MEASUREMENT OF GROSS ALPHA AND BETA RADIOACTIVITY IN RIVER KADUNA

By

Juliet Ebele Nwoke
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Dedication

This work is dedicated firstly to the Almighty God, the great I AM THAT I AM, Whose mercy and grace have been sufficient for me throughout the period. It is also dedicated to my beloved husband Pastor J.C. Nwoke and my lovely Children Favour, Goodness and Mercy (Little Angels).

Declaration

I, Juliet Ebele Nwoke do hereby declare that the thesis entitled "Measurement of Gross Alpha and Beta Radioactivity in River Kaduna" is my own work. That it has not been submitted for an award of a degree or diploma to any other University or institution before. Information from published works of other researchers used in the thesis have been duly acknowledged and referenced.

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Juliet Ebele Nwoke Date

Certification

This thesis titled "Measurement of Gross Alpha and Beta Radioactivity in River Kaduna", meets the requirements for the award of the Master of Science Degree in Radiation Biophysics of the Ahmadu Bello University Zaria and is approved for its contribution to knowledge and literary presentation.

_____	_____
Dr. T.C. Akpa Chairman Supervisory Committee	Date
_____	_____
Dr. (Mrs) I.G.E Ibeanu Member Supervisory Committee	Date
_____	_____
Professor N. Hariharan Head of Physics Department	Date
_____	_____
Professor J.U. Umoh Dean, Post – Graduate School	Date

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Abstract

Thirty samples of river water were taken from the three zones, Farming, Residential/Commercial and Industrial Zones along the course of River Kaduna. The Total dissolved solids (TDS) was determined for the water samples. Also radionuclides present in the water samples were identified using the Exploranium, the identifier. The radionuclides are ^{238}U, ^{232}Th and ^{40}K. The specific activities of the radionuclides in the river water samples were calculated, the average specific activity of ^{238}U was 9.00 Bq/g that of ^{232}Th was 3.93 Bq/g, and for ^{40}K the average specific activity was 199.10 Bq/g. An aliquot of each sample was evaporated to dryness, based on the total dissolved solids (TDS) of the sample, and the residue counted for gross alpha and beta activity using the proportional counter. The results of characterization show that the counter has low background and good plateau, which were all reproducible, for all the channels and for different counting modes. Results also show that the average alpha activity in the Farming Zone is $0.027 \pm 0.002 \times 10^3 Bq/m^3$, average alpha activity in the Residential/Commercial Zone is $0.025 \pm 0.001 \times 10^3 Bq/m^3$ and that in the Industrial zone is $0.03 \pm 0.003 \times 10^3 Bq/m^3$. The average beta activity in the farming Zone is $0.585 \pm 0.007 \times 10^3 Bq/m^3$, that in the Residential/Commercial Zone is $0.411 \pm 0.006 \times 10^3 Bq/m^3$ while that in the Industrial Zone is $0.321 \pm 0.005 \times 10^3 Bq/m^3$. The overall results show that both alpha activity and beta activity in the three zones are far below the practical screening level of radioactivity in drinking water of $100 Bq/m^3$ for alpha and $1000 Bq/m^3$ for beta, as recommended by CEC-FAO and WHO.

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CHAPTER ONE

INTRODUCTION

1.1 General Introduction

Water is an essential substance to man, animal and all that surrounds them. It has been in existence right from the origin of the universe itself. Water forms greater percentage of man's and animal's blood and tissue.

The use of water cuts across industrial agricultural and domestic uses. The two main sources of water are rain and ground water sources. The ground water can be deep ground water like wells and boreholes, or surface ground water, like rivers, seas, oceans, lakes and streams. This surface water can also be collected, passed through purification processes and channelled through pipes as tap water. This is the most portable source of drinking water in Nigeria.

However, water sources are constantly polluted by some human activities and natural phenomena; thus adversely affecting the quality of water. Water pollution arises from wastes and sewage disposals into rivers and streams from industries, hospitals and rain-wash out from fertilizers used for farming. Some of these pollutants are radionuclides. Another source of water pollution arises from the secondary particles of cosmic radiation, which release radionuclides into the atmosphere, and these radionuclides, are washed down by rain into ground and surface water bodies. Water sources are equally polluted by naturally occurring radioactive materials (NORM) of the earth's crust (terrestrial radioactivity); which emits alpha, beta and gamma radiations. These materials normally elements in the uranium and thorium series and are more concentrated in deep ground water than in surface water. They contaminate the water body directly with their radionuclide products; and indirectly, through the radon and Thoron gaseous products which can solidify and attach themselves as aerosols to the air

particles and are washed down by rain into water bodies. Furthermore, flowing water encounters shelves, sedimentary rocks, igneous rocks and phosphate rocks all of which are also radioactive (Santchi and Honeyman, 1989). All these contribute to the level of radioactivity in water.

Radioactivity in drinking water is an easy means of man's internal contamination with radionuclides. The most important natural radionuclide in drinking water are tritium, potassium, radium, radon and their progeny, which are also alpha, beta and gamma emitters. Hence it is needful to determine the specific activities of radionuclides present in drinking water and also the concentration of alpha and beta in drinking water.

1.2 Previous Work on Radioactivity in Water in Nigeria

Some works had been done in the field of radioactivity in water in different parts of Nigeria in the past. A survey had been carried out to determine radioactivity, physical and chemical parameters of underground and surface water in Qua Iboa River Estuary by Ekpo and Inyang (2000). Nwogu (2001) determined the concentration of trace elements in commercial water supplies. There was an analysis of fadama water, soil and vegetation for heavy metals by Odogu (2001). All these studies did not give the result of actual concentration of alpha and beta radiations in water. Onoja (2004) determined the gross alpha and gross beta radioactivity in well water in Zaria. This study, though gave the concentrations of alpha and beta radiations in the sampled water was limited to well water. Surface water, like river is the major source of water for water boards' purification and supply as tap water widely use nation wide; it is also the major source of drinking water for livestock, irrigation for agriculture, fishing and so many other uses by industries. There is therefore the need to determine the gross alpha and gross beta activities as well as the specific activities of the radionuclides present in different sources of water in different parts of Nigeria.

1.3 The Research Problem

Water pollutants from residential, industrial and hospital wastes, as well as from fertilizers on farmlands; from rainwater and the NORMS in a particular area affect the quality of water in the area. Some of these pollutants are radioactive and their deposition into the human body can be hazardous to health. In Kaduna town, the Kaduna River runs from the north to the southern part of the town and is greatly used for irrigation, fishing, water supply to water board for purification and distribution as tap water, means of inter-community transport by those communities separated by the river, source of drinking water for livestock, and some communities without portable water supply. It is major source of water supply to industries. The settlements along the Kaduna river are in three categories: the predominantly farming activity region; the residential/commercial region and the industrial region. It may be possible that the water in river Kaduna is contaminated with high concentration of alpha and beta radiations resulting from activities in the three regions. It is therefore necessary to determine the concentration of alpha and beta radiations as well as the specific activities of radionuclides present in water from the three regions of the River Kadun, compare the concentrations in the three regions and determine the region whose activities possess radiological hazards to the inhabitants of Kaduna town via the river Kaduna.

1.4 Aims and Objectives of the Research

The aim of this research is to contribute to the improvement/development of the health sector of the people of Kaduna.

The objectives of the research include:

i. Determine the radionuclides present in the river water samples collected and the specific activities of the radionuclides.

ii. Determine the gross alpha and gross beta radiations in the water samples

iii. Establish the distribution pattern of radioactivity measured in the regions in order to identify areas of elevated activity if any.

iv. Compare the results with already established data.

v. Determine the biological effects of water use in Kaduna and how it affects the health of the people.

1.5 Justification of the Research

Alpha and beta radiations are high Linear Energy Transfer (LET) radiations; hence they deposit their energy at short distances and cause serious biological effects to the organs and tissues in the body. Therefore, there is the need to determine the specific activities of the radionuclides present as well as concentration of alpha and beta radiations in water. The gross alpha and beta counting is the preliminary test, as stipulated in the World Health Organization guideline for water quality determination.

In Kaduna there has not been any established data on radioactivity in river Kaduna. This survey is therefore important in the sense that it is concerned with the health of the populace. It is equally economical because it will provide data necessary for complete purification of water from river Kaduna and if the water in the region is safe some health problems will be eliminated and government will save a lot of money for other developmental effects.

Since this research is a regional one, other bodies or organizations wishing to carry out survey of gross alpha and beta radiations in water in a broader scope will use this work as a reference point for the detailed survey. Also the data from this research will form the basis for the radionuclide specific test where the test is necessary, hence the research will contribute immensely to literature.

1.6 The Scope of the Research

The scope of this research is limited to Kaduna metropolis. The identification of radionuclides was done using the Exploranium the Identifier GR-135 (with its in-built gamma ray energy spectrometry system). The survey of alpha and beta concentration in water ideally should involve proportional counter, alpha spectrometry and liquid scintillation methods. However, because of the non-availability of the certain equipments the researcher limited the methods to proportional counter only.

CHAPTER TWO

LITERATURE REVIEW

2.1 Water Pollution

Water pollution means the contamination of water by the discharge of noxious substances. As defined by the International Oceanographic Commission (IOC) for the United Nations Educational and Scientific Commission (UNESCO), water pollution is the introduction by man, directly or indirectly, of substances into the water body resulting, in such deleterious effects as harm to living resources, hazards and to human health, or hindrance to marine activities and reduction of amenities (Williams, 1926). This supposes that man is a major contributor of water pollution, even though there are natural sources of water pollution. Sources of water pollution can therefore be classified as: natural sources of water pollution and man-made sources of water pollution.

Natural sources of water pollution arise from rocks, rain, flood, oil spillage, aquatic growth and death, NORMS. Igneous rock formed by the solidification of melts, are the major component of the earth's crust, which is now land. These rocks are mainly silicic and basaltic types in the ratio of 2:1 (Johnston, 1976). The major component minerals of these rocks determine fairly predictably the trace elements that solidified out with them. For instance magnesium rich rocks yield chromium ores together with nickel. Basaltic rocks yield copper and zinc and granite rocks yield potassium, beryllium and lead. The weathering of these rocks produces sedimentary rock and unconsolidated sediments (Johnston, 1976). Rivers and streams encounter these sedimentary and igneous rocks and consequently the water is contaminated by the trace elements present in the rocks.

Rainstorm carries dust particles and aerosols from the atmosphere; and also inorganic silt from soil erosion. All these are discharged into the streams and rivers as

pollutants. Oil spillage is also a serious source of water pollution. The oil deposit can be spilt through natural forces like earthquake, leakage can also occur through the oil pipelines through vandalization; or oil spilt from transporting vehicles that are fallen down. In all these ways, the spilt oil can find its way to the surface water bodies contaminating the water seriously.

The death and decomposition of aquatic plants and animals adds significantly to the organic pollution and which depletes the dissolved oxygen particularly if residues are deposited and accumulated in underground water. The dead plants and animals are quickly oxidized by a series of biological activities into stable mineral forms, which are used again by other living things. The water body itself provides the oxygen for this concentration and indirect measure of the organic load, which is a function of the amount of oxygen required in the process. This is referred to as biochemical oxygen demand (Onoja, 2004). The microbes of primary concern in rivers and streams are bacteria, viruses, protozoa and other forms that may be pathogenic to man.

The naturally occurring radioactive materials (NORMS) in the earth's crust comprise of Uranium, Thorium, Radium, with their radon-gas progeny and potassium-40. These materials seep into the ground water, introducing radioactivity into the water body.

Major water pollutants introduced by man's activities include pathogens, chemicals, sediments, toxic organics and inorganic, radionuclide from radioactive wastes, acids and bases among others. Pathogens are introduced in water mainly through untreated sewage from individual households, industrial or passenger ships and other vessels. Large water bodies like rivers, seas, oceans have been the major dumping grounds for sewages the world over. In fact, a substantial volume of sewage of about $2.2 \times 10^5 m^3/d$ (48million gallons) are disposed in the Southampton per day. (Helliwell,

1975) of which about 50% are untreated. Pathogenic bacteria and viruses from these sewages are therefore introduced into the water.

Chemical pollutants are introduced into the water through two different pathways, first by direct drain of rain run off into the water. Secondly is by accumulation of these chemicals as industrial impurities in the atmosphere in which they are dispersed with air masses and are deposited on water surfaces through atmospheric precipitation. Of these chemicals is the petroleum, hydrocarbon, which accounts for 50 to 90 millions tonnes per year of man-made hydrocarbons in the forms of atmospheric currents (Patin, 1982).

Among the heavy metals mercury, lead and cadmium are most common water pollutants these elements (mostly mercury and lead) enter the atmosphere during the combustion of fossil fuels and are deposited on water surface through atmospheric precipitation. It has been estimated that the average daily mercury intake in Southampton, England was about 25% from eating fish (Helliwell, 1975). Though this is within the safe limit, diseases associated with high dose of mercury include disease of the gum and kidney; tremor, mental disturbances, convulsion and even death, in severe cases (Helliwell, 1975).

Fertilizers constitute a serious pollutant as they are washed by flood or rain into various rives and streams. Most fertilizers contain phosphate, potassium and nitrate products. These substances are nutrients to the plants, but some of them constitute serious health risks especially to infants, due to interference of the chemical with blood oxygen transport (Ruesel, 1966). Some of these substances in the fertilizer are radioactive and constitute radiological hazards to man when they contaminate water sources. Table 2.1 shows the activity concentration of natural radionuclides in phosphate fertilizers of some countries.

Table 2. 1: Activity Concentration (Bq/kg) of Natural Radio nuclides in Phosphate Fertilizers

Phosphate Fertilizer	Country	^{226}Ra	^{232}Th	^{40}K
Super Phosphate	Germany	520	15	140
	USSR	110	44	120
	USA	790	20	
	Belgium	910	<25	<180
Tri-Super phosphate	Germany	230	44	52
	USA	780	48	
PK-Fertilizers	Germany	370	15	5700
NP-Fertilizers	Germany	310	30	44
Ammonium Phosphate	USSR	100	48	
Nitro phosphate	USSR	850	10	
N.P.K	USSR	9	54	1200
	Germany	270	15	5200
	Belgium	210	<15	5900

(Pfiscer *et al*., 1976)

Chlorination is one of the processes of water purification in public drinking water supply, mostly tap water. This introduces chlorinated hydrocarbon into drinking water. The case study by the US National Cancer Institute established epidemiological significance or chlorine reaction, products in water. About 8000 people, including 2805 with bladder cancer were examined and significantly higher cancer risk was found from people who drank chlorinated surface water for at least 40 years (Belloni, *et al*., 1995).

Furthermore, radio nuclides from radioactive wastes find their ways into water bodies. Radioactive wastes are generated from radioactive ore mines nuclear reactor operations, hospitals and industries where radioactive sources are used. When these radioactive wastes are disposed, especially through ground repository and water disposal the containment can give way after sometime. The radionuclides from the radioactive wastes thus, can seep into water body and consequently contaminating water supplies leading to man's exposure to ionizing radiation (Winn, 1995).

2.2.1 Radioactivity

For any element there is limited number of neutrons within the nucleus for it to remain stable. Any deviation from this number will result in an unstable atom. An unstable atom can become more stable by emitting energy in the form of radiation. Such atoms are said to be radioactive and the process is called radioactivity.

Radioactivity is therefore defined as the spontaneous transformation of unstable nuclei that results in the formation of new elements with the emission of particles and radiations (Cember, 1996).

The emitted particles are alpha particle, beta particle, or positron and gamma radiations; whose emission only accompanies alpha or beta particle emission. (Cember, 1996). The exact mode of radioactive transformation depends on two factors (i) the type of instability-that is whether the neutron to proton ratio is too high or too low. (ii) the mass-energy relationship between the parent nucleus, daughter nucleus and the emitted particle. Henry Becquerel first discovered the fact that some elements are naturally radioactive in 1896. He observed the blackening of photographic emulsions in the vicinity of a uranium compound and this was subsequently attributed to radiation being emitted by the Uranium (Martin, 1986). This discovery by Becquerel was prompted by an earlier discovery by Roentgen in 1895. In his study of the fluorescence by cathode rays in the Crooke's Tube, Roentgen suddenly discovered that the screen he was using in a dark room fluoresced when the tube was turned on even when the screen was some distance away and he called the resulting radiation x-rays (Turner, 1995). Further intense discoveries revealed that x-rays and gamma rays (from radioactive substances) belong to electromagnetic radiations of same velocity and slightly differing wavelengths. They are ionizing radiation, which can discharge a charged electroscope. Alpha and beta particles are also ionizing radiations. The essential difference between x-rays and gamma rays is their origin. Whereas gamma rays result from changes in the nucleus, x-rays are emitted when atomic electrons undergo a change in orbit (Martin, 1986). Apart from uranium, other natural radioactive elements were discovered. In 1898, the Curies discovered Polonium and Radium (Turner, 1995). Thorium and Potassium-40 are also natural radioactive materials.

2.2.2 Radioactive Decay Law

The instability of a nucleus describes a statistical phenomenon hence; the associated transformation process is probabilistic (random in nature). The random behaviour of a particular radioactive sample is expressed in the radioactive decay law which states that if N represents the number of atoms radionuclides in a given sample at a time, then the change in the number of nuclides dN during a time interval dt is proportional to N thus

$$\frac{dN}{dt} = -\lambda N \tag{2.1}$$

Where λ is called the decay or transformation constant. The negative sign shows that N decreases as time, t increases.

$$\frac{dN}{N} = -\lambda dt \tag{2.2}$$

Solving equation 2.2 by integration and taking natural log will result in equation

$$N = N_0 e^{-\lambda t} \tag{2.3}$$

Where N_o is the number of atoms of the radionuclide at time t=0. Equation 2.3 is the radioactive decay law.

2.2.3 Half Life ($T_{½}$)

Different radionuclides are transformed at different rates, and each radionuclide has it own characteristic transformation rate. Thus the time required for any given radionuclide to decrease to one-half of its original quantity is called the half-life ($T_{½}$) of the radionuclide (Cember, 1996). The half-life of a radionuclide is a measure of the speed with which it undergoes radioactive transformation. From equation (2.3), at half-life, $N=N_o/2$ and $t=T_{½}$, so that the equation transforms to

$$\frac{N_o}{2} = N_o e^{-\lambda T_{1/2}} \tag{2.4}$$

Solving the equation, gives

$$T_{1/2} = \frac{\ln 2}{\lambda} = \frac{0.693}{\lambda} \tag{2.5}$$

2.2.4 Activity

The activity of a radionuclide is the number of atoms of the radionuclide that decays per unit time. It describes the rate of transformation of a radionuclide. The activity of radionuclides increases as in the sample increases; and decreases exponentially with time. It is given by

$$A_t = A_o e^{-\lambda t} \tag{2.6}$$

Where A_o is the activity at time=0 and A_t is the activity at time, t.

2.2.5 Specific Activity

Although, the activity is used as a measure of the quantity of the radionuclide present, it does not consider mass or volume of the radioactive material. The relationship between the activity and the mass of the radioactive material is called the specific activity; which is the activity per unit mass of the radioactive material (Cember, 1996). Specific activity is the measure of activity concentration of a radioactive material; expressed as.

$$A_{SP} = \frac{Act}{A} = \frac{\lambda N_A}{A} \tag{2.7}$$

Where N_A the Avogadro number and A is the atomic mass of the radionuclide.

2.2.6 Sources of Radioactivity

There are two main sources of radioactivity: Natural and Artificial Radioactivity.

(a) **Natural Radioactivity**

Natural radioactivity originates from primordial radionuclides in the earth's crust and from nuclear reactions in the stars. These are called terrestrial radiations and cosmic radiations respectively. Cosmic radiations emanate from the sun and interstellar space; and constitute primarily of 87% proton, 11% alpha particle, 1% heavy ion and 1% electron. These particles produce secondary cosmic radiation, which consists of 80% neutrons and 20% electrons (Martins, 1986) and these secondary cosmic radiations are the ones that get to the earth's surface. The annual external dose rates from cosmic radiations depend largely on the altitude and slightly on the latitude. Table 2.2 shows the altitude dependence of cosmic radiation dose rate in some countries.

Table 2. 2: Altitude Dependence of Cosmic Radiations Dose Rate in some Countries.

Altitude (m)	Dose Rate mSv/y	Example
Sea level	0.31	Los Angeles
1,525	0.55	Denver
3,050	1.37	Leadville; Colo
9,140	19.00	Normal Jetliner
15,240	87.57	Concorde
24,340	127.00	Spy Plane

(Adopted from Gollnick, 1988)

From Table 2.2 result, a pilot that is constantly flying on air is exposed to an appreciable dose of cosmic radiation. The latitude effects arise from the fact that the charged particles of cosmic rays on coming towards the earth's surface are deflected by the earth's magnetic field, away from the equator and towards the poles, thus the dose rate increases with increasing latitude (Martins, 1986). Cosmogenic radionuclides, from the reactions of cosmic rays with the particles of the atmosphere, include ^{3}H, ^{7}Be, ^{14}C and ^{22}Na with their respective annual doses as 0.01mSv, 0.03μSv, 12μSv and 0.15μSv (Turner, 1995). Carbon-14 is produced by the reaction $^{14}N(n, p)^{14}C$. It diffuses into the lower atmosphere, oxidized to carbon dioxide (CO_2) and becomes incorporated in plants, animals, or seeps into the water (Cember, 1996). Carbon-14 is an important tool use in radio carbon dating.

Terrestrial radiation results form the primordial radionuclides, which include ^{238}U, ^{232}Th, ^{226}Ra and ^{40}K (Peter, 1989). They exist in the three naturally occurring radioactive decay series, which undergo transition at very slow rate because of their long half-lives and produce several decay products (Progeny). These progeny include ^{266}Ra, ^{210}Po, ^{210}Pb and ^{222}Rn. The Radon gas gets into the atmosphere through emanation and diffusion via soil capillaries and as an inert gas, it has greater residence time in the atmosphere and higher probability of human irradiation (Ibeanu, 1999). The daughter products of ^{222}Rn such as ^{210}Po and ^{210}Pb being solids, attach themselves to the atmospheric aerosols there by contaminating the air inhaled by man. Radon gas and its decay products contribute about 55% of the background radioactivity to man. The primordial radionuclides are present in rocks, soils and building construction materials. Mining and processing of radioactive ores contribute significantly to the enhancement of terrestrial radiation fields in the environment (Ibeanu, 1999). These radioactive rocks and soils are constantly encountered by flowing rivers, streams and ground water and consequently they contaminate the water sources.

Our food typically contains about 10Bg/kg of ^{40}K, our body incorporates them into soft tissues and bone irradiating the body continually, and hence our body is naturally radioactive. This is referred to as NORM internal to human body. The activity in the body of a reference person of 70kg is about 4,000Bq, mainly as a result of the presence of ^{40}K and ^{14}C (Alison, 1968). This delivers a dose of about 7μSV per year to the skeleton (Eisenbud, and Paschoa, 1989).

(b) Artificial Radioactivity

Artificial or man-made radioactivity results from a number of man's activities leading to the designing and building of many types of apparatus that produce radiation and/or radioactive materials. These human activities include the use of X-rays for diagnostic and therapeutic purposes in medicine, research, industry and agriculture; the

generation of electricity through nuclear power plant. All these activities introduce radioactivity into the environment.

Production of fertilizer for agriculture is a major source of artificial radioactivity to the soil, as a part of the constituents of fertilizer is radionuclides. Spalding and Sackette (1972) observed the leaching of Uranium from phosphate fertilizer as in a North American river. Clergy (1958) measured the mean activity concentration of 1464 Bq/kg, which is a factor of about 58 times the mean activity, concentration worldwide in a normal environment.

The phosphate fertilizers are to have more concentration of radium followed by potassium and then thorium. The PK and the NPK fertilizers have higher concentration of potassium than radium (Ibeanu, 1999). When these fertilizers are applied to the soil, they add radioactivity to that of the Uranium and other decay series present in the soil (Eisenbud and Pachoa, 1989).

Seventy percent of the earth's surface is radioactive substances from fertilizers; terrestrial radiation and cosmic radiation return to the water through dry out, rain out or wash out directly into the surface of waters. However, an important portion of the active substances pass through the hydrosphere and is leached out from the soil and arrives in rivers, lakes and seas (Szabo, 1993).

2.2.7 Radioactivity in Water

Radionuclides from both natural and artificial sources of radioactivity can come into contact with water through several ways. They may be deposited from air. They may also be released to the water from the ground through erosion, seepage or human activities such as mining. Some radionuclides that reach either groundwater or surface water move with the water, others are deposited on the surrounding soil or rocks. Some factors affecting their movement are their solubility in water and the ability of the

radionuclides to adhere to the surface of rocks or soil through which the water flows (Audeen, *et al.,* 1989).

These radionuclides found in water include radium, radon, uranium, polonium and few other Isotopes. For instance the US Geological survey recently reported high concentration of radon in well water and Blue Ridge region of the New River watershed located in North Carolina and Virginia respectively. The highest level of concentration in the North Carolina well was 303.14 Bq/m^3 and the lowest found was 12.32 Bq/m^3 (USGS, 2000). This gave a course for concern and the inhabitants were advised to install radon mitigation system, to check radon in air, and radon in water, in their residential houses. Also ^{210}Po has been detected in the water of east central Florida (Baratta, 1990). The geographical formation of an area determines, to some extent the radionuclide in water. Application of phosphate fertilizers in the soil, and industrial wastes disposal also introduce radioactivity in water.

The volume, depth, chemical composition and the state (flowing or stagnant) of water influence the radioactivity of surface water. In the case of stagnant water like lakes the depth is very important. The level of radioactivity measured in lakes is usually higher than the activity in flowing rivers or seas, because a significant quantity of the radioactive substances brought by the rivers into the lakes accumulates there (Sajo-Bohus, *et al.,* 1997).

In order to give an approximate idea of the radioactivity of water, the gross alpha and gross beta activity are measured. The gross activity does not indicate which radionuclide is responsible for the radioactivity measured. Also the results obtained cannot be used for exact direct dose calculation but it gives only the degree of contamination. Gross radioactivity accounting also cannot measure tritium concentration in water, as water with tritium evaporates and the ruminant may not contain tritium. Natural radioactivity in water is shown in Table 2.3 (Szabo, 1993).

Table 2. 3: Natural Radioactivity in water

Type of water	U-Conc (μg/l)	Activity (mBq/l)			
		^{226}Ra	^{222}Rn	^{210}Pb	^{210}Po
Rain water		4.6 + 0.3			
Tap water		5.1 + 0.3			
Drinking water	0.3-50	3.7-37			
		26-1850			
Surface fresh water			37-3920		
Lakes in fin land				0.9-16.7	0.3-8.5
Baltic sea				0.3-6.8	0.1-8.5
Pacific ocean				0.7-4.8	0.9

(Adopted from Szabo 1993)

2.2.8 Physical Effects of Radiation

Ionizing radiation produces physical, chemical and biological changes in the human system. The mammalian cell constitutes typically of 70-85% of water, 10-20% of protein, 10% of carbohydrates and 2-3% of lipids (Turner, 1995). As water is the major constituent of the human cell, the radiation effects on water is given paramount attention in this write up. The initial physical changes that occur when water is irradiated are the creation of ionized and excited molecules, and free sub excitation elections as in Turner (1995)::

$$H_2O \xrightarrow{Radiation} H_2O + e^-$$

$$H_2O \xrightarrow{Radiation} H_2O^+ + e^-$$

This event occurs in a very short time of about 10-16s in local track region (Alan, 1986). Water begins to adjust to the sudden physical appearance of the new species even before the molecules can move appreciably in their normal thermal agitation.

Radiation effects on carbohydrates include decease in melting point, reduction in optical rotation, browning and changes in absorption spectra of the carbohydrates (Wiser, 2000). In lipids radiation induces formation of free radiation, which decay with increasing temperature, and at about 70kGy radiation causes polymerization (hardening) of fats, which results in increase in viscosity of fats. Proteins are broken

into their constituent amino acids (degradation) by radiation (Wiser, 2000). The physical effect of radiation is a function of the degrees of energy deposition of the radiation on the medium. The intensity of the radiation I is related to the thickness of the medium x, thus:

$$I = I_o e^{-\mu x} \qquad 2.8$$

Where μ is the linear attenuation coefficient, Io is the initial intensity of the radiation. Thus high energy radiations (like x-rays and γ-rays) are less attenuated and have less energy deposition, than low energy radiations (like α and β) which are more attenuated and deposit more energy, within a short distance resulting in the physical changes (Tuner, 1995).

2.2.9 Chemical Effects of Radiation.

The chemical effects of radiation on water set at about 10-12s, after the physical changes. The initial species formed by radiation on water are mostly free radicals, very reactive chemical species. These include OH, H, e_{aq}; which react with themselves and with the water molecules in a series of reaction, Turner (1995):

$$OH + OH \rightarrow H_2O_2$$

$$OH + e_{aq} \rightarrow OH$$

$$OH + H \rightarrow H_2O$$

$$H_3O + e_{aq} \rightarrow H + H_2O$$

$$e_{aq} + e_{aq} + 2H_2O \rightarrow H_2 + 2OH^-$$

$$H + H \rightarrow H_2$$

The reaction of these radicals and their effects on the medium is through indirect action, which is more damaging to the medium than direct action. Thus the

formation of chemical species by radiation results in chemical reactions of the species with the medium, which causes damages to biological organs (Alan, 1986).

2.2.10 Biological Effect of Radiation

Some substances formed from the chemical reactions of the radiation produced radicals, such as hydrogen peroxide, are strongly toxic to biological cells and are stable within the cell. They may be removed by enzymes that are specifically to protect against these materials (BEIR, 1980). The cell damage may be in the form of:

(i) Early death of the cell

(ii) Prevention or delay of cell division

(iii) A permanent modification (mutation) which is passed on to the daughter cells (Alan, 1986).

Biological effects of radiation can be acute or chronic. The acute radiation effect is a short term, deterministic effect in which high dose of radiation is received within a very short period. The individual or group must be exposed before acute effect can be got because there is a threshold amount of radiation dose (Alan, 1986). The acute radiation syndromes include vomiting, diarrhoea, haemorrhage, gastrointestinal disorders, neuromuscular damage, shock and even death, depending on the dose of radiation (Mark and Barnett, 1976).

Chronic or long-term radiation effects are those that manifest themselves long time after the original exposure. They result from low-level exposures over a very long time, or sparsely from previous acute dose effects. From the stand point of public health significance, the possibility of long term effects on the large number of people receiving low, chronic exposures is a cause for greater concern than the short-term radiation effects, which involves only a few individuals. Among the long-term effects of ionizing radiation thus far observed are cancer, cataracts, life span shortening,

genetics mutation and embryological defects (BEIR, 1980). Thus ionizing radiation is said to be a carcinogen. However, no pathologist can say for certainty whether the cancer would not have occurred if the people were not exposed to the carcinogen. The long-term effect is stochastic, probabilistic and has no threshold and can result whether one is exposed to radiation field or not. Thus every increment of radiation dose, no matter how small, carries with it a corresponding increased probability of the long-term effects (Arno, 1988). Stochastic effects could be caused by radiation exposures through external contact with water, drinking of contaminated water, eating of contaminated food stuff, eating of meat or drinking of milk from contaminated animals.

2.2.11 Health Implications of Radioactivity in Water

When a radionuclide gets into the body through ingestion, inhalation or absorption through the skin, it continues to decay or disintegrate, emitting radiation such as alpha, beta or gamma radiation such that the organ or tissue is continuously irradiated. Consequently the tissue is damaged, the degree of which depends on the type of radiation. The damage is greatest with alpha, and least with gamma radiation. Some radionuclides are chemically similar to some minerals in the body and so when they are taken into the body, they mimic those minerals in the organs. For instance radium, strontium and barium are found to have chemical similarity with calcium in the bone. When these radionuclide gets into the body., they are deposited at the bone (bone seeking) causing damage to the bone cells through Osseo sarcoma (bone cancer)(Arno, et al., 1988). This was the case of the radium dial painters in the early 20th century, many of whom suffered degeneration of jawbones and died of anaemia following swallowing of minute amounts of radium each time a paint brush was pointed with their lips (Cember 1996). Uranium is known to have deleterious or chemo toxic effect to the kidney (Latouche, *et al.,* 1987).

The international commission on radiological protection (ICRP) estimates that the blood stream from gastrointestinal tract absorbs an average of 5 per unit of ingested uranium. It also suggests that the value could possibly be as high as 20 as had been shown by ICRP (Cothern, *et al.,* 1983). Radioactivity in drinking water was estimated for gastrointestinal absorption to be 1.4% (Wrem, *et al.,* 1985). In preliminary results from experiments that used fasting human subjects a value of between 0.5% to 1% was suggested (Crawford Brown, 1990). In view of these results both 1.4% and 5% estimates are reasonable average level to use in risk calculations (Milla, 1990).

The radioactive radon, which has the largest single contribution to background radioactivity, has been attributed to the incidence of lung cancer. This was thought so at about 1924, following the increased incidence of lung cancer death among the miners in Schoenberg and Joachimsthal regions in the Carpathian Mountains as at the sixteenth century (Cember, 1996). It was discovered that the mine, though worked for mainly cobalt, was very rich in uranium and radium. As a consequence of high radium content of the soil, radon gas the radioactive daughter of radium, is produced and diffuses out of the ground into the air of the mine shaft, thus leading to high concentration of radon and radon daughters in the air around the mine, of the order of 3.7 x 105 Bq/m^3 (Cember, 1996). This concentration is high if compared to 1000Bq/m^3 recommended by WHO. Stomach cancer is also attributed to ingestion of radon daughters (Crawford-Brown, 1990).

External contamination from low LET radiations such as X-rays and γ-rays is also detrimental to health. This is evidence from the incidence of skin cancer discovered among X-ray workers at the early discovery of medical use of X-ray. Over 100 cases of skin cancer associated with over exposure to radiations had been recorded (Cember, 1996)

2.2.12 Regulation on Radioactive Contamination in Drinking Water.

The regulations on the contamination level of radioactivity in water as set by the 1976 National Interim Regulation of the USEPA (Milvy and Cothern, 1990) is as follows:

Gross alpha	550Bq/m^3
Radium-226 and Radium-228	185Bq/m^3
Gross Beta	1850Bq/m^3

The maximum regulatory equivalent dose from man-made radionuclides was set at 0.04mSv. It is believed that no interium maximum contamination level standard for uranium in drinking water exists (Milvy and Cothern, 1990). Many experts have suggested that maximum contamination level be set in the range of 0.74 x 10^{-3}Bq/m^3 to 3.7 x 10^{-3}Bq/m^3, based on both chemotoxic and radiological risk of uranium. Data from the United States national inorganic radionuclide survey (NIRS) shows that less than 4% of the nation's 60,000 public water supplies exceed the lower regulatory level. Also less than 0.5% exceeds the higher value level (Longtin, 1988).

2.2.13. Quantification of the Effects of Radioactivity in Drinking water

The calculation of the absorbed dose from internally deposited radioisotopes has to be done with the assumptions that as radioisotopes gets into the body, they are accumulated in one or more organs in the body. After its deposition these radioisotopes are eliminated from the organ at the rate determined by its half-life. The retention of the radioisotopes in the body is given (Cember, 1996) as

$$Q = Q_o e^{-\lambda_E \tau} \qquad 2.8$$

Where Q_o is the initial activity of the radioisotopes at time t = 0, Q is the activity remaining after a time t and λ_E is the effective elimination constant.

If the intake continues, then the accumulation of the isotopes is given by

$$Q = \frac{K}{\lambda_E}\left(1 - e^{\lambda_E \tau}\right) \qquad 2.9$$

Where k is the intake of activity per unit time (Bq/day). As t increases, $e^{-\lambda_E T}$ decreases and the body burden Q approaches the limiting (Cember, 1996) as

$$Q = \frac{K}{\lambda_E} \qquad 2.10$$

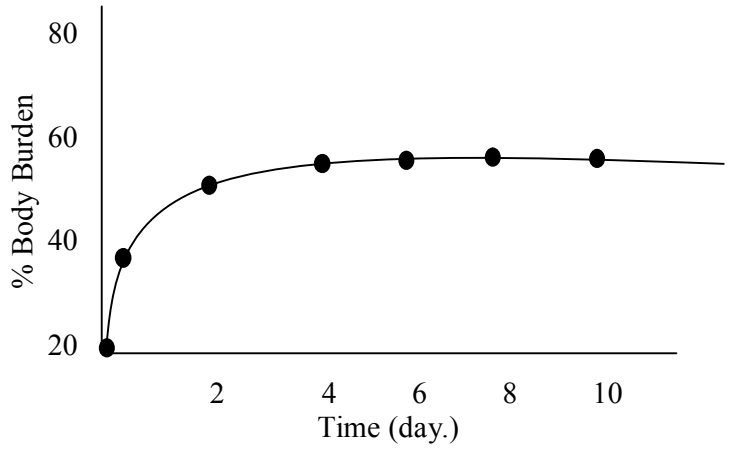

Fig. 2. 1: Build-up of a Radioisotope in the Body Resulting from Continuous Intake.

(United Nation Scientific Committee 1982)

The limiting value, for practical purposes is reached after about six-effective half lives. At this time a steady state is reached, in which the amount of activity deposited is equal to the amount of activity eliminated (Cember, 1996).

For estimation of maximum permissible concentration (MPC) of radioisotope in drinking water, some physical and biological data must be known. These include the type of radiation (α, β and γ), the energy of the radiation, and the radiological half-life (physical data). The biological data include identification of the critical organ, biological clearance rate from the critical organ and the fraction of the ingested activity that is systematically deposited. For example, ICRP publication 2 shows that ^{131}I, a beta-emitter, with activity of 5.4×10^3 Bq had the maximum permissible body burden

of 2.7 x 10^4 Bq. The quantity of a radioisotope when uniformly distributed throughout an organ delivers the maximum recommended dose rate to the organ (Cember, 1996) This dose rate is given by:

$$q = \frac{A_o E_o}{m} \qquad 2.11$$

where q is the dose rate in Gy/s, A_o is the activity in Bq, E_o is the effective energy in MeV and m is the mass in kg.

To estimate the maximum concentration in drinking water for any radionuclide in a steady state conditions it is assumed that The activity deposited is equal to the activity eliminated therefore,

$$C(Bq/ml) \times 2.2 \times 10^3 (ml/day) \times F = \lambda_E (day^{-1}) \times A_o (Bq) \qquad 212$$

where C is the maximum permissible concentration of isotope in water, F is the fraction of intake that is deposited in critical organ, λ_E is the effective elimination constant and A_o is the steady state activity in critical organ. ICRP publication 2 lists the MPC in water for continuous ingestion as 0.74 x 10^{-6} Bq/m^3. For forty hour per week of occupational exposure the MPC in water for ^{131}I is 2.22 x 10^{-6} Bq/m^3 (Cember, 1996). Table 2.4 below shows the equivalent dose rate to some organs due to intake of radionuclide

Table 2. 4: Equivalent Dose rates of Different organs

Daily Equivalent dose rate (104 μSv)	Critical Organ
1.4	Whole body, hemopoetic system, gonads
8.6	Throid
4.3	Other organs or tissues

(Cember, 1996)

2.3 Measurement of Radioactivity in water

2.3.1 Sampling

The observed results of samples collected from the river may vary with depth of water, river flow and distance from shore and from one shore to the other (Williams, 1977). For this course if equipment is available, an integrated sampling is preferred.

This is taken from top to bottom in the middle of the river or from side to side at the mid-depth in such a way that the square is integrated according to flow (Williams, 1977). However, if only a grab or catch sample can be collected; it should be taken from the middle of the river or stream and at mid-depth (Williams, 1977).

Considering gross radioactivity measurement of river vis-à-vis regions, the regional radioactivity is the focal point. This is a function of the prevailing activity in the environment (farming, industry and so on) and samples near the riverbank will reveal this situation mostly. Thus sample collection near the bank of river is the adopted method for this work.

2.3.2 Radioactivity Measurement

Radioactivity in water can be determined by gas-filled detectors, scintillation and semi-conductor detectors. Alpha and beta activities can be detected by the proportional counters. Gamma activity can be detected by scintillation detectors and semiconductor detector like Ge (Li), HpGe detectors.

(a) Thin-windows Proportional Counter

This counter can detect alpha and low energy beta radioactivities. The counter is of very thin shielding, of plastic films less than 250 $mgcm^{-2}$, and tube of about 5cm in diameter; and/or anti coincidence guard circuitry. It is about one-half as sensitive as internal proportional counter due to poor geometry; and absorbing losses (Jarrettee, 1946). The counter is less affected by contamination from loose residues, and poor electrical conductance, because the sample is outside (Jarrettee, 1946), unlike the internal proportional counter.

(b) Low Background Beta Counter

This may be ionization for beta emitters having maximum energy of 0.3 MeV (Arnold, *et al.,* 1992). The detector window thickness usually is less than $1.0mg/cm^2$

and alternation of high-energy radiation of moderate energy. The sample used may have a diameter less than that of the window. Instrument with a lead or steel shield and an anti-coincidence device of one or more guard detectors with an electronic is used to obtain a background counting rate of 1cpm or less.

2.3.3 Internal Proportional Counter

Proportional counters as gas filled detectors operate on the principle of ionization of the counting gas by the incident radiation, and subsequent charge collection at the electrodes. These collected charges give the measure of the energy of the incident radiation.

Internal proportional counters are suitable for determining alpha activity, at the alpha operating plateau and alpha plus beta activity at the beta-operating plateau The alpha or beta activity, or both, can emanate from a single or several radionuclides. The internal proportional counter accepts counting pans within the counting chambers and at the beta operating voltage records all alpha, all beta and some gamma radiations emitted into the counting gas (Arnold, *et al.,* 1992). Theoretically half of the radiation is emitted in the direction of the counting pan. Some of the beta radiation, but only 1% to 2% of the alpha radiation, is backscattered into the counting gas by sample solids, the counting pans or walls of the counting chamber. The percentage of beta radiation detected may be around 60% while that of the alpha radiation is 50% for substantially weightless samples (Arnold, *et al*., 1992).

2.3.4 Problems with Counting Instruments

The different counting instruments have different modes of operation and each has problems associated with it. A typical problem of most counters is the background or instrument counting rate, usually due to cosmic radiation contaminations in instrument parts and the counting room construction materials, and due to nearness of radioactivity source (Onoja, 2004).

The background noise is roughly proportional to the size or mass of the counting chamber of the detector, but can be reduced by metal shielding (Arnold, *et al.,* 1992). Instrument "Noise" or false recording of radiation event, may be caused by faulty circuitry, too sensitive a gain setting, high humidity and variable line voltage or transients. These problems can be remedied by using constant voltage transformer with transient fitters, poorly adjusting gain setting as specified by the manufacturer, and air-conditioning of the counting room (Arnold, *et al.,* 1992).

Also the coincidence and anti coincidence events are worthy of mentioning. Coincidence unit is an electronic device that accepts pulse/events in two or more input channels. It gives an output signal only if the two input pulses arrive within a set time. On the other hand an anticoincidence unit is the one that accepts pulses/events in two input channels and provide an output signals only if the events do not arrive within a set time (Knoll, 1999). In measurement or counting of radiation there is need for background radiation and this is achieved by coincidence and anticoincidence shielding.

2.3.5 Coincidence Counting

If a radioactive sample that emits more than one distinguishable radiation in coincidence is to be counted, an effective background can greatly be reduced using coincidence technique. A suitable arrangement for this consists of separate beta particle and gamma ray detector in which the source is mounted to maximize the corresponding interaction rates in each detector. By demanding coincidence between pulses from the two detectors, many background interferences will be eliminated because they will occur in only one detector at a time (Onija, 2004).

2.3.6 Anti coincidence Shielding

Highly penetrating cosmic radiating which may interfere with the walls of a detector and cause background effect can be eliminated or reduced using anticoincidence, shielding.

A second detector surrounds the primary detector and the output of the primary detector is accepted only when coincident pulse in the outer detector does not accompany it (Onoja, 2004). The source to be counted is oriented and shielded so that it produces interactions in the primary detector only when a coincident pulse in the outer detector does not accompany it. Therefore in the simplest case, no pulses are affected which correspond to the complete absorption of the source radiation within the primary detector.

However, the cosmic radiation will likely penetrate both detectors. Therefore, it can be eliminated from the output of the primary detector through the anti-coincidence arrangement (Onoja, 2004).

2.4.0 Review of the Previous Works

Al- masri and Blackburn (1995) researched on application of Cerekov radiation for the assay of ^{226}Ra in natural water. The first count rate they obtained was due to ^{228}Ac (the daughter product of ^{228}Ra) ^{214}Bi and ^{214}Pb (the daughter product of ^{228}Ra); and the second count rate was due to ^{228}Ac and the build up of ^{226}Ra activity Banwo (1989) measured radioactivity in living houses within Zaria but not in water.

Ekpo and Inyang (2000) determined radioactivity, physical and chemical parameter of under ground and surface water in Qua iboe but did not give the results on the radioactivity measurement of this area. Rather, they produced result on the radionuclide present in the area.

In his work Isma (1993) wrote on fluoride in local water supplied in Zaria, while Ososami (1994) assessed the ground water in the Kubani valley-Zaria and these two works never gave data on radioactivity.

In optimization and comparison of three different methods for the determination of ^{222}Rn in water, Belloni, *et al*. (1995) extracted ^{222}Rn from water by degasification in his first method. It was counted using a Lucas cell, for 10 minutes. In the second method; ^{222}Rn was extracted directly from water and counted in a liquid scintillation counter for one hour. In the third method water was sampled using a Marinelli beaker and after four hours the water was counted for gamma using NaI(Tl) scintillator. The results obtained by all the three methods agreed, with first method having detection limits of 20 MBq/l, the second method having 200 MBq/l and the third methods having 1.75 Bq/l.

Van Briston, et al. (1995) worked on a rapid method for the determination of uranium in surface water using an absorber resin, saturated after agitation in 2m-HNO3 and saturated with ammonium chloride and directly electrolyzed for alpha measurement. Their results showed that uranium obtained from the resin after agitation for 30 minutes produces a recovering of 10-90% with RSD < 15%. The detection limits were 2ppb for uranium using ICPS and 0.4ppb by alpha-particle spectrometry.

Alvarado *et al.* (1995) worked on rapid determination of radium isotopes by alpha spectrometry. The analysis showed the presence of ^{224}Ra and ^{226}Ra with the detection limits of 0.3 and 0.2 MBq respectively. The relative error for the determination of 3.45 MBq/l of ^{226}R was 0.9% and the RSD (n-20) was 4.6%.

In his work (Surbeck (1995) detected radionuclide in drinking water. The analysis showed the presence of ^{226R}a, ^{210}Po and ^{224}Ra, which were obtained from 80ml sample of drinking water. This was exposed to Ra absorbing discs for 20 hours and the

discs were measured by alpha-particle spectrometry using a silicon surface barrier alpha detector. The results also show that the detection limit for these three radionuclide were 2.0 x 10^{-5} Bq/m^3.

The radionuclides ^{238}U, ^{234}U and ^{210}Po were also measured using liquid scintillation alpha-spectrometer with alpha-beta discrimination and energy resolution of 200-300 keV. The detection limit was 1.0 x 10^{-1} Bq/m^3. In evaporating drinking water, ^{226}Ra, ^{210}Po and ^{228}Ra were measured using ^{228}Au -line ^{228}Th and ^{224}Ra were measured using ^{212}Pb line. Also ^{238}U was measured using ^{234}Th -line. All measurements were made using high pure germanium (HpGe) detector with detection limit of 100, 30, 30, 10, 10 and 50 x 10^{-3} Bq/m^3.

Robertson, *et a.l.* (1995) worked on chemical speciation of radionuclide migration in ground water. In the analysis, they concluded that most radionuclide exists as stable anionic complexes with organic ligands and a significant fraction of the radioisotopes were associated with macromolecules. Some works have also been done on trace elements in water samples Nwogu (2001) observed that water with chlorine above 250 mg/l, whose alkalinity range between 100mg/l-400mg/l produces no harm to individuals. The trace elements analyzed include:- iron, copper, manganese and so on. In analysis of fadama water, soil and vegetables for heavy metals, Alabi (2001) could not tell whether water is polluted or not. He analyzed heavy elements such as iron. Odogu (2001), also in his analysis of heavy metals in fadama water, soil and vegetables (spinach) plant behind Sabon-gari market, Sabon-gari Zaria, only analyzed the presence of trace elements such as iron, copper, manganese and zinc. These were the heavy metals determined.

In his chemical analysis of Wikki spring water in Bauchi state and Kerang spring water in Plataeu state, Abba-Gana (1986) found out the physical parameter studied (such as colour, odour, temperature, pH, hardness, dissolved oxygen); the

mineral metals (for example sodium, potassium, calcium and magnesium) are within the WHO standards. Among toxic elements, arsenic and silver are found to be below detectable limits, whereas the remaining (Pb, Ni, Cd, Cr) are present but their values are within the tolerable limit.

Of all these works reviewed, none has provided any result on radioactivity in river water. However, Oguejiofor (1984) worked on pollution and self-purification of river Kubani in Zaria. His work did not produce data on radioactivity. Onoja (2004) surveyed the gross alpha and gross beta radioactivity in well waters in Zaria. In her analysis the water samples collected were evaporated in a beaker and transferred into planchettes. They were counted for gross alpha and gross beta activities with an eight-channel gas filled proportional counter. The counter was characterized for background, plateau and detection limit. Her results showed that the range of alpha activity in water in the area is 0.58-42.19 Bq/m^3; with a geometric mean of 6:35 + 0.45 Bq/m^3; for beta activity, the range is 3.58-622 Bq/m^3 and geometric mean of 75.34 + 1.53 Bq/m^3. The over all result showed that both the alpha and beta activities are below the practical screening level of radioactivity in drinking water of 100 Bq/m3 for alpha and 1000 Bq/m3 for beta recommended by CEC-FAO and WHO. Even though this work produced data on gross alpha and gross beta radioactivity in well water in Zaria, it did not provide any data on radioactivity in river water and also did not identify radionuclides present.

Ali (2004) survey on aspects of pollution of makera drain, a tributary of Kaduna river, showed that the concentration of Pb, Cu, Fe, Cd in water of makera drain exceeded the WHO limit for drinking water, while concentration of Pb and Cr in irrigated crops were above WHO/Federal Ministry of environment limits for metallic contamination in food. This work also has not provided data on the radioactivity in Kaduna River, hence the need for the determination of radioactivity in River Kaduna.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Materials

3.1.1 The Exploranium

The Exploranium GR-135 model was used for identifying the radionuclides present in the samples. The GR-135 – The identifier is a two – detector system utilizing NaI detector for high sensitivity and a Geiger Muller (G-M) detector for extended dose rate range. It can be operated in automatic mode or manual mode in two primary radiation-monitoring functions:

Search + Dose Mode - in which the G-R – 135 is used to display the count rate in counts/sec, as well as accumulated dose from the time the model was enabled. This mode is used to search for radioactive material or to carry out Total –Count grid search.

Identify mode – Nuclide Identification. In this mode the GR-135 accumulated spectral data from a sample and analyses the spectrum in terms of emitted energy level and net count contribution. The nuclides responsible for producing the spectrum are identified by comparison to a nuclide library and presented in tabular form. This essential information can be used to determine risk assessment.

The 4.0 cu in (0.065 l) sodium Iodide NaI (Tl) detector assembly is specially designed for rugged environments. The NaI crystal rubber sleeve is to give a high degree of mechanical protection against shock and is fully enclosed within the instrument body. The GM tube is mounted just behind the instrument from face and is used to extend the dose rate range to IR + for special applications.

3.1.2 The Proportional Counter

The equipment used for the gross alpha and gross beta counting is a gas flow proportional counter with 450 mg/cm^3 thick window of diameter 0.06m. It is an EURISYS MEASURE IN20 low background multiple (eight) channel alpha and beta counter. The counting system incorporates an anticoincident guard counter used to

eliminate interference from high-energy cosmic radiation into the measuring environment. The chambers are covered with 0.1m lead and the inside dimensions are 0.48 x 0.28 x 0.10^5 m^3 with stainless steel linings to prevent part of ambient gamma rays from entering the measuring environment. Thus the only contribution to the counting would be from impurities in the chamber constructing materials.

The counting gas is an argon-methane mixture in the ratio of 90% to 10%. For signal processing purpose, the system is connected to a microprocessor IN – SYST, a spreadsheet programme, QUARTTRO – PRO and a graphic programme MULTIPLAN (Akpa*, et a.l.* 2004)

3.1.3 Standards

For the alpha activity, the standards are ^{239}Pu alpha sources of diameter 0.038 m in an oxidable disc of 0.003m thickness. These sources contain a range of impurities varying from 0.74% to 0.82% of ^{241}Am and ^{240}Pu. For the eight channels, the activities as at the time of calibration 29/11/2000 vary from 133.3 Bq to 185.8 Bq at 2π stearadians. The activities of the standards at present 21/2/2006 and the identification serial numbers of the standards are shown in Table 3.1

Table 3. 1: The Alpha Standard Sources Serial Numbers and Activities

Serial Number	Activity in (Bq) at 22/11/2000	Activity in (Bq) at 21/2/2006
EBSB20/50026	160.1	160.0
“ 50050	170.3	170.2
“ 50051	157.4	157.3
“ 50052	133.3	133.3
“ 50052	168.1	168.0
“ 50054	185.5	185.4
“ 50055	185.8	185.7
“ 50056	168.3	168.2

From Table 3.1 the activity values did not change much. This is because the alpha standards ^{239}Pu have a long half-life (24000 yrs.). The standards for Beta activity counting are ^{90}Sr beta sources of diameter 0.038m and an active film of 12 mg/cm^3 thick. The activities for the sources vary from 105.1 Bq to 117.7 Bq at 4π steardian, as at the time of calibration, which was on 22/11/2000. The radionuclide impurity in each

of them is less than 0.1%. The present activities of the standards and their identification serial numbers are shown in Table 3.2.

Table 3. 2: The Beta Standard Sources Serial Numbers and Activities

Serial Number	Activity in (Bq) at 22/11/2000	Activity in (Bq) at 21/2/2006
EBSB20/14529	118.5	87.7
" 14530	117.7	87.1
" 14531	106.9	78.7
" 14533	105.5	78.1
" 14535	113.1	83.7
" 14536	106.9	78.7
" 14537	106.4	78.6
" 14539	105.1	77.8

From Table 3.2 the beta activity values at present has decreased significantly. This is because ^{90}Sr has shorter half-life than ^{239}Pu (27.7 yrs.). All measurements were certified by CERCA and LEA Laboratories in France.

3.1.4 Other Materials

Other materials used for various experimental stages of this work include: For sampling plastic container of about 2-l volume, conductivity meter, Geographical Positioning System (GPS) for measuring the geographical co-ordinates, thermometer and Nitric acid. For TDS experiment the materials used are: Cellulose membrane filter of 0.45 μm pore size, filtration apparatus, mechanical suction pump, Analytical balance capable of weighing up to 0.1 mg, measuring cylinder, beakers and evapourating dish. For sample preparation, the materials used are: hot plate for evaporation, vinyl Acetate, Ethanol for even spread of the sample in the planchette, $CaS0_4$ and $UO_2(NO_3)_2$ for preparation of alpha standards, KCl for beta standards, deionized water and the planchette of about 0.3m in diameter and 0.002m thickness, made of stainless steel to resist corrosion from samples and reagents that may be placed in them.

3.2 Methods

3.2.1 Sampling

Sampling Location

The area under survey is Kaduna metropolis; the state Capital of Kaduna State and one of the major cities in Northern Nigeria with a population of about 3.5 million.

Kaduna town is bounded in the South by the Federal Capital Territory Abuja, and located at longitude 10.43ºS 10.57ºN and latitude 7.38ºW, 7.50ºE as shown in the topographic map of Kaduna SE sheet 123 SE and Kakuri NE sheet 144 NE in Figure 3.1.

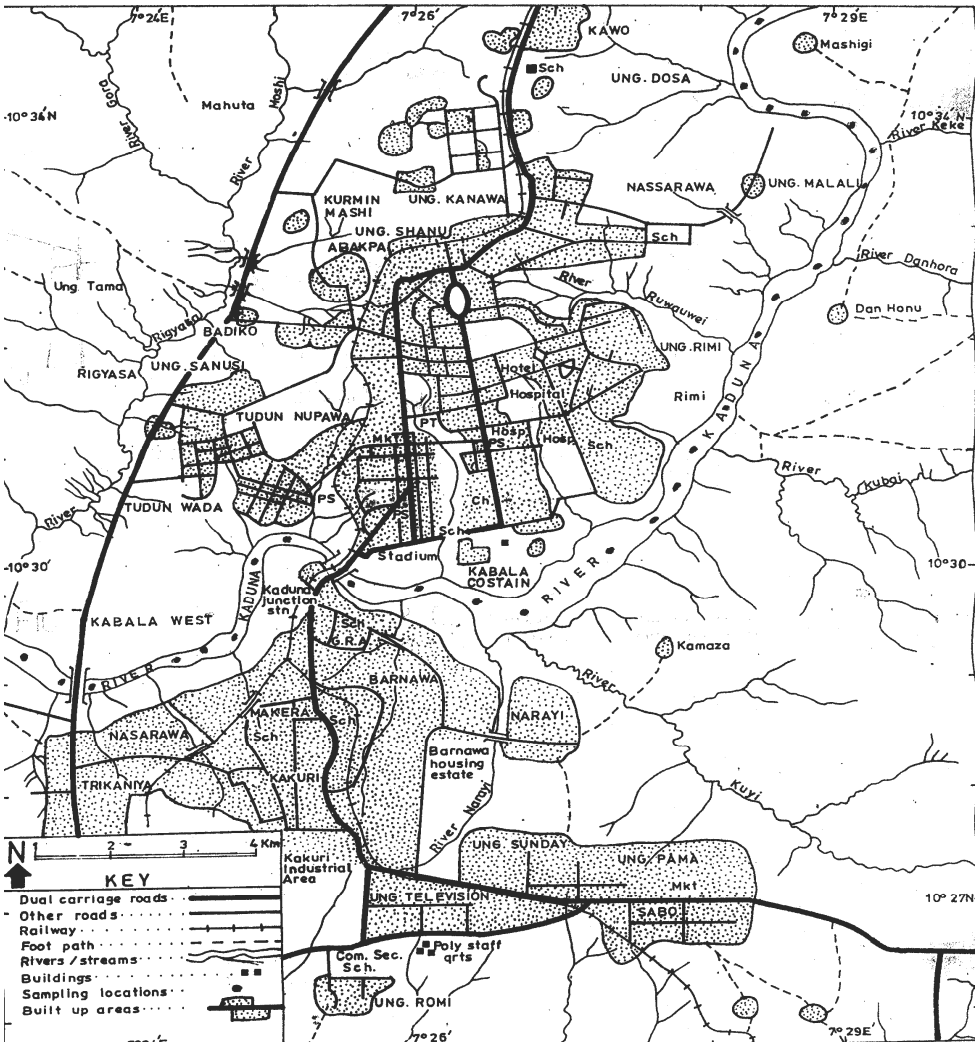

Fig. 3. 1: Topographic Map of Kaduna Metropolis

(Kaduna SE sheet 123 SE and Kakuri NE sheet 144NE)

Kaduna is a cosmopolitan city and from the topographic map, the Northern part of the city has very sparce settlement and this suggest predominant farming activity going on there. The central part of the city has dense settlements and also the central market of the city is located there so that a lot of commercial activities go on there, suggesting predominant residential area. The Southern part of Kaduna is the Industrial layout and most of the industries are located there suggesting predominantly Industrial activities zone.

The River Kaduna runs from the north to the southern part of the city, and thus there are three categories of settlement along the course of the river Farming zone, Residential/Commercial zone and Industrial zone.

Therefore River Kaduna is used for various purpose like irrigation, fishing, swimming, industrial use, drinking for livestock and major source of water supply to the water board for purification, treatment and distribution as portable water (tap water) to the residents of the town. Some communities without portable source of water also depend on it for drinking and other domestic activities.

Sample Selection: The stratified random sampling (Williams, 1977) was used and in each of the 3 regions, ten samples were collected with a distance of about 500m between one sampling point and the other. A total of 30 sampling points was got.

Sample Collection and Preservation: In sample collection, plastic bottle of about 2litre volume was used. The container was rinsed three times with the sample water in order to minimize contamination from the original content of the container. The water was collected near the bank of the river where there is less dilution of the washout from the surrounding environment. The temperature of the water was taken and the conductivity of the water was measured using the conductivity meter. Then the sample water was acidified with about 20ml of nitric acid per litre to reduce the pH to 2,

immediately after the conductivity measurement. This is to minimize precipitation of the radionuclide present in the sample water and also to prevent the absorption of radioactivity by the walls of the sample container. The sample container was tightly covered with a space of about 1% of the volume left for expansion of water and date, time and location of sample collected were recorded. The samples were kept in the Laboratory until they were analyzed.

3.2.2 Identification of Radionuclides present in the sample.

The Exploranium, GR-135, the identifier was used to identify the radionuclides in each of the 30 samples collected. The radionuclides identified in the samples are ^{238}U, ^{232}Th, ^{40}K and unidentified radionuclides, which are the radionuclides that are not in the library of the identifier. The energy peaks of the various radionuclides were obtained from the Exploranium. The standards for the various radionuclides were got using deionized water and the compound of each of the radionuclide like $UO_2(NO_3)_2$ for the uranium standard, KCl for the potassium, and ThO_2 for thorium standard. A specific quantity (mass) of each compound is added into deionized water and the size (amplitude of the peak) of the radionuclide is obtained from the Exploranium. The specific activity of the radionuclide is calculated using the mass of the compound of the radionuclide added in the deionized water. The graph of Activity against size is plotted to get a straight-line curve. Then the activity of each radionuclide in each sample is traced to the curve from the peak size of the radionuclide in the sample. The specific activity of each of the radionuclide is obtained by dividing the activity of the radionuclide with the mass of the radionuclide corresponding to the size of the radionuclide in the Exploranium. The contour distribution for the specific activities for each of the radionuclides was got.

3.2.3 Determination of Total Dissolved Solids (TDS).

Certain volume (100ml) VA of each of the samples was filtered in the filtration unit with suction pump using cellulose membrane filter of 47 mm in diameter with effective pore size of 0.45μm. The filtrate was transferred to porcelain evaporating dish of mass MB in grams and evaporated to dryness in a hot plate. The mass of the evaporating dish and dried residue MC was obtained. The difference between the former and the later weighing gave the mass of the residue MC-MB (g). The total dissolved solids (TDS) for each of the samples was calculated in mg/l using the formular (ISO 9697 1992)

$$TDS = \frac{M_C - M_B}{V_A} \times 10^6 \qquad 3.1$$

The graph of the calculated TDS against conductivity, measured at collection of samples was plotted to get a straight-line curve. The person correlation was obtained for the two quantities. The value of the TDS for each sample was used to calculate the volume of sample Vp which when evaporated will give a mass of residue corresponding to 0.1A mg where A is the area of planchette, which from equation 3.3 is

$$V_p = \frac{0.1A}{TDS} \times 10^6 \qquad 3.2$$

3.2.4 Sample Preparation

The preparation of the samples for the gross alpha and gross beta counting was done in the following way: The calculated volume Vp of each of the samples was measured into a beaker and evaporated on a hot plate to about 50ml volume and then transferred to a clean dry evaporating dish. Few drops of vinyl Acetate were added to the sample during evaporation to act as a binder to prevent the precipitation of source of the radionuclides in the sample. The sample was evaporated to dryness on hot plate. The residue was transferred onto a clean, dry and previously weighed planchette. The

planchette and residue was weighed and the difference between the mass of empty planchette and that of planchette and residue gives the mass of the residue M_T. The residue was uniformly spread on the planchette by dropping a few drops of Ethanol. The residue was allowed to dry and then covered with mylar film ready for counting.

3.2.5 Preparation of Counting Standard for Alpha Activity Measurement

The alpha activity counting standard was prepared according to (ISO 9696 1992) About 2.5g of $CaSO_4$ was weighed into a beaker and 10ml of hot nitric acid was added to the $CaSO_4$ and stirred. Then about 100ml of hot water was added to dissolve the residue. Then about 0.002g of $UO_2(NO_3)_2$, which is mass that can produce activity of 10Bq by the ^{238}U in the compound was added in the mixture. The solution was transferred to an evaporating dish previously weighed and evaporated to dryness. The mass of the dry residue M_R was obtained. The specific activity as of $CaSO_4$ in Bq/g was also obtained using the mass of the residue M_R and the amount of activity added as ^{238}U. To each of the planchettes, 0.10A (mg) of the residue was measured and sent for counting to get the measured count rate for standard R_S (s^{-1}).

3.2.6 Preparation of Beta Counting Standards

The beta standard used is potassium chloride (KCl). A certain mass 0.10A (mg) of the standard was weighed into the planchettes. The standard was evenly distributed in the planchette and counted, to get the beta standard count rate R_S in count/second.

3.2.7 Detector Characterization

For the detector to be put into use certain measurements were made. These include the background measurement and the plateau test.

Background Measurement: This measurement is aimed at getting the channel efficiency. It was carried out with empty counting planchette, washed with deionized water and dried. The operational high voltages, 1600V for alpha and 1700V for beta was set and background radioactivity was measured for thirteen cycles for 900s per

cycle for alpha background and twenty-five cycles of 180s per cycle for beta. A histogram and a scatter graph of the counts against channel number were obtained for all the eight channels measured simultaneously. The background count rates were recorded in counts per minute in alpha only and beta only modes.

Plateau Test: This test is designed to verify the suitable optimal and operational voltages for the different counting modes. The modes are alpha (α) only and beta (β) modes using 239Pu and 90Sr standards respectively. For each of the modes, the voltage is varied from the minimum to a maximum specified voltage at intervals of 50V. The 4π-stearadian detection efficiency at each voltage is calculated and plotted against the voltage values, from this the figure of merit (slope) is determined for the eight channels. Also the average efficiency for each channel, optimal and operational voltages are determined and all the results displayed by the system.

3.2.8 Counting

The counting equipment is automated. The procedure involves entering the present time, number of cycles and the counting (operational) voltage. Also the counter characteristics (channel efficiency and background count rate), volume of sample used and sample efficiency were entered. The sample efficiency was calculated as:

$$Sample..efficiency = \frac{M_T}{0.1A} \times 100\% \qquad 3.3$$

Where MT is the mass of residue in the planchette got from sample preparation and 0.1A (mg) is the expected mass of the residue in the planchette.

(a) Gross alpha counting

For gross alpha counting, the high voltage was set at 1600V and samples were counted for 3 cycles of 3600s per cycle. The results were displayed as raw counts; count rate (count/min), activity and standard deviation. The data were acquired for

alpha only mode and the alpha count rate as well as alpha activity were calculated using the formula.

$$Rate\alpha\left(count/\sec\right)=\frac{Raw\,\alpha\,count\times 60}{count\,time\,(\sec)} \qquad 3.4$$

$$Activity\,\alpha=\frac{Rate\,\alpha\times Bgd\,\alpha\times\alpha\ \ unit\,coefficient}{Channel\,\alpha\ \ efficiency\times Sample\,efficiency\times SampleVol.} \qquad 3.5$$

Where unit coefficient is the multiplication coefficient making it possible to obtain the results expressed in the units used by the operator (e.g in Pci/l, efficiency in %).

(b) Gross beta Counting

The high voltage for gross beta counting was set at 1700V and samples were counted for three – 3600S in beta only mode. The count rate and the activity were calculated using the formula.

$$Rate\,\beta\left(count/\sec\right)=\frac{Raw\,\beta\,count\times 60}{count\,time\,(\sec)} \qquad 3.6$$

$$Activity\,\beta\alpha=\frac{Rate\,\beta\times Bgd\,\beta\times\beta\ \ unit\,coefficient}{Channel\,\beta\ \ efficiency\times Sample\,efficiency\times SampleVol.} \qquad 3.7$$

3.3 Data Presentation

3.3.1 Alpha – Activity

The alpha activity is expressed as activity concentration C in Becquerrel per litre (Bq/l).

The activity concentrate C is calculated using the formula [ISO 9696: 1992 (E)]

$$C=\frac{R_b-R_o\times a_s\times m\times 1.02}{R_s-R_o\times 1000\times V} \qquad 3.8$$

where R_b is the observed sample count rate (s^{-1}), R_o is the background count rate (s^{-1}), Rs is the observed standard count rate (s^{-1}), a_s is the specific activity of the alpha standard, V is the volume of the sample evaporated in litre, and m is the mass in mg, of the residue from volume V and the factor 1.02 is included to correct for 20ml of nitric acid added per litre as a stabilizer.

3.3.2 Beta – Activity

The gross beta activity is expressed as activity concentration C in Bq/l calculated [ISO 9697: 1992 (E)] as

$$C = \frac{R_b - R_o \times 14.4 \times m \times 1.02}{R_s - R_o \times 1000 \times V} \qquad 3.9$$

where: $\frac{14.4}{1000}$ represent the specific activity of 40K in KCl, all other terms have their usual meaning. The activity concentration C was converted to Bq/m3

3.3.3 Contour Distribution

The specific activities of the radionuclides as well as the gross alpha and gross beta activity concentrations were shown in contour distributions. This is aimed at finding out the areas of high distribution.

3.4 Analysis of Data

Statistical Precision: This was calculated for each channel on each measurement and it depends only on the preset count whose value is declared indirectly. Assuming N measurements are made during a time T so that xi values are obtained (from N measurements), according to a normal distribution law of averages, the average (mean) value X is given by

$$\overline{X} = \sum \frac{x_i}{N} \qquad 3.10$$

Standard Deviation: The standard deviation δ, associated with the activity of the sample corrected for background is calculated (ISO 9697: 1992 (E)) as

$$\delta = \sqrt{\frac{R_b}{t_b} + \frac{R_o}{t_o}} \times \frac{14.4 \times m \times 1.02}{(R_b - R_o) \times 1000 \times V} \qquad 3.11$$

Statistical Analysis: The statistical analyses used for the analysis of the specific activities of the radionuclides; and for the alpha and beta activity concentration include estimation of the central tendencies, deviations and histogram distributions.

CHAPTER FOUR

RESULTS

4.1 Preliminary Results

The preliminary results area based on the conductivity measurement of the 30 samples of water from different zones along the course of River Kaduna, that is farming zone Residential/Commercial zone and Industrial zone; and also the total dissolved solids (TDS) determined from the water samples. Figure 4.1 shows the graph of conductivity against Total dissolved solids (TDS).

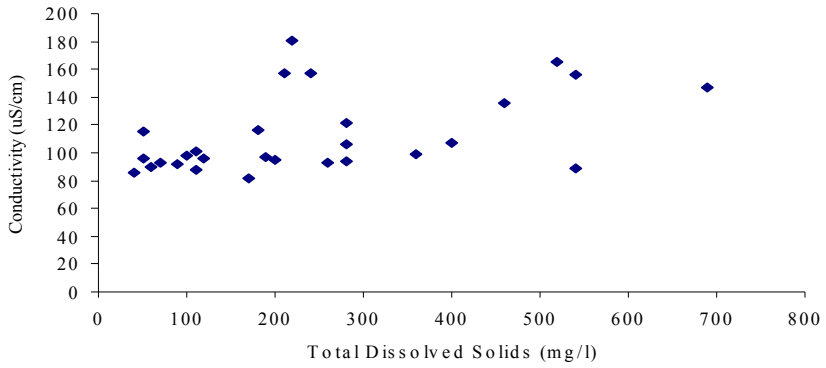

Fig. 4. 1: Conductivity vs TDS in the Samples

The aim of the graph is to see if there is a relationship between the two parameters thus to get the conversion factor for the type of water being analyzed. The Pearson correlation from the graph is 0.24 showing poor relationship between the TDS and the Conductivity. Thus the conversion factor for the conductivity and TDS relationship for River Kaduna water is 0.24.

4.2 Characterization of Equipment

(a) The Exploranium (The Identifier)

To characterize the Exploranium, the instrument was used for background identification of radionuclides in the Laboratory. The radioisotopes identified in the background were ^{40}K, ^{232}Th and unknown isotopes which are isotopes that are not

found in the radioisotopes Library of the identifier. Table 4.1 shows the peak sizes of the identified radionuclides in the background and their specific activities.

Table 4. 1: Radionuclides Identified in the Background and their Specific Activities.

Radionuclide	Peak size	Specific activity (Bq /g)
^{40}K	18	199
^{232}Th	74	4.00

Efficiency Determination: The efficiency of the identifier regarding the identification of the radionuclides identified from the water samples (^{238}U, ^{232}Th and ^{40}K) was calculated using the formula.

$$Efficiency = \frac{Average\,Specific\,Activity}{Specific\,Activity\,of\,S\tan dard} \times 100\% \qquad 4.1$$

The efficiency in detecting each of the radionuclides is shown in Table 4.2

Table 4. 2: Efficiency of identifying the Radionuclides with Exploranium from the Samples

Radionuclide	Efficiency (%)
^{238}U	82
^{232}Th	95
^{40}K	80

From Table 4.2 ^{232}Th has the highest efficiency of detection (95%) while ^{40}K has the lowest efficiency of detection (80%). Generally the radionuclides have high efficiency of detection.

Limit of Detection of Radionuclides: The limit of detection instrumental, for the radionulcides identified from the samples was calculated (Curie 1968) as

$$Minimum\,Detectable\,Count\,(MDC) = 2.71 + 4.65\sqrt{B} \qquad 4.2$$

Where B is the background count.

$$LOD = \frac{N_P}{MDC} \times Specific\,activity\,of\,the\,s\tan dard \qquad 4.3$$

Where Np is the count with the sample

Table 4. 3: limit of detection of the radionuclides in water from River Kaduna

Radionuclide	Limit of detection (Bq/g)
^{238}U	5.23 ± 0.03
^{232}Th	1.73 ± 0.04
^{40}K	113 ± 0.31

(The quoted errors represent the standard deviation from repeated measurements)

(b) Alpha-Beta Detector

In characterizing the proportional counter, used for alpha and beta activity measurement, the background and the plateau tests were carried out and the results are presented as:

Background Count Rates in Different Modes| Figures 4.2 and 4.3 show the background count rates in alpha only and beta only modes respectively.

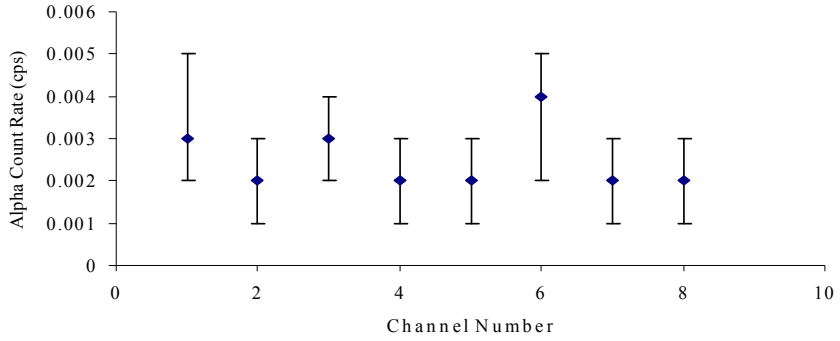

Fig. 4. 2: Alpha Background Count Rate per Channel

The error bars shown in the graph of Fig. 4.2 are lower and upper confidence limits. The overall results show that the average count rate of alpha in alpha only mode is 0.0030 ± 0.001 cps.

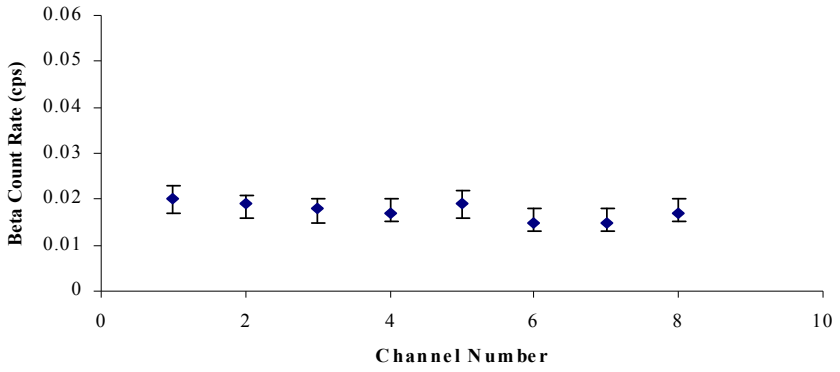

Fig. 4. 3: Beta Background Count Rate Per Channel

The overall results show that the average count rate of beta in beta only mode is 0.018 ± 0.001cps.

Measured Alpha and Beta Plateau: Figure 4.4 shows the graph of alpha and beta plateau slope in different channels of the detector.

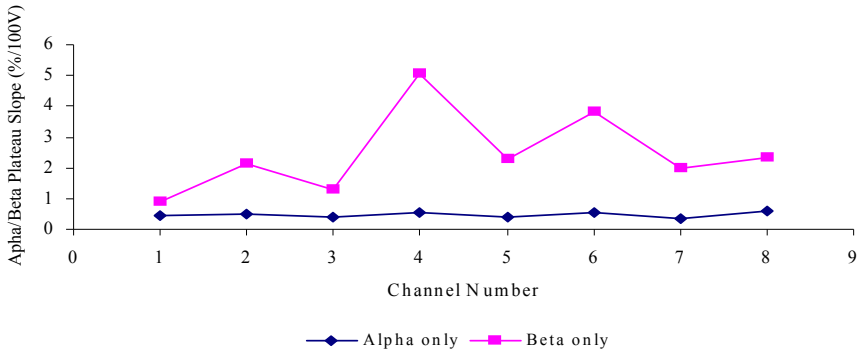

Fig. 4. 4: Alpha/Beta Plateau Slope in Different Modes

The results show that the plateau slope of alpha is generally low and that of beta is higher than that of alpha. It also shows significantly high beta Plateau slopes in channel four (5.05%/100V) and followed by channel 6 (3.82%/100V). These high values, especially in channel 4 may be an indication that the detector is drifting. From the results, the average slope for alpha only mode is 0.47 ± 0.01%/100V while that for beta only mode is 2.47 ± 0.02%/100V.

Measured Detector Efficiency: The results of the efficiencies of the different channels of the detector in alpha only and beta only modes are shown in Table 4.4.

Table 4. 4: Channel Efficiencies for different modes of measurement.

Channel Number	Alpha Only Mode		Beta Only Mode	
	4πEfficiency	r2	4πEfficiency	r2
1	35.29	0.9500	56.37	04147
2	35.96	0.9080	51.93	0.8832
3	35.02	0.9176	52.06	0.6344
4	35.65	0.8770	50.79	0.8746
5	34.67	0.9514	51.40	0.8185
6	35.24	0.9084	51.92	0.8440
7	35.33	0.9906	51.55	0.7957
8	35.26	0.9002	52.82	0.9088
Minimum	34.67		50.79	
Maximum	35.96		56.37	
Average	35.32 ± 0.05		53.58 ± 0.11	

(The errors represent the standard deviation of repeated measurements.)

From Table 4.4 it is seen that the average efficiency of alpha in alpha only mode is 35.32 ± 0.05 while that of beta in beta only mode is 53.58 ± 0.11 thus the average efficiency of beta is greater than the average efficiency of alpha with the alpha to beta efficiency ratio approximately 4/5.

Limit of Detection of Alpha and Beta Activity. The limit of detection gives the lowest activity that could be detected by the detector. Table 4.5 shows the limit of detection of the different channels of the proportional counter for alpha only and beta only modes.

Table 4. 5: Limit of detection of proportional counter per channel

Channel Number	Limit of detection (Bq)	
	Alpha	Beta
1	0.0051	0.0214
2	0.0051	0.0279
3	0.0048	0.0206
4	0.0075	0.0458
5	0.0044	0.0193
6	0.0115	0.0325
7	0.0079	0.0296
8	0.0063	0.0867
Average	0.008 ± 0.001	0.0529 ± 0.002

The errors represent the standard deviation of repeated measurements

The results show that the limit of detection for alpha ranges from 0.0044Bq to 0.0115Bq with an average value of 0.008 ± 0.001Bq while the limit of detection of beta ranges from 0.0193Bq to 0.0867Bq with an average value of 0.0529± 0.002Bq.

4.3 Major Results

4.3.1 Identified Radionuclides from the Samples

Table 4.6 shows the specific activities of the radionulcides identified from the 30 samples of water from the 3 zones along the course of River Kaduna.

Table 4. 6: Specific Activities of The Radionuclides in River Kaduna Water Samples

S/N	Location		Specific Activity (Bq /g)		
	Geographical Co-Ordinate	Name	^{238}U	^{232}Th	^{40}K
1	10.59°N, 7.49°E	Rafi Guza 1	-	3.85	215.00
2	10.58°N, 7.48°E	Rafi Guza 2	-	4.00	190.00
3	10.58°N, 7.47°E	Hanyin Kogi 1	8.60	-	190.00
4	10.58°N, 7.47°E	Hanyin Kogi 2	-	4.30	170.00
5	10.66°N, 7.47°E	Ungwan Dosa	9.80	-	225.00
6	10.61°N, 7.47°E	Ungwan Yaro	9.00	-	225.00
7	10.57°N, 7.47°E	Badarawa	9.00	-	215.00
8	10.57°N, 7.47°E	Ungwan Gado	9.80	-	200.00
9	10.58°N, 7.48°E	Keke	9.00	-	190.00
10	10.57°N, 7.47°E	Ungwan Kudu	-	4.20	215.00
11	10.56°N, 7.48°E	Malali Low Cost	-	3.60	215.00
12	10.57°N, 7.47°E	Malali High Cost	-	4.00	215.00
13	10.57°N, 7.48°E	Mashiga	9.00	-	190.00
14	10.56°N, 7.44°E	Ungwan Shekara	9.00	-	225.00
15	10.56°N, 7.49°E	Kad North Water Board	-	3.72	215.00
16	10.55°N, 7.48°E	Ungwan Rimi	8.80	-	190.00
17	10.49°N, 7.44°E	Kabala Costain	9.00	-	170.00
18	10.49°N, 7.43°E	Kigo Road	8.80	-	200.00
19	10.49°N, 7.42°E	Barnawa	8.80	-	190.00
20	10.50°N, 7.42°E	Stadium	-	4.40	200.00
21	10.49°N, 7.38°E	Kudenda	-	4.15	190.00
22	10.49°N, 7.38°E	Nariya	-	3.60	225.00
23	10.47°N, 7.39°E	Ideal Flour Mill	10.00	-	190.00
24	10.48°N, 7.39°E	Nasarawa 1	-	4.12	200.00
25	10.48°N, 7.40°E	Nasarawa 2	8.00	-	200.00
26	10.48°N, 7.40°E	Ungwan Mission	9.00	-	200.00
27	10.49°N, 7.40°E	Fed. Superphate Fet. Co.	-	3.20	170.00
28	10.48°N, 7.40°E	Nig. Brewery	9.00	-	162.00
29	10.49°N, 7.40°E	United Nig. Textile Co.	9.00	-	190.00
30	10.50°N, 7.42°E	Kad. South Water Board	9.00	-	200.00

The first 10 locations on the Table 4.6 represent the farming zone, the second 10 represent Residential/commercial zone while the last 10 represent the industrial zone. The results show that ^{238}U was identified in 18 samples, with average specific activity of 9.00 Bq/g, ^{232}Th was identified in 12 samples with an average specific activity of 2.93 Bq/g while ^{40}K was identified in all the 30 samples with an average specific activity of 199.10 Bq/g.

Figure 4.6 shows the graph of the specific activities of the radionuclides in the river water samples.

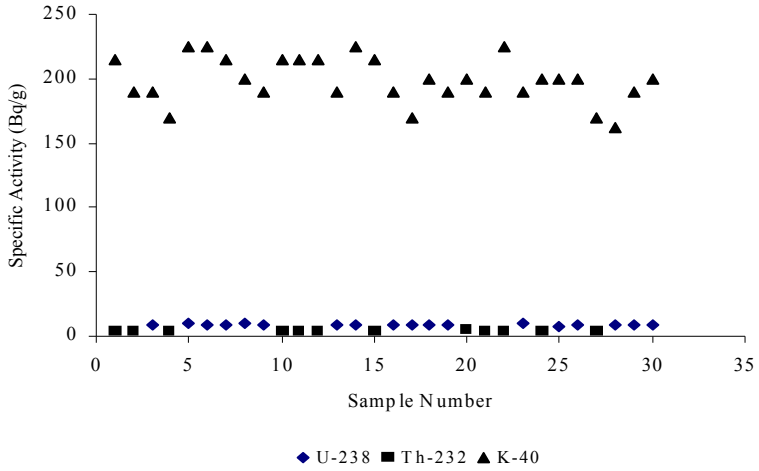

Fig. 4. 5: Specific Activity of Radionuclides in the Samples

Examination of figure 4.5 shows that distribution of ^{40}K in all the samples lies between 150 Bq/g and 230 Bq/g while distribution of ^{238}U lies between 5 Bq/g and 10Bq/g and ^{232}Th lies between 0 Bq/g and 5 Bq/g. Table 4.7 shows the breakdown of the specific activities of the radionuclides in the 3 zones:

Table 4. 7: Summary of Distribution of the Specific Activities of Radionuclides in Different Zones

Statistical Parameters	Values and Percentages of Measured Specific Activity								
	^{238}U			^{232}Th			^{40}K		
	Farm.	Resid.	Indus.	Farm.	Resid	Indus	Farm.	Resid.	Indus.
Minimum Act.(Bq/g)	8.60	8.8	8.00	3.85	3.60	3.20	170	170	162
<10Bq/g	100%	100%	83	100%	100%	100%	-	-	-
≥10<50Bq/g	-	-	17%	-	-	-	-	-	-
≥50<200Bq/g	-	-	-	-	-	-	40	40%	50%
≥200<250Bq/g	-	-	-	-	-	-	60	60%	50%
Maximum Act. (Bq/g)	9.8	9.0	10.0	4.3	4.0	4.2	225	225	225
Number of Samples	6	6	6	4	4	4	10	10	10
Geometric Mean	6.5	6.3	6.4	2.3	2.7	2.6	141	141	138

4.3.2 Measured Alpha and Beta Activity in the River Water Samples

The results of the measured alpha and beta activity concentration are shown in Table 4.8. From Table 4.8, the average alpha activity concentration in the farming zone is $0.027 \pm 0.002 \times 10^3 Bq/m^3$, in the Residential/commercial zone the average alpha activity concentration is $0.025 \pm 0.001 \times 10^3 Bq/m^3$ and that in the industrial zone is $0.03 \pm 0.003 \times 10^3 Bq/m^3$.

The average beta activity concentration in the farming zone is 0.585 ± 0.007 x 10^3Bq/m^3, that in the Residential/commercial zone is 0.411 ± 0.006 x 10^3Bq/m^3 while that in the Industrial zone is 0.321 ± 0.005 x 10^3Bq/m^3.

In comparison of the three zones, the alpha activity is highest in the Industrial zone (average of 0.03 x 10^3Bq/m^3) followed by that in the farming zone (0.027x10^3 Bq/m^3) and least in the residential zone (0.025 x 10^3Bq/m^3). Comparing the beta activity in the three zones, the activity is highest in the farming zone (average of 0.585 x 10^3Bq/m^3) followed by that in the Residential zone (0.411 x 10^3Bq/m^3) and least in the industrial zone (0.321 x 10^3Bq/m^3).

Table 4. 8: Alpha/Beta Activity Concentrations of the Water Samples Analyzed.

S/No	Geographical Co-Ordinate	Location	Activity Concentration (x10^3Bq/m^3)	
			Alpha	Beta
1	10.59ºN, 7.47ºE	Rafi Guza 1	0.019 ± 0.003	0.110±0.008
2	10.58ºN, 7.48ºE	Rafi Guza 2	0.012 ± 0.002	0.064±0.005
3	10.58ºN, 7.47ºE	Hanyin Kogi 1	0.022 ± 0.003	0.121±0.007
4	10.58ºN, 7.47ºE	Hanyin Kogi 2	0.018 ± 0.002	0.767±0.003
5	10.66ºN, 7.47ºE	Ungwan Dosa	0.022 ± 0.003	0.098±0.006
6	10.61ºN, 7.47ºE	Ungwan Yaro	0.020 ± 0.003	0.100±0.007
7	10.57ºN, 7.47ºE	Badarawa	0.018 ± 0.003	0.088±0.006
8	10.57ºN, 7.47ºE	Ungwan Gado	0.027 ± 0.003	2.679±0.023
9	10.58ºN, 7.48ºE	Keke	0.087 ± 0.005	1.743±0.021
10	10.57ºN, 7.48ºE	Ungwan Kudu		
11	10.56ºN, 7.48ºE	Malali Low Cost	0.021 ± 0.002	0.077±0.006
12	10.57ºN, 7.47ºE	Malali High Cost	0.023 ± 0.003	0.111±0.004
13	10.57ºN, 7.48ºE	Mashiga	0.035 ± 0.004	0.173±0.009
14	10.56ºN, 7.49ºE	Ungwan Shekara	0.023 ± 0.003	0.077±0.006
15	10.56ºN, 7.49ºE	Kad North Water Board	0.013 ± 0.002	0.107±0.007
16	10.55ºN, 7.48ºE	Ungwan Rimi	0.014 ± 0.002	0.033±0.003
17	10.49ºN, 7.44ºE	Kabala Costain	0.006 ± 0.001	3.097±0.022
18	10.49ºN, 7.43ºE	Kogi Road	0.018 ± 0.002	0.017±0.003
19	10.49ºN, 7.42ºE	Barnawa	0.022 ± 0.003	0.030±0.006
20	10.50ºN, 7.42ºE	Stadium	0.083 ± 0.004	0.073±0.006
21	10.49ºN, 7.38ºE	Kudenda	0.038 ± 0.005	0.393±0.010
22	10.49ºN, 7.38ºE	Nariya	0.014 ± 0.003	0.098±0.010
23	10.49ºN, 7.39ºE	Ideal Flour Mill	0.016 ± 0.002	0.044±0.006
24	10.48ºN, 7.39ºE	Nasarawa 1	0.021 ± 0.004	0.055±0.006
25	10.48ºN, 7.40ºE	Nasarawa 2	0.021 ± 0.003	1.795±0.021
26	10.48ºN, 7.40ºE	Ungwan Mission	0.017 ± 0.003	0.044±0.006
27	10.49ºN, 7.40ºE	Fed. Superphate Fert. Co.	0.017 ± 0.002	0.053±0.008
28	10.48ºN, 7.40ºE	Nig. Brewery	0.057 ± 0.008	0.031±0.006
29	10.49ºN, 7.40ºE	United Nig. Textile Co.	0.013 ± 0.003	0.040±0.006
30	10.50ºN, 7.42ºE	Kad. South Water Board		

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In further analysis of data the graph of the alpha/beta activity in the samples is shown in Figure 4.6.

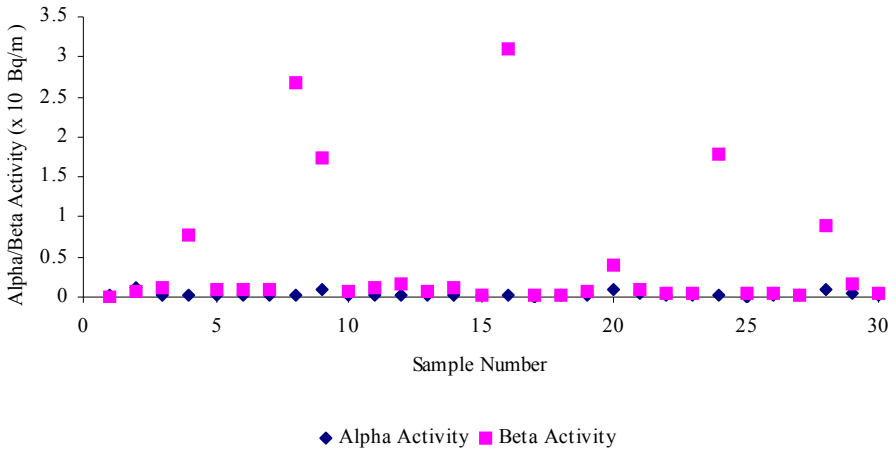

Fig. 4. 6: Alpha/Beta Activity in the Samples

Examining the graph shows a general low distribution of alpha activity in the three zones. On the other hand the beta activity shows about 30% of high elevation in the farming zone, about 10% of high elevation in the Residential zone and about 20% of high elevation in the industrial zone. The breakdown of the alpha and beta activity concentration in the three zones is shown in Table 4.9

Table 4. 9: Summary of the distribution of Alpha and Beta Activity in the different zones.

Statistical parameters ($\times 10^3 Bq/m^3$)	Values and percentages of measured activity concentration					
	Alpha			Beta		
	Farm.	Resid.	Indus.	Farm.	Resid.	Indus.
Minimum Act.	0.012	0.006	0.011	0.064	0.017	0.031
< 0.01	-	10%	-	-	-	-
≥ 0.01 < 0.05	90%	80%	80%	-	30%	40%
≥ 0.05 < 0.1	10%	10%	20%	50%	30%	40%
≥ 0.1 < 1.0	-	-	-	20%	40%	10%
≥ 1.0 < 5.0	-	-	-	30%	-	10%
Maximum Act.	.08	0.083	0.089	2.679	3.097	1.795
Number of samples	10	10	10	10	10	10
Mean	0.050	0.045	0.050	1.372	1.557	0.913

4.4 Analysis by Histogram

In further analysis the histograms of the specific activities of the radionuclides, and alpha and beta activities were used to show the frequency distributions of the parameters. Figure 4.8 shows the histogram of frequency distribution of ^{238}U specific activity.

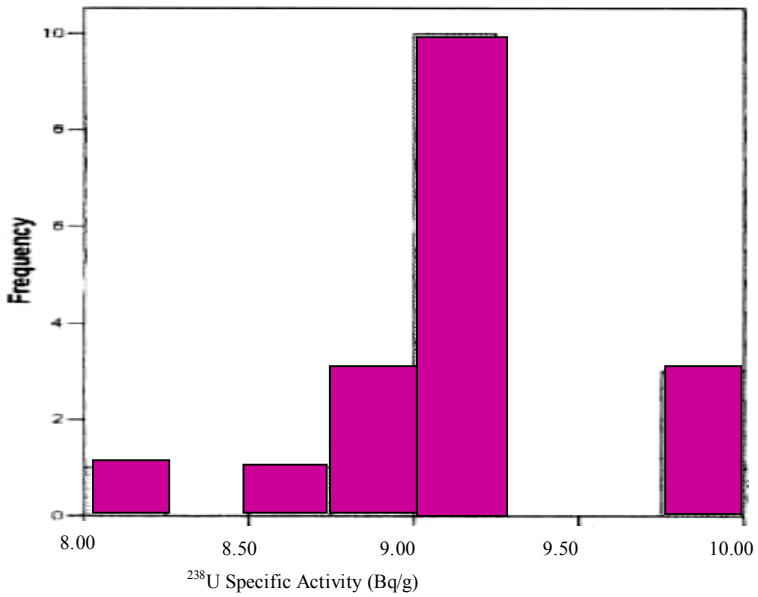

Fig. 4. 7: Histogram of Distribution of Specific Activity of ^{238}U in River Kaduna Water

The result from Fig. 4.7 shows the highest frequency of 10 at 9.00 Bq/g and the lowest frequency of 1 at 8.00 Bq/g and 8.60 Bq/g. The distribution skewed more to the centre, showing relatively high distribution. It has a mean of 9.03 Bq/g and a standard deviation of 0.46. The histogram for the distribution of ^{232}Th specific activity is shown in Fig. 4.8.

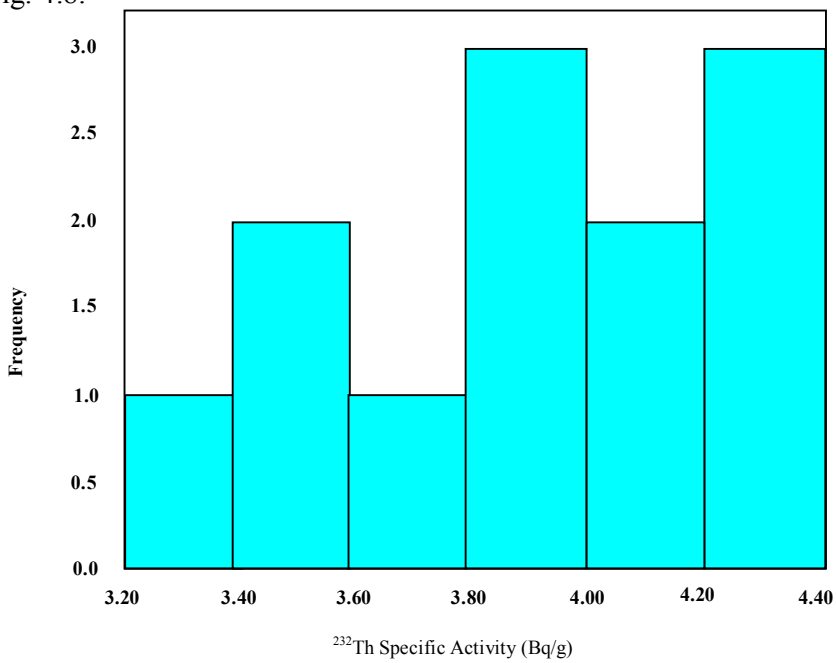

Fig. 4. 8: Histogram of Distribution of Specific Activity of ^{232}Th in River Kaduna Water

The result of Fig. 4.8 shows the highest frequency of 3 between 3.80 Bq/g and 4.00 Bq/g and between 4.20 Bq/g and 4.4 Bq/g with lowest frequency of 1 at between 3.20 Bq/g and 3.40 Bq/g and between 3.60 Bq/g and 3.80 Bq/g.

The distribution is skewed toward the right, showing a high distribution of ^{232}Th in the river water samples.The distribution has a mean value of 3.93 and a standard deviation of 0.35.

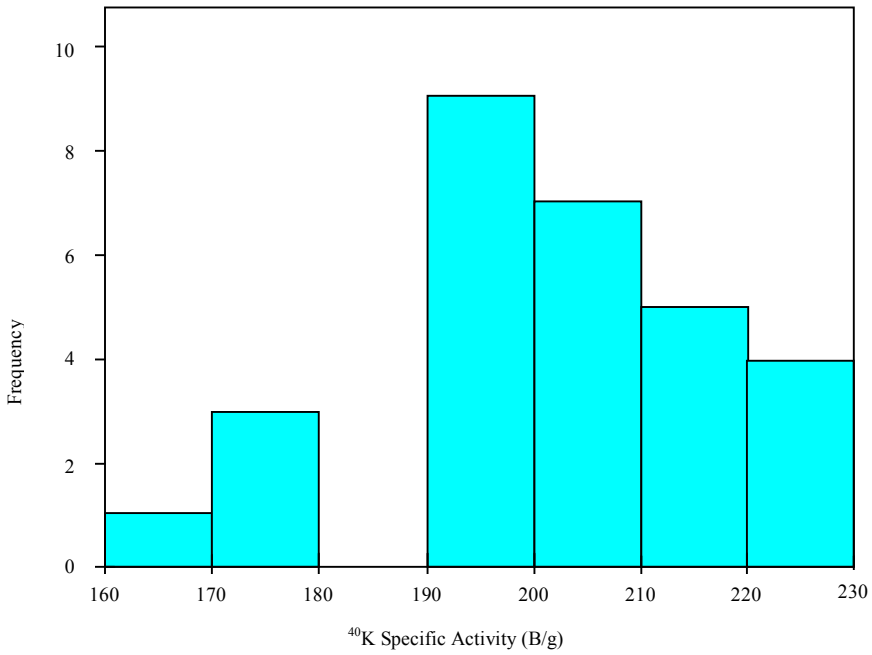

Fig. 4. 9: Histogram of Distribution of Specific Activity of ^{40}K in River Kaduna Water

Examining Fig. 4.9 the result shows that the highest frequency distribution of 9 is between 190.00 Bq/g and 200.00 Bq/g, and the lowest frequency distribution of 1 is between 160.00 Bq/g and 170.00 Bq/g. It also shows a high distribution of 40K in the samples, because the distribution is skewed towards the right. The mean of the distribution is 198.52 Bq/g and standard deviation of 17.53

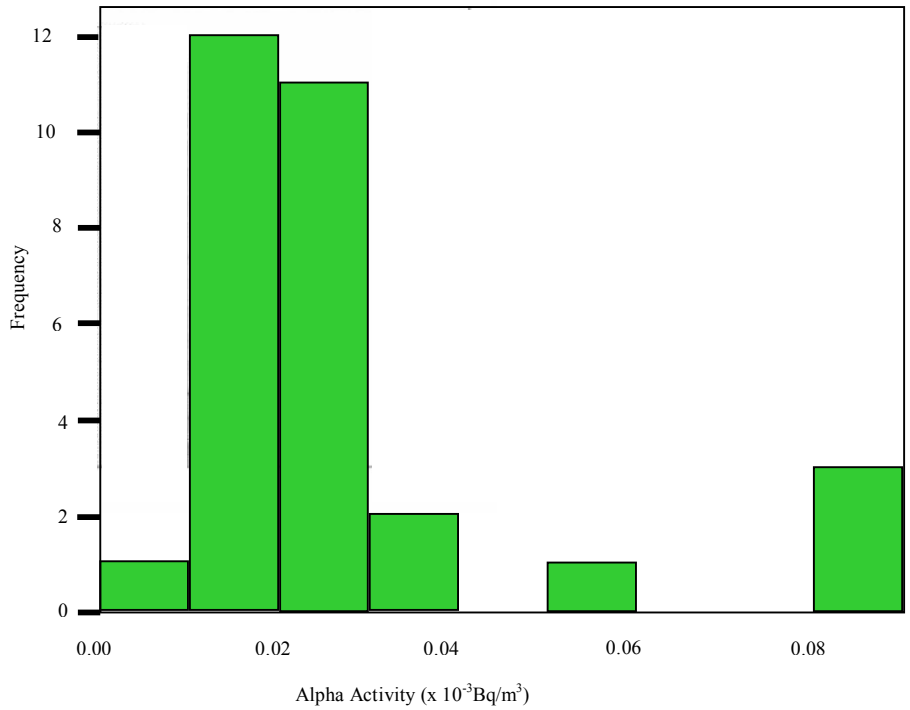

Fig. 4. 10: Histogram of Distribution of Alpha Activity in River Kaduna Water

From Fig. 4.10, the result shows the highest frequency distribution of 12 between 0.01 x 10^3 Bq/m^3; and a closely following frequency distribution of 11 between 0.02 x 10-^{3} Bq/m^3 and 0.03 x 10^3 Bq/m^3. The lowest frequency distribution of 1 is between 0.00 x 10^3 Bq/m^3 and 0.01 x 10^3 Bq/m^3. The distribution is skewed towards the left. This shows a generally low alpha activity in the river water samples. The mean of the distribution is 0.03 x 10^3 Bq/m^3 and standard deviation of 0.02

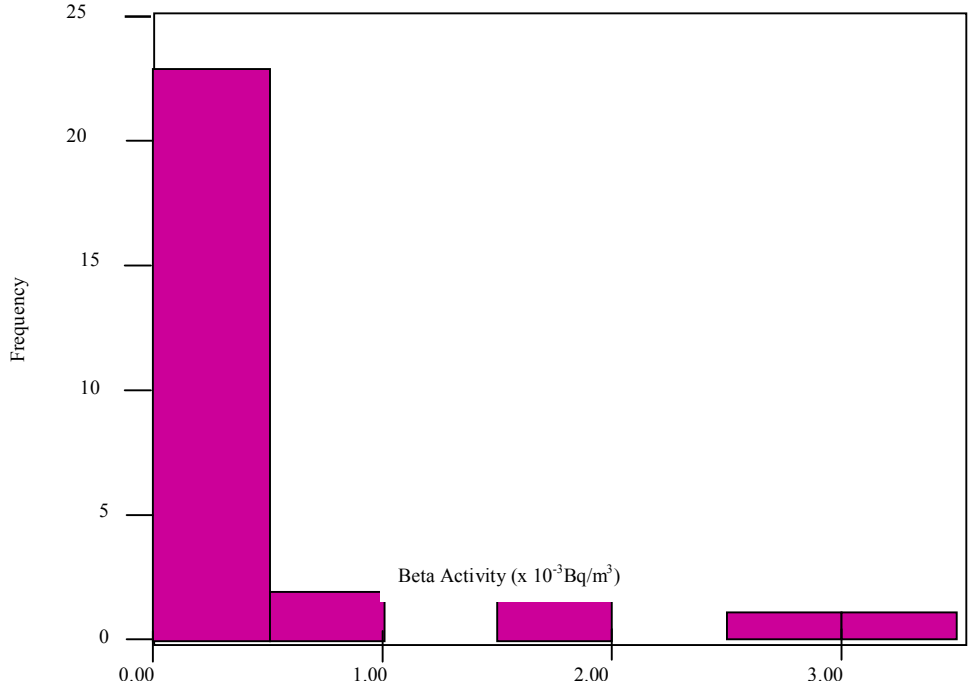

Fig. 4. 11: Histogram of Distribution of Beta Activity in River Kaduna Water

Examination fig. 4.12 shows that the highest frequency distribution of the beta activity is 24 which is between 0.00 x 10^{-3}Bq/m3 and 0.05 x 10^{-3}Bq/m^3 while the lowest frequency distribution of 1 is between 3.00 x 10^{-3}Bq/m^3 and 4.00 x 10^{-3}Bq/m^3.

The distribution skewed towards the left, showing low distribution, with a mean of 0.45 and standard deviation of 0.82.

4.5 Distribution by Contour

Contour graphs were also used for the analysis of the results of the specific activities of the radionuclides and the alpha and beta activity concentration in the river water samples from River Kaduna. Figures 4.12 to 4.14 show the contours graphs of the radionuclides

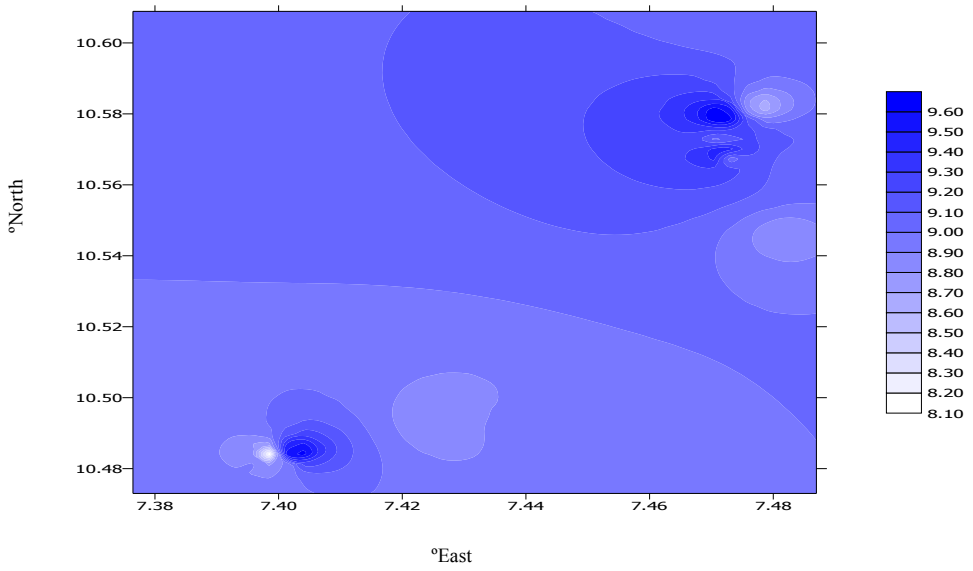

Fig. 4. 12: Contour Plot of 238U Specific Activity in River Kaduna Water

From the results of Fig. 4.12, the ^{238}U specific activity show high distribution of 9.60 Bq/g and above around areas bounded by latitude 10.58° – 10.59° and longitude 7.47° – 7.48°. The areas include Hanyin Kogi 1, and Keke, all in the farming zone. Other areas that show high distribution of 9.60 Bq/g are areas bounded by latitude 10.48° –10.49° and longitude 7.40° – 7.41°, which include Nasarawa 2, Ungwan Mission, Nigerian Brewery, and United Nigerian Textile Company, all in the Industrial zone.

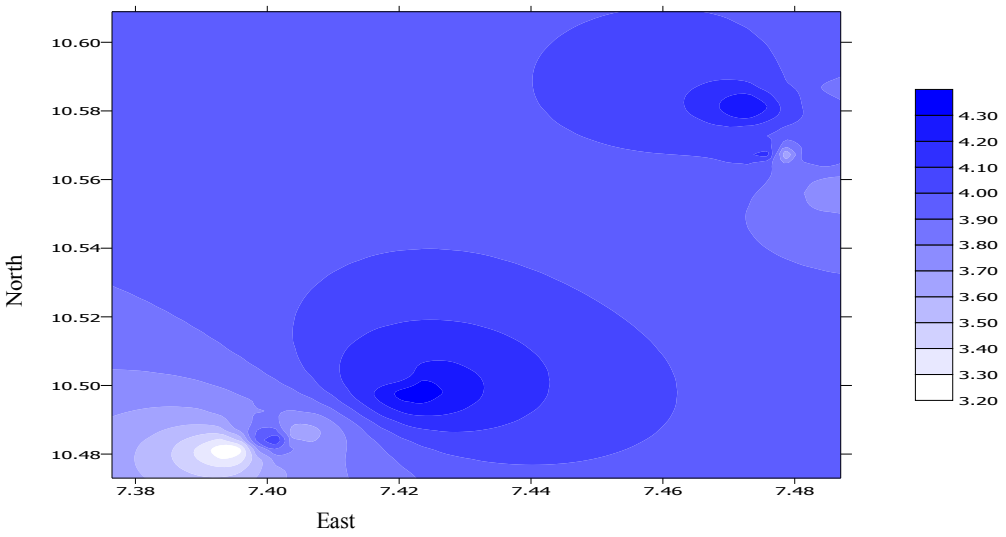

Fig. 4. 13: Contour Plot of ^{232}Th Specific Activity in River Kaduna Water

Examination Fig. 4.13 shows high distribution of ^{232}Th specific activity of 4.10 Bq/g at areas bounded by latitude 10.58^{o} –10.59^{o} and longitude 7.46^{o} – 7.48^{o}. The areas include Rafi Guza 2 and Hanyi Kogi2 in the farming zone. Other area with high distribution of 4.10 Bq/g are bounded by latitude 10.48^{o} – 10.51^{o} and longitude 7.42^{o} - 7.44^{o} and the area is stadium in the Residential zone. Areas bounded by latitude 10.49^{o} – 10.50^{o} and longitude 7.38^{o} – 7.40^{o} have activity distribution of 3.80 Bq/g and the areas are Kudenda, Nariya and Federal Superphosphate Fertilizer Company, all in the Industrial zone.

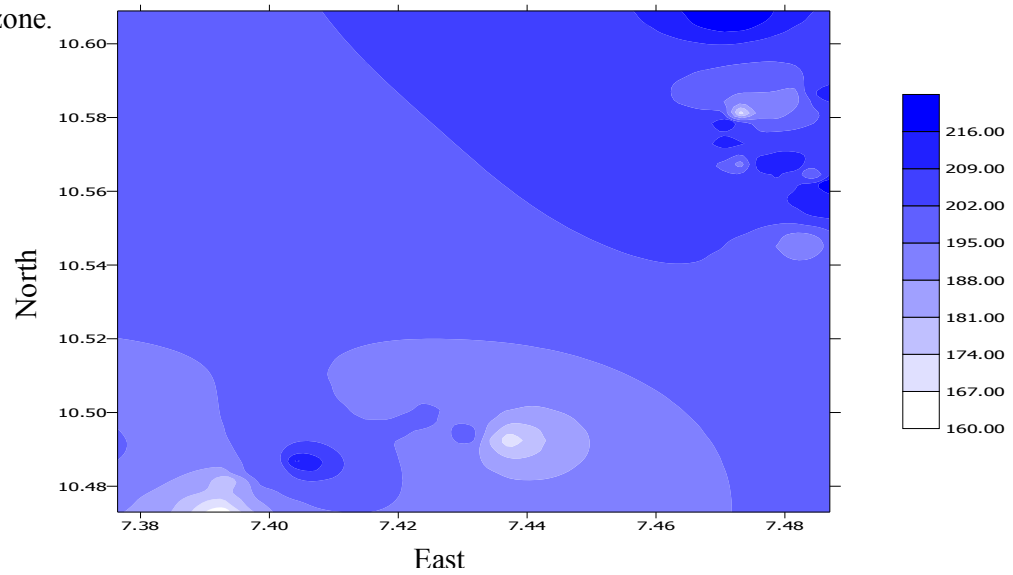

Fig. 4. 14: Contour Plot of ^{40}K Specific Activity in River Kaduna Water

Figure 4.14 show high distribution of ^{40}K specific activity of 202 Bq/g and above in the areas bounded by latitude 10.54^{o} – 10.60^{o} and longitude 7.44^{o} – 7.48^{o} and the areas include Rafi Guza 2, Hayin Kogi 1 and 2, Badarawa, Keke and Ungwan Kudu in the farming zone, and Malali low cost, Malali High cost, Mashiga and Ungwan Rimi in the Residential zone. The contour graphs for alpha and beta activity concentration are shown in figures 4.15 and 4.16 respectively.

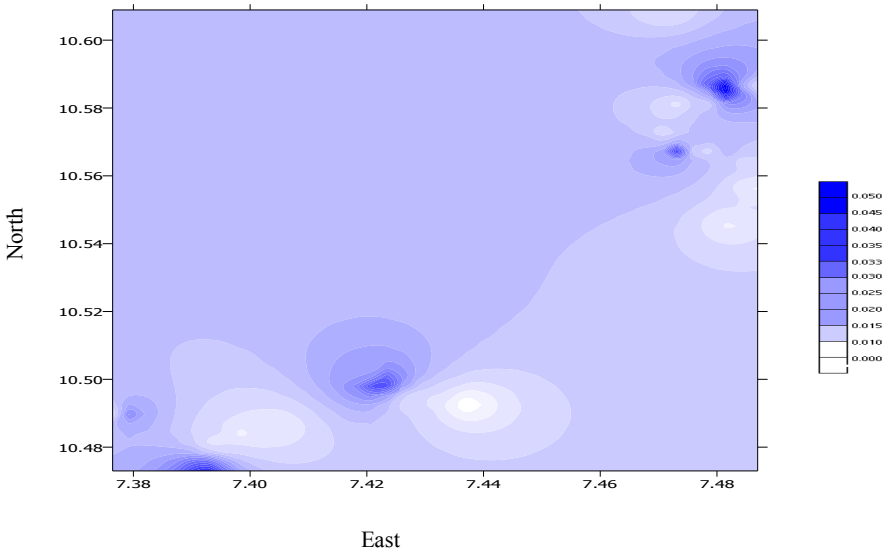

Fig. 4. 15: Contour Plot of Alpha Activity in River Kaduna Water

Examining Fig. 14.15 shows high alpha activity distribution of 0.05 x $10^{3}Bq/m^{3}$ and above at a narrow area bounded by latitude 10.50^{o} and longitude 7.42^{o}. The areas include stadium, in the Residential zone and Kaduna South Water Board filter, in the Industrial area. There is also a high distribution of 0.04 x $10^{3}Bq/m^{3}$ at areas bounded by latitude 10.56^{o} – 10.57^{o} and longitude 7.46^{o} – 10.60^{o} and longitude 7.46^{o} – 7.48^{o} and finally areas bounded by latitude 10.49^{o} – 10.52^{o} and longitude 7.42^{o} – 7.43^{o}. These areas include Ungwan Gado and Keke in the farming zone, Kigo Road and Stadium in the Residential zone and Kaduna South Water Board filter in the Industrial zone. The areas bounded by latitude 10.48^{o} – 10.49^{o} and longitude 7.40^{o} – 7.41^{o} have low distribution of 0.02 x $10^{3}Bq/m^{3}$. The areas is the Federal Supersphate fertilizer company in the Industrial zone.

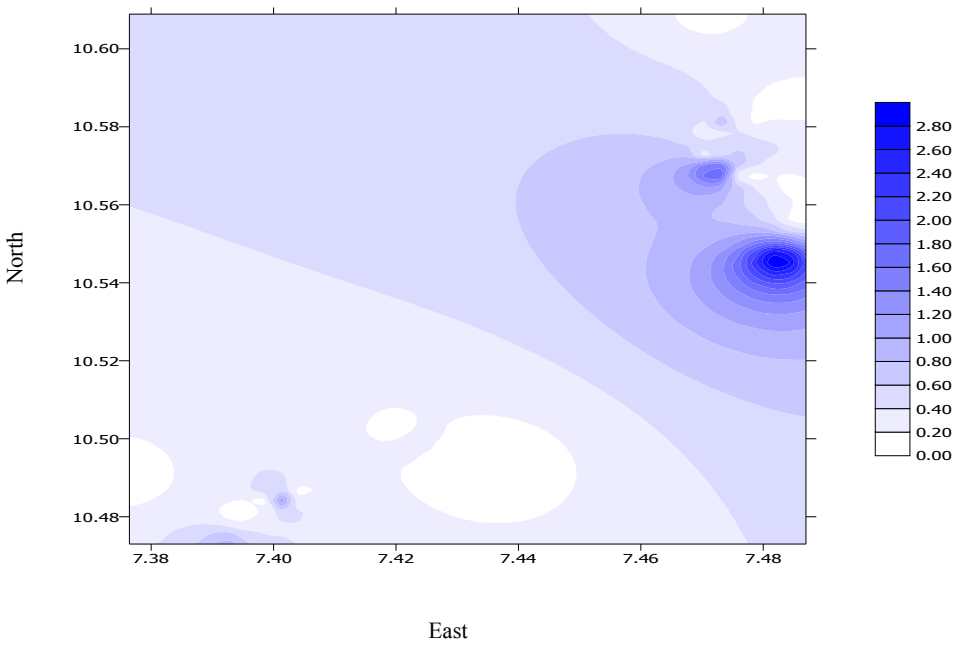

Fig. 4. 16: Contour Plot of Beta Activity in River Kaduna Water

Figure 4.16 shows a high distribution of beta activity of 2.80 x 10^3Bq/m^3 and above in the areas bounded by latitude 10.55^o – 10.56^o and longitude 7.48^o. The areas include Ungwan Rimi and Malali low cost, all in the residential zone. There is also high distribution of 2.6 x 10^3Bq/m^3 and above at areas bounded by latitude 10.57^o and longitude 7.47^o, which are the areas of Ungwan Gado and Badarawa all in the farming zone. There is the extremely low distribution of 0.20 x 10^3Bq/m^3 and below in the areas bounded by latitude 10.48^o – 10.50^o and longitude 7.42^o –7.45^o which include Kabala Costain, Kigo road in the Residential zone and Kaduna South Water Board filter in the Industrial zone.

4.6 Relationship between Measured Parameters.

Figure 4.17 shows the graph of the specific activities of ^{238}U and ^{232}Th against alpha activity.

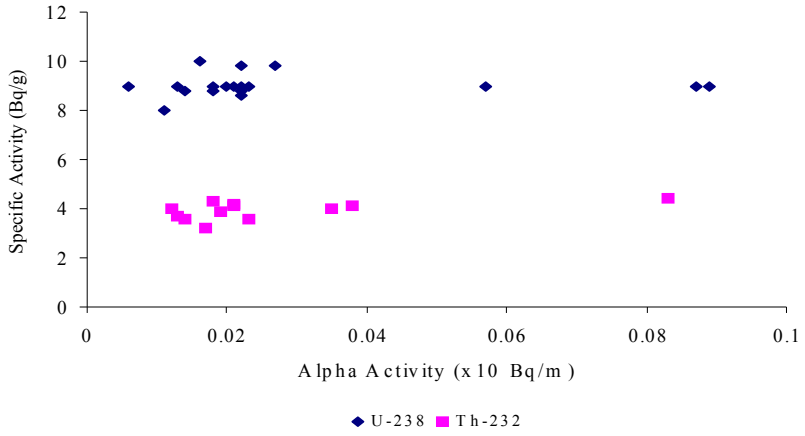

Fig. 4. 17: Radionuclides Specific Activity vs Alpha Activity in River Kaduna Water Samples

From the result of Figure 4.17 the Pearson correlation of ^{238}U is 0.002, which is very low showing very poor relationship between specific activity of ^{238}U and alpha activity concentration. Also the Pearson correlation of ^{232}Th is 0.27 showing a better relationship between ^{232}Th specific activity and alpha activity than ^{238}U.

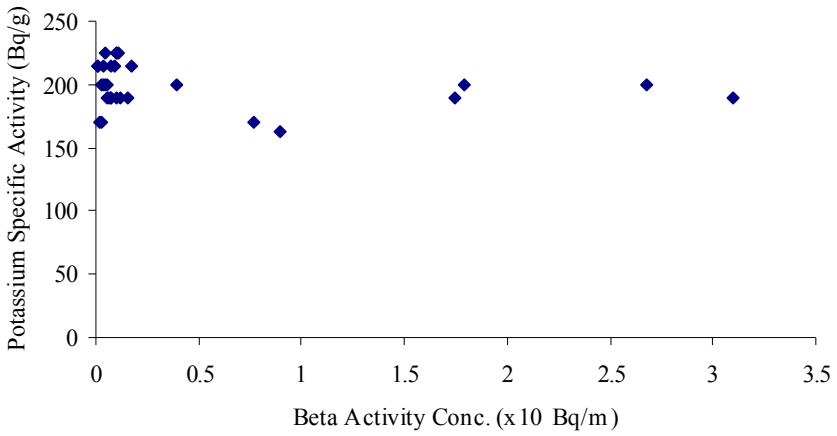

Fig. 4. 18: Potassium Specific Activity vs Beta Activity in River Kaduna water Samples

From figure 4.18 the Pearson correlation is 0.04 showing low variation between 40K specific activity and the beta activity.

Result from figures 4.17 and 4.18 could be as a result of the fact that the cause of mineralization in flowing water like River Kaduna is not strictly from the geological constituents. Also mineralization may be affected by the modification and degradation due to farming, road building, industrial waste disposals and so on.

Figure 4.19 shows the graphs of alpha and beta activity against the total dissolved solids (TDS).

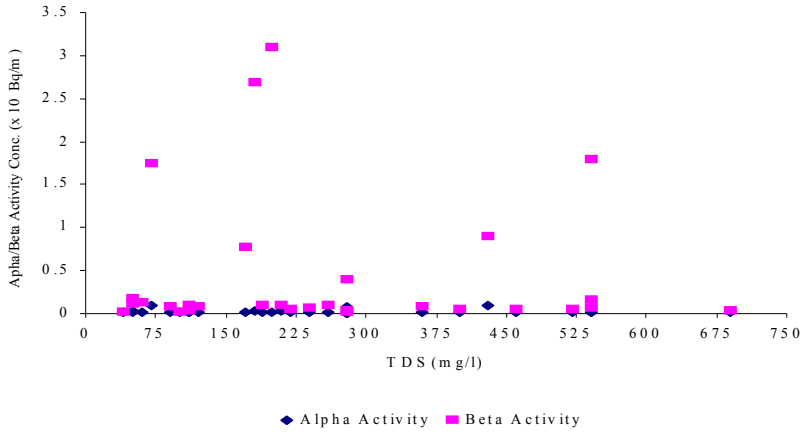

Fig. 4. 19: Alpha/Beta Activity Conc. vs TDS in Water Samples from River Kaduna

The results from Figure 4.19 shows Pearson correlation of 0.022 and 0.002 for alpha and beta activity respectively with TDS suggesting that there is very poor relationship between them. This suggests that the dissolved substances may not predominantly be of alpha and beta emitting elements.

4.7 Summary of Results.

The Exploranium, the identifier GR-135 was characterized for background, efficiency and detection limit. The detection limit is 5.23 ± 0.03 for ^{238}U, 1.73 ± 0.04 Bq/g for ^{232}Th and 113 ± 0.31 Bq/g for ^{40}K. The average efficiency of detection of radionuclides with the instrument was obtained as 84%. The instrument was used to identify ^{238}U, ^{232}Th and ^{40}K. The average specific activity of ^{238}U is 9.00 Bq/g and was identified in 18 samples. The average specific activity of ^{232}Th is 3.93 Bq/g and it

identified in 12 samples. The average specific activity of ^{40}K is 199.10 Bq/g and it was identified in all the 30 samples. Statistical analysis of the results shows high distributions of ^{238}U, ^{232}Th and ^{40}K, with highest frequency of each distribution at high specific activity value. This means that majority of the areas have high specific activity of the radionuclides. The Contour plots were also used to show areas of high and low specific activity. Areas of elevated ^{238}U specific activity include Hanyin Kogi 1 and Keke in Farming zone, Unguwan Mission, Nigerian Brewery and United Nigerian Textile Company in Industrial zone. Area of elevated ^{232}Th specific activity include Hanyin Kogi 2 and Rafin Guza 2 in Farming zone; Stadium in Residential zone; Kudenda, Nariya and Federal Supersphate Fertilizer Company in Industrial zone, while areas of elevated ^{40}K Specific activity include Rafi Guza 2, Hayin Kogi 1 and 2, Badarawa, Keke and Ungwan Kudu in the farming zone; Mashiga, Malali low cost and Ungwan Rimi in Residential zone.

The proportional counter was characterized for background, plateau, efficiency and limit of detection, in all the eight (8) channels of the counter and the results obtained were reproducible. The average background alpha count rate is 0.002 ± 0.001 cps and that of beta is 0.018 ± 0.001cps. The average plateau measurement for alpha activity is $0.47 \pm 0.01\%$ per 100V and the average plateau for beta activity is $2.47 \pm 0.02\%$ per 100V. The average detection limit for the counter is 0.008 ± 0.001 Bq for alpha and 0.0529 ± 0.002 Bq for beta. The gross alpha and gross beta activity in the river water samples from the three zones was determined using the counter. The average alpha activity in the farming zone is $0.027 \pm 0.002 \times 10^3$ Bq/m^3, $0.025 \pm 0.001 \times 10^3$ Bq/m^3 in the Residential/ Commercial zone and $0.030 \pm 0.003 \times 10^3$ Bq/m^3 in the Industrial zone. The average beta activity is $0.585 \pm 0.007 \times 10^3$ Bq/m^3 in the farming zone, $0.411 \pm 0.006 \times 10^3$ Bq/m^3 in the Residential/Commercial zone and $0.321 \pm 0.005 \times 10^3$ Bq/m^3 in the Industrial zone.

From the statistical analysis, the alpha and beta activities skewed towards the left with highest frequency of each, at low activity values. This means that most of the areas of the samples have low alpha activity and low beta activity. Areas of elevated alpha activity include Kigo Road and Stadium in the Residential zone; Kaduna South Water Board filter in the Industrial area, Keke and Ungwan Gado in the Farming zone. Areas of elevated beta activity include Ungwan Gado and Badarawa in the Farming zone; Ungwan Rimi and Malali low cost in the Residential zone.

CHAPTER FIVE

DISCUSSION, CONCLUSION AND RECOMMENDATION

5.1 Discussion.

5.1.1 Performance of the Exploranium

The characterization of the Exploranium, the identifier – GR-135 was achieved by background measurement; and detection of efficiency and limit of detection. The results of the measurements were reproducible.

5.1.2 Performance of the Proportional Counter.

The IN20-SYST, EURYSIS proportional counter was characterized for background and plateau measurements in all the eight (8) channels. The results of the alpha and beta background measurements and Plateau measurements for alpha only and beta only modes respectively were reproducible in terms of channels and mode of measurement. Apart from the proportional counter, other detectors like Geiger-Mueller (GM) counters, ionization chamber, silicon surface barrier detector, scintillation and semi conductor detectors can also be used for low alpha and low beta activity measurement. The choice of the gas-filled proportional counter was based on availability. The nearly uniform low background, low plateau and good channel efficiency measured in all the channels of the counter simultaneously are an added advantage of using this counter.

5.1.3 Comparison of Results

Results from alpha and beta activity measurements in rivers from other areas; and the results of the measurements from the three zones along River Kaduna as well as the WHO limits of alpha and beta activity in water is shown in table 5.1.

Table 5. 1: Alpha and Beta activity in Rivers in Different Places and WHO Contaminant Limit

Area	Measured Activity (x 10^{-3} Bq/m^3)		Source
	Alpha	Beta	
Woronora River Health Rd.	0.019	0.049	ARPANSA(2003)
Mills Creek	0.154	0.186	,,
Causeway River	0.021	0.055	,,
Woronora River Down Stream (Saline)	3.600	7.200	Szabo(1993)
Finland Lakes	0.009	-	,,
Baltic Sea	0.004	-	,,
River Kaduna	-	-	This work
Farming Zone	0.027	0.585	,,
Residential Zone	0.025	0.411	,,
Industrial Zone	0.030	0.321	,,
WHO Limit	100 (Bq/m^3)	1000 (Bq/m^3)	Milvy and Cothern (1990)

From the results in table 5.1 the alpha activity in the farming zone of River Kaduna is about 0.8% of that in the saline Woronora River at down stream in Australia while the alpha activity in the Industrial zone is about 19% of the alpha activity of Mills creek in Australia. The alpha activity of Causway River in Australia is about 84% of alpha activity in Residential zone of River Kaduna. The alpha activity in Baltic sea, in Australia is very low, about 13% of the alpha activity in Industrial zone of River Kaduna. This can be explained from the fact that a sea is a larger volume of water body compared to a river. The beta activity in Industrial zone of River Kaduna is about 4.5% of the beta activity in Saline Woronora River down Stream. Beta activity in the Mills Creek in Australia is about 32% of beta activity in the Farming zone of River Kaduna. The results from the alpha and beta activity measurements of rivers in different places are far below the contamination limit of radioactivity in water as set by CEC-FAOand WHO that is 100 Bq/m^3 for alpha and 1000 Bq/m^3 for beta.

5.2 Conclusion.

In this work, the radionuclides identified from water samples collected from the Farming, Residential/Commercial and Industrial zones of River Kaduna are ^{238}U, ^{232}Th and ^{40}K which are all natural radionuclides with their average specific activities as 9.00 Bq/g, 3.93 Bq/g and 199.10 Bq/g respectively. Thus the water in River Kaduna does not contain artificial radionuclides.

The gross alpha and gross beta activity measured from the river water samples showed average alpha activity of $(0.027 \pm 0.002) \times 10^{-3}$ Bq/m^3 in the farming zone, $(0.025 \pm 0.001) \times 10^{-3}$ Bq/m^3 in the Residential/Commercial zone and $(0.030 \pm 0.003) \times 10^{-3}$ Bq/m^3 in the Industrial zone. The average beta activity is $(0.585 \pm 0.007) \times 10^{-3}$ Bq/m^3 in Farming zone $(0.411 \pm 0.006) \times 10^{-3}$ Bq/m^3 in the Residential zone and $(0.321 \pm 0.005) \times 10^{-3}$ Bq/m^3 in the Industrial zone. In comparison the alpha activity is highest in the Industrial zone and lowest in the Residential zone. Beta activity is highest in the Farming zone and lowest in the Industrial zone.

It can be concluded that the comparatively high beta activity in the farming zone may be as a result of the fertilizer use in farming. Also the comparatively high alpha activity in the Industrial zone may be as a result of the industrial wastes such as wastes from dyes and other chemicals that may contain alpha emitting elements, use in textile industries which are washed into the river. In general the alpha and beta activity in the three zones are far below the WHO limits.

The results also show poor relationship between the total dissolved solids (TDS) and the alpha and beta activity from the samples. It can also be concluded that the dissolved substances may not be mainly alpha and beta emitting elements. Since the alpha and beta activities in the three zones are far below the WHO contamination limit, the activities in the zones do not contaminate the river to any significant level. The alpha and beta activity in the river along the three zones are just background radioactivity. Therefore water from River Kaduna along the Farming, Residential/Commercial and Industrial zones poses no radiological hazards to the inhabitants of Kaduna, since the radioactivity in the river is only background.

5.3 Recommendations

For expanding this results, more works are needed in these areas:

i. The elemental constituents of the river water should be studied.

ii. There is also the need to study the soils along the course of the River in the three zones and compare it with the radioactivity of water from the river.

iii. There is need for seasonal study of the radioactivity of the river in the three zones to see whether the radioactivity is affected by seasons.

iv. A more improved method of identifying radionuclides in water as well as the alpha and beta activity resulting from such radionuclides should be used

v. Survey of other sources of water like wells, boreholes and tap water in Kaduna should be carried out.

vi. The work should be expanded to other sources of water in other parts of the country.

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