ^{228}Th in which it has the second highest activity concentration behind Shaki soisl, in ^{40}K in which it has third highest behind Igbeti 10-15cm and 20-25cm Depth soil and also in ^{234M}Pa with 35.22 ± 38.90 Bq/kg in which it has the least activity concentration among the 6 samples where the radionuclide was detected. The high activity concentration of the radionuclides in Eruwa top soil is as a result of the rocky nature of the area. It is likely that the presence of rock phosphate and minerals in the rocks influenced the level of radioactivity. The details of the result from Eruwa soil samples are clearly shown in Table 4.1 and figures 4.9a – 4.9d above.

4.1.9: General Radioactivity Level in the State

Generally, the radionuclides were variably distributed in the study area. The value of the activity concentration of ^{40}K in the area is generally high and covers about 50% of the combined activity concentration values of all the radionuclides. With detection of ^{40}K, ^{208}Tl as an indicator for ^{232}Th and ^{214}Bi as an indicator for ^{238}U in the decay series, (these three being the primordial radionuclides) the mean activity concentration values of soil radionuclides in the area were found to be lower for ^{208}Tl (32.89 Bq/kg) and ^{214}Bi (32.10 Bq/kg) but higher for ^{40}K (592.59 Bq/kg) than the earth's crustal mean of between 37.8 Bq/kg and 49.00 Bq/kg for ^{238}U (being indicated by ^{214}Bi) and about 60.00 Bq/kg for ^{232}Th (being indicated by ^{208}Tl), (Taylor, 1964). This can be attributed to the fact that the geology of the area is mainly of sedimentary origin. The high activity concentration of ^{40}K at locations like Igbeti, Eruwa and Ibadan when compared to other locations in the region could be attributed to the rocky nature, industrial activity and the use of fertilizer.

4.2: Calculation of Gamma Dose Rates in Air in the State

The risk associated with radiation exposure in an environment due to radioactivity in the soil can be evaluated when the soil activity concentration is converted to absorbed gamma dose rates in air. Beck et al, (1972) relates the soil specific activity to absorbed gamma dose rate in air at 1m above the ground by:

$$D = 0.042S_k + 0.429S_u + 0.666S_{Th} \qquad 4.1$$

where D is the absorbed dose rate in air ($nGyh^{-1}$), and S_k, S_u and S_{Th} are the soil specific activities of ^{40}K, ^{238}U, and ^{232}Th respectively (taking ^{214}Bi and ^{208}Tl as indicators for ^{238}U and ^{232}Th respectively). The calculated absorbed dose rates in air in the locations using equation 4.1 is presented in Table 4.2

4.3: Distribution of Radionuclide Activities in the State

Samples were taken at five sites in each of the 9 selected cities in the state and activity level of those analysed was presented in Table 4.1. The values quoted in Table 4.1 are measures of the distribution of activity concentrations of natural radionuclides in various locations. Fig 4.1 shows that the variations of the activity concentrations of ^{40}K within the state ranged from 85.83 ± 4.04 $Bqkg^{-1}$ at Egbeda to $1,850 \pm 36.83$ $Bqkg^{-1}$ in Igbeti. The activity concentrations of ^{214}Bi, an indicator for ^{238}U within the State ranged from 7.82 ± 0.48 $Bqkg^{-1}$ also at Egbeda to 64.65 ± 2.00 $Bqkg^{-1}$ at Eruwa The activity concentrations of ^{208}Tl, an indicator for ^{232}Th ranged from 5.23 ± 0.34 $Bqkg^{-1}$ at the same Egbeda To 198.31 ± 4.10 $Bqkg^{-1}$ at Eruwa. The mean activity concentrations for ^{40}K, ^{214}Bi (^{238}U) and ^{208}Tl (^{232}Th) are 592.59 ± 17.00 $Bqkg^{-1}$, 32.10 ± 1.33 $Bqkg^{-1}$ and 32.89 ± 1.14 $Bqkg^{-1}$, respectively.

4.4: Distribution of Radionuclide Activities with Rock Formation in the State

The activity concentration of ^{40}K has been found to account for the highest percentage of 90.1% compared to 4.9% and 5.0% for ^{214}Bi (^{238}U) and ^{208}Tl (^{232}Th) respectively. This is consistent with Ahrens (1957) who noted that the activity of

^{40}K in sedimentary rocks depends upon the relative amounts of feldspar, mica and clay minerals that make up the mineral-aggregate sediments. The high percentage of ^{40}K could be attributed to the presence of feldspar and clay that characterized the Igbeti, Eruwa, Ibadan, Shaki and Oyo soils.

Ragland and Rogers (1961) observed that most of the thorium in sedimentary rocks like sandstones is carried by quartz and feldspar. Hence, the thallium/bismuth (indicators for thorium /uranium) ratio, which was found to be greater than unity in the overall activity, and the thallium mean value (32.89 ± 1.14 $Bqkg^{-1}$) that represents 5.0% of the total radionuclides activity concentration values in the state may be due to the presence of sandstones and feldspar (rock types) in the Igbeti and Eruwa formation.

4.5: Absorbed Dose Rates in Air in the State

The absorbed gamma dose rates in air at 1m above the ground have been calculated for the study area using equation 4.1. The values for each of the radionuclides was calculated using their respective activities from Table 4.1 and the results are presented in Table 4.2. The variation of the absorbed dose rates due to the individual natural radionuclide at the different locations is shown in Fig. 4.2. It can be observed from the figure that the highest contributor to the total dose rate in some locations like Eruwa and Fiditi is thallium (indicator of thorium) despite the higher activity of ^{40}K. These results show that the contribution of a radionuclide to

the total dose rate does not depend only on how high or low the activity is, but depends also on the gamma energy of the radiation emitted by the radionuclide. The relative contributions of ^{40}K, ^{238}U and ^{232}Th are depicted by the coefficients of each term in equation 4.1.

The absorbed dose rate in air for the region due to ^{40}K ranged from 0.0036μGyh^{-1} at Egbeda to 0.078 μGyh^{-1} at Igbeti with mean of 0.025 ± 0.00071 μGyh^{-1}. The values for ^{214}Bi, an indicator of ^{238}U ranged from 0.0079 μGyh^{-1} at the same Egbeda to 0.028 μGyh^{-1} at Eruwa with mean of 0.014 ± 0.00057 μGyh^{-1}. The values for ^{208}Tl, an indicator for ^{232}Th ranged from 0.0035 μGyh^{-1} still at Egbeda to 0.13 μGyh^{-1} at Eruwa. With mean value 0.022 ± 0.00076 μGyh^{-1}. The average total absorbed dose in air for the study area was calculated to be 0.060 ± 0.0020 μGyh^{-1}. This value is higher than the world average value of 0.055 μGyh^{-1} (UNSCEAR, 1988) and is about 77.9% of the value of 0.077 μGyh^{-1} obtained for Nigerian cities by Jibiri (1998).

Table 4.2: Evaluation of Absorbed Dose Rate in Air from Activity Concentration

	^{40}K		^{208}Tl		^{214}Bi		Total Absorbed Dose rate in air ($nGyh^{-1}$)
	Activity ($Bqkg^{-1}$)	Absorbed Dose rate in air ($nGyh^{-1}$)	Activity ($Bqkg^{-1}$)	Absorbed Dose rate in air ($nGyh^{-1}$)	Activity ($Bqkg^{-1}$)	Absorbed Dose rate in air ($nGyh^{-1}$)	
Shaki	480.07 ± 19.12	20.16 ± 0.80	13.23 ± 0.86	8.81 ± 0.57	35.00 ± 1.65	15.02 ± 0.71	43.99 ± 2.08
Oyo	470.90 ± 19.07	19.78 ± 0.80	12.25 ± 0.89	8.16 ± 0.59	25.66 ± 1.46	11.01 ± 0.63	38.95 ± 2.02
Fiditi	121.26 ± 5.78	5.09 ± 0.24	14.40 ± 0.80	9.59 ± 0.53	32.64 ± 1.44	14.00 ± 0.62	28.68 ± 1.39
Ibadan 1	618.96 ± 15.05	26.00 ± 0.67	16.57 ± 0.76	11.04 ± 0.51	18.30 ± 0.93	7.85 ± 0.40	44.89 ± 1.58
Ibadan 2	463.76 ± 13.38	19.48 ± 0.56	28.06 ± 0.96	18.69 ± 0.64	2.78 ± 1.04	14.06 ± 0.45	52.23 ± 1.65
Egbeda	85.83 ± 4.04	3.60 ± 0.17	5.23 ± 0.34	3.48 ± 0.23	7.82 ± 0.48	3.35 ± 0.21	10.43 ± 0.61
Igbeti 1	473.08 ± 17.80	19.87 ± 0.75	36.08 ± 1.64	24.03 ± 1.09	46.54 ± 1.81	19.97 ± 0.78	63.87 ± 2.62
Igbeti 2	1,850.60 ± 36.83	77.73 ± 1.55	39.17 ± 1.10	26.09 ± 0.73	38.39 ± 0.97	16.47 ± 0.42	120.29 ± 2.7
Igbeti 3	1,735.91 ± 42.15	72.91 ± 1.77	41.03 ± 1.27	27.33 ± 0.85	39.69 ± 1.40	15.74 ± 0.60	115.98 ± 3.22
Ogbomoso 1	260.25 ± 10.75	10.93 ± 0.45	16.52 ± 0.92	11.00 ± 0.61	39.43 ± 1.80	16.92 ± 0.77	38.85 ± 1.83
Ogbomoso 2	186.63 ± 7.35	7.84 ± 0.31	11.94 ± 0.58	7.95 ± 0.39	25.61 ± 0.99	10.99 ± 0.42	26.78 ± 1.12
Ogbomoso 3	254.23 ± 12.51	10.8 ± 0.53	12.25 ± 0.97	8.16 ± 0.65	29.52 ± 1.80	12.66 ± 0.77	31.50 ± 1.95
Eruwa 1	1,188.14 ± 25.87	49.90 ± 1.09	198.31 ± 4.10	132.07 ± 2.73	64.65 ± 2.00	27.73 ± 0.86	209.7 ± 4.68
Eruwa 2	338.05 ± 10.18	14.20 ± 0.43	26.26 ± 0.86	17.49 ± 0.57	24.96 ± 0.97	10.71 ± 0.42	42.4 ± 1.42
Eruwa 3	361.12 ± 14.07	15.17 ± 0.59	22.02 ± 1.07	14.67 ± 0.71	20.51 ± 1.14	8.80 ± 0.49	38.64 ± 1.79
Total	8888.79 ± 254.95	373.34 ± 0.71	493.32 ± 17.12	328.34 ± 1.40	481.5 ± 19.88	206.56± 8.53	907.18 ± 30.66

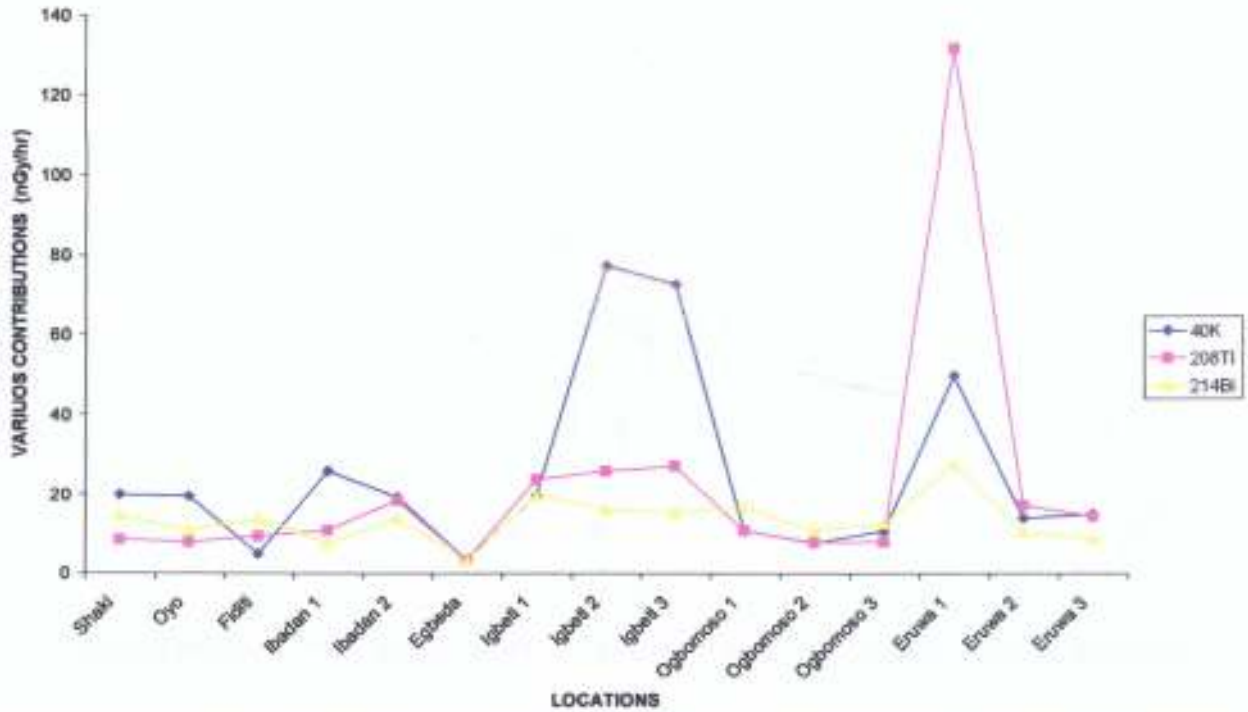

Fig 4.10: GRAPH OF VARIOUS CONTRIBUTIONS OF ABSORBED GAMMA DOSE RATE IN AIR FOR THE NATURAL RADIONUCLIDES IN VARIOUS LOCATIONS

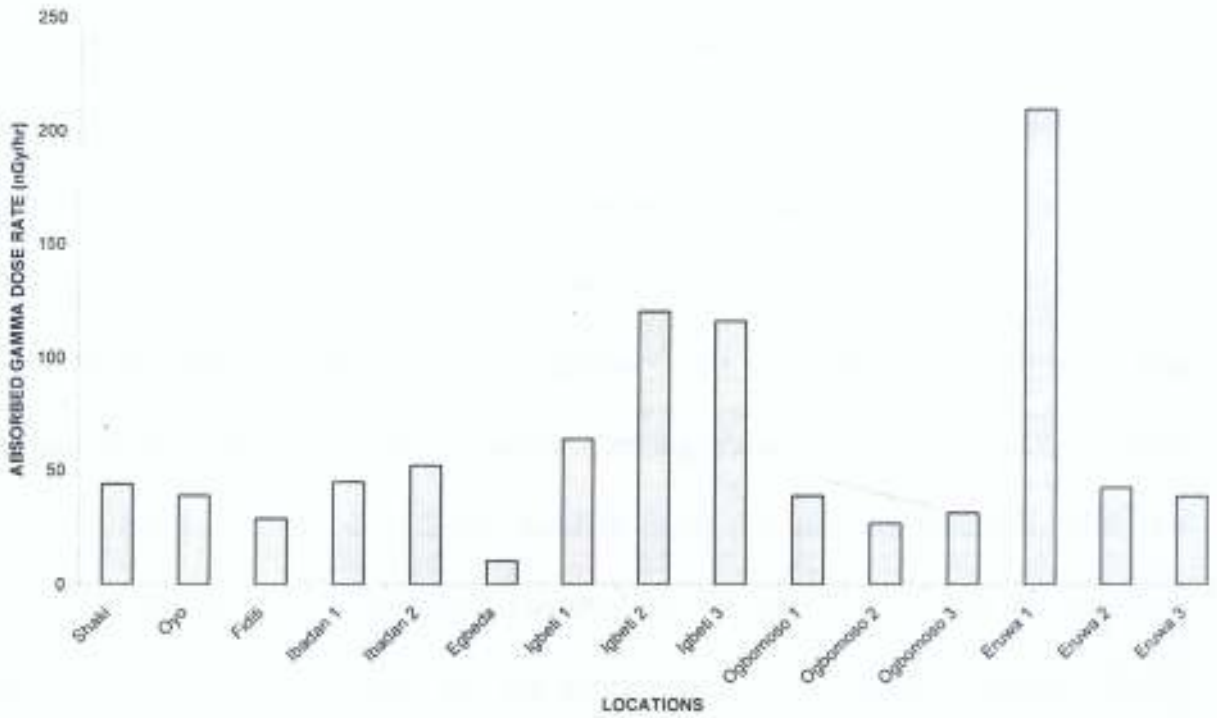

Fig 4.11: ABSORBED GAMMA DOSE RATE IN AIR AT VARIOUS LOCATIONS IN THE STATE

4.6: Outdoor Effective Dose Equivalent

In estimating the outdoors effective dose equivalent in any environment, the two factors of importance are the conversion factor from Gyh^{-1} to Svh^{-1} and the occupancy factor. The former gives the human dose equivalent (Svy^{-1}) from the absorbed dose rate in air (Gyh^{-1}) while the latter gives the fraction of the time that an individual is exposed to the outdoor radiation. The first factor has been recommended by the United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 1988) as 0.7 $SvGy^{-1}$ and the second factor as 0.2, which suggest that an average individual stays about 4.8hrs outdoor daily.

In this work, the first factor of 0.7 $SvGy^{-1}$ has been retained while the second factor of 0.2 was modified to suit the reality of the environment we are studying. In this case, majority of the city people spend more hours of the day indoor (inside vehicles, offices, workshop, etc) and even greater percentage of the 12hrs in the night sleeping indoors, the 0.2 factor will be justified.

In the rural areas however, the majority of the rural dwellers spend more time outdoor in their farm and other exposed working places. Hence, the average rural dwellers spend an average of 2.4hrs outdoor more that the city dwellers. With this estimation therefore, the average individual in the rural areas will be spending approximately 7.2 hrs outdoor per day representing 0.3 outdoor occupancy factor. Using the total absorbed dose rate values given in Table 4.2 for the cities, the conversion factor of 0.7 $SvGy^{-1}$ and the occupancy factor of 0.2, the average outdoor annual effective dose equivalent for the urban areas are presented in Table 4.3. Using the total absorbed dose rate values given in Table 4.2 for the rural areas, the conversion factor of 0.7 $SvGy^{-1}$ and the occupancy factor of 0.3, the average outdoor annual effective dose equivalent for the rural areas are presented in Table 4.4. The average outdoor annual effective dose equivalent for all other areas except Igbeti and Eruwa are less than 90% of the world value (70 μSvy^{-1}) given by UNSCEAR (1988) and 65% of the Nigeria value (98 μSvy^{-1}) given by Jibiri (1998). The cities within the state have an average outdoor effective dose equivalent of 50.25 μSvy^{-1} representing 71.78% of the world average value given by UNSCEAR (1988) and 51.27% of the

value estimated for the Nigerian cities by Jibiri. The rural average effective dose equivalent in the state is 108.57μSvy^{-1}. This high value comes as a result of the high dose rate of rocky areas in the rural settings, especially Igbeti and Eruwa.

This value is more than twice the value (50.25 μSvy^{-1}) estimated for the cities in the state. The average value estimated for the rural areas is higher than the average value obtained for the cities despite the higher tendency for industrial activity in the cities. This result shows the effect of rocks and importance of the duration of exposure to the absorbed dose rate in air by an individual. However, the overall effective dose equivalent to individual depends also on the indoor-absorbed dose rate and the time spent indoors. The outdoor effective dose equivalent for the study area is 79.41μSvy^{-1}.

The mean outdoor effective dose equivalent (OEDE) for the urban areas is calculated thus,

OEDE = Conversion factor (0.7Sv/Gy) x occupancy factor (4.8 hrs/day) x 365 days (1yr)

The absorbed dose rate in air calculated in Grey/hour can be obtained from Table 4.2

Table 4.3: Mean Outdoor Effective Dose Equivalent For Urban Areas

Location	Effective Dose (μSvy^{-1})
Shaki	53.95
Oyo	47.77
Ibadan	59.55
Ogbomosho	39.71

The mean outdoor effective dose equivalent (OEDE) for the rural areas is calculated thus,

OEDE = Conversion factor (0.7Sv/Gy) x occupancy factor (7.2 hrs/day) x 365 days (1yr)

The absorbed dose rate in air calculated in Grey/hour can be obtained from Table 4.2.

Table 4.4: Mean Outdoor Effective Dose Equivalent For Rural Areas

Location	Effective Dose (μSvy^{-1})
Fiditi	52.76
Egbeda	19.19
Igbeti	184.05
Eruwa	178.28

4.7: Calculation of Collective Effective Dose Equivalent

The collective effective dose equivalent to N population is a measure of the collective detrimental effects and the percentage of people at risk of incurring radiation induced diseases. This was calculated for the urban and rural areas in the State using equation 1.4 given by ICRP (1990). This equation 1.4 shows a direct proportionality between the average annual effective dose equivalent and the exposed population. The collective dose equivalents S_E for the urban and rural areas have been calculated using the average annual effective dose equivalent shown in Tables 4.3 and 4.4 respectively and the projected population figures for year 2005 based on annual growth rate of

2.52% (NPC, 1991). The projected population up to the year 2005 for the urban cities, the rural areas and the region as a whole from the 1991 population census is estimated as 2,183,848, 4,433,872 and 6,617,720 respectively. These population figures were arrived at using the 1991 population census, which shows that 33% of the total population resides in the urban areas. Using equation 1.4 And these projected population figures, the outdoor annual collective effective dose equivalent calculated for the urban areas, rural areas and the region are 1.10×10^2 man-Svy^{-1}, 4.81×10^2 man-Svy^{-1} and 5.26×10^2 man Svy^{-1} respectively.

4.8: Collective Health Detriment

The linear no threshold relationship between dose equivalent and health risk has been employed in this work to relate the absorbed dose from terrestrial gamma radiation in the soil to the risk of incurring detrimental health effects in the region. This risk, G, to the people of Oyo state was estimated using equation 1.7. The number of individuals at risk of incurring fatal cancer from the cities and rural areas in the region are $2y^{-1}$ and $8y^{-1}$ respectively. The results show that the total number of people at risk per year due to outdoor terrestrial gamma radiation dose level from primordial radionuclides in the soil is 10 for the entire region. This result represents 6.25% of the estimated 160 people at risk per year in some 18 Nigerian cities obtained by Jibiri (1998)

CHAPTER FIVE

5.0 CONCLUSION AND RECOMENDATION

5.1 CONCLUSION

The activity concentration of natural radionuclides, namely, ^{40}K, ^{238}U and ^{232}Th in the soil have been measured in Oyo state using gamma ray spectroscopy. This activity has been used to estimate the outdoor absorbed dose rate in air and the resulting radiological implications to the inhabitants of the state. It has been concluded that there is extremely high soil radioactivity in rocky areas, moderately high in industrialized area and low in the rest (non-rocky and non-industrialized) areas. This result further confirms results of previous studies (Ibrahim et al., 1993; Farai and Jibiri, 2000) that local variability of natural radionuclides in the soil depends strongly on local geology.

The mean outdoor absorbed dose rate in air for the state is 0.0605 ± 0.002 μGyh^{-1}. This value represents about 110.0% of the world average value of 0.055 μGyh^{-1} (UNSCEAR, 1988) and about 78.6% of the value (0.077 μGyh^{-1}) quoted for some 18 Nigerian cities by Jibiri (1998). The absorbed dose rate in air calculated for rural areas is higher than the value calculated for the urban areas.

The rural average effective dose (108.57 μSvy^{-1}) is more than the urban value (50.25 μSvy^{-1}). This made the expected number of people at risk of radiation induced cancer per year in the state to be 10 (i.e. 2 from urban areas and 8 from rural areas)

From this conclusion, it is therefore recommended that human habitations should be distant from rocks or rocky area to prevent excess risk of radiation – induced cancer.

5.2 RECOMMENDATION

From the result of this research work which shows that rocky areas are very much concentrated with high percentage of primordial radionuclides, I will like to suggest that more research work should be focused on rocky hills and places that are characterized by sand stones, lime stones and granites. Also contributions to total radiation in the environment from other sources could still be investigated.

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