DETERMINATION OF ACTIVITY CONCENTRATIONS OF NATURAL RADIONUCLIDES AND RADIATION HAZARD INDICES IN THE SEDIMENTS OF OGUN RIVER

BY

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DEDICATION

This reseach work is dedicated to the MOST HIGH GOD, WHO WAS, WHO IS AND WHO IS TO COME, THE ALPHA AND OMEGA OF EVERYTHING.

Also, to my wonderful, loving and best Dad, Late Prof. Theophilus Olaitan KAMIYOLE and uncomparable one in a million Mum, Mrs Christiana Adetoun KAMIYOLE.

And finally to my heartthrob, Mr Michael Adebayo Okeyode and our loving children, Oreoluwa, Ifeoluwa and Ayooluwa Okeyode.

ABSTRACT

River sediments are known to contain natural radionuclides, the concentrations of which if beyond certain limits can cause adverse health effects. The sediments from Ogun river provide large quantities of sand for construction purposes in Nigeria. Despite this, data are scarce on the natural radionuclides: ^{40}K, ^{226}Ra and ^{232}Th distribution in the river sediments. This work was aimed at determining the spatial distribution of these natural radionuclides and their concentrations in the sediments of Ogun river, and to evaluate the radiological implications on the population living in houses built with the river sediments.

A total of 320 sediment samples were randomly collected along the course of the river; 60 in the upper region (Igboho to Idi- Ata; Oyo – Ogun axis), 90 in the middle region (Olopade to Mile 8 Oba; Ogun –Lagos axis) and 170 in the lower region (Abata to Apa Osa; Lagos axis). The number of samples collected in each region was determined by accessibility. The samples were air dried, pulverized and sieved using a 2 mm mesh size. Two hundred and fifty grams of the sieved samples were transferred into plastic containers of uniform sizes, sealed and left for 4 weeks to attain secular radioactive equilibrium. The activity concentrations of the natural radionuclides in the samples were determined using gamma-ray spectrometer comprising 76mm x 76mm NaI(Tl) detector coupled to a multichannel analyser. These concentrations together with standard equations were used to evaluate indoor effective dose rates, radium equivalent, external and internal hazard indices, representative gamma index and Excess Lifetime Cancer Risks (ELCR) and results were compared with available data from India, Egypt and Turkey. Data were analysed using descriptive statistics.

The activity concentrations (in Bq/kg) of ^{40}K, ^{226}Ra and ^{232}Th ranged from 371.0 (middle) – 608.0 (lower), 5.6 – 20.4 (middle) and 5.0 (lower) – 23.1 (middle) respectively. These were similar to data from other locations of the world. The upper region of the river indicated no location effect, in the middle and lower regions, significant location effects were observed and these were attributable to industrial activities. The mean annual indoor effective dose rates were 0.31 ± 0.02 mSv (upper), 0.30 ± 0.05 mSv (middle) and 0.33 ± 0.05 mSv (lower region). The radium equivalent activity for upper, middle and lower regions respectively, were 65.16 ± 4.14 Bq/kg, 64.10 ± 10.78 Bq/kg and 71.00 ± 11.78 Bq/kg, while external hazard indices were 0.18 ±

0.01, 0.17 ± 0.03 and 0.19 ± 0.03. Internal hazard indices were 0.21 ± 0.01, 0.21 ± 0.04 and 0.23 ± 0.05, representative gamma indices were 0.52 ± 0.03, 0.51 ± 0.08 and 0.56 ± 0.09, whereas ELCR values were $(0.141 \pm 0.01) \times 10^{-3}$, $(0.137 \pm 0.02) \times 10^{-3}$ and $(0.148 \pm 0.03) \times 10^{-3}$.

The radiological hazard indices evaluated for Ogun river sediments were less than acceptable limits and therefore posses no radiation risk on the populations living in the houses built with materials incorporating the river sediments.

Keywords: River sediments, Ogun river, Activity concentrations, Natural radionuclides, Radiological hazard indices

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Thank you all and God bless.

Okeyode, I.C

August 2012

CERTIFICATION

I certify that the work described in this thesis was carried out under my supervision by **Okeyode Itunu Comfort (73810)** in the Department of Physics, University of Ibadan, Ibadan, Nigeria.

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INTRODUCTION

1.1 NATURAL RADIOACTIVITY

All matter are made up of atoms and their effective diameters are about $3x10^{-10}$ m. Nearly all the mass of the atom is concentrated in the nucleus which is centrally place within the atom. The nucleus of an atom is composed of protons and neutrons, these are bound together by the nuclear force which is a very strong and short- range force (Jibiri, 2000). There exists a limit to the stability of the nuclei which is determined by the balance between the nuclear force and electrostatic force. This stability depends largely on the ratio of number of neutrons (N) to number of protons (Z) (Cember, 1989). For light nuclei, the ratio of N to Z being unity is the ideal situation for their stability while for heavy nuclei, the ratio N to Z being about 1.5 is ideal for stability (Jevremovic, 2005 and Isinkaye, 2009). Any departure from these usually results in nuclear instability. When the nucleus is unstable, it experiences a spontaneous nuclear transformation (disintegration), which shifts the N to Z ratio to a more stable configuration and in the process emitting nuclear particles. This process is known as radioactivity or radioactive decay and it always results in the formation of new nuclides which may be stable or radioactive. The particles emitted in natural radioactivity include the heavy charged particles (He^{++}) and the light β- particles (e^{+},e^{-}) accompanied by the nuetral and much light particles –the neutrinos. In the process of α- decay, an atom with the atomic mass A and atomic number Z would be transformed into a new atom with atomic mass A-4 and atomic number Z-2. In the case of a β -decay, it transforms the same atom into a new atom with a change in Z but no change in A, causing an increase in Z by 1 (Z+1) or a decrease in Z by 1(Z-1). These particles are released with great energies and are usually accompanied with the emission of a highly penetrating electromagnetic radiation, γ-rays (Jibiri, 2000). The process of radioactive decay is random in its nature. It can not be predicted precisely when an atom will decay in a radioactive material. The rate at which a particular radionuclide decays is directly proportional to the number (N) of radioactive nuclei present at a given time (t). The constant of proportionality called decay constant λ, (s^{-1}) represents the probability that a radionuclide will decay in a unit time. Radioactive decay is a

nuclear process that originates in the nucleus and is therefore not determined by the chemical and physical states of the radioisotope. The radioactive decay obeys the exponential law:

$$N = N_0 e^{-\lambda t} \qquad (1.1)$$

Where N is the number of nuclei remaining at a later time *t*.

No is the number of unstable nuclei at time *t=0*

t =time

The time taken for the number of radioactive nuclei to reduce to half of its initial value is known as half life ($T_{1/2}$) and can be expressed as

$$T_{1/2} = \frac{0.693}{\lambda} \qquad (1.2)$$

The half-lives of naturally occuring radionuclides can range from fractions of second to billions of years. For example, the radionuclides ^{40}K, ^{238}U, ^{232}Th and ^{235}U have half-life of 1.3 x 10^9 years, 4.5 x 10^9 years, 14 x 10^9 years, and 0.7 x 10^9 years respectively.

1.2 SOURCES OF NATURAL RADIOACTIVITY

Radionuclides, radiation and radioactivity have been an essential constituent of the earth since its creation. Radionuclides are classified according to their origins. Radionuclides classified as natural are referred to as Naturally Occurring Radioactive Materials (NORM), technologically enhanced radiouclides as Technologically Enhanced Natural Occurring Radioactive Material (TENORM) and the artifically induced known as man-made or anthropogenic radionuclides. Both NORM and TENORM have the same natural origin except that TENORM exists as a result of human activities, such as tobacco smoking, uranium and phosphate mining and milling, air travel, coal fired power plants, oil exploration and others, that could enhance and modify the concentration of NORM, their environmental distribution and radiation exposure dose to human-beings. Generally, some of the non-nuclear industrial processes causes a considerable contribution to the radio-ecological pollution such as phosphate ore mining and phosphate fertilizers manufacture and

agricultural applications (UNSCEAR,1988; Oosterhuis,1992), and they also contribute technologically. In term of population radiation dose, the sources of natural radiation are most significant and the main contributor to the population collective doses (UNSCEAR,1988; Abdulkareem, 2009). Natural radiation sources are classified into three categories; cosmic radiation, cosmogenic radionuclides and primordial (terrestrial) radionuclides.

1.2.1 Cosmogenic radionuclides and radiation

Cosmogenic radionuclides are produced following result of collision of highly energetic cosmic ray particles with stable elements in the atmosphere and in the ground. The entire geosphere, the atmosphere and all parts of the earth that directly exchange material with the atmosphere contains cosmogenic radionuclides with the major production being from the interaction of cosmic rays with atmospheric gases (Alatise, 2007). These radionuclides are formed primarily through bombardment of the upper atmosphere by high energy heavy particles. The cosmogenic radionuclides include tritium, ^{14}C, ^{7}Be, and ^{22}Na. Only tritium and ^{14}C really contribute to any significant exposures to the worldwide population. The exposures from these sources are relatively low and uniform over the surface of the planet (Bennett, 1997). Carbon-14 is present in carbon dioxide in the air, in the terrestrial biosphere, and in bicarbonates in the ocean. This radionuclide is produced in the atmosphere by the ^{14}N capture of neutrons. The neutron spectrum covers a wide energy range in the lower atmosphere, from thermal to 100 MeV (UNSCEAR, 1993).

Cosmic radiation refers to both the primary energetic particles of extra- terrestrial origin and to secondary particles generated by the interaction of primary particles with the atmosphere.The annual external dose rates from cosmic rays depend slightly on latitude and strongly on altitude. Biehl et al., (1949) studied the effects of geomagnetic latitudes on the total cosmic ray and found that the ratio of latitude effects at low geomagnetic latitudes to those at higher latitudes is roughly 65 : 100. Spatial variations of cosmic-rays with altitude and latitude have also been reported in the works of Light et al., (1973) and Merker et al., (1973). The dose rate at sea level from ionizing component of cosmic rays is estimated to be 32 nGy/h (UNSCEAR, 2000), which is about 15% of natural radiation in the environment.

1.2.2 Terrestrial radionuclides

Terrestrial radionuclides are the radionuclides found in the earth. They are long-lived nuclear species, which have been present on earth since the formation of the earth about 4.5×10^9 years ago. They are classified into two series: Series radionuclides and non-series radionuclides.

1.2.2.1 Series radionuclides

These are radionuclides that are headed by parent radionuclides that decay in sequence to other radionuclides with different half lives and decay modes, and finally end to stable isotopes (NCRP, 1992). There are three natural decay series. There are Uranium-238 series, Thorium-232 series and Uranium-235 series. These series and their main members are shown in Figures 1.1, 1.2 and 1.3 respectively.

1.2.2.2 Non-series radionuclides

The non-series decays directly to stable nuclide. The most important radionuclides in this category are the isotopes of Potassium-40, Vanadium-50, Rubidium-87, Cadmium-113 and Indium-115. In term of population dose, the most significant radionuclides are Potassium-40 and Rubidium-87 (NCRP, 1992).

The radionuclides ^{238}U, ^{232}Th and ^{235}U have half-life of 4.5×10^9 years, 14×10^9 years, and 0.7×10^9 years respectively. These radionuclides do not decay to a stable isotope in one step, but give rise to decay series (Figures 1.1 and 1.2 and 1.3). For ^{232}Th it takes about ten steps to reach stable ^{208}Pb, with 346 possible γ-ray emissions. The decay of ^{238}U (Uranium – Radium) series takes about 14-16 steps to reach ^{206}Pb, with 458 possible γ-rays. The decay of ^{235}U (Uranium – Actinium) series leading via 11-14 radionuclides to ^{207}Pb. When an unstable nuclide decays, it is nearly always emitting α or β radiation. Most of α or β decays leave the final nucleus in an excited state. These excited states decay rapidly to the ground state through the emission of one or more γ rays (Firestone, 1998). The average number of emitted photons per decaying nuclide equals 2.628 for ^{232}Th and 2.197 for ^{238}U (NCRP, 1992). Not all nuclides of the series emit γ-radiation, and the detection of thorium and uranium depends on γ-rays emitted by some of their decay products. The most important γ-rays for ^{232}Th are the 0.58 and 2.61 MeV transitions from ^{208}Tl, and for ^{238}U the 0.61, 1.12 and 1.74 MeV γ-rays from ^{214}Bi (NCRP, 1992). All decay products have half-lives shorter

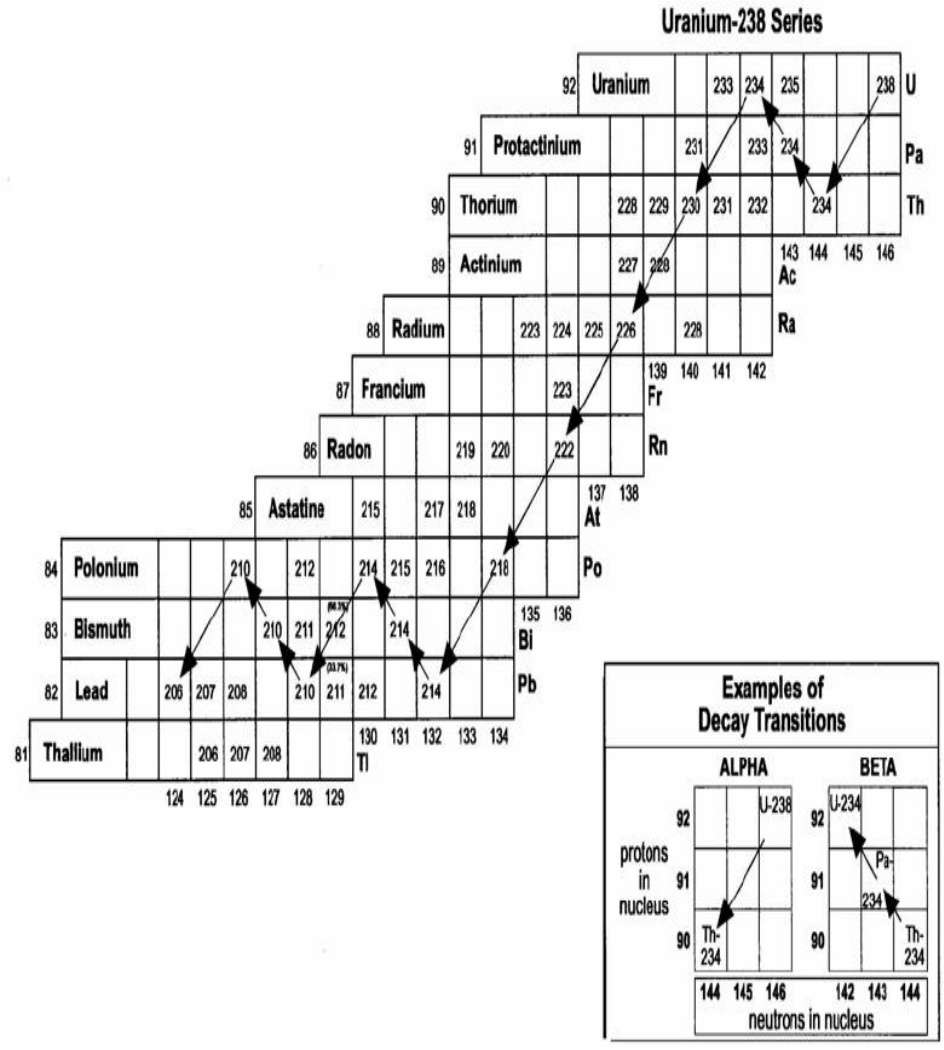

Fig. 1.1: A schematic diagram of the uranium -238 series (Harb, 2004)

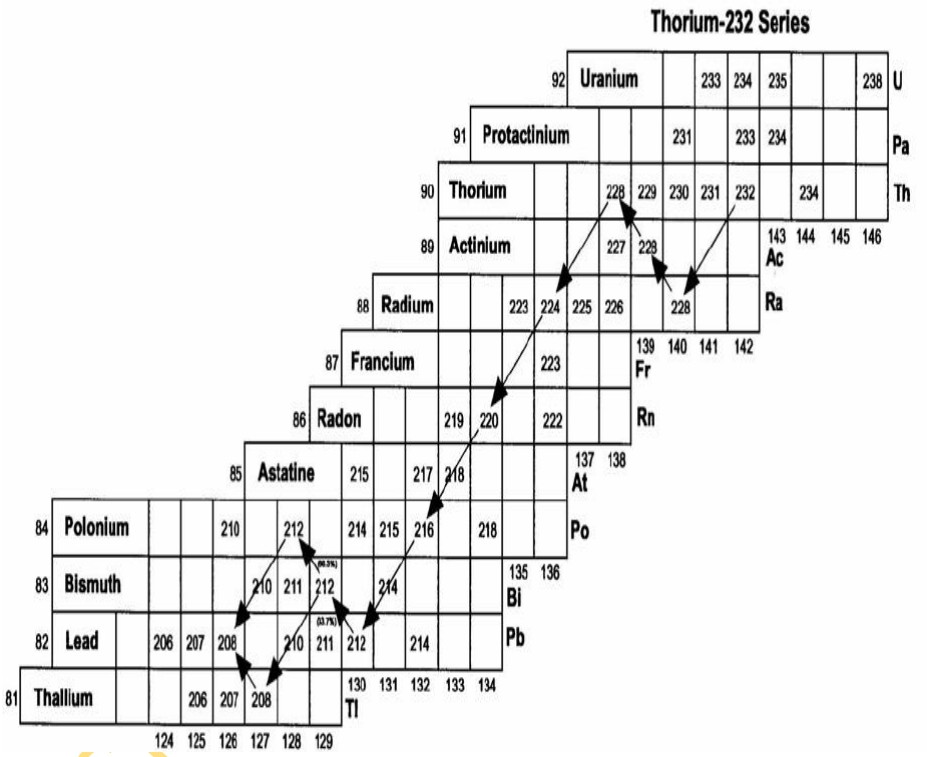

Fig. 1.2: A schematic diagram of the Thorium -232 series [Harb, 2004]

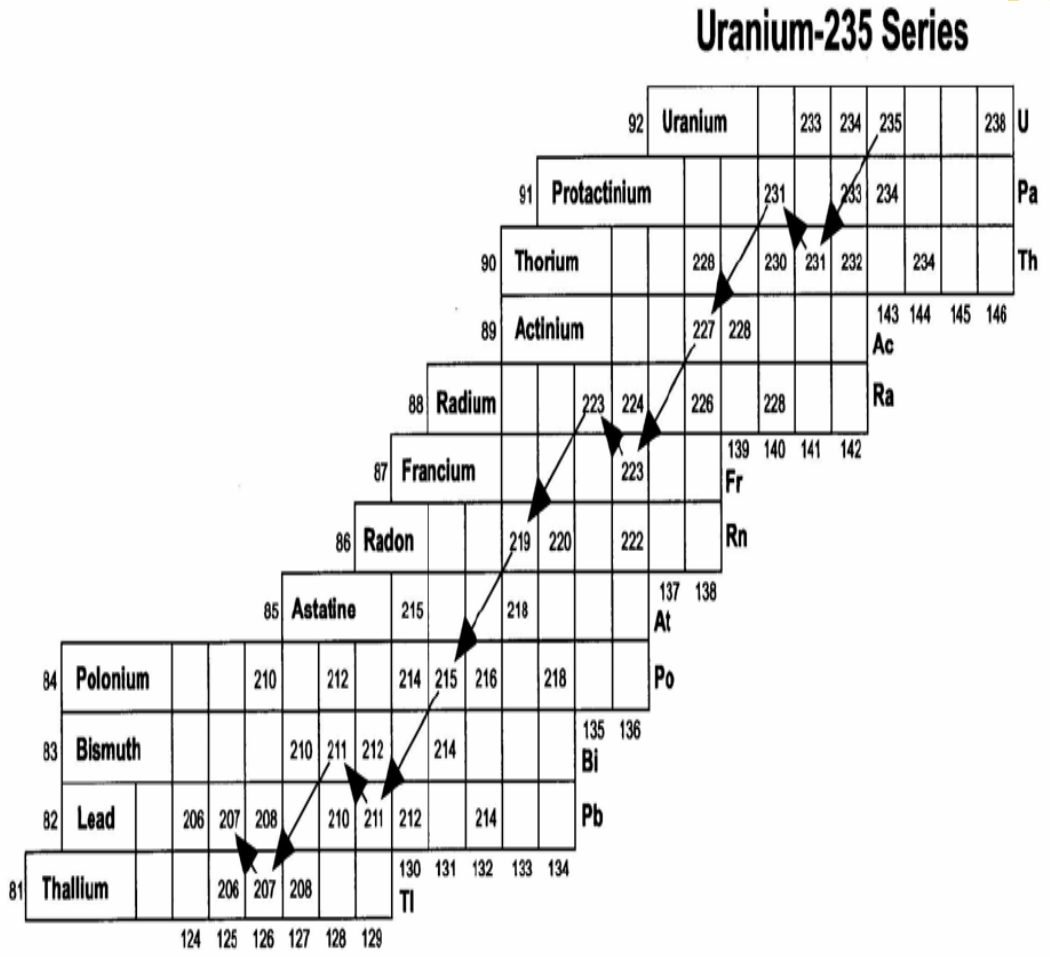

Fig. 1.3: A schematic diagram of Uranium-235 radioactive decay series (actinium) [Harb, 2004].

than ^{232}Th and ^{238}U, so in a closed systems secular equilibrium develops. Secular equilibrium in the decay series of ^{238}U can be distorted by the escape of ^{222}Rn. This radionuclide has a half-life of 3.8 days and is an inert gas, allowing it to move out of the system, for example in the sediment or soil. Decay products of radon once escaped from the soil can be deposited again by precipitation. These processes affect the activities of the radon decay products in the sediment and at the soil surface. The main γ-rays that are used for the detection of ^{238}U are emitted by decay products of ^{222}Rn. Therefore, the possibility of radon escape should be taken into account when detecting ^{238}U. In a laboratory setting the escape can be prevented by sealing samples in radon-proof containers and leaving them for some time, to establish secular equilibrium. Another radionuclide that can cause a break in secular equilibrium in the Uranium series is ^{226}Ra ($t_{1/2}$ = 1600 yr), which is soluble in water. Radon also appears in the decay series of ^{232}Th, but its isotope, ^{220}Rn, has a half-life time of 55.6 secs which is too short for significant escape.

Among the primordial radionuclides, ^{40}K, ^{238}U and ^{232}Th and any of their decay products such as radium and radon mainly contribute to the total dose from natural backgound radiation. These primordial radionuclides are found in trace amount in drinking water, coal, phosphate rocks, sediments and plants resulting in internal exposure by ingestion, in addition to these is the low exposure by inhalation of airborne suspended particles.

Potassium -40 has been found to be the most significant primordial radionuclide of terrestrial origin. It has a half- life of 1.3 x 10 ^{9} years and the main decay modes of ^{40}K are β- decay to stable ^{40} Ca and electron capture to an excited state of ^{40}Ar, emitting 89% of 1.314 Mev of β- particles most of the time (Kathren, 1998). ^{40}Ar decays to its ground state by the emission of a γ-ray of 1.461 MeV, which happens in 10.67% of all decays. This photon value makes it easy to identify and quantify ^{40} K by γ- ray specrometry. It is also an excellent calibration point because of the presence of potassium in essentially all environmental samples (Alatise, 2007).

Thorium is essentially insoluble. Therefore, concentrations of this radionuclide in biological material is almost negligible. This radionuclide also is not mobile in the environment. The highest concentrations of thorium in the body have been found predominantly in the pulmonary lymph nodes and lungs. The presence of high concentrations

in this area of the body indicates that infiltration occurs mainly as a result of inhalation of soil and dust particles (NCRP, 1992).

The isotope of ^{238}U occurs with a natural abundance of 99.28%, ^{235}U occurs with a natural abundance of 0.71%, and ^{234}U occurs with a natural abundance of 0.0058%. Uranium is prevalent to some degree in all common types of rock and soil. Common rock types contain concentrations of uranium in the range of 0.5 ppm to 4.7 ppm. These concentrations, however, do not only just refer to ^{238}U itself, but also to the daughter products inherently contained in the uranium decay chain. Each radionuclide in this decay chain emit several different types of radioactive particles and photons. Over a sufficiently long time, the decay chain essentially behaves as a single, large source of ionizing radiation. Considerable energy releases occur as a result of the decay of Uranium series. Uranium radionuclide is present in food and human tissues. The annual intake of Uranium from all dietary sources averages approximately 320 pCi (13 Bq) (Eisenbud, 1987). The specific levels of terrestrial environmental radiation are related to the geological composition for each lithologically separated area, and to the content of Uranium, Thorium and Potassium in the rock from which the soil originated in each area (Merdanoglu and Altinsoy, 2006; Chowdhury et al., 2006). These radionuclides when ingested or inhaled enter the human body and are distributed among body organs according to the metabolism of the element involved. The organs normally exhibit varying sensitivities to the radiation and thus, varying doses and risks result from their consumption or inhalation. UNSCEAR (1993) and Mettler and Sinclair (1990), showed that terrestrial sources are responsible for most of man's exposure to natural radiation and Kullab et al., (2006) reported that the natural radionuclides concentration in soil and rock would affect the natural radioactivity level of river sediments.

1.3 SOURCES OF ARTIFICIAL RADIOACTIVITY

Artificial radioactivity are created via human activities that vary with time and location according to domestic and/or world activities. Sources of man-made radionuclides include nuclear tests, nuclear power plants and reprocessing facilities, sources used for medical, industrial and agricultural applications, and sources used for research purposes (UNSCEAR, 1988; Eisenbud, 1987). Most of these radionuclides find their ways into the environment through transport, routine release, accidents, loss and inproper disposal or misuse of radioactive materials. Man made sources of radiation can only affect a small fraction of the population at any time under controlled management. Radiation used in medicine for both diagnostic and therapeutic purposes especially the management of cancer in humans make a significant contribution to man's exposure (Pascal, 2006).

Some common consumer products enhance man's exposure, like the luminous watches and clock which contain ^{3}H, ^{147}Pm or ^{226}Ra as the activating agent (UNEP, 1991; NCRP, 1977). Television sets produduce x-rays, but modern sets have been designed to produce negligible amounts when used correctly and serviced appropriately (Larmash, 1983). Also, smoke detectors contain alpha-emmiting sources such as Americium-241. Some porcelain dentures and eye glasses which contain Uranium and Thorium (NCRP, 1977) also enhance exposure. Starters for fluorescent tube lights and some electrical appliances contain sealed radionuclides although they do not cause any hazard unless they are broken (NCRP, 1977), X-ray machines used for screening travelers (Mettler and Sinclair, 1990), cigarette smoke and tobacco which contain Pb-210 and Po-210 (Larmash, 1983; NCRP, 1977, Pascal, 2006) and combustible fuels as well as building materials which could be mixed with Uranium, Thorium and Pottasium containing waste etc (NCRP, 1977). All these radiation sources could contaminate the human body through irradiation, inhalation and ingestion leading to varying doses of radiation to man (Pascal, 2006; NCRP, 1997).

1.4 TRANSPORT OF RADIONUCLIDES IN THE ENVIRONMENT

Radionuclides in the environment can give rise to radiation doses to humans. External irradiation is exposure from environment to human directly. Internal irradiation means uptake by human via a variety pathway such as inhalation of contaminated dust, ingestion of

dirt and dust, inhalation of radon diffusing from the material and skin contamination (see Figures 1.4 and1.5). Radioactive materials can be released into air or directly into water or soil. When released in the air, they can travel some distance, depending upon such factors as wind speed and direction and altitude of the release. The products of airborne releases can be transported to humans by a variety of paths. First, direct inhalation is possible. Secondly, the materials will eventually deposit themselves on the ground, where they will find their way into plant and animal life and thereby, into the food chain. Third, deposition of airborne contaminants into water can reach humans either by direct ingestion or via the food chain. Similarly, direct soil and water depositions find their way into the food chain via both plant and animal life. Rain water runoff can carry soil into rivers and streams, thereby transporting any soil (sediment) contamination to water. Additionally, radioactive materials can leach into porous soils and into ground water (Doendara, 2007). Apart from all these pathway radionuclides in the aquatic environment could cause external exposure through the use of riverbed sand (sediment) as building materials. It is now a common knowledge that sediment from rivers, lakes and beaches are used as materials for the construction of buildings (Xinwei and Xiaolan, 2006).

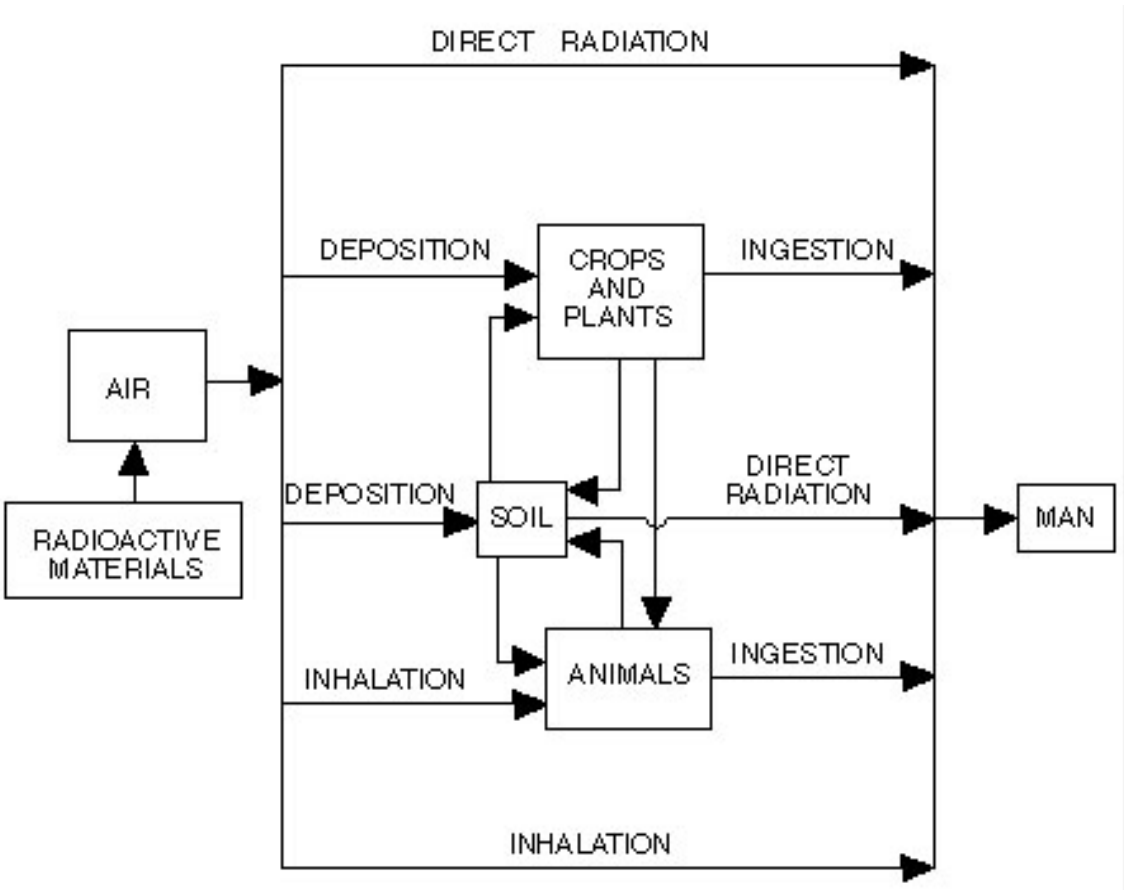

Fig. 1.4: Simplified pathways for airborne releases to man (Doendara, 2007).

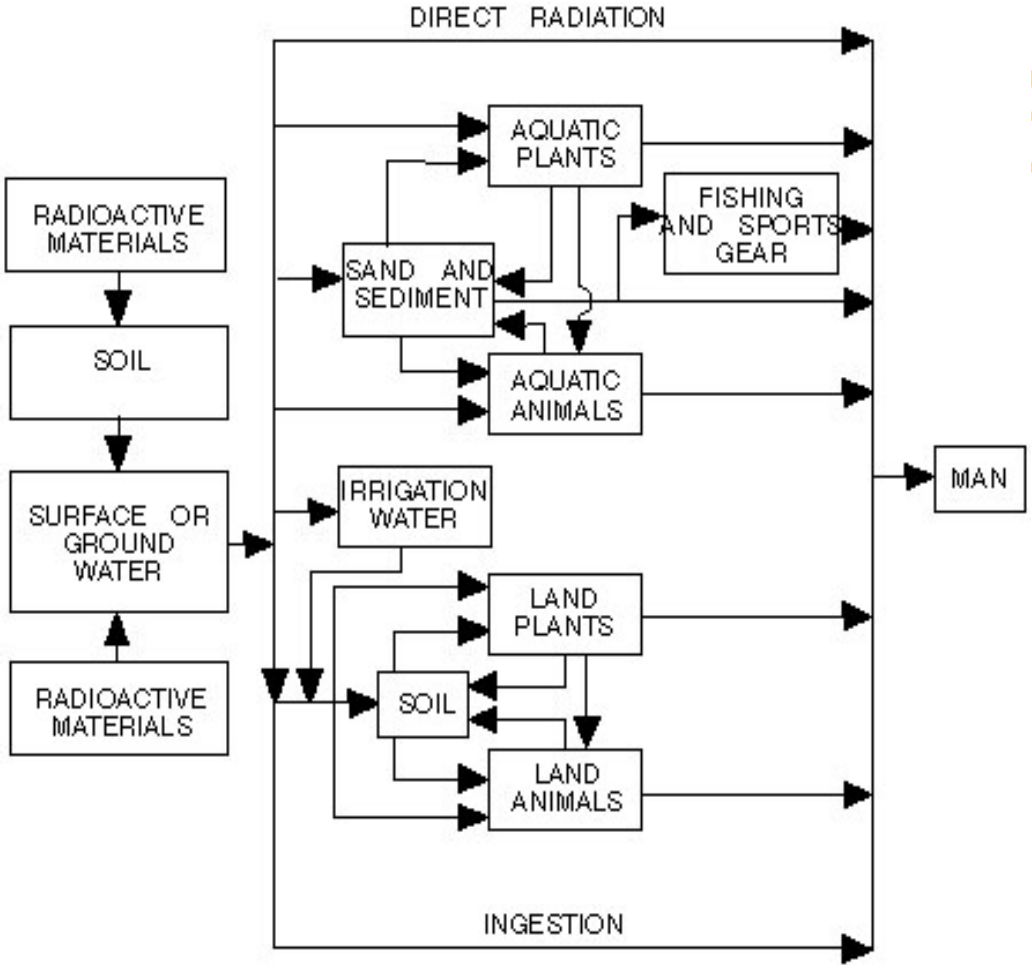

Fig. 1.5: Simplified pathways for waterborne releases to man (Doendara, 2007).

1.5 BIOLOGICAL EFFECTS OF RADIATION

The human body is made up of many organs which are composed of tissues. The tissues are made up of cells while the cells are made up of nucleus and cytoplasm. The cells contains 70% of water. When radiation transfers energy to a biological medium, some chemical reactions take place. Most of the energies are absorbed by the water content of the cell thereby causing excitation and ionization. Following these process is the breakage of chemical bonds of water as follows:

H_20 ..... $OH^- + H^+$ (1.3)

H_20 ..... $OH^+ + H^-$ (1.4)

H_20 ..... $OH^o + H^o$ (1.5)

H_20 ..... $H_20^+ + e^-$ (1.6)

The end products of the breakage of the bonds of water (H_20) are formation of free radicals (OH^o H^o) and the release of aqueous electrons. These free radicals are highly reactive and they may recombine to form stable ions and molecules or the reactive species may attack the molecules present in the cellular environment, mostly the biologically important molecules, Deoxyribonucleic acid (DNA) and Ribonucleic acid (RNA). The concentration of the reactive species at a sight determines which of the above two competing mechanisms will occur. This in turn depends on the linear energy transfer (LET) of the incident radiation, and on the nature of the biological system. The effectiveness of a radiation in destroying cells is called Relative Biological Effectiveness (RBE) and it depends on LET. It is important to note that radiation does not result into biological effects that are new, unique or characteristic, rather it increases the frequency of diseases which are already known to occur in human race.

1.5.1 CLASSIFICATION OF RADIATION EFFECTS ON BIOLOGICAL SYSTEM

There are various criteria for the classification of the detrimental biological radiation effects on biological system. The most recent depends on presence or absence of a threshold radiation dose to produce the effect. Radiation effects that occur after a threshold of dose are called deterministic effects and those that occur without a threshold of dose are called

stochastic effects. A deterministic effect occurs only after a threshold dose and the severity depends on magnitude of the dose, dose rate and fractionation. There are some other deterministic effects which normally show after a latent period, usually some few years after the exposure to radiation, these are the delayed deterministic effects, example is cataract. Cataract is a change in transluscency of the optic lens and it is due to the damage of the individual cell of the lens epithelium. Abnormal cells and resultant debris accumulate at the poles of the lens, after a threshold dose that falls within the range 0.2 Gy and 0.5 Gy. Cataracts would manifest within three years of initial exposure. Also, radiation infertility, is the cell damage to the gonads, depending on the dose, it could be temporary or permanent damage. The cummulative effects of radiation caused infertility, raise the possibility of gradual human extinction. It was found that those living on the high radiation backgound had twice the rate of couples who want children but are unable to have children compared to those living on the normal backgroung soil.

The stochastic effects have no evidence of causative threshold dose and the chance of occurence is basically probabilistic. Severity of the effect is not a function of magnitude of dose but the probability of occurence or risk is a linear function of the magnitude of the dose. Stochastic effect results from damage due to low –level radiation on the genetic material of the cell which is transferred to the descendant of the cell. Apart from hereditary effects which are due to chromosome aberations and gene mutation in gonadal cells, cancer of different forms is much the most important ultimate effect of damage to a cell by low level radiation. Major concern is based on the general public and radiation workers since the effects may manifest immediately after exposure and through accidental exposure of the public.

1.6 AIMS AND OBJECTIVES

River sediments are known to contain natural radionuclides, the concentrations of which if beyond certain limits can cause adverse health effects. The sediments from Ogun river provide large quantities of sand for construction purposes in Nigeria. Despite this, data are scarce on the natural radionuclides: ^{40}K, ^{226}Ra and ^{232}Th distribution in the river sediments.

The measurement of radioactivity of Ogun river sediment from the source in Oyo state around Ago Fulani through Ogun state, down to the sink in Lagos Lagoon was designed

to establish the trends of the distribution of radionuclides through the measurement of the concentrations of these natural radionuclides in the river sediments and to establish the current status of the radiological implications of that environment. The assessment involves the measurement of radiation dose equivalents for reasons related to the radioactivity in the sediments of the river since sediments are derived from weathering and erosion of rocks and soil, these sediments contain certain concentrations of naturally occurring radionuclides which will depend on the concentrations of such radionuclides in rocks and soil of their origin. Human and industrial activities around the river may also increase the level of radioactivity in the sediments. The three states through which the river passes, are heavily industrialised cities: Lagos and Sango – Ota (Ogun state) for instance, about six major industries including Vitabiotics, Nestle, Glaxos, Smith kline, Sona Breweries and Nigerian German chemicals discharge their wastes into the river. The aim of this work is to investigate the extent of radioactive pollution in the river, if any, and to assess if sediment materials obtained from this river used for the construction of dwellings are radiologically safe. The aim is achieved through the following objectives:

i. To investigate and interpret the distribution of radionuclides in the sediments along Ogun river course.
ii. To provide a baseline data on the distribution of natural radionuclides in sediments from Ogun river.
iii. To investigate if there are obvious/significant variations in the radionuclides' concentrations due to different locations based on economic activities.
iv. To evaluate the environmental gamma dose rates and other radiation hazard indices for determining the health implications through the use of the sediments from the river for construction purposes.
v. To determine the excess lifetime cancer risk associated with the use of the sediments as building material.
vi. To carry out geotechnical study of the sediments.
vii. To determine the distribution of basic mineral composition and heavy minerals (opaque and non- opaque) in the river sediments.

CHAPTER TWO
LITERATURE REVIEW

2.1 Radioactivity in River Sediments

A river is a natural watercourse usually freshwater, flowing toward an ocean, a lake, a sea or another river. In few cases, a river simply flows into the ground or dries up completely before reaching another body of water. Small rivers may also be termed by several other names, including stream, creek and brook. In the United States a river is generally classified as a watercourse more than 18 metres wide. The water in a river is usually in a channel, made up of a stream bed between banks. In larger rivers there is also a wider floodplain shaped by flood-waters over-topping the channel. Flood plains may be very wide in relation to the size of the river channel. Rivers are a part of the hydrological cycle. Water within a river is generally collected from precipitation through surface runoff, groundwater recharge, springs, and the release of water stored in glaciers and snowpacks (Marriam, 2010).

Rivers are of immense importance geologically, biologically, historically and culturally although they contain only about 0.0001% of the total amount of water in the world at any time. They are vital carriers of water and nutrients to areas around the earth (Murugesan, 2004). They are crucial components of the hydrological cycle, acting as drainage channels for surface water. The world's rivers drain nearly 75% of the earth's land surface (Iwena, 2000). Rivers play vital roles in the provision of habitat, nurishments and means of transport to many organisms, travel routes for exploration, recreation and even commerce, importantly they leave valuable deposits of sediments, such as gravel and sand, even forming floodplains where many cities were built (Murugesan, 2004).

Sediments are particles of organic or inorganic matter that accumulate in a loose, unconsolidated form that settles at the bottom of water bodies as a result of the erosive force of water's contact with rock, soil and plant materials (Thompson, 2007). There are two primary sources for particles accumulating as sediments today, the detrital sediments – originated and are transported as solid particles derived from weathering of the land accumulations and the other is known as the chemical sediments originating from the dissolved materials derived from weathering which are precipitated from water streams, lakes, or the ocean accumulations (Murugesan, 2004; Oyebanjo, 2010).

Radioactivity in river sediments originates from the near surface, from exposed igneous, volcanic and sedimentary rocks. Some of these rocks are easily eroded and others most especially the crystalline and the metamorphic rocks are affected by streams only when altered in the surface layers, (Joshua and Oyebanjo, 2010). Radionuclides have an affinity for silts and clays in the soils. These soils and attached radionuclides are subject to sheet erosion and transport into streams and rivers, the fine sediments are most representative of the sediment transport of radionuclides (Purtymun et al., 1980). In spite of the low concentrations in the aquatic environment, the aquatic behaviour of radionuclides plays an important role in the ecosystem, since water is crucial to life and it is one of the prime agents that help to move and distribute elements on the earth (Khan et al., 2003; Isikaye, 2009). Distribution of sediments is determined by climate (temperature), environmental factors (nutrients, possible chemical reactions, activity of physical environment) supply, size and rate of accumulation (Thompson, 2007). Resources from sediments are sand and gravel for construction, phosphorite for fertilizers, sulphur for sulphuric acid for industry, coal for energy, oil and gas for energy and transportation. Manganese nodules for Mn, Fe, Co, Cu and Ni, etc (Thompson, 2007).

Sand whether found on beaches or in rivers and streams, is mostly quartz grain (Ramasamy et al., 2010). The weathering of rocks such as granites form the quartz grain, grains of other weather-resistant minerals too are found in quartz sand as well. The use of sand and gravel are of two categories, some are used in construction where it may be mixed with other materials or used as it is. The second use is the industrial use, where the sand and gravel are used in some way in the production of other materials (Murugesan, 2004).

Along with industrial development of the world, water reservoirs, such as soil become, although in considerably smaller degree, the place of accumulation of different kind of contaminants. Introduction of organic, inorganic, and radioactive substances produces dramatic, often irreversible changes of physicochemical and biological properties of these reservoirs. The geochemical composition of sediments, gathering on the bottom of rivers and water reservoirs is a very good indicator of quality of surface waters and the presence of contaminants (Jan et al., 2006).

Although soil has always been important to humans and their health, it is also providing a resource that can be used for shelter and food production. Through ingestion, inhalation and

dermal absorption, the mineral, chemical and biological components of soil can be directly detrimental to human health. Example of such effect to human is cancers caused by the inhalation of fibrous or radon gas derived from the radioactive decay of uranium in soil minerals (Abdulkareem, 2009). The knowledge of uranium concentration in sediments and soils is important not only to assess the contamination level but also to understand the transference processes which have occurrence at different trophic levels of the feed chain (Ricardo et al., 2009). Dim et al., (2000) determined the uranium – thorium levels of the Kubanni river sediments in the Northern Nigerian Basement Complex and was observed to be enriched with mean values of 9.06 and 21.44 (ppm) respectively. The high geochemical mobility of radionuclides in the environments allows them to move easily and to contaminate mainly the environment with which human come in contact. Uranium -238, in particular is easily mobilized in ground water and surface water. As a result, uranium and its decay product enter the food chain through irrigation water, and enter the water supply through ground water, well and surface water streams and rivers (Otton, 1994). Igneous rock like granite has high concentration of uranium. Also the solubility of ^{232}Th in natural water such as river is detected in high concentration in sediments and deposits (Arogunjo, 1994). Moreover, ^{232}Th and ^{238}U are more abundant in sedimentary rocks than in igneous and metamorphosed sediments (Egunyinka et al., 2009). Kullab et al., (2006) determined the concentrations of some naturally occurring radioisotopes in sediments of the Kufranja river basin in Jordan, by means of γ-ray spectrometry and found that the natural radioactivity level of river sediment could be affected by the natural radionuclides concentration in soil and rock, since most of the sediments that settle in river are silts and sands derived from weathering and erosion of rock and soil. Oni et al., (2011), measured the natural radioactivity level in the coastal areas of Nigeria by gamma counting of river sediment samples and results showed that the radioactivity concentrations of ^{40}K, ^{226}Ra and ^{228}Ra in the sediment samples of oil producing areas were 122.39 ± 47.49; 18.93 ± 12.53 and 29.31 ± 18.67 Bq /kg respectively, in the sediment samples from the non oil producing areas, the respective mean values were 88.48 ± 8.22, 14.87 ± 3.51 and 16.37 ± 3.87 Bq /kg respectively. The concentrations of natural radionuclides: ^{40}K, ^{238}U and ^{232}Th in the sediment of rivers and streams in the Northern part of Ibadan City, Nigeria was examined by Fasewa (2007) and the mean radioactivity concentrations obtained were (0.0564 ± 0.0056), (0.0128 ± 0.0017) and

(0.0175 ± 0.0037) kBq/kg respectively. Some other researchers from different countries in the world had also carried out different works on the measurement of activity concentrations of naturally occurring radionuclides in sediments, few of such works are presented in Table 2.1. Human activities such as application of phosphate fertilizer in surrounding farmlands and the discharge of both industrial and domestic waste into rivers and stream may also increase the radioactivity levels in water sediments (Isinkaye, 2009). Considerable amounts of natural radionuclides can be found in river sediments as the end result of fertilizer washing and industrial activities (Krmar et al., 2009; Ramasamy et al., 2009). The environmental uranium and partial thorium concentrations are increased due to the fertilizers. Usually fertilizers are considered to technologically enhance natural radiation (El Gamal et al., 2007). The presence of radionuclides in phosphatic fertilizers have been reported by several studies (Guimond and Hardin, 1989; Khan et al., 1998; Zielinski, et al., 2000; San Miguel et al., 2003; Becegato et al., 2008).

Table 2.1: Activity concentrations (Bq/kg) of naturally occurring radionuclides obtained by researchers from different parts the world

S/N	Country	^{40}K	^{226}Ra	^{232}Th	References
1	India (Kali river)	296.0 - 525.0 (394.7)	34.1 - 49.4 (40.1)**	4.6 - 12.2 (6.9)	Narayana et al., (2007)
2	Bangladeshi (Shango River)	212- 292 (255)	21.6 - 28.3 (25.4)**	52.4 - 61.7 (57.5)	Chowdhurry et al., (2009)
3	Algeria (Algiers Bay)	56 - 607 (374)	4.45 - 25.04 (15.8)**	6.5 - 31.7 (19.5)	Benemar et al., (1997)
4	China (Wei River)	514.8 - 1175.5 (833.3)	10.4 - 39.9 (21.8)	15.3 - 54.8 (33.1)	Xinwei et al., (2008)
5	Egypt (Eastern Desert)	298.6 – 955.8	9.7 – 19.0	10.0 – 17.7	Harb, (2008)
6	Egypt, Wadi Nugrus,	306.7 -626.0	24.7 - 86.45 (43.91)**	20.3 - 48.72 (26.62)	Abdel-Razek(2008)
7	Turkey	155.7 -868.7	26.8 - 49.8 **	17.06 - 35.62	Kam and Bozkurt (2007)
8	Bengal	118 - 608	5.9 - 27.9	10.4 - 64.0	Alam et., (1997)
9	Pakistan	(647.4)	(32.9)	(53.6)	Matiullah et al., (2004)

** = ^{238}U, ( ) = mean concentration

2.2 Sands and Muds

The composition of a natural sediment bed is the result of various morphodynamic processes and can be characterised by its sand (> 63 and < 2000 μm) and clay (< 2 μm), silt (< 16 μm) and mud content (< 63μm) (Wijngaarden et al., 2002). Especially in delta systems where the deposition or erosion of mud and sand occurs under specific (tidal) conditions, such a classification appears often to be more functional than grain-size information expressed by a median diameter. The sand or mud content provides information with respect to:

(i) the sediment-transport processes active in a water system and

(ii) the (potential) degree of pollution of the sediments, which is strongly correlated to the mud content (Horowitz and Elrick, 1987; Zwolsman et al., 1996; Wijngaarden et al., 2002). Sand and mud have different geochemical and physical properties and are transported in a different manner. Sand is an inorganic, silicon-rich coarse material, which is transported mainly as bedload. Mud is a fine, cohesive material, still rich in silicon, quartz and feldspars, also contains inorganic matter and clay minerals but it is transported in suspension. The main constituent of these clay minerals is Al_2O_3. Moreover, clay minerals have a high adsorption potential for trace metals and radionuclides (Ramasamy et al., 2009; Wijngaarden et al., 2002). Studies suggest that as a result of their specific adsorptive behaviour, radionuclides can function as indicators for the mud and sand content of submerged sediments (Duursma and Bosch, 1970; Duursma and Eisma, 1973; Venema and De Meijer, 2001; Wijngaarden et al., 2002).

In radiometric sedimentology, various sediment components are characterised using the concentration of natural gamma-ray emitting radionuclides. Three of the main radionuclides in the natural environment, ^{238}U, ^{232}Th and ^{40}K, are generally used as they have half-lives longer or comparable to the earth's existence. Accordingly, these nuclides form excellent indicators for intrinsic sediment properties. Their presence can be measured through the emission of gamma rays during decay, either directly (^{40}K) or via decay products ^{238}U and ^{232}Th, (Wijngaarden et al., 2002).

2.3 Environmental Radiation Monitoring

The radiation monitoring involves the measurement of radiation dose or radionuclide contamination for reasons related to the assessment or control of exposure to ionizing radiation or radioactive substances, and the interpretation of the results. The measurement of dose often means the measurement of a dose equivalent quantity as a proxy (i.e. substitute) for a dose quantity that cannot be measured directly (IAEA, 2007). Also, sampling may be involved as a preliminary step to measurement of the content of radionuclides in environmental media. International Atomic Energy Agency, (IAEA, 2010) gave the methodological and technical details of the design and operation of monitoring programmes and systems for different radionuclides, environmental media and types of facility. The majority of the reported articles are now about monitoring of the radiological health hazards of naturally occurring radionuclides. In a few articles, use of the radionuclides have been reported for the exploration of uranium and thorium deposits (Said et al., 2008). The great and global interest in the study and survey of natural occuring radiation and environmental radioactivity had been essentially based on the importance of using the results from such studies for the assesment of public radiation exposure rates and the importance of epidemiological studies, as well as reference radiometric data relevant in studying the possible change in environmental radioactivity due to nuclear, industrial and other human technology- related activities (UNSCEAR, 2000: Jibiri et al., 2009).

Human health can also be influenced in more indirect ways as soils interact with atmosphere, biosphere and hydrosphere, e.g. the frequent detrimental chemical and biological quality of drinking and recreational water that are influenced by processes of soil erosion, surface runoff, interflow and leaching (Abrahams, 2002). Gamma rays spectroscopy has been used extensively as a reliable tool to determine the concentrations of uranium-238 and thorium-232 concentrations in the different environment matrices (Mohsen et al., 2008).

Continuous exposure to even low level radiation may adversely affect human health. It is important to monitor the concentration of radionuclides in building materials and to assess the radiation exposure to the people (Xinwei and Xiaolan 2006). Most of the developed and developing countries in the world are carrying out nation-wide surveys to assess the amount of radioactivity in order to establish possible radiological hazards and to take safety measures if necessary (Beretka and Mathew, 1985; Oyedele, 2006; Abbady et al., 2006; Henaish et al.,

1994). The human environment is the basis for any economic, social and Cultural development. It is therefore important that its quality be maintained in a good state to ensure a high level of social performance, which can be achieved by closer monitoring of pollution factors (Avwiri and Ebeniro, 1998; Avwiri et al., 2007).

Environmental monitoring describes the processes and activities that need to take place to characterise and monitor the quality of the environment. Environmental monitoring is used in the preparation of environmental impact assessments, as well as in many circumstances in which human activities carry a risk of harmful effects on the natural environment (IAEA, 2010). All monitoring strategies and programmes have reasons and justifications which are often designed to establish the current status of an environment or to establish trends in environmental parameters (IAEA, 1995). Industrial and domestic activities such as oil exploration and exploitation, manufacturing and process industries may lead to the perturbation of the natural ecosystem and the environment that ultimately occurs as pollution (Avwiri, 2005). Increase in the background ionization radiation from numerous sources has various health side effects on the populace (Avwiri, 2005).

The controlled release of radionuclides to the atmospheric and aquatic environments is a legitimate waste management practice in the nuclear industry and its related facilities (IAEA, 1995). Typically, controlled discharges of gaseous and particulate material containing radionuclides are made through stacks, although for small facilities they may be made through discharge vents or working hoods, for example. Controlled liquid discharges are typically made via pipelines into rivers, lakes or the sea, but they may also be made via the normal sewer systems from small establishments. An important and essential element in the control of the discharges is regular monitoring (IAEA, 1995), both at the source of the discharge and in the receiving environment in order to ensure the protection of the public and the environment.

2.4 Radioactivity in Building Materials

An extremely wide range of materials can be used for building and other structure. These can be either natural or man-made. Natural materials include aggregates, bitumen, clays, rubber, stone, and wood whille man-made materials include brick, inorganic cements,

glass, plaster, metals and their alloys, synthetic polymers, and wood preservatives, (Cheriton and Gupta, 2005).

All building materials contain small amounts of radioactive substances. Materials originating from rock and soil contain mainly natural radionuclides including Uranium ^{238}U and Thorium ^{232}Th and their decay products and the radioactive isotope of Potassium ^{40}K. Some industrial by products may also contain radionuclides originating from radionuclide fallout. If such a by- product is incorporated in building materials, the final product will also contain the artificial nuclides. The action level for the radiation dose to the public due to the gamma radiation caused by building materials is~ 1 mSv per year (STUK, 2003).

Generally, dose contributions from building materials in dwellings are small compared to those from underlying bed rocks and soils (Al- Jundi et al., 2005). However several articles have identified building materials as the major contributors, this is true when the materials are either made from the radioactive industry with products such as fly ash and slag (Al- Jundi et al., 2002). In addition, ^{232}Th and ^{226}Ra can also increase the concentrations of ^{222}Rn and ^{220}Rn and their daughters in the building. Building and industrial materials, which are brought from the deserts like sands, also contribute to environmental radioactivity in two ways. First by gamma radiation mainly from ^{226}Ra, ^{232} Th and ^{40}K, and their progenies to a whole body dose and in some cases by beta radiation to a skin dose. Secondly by releasing the noble gas radon, its radioactive daughters, which are deposited in the human respiratory tract (Quindos et al., 1987). Enhanced or elevated levels of natural radionuclides in such materials may cause dose equivalents in the other of several mSv/y (Ngachina et al., 2007). The measurement of natural radioactivity due to gamma rays is needed to implement precautionary measures whenever the dose is found to be above the recommended limits (Ahmed et al., 2006: Abel-Ghany et al., 2009). A number of activity measurements have been performed for different types of materials in different places. Akkurt et al., (2009a) measured activity of coal used in Turkey and some building materials (Akkurt et al., 2009b). The natural activity in building materials used in different countries has been measured and reported (Ahmed 2005; Ahmad et al., 1997; Armani et al., 2001; Bou - Rabee et al., 1996; Iqbal et al., 2000; Krstiica et al., 2007; Ngachina et al., 2007). Radioactivity of various building materials measured by many authors include ceramics, gypsum, sand, mosaic tiles, marbles, granites, river sediments, etc., in different parts of the world (Tzortzis and

Haralabos (2003); Ramasamy *et al*., (2002, 2004, 2005a , b and 2006). Al- Jundi et al., 2005, also measured some Jordanian building materials and found that the activity concentrations of ^{226}Ra measured in fine aggregates was found to be among the highest values obtained. In Nigeria, Ademola and Farai (2004 & 2006), Farai and Ademola, (2001) and Ademola, (2008a) measured the mean radioactivity concentrations in the different building materials while the measurement of ^{226}Ra, ^{232}Th and ^{40}K activity concentrations of natural radioactivity in Italian ceramic tiles was reported by Righi et al., (2009). Samples of limestone, sand, marble, clay brick, red brick, gypsum, Portland cement and white cement collected from upper Egypt have been analyzed for the natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K by (Abbady, 2006) using γ-ray spectrometry. Radium equivalent activities, dose rate and the annual gonadal dose equivalents were calculated for the measured samples to assess the radiation hazard arising from using those materials in the construction of dwellings. Study of natural radionuclides and radon emanation in bricks used in the Attica region, Greece was also studied by Savidou et el., (1996). The cement industry is considered as one of the basic industries that plays an important role in the national economy of developing countries. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in Assiut cement and other local cement types from different Egyptian factories had been measured using γ-ray spectrometry and reported by (El- Tahera, 2010). The manufacturing operation of cement reduces the radiation hazard parameters, (El- Tahera, 2010). Increased interest in measuring radionuclides and radon concentrations in fly ash, cement and other components of building products is due to the concern of health hazards of naturally occurring radioactive materials (NORM) (Kovler et al., 2005). Kovler et al., (2005) reported that, despite the higher ^{226}Ra content in fly ash, FA (more than 3 times, compared with Portland cement) the radon emanation is significantly lower in FA (7.65% for cement vs. 0.52% only for FA). Alam et al., (1999); Singh et al., (2005); Veiga et al., (2006); Xinwei and Xiaolan, (2006), studied the distribution of naturally occurring radionuclides and have revealed radiological implication of these elements due to the γ-ray exposure of the body and irradiation of the lung tissues from the inhalation of radon and its decay products. As natural marbles may contain some elements which above a certain concentration have a toxic and sometimes cancerous effect on the organism, it is indispensable to identify and to determine quantitatively the possible impurities in the marbles before use. This is very important for their industrial application, too. Marbles from

deposits in Yugoslavia used in industry and agriculture have been analyzed by non-destructive radioactivity (Draskovic and Draskovic, 1970). Draskovic and Draskovic, (1970) also carried out measurements of irradiated samples of marbles with a γ-spectrometer using a NaI(T1) detector and proved the presence of Cu, Mn and Na impurities. Akkurt et al., (2010) determined natural radioactivity of ^{238}U, ^{232}Th and ^{40}K in some marble materials produced in Afyonkarahisar region of Turkey. Due to the widespread use of marble as a building/construction material formations in Pakistan, experimental measurements of ^{226}Ra, ^{232}Th and ^{40}K activities in marble had been carried out using a NaI(Tl) gamma-ray spectrometer with a matrix-inversion-based spectral stripping technique by Muhammad et al., (2000). Higher values of ^{226}Ra and ^{232}Th were obtained in marble from Egypt by Abbady (2006) using gamma-ray spectrometry. The reported activity concentration values obtained by different authors from Nigeria and some other parts of the world in some building materials are presented in Table 2.2.

Table 2.2 Activity concentrations (Bq/kg) of naturally occurring radionuclides in some building materials obtained by researchers from different parts of the world

S/N	MATERIALS	COUNTRY	^{40}K	^{226}Ra	^{232}Th	REFERENCES
1	Concrete blocks	Nigeria	(352)	(47)	(52)	Farai and Ademola, (2001)
2	Granite	Egypt	(1099)	(76.4)	(80)	Alharbi et al., (2011)
3	Bitumen soil	Agbabu, Nigeria	(65.75)	(9.83)	(8.64)	Isinkaye (2008)
4	Tiles	Turkey	(450.1)	(81.2)	(61.4)	Turhan and Varinlioglu, (2012)
5	Marbles	Turkey	(58.1)	(8.2)	(5.5)	Turhan and Varinlioglu, (2012)
6	Ceramic tiles	Italy	(500)	(100)	(50)	Righi et al., (2009)
7	Marbles	Afyonkarahisar, Turkey	106. 264 - 351.755	38.883 - 195.726	32.165-47.814	Akkurt et al., (2010)
8	Marbles	Pakistan	7 – 105	4 – 63	9 – 40	Muhammad et a., (2000)
9	Concrete blocks	Jos, Nigeria	(589)	(66)	(126)	Ademola and Farai (2006)
10	Concrete blocks	South Western Nigeria	176.2-336.8	13.3-18.4	28.2-71.6	Ademola and Farai (2005)

2.5 Sediments and Minerals

Sediments are detrital products of rocks and bear the mineralogical properties of the original rock formation. The principal constituents of most of the sediments are quartz, feldspar, carbonates and clay minerals. Out of these, quartz is overwhelmingly the most abundant. Feldspar, though more abundant in parent igneous rock, is of intermediate durability and so runs second place to quartz in sediments (Ramasamy et al., 2010). The other minerals, though more durable than feldspar, are simply far less abundant in source materials (Dott & Battan, 1976: Ramasamy et al., 2010). The mineralogical properties of sediments reflects the geological history of transport and sorting process. Solid mineral is a crystalline solid of inorganic origin formed as a result of geological processes and which have a well-defined chemical composition (Dexter, 2002; Avwiri et al., 2010). They constitute rocks that are found in the earth and exist together with the naturally occurring radioisotopes in the earth crusts. Mining of solid minerals could enhance the exposure of the environment to terrestrial radioisotopes (Avwiri et al., 2010).

Beach sediments are mineral deposits formed through weathering and erosion of either igneous or metamorphic rocks. These rocks may be rich in U and Th-bearing accessory minerals which migrate during the weathering and erosion of such rocks and precipitate and enrich in sediments (Ramasamy et al., 2009a; Uosif et al., 2008). The way minerals incorporate into radionuclide depend on several geological conditions, but it is most strongly dependent on the mineral species and geological formation from which they originate. All the U and Th decay series elements are incompatible in the major rock forming minerals such as quartz. There are, however, less incompatible in trace or accessory minerals (Orgun et al., 2007). The ^{238}U and ^{232}Th radionuclides are associated with heavy minerals, whereas ^{40}K is concentrated within the clay minerals (Tsabaris et al., 2007). El-Gamal et al., (2007) reported that the mineralogical structure of the sediments is one of the controlling factors for the level of radioactivity in river sediments.

2.6 The Geography of The Study Area

Ogun river and its tributries are located in the Southwestern Nigeria, Figure 2.1. It is one of the series of West African rivers which do not drain into the Niger system but

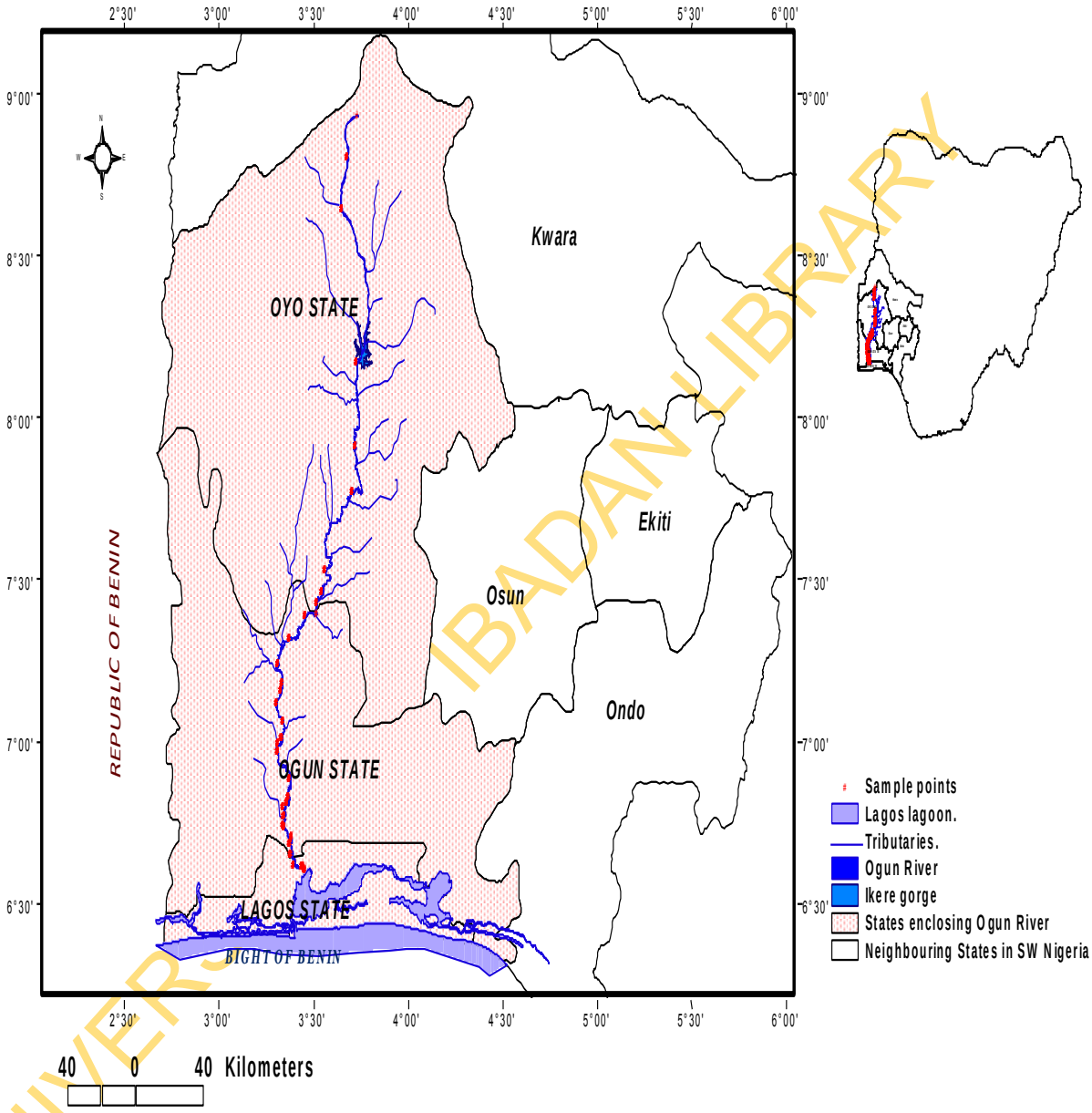

Fig. 2.1: Map of South Western Nigeria showing the study area and the three states the river traversed

discharges into coastal lagoons and creeks bordering the Atlantic ocean (Sydenham, 1977). The main channel of this river rises at approximately 8º51' N, 3º38'E in Oyo State of Nigeria around Ago Fulani area runs and passes through Ogun state and enters the Lagos Lagoon at a point on longitude 3º25' E and latitude 6º35' N.

The river channel in the upper section cut through the basement rocks on areas where the shallow aquifer is within 5 m of land surface. Therefore, there is a direct hydraulic connection between the river system and the upper portion of the shallow aquifers. This has encouraged fast depletion of groundwater due to rapid loss through the bottom of the channel. As cessation of rainfall starts in the month of November, the river discharges starts to decrease but can only be sustained by groundwater discharge. The low flow condition in the river (by December) makes the water level in Ogun river to drop. At the lower section of Ogun river, there is continuous interaction between the aquifer and the river channel. This confirms that there is a hydrodynamic interaction of surface and groundwater in the river sections. It is evident that surface water bodies are integral parts of groundwater flow systems. Generally, it is assumed that groundwater is recharged from areas of high elevation and discharges at lower areas; this may be true primarily for regional flow systems. Complex interactions between surface water and groundwater exist as a result of the surface water bodies being associated with the entire local flow systems (Bhattacharya and Bolaji, 2010).

Ogun river has a flowing rate and density which change depending on the geomorphology of the area between its spring and the point at which it joins the Lagoon. Taking these into consideration, the river was divided into three main parts traversing the course of the river: as Upper, Middle and Lower regions. The upper course of the river is known as the upper Ogun, the middle course, middle Ogun and lower course is known as the lower Ogun. It covers part of the following states: Oyo, Ogun and Lagos State. Some of the communities and towns along the course of the river from upper Ogun through the middle and then the lower Ogun river are: Igboho, Sepeteri, Ojubo Sango, Odo Ogun-Oyo West, Lasupo, Idi –Ata, Olopade, Olokemeji, Ekerin, Opeji, Lerin, Ago Odo, Sokori, Adigbe, Mile 8 (Oba), Abata, Owere, Ogunpa Wasimi, Iro, Magbon, Ilate, Oba Oseni, Ibaragun, Orudu, Maidan, Igaun, Akute, Kara, Mile 12- Maidan, Towolo, Agbariwu and Apa Osa. The river flows southwards for a distance of approximately 440 km, discharging into the Lagos

Lagoon through two distributries 15 km to the North –East of Lagos city. The major tributaries of Ogun river are the Oyan and the Ofiki systems (Bhattacharya & Bolaji, 2010).

2.6.1 The Upper Ogun River

Two seasons are distinguishable in the upper Ogun river; a wet season with mean monthly rainfall of 972 mm from April through October, while a dry season with mean monthly rainfall of 56 mm, this occured between November and March (Adebisi, 1981). The water bed comprises mainly of fine and coarse sand particles. The river is banked by either exposed rock or muddy banks. It is composed of savanna and forest trees with aquatic grasses and shrubs. Due to the seasonal changes in the rainfall of the drainage area, there has always been an alteration in the hydrological system of this river. From July through December, the water level of the river rises as a result of the rain, making the water flow unidirectionally. After the rains the water level goes back to a point and by January, the river broke up into chain of pools. From November through April, the maximum air temperature ranged from 30.8 to 35.6ºC, between April and October , the minimun temperature varied between 18.8 and 21.7ºC (Adebisi, 1981).

2.6.2 The Middle Ogun River

The middle Ogun river is in the moderately hot, humid tropical climatic zone of Southwestern Nigeria. There are two distinct seasons in this region, the rainy season which lasts from March/April to 0ctober/ November and the dry season which lasts for the rest of the year. The temperature is relatively high during the dry season with 30ºC as the mean. Low temperatures are experienced during the rainy season, especially between July and August when the temperatures could be as low as 24ºC. The distribution of rainfall varies from about 1000 mm and about 2000 mm. Soils in the southwestern part of the area and most of the western part are sandy and could only support savannah vegetation. The river valleys have alluvial soils. Two main types of vegetation are observed here, tropical rain forest and guinea savanna. Soils in the northern part of the area are derived from the basement complex rocks. Soils derived from sedimentary rocks in the southern part of the area also varied in the components and texture.

2.6.3 The Lower Ogun River

The topography of the area is generally low-lying undulating flat landform, but with some very rugged areas having scarp slopes and gorges. The area is covered with clay-sandy soil along the coastal axis in the south and clay-loamy soil at the interior part. Apart from that, the area is still covered by forest, most of the clay-loamy soil of the interior have been greatly leached and presently look more like laterite soil. The soils are well drained with the exception of those found in the wetland areas. The vegetation of the region is that of coastal swamp and marsh/mangrove forest, part of which had given way to the construction of houses, markets and other infrastructures. Places like Apa Osa, Towolo, Akute, Maidan – Mile 12, etc. Are some of the towns in this region. The climate of the area is influenced by two air masses, namely: Tropical maritime and the Tropical continental air masses. The tropical maritime air mass is warm, wet and originates from the Atlantic Ocean. The tropical continental air mass is warm, dry, dusty and originates from the Sahara desert. Hence, the climate of the area is similar to that of the other coastal region of the tropical West Africa with tropical sub-equatorial climate. The temperature is high throughout the year with an annual mean of the maximum temperature as 33.27ºC, while annual mean of the minimum temperature is 20.27ºC and the annual mean temperature is 26.77ºC.

This area experiences two separate seasons, namely: the wet season, which runs from April to October, with August being the little dry season period. The main dry season is from November to March. The area records an average annual rainfall of about 1830mm, with maxima in June and September. Most rainfall experienced are of conventional origin; however, various disturbances contribute to the rainfall especially between February and May. The mean daily relative humidity of the area is 81.65% (Tejuoso, 2006).

2.7 THE GEOLOGY OF THE STUDY AREA

The geology of the study area, Figure 2.2 is described as a rock sequence that starts with the Precambrian Basement (Jones and Hockey, 1964) and which consists of quartzites and biotite schist, hornblende-biotite, granite and gneisses. The foliation and joints on these rocks control the course of the rivers, causing them to form a trellis drainage pattern, particularly to the north of the area. The sedimentary rock sequences are from Cretaceous to Recent; the oldest of them, the Abeokuta formation, consists of grey sand intercalated with

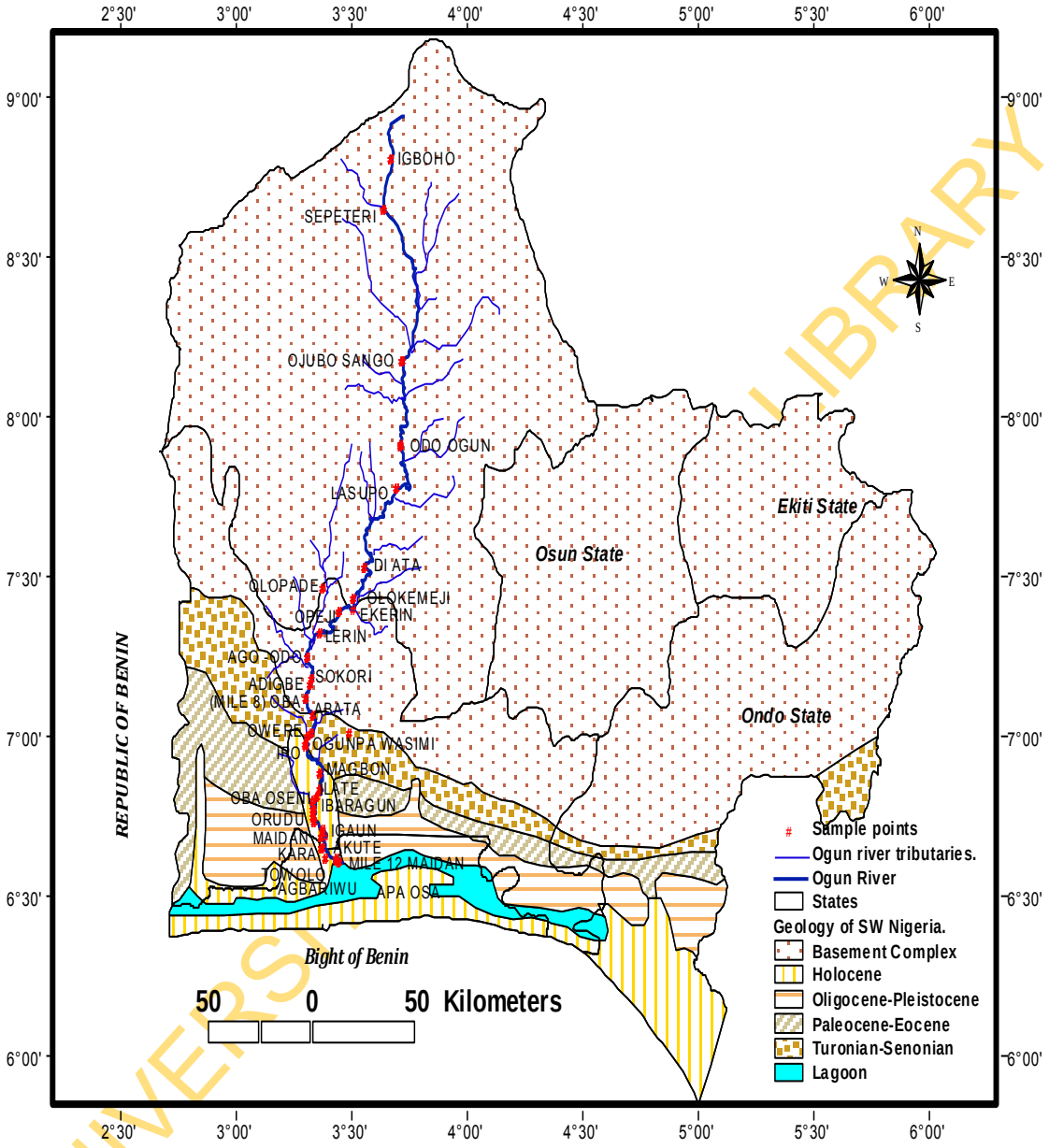

Fig. 2.2: The geological map of SouthWestern Nigeria showing the distribution of major rock types

brown to dark grey clay. It is overlain by Ewekoro formation, which typically contains thick limestone layers at its base. About 9 km upstream of Abeokuta town there is a sharp change in land gradient, changing the river morphology from fast flowing to slow moving and leading to the formation of alluvial deposits overlying the sedimentary formation of Ewekoro, Ilaro and Coastal plain sands in sequence towards the Lagos lagoon (Bhattacharya & Bolaji, 2010).

2.8 SOCIAL – ECONOMIC ACTIVITIES OF THE STUDY AREA

Ogun river serves three states (Oyo, Ogun and Lagos) greatly in terms of economic and social importance. In areas of high population density the river is used for domestic purposes such as bathing, washing and drinking. Fishing is also carried out in major part of the river. Artisanal fisheries are major activities in lower Ogun river. At Isheri-Olofin, lower Ogun river receives effluents from 'Kara'Abattoir which was established in 1984**.** An average of 200 cows are slaughtered and butchered at the abattoir on daily basis (Ikenweiwe et al., 2011). Meat and milk production are done around the river banks. The effluents being discharged into the river chiefly contain the gut contents of the slaughtered and butchered cows, therefore the river acts as sink to most organic wastes from abattoirs located along its course. The source of income of most people are based on this river because sanding and escavations are done day and night.

The sediments obtained from the river is used to build houses where people live. Importantly, the three states through which the river passes, are heavily industrialised cities: most especially, Lagos and Sango – Ota(ogun state) for instance, about six major industries including Vitabiotics, Nestle, Glaxos, Smith kline, Sona Breweries and Nigerian German chemicals discharge their wastes into the river (Farombi et al., 2007). The study area is an area where there is diversification of trade. There is a dam, Ikere Gorge, situated on Ogun River, about 8 km east of Iseyin around Ojubo Sango in Oyo state. There is also a basin, which lies between latitudes $6^{o}33N$ and $8^{o}58N$ and between longitudes 2^{o} 40E and $4^{o}10E$ with total area of about 23,700 km^2. Different water uses, including domestic, commercial, industrial and agricultural takes place within the basin (Ojekunle et al., 2011). Farming activities completed with the use of fertilizer to facilitate good crops, most especially cassava

plantation, hunting, mat making, fishing, cloth dyeing have been the chief occupations of the local people for many decades. However, commerce and industry are other major human activities within the area, which include the Planet Plastic industries in Mile 12, sawmill (plank) industries, as well as the popular food market at Mile 12 (Tejuoso, 2006). Human and industrial activities are higher at the middle and toward the lower parts than at the upper part of Ogun river.

CHAPTER THREE

RADIATION DETECTION TECHNIQUES

3.1 Interaction of Electromagnetic Radiation With Matter

Gamma rays can be defined as an electromagnetic radiation with both particle and wave-like characteristics. They travel at the speed of light (c), and have a discreet energy (E), frequency (f), and wavelength (λ). These are related by:

$$E = hf = \frac{hc}{\lambda} \qquad (3.1)$$

where h = Planck's constant 6.6261×10^{-34} Js; c = velocity of light.

Gamma rays are produced by transitions between nuclear energy states. The gamma –ray energies are typically ~100 keV to ~5 MeV (Knoll, 2000). Although there are many possible interaction mechanisms of gamma rays with matter, only three most important processes play a significant role in radiation detection measurements. These are the photoelectric absorption, Compton scattering and pair production. In photoelectric absorption process, the incident photon transfers all of its energy to a bound

electron. Photon disappears and electron is ejected from the atom (mainly from the k shell). The vacancy shell will be filled quickly through capture of a free electron from other shells of the atom. Therefore, characteristic X-ray photons may also be generated.

The photoelectron appears with an energy given by

$$E_e = h\nu - E_b \qquad (3.2)$$

Where $h\nu$ and E_b represent the energy of the photon and the binding energy of the photon respectively. The photoelectric effect is generally the dominant attenuation mechanism for incident photon energies ≤ 200 keV, i.e photoelectric effect is the predominant absorption process at low gamma energies. The probability of photoelectric absorption τ (m^2) varies approximately with the atomic number (Z) of absorber material and photon energy ($E\gamma$), according to the equation (Knoll, 2000),

$$\tau \equiv Constant \times \frac{Z^n}{E\gamma^{3.5}} \qquad (3.3)$$

Where n varies between 3 and 4 and $E\gamma$ is the γ-ray energy. The reason why high atomic number materials such as lead are used to shield radiation detectors from X-ray sources is

because of the strong influence of atomic number on the probability of photoelectric absorption. For the Compton effect, it is the elastic scattering of gamma photons by free or loosely bound electrons. In this process, the photons imparts parts of its energy to a free or loosely bound electron and the gamma photon is deflected as though the electrons were at rest with rest mass m and an elastic collision had taken place. This elastic scattering is characterised by the kinetic energy exchange between the colliding particles without loss of energy in excitation and without transition of energy into the bound state. During this process, the incident photon with energy hν is deflected and scattered through an angle θ with respect to its original direction and its original energy reduced from $h\nu$ to $h\nu'$. The frequency is changed and its wavelength increased from λ to λ'. The probability of Compton effect occuring is inversely proportional to the atomic number of the absorbing material and proportional to the gamma ray energy. Compton scattering predominates at moderate gamma-ray energies typical of environmental radioactive materials (Knoll, 1989).

Pair Production is the conversion of photon energy to mass in the vicinity of the nucleus of the atom. This is only possible if $E\gamma > 1.022$ MeV, the rest mass of the pair. It is the process in which high energy photons interact with matter. Here, the gamma photon interacts with the coulomb field surrounding a nucleus or an electron and it disappears with the creation of an electron and positron pair whose total energy is equal to the energy of the initial photon. Both the positron and electron produced lose their kinetic energies by excitation of the absorbing crystal. Positron then annihilates with an electron to produce two photons, each with 0.511MeV energy in approximately 180^0 to conserve momentum which may in turn undergo either photoelectric effect or Compton effect. The dominance of the above effects as a function of γ-ray energy and the atomic number of the absorber is given in Figure 3.1. For the energy range of the natural radionuclides, the Compton effect is most important. When a beam of γ-ray photons passes through matter, it is attenuated by the interaction processes in the material. The probability per unit path length that the γ-ray photon is removed from the beam (Knoll, 2000) is expressed in the linear attenuation (absorption) coefficient σ (cm^{-1}):

$$\frac{I}{I_O} = e^{-\sigma x} \qquad (3.4)$$

where I is the intensity of the beam of photons with energy $E\gamma$ after attenuation, I_0 is the

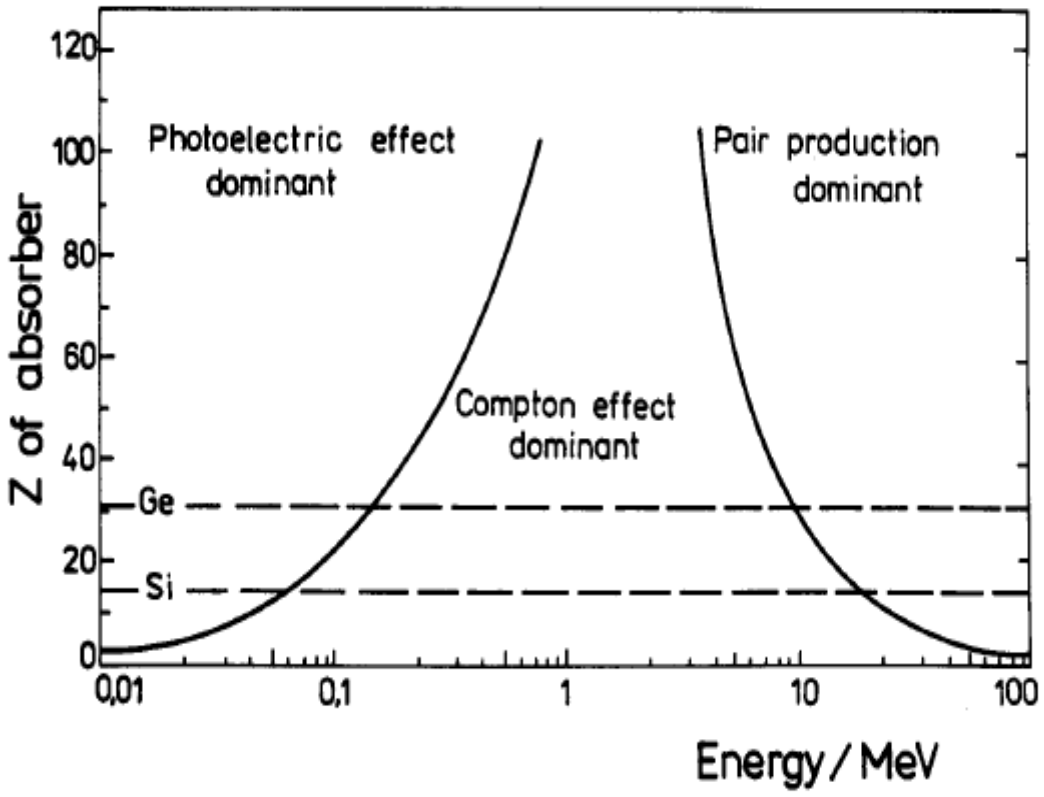

Fig. 3.1: The interaction of gamma rays with matter (Sakanoue, 1994).

initial intensity and *x* the traversed distance in the material. The linear attenuation coefficient depends on γ-ray energy and density ρ of the absorber. The attenuation coefficient can also be expressed in the form of the mass-attenuation coefficient σ/ρ (cm^2 g^{-1}), which depends on γ-ray energy but is almost independent of the state of the material.

3.2 Radiation Detection Techniques

The general principle involved in radiation detection is that whatever the form of radiation, the radiation either gives off some or all its energy to the medium of the detector by either ionizing it directly or causing emission of charged particles which later produces ionization of the medium.

Ionizing radiation can be measured through the physical and chemical effects of its interaction with matter. Field and laboratory methods are based mainly on the ionizing properties of radiation and the use of instruments that convert the radiation to electrical signals. Ionization chambers, proportional counters, Geiger-Muller tubes, scintillation counters, semiconductor detectors, thermoluminiscence detectors and various mechanical and chemical track detectors are used to monitor and quantify α,β,γ and neutron radiation in the environment. The nature and character of the radiation governs the selection of a suitable detector. Different types of radiation detection methods are available, based on the type of ionization and excitation, radiation detectors are divided into three main groups which are:

(i) Counters
(ii) Track Visualization
(iii)Dosimeters

(i) Counters are radiation detectors in which radiations are detected in form of electrical pulses and are counted by electrical circuits. Examples are ionization chamber, Geiger – muller counters, proportional counters and scintillation counters, which is the kind that was used for this work.

(ii) Track visualization detectors are those in which the trajectories of individual ionizing particles through the medium are recorded. Example of these ones are Wilson cloud chamber, spark chamber and bubble chamber.

(iii) Dosimeters: In dosimeters, the integrated effects of several ionizing radiations over a period of time are measured and examples are thermoluminescence dosimeter and film badge dosimeter.

3.2.1 Principle of Scintillation Counters

It is very essential to discuss the principle and application of scintillation counters since it is the method used for detecting and measuring radiation in this work. Gamma –ray scintillation method has been chosen using a sodium iodide crystal which has been dopped with some thalium impurities (NaI(Tl)) as the detector. The detector has a unique suitability in gamma – ray measurement because of its high efficiency for gamma-rays. The detector is highly hygroscopic and due to this fact, has to be enclosed in a light metal e.g aluminium, with an optical window through which it is then attached to a photomultiplier, Figure 3.2 is the schematic diagram of a scintillation detector system. An incident gamma photon dissipates its energy E = $h\nu$ completely on the scintillation producing,

$$N=\frac{E}{W_o}q_o \text{ photons (Birks, 1964).} \qquad (3.5)$$

W_o is the average energy of a single photon which is about 3eV for NaI(Tl) and q_o is the luminnescence quantum efficiency which is the probability of a photoelectric interaction of the incident photon. A frection G, of these photons, called light collection efficiency impinge on the photocathode and are converted into electrons. The efficiency of this conversion is mc_{pe} where m is a factor between 0 and 1 depending on the degree of spectral matching between the scintillation spectral response of the photocathode. c_{pe} is the photoquantum efficiency of the window- cathode system.

The $\frac{E}{w_o}q_o mc_{pe}G$ (3.6)

electrons from the photocathode are collected with an efficiency g_e by the first dynode. The total number N of electrons arriving at the dynodes is thus given by: (Birks, 1964; Farai, 1989).

$$N=\frac{E}{w_o}q_o mc_{pe}g_e G \qquad (3.7)$$

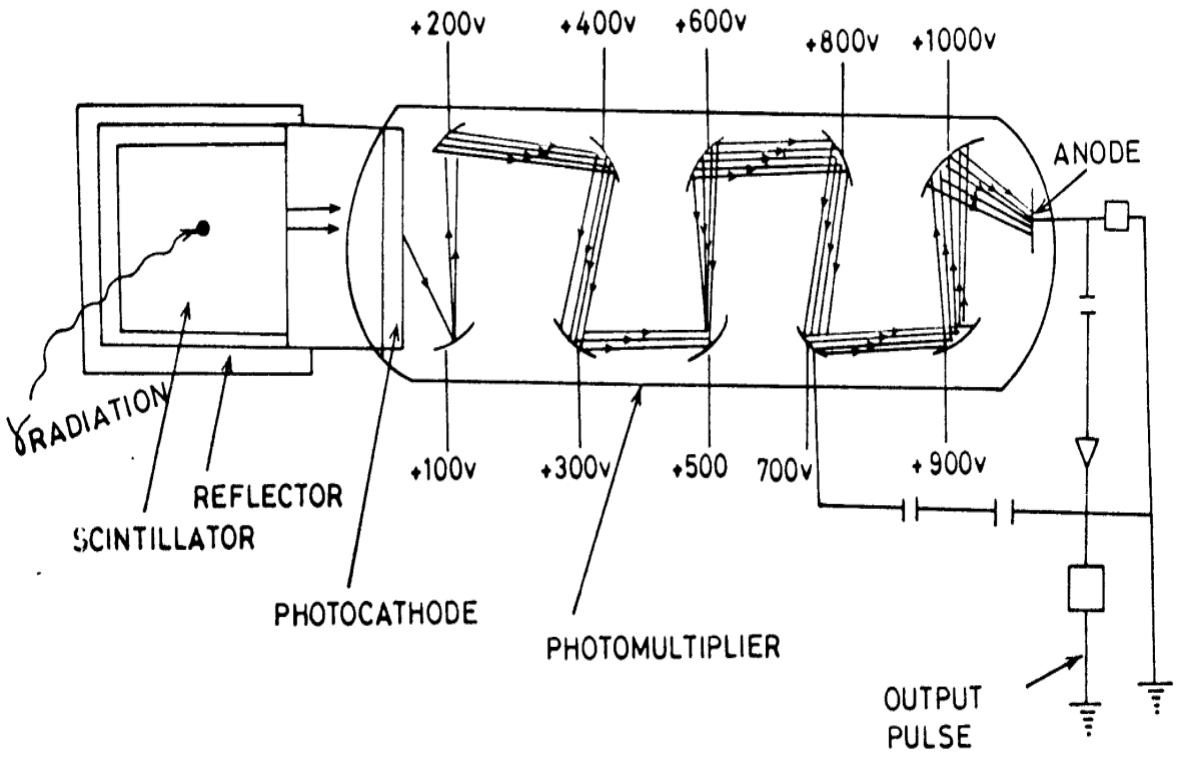

Fig 3.2: Schematic diagram of the sequence of events in the detection of gamma ray photon by a scintillation detector.

There are several factors affecting the efficiency above, G is determined by the self-absorption, reflection loses, light trapping, optical flaws and the optical geometry of the photocathode. The efficiency factor $mC_{pe}g_e$ depends in a complex manner on the wavelength and the point of incident of the light photons on the photocathode, c_{pe} is a function of the material and thickness of the photocathode while *ge* is a function of the structure and potential of the first dynode.

The N electrons given by equation (3.7) are multiplied at K successive dynodes which have an overall gain $M = \prod_{i}^{K} m_i$ (3.8)

where mi is the multiplication at the ith dynode.

m_i is roughly proportional to the voltage between the dynodes. The total number Q_o of electron at the last dynode collected at the anode is given by (Jibiri, 2000):

$$Q_o = M\frac{E}{w_o}q_o mc_{pe}g_e G \qquad \Rightarrow \quad Q_o = MN \tag{3.9}$$

Q_o is therefore a linear function of the energy E of initial incident photon. Apart from the number of the electrons given by equation (3.9), there are a number of electrons due to thermionic emisssion. The number n_T is a function of temperature as expressed by

$$n_T = AT^2 \exp(-\frac{Qe}{kT}) \tag{3.10}$$

Where T is the absolute temperature, e is the elctronic charge, k is the Boltzmann's constant, A and Q are the characteristics of the cathode material (Birks, 1964). These thermionic electrons are also multiplied in the photomultiplier tube (PMT) and constitute the dark current, the photomultiplier tube function is dependent on temperature. The dark current is the current produced in the photomultiplier in the absence of incident radiation. The pulses form part of the background of the energy spectrum. This may pose a significant problem when low energy radiation or weak source are being measured (Birks, 1964; Farai, 1989; Kamiyole, 2001).

3.2.2 Gamma Ray Spectrometer

Gamma ray spectrometer utilizes the direct proportionality between the energy of an incoming gamma ray and the pulse amplitude at the output of the detector. Figure 3.3 shows a block diagram of a gamma ray spectrometer. After amplification and digitisation, the pulse amplitudes are analysed, and the output of the spectrometer is an energy spectrum of detected radiation. Since individual radionuclides emit specific gamma ray energies, gamma ray spectra can be used to diagnose the source of the radiation.

Gamma ray spectrometers are either "integral" or "differential". Integral spectrometers record only those pulses with amplitudes exceeding a discrimination threshold. This threshold can be changed to allow the discrimination of individual radionuclides. Differential gamma ray spectrometers record pulses whose amplitudes fall within a given amplitude interval (or channel), corresponding to a discrete range of gamma ray energy. Wider energy intervals comprising several channels are called energy windows. Modern analyzers use as many as 256 or 512 channels, with a width of several keV per channel. Older systems are limited to recording several distinct energy windows.

Gamma ray spectrometers are built with amplitude gain stabilization to avoid the effect of energy spectrum drift. Gain stabilization can be accomplished by controlling the temperature of the detector, or by spectrum energy stabilization using either a reference radioactive source or the measured spectrum.

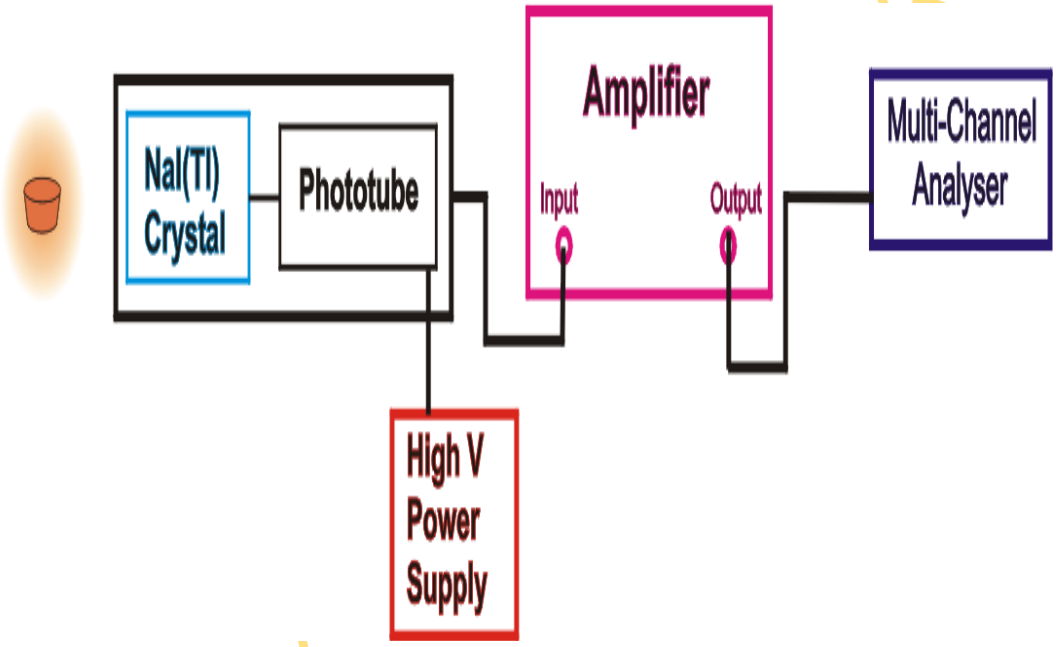

Fig. 3.3: Block diagram of a gamma ray spectrometer.

3.2.3 Stabilized High- Voltage Power Supply (HVPS)

This provides the charge collection voltage, that is the high voltage necessary for the working of the detectors and converts the alternating voltage provided by the mains into a direct voltage. There is little effect on the output pulse amplitude with changes in the high voltage. Many factors can cause instability in the HVPS, some of which are temperature change, line voltage variations, time , load and amount of current drawn by the detector. One needs to be careful to avoid increasing the current load above the output current rating of the HVSP (Knoll, 1989 ; Sorenson and Phelps, 1980) .

The HVPS Unit Canberra model 31060 NIM BIM that was used for this work provided protection features that included electronic short circuit protection on the regulated outputs (instant reset), thermal warming indicator and thermal cut out, and an ac line fuse . When approaching the design limit of the power supply, indicating lamp signals a heat sink temperature.

3.2.4 Preamplifier

The preamplifier is mounted directly on the detector as close as possible in order to reduce the attenuation of the output signal in a way that maximizes the electronic signal to noise ratio (S/N), hence amplifying the signal before additional noise or signal distortion can occur. The preamplifier is the first element in a signal – processing chain. The preamplifier converts the ionization charge developed in the detector during each absorbed nuclear event to a step function output pulse whose amplitude is proportional to the total charge accumulated in that particular event.

The amplifier used for this work is the Camberra model 2002, which has a gain in the range 100mV/MeV and 500mV/MeV respectively and the nominal voltage gain between test input and energy (or timing) output is 1 for 100mV/MeV and 5for 500mV/MeV respectively. Special circuits monitor both the temperature and the activity of the detector , when there is an improper operating condition , then they become warm. The fast rise time of this model 2002 is maintained over a wide range of detector capacitances, and this makes the amplifier a good choice for timing measurements.

3.2.5 Main Amplifier

The main amplifier that was used for this work is the Canberra model 2020. The principal functions of an amplifier in pulse analysis are mainly to expand the amplitude of pulse coming from the preamplifier (mV) into a range (Volts) of sufficient amplitude that can be measured with greater ease and accuracy to drive auxilliary equipment, and also to shape the pulse from the preamplifier like a Gaussian and to filter it to improve the signal- to noise ratio. It also prevents overlap. The amplifier must be non- overloading, which means that it must amplify equally well at high count rates as it does at low count rates.

The model used includes circuitry which automatically and continuously samples the amplifier output noise and count rate. It automatically sets the respective restorer threshold and rate with precision for optimumperformance. This model 2020 also inspects and sees if there are pile ups during the amplifier and ADC processing time, and permits the ADC to convert only those detector signals resulting from the single energy event.The six shaping time positions ranges from 0.25 to 6 µSeconds. It can be operated by unipolar or bipolar output.

3.2.6 Analog – to- Digital Converter (ADC)

The Analog – to – Digital Converter (ADC) derives a digital number that is proportional to the amplitude of the pulse presented at its input. The ADC that was used for this work is the canberra model 8075. This model has the performance characteristics of the speed of conversion, also, the linearity of conversion, and the resolution of the conversion. The conversion gain specifies the channel where the maximum voltage is stored.

The analog –to – digital converts the analog Gaussian pulse from the main amplifier to a digitized signal which is stored as an event in an appropriate memory channel. This is possible by allowing a capacitor to charge up to the peak voltage of the input pulse. The capacitor is then discharged using a constant current source. The time it takes for this discharge to occur is a direct measure of the input pulse voltage and this is found by counting the number of pulses generated by a high frequency of the oscillator.

3.2.7 Dead Time

When the ADC is perfoming, it carries out a conversion on an individual pulse, the instrument will not be able to accept other pulses which is contributed to the dead time of the instument. Dead time refers to the finite time required for a detector to process an individual particle of radiation. During this time, all incoming pulses are ignored. Dead time should thus be as small as possible. Therefore, the dead time resulted from the fact that pulses can not undergo more than one operation at a time. The dead time is eventually the difference betweeen the real counting time and the live time for which the system was able to process pulses, and the dead time is expressed in percentage thus:

$$\text{Dead Time} = \left(\frac{\text{Real Time} - \text{Live Time}}{\text{Real Time}}\right) x \quad 100 \qquad (3.11)$$

The dead time is corrected for by extending the real time by an appropriate amount to account for the losses (Alatise, 2007).

This is done electronically by measuring the live time of a spectrum using a clock which is gated with the busy signal from the ADC (and the main amplifier). Each time the busy signal goes high, the clock is stopped (dead time incurred due to pulse pile –up, conversion or memory cycle). The clock restarts when the busy signal resets to low.

In this manner, the total time for counting the spectrum, represents the total time which the electronics used to process the pulses. If the activity of the sample is high, the dead time may be high. The reference material was more active than the field samples and the counting geometry ensured that there was no dead time problem with the counting of the reference material, hence, none with the sediment samples as well.

3.2.8 Multi channel Analyzer

The operation of the Multichannel analyzer (Canberra series 100), is basically based on the principle of converting analog to digital number. The heart of the MCA is an analog – to digital – converter (ADC), which measures and sorts out the incoming pulses according to their amplitudes (Pascal, 2006). The output is then stored in the computer-type memory, which has many addressable locations and the number of channels into which the recorded spectrum can be divided; each channel is capable of storing up to 10^5 – 10^6 counts per seconds. Input gate blocks pulses from reaching ADC while busy. A logic signal level

inform the gate of the state of readiness of the ADC, resulting in dead time during which input pulse is lost. The contents of the memory after a measurement can be recorded or displayed as a graphical representation of the height spectrum (Knoll, 1989; Pascal, 2006).

3.3 Gamma -Ray Spectrometer Used In This Work

The detector system and the electronic system used in this work is shown in Figure 3.4. The counting system used in the determination of natural radionuclide concentrations of the sediment samples consists of a scintillation detector and a multichannel spectroscopic analyzer (Canberra series 100), connected to a computer system. The detector used is a Thallium-activated sodium iodide NaI(Tl) crystals Bircom (Model no. 3142). This detector was surrounded by a cylindrical shield consisting of lead with thickness 5 cm, which provided an efficient suppression of background gamma radiation present at the laboratory site. NaI(Tl) detectors are hygroscopic but has two principal advantages: It can be produced in large crystals, yielding high efficiency, and it produces intense bursts of light compared to other spectroscopic scintillators. It is also rugged, inexpensive, and they require no detector cooling. It is also convenient to use, making it popular for field applications such as the identification of unknown materials for law enforcement purposes.

This detector is interfaced with the electronic system through coaxial cable. In the process of detecting radiation, the radiation detectors produce electrical signals and these signals are processed through the processes of amplification, shaping and analysis (Singnu, 1981; Alatise, 2007). From the detector, electrical signals are passed to the preamplifier (model no. 2002) and in the preamplifier, preliminary shaping and amplification occurs. Next is the main amplifier, (model 2020) where the final shaping and amplification take place. The signals, leaving the main amplifier goes to the analogue – to – digital converter (model no. 8075), where the signals are converted from analogue to digital. The multichannel analyser (MCA), (Canberra series 100) is the next component of the spectrometer where detected pulses are sorted and stored. The MCA accumulates gamma spectrum as a histogram of the numbers of the detected events as a function of photon energy, and the monitor displays the spectra obtained. Gamma-rays spectrometers are selected to take advantage of several performance characteristics. Prominent among these characteristics are the detection efficiency and detector energy resolution (Jibiri et al., 1999) .

Fig. 3.4: The set up of the gamma ray spectrometer used for this work.

3.3.1 Detection Efficiency

The efficiency of a detector is a measure of the probability that an incident photon will be absorbed in the detector. It is usually quoted as the ratio of recorded counts to incident photons. Not all gamma rays that are emitted by the source and pass through the detector will produce a count in the system, the probability that an emitted gamma ray will interact with the detector and produce a count is a measure of the detector efficiency. Detector efficiency therefore can be defined as the percentage of the number of counts under the spectrum to the actual number of particles emitted by the source for a given time interval. Several factors such as volume and shape of the detector crystal, the absorption cross section in the crystal, the dimensions of the source and the distance and position from the source to the detector (also known as source-detector geometry) determine the efficiency of the detector (Deberting and Helmer, 1988, Perez- Andujar and Pibida, 2004, Isinkaye, 2010). Detector efficiency is usually measured by using a gamma spectrum of a source of known activity, and comparing the count rates in each peak to the count rates expected from the known intensities of each gamma ray (Isinkaye, 2010).

3.3.2 The Energy Resolution of a detector

The energy resolution of a detector is a measure of its ability to distinguish between two gamma rays of only slightly different energies. This is usually defined as the full width of a photopeak at half the maximum amplitude (FWHM) divided by its energy corresponding to the highest point in the photopeak of a reference radioisotope expressed as a percentage, Figure 3.5. If the full width at half-maximum amplitude is ΔE, then the energy resolution at E is given as (Cember,1989).

$$R = \frac{\Delta E}{E} x100\% \qquad (3.12)$$

The smaller the energy spread ΔE, the better the ability of a detector to separate full energy peaks that are close together. The resolution of a detector is a function of energy. The intensity of the gamma ray together with the efficiency of the detector determines the area of the photopeak while the horizontal position of the peak is determined by the energy of the gamma ray (Jibiri et al., 1999). Figure (3.6) shows a typical gamma ray spectrum which shows the positions of the energy windows for a NaI(Tl) detector.

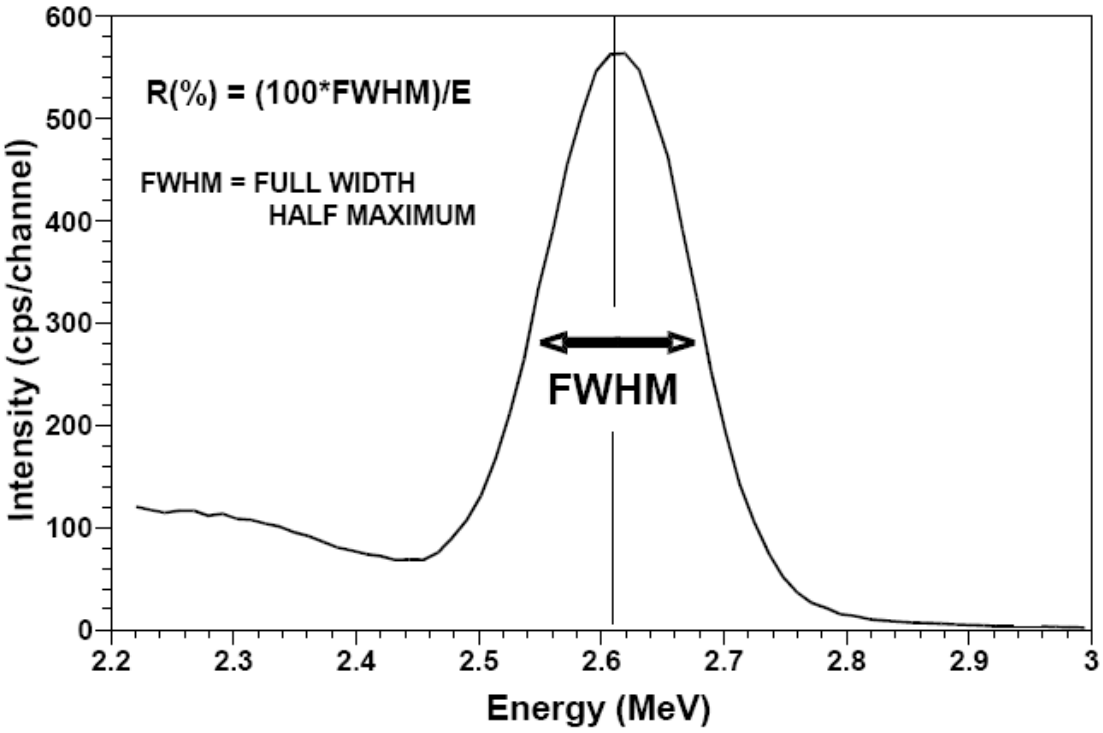

Fig. 3.5: The energy resolution of a gamma ray spectrometer (IAEA, 2003).

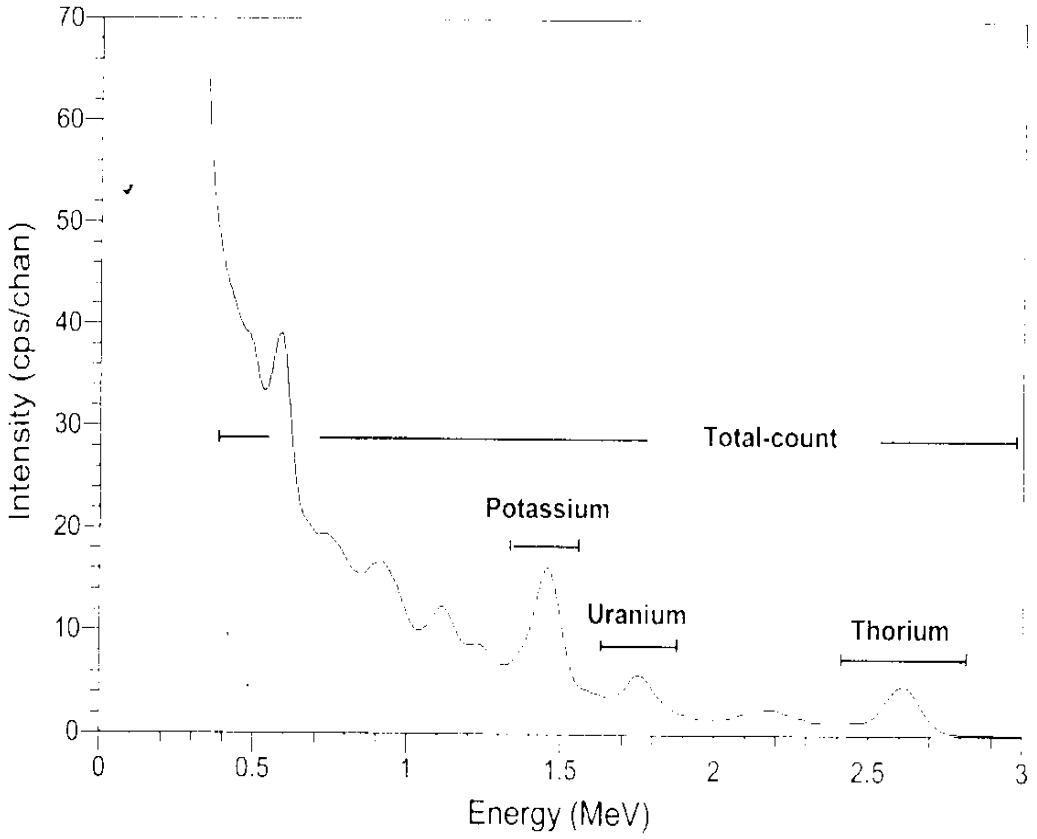

Fig. 3.6: A typical gamma ray spectrum showing the positions of the energy windows for a NaI(Tl) detector (Isikaye, 2010).

NaI(Tl) detector has poor (low) energy resolution compared with the resolution of other detectors like the hyper pure germanium (HpGe) or the lithium drifted germanium (Ge(Li)). The detector system used in this work has a resolution of 8% Full Width at Half Maximum (FWHM) at ^{137}Cs energy of 0.662 MeV. This was good enough to distinguish the gamma-ray energies of interest in the present study.

3.4 Counting Statistics (Statistical Nature of Radioactive Decay)

Radioactive decay is a statistical phenomenon. Each atomic disintegration during radioactive decay occurs completely independently of every other decay event, and the time interval between disintegrations is not constant. For a large number of randomly disintegrating atoms of a particular radionuclide, the frequency of radioactive decay is given by Poisson's distribution. If $\bar{n}$ is the mean decay rate, the probability, *P*, that the number of atomic nuclei, *n*, will decay within a time unit is (kamiyole, 2001):

$$P(n)=(\bar{n}^{n})/ n! \exp(-\bar{n}) \quad (3.13)$$

For Poisson's distribution it holds that the variance σ^2 of a distribution is equal to its mean value, and σ is the standard deviation. The range of ±1σ about the mean encompasses 68.3 percent of the distribution, ± 2σ encompasses 95.5 percent of the distribution, and ±3σ encompasses 99.7 percent of the distribution(IAEA) (2003).

The emission of particles and gamma rays in radioactive decay is proportional to the number of disintegrating atoms, and the standard deviation may be used to estimate the range of deviations and errors of the radiometric measurements.

If *N* counts are recorded in time *t*, then

the standard deviation of the recorded counts is:

$$\sigma(N) = \sqrt{(\bar{N})} \quad (3.14)$$

where $\bar{N}$ is the mathematical expectation of the number of counts (the mean count of repeated measurements). The fractional standard deviation of a count (error of measurement of *N*) is:

$$\frac{\sigma(N)}{\bar{N}} = \frac{1}{\sqrt{N}} \quad (3.15)$$

For a count rate $n = N/t$ (c/s), the standard deviation is given by

$$\sigma(n) = \frac{\sqrt{N}}{t} = \sqrt{(n/t)} \quad (3.16)$$

and the fractional standard deviation of the count rate n (error of measurement of n) is:

$$\frac{\sigma(n)}{n} = \frac{1}{\sqrt{nt}} \qquad (3.17)$$

The probable deviation ($P = 0.5$) is 0.674 σ, a multiple of standard deviation. Equations (3.15) and (3.17) indicate that the precision of radiometric measurements can be increased by (a) increasing the counts, N, (b) increasing the count rate, n, and (c) increasing the counting time, t. This can be accomplished by the use of more sensitive equipment, improving the geometry of measurement, or extending the counting time. In practice, errors are also affected by background radiation. The background radiation is kept to a minimum by shielding the detector.

CHAPTER FOUR

EXPERIMENTAL TECHNIQUES AND RADIOACTIVITY MEASUREMENTS

4.1 Calibration of The Gamma -Ray Detector system

The calibration of the detector is a very important aspect of gamma –ray spectroscopy for radioactivity measurements.This is to ensure that the gamma ray spectra are accurately interpreted in terms of energy and specific activity. An essential requirement for the measurement of gamma emitters is the exact identity of photopeaks present in a spectrum produced by the detector system. The procedure for identifying the radionuclides within a spectrum relies upon methods which match the energies of the principal gamma- rays emitted by known radionuclides. This requires accurate energy calibration for the NaI(Tl) detector system so that correct energies be assigned to the centroid of each full- energy- peak (FEP) in a sample spectrum.

4.1.1 Energy Calibration

The energy calibration was done in order to obtain a relationship between peak position in the spectrum and the corresponding gamma- ray energy. The height of each pulse output from a photomultiplier tube and hence the channel corresponding to it is directly proportional to the initial gamma energy producing the pulse. The calibration process involved using different gamma emitter sources of known energies, these include cesium-137 (661.66 kev), cobalt-57 (122.00 κeV), Sodium-22 (1274.51keV), Manganese-54 (834.83 keV), and Cadium-109 (88.03 keV) from International Atomic Energy Agency (IAEA 375) model 2000, in Austria. The gamma emitter sources were exposed to the NaI(Tl) detector and gamma spectrum was acquired under suitably long counting time. The channel numbers corresponding to the gamma energies of the radionuclides are given in Table 4.1. Using the data in Table 4.1, the energy- channel number calibration graph, (Figure 4.1) was drawn and the points fit a linear equation given by:

$$E(keV) = 0.4904n + 3.8646 \qquad (4.1)$$

Where n is the channel number. Equation (4.1) was stored in the memory of the multichannel analyser system, and it remained operational settings of the system throughout the experiment so that the channel numbers are read in keV unit of energy, in order that the

Table 4.1: Energy (keV) – Channel number calibration

Source	Energy (keV)	Channel number
Cd-109	88.03	170
Co-57	122.00	241
Cs-137	661.66	1343
Mn-54	834.83	1696
Na-22	1274.51	2589

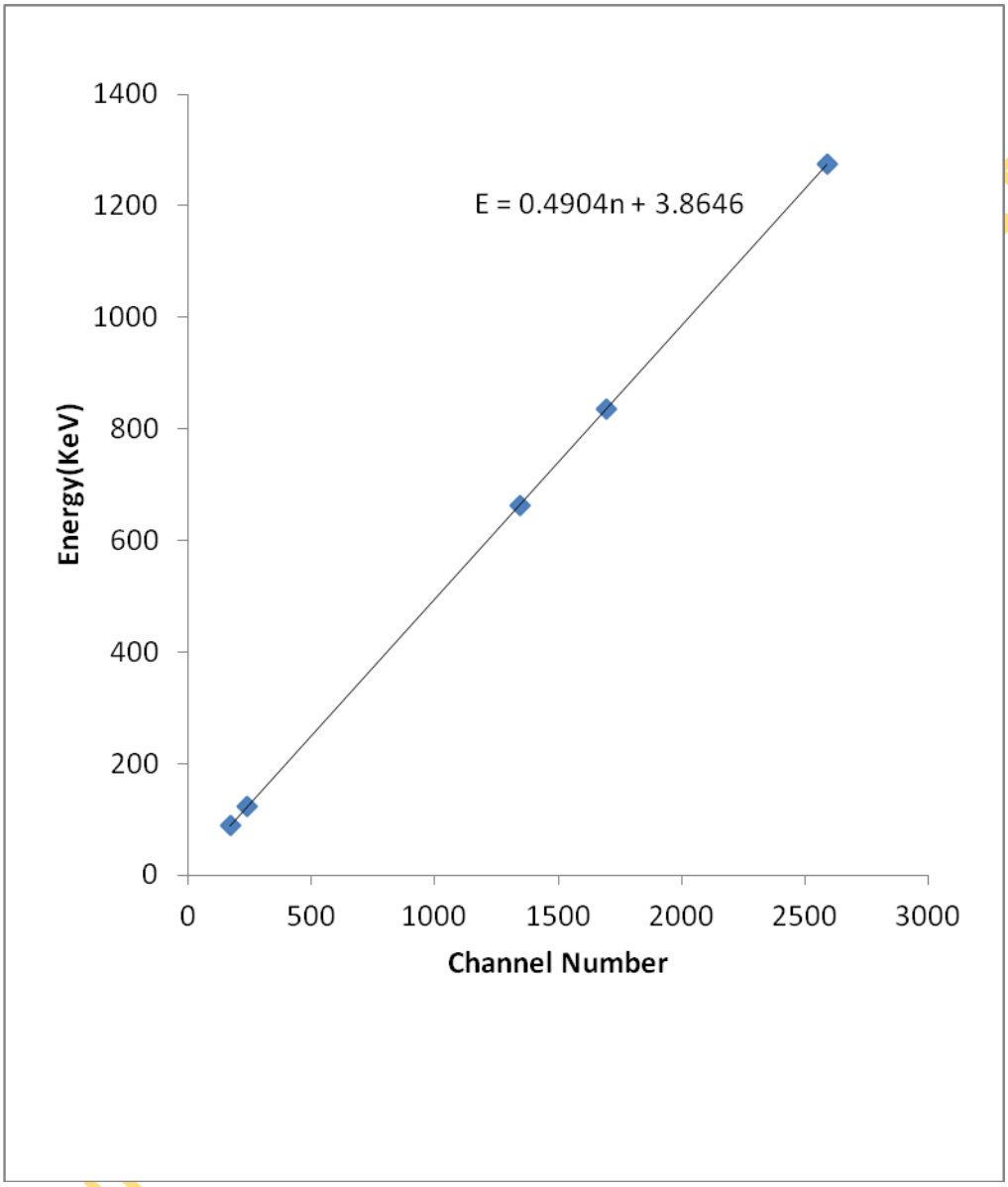

Figure 4.1 Energy (keV) – Channel Number Calibration Curve

various radionuclides present in the sediment samples can be identified by the gamma energies they emit.

4.1.2 Efficiency Calibration

In gamma –spectrometry, the peak area in the spectrum is related to the amount of radioactivity it represents. This requires the absolute full- energy peak efficiency. This gives a relationship between the peak area and the number of gamma rays emitted by the source. The efficiency was determined for the energy range of 0.352–2.62 MeV by counting the certified reference sediment sample (IAEA-375) from International Atomic Energy Agency (IAEA), in Austria. It was ensured that the calibration standard reference sample represented the sediment samples to be counted i.e calibration standard and samples to be counted are identical in size, shape, density, spartial distribution of material etc, and was counted for 10 hrs under the same condition as the sediment samples. The sample counting configuration (geometry) of the container whose dimensions suit well with the dimensions of the detector and lead shield was used in determining the efficiency calibration. The detection efficiency was determined for each of the gamma energies under consideration in this study and their values are listed in Table 4.2. The depedence of the detection efficiency on the gamma ray energy is shown in Figure 4.2. The reference sediment sample must depend on the geometrical arrangement of the source and the detector. The specific activity of dried mass of a radionuclide in the sediment samples was related to the detection efficiency and other quantities by equations 4.2 and 4.3 (Jibiri and Emelue, 2009).

$$C(Bq/kg) = KC_n \tag{4.2}$$

$$K = \frac{1}{P_\gamma M \varepsilon_P} \tag{4.3}$$

Where C = the specific activity concentrations of nuclide n in Bq/kg of dried mass.

C_n = Count rate (cps), of nuclide n of the sediment

ε_P = efficiency of the detector for radionuclide n

M = dried mass of the sediment sample used for measurement (kg).

P_γ = gamma emission probability

Table 4.2: The Radionuclide energy and Detection Efficiency

Radionuclides	Energy(MeV)	Detection Efficiency (CPS/Bq)
Tl-208	2.615	0.0046
Bi-214	1.765	0.011
K -40	1.461	0.013
Bi- 214	1.12	0.018
Tl -208	0.911	0.024
Bi-214	0.609	0.046
Tl-208	0.583	0.048
Pb-214	0.352	0.090

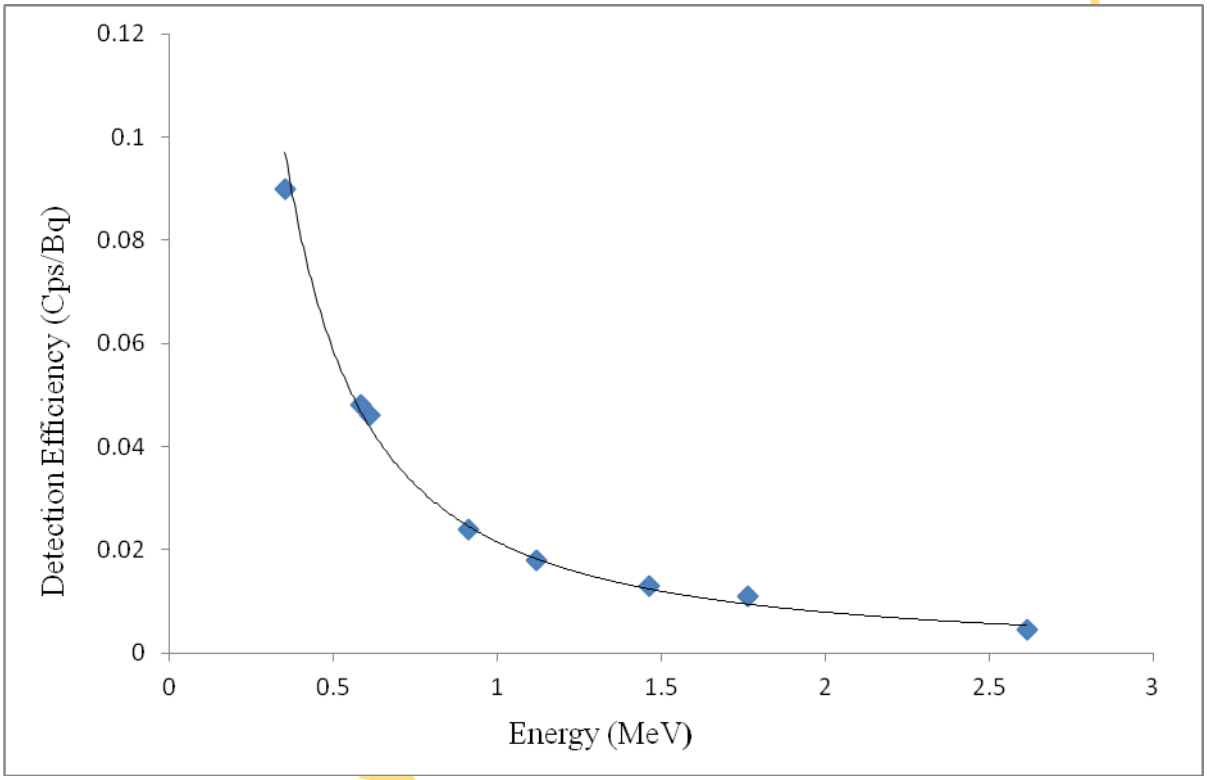

Fig 4.2: Detection efficiency curve of the detector

4.2 Sample Collection

The Ogun river flows southwards covering a distance of approximately 400 km, traversing through three states in South western Nigeria. For the ease of sampling to cover the long stretch course of the river and analysis, the river course was divided into three: Upper, Middle and Lower regions (Figure 4.3). Sediment samples were collected at each sampling point at approximately 500–700mm from the river banks in the dry season around January through late April, 2007. The surface sediment (0–50mm depth) was collected (Golterman et al., 1983; Keith, 1991) and packed in a nylon bagmade of non-radioactive material, sealed and labeled to avoid contaminations. A total of 320 sediment samples were collected in this study. It is composed of 10 sediment samples from each of the 32 sampling locations along the entire course of the river. The distance between each location was about 300–500m depending on local terrain and accessibility. The map showing the locations where the sediment samples were collected along the course of the river is shown in Figure 4.3. The location of each sampling point was taken by means of a Global Positioning System.

4.3 Dectection Limit

The detection capability of a measuring system under certain conditions is expressed in terms of the detection limit. The detection limit (DL) of a measuring system describes its operating capability without the influence of the sample. It is a minimum response which can be obtained with the instrument and it depends on the sample matrix, the background count, the acquisition time and the detection efficiency of the measuring system (Rybach, 1988). The lower limit of detection (LLD) given in Bq/kg, which is required to estimate the minimum detectable activity in a sample was obtained using the Equation (4.4) (Pascal, 2006 ;Volchock and De planque, 1983; Jibiri and Emelue, 2009):

$$LLD(Bq/kg) = 4.65\frac{\sqrt{C_b}}{t_b}K \qquad (4.4)$$

where C_b is the background count in the corresponding peak, t_b is the background counting time (s) and K is the factor that converts counts per second (cps) to activity concentration (Bq/kg) as given in Equation (4.2). With the measurement system used in this work, detection limits obtained were 17.3 Bq/kg, 4.2 Bq/kg and 5.1 Bq/ kg for ^{40}K, ^{226}Ra and ^{232}Th, respectively. Values below these numbers were taken in this work as being below the lower

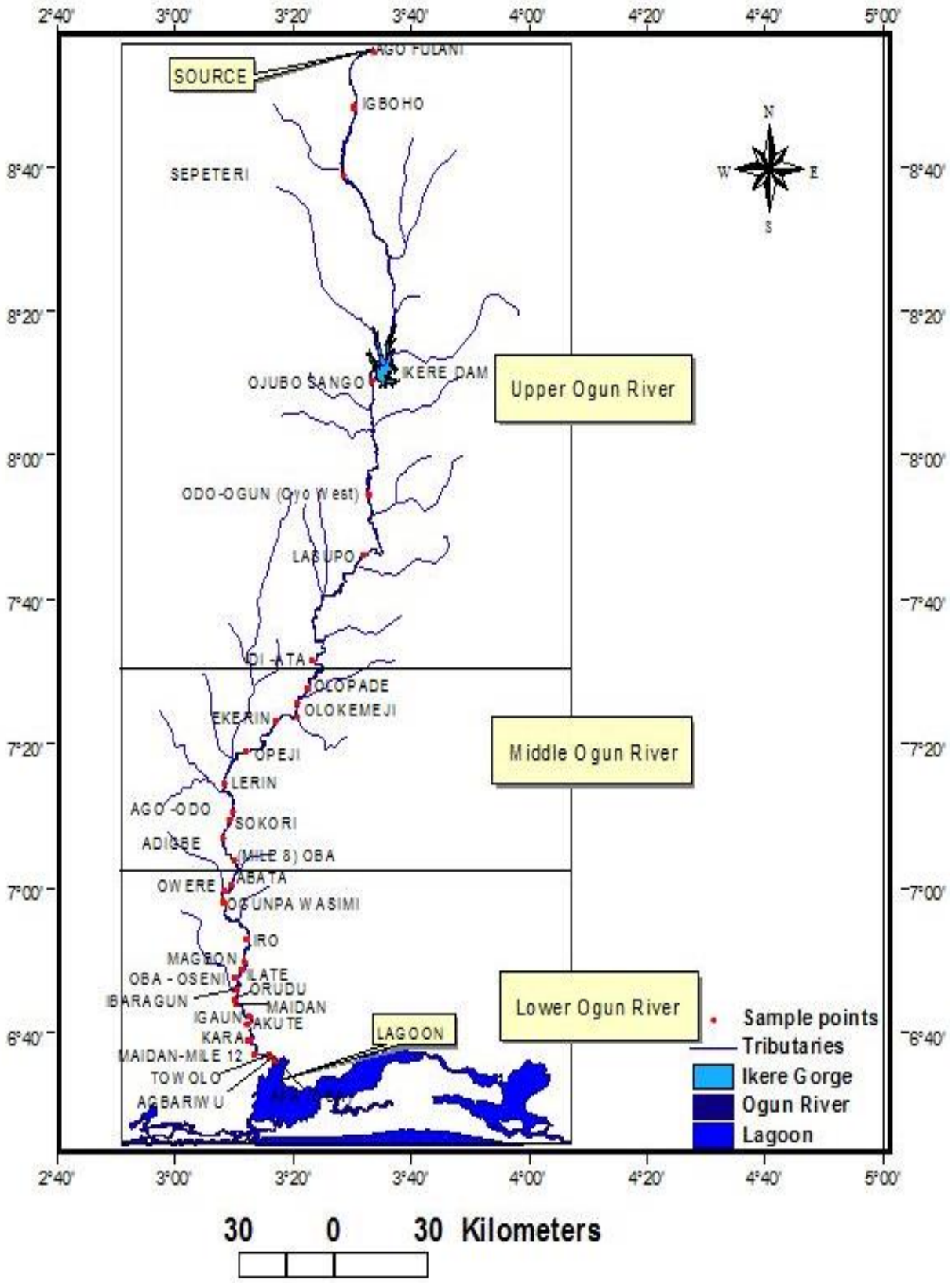

Fig. 4.3: Locations Where Sediment Samples Were Collected

limit of detection (BDL) of the detector.

4.4 Sample Preparations

The sediment samples were air dried, pulverized/crushed and made to pass through a 2 mm mesh sieve. About 250g of the dried, pulverised and sieved sediment samples were transferred into plastic containers of uniform sizes. To avoid distribution of the gamma radiation emitting decay products in the gas room on top of the sample masses, the sample counting containers of uniform size (60 mm height x 65 mm diameter) were filled up almost totally (filling height 60 mm). With this filling height the sample masses after corrections were approximately 250 g corresponding to the sample size limit capacity of the detector. The samples were sealed and left to cure for a period of about 30 days. This was done in order to allow for secular equilibrium between ^{226}Ra and the progenies of ^{222}Rn prior to gamma spectroscopy (Prakash et al., 2007). The reference sediment sample was also transferred to a container of the same material and dimensions as were used for the sediment samples from the river. This was to ensure the same geometry configuration. The variations in the effective sample density caused by this are seen not to affect the activity results within the experimental error of the measurement technique employed in this work. Differences between the effective atomic numbers in the chemical composition of the sediments and the standard samples would not affect the results since the mass attenuation co-efficient does not depend on the atomic number in the energy range under consideration to a very good approximation up to an atomic number of 40 (Zr) (Pfister et al., 1976). Thus self absorption correction could be neglected. From the relative photon emission intensities and from the full energy peak efficiencies, the activities of the gamma emitting decay products could be calculated, which equal the activities of the parent nuclides under the conditions of radioactive equilibrium. The standard reference sample used was IAEA-375 of mass 0.25 kg obtained from International Atomic Energy Agency's Laboratories in Austria.

4.5 Measurement of Activity Concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the Sediment Samples

NaI(TI) Scintillation, Bicron (Model no. 3142) detector was used to determine the concentrations of the primordial radionuclides (^{226}Ra, ^{232}Th and ^{40}K) in the sediments

samples following the calibration procedures and the use of the International Atomic Energy Agency (IAEA) Standard discussed in section 4.1. The choice of the gamma-ray energies of the radionuclides to be detected as a reference was made considering the fact that the NaI(TI) detector used in this study had a modest energy resolution. Hence, the photons emitted by them would be sufficiently discriminated if their emission probability and their energy were high enough and the surrounding background continuum low enough. Therefore, the activity concentration of ^{214}Bi (determined from its 1.760 MeV γ-ray peak) was chosen to provide an estimate of ^{226}Ra in the sediment samples, while that of the daughter radionuclide ^{208}TI (determined from its 2.615 MeV γ-ray peak) was chosen as an indicator of ^{232}Th. Potassium-40 was determined by measuring the 1.460 MeV γ-rays emitted during its decay. These transition gamma-ray peaks of the higher energies chosen for the determination of concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the sediments were sufficiently separated such that the contribution of background continuum in their peak areas determination was very low. However, the percentage contribution of the background to the peak area determination was not determined in this study but was considered very low since the peaks were sufficiently separated from each other and with very low continuum. Though the lower energy transition gamma-ray lines such as ^{214}Bi (609 keV) and ^{214}Pb (351 keV) have high emission probabilities 0.461 and 0.376 respectively, but choosing them would introduce higher uncertainties in the peak area determination of the radionucildes considering the poor resolution of the detector (about 8% at 0.662 MeV of ^{137}Cs) used in this study and the MCA employed in the spectral analysis does not possess the requisite software.

In order to determine the background counts in the environment around the detector, an empty container having the same geometry as the samples' containers was counted for 10 hrs. The spectra of the background count was subtracted from each of the counts of the samples. The samples were also placed symmetrically on top of the detector and measured for a counting period of 10 hrs. The net area under the corresponding peaks in the energy spectrum was computed by subtracting counts due to Compton scattering of higher peaks and other background sources from the total area of the peaks.

Measurement of each sample was repeated three times and the mean net area was determined. The overall experimental error of the results caused by statistical counting error, area determination, calibration etc, was generally less than ±10%. From the net area, the

activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in the 320 samples were determined using computer programme following equation (4.2) (Jibiri and Emelue, 2009).

4.6 Grain Size And Heavy Mineral Analysis of The Sediments

For completeness of this study, it was necessary to determine some physicsl properties of the sediments through the grain –size analysis and also the distribution of the basic mineral compositions and heavy minerals (opaque and non- opaque) in the sediments. These are briefly described below.

4.6.1 Grain- Size Analysis

Grain size analysis was carried out on the 32 representative sediment samples. The analysis was carried out at the sedimentological laboratory of the Department of Geology, University of Ibadan. The analysis was aimed at measuring the individual grain sizes of the sediment samples. The samples were dried and the mechanical sieving method using a Ro-tap shaker was chosen for the analysis. About 100g of each sample was disaggregated using a porcelain mortar and pestle. The disaggregated samples were thoroughly mixed and split into quarters. This was weighed in a meter balance (P20 model) of a precision 0.011g. Then each sample was poured into a set of US mesh sieves comprising of 2.00, 1.18, 0.85, 0.60, 0.425, 0.30, 0.25, 0.15, 0.075 and 0.063 mm and a receiving pan. The fraction retained in each sieve and the pan was weighed in a balance and its weight recorded and tabulated. The percentage aggregate was visually estimated and expressed in percentage.

The individual weight percentage was calculated and also the cumulative weight percentage. The grain size (in phi) was then plotted on the abscissa while the individual sample weight (in %) was plotted on the ordinate, thus forming a pictorial chart showing grain size distribution (histogram) and frequency curve for each sample. The cumulative frequency curve is plotted on a probability graph paper by plotting the grain size (in phi scale). The phi values of the following percentile; 5%, 16%, 25%, 50%, 75%, 84% and 95% were read off from the ogive curve. These were used to calculate the statistical parameters of standard deviation, skewness, kurtosis, mean and median as shown below following Folk and Ward (1957).

Graphic mean (M_Z) is given by:

$$M_Z = \frac{\phi(16+50+84)}{3} \qquad (4.5)$$

(ϕ = grain size corresponding to each percentile)

Inclusive graphic standard deviation (Sorting, S_D) is given by:

$$S_D = \frac{\phi(84-16)}{4} + \frac{\phi(95-5)}{6.6} \qquad (4.6)$$

Where	< ϕ 0.35	indicates	Very well sorted
	ϕ 0.35 to ϕ 0.5	,,	Well sorted
	ϕ 0.50 to ϕ 0.71	,,	Moderately well sorted
	ϕ 0.71 to ϕ 1.0	,,	Moderately sorted
	ϕ 1.0 to ϕ 2.0	,,	Poorly sorted
	ϕ 2.0 to ϕ 4.0	,,	Very poorly sorted
	> ϕ 4.0	,,	Extremely poorly sorted

Inclusive graphic skewness (S_K) is given by:

$$S_K = \frac{\phi 16 + \phi 84 - 2\phi 50}{2(\phi 84 - \phi 16)} + \frac{\phi 5 + \phi 95 - 2\phi 50}{2(\phi 95 - \phi 5)} \qquad (4.7)$$

Where	ϕ 1.0 to ϕ 0.3	indicates	Very fine skewed
	ϕ 0.3 to ϕ 0.1	,,	Fine skewed
	ϕ 0.1 to ϕ -0.1	,,	Near symmetrical
	ϕ -0.1 to ϕ -0.3	,,	Coarse-skewed
	ϕ -0.3 to ϕ -1.0	,,	Very coarse skewed

Graphic Kurtosis (K_G) is given by:

$$K_G = \frac{\phi 95 - \phi 5}{2.44(\phi 75 - \phi 25)} \qquad (4.8)$$

Where	< ϕ 0.67	indicates	Very Platykurtic
	ϕ 0.67 to ϕ 0.90	,,	Platykurtic

ϕ 0.90 to ϕ 1.11	,,	Mesokurtic
ϕ 1.11 to ϕ 1.50	,,	Leptokurtic
ϕ 1.50 to ϕ 3.00	,,	Very leptokurtic
> ϕ 3.00	,,	Extremely leptokurtic.

4.6.2 Heavy Mineral Determination

The heavy minerals analysis was carried out on the 32 representative sediment samples. The heavy minerals in sediments are defined by a lower limit of specific gravity, 2.85g/cm^3, which corresponds to that of a common separating fluid-bromoform. Thirty –two representative sediment samples were analyzed for the purpose of having a uniform size range. The samples were seperated by the specific gravity method, where 5g of each sample was poured into the bromoform in a separating funnel, stirred vigorously and allowed to settle gravitationally. The settled minerals were then flushed out through the separating funnel tap into another funnel lined with filter paper.

The resulting filtrates (heavy minerals) were then treated with dilute hydrochloric acid and acetone (CH_3OCH_3) to remove carbonate clay or iron oxide coating. After being oven dried, the heavy minerals were mounted on micro-glass slides with Canada balsam. The slides were later examined under a petrographic microscope using transmitted light to observe the minerals. Each mineral type was identified based on such optical characteristics as colour, pleochroism, absorption, relief, extinction and birefringence, size, crystal form, elongation, inclusions, cleavage and twinning. The opaque were further examined under reflecting light. This analysis was carried out at the Geochemical Laboratory, Department of Geology, University of Ibadan, Nigeria.

4.6.3 Petrographic Analysis of The Sediments

Thin sections were made for the 32 representative sediment samples selected from the study area. The loose (poorly consolidated) to fairly indurated samples used were first impregnated with Lakeside 70W and Canada balsam heated in a hot flame for a period of 30 minutes. After impregnation, the samples now hardened and were cut into small slides of about 1cm thickness. They were smoothened with carbonrundum 90 grits to remove saw marks from the surface. This was followed by the carbonrundum 400 grits to smoothen the

surface before displaying on hot plates. The samples were then molted on glass slides with aradite and pressed together to remove air bubbles using forcept.

After solidification, molted samples were allowed to cool at room temperature before reduction to 3mm - 4mm by Logitech machine (a kind of thin section microcutter machine). This was followed by grinding and smoothening with carbonrundum 400, 600 and 800 grits with occasional checking under the microscope till thinning get to 0.03mm thickness. The slides were then washed with water and allowed to dry before covering with a cover slip and label led in preparation for petrographic studies. Optical characteristics of various minerals in the slide were employed in their identification. This analysis was done at the Thin Section of the Department of Geology, University of Ibadan, Nigeria.

CHAPTER FIVE

RESULTS

5.1 Activity Concentrations of ^{40}K, ^{226}Ra and ^{232}Th in the Upper, Middle And Lower Regions of Ogun River..

The range and the mean of the activity concentrations of a particular radionuclide in the upper, middle and lower region of the river are presented in Tables 5.1, 5.2 and 5.3 respectively and appendix I shows the activity concentrations of each radionuclides for 10 typical sites in the 32 locations.

5.2.1 Radium Equivalent Activity (Bq/kg) of Ogun River Sediments

Distribution of ^{40}K, ^{226}Ra and ^{232}Th in the environment is not uniform, so with respect to exposure to radiation, the radioactivity has been defined in terms of Radium equivalent activity (Ra_{eq}) in Bq/kg to compare the specific activity of materials containing different amounts of ^{40}K, ^{226}Ra and ^{232}Th (Beretka and Mathew, 1985). The radium equivalent activity (Ra_{eq}) can be used as a common index to compare the specific activities of the sediment samples. It is the radium equivalent that gives the useful guideline in the regulation of the safety standards on radiation protection for the general public. It is the sum of the weighted activities of ^{40}K, ^{226}Ra and ^{232}Th based on the estimation that 10 Bq/kg of ^{226}Ra, 7 Bq/kg of ^{232}Th and 130Bq/kg of ^{40}K will deliver an equal or same gamma dose rate (Tufail et al., 2007; Ademola, 2008a-b; shiva Prasad et al., 2008; Jibiri et al., 2009). Using equation (5.1), the equivalent activity of the samples were calculated:

$$Ra_{eq}(Bq/kg) = C_{Ra} + 1.43C_{Th} + 0.077C_K \qquad (5.1)$$

Where C_{Ra}, C_{Th} and C_K are specific activity concentration in Bq/kg of ^{40}K, ^{226}Ra and ^{232}Th, respectively.

The range and mean were presented in Tables 5.4, 5.5 and 5.6 for the upper, middle and lower regions respectively.

Table 5.1: The range and mean of the activity concentrations of the radionuclides (^{40}K, ^{226}Ra and ^{232}Th) in the upper region of Ogun river

		^{40}K (Bq/kg)		**^{226}Ra (Bq/kg)**		**^{232}Th (Bq/kg)**	
S/N	**Locations**	Range	Mean	Range	Mean	Range	Mean
1	IGBOHO	186.6 -694.9	581.9 ± 24.1	5.9 -9.0	10.3 ± 3.2	2.85-13.4	8.6 ± 2.9
2	SEPETERI	447.1 -692.9	565.2 ± 23.8	3.6 -16.7	11.7 ± 3.4	2.8 - 12.8	9.1 ± 3.0
3	OJUBO SANGO	431.6 -564.7	510.2 ± 22.6	7.1- 15.0	10.6 ±3.3	6.3 - 12.7	9.6 ± 3.1
4	ODO -OGUN (OYO WEST)	458.5 -624.7	507.6 ± 22.5	8.7 - 20.4	13.9 ± 3.8	7.0 - 13.8	9.8 ± 3.1
5	LASUPO	239.7 -732.2	504.9 ± 22.5	8.9 - 18.2	14.1 ± 3.8	3.3 - 12.6	9.6 ± 3.1
6	IDI –ATA	358.5 -539.0	445.8 ± 21.1	3.2 - 16.5	11.2 ± 3.4	3.8 - 13.2	8.3 ± 2.9
	Weighted Mean		**519.3 ± 48.7**		**11.96 ± 1.7**		**9.2 ± 0.6**

Table 5.2: The range and mean of the activity concentrations of radionuclides (^{40}K, ^{226}Ra and ^{232}Th) in the middle region of Ogun river.

		^{40}K (Bq/kg)		**^{226}Ra (Bq/kg)**		**^{232}Th (Bq/kg)**	
S/N	**Locations**	Range	Mean	Range	Mean	Range	Mean
1	OLOPADE	261.4 -783.7	370.97 ± 19.3	4.4 -24.3	14.9 ± 3.9	2.6 - 16.3	7.9 ± 2.8
2	OLOKEMEJI	347.7 - 553.8	460.6± 21.5	1.0 - 23.4	9.2 ± 3.0	BDL - 12.6	7.5 ± 2.7
3	EKERIN	321.3 - 706.5	494.7 ± 22.2	BDL - 20.3	5.6 ± 2.4	BDL - 20.5	8.0± 2.8
4	OPEJI	348.0 - 521.2	431.97 ± 20.8	3.2- 20.9	12.8 ± 3.6	BDL - 9.5	6.5 ± 2.5
5	LERIN	521.1 - 629.3	562.2 ± 23.7	3.7 - 15.1	10.3 ± 3.2	3.6 - 14.4	8.8 ±3 .0
6	AGO ODO	344.8 -694.5	536.3 ± 23.2	6.6 - 24.6	10.7 ± 3.4	4.7 - 17.6	8.9 ±3.0
7	SOKORI	214.2 -602. 8	446.8 ± 21.1	14.7 - 27.2	20.4 ± 4.5	13.9 - 31.5	23.1 ±4.9
8	ADIGBE	318.8 - 562.4	461.6 ± 21.5	7.7 - 21.1	15.8 ± 4.0	7.8 - 14.6	11.7 ± 3.4
9	MILE 8 (OBA)	530.4 - 681.1	588.9 ± 24.3	4.6 - 11.0	8.4 ± 2.9	8.6 - 14.2	10.9 ± 3.3
	Weighted Mean		**483.8 ± 68.8**		**12.01 ± 4.4**		**10.4 ± 5.0**

Table 5.3: The Range and the Mean of the activity concentrations of the radionuclides (^{40}K, ^{226}Ra and ^{232}Th) in the Lower region of Ogun river

		^{40}K (Bq/kg)		**^{226}Ra (Bq/kg)**		**^{232}Th (Bq/kg)**	
S/N	**Locations**	Range	Mean	Range	Mean	Range	Mean
1	ABATA	399.5 - 510.8	465.95 ± 31.7	5.7 - 26.9	17.1 ± 8.7	3.3 - 31.4	20.1 ± 9.6
2	OWERE	533.8 - 654.0	608.0 ± 24.7	8.7 - 12.97	11.3 ± 3.4	7.98 - 19.7	12.3 ± 3.5
3	OGUNPA WASIMI	494.8 - 666.8	549.9 ± 23.5	8.9 - 29.9	18.4 ± 4.3	11.5 - 29.8	21.0± 4.6
4	IRO	450.9 - 637.6	541.8 ± 23.3	4.3 -27.9	16.5 ± 4.1	7.8 - 23.7	15.0 ± 3.9
5	MAGBON	439.2 - 594.0	504.4 ± 22.5	6.6 - 22.4	14.6 ± 3.8	BDL - 21.7	8.8 ± 3.0
6	ILATE	401.8 - 620.8	501.3 ± 22.4	3.1 - 32.5	15.4 ± 3.9	4.1 - 27.7	18.2 ± 4.3
7	OBA OSENI	446.3 - 554.8	492.9 ± 22.2	2.9 - 27.5	14.1 ± 3.8	16.4 - 26.1	22.5 ± 4.7
8	IBARAGUN	394.5 - 618.2	488.4 ± 22.1	3.9 - 17.7	9.9 ± 3.1	3.7 - 17.4	10.7 ± 3.3
9	ORUDU	278.1 - 603.6	487.4 ± 22.1	6.1 - 15.5	11.1 ± 3.3	5.1 - 12.3	8.0± 2.8
10	MAIDAN	341.0 - 562.9	507.0 ± 22.5	BDL -17.3	9.97 ± 3.2	1.7 - 11.9	8.0 ± 2.8
11	IGAUN	334.2 - 430.4	393.2 ± 19.8	6.0 - 24.5	17.0 ± 4.1	5.8 - 14.6	10.9 ± 3.3
12	AKUTE	487.1 - 625.2	557.8 ± 23.6	8.8 - 26.2	16.1 ± 4.0	13.6 - 23.5	18.5 ± 4.3
13	KARA	316.2 - 547.5	445.4 ± 21.1	4.98 - 15.5	8.3 ± 2.9	2.8 - 8.3	5.5± 2.3
14	MILE 12-MAIDAN	348.7 - 595.1	495.0 ± 22.3	0.90 - 16.8	7.8 ± 2.8	BDL - 10.79	5.0 ± 2.2
15	TOWOLO	320.2 - 485.0	432.0± 20.8	1.68 - 27.43	15.3 ± 3.9	8.58 - 27. 2	17.0 ± 4.1
16	AGBARIWU	315.64 -526.6	439.6 ± 21.0	4.35 - 17.4	9.0 ± 3.0	11.6- 27.1	17.2 ± 4.1
17	APA OSA	490.8 - 697.1	603.5 ± 24.6	5.66 - 19.7	13.2 ± 3.6	3.6 - 13.31	9.6 ± 3.1
	Weighted Mean		**500.8 ± 58.2**		**13.2 ± 3.4**		**13.4 ± 5.6**

(NOTE: The regional weighted mean is the value of the average of the concentrations of a particular radionuclide in a particular region. Region, e.g upper, middle and lower regions. Regional range is the range of the concentrations of a particular radionuclide in a particular region.

Total mean is the value of the average of the concentrations of a particular radionuclide which is the representative value for the whole river considering the three regions together, it is also the overall mean).

TABLE 5.4: Range and mean of radium equivalents (Bq/kg) for each location in the upper region of Ogun river.

S/N	**Locations**	**(Ra_{eq}) Range**	**(Ra_{eq}) Mean**
1	IGBOHO	23.72 - 82.50	67.44 ± 16.30
2	SEPETERI	43.43 - 80.25	68.21± 11.78
3	OJUBO SANGO	52.21 - 74.87	63.62 ± 7.21
4	ODO -OGUN (OYO WEST)	58.91 - 76.59	67.59 ± 6.57
5	LASUPO	50.60 - 91.57	66.71± 13.37
6	IDI –ATA	47.47 - 65.53	57.39± 7.12
	Regional Weighted Mean		**65.16 ± 4.14**

TABLE 5.5: Range and mean of radium equivalents (Bq/kg) for each location in the middle region of Ogun river.

S/N	**Locations**	**(Ra_{eq}) Range**	**(Ra_{eq}) Mean**
1	OLOPADE	36.55 -96.72	54.81± 18.32
2	OLOKEMEJI	27.80 -73.45	55.46 ±14.36
3	EKERIN	26.29 - 99.42	55.11 ± 25.42
4	OPEJI	31.38 - 68.46	55.32 ± 12.18
5	LERIN	49.32 - 82.54	66.10 ±8.57
6	AGO ODO	55.94 - 88.08	64.81 ±9.63
7	SOKORI	79.00 - 101.27	87.83 ±6.46
8	ADIGBE	55.89 - 79.65	68.08 ±9.32
9	MILE8(OBA)	61.78 - 81.85	69.37 ±6.41
	Regional Weighted Mean		**64.10 ± 10.78**

TABLE 5.6: Range and mean of radium equivalents (Bq/kg) for each location in the lower region of Ogun river

S/N	Locations	(Ra_{eq}) Range	(Ra_{eq}) Mean
1	ABATA	49.33 - 102.60	81.68 ± 17.94
2	OWERE	67.47 - 90.85	75.66 ± 7.12
3	OGUNPAWASIMI	69.24 - 115.93	90.84 ± 14.37
4	IRO	50.19 - 103.40	79.69 ±17.90
5	MAGBON	48.85 - 93.83	66.01 ±14.95
6	ILATE	47.49 -110.75	79.98 ± 21.67
7	OBA OSENI	73.23 - 95.03	84.18 ± 7.63
8	IBARAGUN	41.55 - 79.84	62.82 ± 11.76
9	ORUDU	35.06 - 78.00	60.1 ± 13.76
10	MAIDAN	45.23 - 71.96	60.37 ± 7.80
11	IGAUN	55.68 - 72.34	62.88 ±5.93
12	AKUTE	69.87 - 97.83	85.48 ± 10.24
13	KARA	38.47 - 64.65	50.52 ± 8.44
14	MILE 12MAIDAN	28.89 - 72.23	53.1 ± 15.35
15	TOWOLO	51.44 - 84.98	72.85 ± 11.73
16	AGBARIWU	51.42 - 93.80	67.43 ± 13.00
17	APA OSA	53.78 - 82.25	73.4 ± 8.90
	Regional Weighted Mean		**71.00 ±12.10**

5.2.2 The External Hazard Index (H_{EX})

The importance of the measured hazard index (H_{EX}) in building materials is to estimate the radiological suitability of the material for building purposes. That is, the use of the measured activities in building materials is to estimate the radiation dose expected to be delivered externally if a building is constructed using these materials. To limit the annual external gamma-ray dose to 1.5 mGy/y (Saito et al., 1998; Yang et al., 2005; UNSCEAR, 2000). The external hazard index due to gamma radiation was calculated using equation (5.2) (Turhan and Gunduz, 2007; UNSCEAR, 2000; Bereka and Mathew, 1985):

$$H_{EX} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \qquad (5.2)$$

Where C_K, C_{Ra} and C_{Th} are the specific activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in Bq/K respectively.The external hazard index is obtained from the expression of the radium equivalent through the supposition that its maximum allowed value corresponds to the upper limit of R_{aeq} (370Bq/Kg) ($H_{EX} = \frac{R_{aeq}}{370}$), so that the annual external dose rate does not exceed 1.5mGy. To limit the external gamma dose of materials to 1.5 mGy/y for the radiation hazard to be negligible or insignificant, then the external hazard index must be in conformity with the criterion of $H_{EX} \leq 1$ (Jibiri et al., 2009; Bereka and Mathew, 1985; Xinwei et al., 2006).

The results obtained for the range and mean of the external hazard index from the sediments in the upper, middle and lower regions of Ogun river respectively are presented in Tables 5.7, 5.8 and 5.9.

TABLE 5.7: Range and mean of external and internal hazard indices for each location in the upper region of Ogun river.

S/N	Locations	(H_{Ex}) Range	Mean	(H_{IN}) Range	Mean
1	IGBOHO	0.064 - 0.223	0.182± 0.04	0.078 - 0.268	0.210±0.05
2	SEPETERI	0.117 - 0.217	0.1842 ± 0.03	0.1270 - 0.255	0.216± 0.04
3	OJUBO SANGO	0.141 - 0.202	0.1718 ± 0.02	0.163 - 0.240	0.200 ± 0.03
4	ODO OGUN (OYO WEST)	0.154 - 0.207	0.183 ± 0.02	0.181 - 0.259	0.220 ± 0.03
5	LASUPO	0.137 - 0.247	0.180 ± 0.04	0.161 - 0.296	0.218 ± 0.04
6	IDI - ATA	0.128 - 0.177	0.155 ± 0.02	0.140 - 0.210	0.185 ± 0.03
	Regional Weighted Mean		**0.176 ± 0.01**		**0.208 ± 0.01**

TABLE 5.8: Range and mean of external and internal hazard indices for each location in the middle region of Ogun river

S/N	Locations	(H_{Ex}) Range	Mean	(H_{IN}) Range	Mean
1	OLOPADE	0.099 - 0.261	0.148 ± 0.05	0.121 - 0.306	0.188 ±0.06
2	OLOKEMEJI	0.075 - 0.198	0.150 ±0.04	0.078 - 0.262	0.175 ±0.05
3	EKERIN	0.071 - 0.269	0.149 ± 0.07	0.071 - 0.311	0.164 ± 0.09
4	OPEJI	0.085 - 0.185	0.149 ±0.03	0.093 - 0.241	0.184 ±0.05
5	LERIN	0.133 - 0.223	0.179 ±0.02	0.143 - 0.259	0.206 ±0.03
6	AGO ODO	0.151- 0.238	0.175 ±0.03	0.173 - 0.304	0.204 ±0.04
7	SOKORI	0.213 - 0.274	0.237 ±0.02	0.260 - 0.331	0.292 ±0.03
8	ADIGBE	0.151 - 0.215	0.184 ±0.03	0.181 - 0.270	0.227 ±0.03
9	MILE8(OBA)	0.167- 0.221	0.187 ±0.02	0.186 - 0.249	0.210 ±0.02
	Regional Weighted Mean		**0.173 ±0.03**		**0.206 ±0.04**

TABLE 5.9: Range and mean of external and internal hazard indices for each location in the lower region of Ogun river.

S/N	Locations	(H_{Ex}) Range	Mean	(H_{IN}) Range	Mean
1	ABATA	0.133 - 0.277	0.221 ± 0.05	0.155 - 0.350	0.267 ± 0.07
2	OWERE	0.182 - 0.245	0.204 ± 0.02	0.213 - 0.279	0.235 ± 0.02
3	OGUNPAWASIMI	0.187 - 0.313	0.245 ± 0.04	0.217 - 0.394	0.295 ± 0.05
4	IRO	0.136 - 0.279	0.215 ± 0.05	0.147 - 0.355	0.260 ±0.07
5	MAGBON	0.132 -0.253	0.178 ± 0.04	0.158 - 0.314	0.218 ± 0.05
6	ILATE	0.128 - 0.299	0.216 ± 0.05	0.157 - 0.381	0.258 ± 0.08
7	OBA OSENI	0.198 - 0.26	0.227 ± 0.02	0.215 - 0.327	0.265 ± 0.05
8	IBARAGUN	0.112 - 0.216	0.171 ± 0.03	0.125 - 0.263	0.196 ± 0.04
9	ORUDU	0.095 - 0.213	0.162 ± 0.04	0.112 - 0.253	0.192 ± 0.05
10	MAIDAN	0.122 - 0.194	0.163 ± 0.02	0.112 - 0.253	0.190 ± 0.03
11	IGAUN	0.150 - 0.195	0.170 ± 0.02	0.167 - 0.251	0.216 ± 0.03
12	AKUTE	0.189 - 0.264	0.231 ± 0.03	0.215 – 0.335	0.274 ± 0.05
13	KARA	0.104 - 0.175	0.136 ± 0.02	0.117 - 0.212	0.159 ± 0.03
14	MILE 12MAIDAN	0.078 - 0.195	0.143 ± 0.04	0.080 - 0.236	0.164 ± 0.06
15	TOWOLO	0.139 - 0.230	0.197 ± 0.03	0.248 - 0.418	0.342 ± 0.06
16	AGBARIWU	0.139 - 0.253	0.182 ± 0.04	0.152 - 0.296	0.207 ± 0.04
17	APA OSA	0.145 - 0.222	0.198 ± 0.02	0.161 - 0.270	0.234 ± 0.03
	Regional Weighted Mean		**0.192 ±0.03**		**0.234 ±0.05**

5.2.3 The Internal Hazard Index

For the safe use of a material in the construction of dwellings, the maximum value of the internal hazard index (Hin) should be less than unity (Iqbal et al., 2000). The internal hazard index (Hin) is defined in such a way as to reduce the maximum permissible concentration of $^{226}R_a$ to half the values appropriate for the external exposure alone(Shiva Prased et al., 2008; Jibiri, 2009). The gaseous short- lived decay product of ^{226}Ra called Radon (Rn- 222) posses threats to the respiratory organs. In addition to the external hazard index, internal exposure to radon and its products is quantified by estimating the internal hazard index using equation (5.3). The internal exposure to ^{222}Rn and its radioactive progeny is controlled by the internal hazard index (Hin) (Quindos et al., 1987; Cottens, 1990 ; Beretka and Mathew , 1985; Iqbal et al., 2000).

$$H_{IN} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \qquad (5.3)$$

Where C_K, C_{Ra} and C_{Th} are the specific activity concentrations of ^{40}K, ^{226}R and ^{232}Th in Bq/kg respectively. If the maximum concentration of $^{226}R_a$ is half that of the normal acceptable limit, then H_{in} will be less than unity. For safety precautions in the use of materials in the construction of dwellings, the criterion is that $H_{IN} \leq 1$(Beretka and Mathew, 1985). The range and mean values of the internal hazard index for each location in the upper, middle and lower regions are also presented in Tables 5.7, 5.8 and 5.9 respectively.

5.2.4: The Representative Gamma Index

In order to examine whether the samples meet these limits of dose criteria, Another radiation hazard index, the representative level index, (Iγr), which is used to estimate the level of γ- radiation hazard associated with the natural radionuclides in specific investigated samples, is defined (NEA-OECD, 1979) following Equation (5.4) as:

$$I_{\gamma r} = \frac{C_{Ra}}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \qquad (5.4)$$

Where C_K, C_{Ra} and C_{Th} are the specific activity concentrations of ^{40}K, ^{226}R and ^{232}Th in Bq/kg of the sediments respectively. This gamma index is mostly used to correlate the annual dose rate due to the excess external gamma radiation caused by superficial materials. It is used only as screening tool for identifying materials that might become health concerns when used as construction materials (Tufail et al., 2007). Values of $I_{\gamma r} \leq 1$ correspond to an annual effective dose of less than or equal to 1mSv, while $I_{\gamma r} \leq 0.5$ corresponds to an annual effective dose less or equal to 0.3msv (Turhan et al., 2008). The range and mean values of the representative gamma index for the sediment samples in the upper, middle and lower regions of the river are presented in Tables 5.10, 5.11 and 5.12 respectively.

5.2.5: The Indoor Gamma Dose Rate

The indoor gamma rate (D_{in}) in (nGy/h) due to the emmissions of gamma –rays from the radionuclides (^{40}K, ^{226}R and ^{232}Th) in the sediments samples used as building materials were calculated using the equation 5.5 for a standard room dimension of 4m x 5m x 2.8m. (UNSCEAR 2000 ; EC 1999; Jibiri et al., 2009):

$$D_{IN}(nGy/h) = 0.92 \times A_{Ra} + 1.1 \times A_{Th} + 0.080 \times A_K \qquad (5.5)$$

Where A_K, A_{Ra} and A_{Th} are the concentrations of ^{40}K, ^{226}R and ^{232}Th in Bq/kg, respectively. The range and mean values of the indoor gamma dose rates in the upper middle and lower regions of the river are presented in Tables 5.13, 5.14 and 5.15 respectively.

5.2.6 The Indoor Effective Dose Rate

The effective dose rate resulting from the indoor gamma absorbed doses (D_{in}) was calculated using the expression in equation (5.6).

$$\text{Effect. Dose (mSv/yr)} = D(nGy/hr) \times 8760(hr/y) \times 0.7(Sv/Gy) \times 0.8 \times 10^{-6} \qquad (5.6)$$

The United Nations Scientific Committee on the Effect of Atomic Radiation (UNSCEAR, 2000) has recommended 0.7 Sv/Gy as the conversion coefficient from absorbed dose in air to effective dose and 0.8 (19/24) as the value for the indoor occupancy factors. This second factor implies that the average individual spends about 19 hrs per day indoors. The range and mean values of the indoor effective dose rates, for each location resulting

TABLE 5.10: Range and mean of representative gamma index for each location in the upper region of Ogun river.

S/N	**Locations**	**($I_{\gamma r}$) Range**	**($I_{\gamma r}$) Mean**
1	IGBOHO	0.188 - 0.661	0.543± 0.13
2	SEPETERI	0.360 - 0.647	0.546± 0.09
3	OJUBO SANGO	0.418 - 0.591	0.507 ± 0.05
4	ODO -OGUN (OYO WEST)	0.454- 0.604	0.534 ± 0.05
5	LASUPO	0.380 - 0.728	0.527 ± 0.11
6	IDI –ATA	0.380 - 0.523	0.455 ± 0.06
	Regional Weighted Mean		**0.519 ± 0.03**

TABLE 5.11: Range and mean of representative gamma index for each location in the middle region of Ogun river

S/N	**Locations**	**($I_{\gamma r}$) Range**	**($I_{\gamma r}$) Mean**
1	OLOPADE	0.292 - 0.771	0.426 ±0.15
2	OLOKEMEJI	0.239 - 0.570	0.444 ± 0.11
3	EKERIN	0.226 - 0.781	0.447 ± 0.19
4	OPEJI	0.265 - 0.533	0.438 ±0.09
5	LERIN	0.411 - 0.654	0.531 ±0.06
6	AGO ODO	0.431 - 0.672	0.519 ±0.07
7	SOKORI	0.600 - 0.779	0.665 ±0.05
8	ADIGBE	0.429 - 0.614	0.530 ±0.07
9	MILE8(OBA)	0.500 - 0.654	0.558 ±0.05
	Regional Weighted Mean		**0.506 ±0.08**

TABLE 5.12: Range and mean of representative gamma index for each location in the lower region of Ogun river

S/N	**Locations**	**($I_{\gamma r}$) Range**	**($I_{\gamma r}$) Mean**
1	ABATA	0.404 - 0.766	0.625 ± 0.12
2	OWERE	0.537 - 0.715	0.603 ± 0.05
3	OGUNPAWASIMI	0.544 - 0.873	0.700 ± 0.10
4	IRO	0.407 - 0.783	0.621 ± 0.13
5	MAGBON	0.393 - 0.716	0.522 ± 0.11
6	ILATE	0.380 - 0.838	0.619 ± 0.16
7	OBA OSENI	0.578 - 0.717	0.647 ± 0.05
8	IBARAGUN	0.342 - 0.632	0.499 ± 0.09
9	ORUDU	0.279- 0.625	0.479 ± 0.11
10	MAIDAN	0.388 - 0.570	0.484 ± 0.05
11	IGAUN	0.436 - 0.553	0.485 ± 0.05
12	AKUTE	0.548 - 0.752	0.664 ± 0.07
13	KARA	0.314 - 0.513	0.408 ± 0.07
14	MILE 12MAIDAN	0.246 - 0.574	0.432 ± 0.11
15	TOWOLO	0.400 - 0.646	0.560 ± 0.09
16	AGBARIWU	0.407 - 0.718	0.525 ± 0.10
17	APA OSA	0.446 - 0.660	0.586 ± 0.07
	Regional Weighted Mean		**0.556 ±0.09**

TABLE 5.13: The range and the mean of the indoor gamma dose rates ($nGyh^{-1}$) and indoor effective dose rates (mSv/y) for the upper region

S/N	Locations	$D(nGyh^{-1})_{Indoor}$ Range	Mean	Effect. Dose Rate$(mSv/y)_{Indoor}$ Range	Mean
1	IGBOHO	22.92 - 80.06	65.51± 15.83	0.112 - 0.393	0.321 ± 0.08
2	SEPETERI	43.23 - 77.72	65.97 ± 10.66	0.212 - 0.381	0.324 ± 0.05
3	OJUBO SANGO	50.32 - 71.45	61.13 ± 6.52	0.247 - 0.350	0.3 ± 0.03
4	ODO -OGUN (OYO WEST)	54.97 - 73.89	64.78 ± 6.00	0.270 - 0.363	0.318 ± 0.03
5	LASUPO	46.04 -88.38	63.93 ± 13.73	0.226 - 0.434	0.314 ±0.07
6	IDI –ATA	45.52 - 63.43	55.08 ± 6.94	0.223 - 0.311	0.27 ± 0.03
	Regional Weighted Mean		**62.74 ± 4.12**		**0.308 ±0.02**

TABLE 5.14: The range and the mean of the indoor gamma dose rates ($nGyh^{-1}$), and indoor effective dose rates (mSv/y) for the middle region

S/N	Locations	$D(nGyh^{-1})_{Indoor}$ Range	Mean	Effect. Dose Rate$(mSv/y)_{Indoor}$ Range	Mean
1	OLOPADE	35.73 - 93.18	52.11 ± 17.46	0.175 - 0.457	0.256 ± 0.09
2	OLOKEMEJI	28.76 - 70.46	53.62 ± 12.91	0.141 - 0.346	0.263 ± 0.06
3	EKERIN	26.97 - 93.52	53.50 ± 23.07	0.132 - 0.459	0.263 ± 0.11
4	OPEJI	32.22 - 65.24	53.45 ± 10.91	0.158 - 0.320	0.262 ± 0.32
5	LERIN	49.41 - 78.59	60.77 ± 7.51	0.242 - 0.386	0.314 ± 0.04
6	AGO ODO	52.41 - 81.78	62.61 ± 8.59	0.257 - 0.412	0.307 ± 0.04
7	SOKORI	71.91 - 93. 63	79.92 ± 6.16	0.352 - 0.459	0.392 ± 0.03
8	ADIGBE	52.54 - 74.69	64.33 ± 8.69	0.258 - 0.366	0.316 ± 0.04
9	MILE8(OBA)	59.88 - 78.32	66.86 ± 6.13	0.294 - 0.384	0.328 ± 0.03
	Regional Weighted Mean		**60.80 ± 9.03**		**0.300± 0.05**

TABLE 5.15: The range and the mean of the indoor gamma dose rates ($nGyh^{-1}$), and indoor effective dose rates (mSv/y) for the lower region

S/N	Locations	$D(nGyh^{-1})_{Indoor}$ Range	Mean	Effect. Dose Rate$(mSv/y)_{Indoor}$ Range	Mean
1	ABATA	49.03 - 92.31	75.09 ± 14.63	0.241 - 0.453	0.368 ± 0.07
2	OWERE	64.70 - 85.33	72.52 ± 6.07	0.317 - 0.419	0.356 ± 0.03
3	OGUNPAWASIMI	65.23 - 105.38	84.08 ±12.09	0.320 - 0.517	0.412 ± 0.06
4	IRO	48.62 - 94.97	75.04± 15.89	0.239 - 0.466	0.368 ± 0.08
5	MAGBON	48.96 - 86.43	63.46 ± 12.62	0.240 - 0.424	0.311 ± 0.06
6	ILATE	46.49 -101 - 48	74.26 ± 19.19	0.228 - 0.498	0.364 ± 0.09
7	OBA OSENI	68.23 - 87.71	77.11 ±6.94	0.335 - 0.430	0.378 ± 0.03
8	IBARAGUN	41.21 -76.93	59.95 ± 10.89	0.202 - 0.377	0.294 ±0.05
9	ORUDU	33.71 - 75.54	58.03 ± 13.28	0.165 - 0.371	0.285 ± 0.07
10	MAIDAN	46.32 - 69.32	58.47 ±6.65	0.227 - 0.340	0.287 ±0.03
11	IGAUN	51.52 -67.41	59.09 ± 5.42	0.253 - 0.331	0.290 ± 0.03
12	AKUTE	65.31 - 91.61	79.76 ± 9.38	0.320 - 0.449	0.391 ± 0.05
13	KARA	37.88 - 62.33	49.37 ± 8.17	0.186 - 0.306	0.242 ± 0.04
14	MILE 12MAIDAN	29.60 - 69.66	52.30 ±13.88	0.145 - 0.342	0.257 ±0.07
15	TOWOLO	46.49 - 77.32	67.32 ± 10.75	0.228 - 0.379	0.330 ± 0.05
16	AGBARIWU	48.30 - 85.46	62.36 ± 11.18	0.237 - 0.419	0.306 ± 0.06
17	APA OSA	53.82 - 79.56	70.98 ± 8.08	0.264 - 0.390	0.348 ± 0.04
	Regional Weighted Mean		**67.01 ± 10.04**		**0.329 ± 0.05**

from the absorbed dose rates values presented in (mSv/yr) are also presented in Tables 5.13, 5.14 and 5.15 for the upper, middle and lower regions respectively.

5.2.7 Excess Lifetime Cancer Risk (ELCR):

The significance of exposure from natural radioactivity in soil and the potential risk for causing health detriment, especially cancer, have not received the desired attention in Nigeria. With the establishment of Nigeria Nuclear Regulatory Authority (NNRA), the public interest in the long-term effects of radiation has assumed great prominence (Farai et al., 2006). Some regulatory bodies use a quantitative risk assessment process to determine an excess cancer risk over a lifetime (ELCR). Two of these bodies are UNSCEAR and BEIR V i.e Committee on the Biological Effects of Atomic Radiations, known as the BEIR. Both organizations stated that their risk estimates should be reduced for low dose exposures protracted over several months or years to account for a reduced effectiveness of the cell damage mechanism (Brian et al., 1995). Using a maximum reduction factor of 2, UNSCEAR (1993) recommends a lifetime risk estimate of 5% per Sv for fatal cancer following a protracted whole-body exposure of low dose and low dose rate radiation (Brian et al., 1995). The ICRP (1990), while relying mainly on the assessment of the Japanese survivors by organizations such as UNSCEAR and BEIR V, has taken into consideration the entire body of literature in their estimate of risk (Brian et al., 1995). The lifetime risk estimate for low-dose exposures as given in the 1990 recommendations of the ICRP is 5% per Sv for the entire population, based on a linear, no-dose threshold model. On the basis of copious and on-going research in human epidemiology, animal studies, and cell biology, these organizations concluded that the risk estimates at low doses are likely conservative. Therefore, the need to determine the excess cancer risk over a lifetime (ELCR). This approach mathematically calculates the probability of developing cancer over a lifetime at a given exposure level. It is presented as a value representing the number of extra cancers expected in a given number of people on exposure to a carcinogen at a stated dose.

Excess Lifetime Cancer Risk (ELCR) was calculated using equation 5.7 (Taskin *et al.*, 2009).

$$ELCR = AEDE \times DL \times RF \qquad (5.7)$$

Where AEDE, DL and RF are the annual effective dose equivalent, average duration of life (70 years) and risk factor (Sv^{-1}), i.e fatal cancer risk per sievert respectively. For stochastic effects, ICRP 60 uses values of 0.05 for the public (Taskin *et al*., 2009; Brian et al., 1995). The range and mean values of the Excess Lifetime Cancer Risk (ELCR) estimated for each location in the upper, middle and lower regions of Ogun river respectively are presented in tables 5.16, 5.17 and 5.18.

5.2.8 Thorium To Uranium Ratio

The primary mode of transport of Thorium from the continents to the oceans follow the detrital phase, while Uranium minerals are chemically weathered to solubleU(VI) complexes and carried by river water down stream to the ocean (Moore and Krishnaswami, 1972, Haglund, 2004, Masitah et al, 2008). Precipitation of Uranium can occur easily by reduction to insoluble U(IV). Thus environments in which carbonaceous and bituminous shales form are particularly favourable for U removal by reduction of U(VI)to U(IV) (Masitah et al 2008 ; Pliler and Adams, 1962; Adams and Richardson, 1960). Th/U ratio in nature varies widely. In rocks, from which U has been removed high Th/U ratio results, conversely, in rocks precipitated under chemically reducing environment far from suspected rock source, Uranium is enriched over Thorium, thus above average, Th/U ratio are observed in continental sediments, especially in laterites and other residual deposits.

Low Th/U ratio are found in chemically precipitated marine sediments, rock such as evaporated sand, limestone and other, extremely low Th/U ratio are found in cabonateous rock (Brookins, 1984).

Th/U ratio is a parameter that can be used to give an insight of the geology of an area. This value when be less than unity, implies that the uranium contents is greater than the thorium contents, since the denominator determines what happens. If the value is equal to unity, then it imples that the thorium contents and the uranium contents are in equilibrium. If the value is greater than unity, it implies that they are not in equilibrium, the uranium contents is less than the thorium contents. One of the obvious reasons is due to the fact that uranium percolates to higher depth thereby leaving lower concentrations in the surface soil due to its solubility compared with thorium, and since the rate of leaching of uranium is higher than thorium because uranium forms complexes with water. See Tables 5.16, 5.17 and 5.18.

TABLE 5.16: The range and the mean of Excess Life Cancer Risk (ELCR) and Thorium to Uranium ratio for the upper region of Ogun river.

S/N	Locations	ELCR x10^{-3} Range	Mean	Th/U Range	Mean
1	IGBOHO	0.051 - 0.179	0.147±0.04	0.53 - 2.29	0.92± 0.05
2	SEPETERI	0.097 - 0.175	0.148 ± 0.02	0.50 - 1.08	0.80 ± 0.02
3	OJUBO SANGO	0.113 - 0.160	0.137 ± 0.02	0.58 - 1.40	0.94 ± 0.02
4	ODO -OGUN (OYO WEST)	0.12 3- 0.165	0.145 ± 0.01	0.45 - 0.95	0.74 ± 0.02
5	LASUPO	0.104 - 0.198	0.143 ±0.03	0.19 - 0.95	0.71 ± 0.02
6	IDI –ATA	0.103 - 0.142	0.124 ± 0.02	0.35 - 3.74	0.98 ± 0.09
	Regional Weighted Mean		**0.141 ± 0.01**		**0.85 ± 0.11**

TABLE 5.17: The range and the mean of Excess Life Cancer Risk (ELCR) and Thorium to Uranium ratio for the middle region of Ogun river.

S/N	Locations	ELCR x10^{-3} Range	Mean	Th/U Range	Mean
1	OLOPADE	0.080 - 0.290	0.117±0.04	0.14 - 3.69	0.77± 0.05
2	OLOKEMEJI	0.064 - 0.157	0.120±0.02	0.0 - 2.17	0.97±0.08
3	EKERIN	0.061 - 0.211	0.120±0.05	0.0 - 3.26	0.90±0.02
4	OPEJI	0.072 - 0.146	0.120±0.02	0.0 - 0.69	0.45±0.03
5	LERIN	0.111 - 0.177	0.144±0.02	0.51 - 1.14	0.88±0.02
6	AGO ODO	0.118 - 0.183	0.141±0.02	0.69 - 1.23	0.86±0.02
7	SOKORI	0.162 - 0.211	0.180±0.01	0.74 - 1.63	1.14±0.02
8	ADIGBE	0.118 - 0.168	0.144 ± 0.02	0.56 - 1.39	0.78±0.02
9	MILE8(OBA)	0.135 - 0.176	0.150±0.01	0.87 - 3.06	1.46±0.07
	Regional Weighted Mean		**0.137±0.02**		**0.91±0.03**

TABLE 5.18: The range and the mean of Excess Life Cancer Risk (ELCR) and Thorium to Uranium ratio for the lower region of Ogun river.

S/N	Locations	ELCR x10^{-3} Range	ELCR x10^{-3} Mean	Th/U Range	Th/U Mean
1	ABATA	0.110 - 0.208	0.169 ± 0.03	0.31- 3.76	1.45 ± 0.01
2	OWERE	0.145 - 0.193	0.163 ± 0.01	0.73 - 1.72	1.11± 0.03
3	OGUNPAWASIMI	0.147 - 0.238	0.190 ± 0.03	0.91 - 2.31	1.21 ± 0.04
4	IRO	0.110 - 0.214	0.169 ±0.04	0.50 - 2.42	1.16 ±0.06
5	MAGBON	0.108 - 0.195	0.142 ± 0.03	0.0 - 1.23	0.66 ± 0.04
6	ILATE	0.104 - 0.228	0.167 ± 0.04	0.39 - 8.92	2.42 ±0.03
7	OBA OSENI	0.155 - 0.196	0.174 ± 0.02	0.60 - 8.63	2.80 ± 0.02
8	IBARAGUN	0.092 - 0.172	0.135± 0.02	0.56 - 3.29	1.34 ± 0.08
9	ORUDU	0.0617 - 0.138	0.106± 0.02	0.58 - 0.90	0.75 ± 0.01
10	MAIDAN	0.085 - 0.127	0.107 ±0.01	0.0 - 1.27	0.75 ± 0.03
11	IGAUN	0.117 - 0.151	0.132 ± 0.01	0.24 - 2.43	0.81 ± 0.06
12	AKUTE	0.148 - 0.205	0.180 ± 0.02	0.68 - 2.03	1.33 ± 0.05
13	KARA	0.085 - 0.140	0.111 ± 0.02	0.31 - 1.13	0.72 ± 0.02
14	MILE 12MAIDAN	0.066 - 0.156	0.117 ± 0.03	0.0 - 1.08	0.61 ± 0.04
15	TOWOLO	0.106 - 0.175	0.152 ± 0.02	0.36 -16.20	3.42 ± 0.50
16	AGBARIWU	0.109 - 0.194	0.141± 0.02	0.95 - 3.94	2.21 ± 0.09
17	APA OSA	0.121 - 0.179	0.159± 0.02	0.49 - 0.95	0.75± 0.02
	Regional Weighted Mean		**0.148± 0.03**		**1.38± 0.84**

5.3 Grain Size Analysis of the sediments

The typical statistical data obtained from grain size analysis (granulometric analysis) of the 32 representative samples is presented in (Appendix ii). Statistical size frequency parameters such as the graphic mean (mean size), modal size, median, sorting, skewness and kurtosis were calculated using various percentile values in (Table 5.19).

5.3.1 Graphic Mean

The mean size is a function of the size range of available materials and amount of energy impacted to the sediment which depends on current velocity or turbulence of the transporting medium. The mean value for the grain size distribution within the analysed sediments were calculated using equation 4.5 and results are presented in Table 5.20.

5.3.2 Sorting

This is a measure of the standard deviation which is the spread of the grain size distribution. This was calculated using equation 4.6 and results are also presented in Table 5.20

5.3.3 Skewness

This is a reflection of the depositional process. It is simply a measure of the symmetry of the distribution This was calculated using equation 4.7 and results are also presented in table 5.20.

5.3.4 Kurtosis

This is a measure of the peakedness of the curves towards the coarser grain sizes. Calculated using equation 4.8 and results are presented in Table 5.20.

Table 5.19: Percentile Values for Grain Size Analysis.

SAMPLE LOCATIONS	ϕ5	ϕ16	ϕ25	ϕ50	ϕ75	ϕ84	ϕ95
IGBOHO	1.90	2.20	2.30	2.55	3.70	3.90	4.20
SEPETERI	1.95	2.25	2.35	2.55	3.15	3.80	4.10
OJUBO SANGO	-0.27	0.54	0.98	1.40	1.90	2.16	3.44
ODO-OGUN (OYO WEST)	0.60	1.41	1.70	1.97	2.28	2.43	2.97
LASUPO	-0.27	0.54	0.98	1.40	1.90	2.16	3.44
IDI-ATA	0.77	1.08	1.24	1.67	2.03	2.33	3.48
OLOPADE	1.65	1.80	1.95	2.2	2.05	2.65	2.75
OLOKEMEJI	1.80	2.00	2.15	2.45	2.75	3.15	3.90
EKERIN	-0.68	0.56	0.79	1.43	1.89	2.39	2.94
OPEJI	1.40	1.80	1.90	2.20	2.75	3.25	3.90
LERIN	1.90	2.30	2.40	2.60	3.20	3.80	3.90
AGO-ODO	-0.82	-0.08	0.35	1.13	1.92	2.22	3.66
SOKORI	1.45	1.80	1.90	2.20	2.45	2.60	3.75
ADIGBE	0.74	1.54	1.82	2.37	2.85	3.07	3.78
MILE 8(OBA)	-0.02	0.58	0.98	1.64	3.78	3.87	3.91
ABATA	1.85	2.05	2.10	2.35	2.80	3.15	3.80
OWERE	0.60	1.41	1.70	1.97	2.28	2.43	2.97
OGUNPA WASIMI	0.26	0.32	0.65	1.27	1.86	2.27	3.29
IRO	1.85	2.20	2.25	2.60	3.6	3.9	4.1
MAGBON	0.74	1.54	1.82	2.37	2.85	3.07	3.78
ILATE	-0.04	0.41	0.76	1.26	1.61	1.89	3.53
OBA OSENI	-0.09	0.86	1.90	2.37	2.87	3.26	3.85
IBARAGUN	1.50	2.40	2.45	2.65	3.15	3.55	3.95
ORUDU	1.95	2.25	2.35	2.55	3.15	3.80	4.10
MAIDAN	1.65	1.80	1.95	2.20	2.05	2.65	2.75
IGAUN	0.05	0.79	1.02	1.47	1.92	2.11	2.97
AKUTE	0.77	1.08	1.24	1.67	2.03	2.33	3.48
KARA	1.90	2.30	2.40	2.60	3.20	3.80	3.90
MILE 12-MAIDAN	-0.02	0.58	0.98	1.64	3.78	3.87	3.91
TOWOLO	0.50	1.07	1.27	1.60	1.88	1.98	2.53
AGBARIWU	-0.52	0.20	0.61	1.48	2.32	2.81	3.51
APA OSA	0.69	1.32	1.67	1.99	2.30	2.53	2.94

Table 5.20: Summary of Results obtained from Grain Size Analysis and its Interpretation

Sample	Median, ϕ	Mean, ϕ	Mode, ϕ	S.D ϕ	Skewness, ϕ	Kurtosis, ϕ	Interpretation
Igboho	1.48	2.88	0.84	0.77	0.51	0.67	Moderately sorted, Fine skewed and very platykurtic.
Sepeteri	1.97	2.86	2.75	0.71	0.53	1.10	Moderately sorted, Near symmetrical , and leptokurtic
Ojubo Sango	1.40	1.37	1.75	0.97	0.02	1.66	Moderately sorted, Near symmetrical and very leptokurtic
OdoOgun (Oyo West)	1.97	1.94	2.75	0.62	-0.13	1.67	Moderately well sorted,Coarse skewed and very leptokurtic
Lasupo	1.4	1.37	2.75	0.97	0.02	1.66	Moderately sorted, Near symmetrical , and very leptokurtic
Idi –Ata	1.67	1.69	1.75	0.72	0.20	1.40	Moderately sorted, fine skewed and leptokurtic
Olopade	1.64	2.22	1.75	0.38	0.03	4.51	Moderately sorted, near symmetrical and extremely leptokurtic
Olokemeji	1.67	2.53	4.00	0.61	0.30	1.43	Moderately well sorted,Coarse skewed and very leptokurtic
Ekerin	1.43	1.46	1.25	1.01	-0.05	1.35	Poorly sorted, Near symmetrical and loptokurtic
Opeji	1.40	2.42	1.75	0.74	0.40	1.21	Moderately sorted, near symmetrical and leptokurtic
Lerin	1.40	2.9	1.75	0.66	0.32	1.02	Moderately sorted, near symetrical and leptokurtic
Ago –Odo	1.13	1.09	1.25	1.26	0.03	1.17	Poorly sorted, near symmetrical and leptokurtic
Sokori	1.40	2.2	1.75	0.55	0.17	1.71	Moderately well sorted,Coarse skewed and very leptokurtic
Adigbe	2.37	2.33	2.75	0.84	-0.08	1.21	Moderately sorted, near symmetrical and leptokurtic
Mile 8 (Oba)	1.64	2.03	4.00	1.42	0.26	0.58	Poorly sorted, fine skewed and very platykurtic
Abata	1.97	2.52	2.75	0.57	0.47	1.14	Moderately sorted, near symmetrical and leptokurtic
Owere	1.97	1.94	2.50	0.62	-0.13	1.67	Moderately well sorted,Coarse skewed and very leptokurtic
Ogunpa wasimi	1.27	1.29	1.25	0.95	0.18	1.03	Moderately sorted, fine skewed and mesokurtic
Iro	1.97	2.9	2.75	0.77	0.43	0.68	Poorly sorted, fine skewed and very platykurtic
Magbon	2.37	2.33	1.75	0.84	-0.08	1.21	Moderately sorted, near symmetrical and leptokurtic
Ilate	1.26	1.19	1.25	0.91	0.06	1.72	Moderately sorted, near symmetrical and very leptokurtic
Oba Oseni	2.37	2.06	2.75	1.2	-0.25	1.66	Poorly sorted, coarse-skewed and very leptokurtic
Ibaragun	2.37	2.87	0.72	0.66	0.31	1.43	Moderately sorted, near symmetrical and very leptokurtic
Orudu	1.97	2.86	2.50	0.71	0.53	1.10	Moderately sorted, near symmetrical and very leptokurtic
Maidan	1.64	2.22	2.82	0.38	0.03	4.51	Moderately sorted, near symmetrical and extremely leptokurtic
Igaun	1.47	1.46	1.75	0.77	-0.01	1.33	Moderately sorted, near symmetrical and leptokurtic
Akute	1.67	1.69	2.75	0.72	0.20	1.40	Moderately sorted, fine skewed and leptokurtic
Kara	1.40	2.90	2.75	0.66	0.32	1.02	Poorly sorted, Fine skewed and very platikurtic
Mile 12 – Maidan	1.64	2.03	1.75	1.42	0.26	0.58	Poorly sorted, fine skewed and very platykurtic
Towolo	1.60	1.55	1.75	0.54	-0.12	1.36	Moderately well sorted, coarse- skewed and leptokurtic
Agbariwu	1.48	1.50	2.75	1.26	0.01	0.97	Poorly sorted, near symmetrical and mesokurtic
Apa Osa	1.99	1.96	2.75	0.64	-0.13	1.5	Moderately well sorted, coarse- skewed and leptokurtic

5.4 Heavy Mineral, Provenance and Distribution along the river

The primary aim of this study is to interprete the result to study the rock record of the areas source of sediment supply and the petrography (mineralogical composition) of the sediment along the river.

5.4.1 Heavy Mineral and Provenance

The heavy mineral assemblages have been determined following the procedure of section 4.6.2 and the results are presented in Table 5.21.

5.4.2 Mineralogical Composition

The result of petrographic thin section analysis to determine the composition of randomly picked sand samples which was discussed under section 4.6.3 is shown in (Table 5.22). The percentage composition of the QFL (quartz, feldspar and rock fragment) in the sediments are also presented in Table 5.23.

Table 5.21: Data of Heavy Minerals showing Z, T, R and ZTR index

SAMPLE LOCATIONS	(Z)	(T)	(R)	(S)	(Si)	(G)	(A)	(E)	(Op)	Non-opaque	ZTR index (%)
IGBOHO	7	4	5	10	1	2	0	2	94	31	51.61
SEPETERI	4	6	9	9	1	1	0	2	91	32	59.38
OJUBO SANGO	4	3	7	12	1	2	2	1	86	32	43.75
ODO-OGUN (OYO WEST)	6	4	7	11	2	1	0	3	69	34	50.00
LASUPO	7	4	5	14	1	1	3	2	94	37	43.24
IDI-ATA	5	6	9	9	1	2	1	2	72	35	57.14
OLOPADE	6	6	12	10	1	1	3	2	88	41	58.54
OLOKEMEJI	6	9	8	9	1	2	1	2	89	38	60.53
EKERIN	6	9	8	11	2	2	3	2	79	43	53.49
OPEJI	6	4	6	10	1	2	1	1	88	31	51.61
LERIN	6	4	6	10	2	2	0	2	88	32	50.00
AGO-ODO	4	6	7	14	1	2	2	2	84	38	44.74
SOKORI	4	3	7	11	2	2	0	2	114	31	45.16
ADIGBE	7	4	5	10	1	2	1	1	114	31	51.61
MILE 8(OBA)	6	4	12	14	2	1	3	2	77	44	50.00
ABATA	4	6	9	8	0	2	0	1	84	30	63.33
OWERE	5	6	9	12	2	1	2	1	74	38	52.63
OGUNPA WASIMI	6	6	12	10	2	1	3	3	88	43	55.81
IRO	6	4	7	10	1	1	1	2	72	32	53.13
MAGBON	7	4	5	10	1	2	1	2	77	32	50.00
ILATE	6	4	12	12	2	1	0	1	88	38	57.89
OBA OSENI	4	3	7	11	1	2	0	2	76	30	46.67
IBARAGUN	5	6	9	10	1	1	1	1	74	34	58.82
ORUDU	6	4	12	12	1	1	0	1	93	37	59.46
MAIDAN	6	9	8	11	1	2	0	1	89	38	60.53
IGAUN	4	6	7	10	1	2	2	2	68	32	53.13
AKUTE	5	6	9	9	1	1	1	1	86	33	60.61
KARA	4	6	7	14	2	2	2	1	76	38	44.74
MILE 12-MAIDAN	6	4	7	10	1	2	2	3	69	33	51.52
TOWOLO	6	4	6	10	0	1	1	2	74	30	53.33
AGBARIWU	6	4	7	10	1	1	1	1	93	31	54.84
APA OSA	4	6	9	8	1	2	0	1	89	31	61.29
TOTAL	174	164	255	341	39	50	33	54	2697	1110	1708.52

*Note: (Z)-Zircon, (T)-Tourmaline, (R)-Rutile, (S)-Staurolite, (A)-Apatite, (G)-Garnet, (E)-Epidote, (Si)-Sillimanite and (Op)-Opaque.

Table 5.22: Composition of Sediments based on visual estimates in percentage (Modal Analysis)

SAMPLE LOCATIONS	Quatrz	Feldspar	Rock fragment	Cement	Matrix	Mica
IGBOHO	60	15	5	2	3	5
SEPETERI	58	8	18	7	3	4
OJUBO SANGO	55	10	11	10	4	7
ODO-OGUN (OYO WEST)	45	10	20	10	8	8
LASUPO	60	15	5	2	3	5
IDI-ATA	60	11	14	5	2	5
OLOPADE	60	12	15	5	2	3
OLOKEMEJI	52	20	8	10	4	3
EKERIN	52	20	8	10	4	3
OPEJI	45	15	20	8	7	5
LERIN	45	15	20	8	7	5
AGO-ODO	60	15	10	5	2	5
SOKORI	55	10	11	10	4	7
ADIGBE	60	15	5	2	3	5
MILE 8(OBA)	60	12	15	5	3	5
ABATA	58	8	18	7	3	4
OWERE	60	11	14	5	2	5
OGUNPA WASIMI	60	12	15	5	2	3
IRO	45	10	20	10	8	8
MAGBON	60	15	5	2	3	5
ILATE	60	12	15	5	3	5
OBA OSENI	55	10	11	10	4	7
IBARAGUN	60	11	14	5	2	5
ORUDU	60	12	15	5	3	5
MAIDAN	52	20	8	10	4	3
IGAUN	60	15	10	5	2	5
AKUTE	60	11	14	5	2	5
KARA	60	15	10	5	2	5
MILE 12-MAIDAN	45	10	20	10	8	8
TOWOLO	45	15	20	8	7	5
AGBARIWU	45	10	20	10	8	8
APA OSA	58	8	18	7	3	4
Average	55.31	12.75	13.50	6.66	3.91	5.16

Table 5.23 Calculated percentage composition of QFL in the sediments

SAMPLE LOCATIONS	Quartz (Q)%	Feldspar (F) %	Rock fragment (L) %	Mineral maturity index = (Q/F+L)
IGBOHO	75	18.8	6.3	2.99
SEPETERI	69	9.5	21.4	2.23
OJUBO SANGO	72	13	14.5	2.62
ODO-OGUN (OYO WEST)	60	13.3	26.7	1.5
LASUPO	75	18.8	6.3	2.99
IDI-ATA	70.6	12.9	16.5	2.4
OLOPADE	69	14	17	2.23
OLOKEMEJI	65	25	10	1.86
EKERIN	65	25	10	1.86
OPEJI	56.3	18.8	25	1.29
LERIN	56.3	18.8	25	1.29
AGO-ODO	70.6	17.6	11.8	2.4
SOKORI	72	13	14.5	2.62
ADIGBE	75	18.8	6.3	2.99
MILE 8(OBA)	69	13.8	17.2	2.23
ABATA	69	9.5	21.4	2.23
OWERE	75	18.8	6.3	2.99
OGUNPA WASIMI	69	14	17	2.23
IRO	60	13.3	26.7	1.5
MAGBON	75	18.8	6.3	2.99
ILATE	69	13.8	17.2	2.23
OBA OSENI	72	13	14.5	2.62
IBARAGUN	70.6	12.9	16.5	2.4
ORUDU	69	13.8	17.2	2.23
MAIDAN	65	25	10	1.86
IGAUN	70.6	17.6	11.8	2.4
AKUTE	70.6	12.9	16.5	2.4
KARA	70.6	17.6	11.8	2.4
MILE 12-MAIDAN	60	13.3	26.7	1.5
TOWOLO	56.3	18.8	25	1.29
AGBARIWU	60	13.3	26.7	1.5
APA OSA	69	9.5	21.4	2.23
Min				1.29
Max				2.99
Average (%)				2.203125

CHAPTER SIX
DISCUSSIONS AND CONCLUSIONS

6.1 Activity Concentrations of ^{40}K, ^{226}R and ^{232}Th for the Upper, Middle And Lower Regions of Ogun River.

Comparing the activity concentrations values of the radionuclides in the upper, middle and lower regions of the river, Figures 6.1 (a-c) (Tables 5.1-5.3), ^{40}K was highest at the upper region of the river with the (regional) weighted mean activity concentration value of 519.3 ± 48.7 Bq/kg, followed by the value in the lower region 500.8 ± 58.2 Bq/kg and lastly the value in the middle region was 483.8 ± 68.8 Bq/kg. The values of the activity concentrations of ^{40} K in the three regions ranged from 186.6± 16.55 Bq/kg to 732.2 ± 63.6 Bq/kg in the upper region, ranged between 214.2 ± 19.19 Bq/kg and 783.7 ± 37.77 Bq/kg in the middle region and between 278.1 ± 24.5 Bq/kg and 697.1 ± 60.2 Bq/kg in the lower region of Ogun river.

The average concentrations of ^{40}K in some locations had values greater than the world's average of 500Bq/kg (Ramasamy et al., 2009), but none of the location had its value of ^{232}Th or ^{226}Ra greater than the world's average of 50Bq/kg (Ramasamy et al., 2009). Figure 6.2a showed the surface interpolations of ^{40}K concentrations down the river. The activity concentrations of ^{226} Ra in the three regions of the river varied from 3.2 ± 0.18 – 20.4 ± 2.44 Bq/kg, BDL to 27.2 ± 3.79 Bq/kg and BDL to 29.9 ± 4.64 Bq/kg in the upper, middle and lower regions respectively. Figure 6.2b showed the surface interpolations of ^{226}Ra concentrations down the river. The regional mean values of ^{226} Ra were 11.96 ± 1.7, 12.01 ± 4.5 and 13.2 ± 3.4 Bq/kg, for the upper, middle and lower regions respectively. The regional mean value of the middle region and that of the upper region were approximately the same. The activity concentrations of ^{232}Th in the upper, middle and lower regions varied between 2.8 ± 0.78 and 13.8 ± 1.24, BDL and 31.5 ± 6.04 and BDL and 31.4 ± 1.33 Bq/kg respectively. The regional mean values of ^{232}Th were 9.2 ± 0.6 Bq/kg, 10.4 ± 5.0 Bq/kg and 13.4 ± 5.6 Bq/kg, in the upper, middle and lower regions respectively. It was observed that the regional mean values for the concentration of ^{232}Th was increasing down the river. Figure 6.2c showed the surface interpolations of ^{232}Th concentrations down the river.

For the whole of Ogun river, the activity concentrations of ^{40}K, ranged from 186.6 ± 16.55 Bq/kg at Igboho to 783.7 ± 37.77 Bq/kg at Olopade, for ^{226}Ra, Ekerin and Maidan had the least values that were below detection limits and Ogunpa Wasimi had the highest value of 29.9 ± 4.64 Bq/kg, in this particular location, the activity concentration of ^{226}Ra was relatively high compared to the values obtained from the remaining locations, which may be due to geochemical processes around the area (Ricardo et al., 2009). The sediments in this area could be chemical sediments formed from dissolved materials derived from weathering which are precipitated from water streams, lakes or even river accumulations. For ^{232}Th, Mile 12- Maidan,Magbon, Opeji, Ekerin and Olokemeji had the least values which are below detection limits of the machine while Sokori had the highest value of 31.5 ± 6.04Bq/kg. Sokori is in Abeokuta, Ogun state and perhaps that is one of the reasons for the little rise in value of ^{232}Th and ^{226}Ra, compared with other locations, as it had been reported that Abeokuta is one of the places with high natural radioactity in Nigeria (Farai and Jibiri, 2000). The overall mean of the activity concentrations of ^{40}K for the sediments collected was 499.5 ± 59.2 Bq/kg, for ^{226}Ra, the value was 12.7 ± 3.5 Bq/kg and for ^{232}Th the value was 11.8 ± 5.1 Bq/kg. The value of ^{40}K was about the world's average value of 500 Bq/kg, while the values of ^{226} Ra and ^{232}Th were less than the world's average value of 50Bq/kg (Ramasamy et al., 2009). Granite rocks are commonly known to have high level of ^{40}K concentrations. Looking at the trend of ^{40}K especially in the upper region, the value was increasing from Idi- Ata upwards. The increasing trend of ^{40}K in this region may be due to the presence of loamy and clay sediments (El-Gamal *et al.*, 2007), or perhaps, the loamy and clay contents in the sediments in this region were decreasing down the region.

Comparing the results obtained from this study with the results from other studies in Nigeria, and areas in the world, Table 6.1, it was observed that the values of ^{226}Ra and ^{232}Th of Ogun river sediments were lower compared with the values obtained from the twenty dams and Ondo river sediments, but relatively fall within the same range with Osun river sediments in Nigeria. For the value of ^{40}K, the value for Ogun river was higher than that of Osun river, lower than the sediments from the twenty dams and compared relatively well with the Ondo river sediments. Also from the Table, it could be seen that the activity concentrations of the three radionuclides were consistent with values from different parts of the world. Due to this fact, and from the ranges of activity concentrations of the

Table 6.1: The range and (mean) of activity concentrations of the Radionuclides in Bq/kg estimated by different authors in comparison to the present study.

S/N	COUNTRY	^{40}K	^{226}Ra	^{232}Th	REFERENCES
1	Turkey	155.7 -868.7	26.8 - 49.8 **	17.06 - 35.62	Kam and Bozkurt, 2007
2	Egypt (Eastern Desert)	298.6 – 955.8	9.7 – 19.0	10.0 – 17.7	Harb, 2008
3	India (Jaduguda)	396.5 - 513.8 (464.21)	20.1 -120.0 (53.8)	23.8 - 69.9 (44.2)	Maharana et al., 2010
4	Bengal	118 - 608	5.9 - 27.9	10.4 - 64.0	Alam et., 1997
5	Bangladeshi (Shango River)	212- 292 (255)	21.6 - 28.3 (25.4)**	52.4 - 61.7 (57.5)	Chowdhurry et al., 2009
6	India (Kali river)	296.0 - 525.0 (394.7)	34.1 - 49.4 (40.1)**	4.6 - 12.2 (6.9)	Narayana et al., 2007,Isikaye,2009
7	Egypt, Wadi Nugrus,	306.7 -626.0	24.7 - 86.45 (43.91)**	20.3 - 48.72 (26.62)	Abdel-Razek(2008)
8	India (Tamilnadu)	201.23 - 467.71 (384.113)	BDL - 11.6 (7.31)	BDL - 106.11 (46.85)	Ramasamy et al., 2009
9	Egypt, Nile river	(351.9)	(52)	(76.20)	Uosif, 2007
10	Kuwait	(227)	(36)	(6)	Saad and Al-Azmi, 2002
11	Algeria (Algiers Bay)	56 - 607 (374)	4.45 - 25.04 (15.8)**	6.5 - 31.7 (19.5)	Benemar et al., 1997, Isikaye, 2009
12	China (Wei River)	514.8 - 1175.5 (833.3)	10.4 - 39.9 (21.8)	15.3 - 54.8 (33.1)	Xinwei et al., 2008
13	Pakistan	(647.4)	(32.9)	(53.6)	Matiullah et al., 2004
14	Nigeria, Southwest (Twenty Dams)	191.1 - 1025.9 (549.3)	17.1 -51.9 (27.9)**	26.2 - 130.1 (62.0)	Isinkaye, 2009
15	Nigeria, Southwest (Osun River)	175.6 - 188.5	13.1 -28.4 **	11.4 - 16.3	Oyebanjo, 2010
16	Nigeria, Akoko river, Ondo	142.57 -839.28	9.40 -52.71	24.87 - 301.14	Ajayi, 2008
17	**Nigeria, Southwest (Ogun River)**	**186.6 - 783.7 (499.5)**	**BDL - 29.9 (12.7)**	**BDL - 31.5 (11.8)**	**Present Study**

*- ^{228}Ra, **^{238}U ( ), = mean concentration

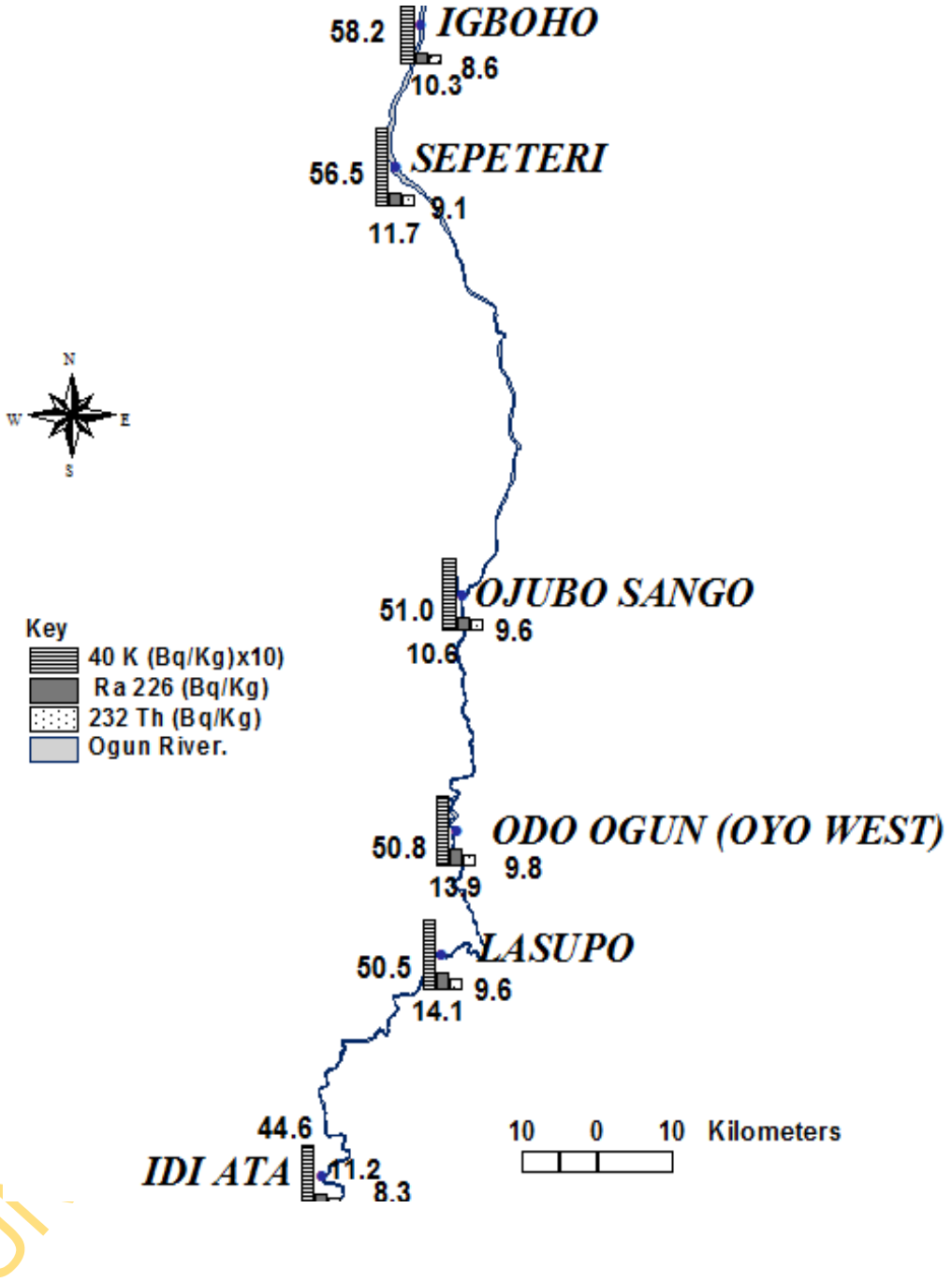

Fig 6.1a Chart of the average values of the three radionuclides in each location from Upper region of the river

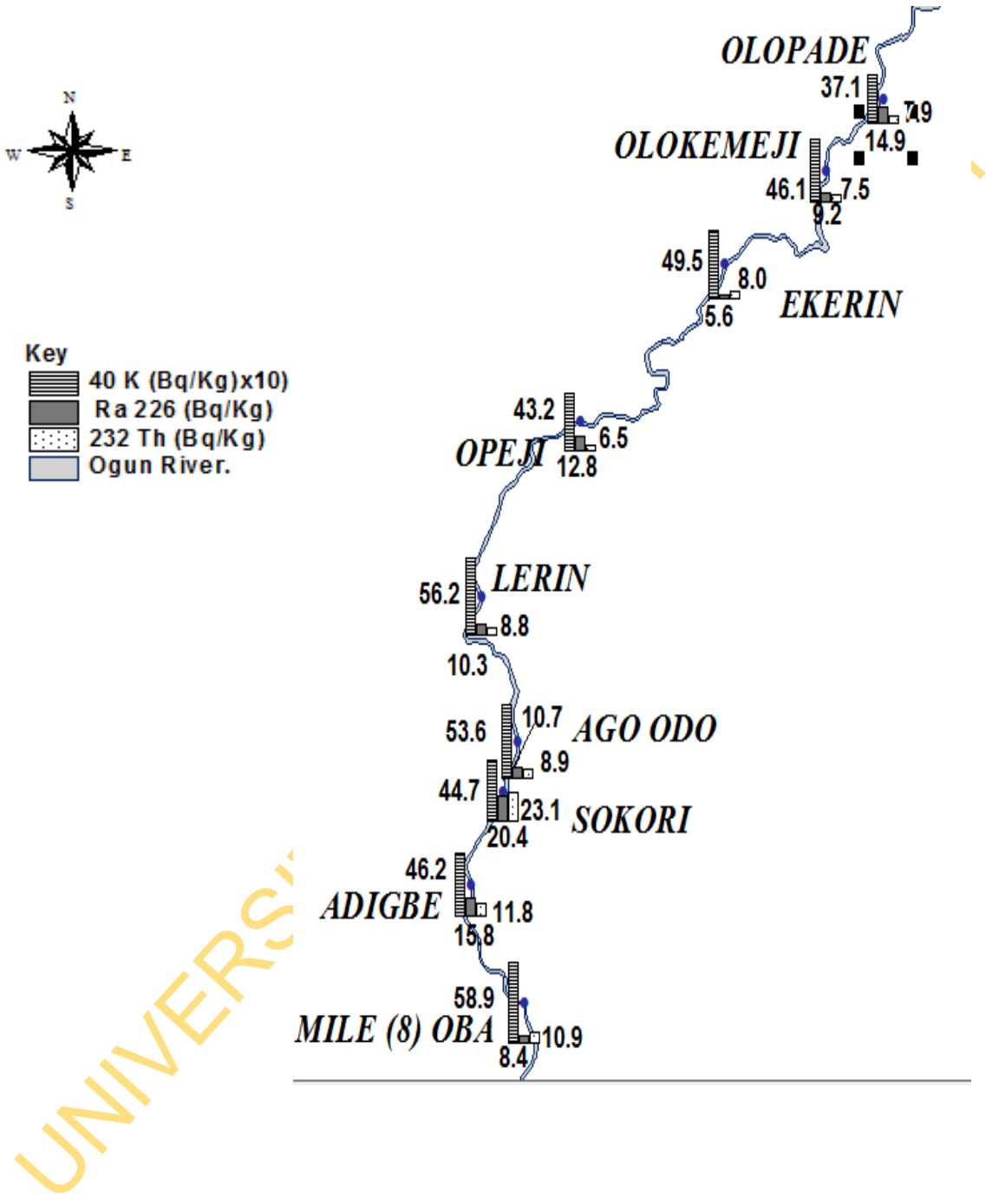

Fig 6.1b Chart of the average values of the three radionuclides in each location from middle region of the river

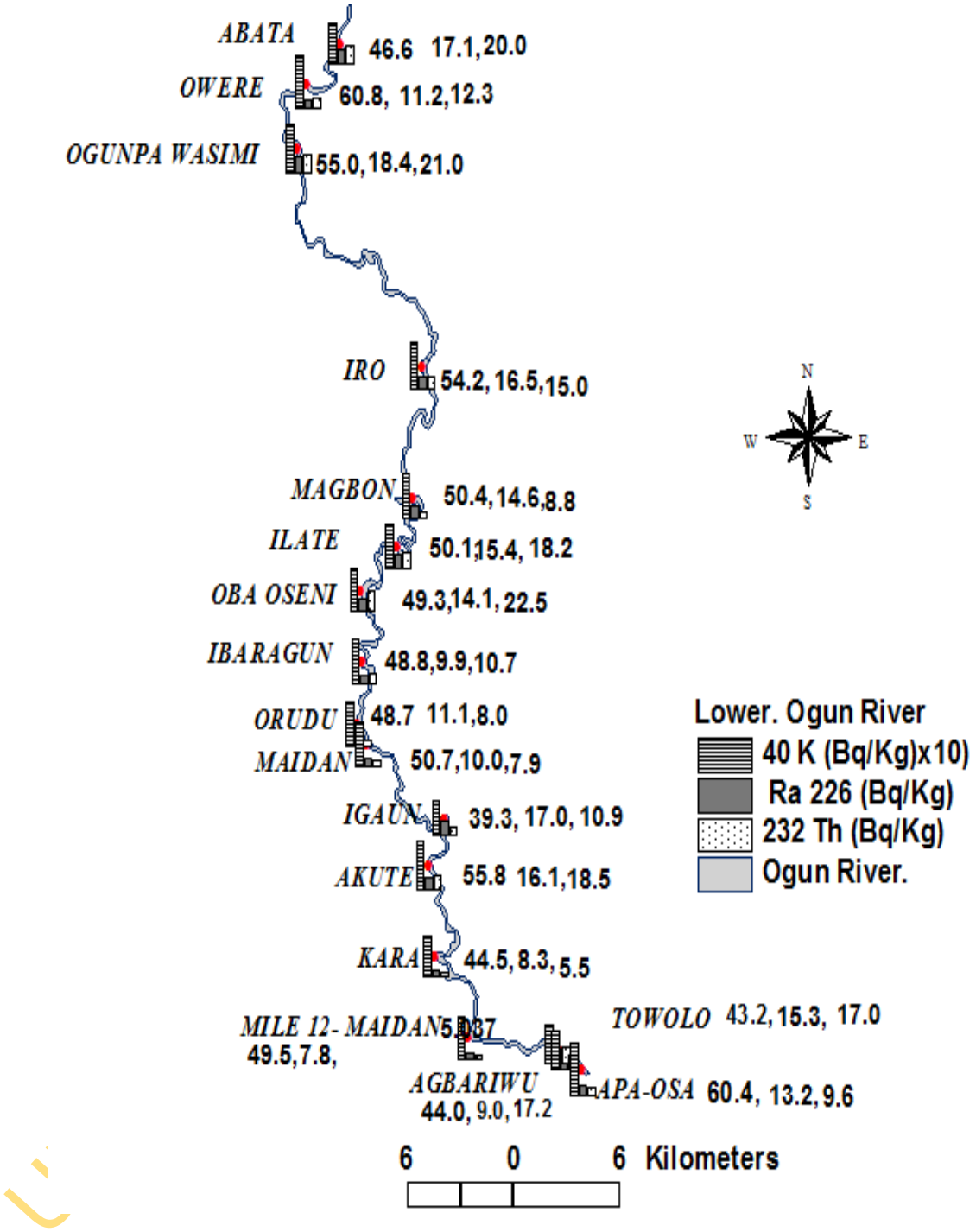

Fig 6.1c Chart of the average values of the three radionuclides in each location from lower region of the river

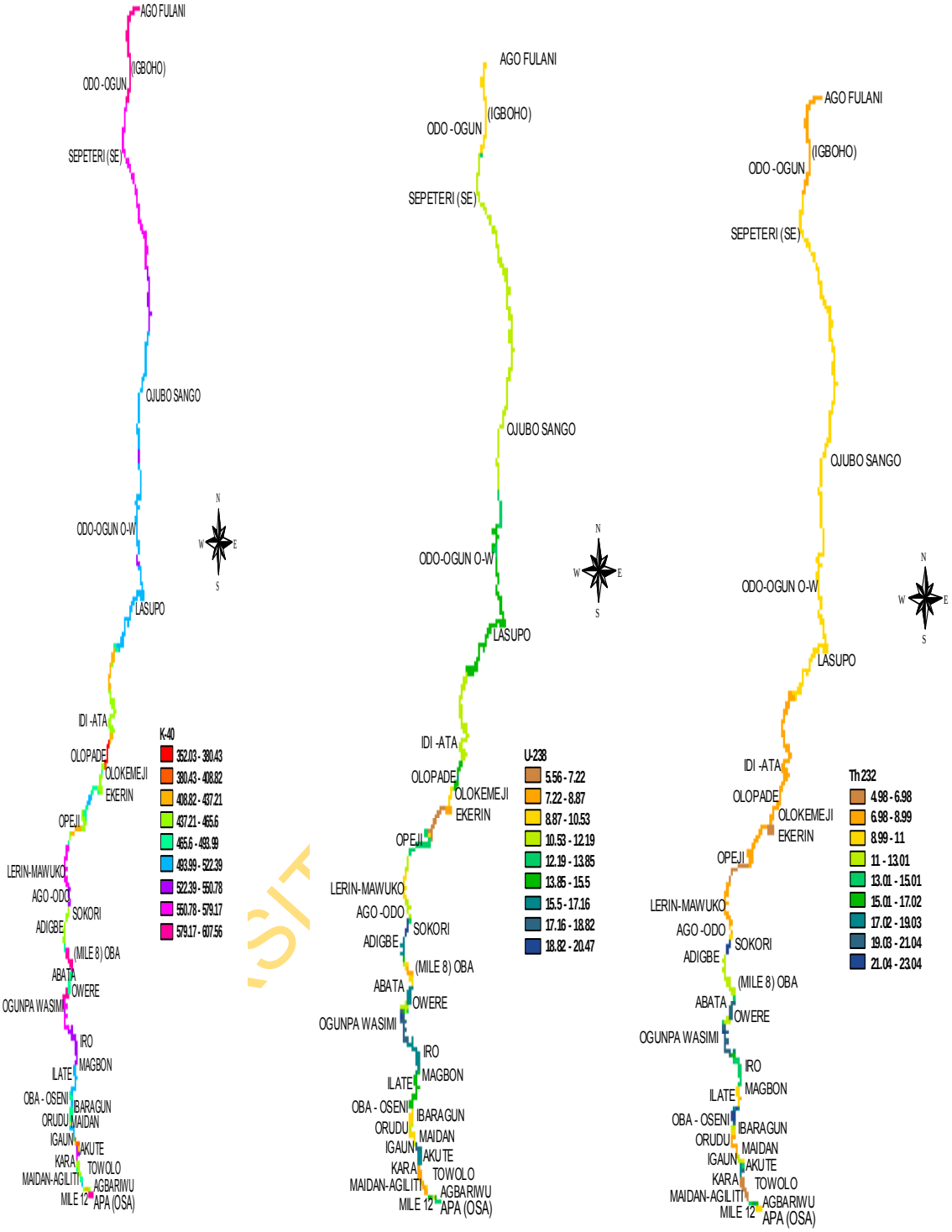

Fig. 6.2(a) Fig. 6.2(b) Fig. 6.2 (c)

Fig 6.2(a-c) Surface interpolation plots of the concentrations of each radionuclides

radionuclides obtained in this study, the activity concentrations of the sediments from Ogun river can be classified under the area with normal background radiation (Isikaye, 2009; Farai and Jibiri, 2000). The along the river ranges observed in this study are within the range of values for crustal concentrations of 140-820 Bq/kg for ^{40}K, 16-110 Bq/kg for ^{238}U and 11-64 Bq/kg for ^{232}Th reported in UNSCEAR (2000) for areas with normal background radiation levels around the world (Isikaye, 2009).

The activity concentrations of natural radionuclides in the study area were in agreement with the global trend on the distribution of natural radionuclides in sediments. The variations observed in the different location could be attributed partly to drainage pattern of the study area. The foliation and joints on these rocks control the course of the rivers, causing them to form a trellis drainage pattern, particularly to the north of the area. Apart from these natural processes, human activities such as agricultural practices in which fertilizers are applied to improve crop yield had been known to contribute to the variations of activity concentrations of natural radionuclides.

6.2 Determination of Radiological Hazard Indices

It is important to assess the gamma radiation hazards to human that is associated with the use of these sediment samples for buildings. These was done by calculating the different radiation hazard indices using the activity concentrations of the radionuclides in the sediment samples

6.2.1 Radium Equivalent Activity (Bq/kg) of Ogun River Sediments

Considering Tables 5.4, 5.5 and 5.6 and Figures 6.3a-c, the highest activity value was found at Lasupo 91.57 Bq/kg, the least activity value was found at Igboho having activity value of 23.72 Bq/kg in the upper region, while in the middle region, Sokori had the highest (101.27 Bq/kg) and Ekerin had the least (26.29 Bq/kg). For the lower region, Ogunpa Wasimi had the highest (115.93 Bq/kg) and the least value was found at Mile -12 Maidan (28.89 Bq/kg), In the upper region, the mean value of the radium equivalent activity was 65.16±4.14Bq/kg, in the middle, the mean value for the parameter was 64.1± 10.78Bq/kg, while in the lower region, the mean value was found to be 71.00 ± 11.78 Bq/kg. For the whole Ogun river, the overall mean activity value for the radium equivalent was 68.00 ±

10.74 Bq/kq. The value ranged from 23.72 – 115.93 Bq/kg. As it could be seen, none of the samples measured had radium equivalent activity value that exceeded 370 Bq/kg. Some of the works reported on radium equivalent are as follows: (Isikaye, 2009), reported a mean of 158 ± 46.7 Bq/kg for the sediments collected from twenty dams in the South western Nigeria. The value of radium equivalent activity of Ogun river sediments was lower than the values of the twenty dams sediments reported by Isikaye (2009). Oyebanjo (2010) reported radium equivalent activity of 42.88 Bq/kg, for the lower , 62.54 Bq/kg for the middle course and 65.68 Bq/kg for the upper course of Osun river in South western Nigeria. Looking at the values obtained from Osun river, the value was decreasing down the river having its highest value at the upper region and the least value was at the lower region, but for Ogun river, the highest value was at the lower region and the least value was at the middle region. The mean value of radium equivalent activity of Akoko river sediments in Ondo by Ajayi, 2008 was 140.54 Bq/kg. The values of the mean and range of radium equivalent activity obtained for the sediments of Ogun river follow a consistent trend with the values reported for sediment of rivers in different locations around the world. Comparing the value of the radium equivalent in Ogun river sediments with some other building materials in upper Egypt by (Abbady, 2006) it was found that 147.5 Bq/kg was estimated for limestone, 175.3 Bq/kg was for sand, 304.1 Bq/kg was estimated for Marble, 181.2 Bq/kg was estimated for clay bricks, 114.3Bq/kg was estimated for red brick, 139.0 Bq/kg was estimated for gympsum, 78.8 Bq/kg was estimated for Portland cement and 54 Bq/kg for white cements. The mean value of radium equivalent activity for Ogun river sediments was higher than the value for white cement reported by Abbady but lower than every other measured materials studied. From the safety limit point of view, the maximum values of the radium equivalent for a material to be used in building construction is $Ra_{eq} \leq 370$ Bq/kg (UNSCEAR, 1982; Beretka and Mathew, 1985; Tufail et al., 2007). The Radium equivalent of 370 Bq/kg corresponds to the dose limit of 1mSv for the general public. The use of materials whose radium equivalent concentration exceeds 370 Bq/kg is discouraged in order to avoid radiation hazards (Sam and Abbas , 2001; Shiva Prasad et al ., 2008). Therefore, Ogun river sediments are safe from radiation hazards since the radium equivalent values of the sediments are lower than 370 Bq/kg.

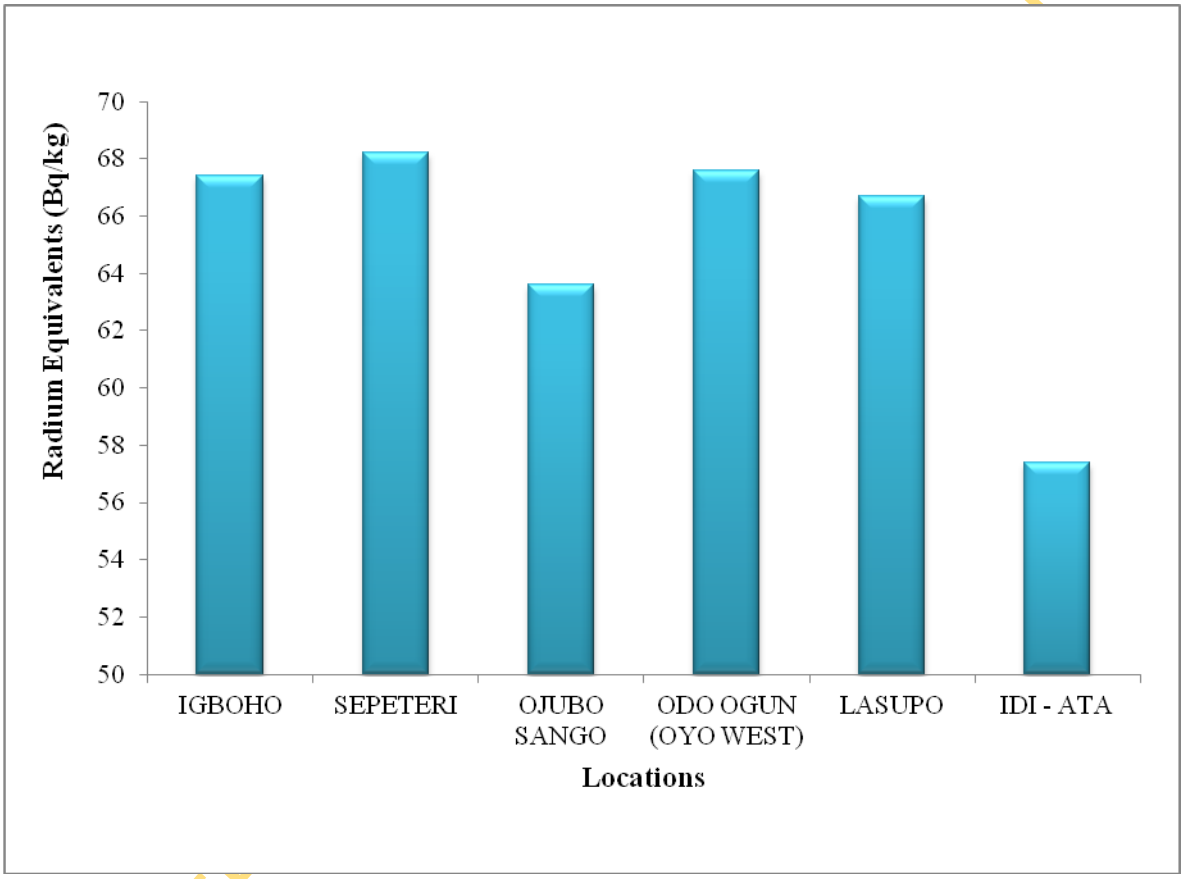

Fig 6.3a: Distribution of the mean radium equivalent activities in the upper region of Ogun river.

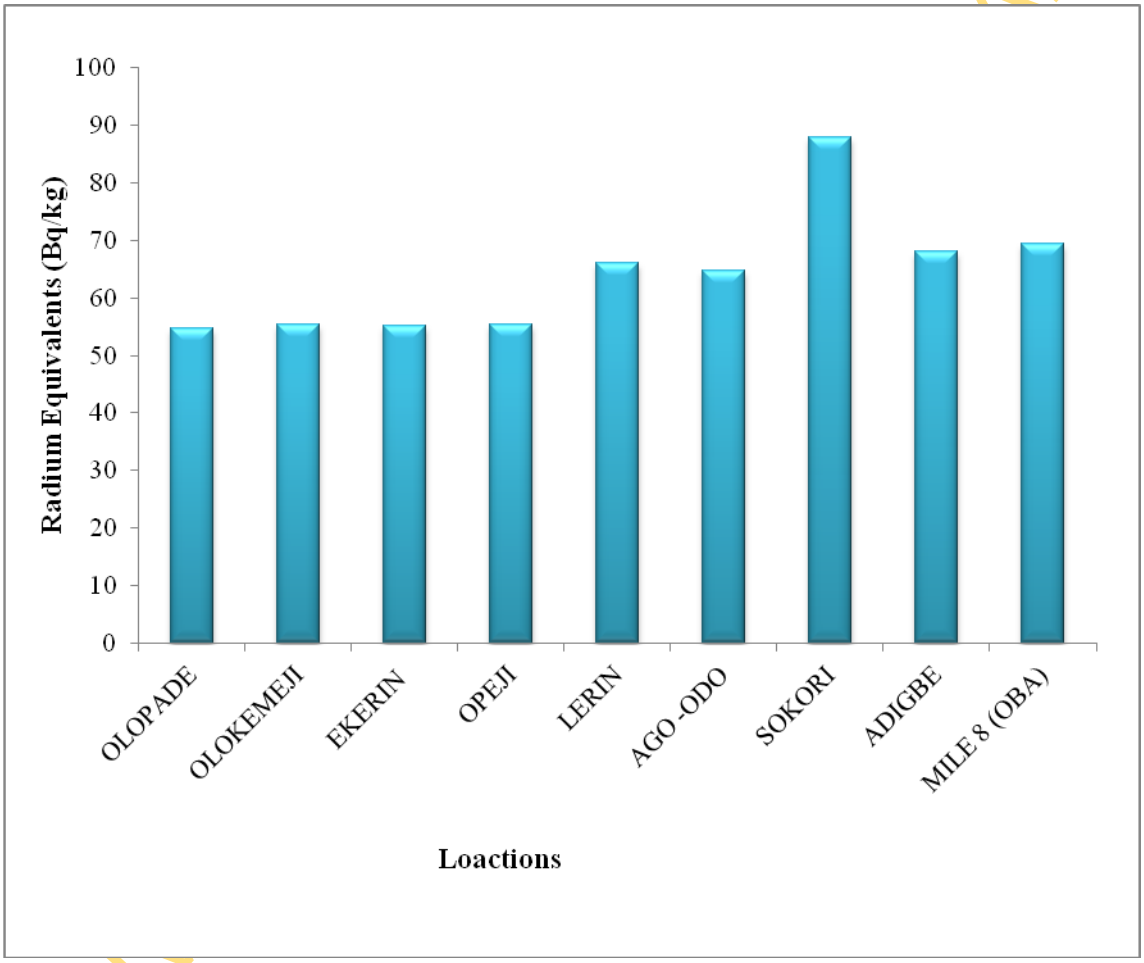

Fig 6.3b: Distribution of the mean radium equivalent activities in the middle region of Ogun river.

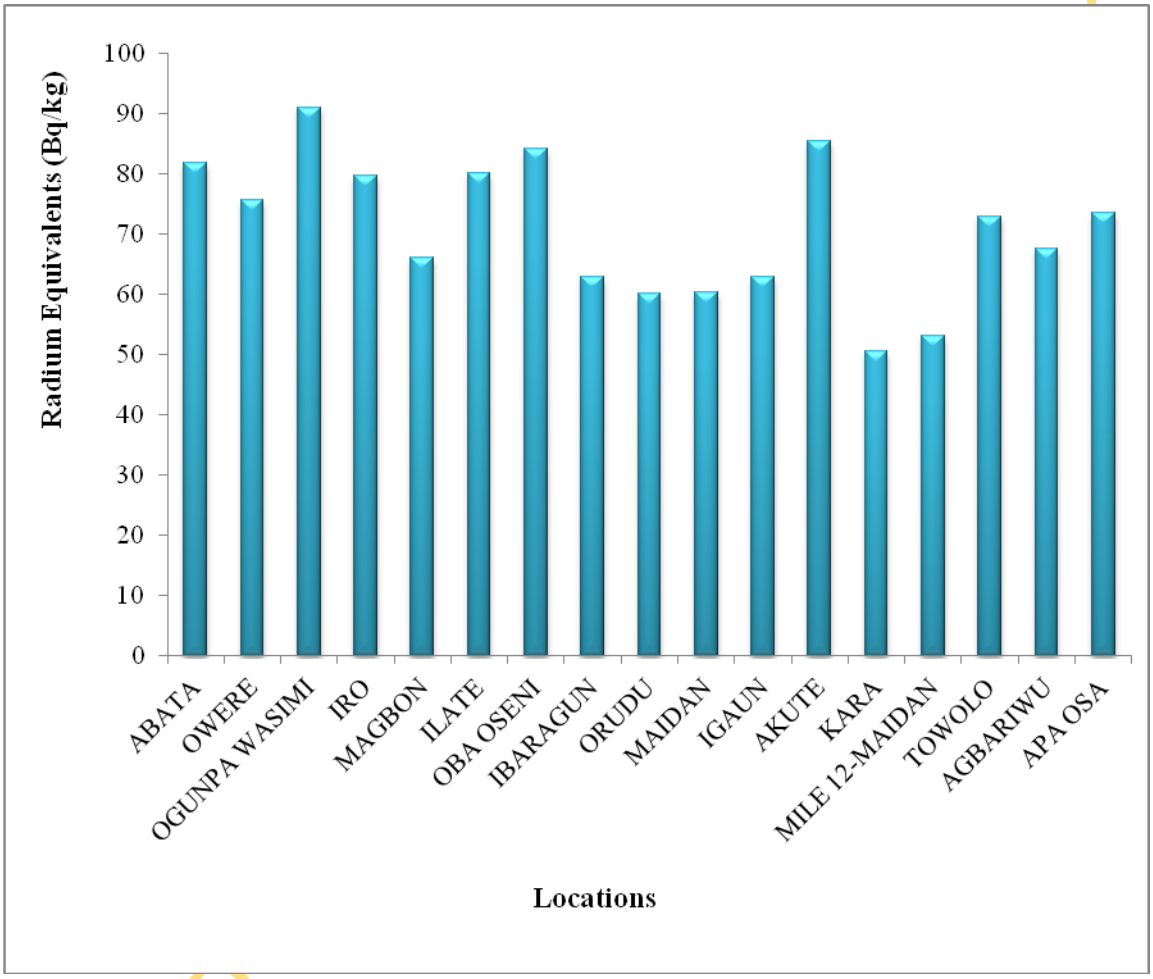

Fig 6.3c: Distribution of the mean radium equivalent activities in the lower region of Ogun river.

6.2.2 The External Hazard Index (H_{EX})

From Figures 6.4a-c, the mean of the external hazard index calculated for the upper region was 0.18 A± 0.01, while the values varied between 0.06 Igboho and 0.25 Lasupo. Also, the mean for the middle region was 0.17 ± 0.03, this region have values varying between 0.07 (Ekerin) and 0.27 (Sokori). The value of (H_{EX}), in the lower region of Ogun river varied between 0.08 (Mile 12-Maidan) and 0.31 (Ogunpa Wasimi), with a mean of 0.19 ± 0.03. The overall mean of the external hazard index in Ogun river was found to be 0.18 ± 0.03, the value ranged between 0.06 and 0.31. Oyebanjo (2010) reported the value of external hazard index in Osun river sediments South Western Nigeria as 0.12 for the upper region, 0.17 for the middle and 0.11 for the lower region. The average values of external hazard index in the upper, middle and lower regions of Ogun river sediments were slightly higher than that of Osun river sediments except for the middle region where the values were the same, although both values are less than the safe limit.

6.2.3: The internal hazard index (H_{IN})

From Figures 6.4 a-c, it was seen that in the upper, middle and lower regions, Lasupo (0.296), Sokori and Ekerin (0.33) and Towolo (0.42) had the highest values of the internal hazard index while Igboho (0.08), Ekerin (0.07) and Mile 12- Maidan (0.80) had the least values respectively for the regions.The mean for each region were 0.208 ± 0.01, 0.206 ± 0.04 and 0.234 ± 0.05 for the upper, middle and lower regions respectively. The overall mean of the internal hazard index for Ogun river was 0.221 ± 0.04, varying from 0.07 to 0.42.

Isikaye (2009) reported that the mean values of the sediments obtained from the twenty dams in South West Nigeria, varied from 0.34 to 0.74 for the internal hazard index. The value from Ogun river sediments was lower than this value. The highest range of the total mean value from Ogun river was just a little higher than the least range of the mean value of the sediments from the twenty dams. Generally, the values are still below the recommended safe limit.

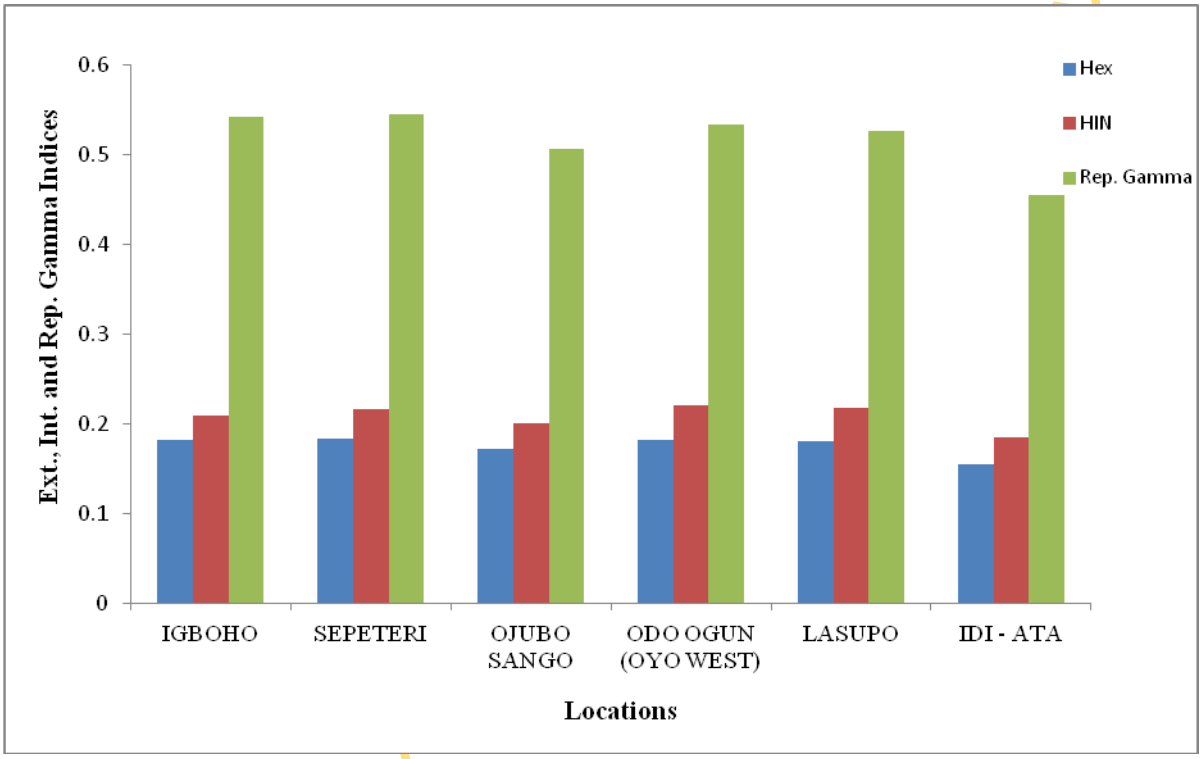

Fig. 6.4a: The distributions of the radiological assessment for the upper Ogun river

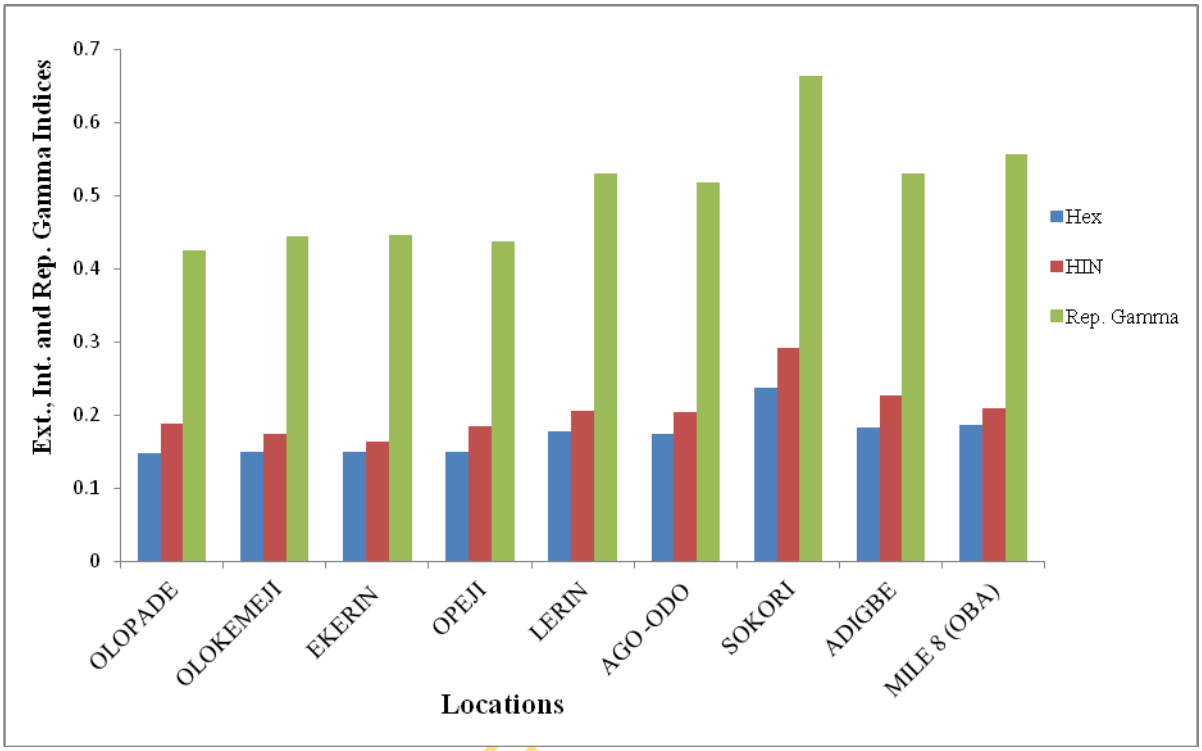

Fig. 6.4b: The distributions of the radiological assessment for the middle Ogun river

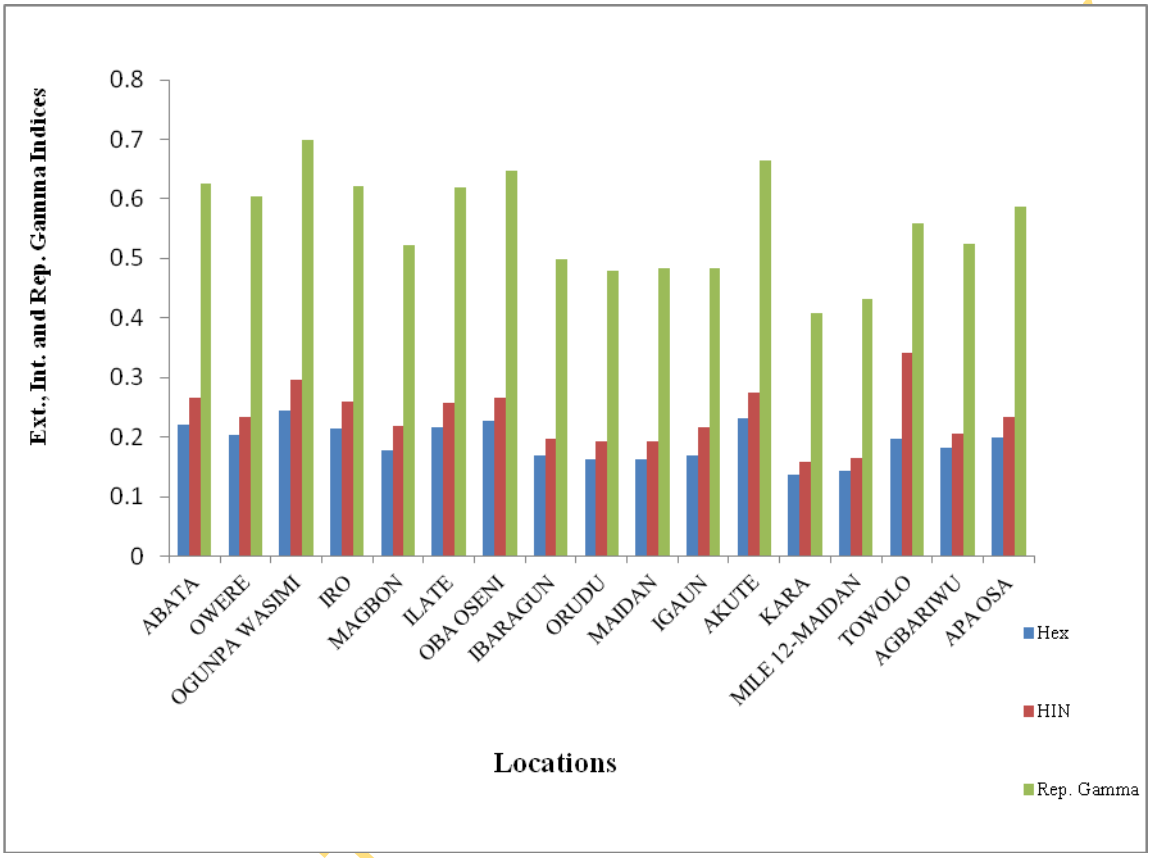

Fig. 6.4c: The distributions of the radiological assessment for lower Ogun river

6.2.4: The Representative Gamma Index

Considering Figures 6.4a-c, in the upper region, the highest value of the representative gamma index was found at Lasupo (0.73) and the least was at Igboho (0.19), the mean for the upper region was 0.52 ±0.03. In the middle region, Sokori and Ekerin had the highest value (0.78) and a site in Ekerin also had the least value (0.23). The mean for the middle region was found to be 0.51 ± 0.08. Lastly, in the lower region, Ogunpa Wasimi had the highest value (0.87) while Mile 12- Maidan had the least (0.25), the mean value for the lower region was 0.56 ± 0.09. The total mean value of the representative gamma index for Ogun river sediments was found to be 0.54 ±0.08, varying from 0.19 to 0.87. The value was below the maximum permissible value of unity recommended by the European Commission for materials used in bulk quantities in building construction so as to limit the indoor effective dose rate to 1.0 mSv/y (Isikaye, 2009). The overall mean value obtained from the sediments of the Twenty dams from south west Nigeria reported by Isikaye, (2009) was 0.59 ± 0.18, this value was slightly higher than the value of the representative gamma index obtained for the sediments from Ogun river, South Western Nigeria.

6.2.5: The Indoor Gamma Dose Rate

The mean value of indoor gamma dose rate estimated for each region were 62.74 ± 4.1, 60.80 ± 9.03 and 67.01 ± 10.03. The overall value of the indoor gamma dose rate from Ogun river sediments was estimated to vary from 22.92 – 105.35 nGy/hr and the mean was 64.5 ± 9.2 nGy/hr. Comparing the value of the gamma absorbed dose rate obtained in Ogun river sediments with the values obtained from the twenty surface water dam in SouthWestern Nigeria, the value varied from 88.6 ± 24.5 nGy/h - 206.2 ± 105.7 nGy/h as reported by (Isikaye, 2009). This value was higher than that value obtained for Ogun river sediments. This could be as a result of high concentrations of the measured radiouclides in the samples from the twenty dams, since the concentrations of the measured radionclides from Ogun river are relatively lower than those from the twenty dams. From Figures 6.5a-c, Tables 5.13- 5.15, it could be seen that Lasupo had the highest value of 88.38 nGy/hr, and Igboho had the least value of 22.92 nGy/hr. In the middlle region of the river, it was seen that Sokori had the highest value of 93.63 nGy/hr, while Ekerin had the lowest value of 26.97 nGy/hr. In the lower region, Ogunpa Wasimi had the highest value of 105.38 nGy/hr,

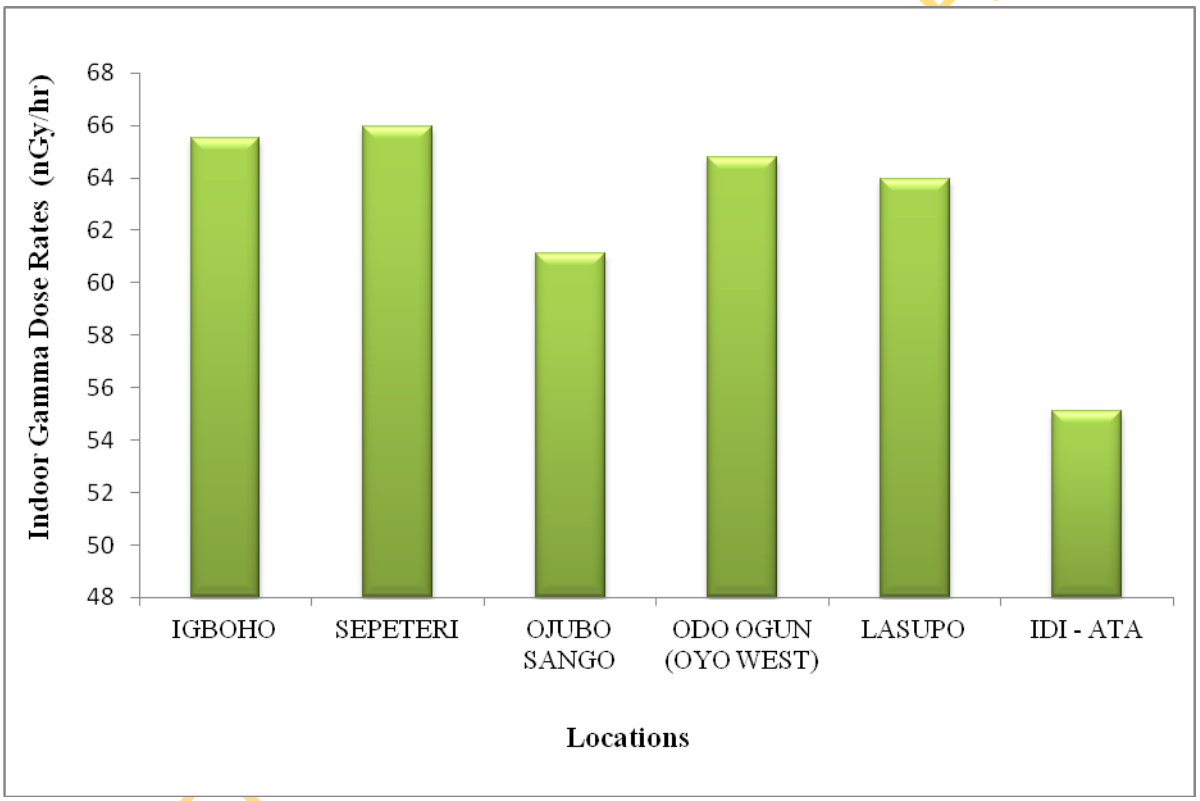

Fig. 6.5a: The indoor gamma dose rate in the upper region of Ogun river.

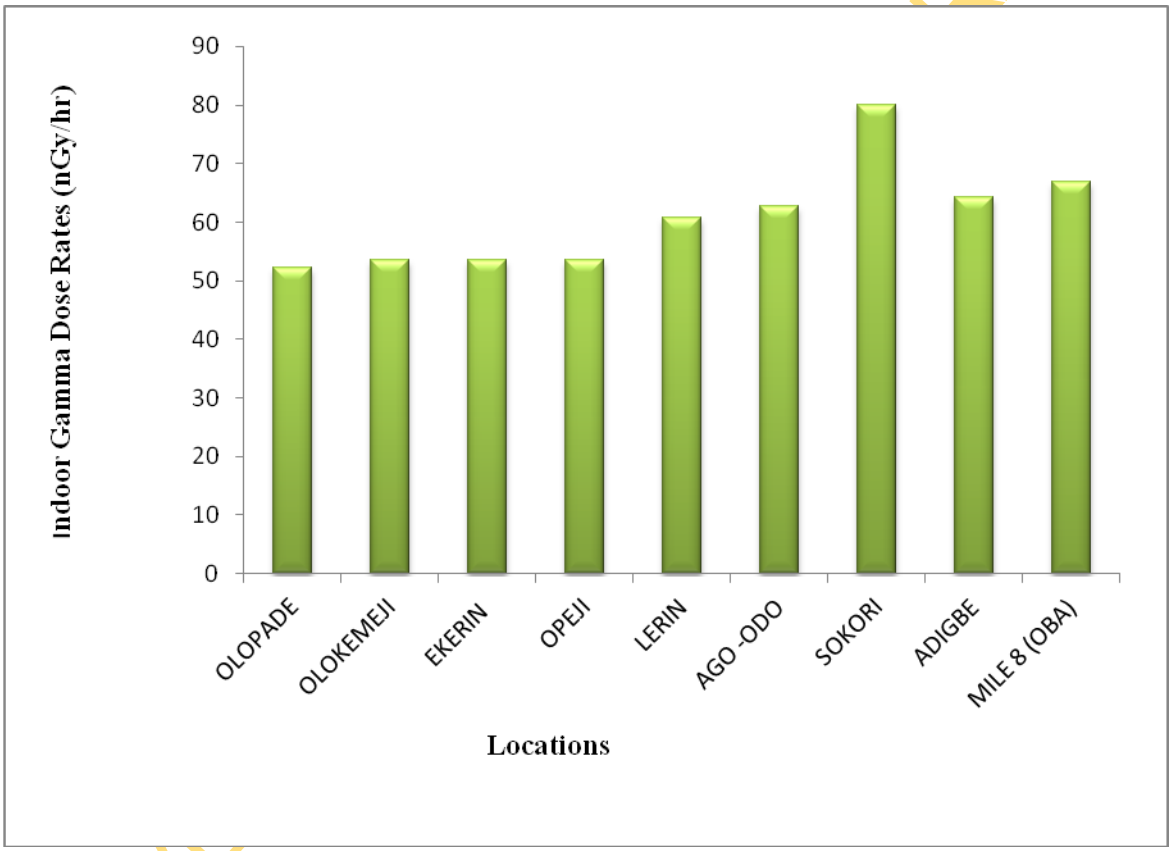

Fig. 6.5b: The indoor gamma dose rate in the middle region of Ogun river.

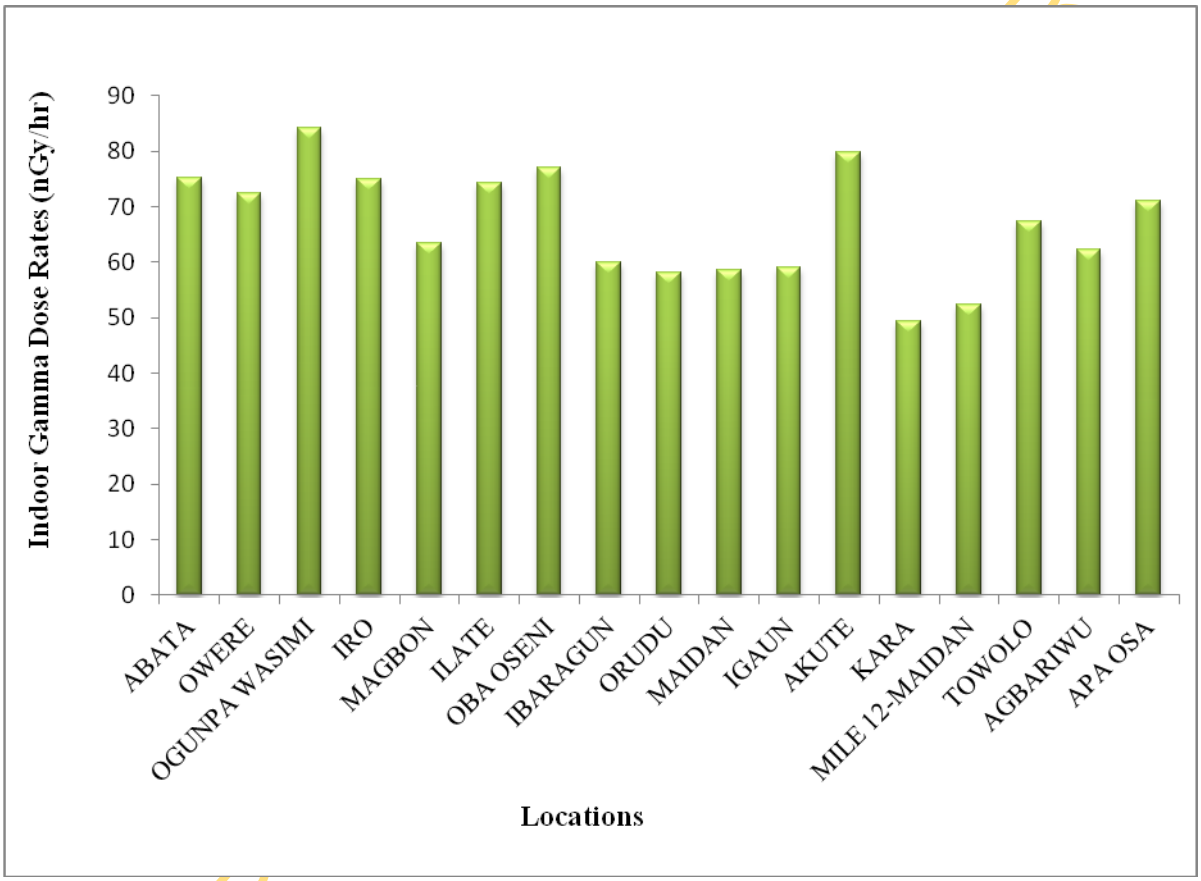

Fig. 6.5c: The indoor gamma dose rate in the lower region of Ogun river

while Mile 12- Maidan had the lowest value of 29.60 nGy/hr. The value of the indoor gamma dose rate was lower than the recommended international standard.

6.2.6 The Indoor Effective Dose Rate

From Table 5.13, and Figure 6.6a, Lasupo had the highest value of 0.43 mSv/yr and Igboho had the least value of 0.11 mSv/yr for the indoor effective dose rate in the upper region. While in the middle region, Sokori and Ekerin had the highest value of 0.46 mSv/yr and a site in Ekerin had the least value of 0.13 mSv/yr from Table 5.14 and Figure 6.6b. In the lower region of the river, the highest value of indoor effective dose rate was found at Ogunpa Wasimi 0.517 mSv/yr and the least was found at Mile 12- Maidan 0.145 mSv/yr, (Table 5.15 and Figure 6.6c). It could be seen that in the upper region, Lasupo had the highest values for both the indoor gamma dose rate and indoor effective dose rate and Igboho had the least values for both parameters. For the two parameters in the middle region, Sokori and Ekerin had the highest and the least respectively. Lastly, Ogunpa Wasimi and Mile 12- Maidan had the highest and the least values respectively for the two parameters in the lower region. The mean value of indoor gamma effective dose estimated for each region were 0.308 ± 0.02, 0.300 ± 0.05 and 0.329 ± 0.05 mSv/yr. The overall value of the indoor gamma effective dose rates varied from 0.11 – 0.52 mSv/y and the overall mean was 0.317 ± 0.045, this is less than the world's average value of 0.450 mSv/y (Orgun *et al.*, 2007) and also lower than the dose criterion of 1 mSv/y. Isinkaye (2009) reported that the mean indoor effective dose rates varied from 0.43 to 1.0 mSv/y with an overall mean effective dose rate of 0.653 mSv/y for the sediments obtained from the twenty dams in southWestern Nigeria. The overall value obtained from Ogun river sediments was seen to be less than half of the over all value for the sediments from the twenty dams from Nigeria southWest. Wadi Nugrus in Egypt sediments were found to have the indoor effective dose rates to vary from 0.26 – 0.66 mSv/y with a mean of 0.39 ± 0.12 reported by Abdel-Razek et al., (2008). Since the result compare well with the results from Nigeria and other parts of the world and it is less than the criterion limit, then the sediment used as building material does not pose any radiological hazard to the public.

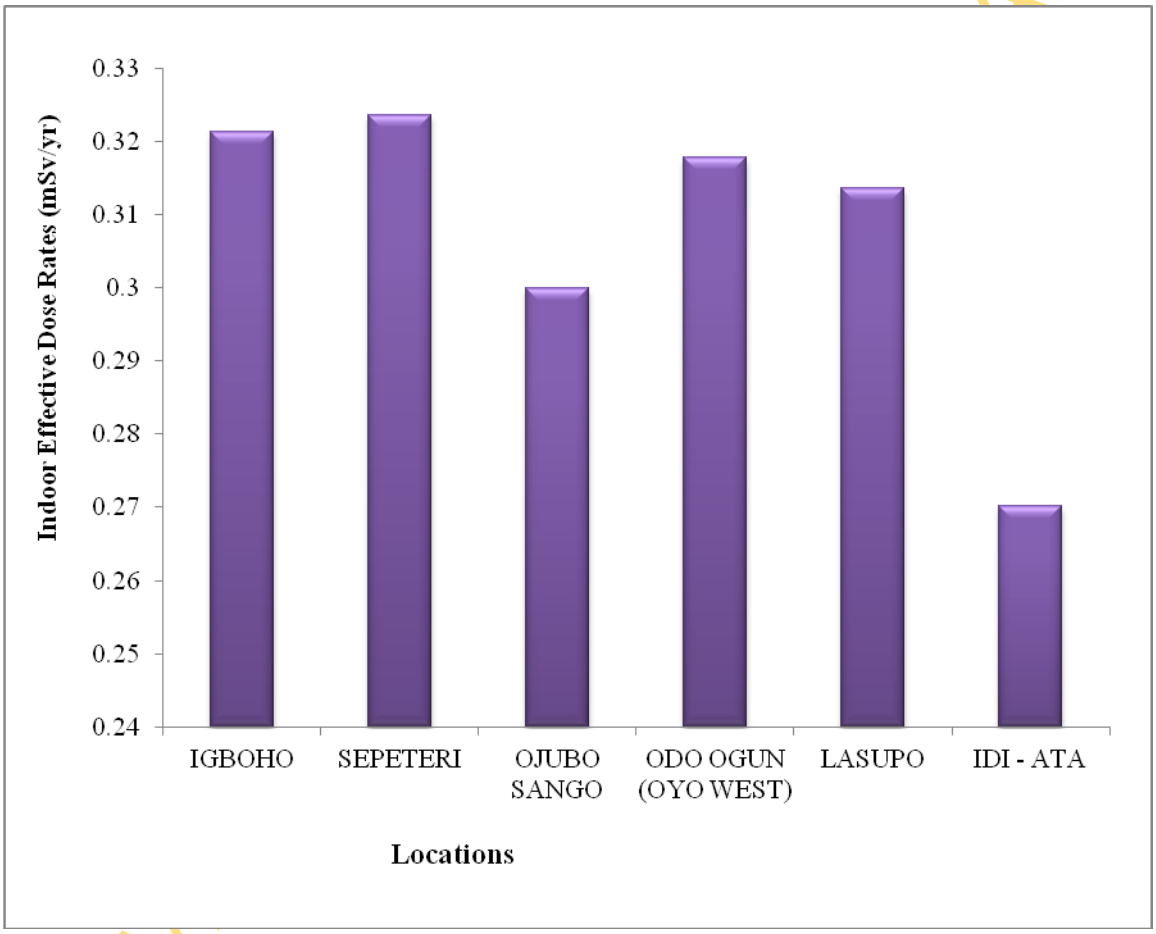

Fig. 6.6a: The indoor effective dose rate in the upper Ogun river

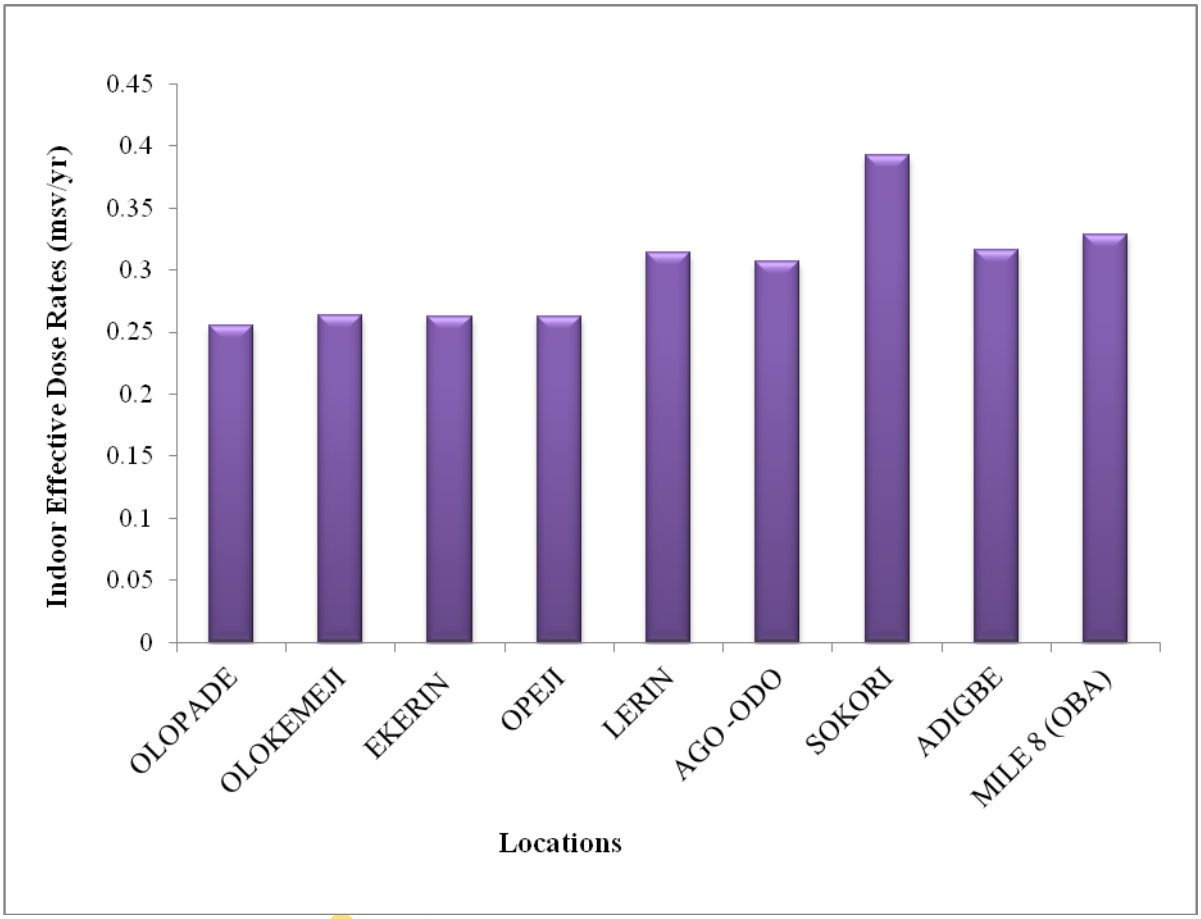

Fig. 6.6b: The indoor effective dose rate in the middle Ogun river

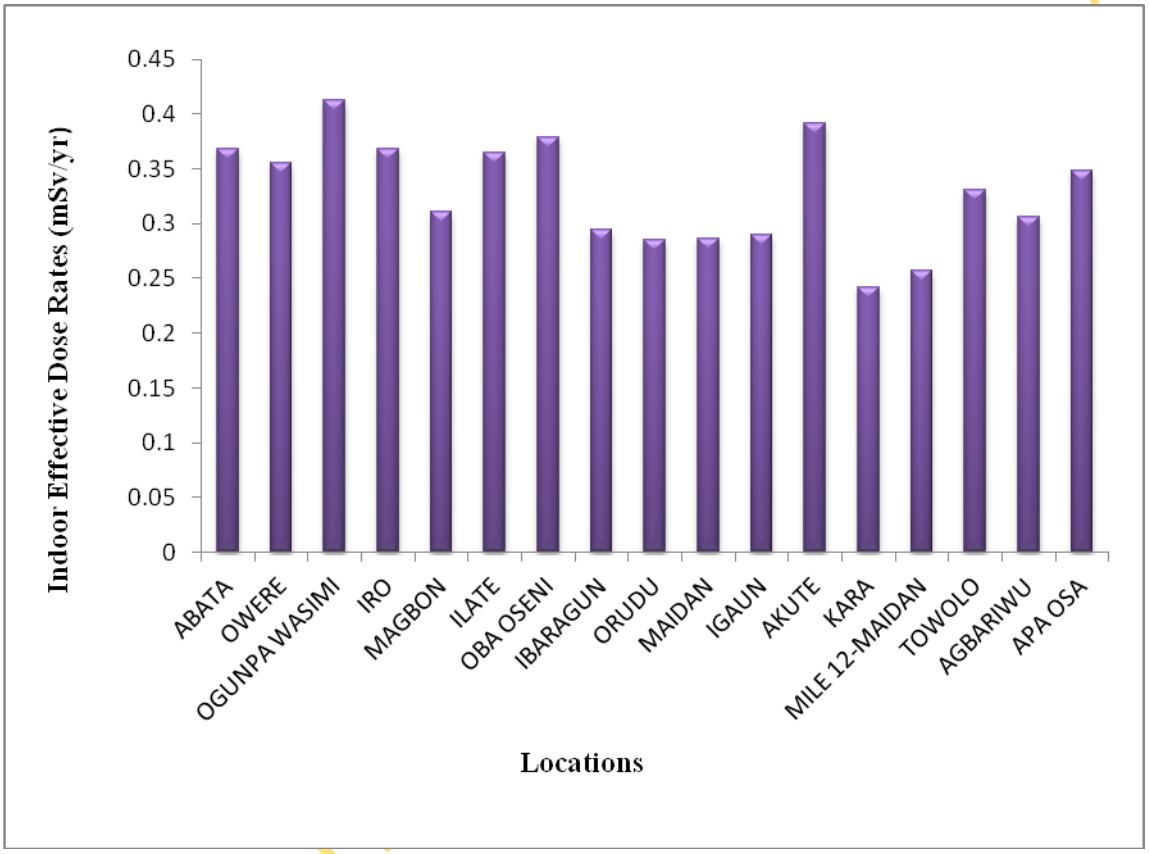

Fig. 6.6c: The indoor effective dose rate in the lower Ogun river

6.2.7 Excess Lifetime Cancer Risk (ELCR):

As could be observed from Table 5.16 - 5.18 and illustrated in Figures (6.7 a-c), in the upper region, the highest value of the ELCR was at Lasupo (0.198×10^{-3}) and the least was at Igboho (0.051×10^{-3}). In the middle region, Olopade had the highest value of (0.290×10^{-3}) while Ekerin had the least value of (0.061×10^{-3}). In the lower region, Ogunpa Wasimi had the highest value (0.238×10^{-3}) and Orudu had (0.062×10^{-3}).

The mean for the upper region was $0.141 \times 10^{-3} \pm 0.009$, for the middle region it was $0.137 \times 10^{-3} \pm 0.02$ and the mean for the lower region was $0.148 \times 10^{-3} \pm 0.03$.

The estimated total value of ELCR for Ogun river sediments was found to be $0.143 \times 10^{-3} \pm 0.02$, ranging from $0.051 \times 10^{-3} - 0.290 \times 10^{-3}$. Comparing the value of the ELCR estimated for Ogun river sediments with the value obtained in Tamilnadu, India, Ramasamy (2009) reported that the average value of ELCR was estimated to be 0.202×10^{-3} and the values ranged from 0.071×10^{-3} -0.370×10^{-3}. The value for Ogun river was lower than this value and was lower than the world's average value of (0.29×10^{-3}) (Taskin *et al.,* 2009). This showed that the probability of developing cancer over a lifetime by the people around Ogun river and its environs who use the sediments for building of dwellings and other purposes is very low.

6.2.8 Thorium To Uranium Ratio

From Table 5.16 and Figures 6.8 a, in the upper region of the river, the highest value of Th/U ratio was found at Idi- Ata (3.74), while the least value was found at Lasupo (0.19). The mean of Th/U ratio for the upper region was found to be 0.848 ± 0.112.

In the middle region of the river (Table 5.17, Figure 6.8b), Olopade had the highest value (3.69) while Opeji, Ekerin and Olokemeji had the same but least value of (0.0). The mean value of Th/u ratio for the middle region was found to be 0.913 ± 0.276. For the lower region, Tables 5.18, Figure 6.8c, Towolo had the highest value of 16.20 while Mile12- Maidan, Maidan and Magbon had the least 0.0. The mean for the lower region was 1.381 ± 0.835. The total mean value for the Th/U ratio estimated for Ogun river sediments was 1.149 ± 0.667 ranging from 0.0 – 16.20. This value was approximately unity. This showed that the uranium contents in the Ogun river sediments were slightly lower than the thorium contents, but the difference were not too significant. It was observed that the trend although not linear but the

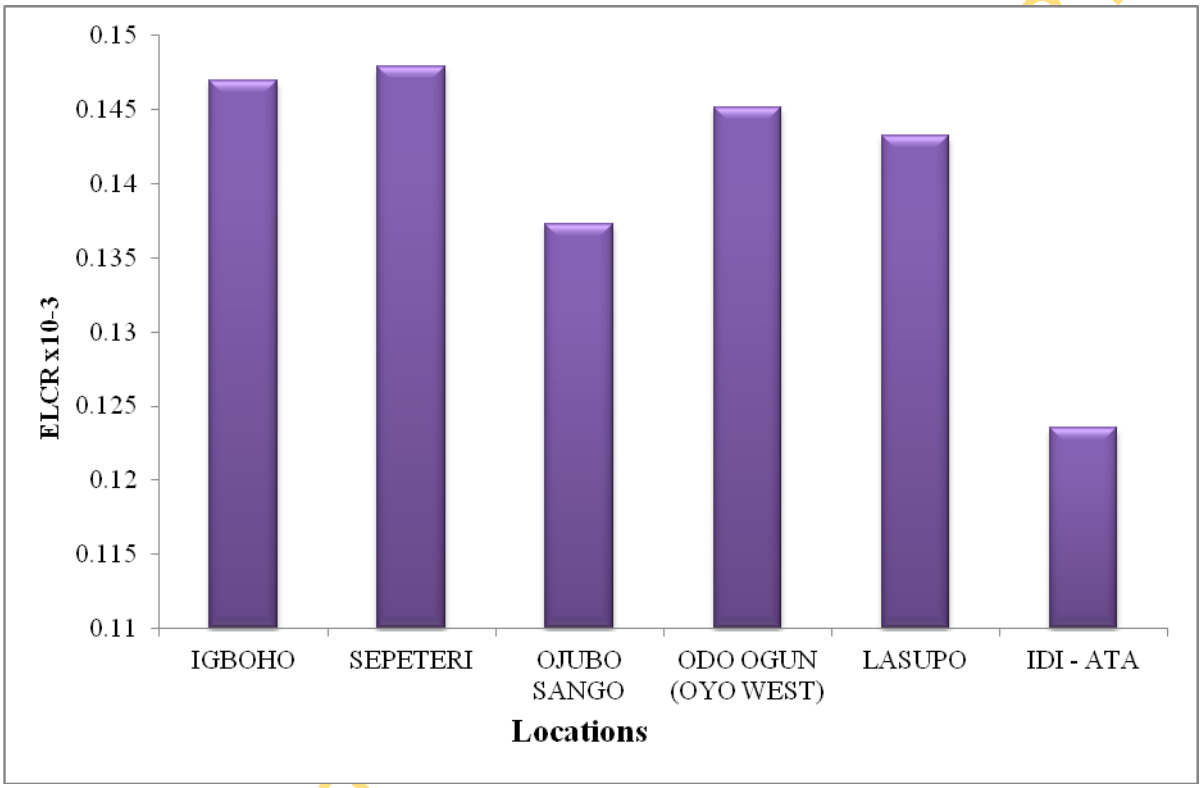

Fig 6.7a: Distribution of the Excess Lifetime Cancer Risks For Upper Region

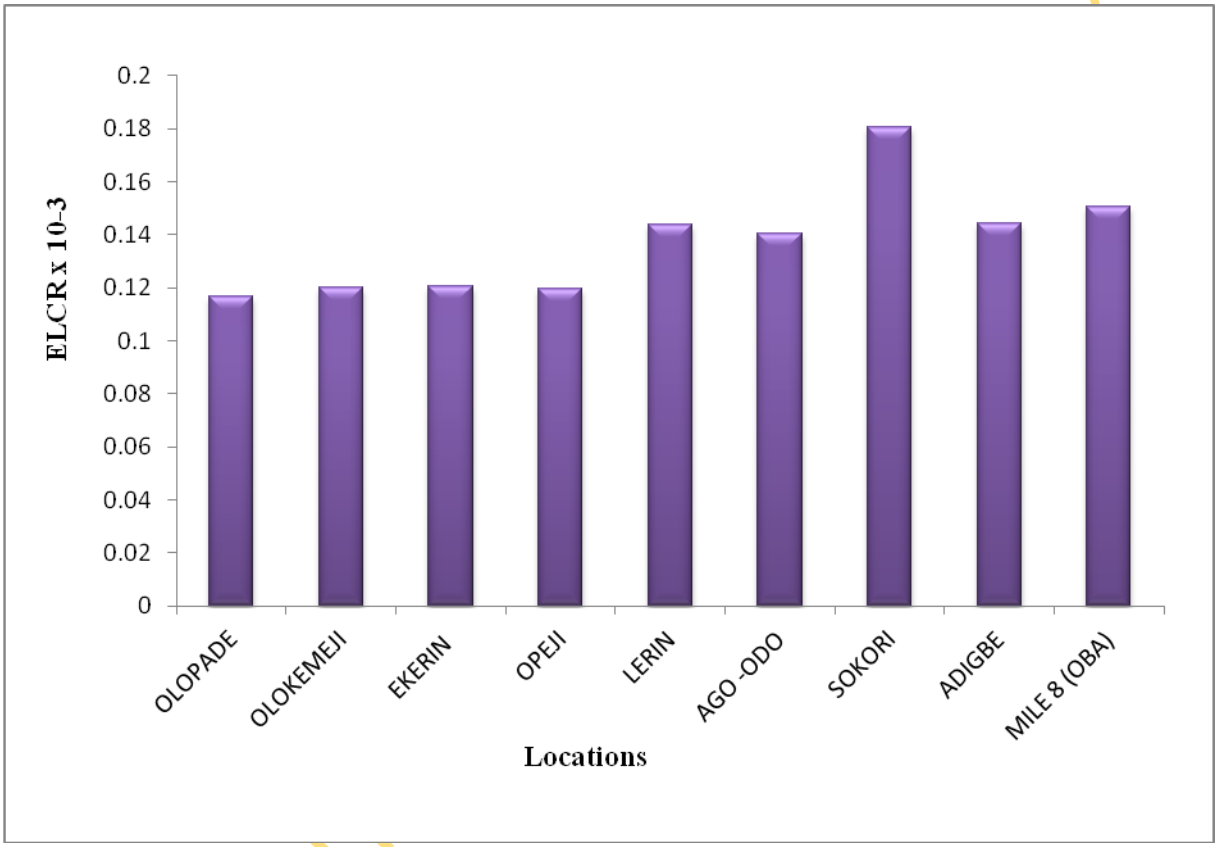

Fig.6.7b: Distribution of the Excess Life Cancer Risks For middle Region

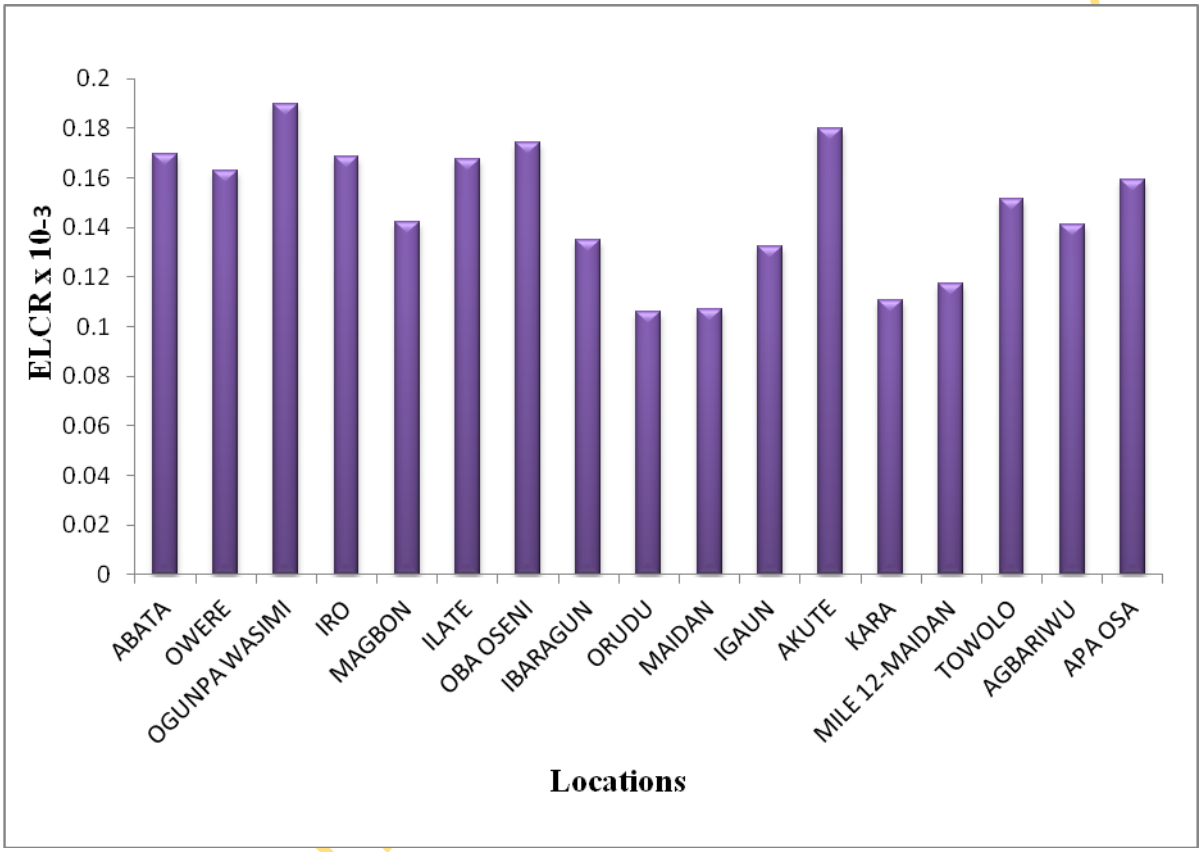

Fig 6.7c: Distribution of the Excess Life Cancer Risks For Lower Ogun River

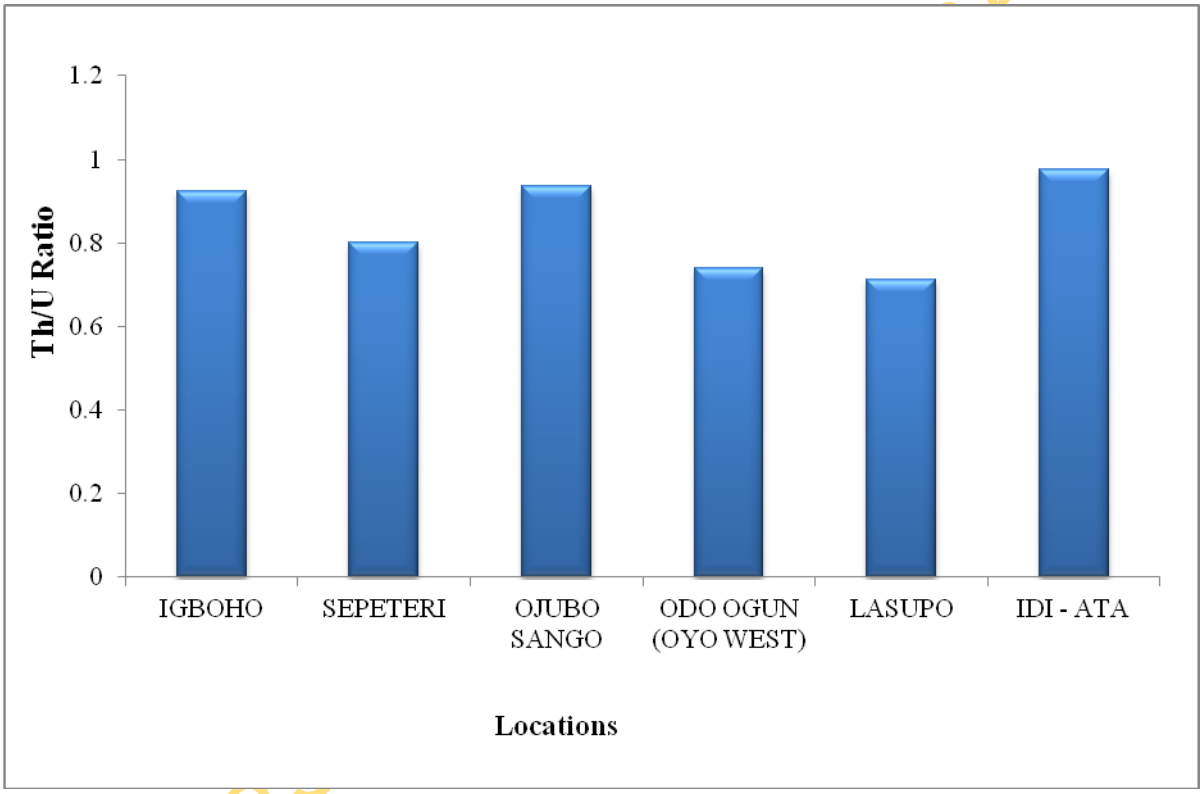

Fig. 6.8a: Th/ U ratio for upper Ogun river

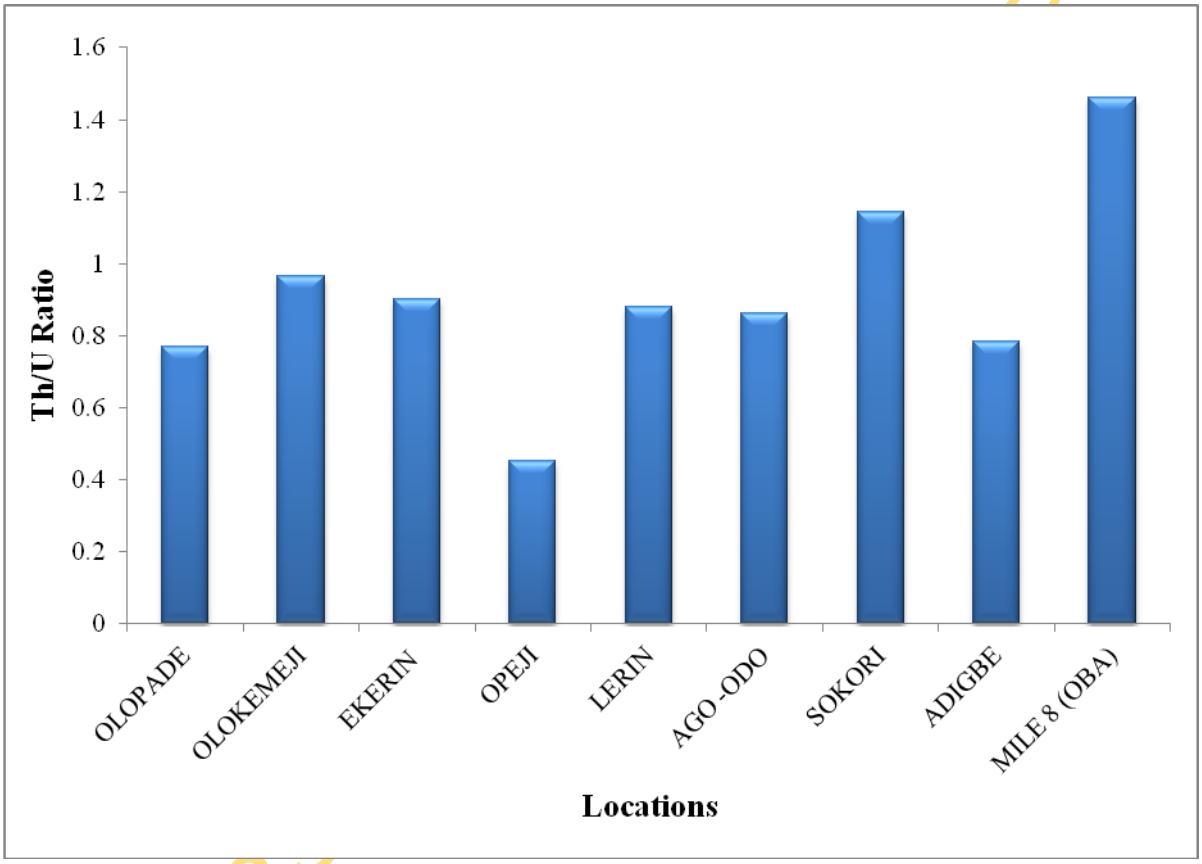

Fig. 6.8b: Th/ U ratio for middle Ogun river

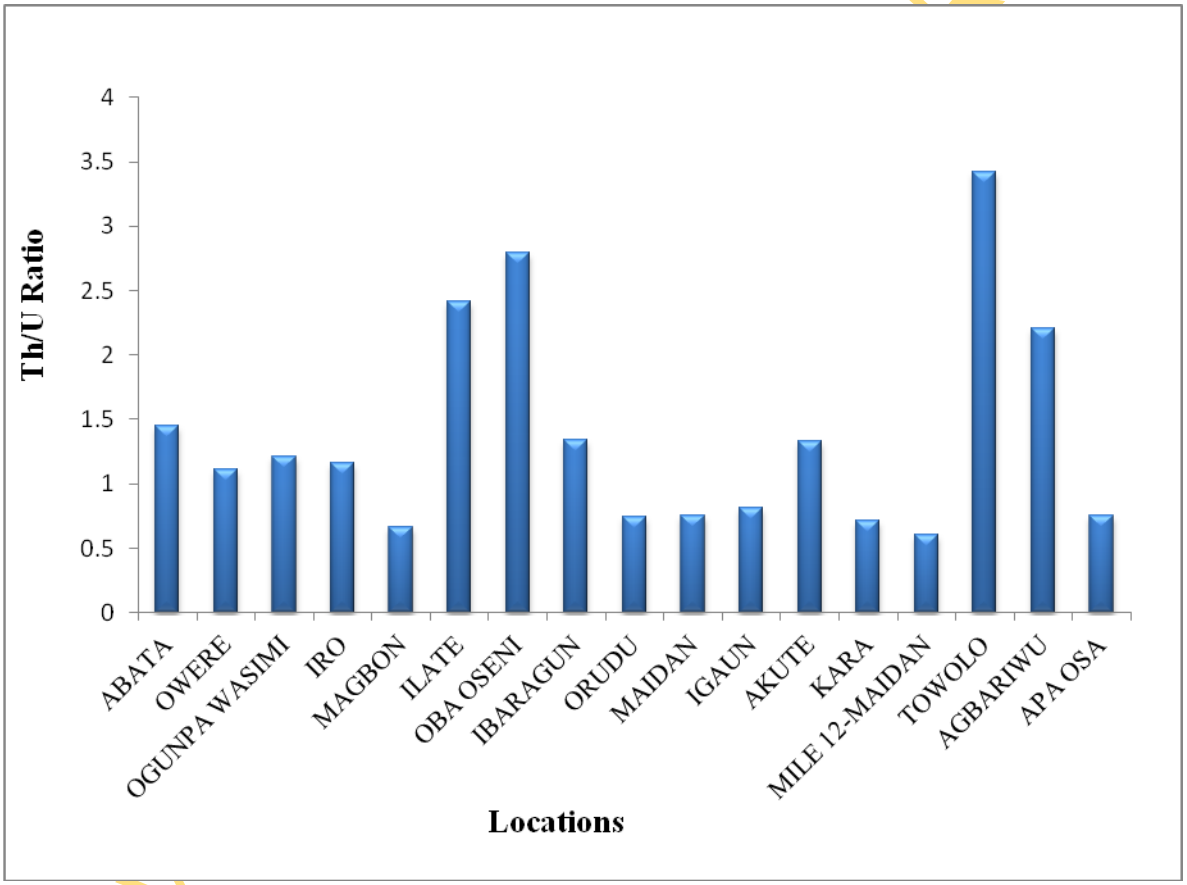

Fig. 6.8c: Th/ U ratio for lower Ogun river

values of Th/U, increases down the regions. The rate of leaching is higher in sedimentary basins than in the basement complex areas. In the middle region both basement complex and sedimentary rocks exists, while in the lower and upper regions, the rock types are the sedimentary and basement complex respectively.

6.3 Statistical Tests on Concentrations of The Radionuclides

Statistical analysis was carried out on the data obtained from the sediments' radioactivity concentrations. Statistical analysis of K, U and Th concentrations within each interpreted unit is useful for extracting subtle information from the data that is not immediately visible. Analysis of variance, Correlation analysis, location effects size measures and cluster analysis, (single linkage, using the method of Euclidean distances-nearest neighbour) were done. The correlation analysis was done so as to determine inter-relation between the concentrations of the radionuclides, correlations between, indoor gamma dose rate, radium equivalent, representative gamma index and excess life cancer risks in the sediments from the upper, middle and lower Ogun river.

6.3.1 Variational Tests on The Concentrations of The Radionuclides of The Sediments Taken From The Upper, Middle and Lower Regions of The River

The analysis of variance (ANOVA) technique was carrierd out using SPSS for Windows 16.0 software. In this analysis, we looked at the three radionuclides in each of the ten sites together across the thirty – two locations, trying to see if there would be a significant difference in the means of the measured parameters in each location between the groups and within the groups. If the P-Value is less than (α) = 0.05 (i.e 5 percent level of significance), then there is significant difference in their means, but if the P-value is greater than 0.05, 5 percent level of significance, then there is no significant difference in their means. It was observed that in the upper region of the river, Table 6.2, the P-values for the three radionuclides were greater than 0.05. Specifically, P = 0.062 for ^{40}K, P = 0.097 for ^{226}Ra and P = 0.824 for ^{232} Th. Therefore in the upper region of the river, there were no significant differences in the means of the three radionuclides. From Tables 6.3 and 6.4, it was observed that the P-values of the three radionuclides were less than 0.05. For the middle region, p = 0.000 for ^{40}K P = 0.000 for ^{226}Ra and P = 0.000 for ^{232}Th, while for the lower region, P = 0.000 for ^{40}K, P = 0.002 for ^{226}Ra and P = 0.000 for ^{232}Th respectively. Hence in the

Table 6.2: Analysis of Variance for the Upper Region

		Sum of Squares	df	Mean Square	F	(P)Sig.
K_40	Between Groups	117243.876	5	23448.775	2.258	.062
	Within Groups	560653.494	54	10382.472		
	Total	677897.370	59			
Ra_226	Between Groups	138.360	5	27.672	1.973	.097
	Within Groups	757.407	54	14.026		
	Total	895.767	59			
Th_232	Between Groups	17.988	5	3.598	.433	.824
	Within Groups	448.977	54	8.314		
	Total	466.965	59			

Table 6.3: Analysis of Variance for the Middle Region

		Sum of Squares	df	Mean Square	F	(P) Sig.
Pottasium-40	Between Groups	378843.869	8	47355.484	4.979	.000
	Within Groups	770349.834	81	9510.492		
	Total	1149193.703	89			
Radium-226	Between Groups	1600.591	8	200.074	7.393	.000
	Within Groups	2192.161	81	27.064		
	Total	3792.752	89			
Thorium-232	Between Groups	2034.167	8	254.271	12.895	.000
	Within Groups	1597.202	81	19.719		
	Total	3631.369	89			

Table 6.4: Analysis of Variance for the Lower Region

		Sum of Squares	df	Mean Square	F	(P) Sig.
Pottasium-40	Between Groups	541937.452	16	33871.091	8.576	.000
	Within Groups	604277.831	153	3949.528		
	Total	1146215.283	169			
Radium-226	Between Groups	1883.258	16	117.704	2.516	.002
	Within Groups	7158.229	153	46.786		
	Total	9041.487	169			
Thorium-232	Between Groups	5045.895	16	315.368	12.299	.000
	Within Groups	3923.236	153	25.642		
	Total	8969.130	169			

middle and lower regions there were significant differences in the means of the concentrations of the radionuclides estimated. This could be attributed to the fact that there are more human activities going on in the middle and lower regions compared to the upper region that had lesser activites.

6.3.2 The Location Effects Size Measures For The Three Regions

As we had investigated the statistical significance of the means difference of the radionuclides' concentrations, it is also needed to look at the location effect size on the radionuclides' concentrations, so that we can compare strength of location effects on the radionuclides' concentrations in each region, that is, to investigate if there were effects of locations on the radionuclides concentrations in the regions. The analysis was done using Windows 16.0 software. Multivariate general linear model was used to compute the location effects index. The effect size index is the Eta Squared and it was calculated by dividing the within – groups sum of squares by the total sum of squares. Eta squared varies between 0 and 1 and it is interpreted in the usual way i.e 0 – 0.1 is a weak effect, 0.1 – 0.3 is a modest effect, 0.3 – 0.5 is a moderate effect and > 0.5 is a a strong effect. Tthe location effects size measures for the three regions is presented in Table 6.5.

For the upper region, looking at our predictor variables, (the row labelled 'location') it was observed that the three radionuclides were statistically not significant (from the 'Sig.' column) at the 0.05 level in this region, since their P- values were greater than 0.05. The effect of locations on the concentrations of ^{40}K was modest (partial eta squared was 0.173), the effect of locations on the concentrations of ^{226}Ra in the upper region was also modest (partial eta squared was 0.154) and the effect of locations on the concentrations of ^{232}Th in that region was a weak effect (partial eta squared was 0.039). Hence there was no significant location effects on the measurements of the concentrations of radionuclides taken at those loations. Looking also at the (row labelled 'intercept') it could be that the intercept (the individual variance within the groups) for the concentrations of the three radionuclides were highly significant (P = 0.000) for each, this basically means that the radionuclides have different concentration values. The partial eta squared values for the (intercept) were 0.967 for ^{40}K, 0.919 for ^{226}Ra and 0.918 for ^{232}Th, which means that there was high variance in concentration values within the group.

Table 6.5: The Location Effects Size measures on the Concentrations of the radionuclides in the upper, middle and lower regions

Source	Dependent Variable	Sig.	Partial Eta Squared
Intercept	Pottasium-40	0.000	0.967
	Radium-226	0.000	0.919
	Thorium-232	0.000	0.918
Upper Locations	Pottasium-40	0.062	0.173 Modest
	Radium-226	0.097	0.154 Modest
	Thorium-232	0.824	0.039 Weak
Intercept	Pottasium-40	0.000	0.965
	Radium-226	0.000	0.855
	Thorium-232	0.000	0.859
Middle Locations	Pottasium-40	0.000	0.330 Modest
	Radium-226	0.000	0.422 Moderate
	Thorium-232	0.000	0.560 Str. Effect
Intercept	Pottasium-40	0.000	0.986
	Radium-226	0.000	0.806
	Thorium-232	0.000	0.887
Lower Locations	Pottasium-40	0.000	0.473 Str. Eff.
	Radium-226	0.002	0.208 Modest
	Thorium-232	0.000	0.563 Str. Eff.

In the middle region, from our predictor variables, it was observed that the three radionuclides were statistically significant at the 0.05 level of significant in this region, since their P- values were less than 0.05. The effect of locations on the concentrations of ^{40}K, was modest (partial eta squared was 0.330), the effect of locations on the concentrations of ^{226}Ra in the middle region was moderate (partial eta squared was 0.422) and the effects of locations on the concentrations of ^{232}Th in the middle region was a strong effect (partial eta squared was 0.560). Hence there was significant location effects on the measurements of the concentrations of radionuclides taken at the middle region.

For the 'intercept', it was observed that the individual variance within the groups for the concentrations of the three radionuclides were highly significant (P = 0.000), this means that the radionuclides have different individual variance concentration values. The partial eta squared values for the within-groups sum of squares (intercept) were 0.965 for ^{40}K, 0.859 for ^{226}Ra and 0.859 for ^{232}Th, which means that there was a high variance in Concentration values within the group. Considering the lower region, it was seen that the three radionuclides were statistically significant at the 0.05 level in this region, since their P-values were less than 0.05.

The effect of locations on the concentrations of ^{40}K was a strong effect (partial eta squared was 0.473, the effect of locations on the concentrations of ^{226}Ra in this region was modest (partial eta squared was 0.208) and the effects of locations on the concentrations of ^{232}Th here was a strong effect (partial eta squared was 0.563). Hence there was significant location effects on the measurements of the concentrations of radionuclides taken at the lower region too.

For the 'intercept', it was observed that the concentrations of the three radionuclides were highly significant (P = 0.000), this means that the radionuclides have different individual variance concentration values. The partial eta squared values for the intercept were 0.986 for ^{40}K, 0.806 for ^{226}Ra and 0.887 for ^{232}Th, which means that there was high variance in the concentration values within the group. It could be seen that it was majorly ^{232}Th that had significant location effect in the middle and lower regions, ^{40}K also added some effects to the lower region. Therefore it may imply that some activities that enhance ^{232}Th and ^{40}K are being carried out in these locations. This may be an indication that the radionuclides might

have accumulated in ionic and particulate form from agricultural drains and also as the drifted pariculates from long shore currents and accredition processes.

6.3.3 Pearson Correlation Analysis between the Concentrations of Radionuclides, Hazard Indices and the Radiogenic Heat Production Rates in the Sediments.

Pearson Correlation analysis technique was carrierd out using Windows 16.0 software package. The analysis was done to determine the inter – relation between the concentrations of radionuclides and the hazard indices.

If the P-value is less than 0.05 or if the P- value is less than 0.01 level of significance, then the parameter under consideration is significant at that level(s) of significance, that means there is a significant relationship between the parameters under consideration. If the value of P is positive, then there is a positive significant relationship but if the value of P is negative, then a negative significant relationship between the parameters is observed. Then, if a parameter is significant at 0.01 level of significance, then the parameter is already significant at the 0.05 level .

In the upper region of the river (Table 6.6), the Pearson correlation analysis to determine the inter – relation between the concentrations of radionuclides in the sediments showed that none of the radionuclides had any significant correlation with each other, at the level of significance considered.

Potassium – 40 significantly correlated positively with indoor gamma dose rate having (0.86) correlation coefficient, indoor effective dose rate having (0.86) correlation coefficient and representative gamma index having (0.87) correlation coefficient, all at 0.05 level of significant.

Thorium- 232 did not correlate significantly with any of the parameters considered at the levels of significance.

Radium equivalence in the upper region showed strong positive significant relationship with indoor gamma dose rate (1.00) at 0.01 confidence limit, showed strong positive significant correlation with indoor effective dose rates (1.00) at 0.01 significant level, strong positive correlation with representative gamma index (0.99) at 0.01 level and perfect positive correlation with the external hazard index (1.00) at 0.01 level of significance.

The indoor gamma dose rates significantly correated positively with ^{40}K (0.89) at 0.05 level of significance, showed strong positive significant correlations with radium equivalence (1.00) at 0.01 level, strong positive significant correlations with representative gamma index (1.00) at 0.01 level of significance, had strong positive significant correlations with external hazard index (1.00) at 0.01 level of significance and had perfect positive significant correlations with indoor effective dose rates (1.00) at 0.01 level of significance.

The indoor effective gamma dose rate had the same relationship that the indoor gamma dose rate had as discussed above only that it correlated perfectly (1.00) at 0.01 level of confidence with the indoor gamma dose rate.

The representative gamma index correlated with ^{40}K (0.87) at 0.05, radium equivalent (0.99) at 0.01, indoor gamma dose (1.00) at 0.01, indoor effective dose (1.00) at 0.01 amd external hazard index (0.99) at 0.01 level of significant.

In the upper region of the river, excess lifetime cancer risk and the internal hazard index did not have any significant correlation with any of the parameters considered at the level of significance.

The external hazard index showed strong positive significant relationship with indoor gamma dose rate (1.00) at 0.01 confidence limit, showed strong positive significant correlation with indoor effective dose rates (1.00) at 0.01 significant level, strong positive correlation with representative gamma index (0.99) at 0.01 level and perfect positive correlation with the radium equivalent (1.00) at 0.01 level of significance.

In the middle region, from Table 6.7, the Pearson correlation analysis to determine the inter – relation between the measured parameters showed that ^{40}K did not correlate with any of the measured parameters considered at the levels of significance. ^{226}Ra correlated positively (0.71) at 0.05 level of confidence with ^{232}Th, ^{226}Ra also showed positive significant correlation (0.80) at 0.05 with indoor hazard index . ^{232}Th showed positive significant correlation with all the parameters considered except ^{40}K.

Table 6.6: Pearson Correlation Matrix of Measured Parameters In Upper Ogun River

	^{40}K	^{226}Ra	^{232}Th	Ra Equiv.	Indoor Gamma	In. Effect.	Repr. Gamma	ELCR	Ext. Hazard	Int. Hazard
^{40}K	1	-0.24	0.04	0.81	0.86*	0.86*	0.87*	-0.14	0.81	-0.52
^{Ra}226	-0.24	1	0.64	0.35	0.28	0.28	0.24	0.64	0.35	0.60
^{232}Th	0.04	0.64	1	0.53	0.47	0.47	0.45	0.34	0.53	0.57
Ra Equiv.	0.81	0.35	0.53	1	1.00**	1.00**	0.99**	0.17	1.00**	-0.09
Indoor Gamma	0.86*	0.28	0.47	1.00**	1	1.00**	1.00**	0.14	1.00**	-0.16
In. Effect.	0.86*	0.28	0.47	1.00**	1.00**	1	1.00**	0.14	1.00**	-0.16
Repr. Gamma	0.87*	0.24	0.45	0.99**	1.00**	1.00**	1	0.12	0.99**	-0.18
ELCR	-0.14	0.64	0.34	0.17	0.14	0.14	0.12	1	0.19	0.27
Ext. Hazard	0.81	0.35	0.53	1.00**	1.00**	1.00**	0.99**	0.19	1	-0.09
Int. Hazard	-0.52	0.60	0.57	-0.09	-0.16	-0.16	-0.18	0.27	-0.09	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Table 6.7 Pearson Correlation matrix of Measured Parameters In middle Ogun River

	^{40}K	^{226}Ra	^{232}Th	Ra Equiv.	Indoor Gamma	In. Effect.	Repr. Gamma	ELCR	Ext. Hazard	Int. Hazard
^{40}K	1	-0.55	-0.05	0.23	0.28	0.33	0.35	0.33	0.23	0.05
^{226}Ra	-0.55	1	0.71*	0.62	0.58	0.55	0.52	0.55	0.62	0.80*
^{232}Th	-0.05	0.71*	1	0.94**	0.92**	0.90**	0.90**	0.90**	0.94**	0.95**
Ra Equiv.	0.23	0.62	0.94**	1	0.99**	1.00**	0.99**	1.00**	1.00**	0.97**
Indoor Gamma	0.28	0.58	0.92**	0.99**	1	0.99**	0.99**	0.99**	0.99**	0.95**
In. Effect.	0.33	0.55	0.90**	1.00**	0.99**	1	1.00**	1.00**	1.00**	0.94**
Repr. Gamma	0.35	0.52	0.90**	0.99**	0.99**	1.00**	1	1.00**	0.99**	0.93**
ELCR	0.33	0.55	0.90**	1.00**	0.99**	1.00*	1.00**	1	1.00**	0.94**
Ext. Hazard	0.23	0.62	0.94**	1.00**	0.99**	1.00**	0.99**	1.00**	1	0.97**
Int. Hazard	0.05	0.80*	0.95**	0.97**	0.95**	0.94**	0.93**	0.94**	0.97**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

Radium equivalent activity showed strong positve significant correlations (0.94) with ^{232}Th, strong positve significant correlations (0.94) with indoor gamma dose rates, strong positve significant correlations (0.99) with representatative gamma index, positve significant correlations (1.00) with ELCR, perfect positve significant correlations (1.00) with the external hazard index, all at the 0.01significant level, but did not correlate significantly with^{40}K and ^{226}Ra. The indoor gamma dose rates showed positive significant correlations with all the parameters considered except with ^{40}K and ^{226} Ra. The correlation coefficients were between (0.82) and (1.00), all at 0.01 level of significance. The indoor effective dose rates showed positive significant correlations with all the parameters considered except with ^{40}K and ^{226} Ra. The correlation coefficients were between (0.09) and (1.00) ELCR, all at 0.01 level of significance. The representative gamma index showed positive significant correlations with all the parameters considered except with ^{40}K and ^{226} Ra. The correlation coefficients were between (0.99) and (1.00) ELCR, all at 0.01 level of significance. ELCR strong positve significant correlations (0.90) with ^{232}Th, strong positve significant correlations (0.995) with radium equivalent, strong positve significant correlations (0.99) with indoor gamma dose rates, perfect positve significant correlations (1.00) with indoor effective gamma dose rates, perfect positve significant correlations (1.00) with representative gamma index, strong positve significant correlations (1.00) with external hazard index and showed strong positve significant correlations (0.94) with internal hazard index. All at 0.01 level of significance. ELCR did not correlate with ^{40}K and ^{226}Ra, at the level of significance considered.

For the inter relation between external hazard index and other parameters, it was observed that there was strong positve significant correlations (1.00) with ^{232}Th, perfect positve significant correlations (1.00) with radium equivalent activity, strong positve significant correlations (0.99) with indoor gamma dose rates, strong positve significant correlations (1.00) with indoor effective dose rates, strong positve significant correlations (0.99) with representative gamma index, strong positve significant correlations (1.00) with ELCR and strong positve significant correlations (0.97) with internal hazard index, all at 0.01 level of significant level. There was no significant correlations between ^{40}K and ^{226}Ra. Implying that where there were high concentration values of ^{40}K might not necessary imply high concentration value of ^{226}Ra.

For the correlations between internal hazard index and other parameters. It was observed that there was positive significant correlation between internal hazard index and ^{226}Ra (0.80) strong positve significant correlations (0.95) with ^{232}Th, strong positve significant correlations (0.97) with radium equivalent activity, strong positve significant correlations (0.95) with indoor gamma dose rates, strong positve significant correlations (0.94) with indoor effective dose rates, strong positve significant correlations (0.93) with representative gamma index, strong positve significant correlations (0.94) with ELCR and strong positve significant correlations (0.97) with external hazard index, all at 0.01 level of significant level. There was no significant correlations between ^{40}K and ^{226}Ra. Only ^{40}K did not correlate with any of the parameters considered.

Table 6.8: Pearson Correlation Matrix of Measured Parameters In lower Ogun River

	40-K	Ra-226	Th-232	Ra Equiv.	Indoor Gamma	In. Effect.	Repr. Gamma	ELCR	Ext. Hazard	Int. Hazard
40-K	1	0.08	0.05	0.44	0.52*	0.52*	0.51*	0.45	0.44	0.15
Ra-226	0.08	1	0.66**	0.77**	0.76**	0.76**	0.74**	0.74**	0.77**	0.78**
Th-232	0.05	0.66**	1	0.89**	0.85**	0.85**	0.86**	0.85**	0.89**	0.80**
Ra Equiv.	0.44	0.77**	0.89**	1	1.00**	1.00**	1.00**	0.96**	1.00**	0.83**
Indoor Gamma	0.52*	0.76**	0.85**	1.00**	1	1.00**	1.00*	0.96**	1.00**	0.81**
In. Effect.	0.52*	0.76**	0.85**	1.00**	1.00**	1	1.00**	0.96**	1.00**	0.81**
Repr. Gamma	0.51*	0.74**	0.86**	1.00**	1.00**	1.00**	1	0.96**	1.00**	0.80**
ELCR	0.45	0.74**	0.85**	0.96**	0.96**	0.96**	0.96**	1	0.96**	0.79**
Ext. Hazard	0.44	0.77**	0.89**	1.00**	1.00**	1.00**	1.00**	0.96**	1	0.83**
Int. Hazard	0.15	0.78**	0.80**	0.83**	0.81**	0.81**	0.80**	0.79**	0.83**	1

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

For the inter relationship in the lower region of the river, it was observed from Table 6.8 that ^{40}K positively correlated significantly although weakly (0.52) with indoor gamma dose rate, weakly (0.52) with indoor effective dose rates and also weakly(0.51) with representative gamma index at the 0.05 level of significance. ^{226}Ra showed fair positve significant correlations with all the parameters considered, except with ^{40}K, all at 0.01 level of significance. Their correlation coefficience ranged between 0.66 (^{232}Th) and 0.78 (internal hazard).

^{232}Th showed positve significant correlations with all the parameters considered, except with ^{40}K, all at 0.01 level of significance. Their correlation coefficience ranged between 0.66 (^{226} Ra) and 0.89 (Radium equivalent and external hazard index).

Radium equivalent showed positve significant correlations with all the parameters considered, except with ^{40}K, all at 0.01 level of significance. Indoor gamma dose rates, indoor effective dose rates ELCR and representative gamma index showed strong positive significant correlations.The correlation coefficience ranged between 0.77 (^{226}Ra) and1.000 (external hazard index). For the inter relation between indoor gamma dose rates and other parameters It was observed that there was inter- relationships between it and all the parameters. strong positve significant correlations (1.00) with radium equivalent, strong positve significant correlations (1.00) with representative gamma index, strong positve significant correlations (0.96) with ELCR, strong positve significant correlations (1.00) with external hazard index, positve significant correlations (0.85) with ^{232}Th, positve significant correlations (0.81) with internal hazard index, positve significant correlations (0.76) with ^{226}Ra, weak but positive significant correlation (0.52) with ^{40}K and perfect positve significant correlations with indoor hazards index, all at 0.01 level of significance.

Indoor effective dose rates showed positve significant correlations with all the parameters considered, all at 0.01 level of significance. Their correlation coefficience ranged between 0.52 (^{40}K) and 1.00 (indoor gamma dose rates). Representative gamma index showed positve significant correlations with all the parameters considered, all at 0.01 level of significance. Their correlation coefficience ranged between 0.510 (^{40}K) and1.00 (indoor gamma dose and indoor effective dose). ELCR showed positve significant correlations with all the parameters considered, except with ^{40}K, all at 0.01 level of significance. Their correlation coefficience ranged between 0.74 (^{226}Ra) and 0.96 (radium equivalent and

external hazard index). All at 0.01 level of significance. External hazards index showed positve significant correlations with all the parameters considered, except with ^{40}K, all at 0.01 level of significance. Their correlation coefficience ranged between 0.77 (^{226}Ra) and 1.000 (radium equivalent). All at 0.01 level of significance. Indoor gamma dose rates, indoor effective dose rates, representative gamma index and ELCR, all had strong correlation with external hazards index in the lower region.

Indoor hazards index showed positve significant correlations with all the parameters considered, except with ^{40}K, all at 0.01 level of significance. Their correlation coefficience ranged between 0.78 (^{226}Ra) and 0.83 (radium equivalent and external hazard index). All at 0.01 level of significance. Buttressing the location effect result, looking specifically at the inter-relationship of the natural radionuclides' concentration with one another, using Pearson correlation analysis, it could be seen that, in the middle and lower regions ^{232}Th most especially correlated well with ^{226}Ra, but ^{40}K did not correlate with any of the two. Showing that ^{232}Th had most significant effect and ^{226}Ra also had weak effect in the regions. In the upper region, the relationship between the concentrations of the three radionuclides falls within linear correlations ($r < 0.3$) and moderate (r between 0.5 and 0.7), which did not give a strong inter- relationship. For the middle region, the relationship between the concentrations of the three radionuclides falls within linear correlations ($r < 0.3$) and moderate as well, but ^{232}Th and ^{226}Ra related significantly although not too obvious. This implies that the presence of one may enhance the other in an area and also enhances any parameter that depends on either of them. Lastly, the lower region has same relationship as the middle.

6.3.4 Cluster Analysis of the Radionuclides Distribution in Ogun River

Cluster analysis is one of the multivariate techniques used to identify and classify groups with similar radiometric character in a new group of observations (Nasr et al., 2006: IAEA, 2003). Each observation in a cluster is mostly like others in the same cluster. Cluster analysis, (single linkage, using the method of Euclidean distances- nearest neighbour was applied to the sample activity concentrations (^{40}K, ^{226}Ra and ^{232}Th), using Windows 16.0 software in the light of identifying locations with similar characters. Figure 6.9a-c showed

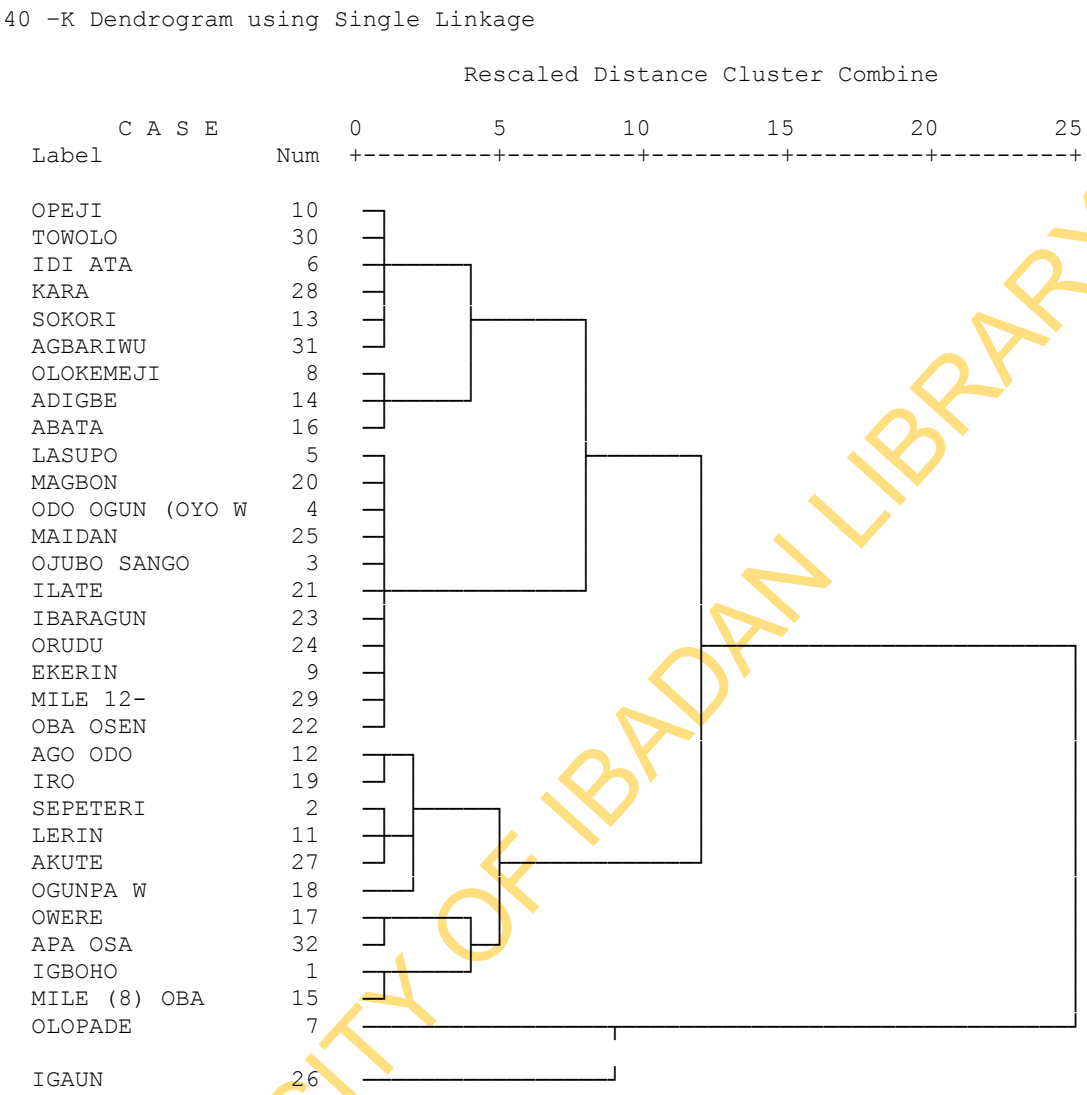

Fig. 6.9a: Dendrogram for classifying sample locations as groups according to the concentrations of ^{40}K in the sediments from Ogun river.

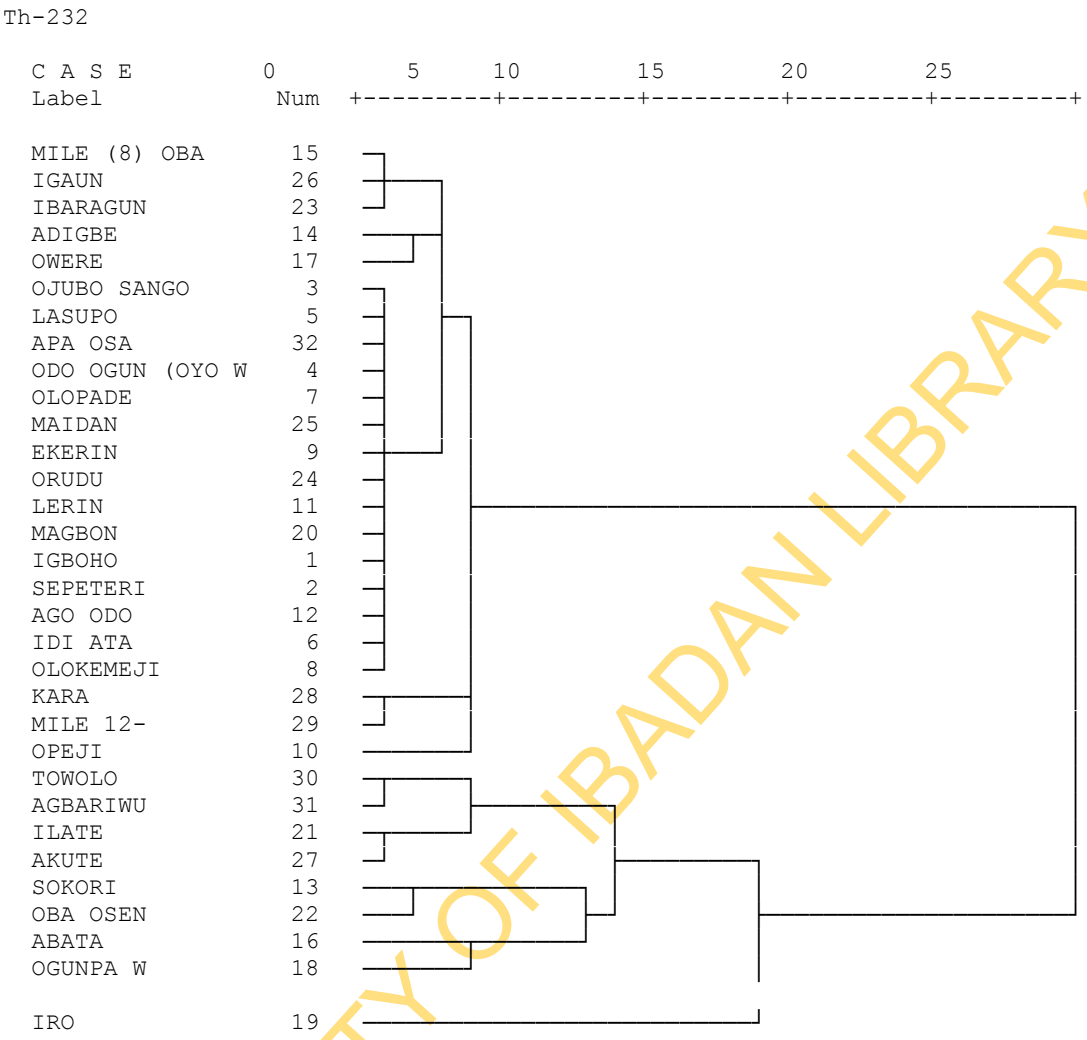

Figure 6.9b: Dendrogram for classifying sample locations as groups according to the concentrations of ^{232}Th in the sediments from Ogun river.

Ra -226

Dendrogram using Single Linkage

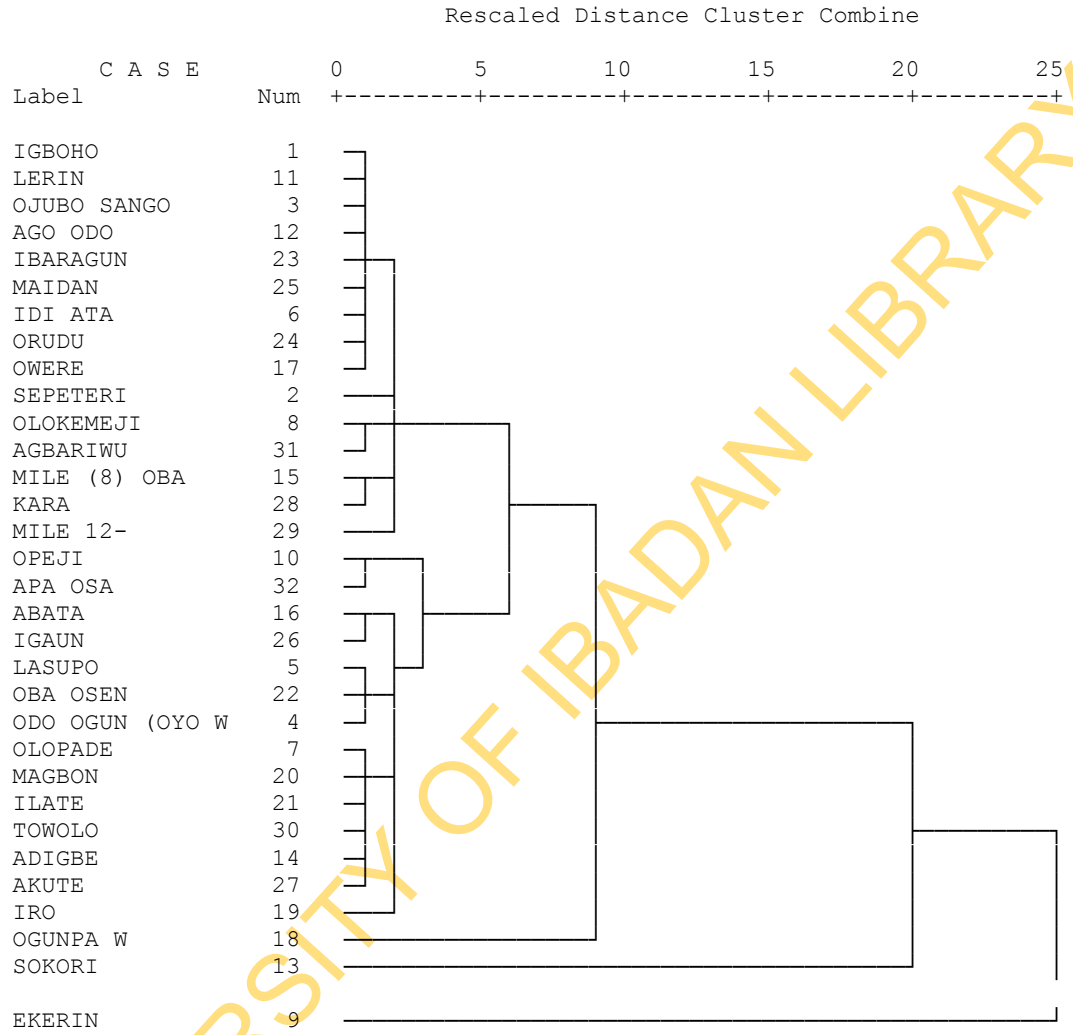

Figure 6.9c: Dendrogram for classifying sample locations as groups according to the concentrations of ^{226}Ra in the sediments from Ogun river

dendrogram of classifying sample locations as groups according to the radionuclides concentrations in the sediments from ogun river.

The Cluster analysis was carried out on the concentrations of the radionuclides to identify and classify groups with similar characters in a new group of observations.

The dendrogram was used to give a pictorial representation of the groups having similar characters just like what a contour map will do, connecting parameters of similar values.

Igaun, Iro and Ekerin were observed to exist as unique locations considering the concentrations of ^{40}K, ^{232}Th and ^{226}Ra respectively. From Figure 6.9a, Olopade was classified as a unique location looking at the figure below, this can be, deduced from the relatively high distance at which its cluster was joined perhaps it was due to the fact that Olopade had the least value of ^{40}K in the whole region (370.97 ± 19.26). Igaun too was classified as a unique location on its own, the location was also the second least location with ^{40}K concentration value (393.19 ± 19.83), although its group was relatively at the forth highest distance and its cluster was not joined to any group.

The closest locations in their characters were Opeji, Towolo, Idi – Ata, Kara, Sokori and Agbariwu in one group. From figure 6.9b, for ^{232}Th, the closest locations in their characters were Mile (8) Oba, Igaun and Ibaragun. Pair of combinations had been identified in the groups, Kara, Mile -12 Maidan, Towolo, Agbariwu, Ilate and Akute. Adigbe, Owere and Sokori, Oba Oseni, also formed Pair of combinations but in a higher order.

Iro exists as a unique location on its own, perhaps because it was the only location having ^{232}Th concentration value of 15.0 ±3.9Bq/kg. From figure 6.9c for ^{226}Ra, the closest locations in their characters were Igboho, Lerin, Ojubo Sango, Ago Odo, Ibaragun, Maidan, Idi – Ata, Orudu and Owere.

Ogunpa Wasimi and Sokori were classified as unique locations, this can be deduced from the relatively high distances at which these clusters were joined. Ekerin was observed to exist as a unique location on its own, perhaps because it had the least value of ^{226}Ra. Olokemeji , Agbariwu, Mile (8) Oba, Kara, Opeji, Apa Osa, Abata, Igaun, all had Pair of combinations and were connected in a higher group. The cluster analysis had been able to show ways of seeing pictorially, relationship within the radionuclides concentrations along the course of Ogun river.

6.4 Grain size Analysis of The Sediment

The statistical data (Appendix ii), obtained from grain size analysis of 32 sediment samples were used for plotting the cumulative frequency and histogram.The curves and histogram plots (Appendix iii), shows the frequency of grains in each size class and usefully give an immediate impression of the grain size distribution.

6.4.1 Graphic Mean

The mean size is a function of the size range of available materials and amount of energy impacted to the sediment which depends on current velocity or turbulence of the transporting medium. The mean value for the grain size distribution within the analysed sediments is 2.1. Graphic means distribution for this sediments range from 1.09 to 2.90. This is indicative of fine-grained sand to medium grained sands. This suggests that the sediments were deposited under low energy condition as sediments usually become finer with decrease in energy of the transporting medium (Folk, 1974).

6.4.2 Sorting

This is a measure of the standard deviation which is the spread of the grain size distribution with the value range of 0.54 to 1.42 and a mean value of 0.97. Sorting is the most useful grain size data since it gives an indication of the effectiveness of the depositional medium in separating grains of different classes (Friedman, 1962).

According to Friedman (1962), the various ranges of sorting in sediments indicate the various environments of the sand, see (Table 6.9). From Table 5.17, most of the samples are moderate to poorly sorted with only a few, which are moderately well sorted. This is indicative of low to fairly high energy current (Friedman, 1961; Blott & Pye, 2001).

Table 6.9: Classification of sands

Ranges of values of standard deviation (ϕunits)	Sorting class	Environments of sandstones
<0.35	Very well sorted	Coastal and lake dunes; many beaches (foreshore), common on shallow marine shelf.
0.35-0.50	Well sorted	Most beaches(foreshore); shallow marine shelf, many inland dunes
0.50 – 0.80	Moderately well sorted	Most inland dunes; most rivers; most lagoons, distal marine shelf
0.80 – 1.40	Moderately sorted	Many glacio-fluvial settings; many rivers; some lagoons; some distal marine shelf.
1.40 – 2.00	Poorly sorted	Many glacio-fluvial settings
2.00-2.60	Very poorly sorted	Many glacio-fluvial settings
>2.60	Extremely poorly sorted	Some glacio-fluvial settings

(After Friedman G.M. 1962)

6.4.3 Skewness

This is a reflection of the depositional process. It is simply a measure of the symmetry of the distribution (see Table 5.20). Skewness is useful in environmental diagnosis because it is directly related to the fine and coarse tails of the size distribution, and hence suggestive of energy of deposition. The skewness values of the samples range from -0.25 to 0.53, thus indicating the presence of fine fraction and coarse fraction in population of particles. The positive values indicate skewness towards the finer grain sizes and the negative values indicating skewness towards the coarser grain sizes.

6.4.4 Kurtosis

This is a measure of the peakedness of the curves towards the coarser grain sizes. The samples are predominantly leptokurtic, that is, the central portions are better sorted at the tails. (Table 5.20). In numerical terms, the range of kurtosis was between 0.58 and 4.51 typifying that 38% of the samples are leptokurtic, 41% are very leptokurtic, 6% are mesokurtic and 15% is very platykurtic. This strongly suggests a fluvial or tidal environment confirming that the sands are river deposited. The unimodality of the grain size distribution chart with the exception of some nearly bimodal chart reveals that the sands were not derived from more than a single source area.

In general and based on average values, the sediments are fine grained moderately sorted sand, associated with moderately high current flows in a fluvial environment.

6.5 Heavy Mineral, Provenance and Distribution along the river

The primary aim of this analysis is to relate the concentrations of ^{40}K, ^{232}Th and ^{226}Ra to rock history of the area source of sediment supply and the petrography (mineralogical composition) of the sediment along the river.

6.5.1 Heavy Mineral and Provenance

The heavy mineral assemblages have long been used as a sensitive indicator of provenance and tectonic mobility (Boswell,1933; Petti-John, 1975). However, the composition of heavy mineral assemblages is not entirely controlled by source rock

mineralogy as other processes that operate during the sedimentation cycle such as weathering, hydrodynamics and diagenesis, may overprint the original provenance signature (Morton and Hallsworth, 1999, Ratcliffe *et al*., 2004). Results were presented in Table 5.21.

From the result presented, it was observed from the selected samples analysis that the non-opaques like Zircon, Tourmaline, Rutile, Staurolite and Apatite predominate the other non-opaques like Garnet, Epidote, Sillimanite suggesting dynamothermal metamorphic rocks origin. The opaques constitute the greater percentage than the non-opaques but are nevertheless not given detailed study. Apatite, Tourmaline and Zircon suite are characteristics of acid-igneous rocks (felsic igneous rocks) and the suite of rounded tourmaline and rounded zircon depict reworked sediment source. Thus, it can be generally inferred that the sediments of these areas are immatured to marginally matured, which are indicated by presence of Zircon, Tourmaline and Rutile. Zircon occurred as minute, prismatic to rounded colourless grain. They also occurred as inclusions. The grains were subrounded to round. Tourmaline grains were prismatic greenish brown and the grains were sub angular to subrounded. Rutile grains were yellowish to reddish brown, showing adamantine luster in reflected light and occured mostly in small prismatic crystals. The grains were sub-angular to sub-rounded.

Hence, the presence of Zircon, Tourmaline and Rutile (ZTR) is indicative of igneous and metamorphic source. Based on Hubert (1962), the ZTR index (43.24% - 63.33%) suggest immature to mature sediments. The abundance composition of individual mineral (Zircon, Tourmalin, Rutile, Staurolite, Apatite, Garnet, Epidote and Sillimanite) in percentage are 15.7%, 14.8%, 23.0%, 30.7%, 3.5%, 4.5%, 3.0% and 4.9% respectively.

6.5.2 Mineralogical Composition

Sediments textures and compositon as observed from petrographic analysis may be used to interprete the history of sand including source area, lithology, paleoclimate, tectonic activity processes acting in the depositional basin and the time duration in the basin (Pamella, 2003).

The result of petrographic thin section analysis to determine the composition of randomly picked sand samples is shown in Table 5.22. Petrographic study of the sediments reveals that they are averagely composed of 55.5% quartz (which is the most abundant

detrital component) suggesting that the paleoclimate at the time of deposition was probably humid and the average amount of feldspar is calculated to be 12.8%, as most of the feldspar has weathered away. The average total amount of rock fragment and cement is revealed to be 13.6% and 6.7% respectively while that of matrix is 3.9%. Figures 6.11a-d shows the variations of the mineralogical compositions in (%) of the sediment samples, ^{232}Th concentations and ^{226}Ra concentrations against locations along the river.

From Figure 6.10a, it was observed that the plot of the distribution of feldspar along the river with concentrations of ^{226}Ra and ^{232}Th did not show positive correlation. It was observed for all the locations between Olopade and Kara, anywhere there were peaks for the distribution of feldspar, there were always deeps for ^{232}Th and ^{226}Ra. This was also the case for Figure 6.10b only that the situation was not as pronouncd as the case of feldspar. This is in agreement with the work done by Ramasamy et al., 2010, where they reported that all the Uranium and Thorium decay series elements are incompatible with the major rock forming minerals such as quartz, olivine and pyroxenes. From Figure 6.10c, the distribution of the rock fragments and rock cement peaked at same locations with ^{232}Th and ^{226}Ra concentrations (Sokori and Abata) and deeped at same location (Magbon). From Figure 6.10d, it was seen that the distribution of mica and matrix with the concentrations of ^{232}Th and ^{226}Ra had peaks and deeps at same locations that fell between Sokori and Ibaragun. The presence of some minerals in sediments can enhance the level of natural radionuclides. Although the way minerals are incorporated into radionuclides depends on several geological conditions but it strongly dependents on the mineral species and geological formation from which they originate.

From Table 5.22, rock fragments exceeds the proportion of feldspar (implying that they are stable) with few feldspars and majority quartz. The sediments range from immature to mature. This also reflects the weathering process in the source area and the degree of extent of transportation. The mineral maturity index of the sediment estimated using (Q/F+L) ratio after Pettijohn (1975) shows an index range of 1.29-3.00 and an average value of 2.20 Ttable 5.23), indicating that the sediments are marginally mature to immature.

The lithology of the sediment is a function of the environment in which it was deposited, its transportational history and the type of rocks from which it was derived. The metastable

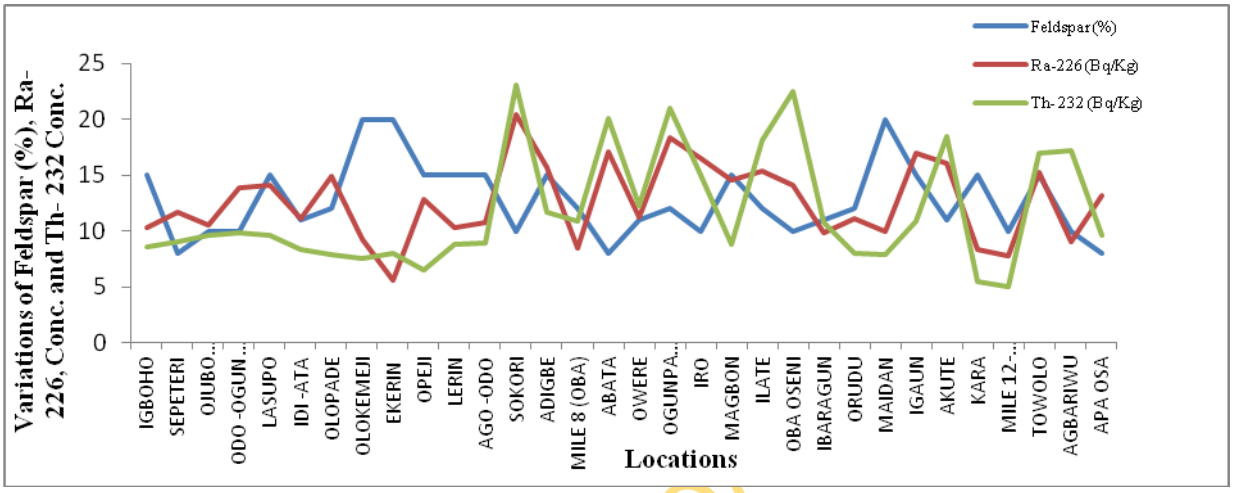

Fig. 6.10a: The variation of the composition of Feldspar (%), ^{226}Ra concentrations (Bq/kg) and ^{232}Th concentrations (Bq/kg) against locations along the river

Fig. 6.10b: The variation of the composition of Quartz (%), ^{226}Ra concentrations (Bq/kg) and ^{232}Th concentrations (Bq/kg) against locations along the river

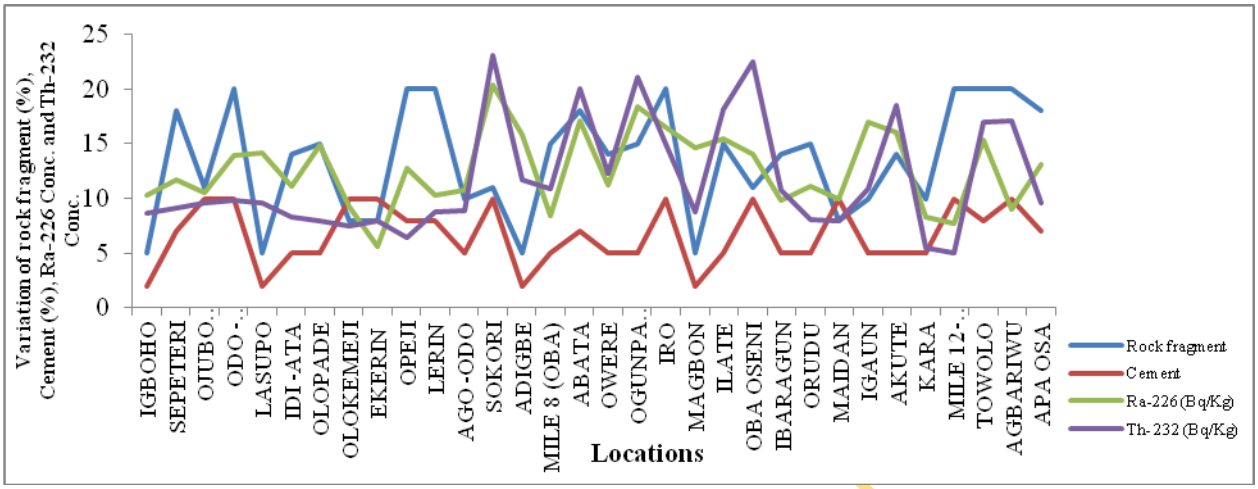

Fig. 6.10c: The variation of the composition of rock fragments and rock cement (%), ^{226}Ra concentrations (Bq/kg) and ^{232}Th concentrations (Bq/kg) against locations along the river

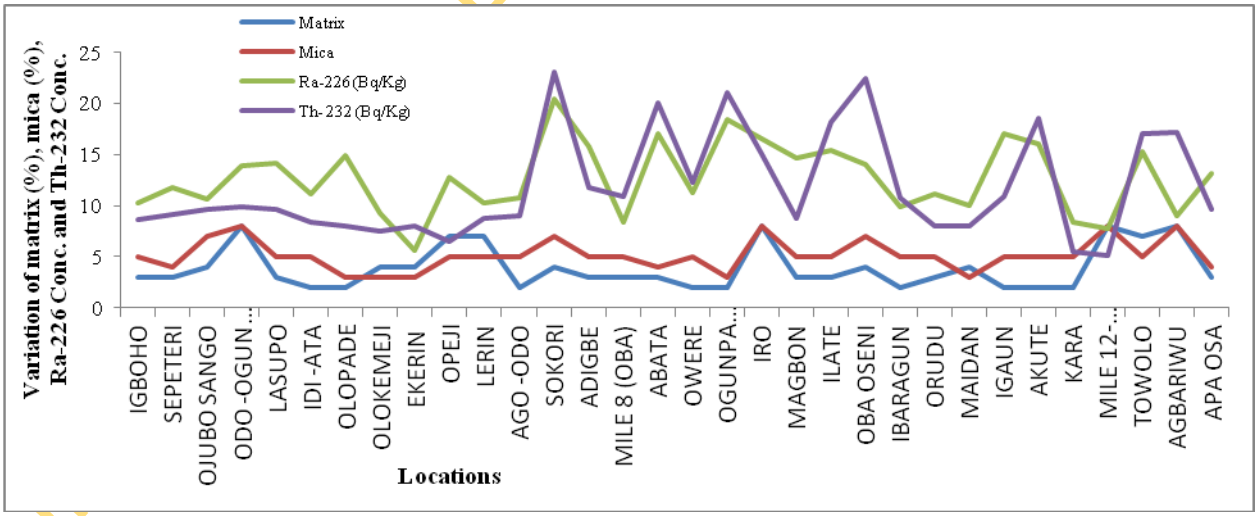

Fig. 6.10d: The variation of the composition of mica and rock matrix (%), ^{226}Ra concentrations (Bq/kg) and ^{232}Th concentrations (Bq/kg) against locations along the river

6.7: Conclusion

Gamma-ray spectroscopy had been used to determine the activity concentrations of ^{40}K, ^{226}Ra and ^{232}Th in 320 sediments samples from Ogun river, Nigeria. The external absorbed dose rates in air, internal gamma dose rates, outdoor annual effective dose rates, indoor annual effective dose rates, external hazard index, internal hazard index, representative gamma index and excess life cancer risks were calculated in order to estimate the radiological implications on the use of the sediments as one of the building materials for construction of buildings for the public. The grain size analysis and heavy mineral provenance and mineralogical composition of the sediments were also analysed in order to relate the concentration of ^{40}K, ^{232}Th and ^{226}Ra to rock history of the source of sediment supply and the petrography of the sediment along the course of the river.

The following are conclusions deduced from the study:

1. The mean of the activity concentrations of ^{40}K for the sediments was 499.5 ± 59.2 Bq/kg, 12.7 ± 3.5 Bq/kg for ^{226}Ra and for ^{232}Th the value was 11.8 ± 5.1 Bq/kg. The value of ^{40}K was about the world's average value of 500 Bq/kg, while the values of ^{226}Ra and ^{232}Th were less than the world's average value of 50Bq/kg.
2. No man made radionuclide was detected in any of the samples analysed, indicating the presence of natural radionuclides only.
3. The Analysis of Variance showed that there was no significant differences in the means of the radionuclides concentrations in the upper region, but in the middle and lower regions, there were significant differences in the means of the concentrations of the radionuclides estimated. The location effects size measures showed that there was no significant location effect on the measurements of the concentrations of radionuclides taken at those loations in the upper region, but there were significant location effects on the measurements of the concentrations of radionuclides taken at the middle and lower regions of the river. This may be attributed to the fact that more human activities are going on in the middle and lower regions compared with the upper region. Although these radionuclides correlated with some other parameters that were studied.
4. The estimated radiological impact assessment indices are lower than the recommended values, hence suggesting that no potential radiological health hazard

could be associated with the use of the sediments. The sediments from Ogun river are safe and can be used for construction of buildings without causing any radiological problems to the inhabitants. The estimated values in this work can serve as baseline values for the area for future reference and epidemological studies of the river.

5. Cluster analysis was carried out on the concentrations of the radionuclides to identify and classify groups with similar characters in a new group of observations. Igaun, Iro and Ekerin were observed to exist as unique locations considering the concentrations of ^{40}K, ^{232}Th and ^{226}Ra respectively.

6. Sedimentological studies have been used to reveal the provenance of the sediment samples. Textural studies indicated sediments of fine to medium grained and poorly to moderately sorted range that is texturally immature to sub-mature. Most of the samples indicated mafic feature that is (relating to rocks that are high in magnesium and iron mineral), quartzose sedimentary and intermediate provenance. It also showed that the major contributing source rock of the sediments are rich in silicate minerals, which include quartz, feldspar and mica group. The sediments are chemically mature and therefore could act as a good reservoir for oil and gas accumulation.
7. Heavy mineral assemblages indicate the presence of opaque and non –opaque minerals. The non-opaque minerals include zircon, tourmaline, rutile and staurolite. These mineral signature suggest high maturity and showed that the sediments are of igneous and metamorphic provenance. Hence, the most probable sources of these sediments are the Cameroun (Highland) basement complex and the Oban Massif. Petrographical studies showed that the mineral composition of the sediments is mainly of quartz, feldspar and rock fragments. Other components are flakes of mica, matrix and cement. Rock fragments are observed to have exceeded the proportion of feldspar which indicates that the sediments are immature to mature.

6.8: Recommendation For Further Studies

The distribution of radionuclides in the sediments along Ogun river course could be monitored by a group or body of researchers funded by a particular organization who could choose particular points along the course where daily or probably monthly monitoring could be done round the year for a length of five years to see if there could be significant variations in the distributions coupled with the hazards as time pass by.

In addition, the transport mechanism due to Th/U ratio should be studied, so as to investigate whether Th/U ratio is rate dependent. i.e if the Th/U ratios against distances along the river course is studied, could their slopes be constant? ($\frac{\Delta y}{\Delta x} = M$, where Δy =Th/U, and Δx = distance).

Finally, chronometry dating of the sediments using U/Th ratios should be studied.

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APPENDIX I: Activity concentrations of each radionuclides for 10 typical sites in the 32 locations

TABLE A- 1: THE LOCATIONS AND ACTIVITY CONCENTRATIONS IN THE SEDIMENTS OF IGBOHO (ODO OGUN)

SAMPLES	N(DEGREES)	E(DEGREES)	ALTITUDE	^{40}K (Bq/Kg)	^{226}Ra (Bq/Kg)	^{232}Th((Bq/Kg)
1	08° 48' 04.2"	03° 40' 47.5"	339m	668.47 ± 58.09	9.81 ± 2.57	8.84 ± 0.98
2	08° 48' 04.1"	03° 40' 47.4"	339m	578.59 ± 50.36	19.85 ± 3.28	10.58 ± 1.36
3	08° 48' 04.2"	03° 40' 47.6"	336m	694.87 ± 60.37	14.39 ± 2.84	10.21 ± 1.88
4	08° 48' 05.2"	03° 40' 47.7"	337m	186.55 ± 16.55	5.28 ± 1.08	2.85 ± 0.16
5	08° 48' 05.3"	03° 40' 47.5"	337m	585.74 ± 50.94	8.94 ± 1.37	8.48 ± 1.94
6	08° 48' 05.5"	03° 40' 47.6"	338m	678.02 ± 58.91	10.25 ± 2.50	7.30 ± 1.60
7	08° 48' 05.6"	03° 40' 47.5"	338m	625.55 ± 54.38	9.99 ± 1.49	6.13 ± 1.27
8	08° 48' 05.7"	03° 40' 47.3"	338m	615.18 ± 53.50	9.45 ± 2.08	11.39 ± 2.50
9	08° 48' 05.8"	03° 40' 47.8"	339m	640.96 ± 55.72	9.04 ± 1.28	7.07 ± 1.66
10	08° 48' 05.9"	03° 40' 47.6"	337m	545.33 ± 47.49	5.88 ± 0.95	13.44 ± 2.59
MEAN				581.926±24.123	10.288 ±3.207	8.629±2.938
MIN.				186.55 ± 16.55	9.04 ± 0.95	2.85 ± 0.16
MAX.				694.87 ± 60.37	5.88 ± 3.28	13.44 ±2.59

APPENDIX II: Granulometric Analysis Data (Typical)

Table A-2: A Typical Granulometric Analysis Data for Igboho

LOCATION: IGBOHO
Raw Wt: 100 grammes
Total Wt: 99.96 grammes
Loss (grammes): 0.04 grammes

Sieve {mm}	Phi {ø}	Raw wt or individual {gm.}	Corrected wt {g}	Cum wt {g}	Cum wt {%}	Ind wt {%}
2	-1	-	-	-	-	-
1.18	-0.25	-	-	-	-	-
0.85	0.25	-	-	-	-	-
0.6	0.75	0.6	0.6	0.6	0.6	0.6
0.425	1.25	3.12	3.12	3.72	3.72	3.12
0. 30	1.75	0.84	0.84	4.56	4.56	0.84
0.25	2	39.94	39.94	44.51	44.51	39.95
0.15	2.75	32.16	32.17	76.68	76.69	32.17
0.075	3.75	16.94	16.95	93.63	93.63	16.95
0.063	4	5.66	5.66	99.29	99.3	5.66
Pan	-	0.7	0.7	99.99	100	0.7

APPENDIX III: Cummulative Frequency Curve And Histogram of Grain Size Data (Typical)

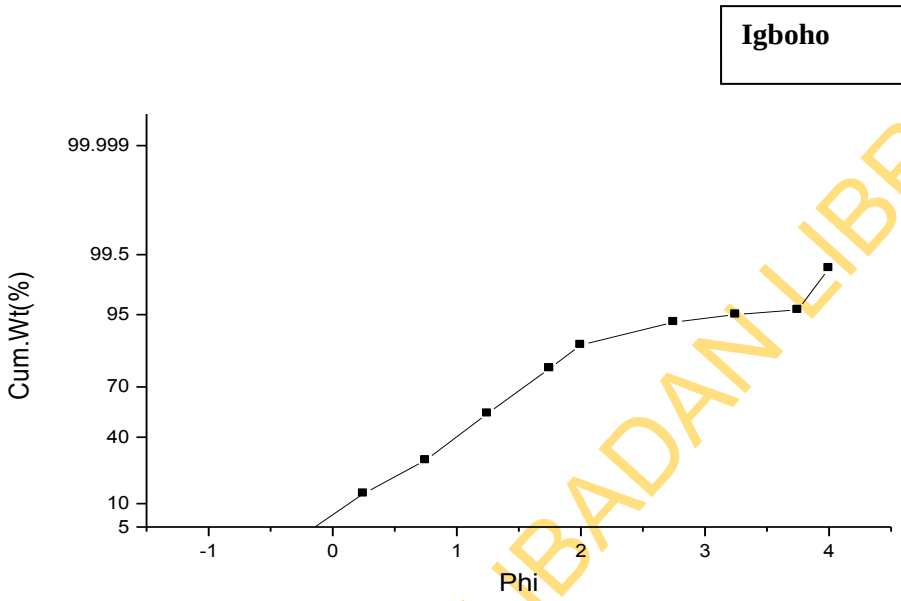

Fig. A-3.1: Typical Cummulative Frequency Curve for Igboho

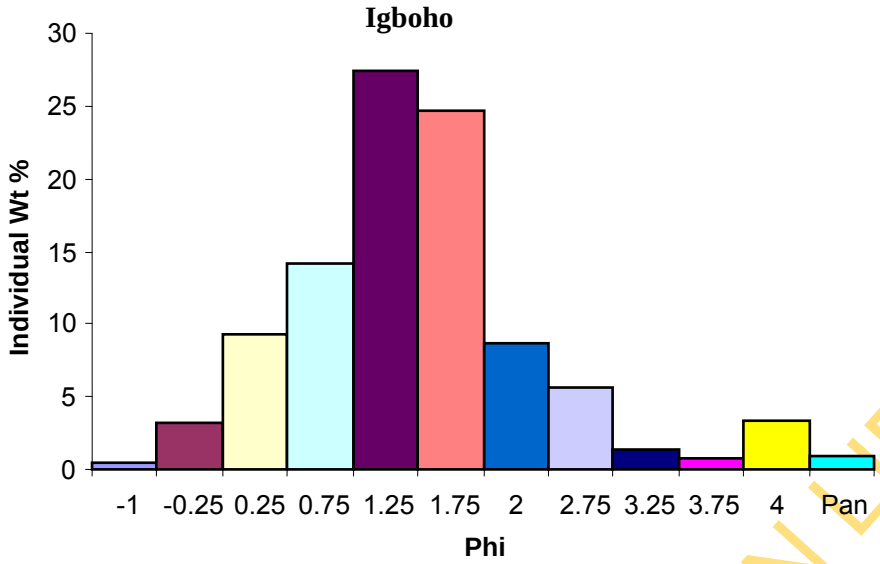

Fig A-3.2: Typical Histogram of Grain Size Data For Igboho