MEASUREMENT OF NATURAL RADIOACTIVITY IN DRILLED AND DUG WELL-WATERS OF OGUN STATE, SOUTHWESTERN, NIGERIA AND CONSEQUENT DOSE ESTIMATES

BY

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CERTIFICATION

(a) **(By the Student)**

This work has not been presented elsewhere for the award of a degree, or any other purpose.

Candidate's Names: ACHUKA, Justina Ada.

Signature: ..... **Date:** 14/9/10.....

(b) **(By the Supervisor and the Head of Department)**

We hereby certify that this research work was carried out by ACHUKA JUSTINA ADA, in the Department of Physics, Federal University of Technology, Akure, and to the best of our knowledge, it has not been submitted elsewhere for the award of any degree.

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DEDICATION

This work is dedicated to the ALMIGHTY GOD, to Him be all the glory forever amen.

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ABSTRACT

Natural radioactivity was measured in twenty samples of well water collected from hand dug wells and drilled wells (boreholes) from Ogun State, Southwestern Nigeria with a view to provide baseline data on radioactivity level in the area, and also to estimate the resulting annual effective dose to the inhabitant as a result of drinking from these well waters.

Using high-resolution gamma spectrometry technique the activity concentrations of the following radionuclides: ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac were found to be having a mean activity concentration of 2.98±1.90, 2.21±0.18, 2.10±0.53 , 4.47±1.13 and 0.62±0.24 Bq l^{-1} respectively.

The total annual effective dose due to the ingestion of the natural radionuclides of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac for ages 2-7, 12-17, and >17yrs were estimated to be 0.82, 3.89, and 0.89 mSv y^{-1} respectively. These values are found to be above 0.1 mSv y^{-1} of WHO recommended limit for radiological safe drinking water.

CHAPTER ONE
INTRODUCTION

1.1 Introduction

Water existed long before man came into existence and is as important to life as the air breathe by humans, because it is indispensable. Man uses water for drinking, laundry, cooking (and for other domestic activities), irrigation, power generation etc.

Hence, monitoring of natural radioactivity in water is an important parameter for public health studies because it allows the assessment of population exposure to radiation by the consumption of water.

The occurrence of radionuclides in drinking water cause health hazards in drinking water owing to human internal exposure from the decay of radionuclides absorbed into the body through ingestion. An average radiation dose of 0.29 mSv yr^{-1} is received worldwide via ingestion of natural radionuclides of ^{238}U – and ^{232}Th –series and ^{40}K during habitual consumption of food and water (UNSCEAR, 2000).

1.2 Sources of drinking water

Sources of drinking water includes;

1) Drilled wells – Drilled wells draw water from deep below the ground surface and are the source of drinking water for many household and communities.
2) Dug wells – Dug wells draw water from shallow water tables. They are more vulnerable to surface water contamination than drilled wells. However, a properly constructed dug well in a good location can produce high quality water.
3) Lakes and Rivers – These are surface water found in rivers, streams, lakes and ponds. Their water is not safe for drinking unless it is treated.
4) Springs – These are waters that flow from rocks.

In summary, water found in lakes, rivers, streams e.t.c., is considered as surface water while water found in wells (either drilled or dug) is known as ground water.
Ground water is any water found below the water table in the earth crust.
However, all water irrespective of its sources contains radionuclides that dissolve into the water as a result of the interaction of water with the earth crust (containing primordial radionuclides) during the circulation of water across the terrestrial crust.

1.3 RADIOACTIVITY IN WATER

All radionuclides dissolved in water are colorless, odorless and tasteless and thus cannot be detected by our senses, unlike many water pollutants that may impart undesirable colors, odors and tastes to water.

Although much is known about the geochemistry of radionuclides in water, it is still very difficult to predict the radionuclides content in a particular ground water supply because of strong influence of local geological and hydro geological conditions.

Much of what is known about the distribution of radionuclides in water has been derived from analysis of water from public water supply systems, which supply slightly more than 80 percent of the population in the United States (Solley et al, 1983).

However, it is difficult to develop site-specific information about the occurrence and activities of radionuclides in specific aquifers (water body) because a public water supply comprises of a blend of water from numerous ground and surface water sources. Relatively little is known of the concentrations of radionuclides in private water supplies, which rely heavily on ground water and supply more than 20 percent of the total ground water used for human consumption.

In recent years, estimates have appeared in scientific literature about the effects of radionuclides in groundwater on human health. (Reid et al.1985). These estimates and the growing body of scientific knowledge of the distribution and levels of radionuclides in

ground water have stimulated a review of the adequacy of standards and regulations for radionuclides in drinking water.

1.4 GEOCHEMISTRY OF RADIONUCLIDES

Radionuclides are found as trace elements in most rocks and soils and are formed principally by the radioactive decay of ^{238}U and ^{232}Th, which are long-lived parent elements of the decay series that bear their names. The parent elements produce intermediate radioactive daughter elements with shorter half-lives.

Decay occurs by the emission of an alpha particle (a nucleus of the helium atom) or a beta particle (an electron) and gamma rays from the nucleus of the decaying element. The geochemical behavior of a daughter element in well water may be quite different from that of the parent element. However, the parent may govern the occurrence and distribution of the daughter element.

The most common radionuclides in well water are; ^{222}Rn, ^{226}Ra and ^{234}U of the ^{238}U decay series, and ^{228}Ra of the ^{232}Th decay series. Other radionuclides of these two decay series and all isotopes of the ^{235}U decay series generally are not present in significant amounts in well water because most are highly immobile and many have very short half-lives that preclude the buildup of large concentrations.

The occurrence and distribution of radionuclides in well water is controlled primarily by the local geology and geochemistry. For daughter radionuclides to be present in large concentration, the parent radionuclides must be present in the rock material composing the aquifer. Each radioactive decay product has its own unique chemical characteristics, solubility, mobility and half-life, which can be very different from those of the parent. For this reason, parent and daughter radionuclides in ground water are not usually found together in similar amounts (Gilkeson et al. 1983): neither do they decay at similar rates or produce the same level of radioactivity.

Therefore, a high concentration of one radionuclide in well water at a specific site does not necessarily imply that similar concentrations of other radionuclides in the same decay series are present.

The movement of many radionuclides is very dependent upon the radionuclides solubility in water. Uranium, which is most soluble in bicarbonate-rich oxidizing (Oxygen-rich) well water with low total dissolve-solids content, is easily dissolved and transported by oxidizing well water, thus, it can be transported to areas far from its original emplacement (Langmuir et al. 1978). Solubility of uranium tends to be enhanced by association with carbonate, phosphate, and fluoride ions or with organic compounds, especially humid substances (Turner-Peterson, 1980). Uranium is less mobile in reducing groundwater and it tends to be absorbed very strongly onto humid substances in the aquifer (Tanner, 1964). Conversely, radium is most mobile in chloride-rich reducing water with high total dissolve-solids content (Tanner, 1964).

Field measurements of dissolved oxygen concentration and oxidation-reduction potential in parts of New Jersey have shown that where the ground water is reducing, elevated levels of radium 226 are associated with high levels of gross alpha activity caused by dissolved uranium (Szabo and Zapecza, 1987).

1.5 The objectives of this work

The objectives of this work are as follows;

1. To measure the activity concentration of gamma-emitting radionuclides present in drilled and dug well water samples from Ogun State with a view to establishing base line data which can be used to evaluate their future changes and for setting of standards for radioactivity in drinking water in Ogun State.
2. To determine the annual effective dose due to the consumption of well water from the study area with a view to estimating the committed effective dose over a life time of 50 years.

CHAPTER TWO

LITERATURE REVIEW

2.1 Characteristics of Radiation and Its sources

Radiation is defined as energy transmitted either in the form of waves (electromagnetic radiation) or in the form of charged or uncharged particles.

Radiation is categorized into two main groups:

- ❖ Ionizing radiation and
- ❖ Non-ionizing radiation.

Non-ionizing radiation is radiation that is not capable of ionizing the medium or material through which it passes. Examples includes; ultraviolet radiation, microwaves or low-frequency electromagnetic radiation.

Ionizing radiation can be directly ionizing or indirectly ionizing

Directly ionizing radiations includes charged particles such as negatrons, positrons, protons, and other heavy ions. This radiation can ionize the medium or material through which it passes promptly: the ionization takes place immediately after the primary interaction.

Indirectly ionizing radiation on the other hand may ionize only by means of secondary created charged particles such as electrons or recoil nuclei and other charged particles. Indirectly ionizing radiation encompasses any uncharged particles, such as neutrons and photons (x-rays, both characteristic and bremsstrahlung, gamma radiation, annihilation radiation).

2.2 Radiation Sources

Radiation sources can be divided into two groups namely;

- Natural radiation sources
- Man-made (artificial) radiation sources

Natural radiation sources include all naturally occurring radionuclides. These radionuclides are classified into terrestrial and cosmogenic radionuclide.

Terrestrial radionuclides- these are radionuclides, which are believed to have been present when the earth was formed some 4.5×10^9yrs ago. They are known as primordial radionuclides.

Cosmogenic radionuclides – These are radionuclides produced by the interactions of cosmic rays with air (e.g. ^{7}Be, ^{14}C, ^{22}N and others).

Man–made/Artificial radiation sources: These are artificially produced radionuclides which comprise of radiation from generating devices (e.g. X-ray tubes), nuclear reactors, nuclear weapons and a variety of sources based on some nuclear reactions (e.g. neutron generators using D-T, D-D reactions e.t.c).

2.3 Radiation Exposure

All persons in the world are exposed to radiation from natural and man-made (artificial) sources. One hundred years ago natural sources were the only sources of radiation exposure. Even today, these sources deliver a larger collective dose to mankind than do all man-made sources combined (UNSCEAR, 1993).

Natural radiation includes cosmic radiation, external radiation from radionuclides in the earth's crust and internal radiation from radionuclides taken into the body by ingestion or inhalation. Natural exposures depend mainly on geographical location, local geology and on some human activities. The dose rate from cosmic radiation is related primarily to altitude, while external terrestrial radiations depend on the local geological conditions and internal exposure is due to the inhalation and ingestion of naturally occurring radionuclides present in air, water and food stuffs. Sometimes, this exposure may be much higher than the average or normally expected exposures. Such elevated radiation levels are usually caused by the so-called enhanced natural sources originating from some human activities. For example, air travel at high altitudes and the redistribution of radionuclides on the

ground due to mining, building and other similar activities that can lead to increasing exposures. Elevated radon and gamma exposures in dwellings are primarily caused by enhanced concentrations of naturally occurring radionuclides in building materials and soil. The exposure from radon depends also on other factors such as the design and the ventilation of houses.

A variety of man-made exposures are the result of the production and use of radionuclides, the testing of nuclear weapons in the atmosphere, the generation of energy by nuclear reactors, and numerous application of radioactive sources and also in some consumer product (for example, smoke detectors, long-lived self-luminizing materials like wristwatches, static eliminators e.t.c). In carrying out these activities, not only do the persons involved in such operations receive some doses directly but the population at large is also affected.

With the exception of exposures to patients undergoing medical examinations or treatments and exposure from severe radiation accidents, individual exposures from man-made radiation sources are usually negligible. Nevertheless, collective doses to large population may be serious enough to warrant attention.

2.3.1 Natural Radiation Exposure

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) assessment of the worldwide annual effective dose from natural sources of ionizing radiation in areas of normal background is estimated to be 2.4 mSv (UNSCEAR, 1993). This result is shown in Table 2.1.

Table 2.1: Annual effective doses to adults from natural radiation sources (UNSCEAR, 1993)

Component of exposure	Annual effective dose (mSv)	
	In areas with normal background	In areas with elevated background
Cosmic ray	0.38	2.0
Cosmogenic radionuclides	0.01	0.01
Terrestrial radiation:		
External exposure	0.46	4.3
Internal exposure (No Radon)	0.23	0.6
Internal exposure from Radon and its decay products:		
Inhalation of ^{222}Rn	1.2	10
Inhalation of ^{220}Rn	0.07	0.1
Ingestion of ^{222}Rn	0.005	0.1
Total	2.4	17

One-third of the total annual effective dose comes from external exposure to cosmic radiation and terrestrial radionuclides while two-thirds are due to internal exposure. More than half (1.3 mSv) of the total is due to exposure to radon and especially to its short half-life decay products.

The effective dose due to external terrestrial gamma radiation is about 0.46 mSv.

Exposures to terrestrial radionuclide are mainly from ^{40}K and radionuclides of ^{238}U and ^{232}Th series. These radionuclides deliver both external and internal doses. Internal exposures are caused by the ingestion of radionuclides in food and water as well as from inhalation, primarily of radon gas and its decay products. The annual exposure from

ingested ^{40}K is relatively constant at 0.17 mSv, since this chemical element is homeostatically controlled in the body (Fujita et al. 1996). Radionuclides from the ^{238}U and ^{232}Th series cause annual internal exposures of 0.052 mSv from ingestion, mainly of ^{210}Pb, ^{210}Po, and about 0.01 mSv from their inhalation (not including radon). Altogether, the internal exposure due to terrestrial radionuclides (excluding radon) is estimated to be about 0.23mSv as shown in Table 2.1.

2.4 Terrestrial Radionuclides

The natural radionuclides characterized as primordial are responsible for more than 70% of the average effective dose to humans from all radiations (UNSCEAR, 1993). Primordial radionuclides can be classified into two categories.

a. Singly occurring radionuclides, and

b. Radionuclides belonging to decay chains or series

2.4.1 Singly occurring radionuclides

There are more than 20 long-lived primordial radionuclides that were present when the earth was created and which still exist as singly occurring or isolated radionuclides not belonging to any of the decay series (Kathren, 1984). In terms of doses, only two of these natural radionuclides, namely ^{40}K and ^{87}Rb, contribute significantly to population exposure.

The radionuclide ^{40}K is present in natural potassium with an abundance of about 0.018% and has a half-life of 1.28×10^9 yrs (ICRP, 1976). It decays by electron capture (about 11%) and beta particle emission (about 89%). Electron capture leads to an excited state of ^{40}Ar which returns to ground state by the emission of an energetic gamma photon. The characteristic of this photon is often used as reference energy for the calibration of detectors in the gamma spectrometry of environmental samples where natural potassium is practically always presents (Sabol and Weng , 1995).

Potassium is widely distributed in nature with concentration ranging from about 0.1% for limestone, 1% for sandstones to as much as 3.5% for granites (Eisenbud, 1987).

In human body, potassium is located in the muscle. Its concentration decreases with age and is usually greater in men than women (Lan and Weng, 1989).

The second singly occurring primordial radionuclide is ^{87}Rb. It has less contribution to human exposure. The concentration of ^{87}Rb in the human body is about 15 Bq kg $^{-1}$ (ICRP, 1976). The radionuclide ^{87}Rb has a half-life of 4.7 x 10^{10} yrs; it is a pure beta emitter and it emit in each decay one beta particle of maximum energy 273 keV.

2.4.2 Radionuclides belonging to decay chains or series

There are three natural radioactive series or chains of consecutive parent and daughter nuclei, beginning and ending among elements with atomic numbers higher than 81. The members of these series undergo alpha and beta decay. In all cases their final product is a stable isotope of lead. Of the three series, namely the uranium series (stating with ^{238}U and ending with ^{206}Pb), the thorium series (beginning with ^{232}Th and ending with ^{208}Pb), and the actinium or ^{235}U series (beginning with ^{235}U and ending with ^{207}Pb), the first two contribute appreciably to population exposure.

The uranium typically found in nature is composed of four isotopes with mass numbers 230, 234, 235 and 238. The parent radionuclide ^{238}U makes up 99.28% of natural uranium and is normally in equilibrium with its great granddaughter ^{234}U, whose content in natural uranium is 0.0058%. Because uranium is present in soils and fertilizers, it is also present in food and water and so inevitably also in the human body.

The radionuclide ^{226}Ra and its decay products from uranium series are responsible for a major portion of the exposure received internally and externally by humans from natural radiation sources. The half-life of ^{226}Ra is 1622yrs it is an alpha emitter. Radium is present in rocks, soils, building materials and water as well as in human tissues in various concentrations.

The average content of ^{232}Th in soils is approximately the same as the content of ^{238}U (on average about 25 Bq kg^{-1}), while its presence in air as ^{220}Rn is half that of ^{238}U (about 0.5 $\mu Bq\ m^{-3}$). (Eisenbud, 1987).

Due to weathering and leaching effects the decay products of ^{238}U and ^{232}Th are not expected to be in radioactive equilibrium with the head of the series. The ranges of the activity concentration of ^{238}U and ^{232}Th series members can vary with their depth and profile in soil and rocks (Fisenne, 1993).

2.5 Internal Exposure

Internal exposure arises basically from the ingestion and inhalation of three main types of natural radionuclides: ^{40}K, long-lived uranium and thorium series radionuclides, and radon and its short-lived decay products. Others have been discussed above with the exception of radon.

2.6 Radon

Radon is found in nature in three isotope formations; ^{222}Rn, ^{220}Rn and ^{219}Rn. The most important of them is ^{222}Rn, the immediate decay product of ^{226}Ra, a member of the uranium decay series. The half-life of ^{222}Rn is 3.8 days. ^{220}Rn is formed in the thorium decay series from the decay of ^{224}Ra. It half-life is 56 s; this limits the distance it can reach before decay.

^{219}Rn can be found in air but its concentration is very low, so that it does not present any radiological hazards. ^{219}Rn is a member of the actinium series.

However, the production of both ^{222}Rn and ^{220}Rn depends on the activity concentrations of ^{226}Ra and ^{228}Ra in the earth's crust. Thus, trace concentrations of radium of various levels are present in soil, rock, water and building materials (Porstendorfer, 1993).

2.7 Health implication of radioactivity in water

Radioactive substances emit radiation of different types such as alpha particles, beta particles and gamma rays. The intake of radioactivity into the body results to internal contamination. Inhalation or ingestion of radioactive materials brings the radiation from them in contact with the body tissues and organs. Fast replication tissues suffer most from damage. Alpha particles, which are essentially helium nuclei deposit a lot of energy at short distances and concentrate their damage. Alpha particles are therefore, the most dangerous specie of radiation in drinking water. Beta particles are simply high-energy electrons. They can travel a longer distance in matter before depositing their energy, thus they deposit their energies thinly over a larger area of the body.

When radioactive elements like barium, calcium or other similar nuclides like strontium and radium are ingested, they concentrate in the bone. For example, the effect of ingested radium on radium watch dial painters in the early part of the last century was reported to have caused bone and head carcinomas in them (Fisenne, 1993). A small number of leukemia was also found in workers that ingested radioactive substances.

Uranium is known to have deleterious or chemotoxic effect on the kidney. In estimating the risk due to uranium in drinking water, the crucial questions are how much ingested uranium goes to the bone and how much goes to the kidney, what are their respective consequences? (Wrenn et al. 1990).

The International Commission on Radiological Protection (ICRP) estimates that the blood stream from the gastrointestinal tract absorbs an average of 5% 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% (Wrenn and Sighn 1987). In preliminary results from experiments that used fasting human subjects, a value of between 0.5% - 1.0% was suggested (Crawford, 1990). In view of these results, both the 1.4% and 5% estimated are reasonable average level to use in risk calculations.

Although, with large uncertainty, work related to the ingestion of radon suggest that number of fatal cancers from radon ingested from drinking water may be equal to a significant fraction of the fatal lung cancers (Corriea et al. 1987).

Radon is the radionuclide that represents the largest risk of all the radionuclides in drinking water. The two diseases of principal concern are stomach cancer from ingestion of radon and lung cancer from inhalation of radon daughters (Crawford, 1990). For ingestion, there is a smaller risk of other cancer due to some fraction tract to circulating systemic blood.

There is no direct evidence that the ingestion of radon via drinking water produces any effects in human and experimental animals. Therefore, estimation of any health risk from the ingestion of radon must be based on indirect evidence, derived from the studies that demonstrate an association between radiation exposure and stomach cancer (Milla, 1990).

2.9 Removal of radionuclides from well water

Conventional water-treatment methods can remove as much as 95% of the radionuclides present in well water. Each radionuclide has its own specific treatment method(s) that will remove it with the greatest efficiency. If several different radionuclides are present in the water, no single treatment method will remove all of them, and multiple treatment techniques may have to be applied. Therefore, it is essential to identify the radionuclide(s) present before selecting the specific water-treatment methods.

Conventional water treatment methods that remove the most abundant naturally occurring radionuclides (uranium, radium and radon) from well water are listed in Table 2.2.

Table 2.2: Conventional water-treatment methods (Reid et al. 1985)

Radionuclide	Water treatment method
Radon	Granular activated carbon
	Aeration
Radium	Ion-exchange water softener
	Radium selective complexor
	Barium co-precipitation
	Manganese coated filters
Radium and Uranium	Reverse osmosis or Electro dialysis
	Lime softening
Uranium	Coagulation
	Anion exchange
	Activated alumina columns

However, some of these water treatment methods are unreliable, expensive, require operational expertise and suitable only for treating large volumes of water. Additional information including detailed methods of operation, comparison of operational expenses and details about potential problems are reported by Brinck et al. (1978) Hahn, (1984), Reid et al. (1985), Menetrez and Watson (1983), and Lowry and Lowry, (1987).

2.10 Review of previous work

In Nigeria, Ajayi and Owolabi (2007) measured natural radioactivity in drinking water in private wells in Akure, Southwestern Nigeria using high-purity germanium (HPGe) co-axial detectors (Canberra, GC2018-7500) coupled to Canberra Multichannel Analyser system. The measured activity concentrations ranged from 0.57 to 26.86, 0.20 to 60.06 and 0.35 to 29.01 Bq l^{-1} for ^{226}Ra, ^{228}Ra and ^{40}K, respectively. Total effective doses

from the intake of these radionuclides in the waters ranged from 0.02 to 76.84, 0.02 to 38.80 and 0.05 to 481.60 mSv y^{-1} for age group <1, 2–7 and ≥17 y, respectively.

Awodugba and Tchokossa. (2008) assessed the radionuclide concentrations in water supply from boreholes in Ogbomoso land, Western Nigeria by gamma ray spectrometry with a high-purity germanium (HPGe) detector connected to a multi channel analyzer. All the water samples from these bore-holes were found to contain acceptable levels of radionuclides with mean activity values of 3.98 ±0.26, 11.00 ±2.58, and 17.73 ± 5.04 Bq l^{-1} for ^{40}K, ^{232}Th, and ^{238}U, respectively. The mean absorbed dose rate for all the area was 0.123 mSv yr^{-1} which is very low when compared to the recommended limit of 1 mSv yr^{-1} for bore-hole water.

Tchokossa et al. (1999) measured the radioactivity in the community water supplies of Ife-Central and Ife-East Local Government areas of Osun State and the average specific activity concentrations of ^{226}Ra, ^{228}Ra and ^{40}K obtained were; 8.67±4.28, 2.31±1.48, and 98.99±6.23 Bq l^{-1} respectively for well water; and 12.45±3.39, 3.02±0.64 and 97.46±6.23 Bq l^{-1} respectively for borehole water; 12.41±1.37, 2.47±0.09 and 85.06±17.27 Bq l^{-1} for tap water; 10.40±1.70, 2.70±1.30 and 72.60±9.10 Bq l^{-1} for dam water.

Onoja (2004) surveyed the gross alpha and beta radioactivity in well water from Zaria area. In her result, the gross alpha activity was 0.58 - 43.19 Bq m^{-3} and 3.58 - 622 Bq m^{-3} for gross beta. The geometric mean values are 6.32 and 75.5 Bq m^{-3} for gross alpha and gross beta respectively. Her values were found to be lower than the screening level recommended by the WHO (1993) for good water quality, which are 10 Bq m^{-3} for alpha and 100 Bq m^{-3} for beta activity.

Al-Masri and Blackburn (1995) worked on application of cerenkov radiation for the assay of ^{226}Ra in natural water. The first count rate he obtained was due to ^{228}Ac (the daughter of ^{228}Ra), ^{214}Bi and ^{214}Pb (the daughter of ^{226}Ra), and the second count rate was due to ^{228}Ac and the buildup of ^{226}Ra activity.

Fatima et al. (2006) measured natural radioactivity in bottled drinking water of Pakistan using gamma spectrometry technique. Mean concentrations of ^{226}Ra, ^{232}Th, ^{40}K were 11.3±2.3, 5.2±0.4 and 140.9±30.6 mBq l^{-1} respectively. The annual cumulative effective doses due to all three natural radionuclides for different age groups of 1-5yrs, 5-10yrs, 10-15yrs and adults (≥ 18yrs) were estimated to be 4.0, 3.4, 3.1 and 4.1 Sv y^{-1} respectively.

Belloni et al. (1995) worked on optimization and comparison of three different methods for the determination of ^{222}Rn in water. In the first method, ^{222}Rn was extracted from water by degasification. It was counted using a Lucas cell for 10 min. In the second method, ^{222}Rn was extracted directly from the 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 activity using NaI(Tl) scintillator. The results obtained by all the three methods agreed with the first method having detection limit of 20 mBq l^{-1}, the second method having 200 mBq l^{-1} and the third method having 1.75 Bq l^{-1}.

Surbeck (1995) detected natural radionuclides in drinking water. This analysis produced the presence of ^{226}Ra, ^{210}Po and ^{224}Ra, which were obtained from an 80 ml sample of drinking water. This was exposed to radium adsorbing discs for 20 hrs and the discs were measured by alpha-particle spectrometry using a Si-surface barrier α-detector. The result also showed that the detection limit for these three radionuclides were 20 mBq l^{-1}. The radionuclides ^{238}U, ^{234}U and ^{210}Po were also measured using liquid scintillation α-spectrometer with α/β discrimination and energy resolution of 200-300 keV. The detection limit was 100 mBq l^{-1}. 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 well type HPGe detector with detection limits of 100, 30, 30, 10, 10 and 50 mBq l^{-1} for ^{226}Ra, ^{210}Po, ^{228}Ra, ^{228}Th, ^{224}Ra and ^{238}U respectively.

Alvarado. et al (1995) worked on rapid determination of radium isotopes by alpha spectrometry. His 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^{-1} of ^{226}Ra was 0.9%.

Cevik et al. (2005), in their study of natural radioactivity in tap waters of Eastern black sea region of Turkey using gamma ray spectroscopy, showed that the natural radioactivity concentrations of ^{214}Pb, ^{214}Bi, ^{226}Ra, ^{137}Cs and ^{40}K in tap waters of the Eastern Black sea Region were generally low with mean specific activities of 6.73, 6.00, 19.16, 168.57 and 5.45 mBq l^{-1} respectively. ^{222}Rn was also determined using liquid scintillation counting and the measured specific activity was 10.82 Bq l^{-1}. The estimated effective doses due to ingestion of ^{214}Pb, ^{214}Bi, ^{226}Ra, ^{137}Cs, ^{40}K and ^{222}Rn were 6.878×10^{-4} μSv y^{-1} for ^{214}Pb, 4.800×10^{-4} μSv y^{-1} for ^{214}Bi, 3.916 μSv y^{-1} for ^{226}Ra, 0.763 μSv y^{-1} for ^{40}K, 0.052 μSv y^{-1} for ^{137}Cs and 5.848 μSv y^{-1} for ^{222}Rn.

Zofia et al. (2004) measured the activity of uranium isotopes in public drinking water in Poland by alpha-spectroscopy. Activity concentration of ^{238}U, ^{234}U and ^{235}U were determined in tap water from municipal water pipes that drew their supply from surface water or ground water in various locations in Poland. Average activity concentrations of ^{238}U, ^{234}U and ^{235}U in tap water from surface water were 9.6±7.1, 12.8±9.7 and 0.41±0.31 Bq m^{-3} respectively, whereas from ground water they were 4.5±6.0, 5.7±6.9 and 0.19±0.27 Bq m^{-3} respectively.

CHAPTER THREE
EXPERIMENTAL

3.1 The Study area

The study area for this research work is Ogun State in Southwestern Nigeria. The state covers total land area of about 16,409.26 km^2 with a population of 3,728,098 people (2008 population census). Ogun State lies within the tropics on latitude of 7.14^0N and longitude of 3.13^0E and its climate follows the tropical pattern, with rainy season starting in April and ending in November, followed by the dry season.

Three cities were selected in the State where water samples were collected at different locations and depths. These cities of choice are widely spread out to ensure that every region of the state was covered, and also to ensure a wide coverage for the measurement of the level of radionuclides contaminations of well water in the State, since the locations are characterized by different geology and topography. These cities are Abeokuta, Ijebu-Ode and Idiroko.

Figure 3.1: Map of Ogun State

3.2 SAMPLE COLLECTION

A total of 20 well (drilled and dug) water samples were collected directly from the three cities. The water samples were collected directly from the dug wells using a manual procedure, which involved the dipping of a clean container firmly tied to a rope long enough to reach the water level in the well. In some cases, surface or subsurface electric pumps were connected to the well whereby water from the well can be pumped directly into overhead water reservoirs, which have been connected to a network of pipes that carry water into the residences. For such a water pumping system, the water taps were first turned on at full capacity for several minutes to purge the plumbing system of any water which might have been there for some time. The taps were turned down to a low rate to reduce turbulence and thus, reduce radon loss. After the water samples were collected as mentioned above, they were then transferred to 2-litres plastic containers. The boreholes (drilled wells) were connected to electric pumping systems, which were connected to a network of pipes and taps. Its water sampling was as described above for electrically pumped dug well water.

3.3 SAMPLE PREPARATION

The 2-l plastic containers were thoroughly washed with pure water and rinsed with hydrochloric (HCl) acid before use to avoid contamination of water samples. Later, all the water samples collected were acidified with 11M of HCl at the rate of 10 ml per litre of sample as soon as possible after collection to avoid adsorption of radionuclides onto the walls of the containers as documented by the International Atomic Energy Agency (IAEA, 1989). The containers were firmly sealed for at least four weeks to ensure that no loss of radon occurs thereby ensuring a state of secular equilibrium to be reached between parent isotopes and their respective progenies.

3.4 SAMPLE ANALYSIS

3.4.1 Chemical Parameter Analysis of Water Samples

The pH of each of the water samples was measured using Microprocessor pH meter (pH 211, Hanna Instruments) with combined electrodes. The calibration of the instrument was carried out using 4, 7 and 9 buffer standard solutions. Metals of sodium (Na), magnesium (Mg), potassium (K) and calcium (Ca) were analyzed by using Atomic Absorption Spectrometer (AAS) model 200 flame techniques. For chloride and bicarbonate, titrimetric method was used while nitrate and sulfate was analyzed using ultraviolet/visible spectrophotometer. Values of chemical parameters measured in the 20 well water samples are given in Table 4.1.

3.4.2 Gamma ray Spectrometric Analysis of Water Samples

Gamma spectrometry measurements were carried out with co-axial type, high purity germanium (HPGe) detector (Canberra Industries Inc.) with about 50% relative counting efficiency and energy resolution of 2.4 keV at 1.33 MeV gamma rays of ^{60}Co. The system was set up to cover about 2 MeV photon energy ranges over 4k channels. The detectors were properly shielded in lead castles to minimize the background radiation count. The detector was calibrated using the LabSOCS calibration software model S574 that requires no reference standard sources for accurate efficiency calibration because the software works over a wide range of geometries. After secular equilibrium, each sample was counted for 86400 s to achieve minimum counting error. To determine the background radiation level, an empty Marinelli beaker was counted at the same time as the samples under identical geometry. Spectral analyses were performed using the Genie 2k spectrometry software, version 2.1 (Canberra Industries Inc). A library of radionuclides, which contained the energy of the characteristic gamma peaks for each radionuclide analysed and their corresponding emission probabilities, was built from the data supplied

in the software. Specific activity of each radionuclide in water were expressed in Bq l^{-1} and corrected for the time elapsed since the samples were collected from the wells.

All analyses were done within 60 d after sampling. All wells were analysed for ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac. The detection limit (DL) of the measurement system, which is needed to calculate the lowest detectable activity concentration of radionuclides in a sample, was obtained by using the relation

$$DL = \frac{1.64\delta_{bs}}{\varepsilon_D P_\gamma t_m v_{ws}}$$ (Turhan, 2008)

where DL = detection limit (Bq l^{-1})

δ_{bs} = square root of the number of count for the background spectrum

ε_D = efficiency (in cps Bq l^{-1}) of the HPGe detector used for measurement

P_γ = emission probability of the gamma decay

t_m = measurement time (in seconds) and

v_{ws} = volume of water sample (in litres).

The lowest detectable activity concentration values obtained for ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac at 95% confidence level for a measurement period of 86400 s and a sample volume of 0.5 l were 0.05, 0.01, 0.02, 0.02 and 0.01Bq l^{-1} respectively. These are the lowest values that could be for the radionuclides. Activity concentration values below these numbers are taken as not detectable (ND) by the detector system used in this work. The measured specific activity concentration of each radionuclide present in the well water samples collected is as shown in Table 4.2.

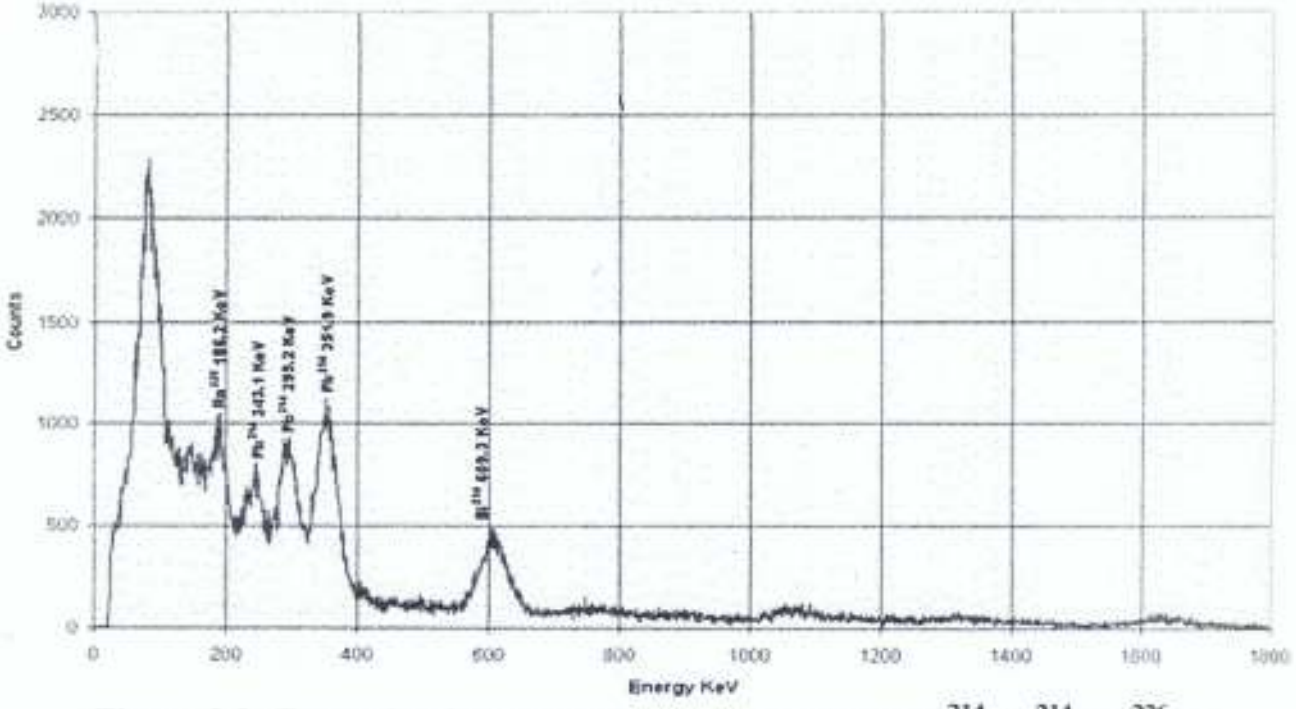

Figure 3.2: Example of characteristic gamma peaks of ^{214}Bi, ^{214}Pb, ^{226}Ra

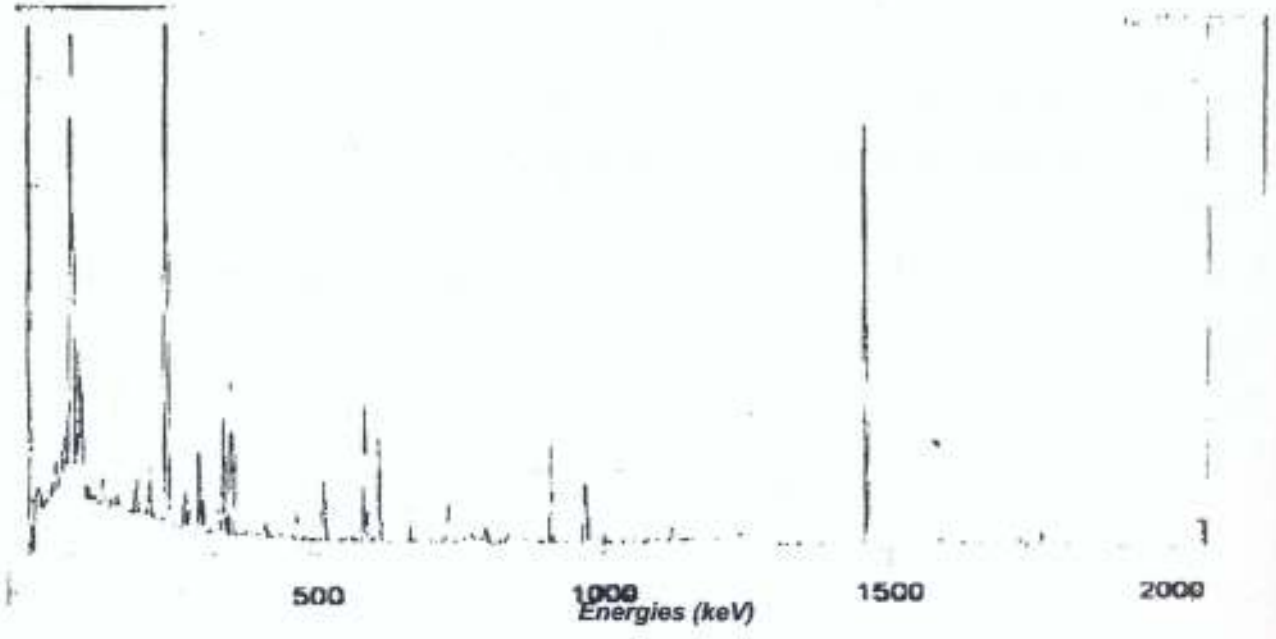

Figure 3.3: Typical Gamma peaks of drilled and dug well waters of Ogun State.

3.4.3 Evaluation of the annual effective dose and committed effective dose

The annual effective dose to an individual due to intake of natural radionuclides of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac from drinking drilled and dug well waters of Ogun State is estimated using the following relationship.

$D_A = C_R . I_F . E_D$ (Alam et al. 1999)

Where D_A = annual effective dose to an individual due to the ingestion of radionuclides (Sv y^{-1}).

C_R = activity concentration of radionuclides in the ingested drinking water (Bq l^{-1}).

I_F = annual intake of drinking water (L y^{-1})

E_D = ingested dose conversion factor for radionuclide (Sv Bq^{-1})

(For this study, C_R values are shown in Table 4.3; I_F in Table 4.10 and E_D in Table 4.9)

The total effective dose D (Sv y^{-1}) to an individual is estimated by summing contributions from ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac present in the well water samples i.e

$D = \sum C_R . I_F . E_D$

The committed effective dose C_d, which is a measure of the total effective dose received over a life time of 50 y following the ingestion of radionuclides is calculated using

$C_d = 50 \times D$,

where D is the total effective dose.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

The results obtained so far were based on the measurement of natural radioactivity of the twenty (20) well water samples collected from different wells (drilled and dug) within Ogun State. The results are discussed below.

4.1 Results of the chemical parameters of well water samples

The results of the analysis are shown in Table 4.1. The pH ranged from 7.4 in Ake to 7.9 in Kenta. Sodium (Na) has the lowest concentration value of 50.5 mg l^{-1} in Oyingbo and the highest value of 95.6 mg l^{-1} in Totoro. Magnesium (Mg) concentration value ranged from 63.6 mg l^{-1} in Kenta to 104.9 mg l^{-1} in Alapara. Potassium (K) value ranged from 69.6 mg l^{-1} in Molipa to 101.4 mg l^{-1} in Kenta. Calcium has the lowest concentration value of 48.6 mg l^{-1} in Ibara and the highest value of 81.2 mg l^{-1} in Penpe. Ibara is the least rich in chloride (42.6 mg l^{-1}) while Elega is most rich in chloride (276.4 mg l^{-1}). Ibara and Alapara sulfate contents are same and the least (50.8 mg l^{-1}) while Elekute is most rich in sulfate (78.4 mg l^{-1}). Similarly, Oyingbo, Ibara and Alagbon have same nitrate content and the least (15.0 mg l^{-1}) while Molipa is most rich in nitrate (31.6 mg l^{-1}). Bicarbonate concentration ranged from 1.0 mg l^{-1} in Ibara to 2.7 mg l^{-1} in Oyingbo. Conclusively, Ibara has the least value in Chloride, Sulfate, Nitrate and Bicarbonate content.

Table 4.1: Chemical Parameters (mg l^{-1}) of Well Water Samples

S/N	Locations	pH	Na	Mg	K	Ca	Cl	SO_4^{2-}	NO_3^-	CO_3^{2-}
1	Abeokuta Rd.	7.5	74.5	90.4	78.3	68.4	156.2	54.0	19.6	1.9
2	Awujale	7.7	55.1	86.3	94.1	50.7	134.9	58.4	17.6	1.7
3	Fidipote	7.7	90.4	96.7	100.9	71.3	106.5	58.4	30.3	1.8
4	Ita Osun	7.8	75.0	76.2	91.1	74.3	241.4	51.6	23.0	1.8
5	Molipa	7.5	56.8	77.8	69.6	67.8	106.5	52.0	31.6	1.3
6	Oyingbo	7.7	50.5	85.4	81.9	72.2	177.5	74.0	15.0	2.7
7	Sabo	7.5	91.4	79.7	80.5	66.1	142.0	66.4	30.3	-
8	Ake	7.4	65.7	97.3	95.2	60.9	120.7	58.4	22.3	1.3
9	Ibara	7.7	75.5	80.3	91.4	48.6	42.6	50.8	15.0	1.0
10	Elega	7.6	76.3	98.2	80.7	59.4	276.4	60.4	19.6	2.6
11	Ijaye	7.6	70.5	71.8	100.5	75.2	170.4	52.0	25.0	2.0
12	Ita Oshin	7.8	66.1	80.8	85.8	70.5	113.6	66.0	18.6	1.6
13	Kenta	7.9	61.9	63.6	101.4	55.6	92.3	51.2	18.0	2.5
14	Totoro	7.7	95.6	102.0	89.1	58.9	78.2	51.6	21.6	1.2
15	Isaga	7.5	70.0	91.7	79.4	68.3	142.0	54.0	23.3	2.2
16	Alagbon	7.7	54.8	87.9	90.0	79.5	113.6	66.4	15.0	1.3
17	Sabo	7.6	62.7	95.0	76.3	80.6	113.6	58.4	21.6	1.6
18	Penpe	7.7	84.3	76.8	70.9	81.2	127.8	54.4	22.0	1.4
19	Elekute	7.7	70.1	92.1	90.5	71.9	134.9	78.4	17.6	1.5
20	Alapara	7.6	82.6	104.9	77.9	65.5	92.3	50.8	18.6	1.2

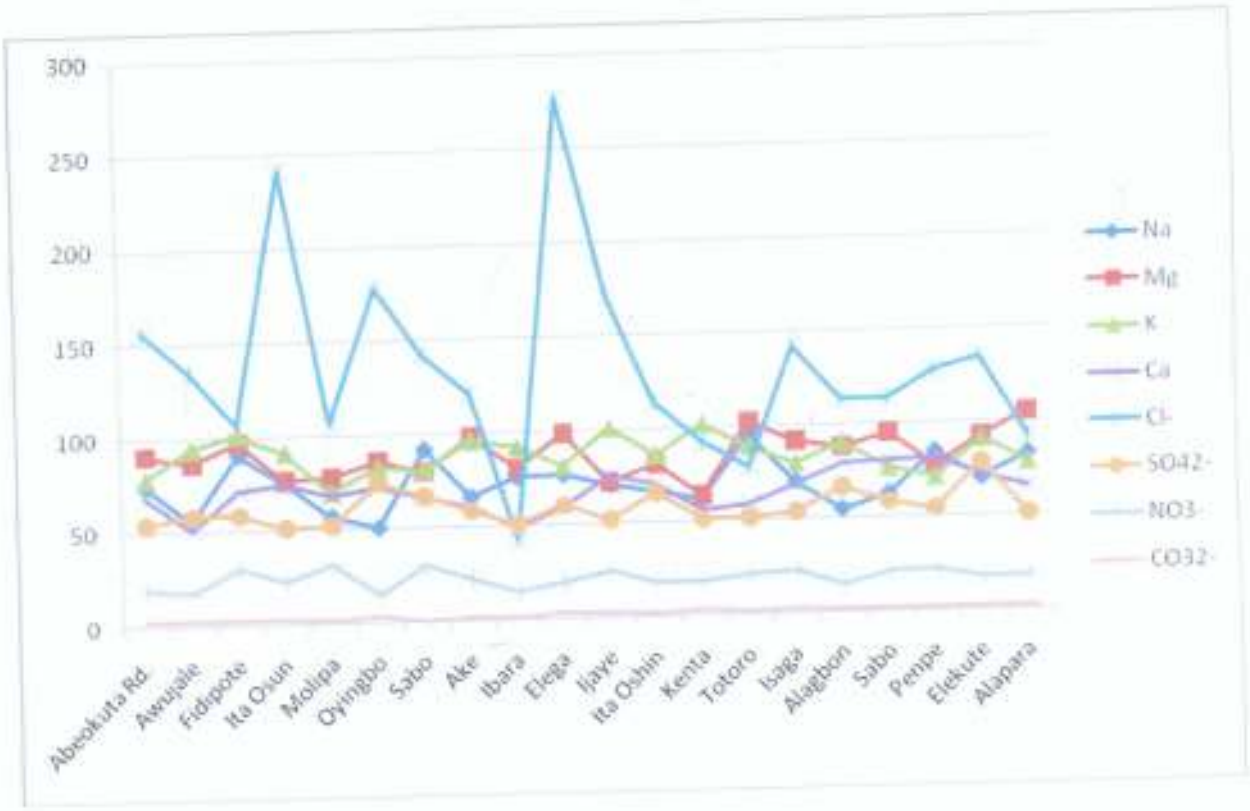

Figure 4.1: Graph showing the chemical parameters (mg l^{-1}) in drilled and dug well waters of Ogun State

Figure 4.1 shows that the well water samples from Ogun State are very rich in chloride (Cl^{-1}) and the concentration vary from one location to the other. This could be attributed to geological distribution of minerals that vary from one location to the other.

4.2 Activity concentrations of radionuclides in drilled and dug well water samples from Ogun State

The result of the activity concentration measurements are shown in Table 4.2. The radionuclides of non-series ^{40}K; ^{214}Bi, ^{214}Pb and ^{226}Ra (of ^{238}U decay series), and ^{228}Ac (daughter of ^{228}Ra belonging to ^{232}Th decay series) were detected in all the samples with the exception of the sample from Ijaiye where ^{88}Y, ^{103}Ru, ^{131}I, ^{144}Ce and ^{192}Ir were detected and the decay series of ^{238}U and ^{232}Th was not detected. Also, ^{137}Cs was detected in all the samples. The presence of ^{88}Y, ^{103}Ru, ^{131}I, ^{144}Ce and ^{192}Ir in Ijaiye sample and ^{137}Cs implies that the wells are also contaminated with artificial radionuclides which may occur from surface runoffs and other pollution sources such as quarrying activities especially where the subsurface geology permits rapid downward movement of water sources from the surface or where well water sources are tapped near the surface.

Table 4.2: Activity concentrations of radionuclides in well waters of Ogun State Southwestern Nigeria

Radionuclides	^{7}Be	^{40}K	^{60}Co	^{134}Cs	^{137}Cs	^{208}Tl	^{210}Pb	^{212}Bi	^{212}Pb	^{214}Bi	^{214}Pb	^{224}Ra	^{226}Ra	^{227}Th	^{228}Ac	^{228}Th	^{234}Pa	^{234}Th	^{235}U	^{241}Am
DRILLED WELL WATER																				
Locations																				
IJEBU ODE (48.0-54.0)m																				
Abeokuta Rd	1.44 ±0.04	3.28 ±0.10	0.18 ±0.02	0.17 ±0.02	0.20 ±0.04	0.20 ±0.09	8.17 ±0.52	2.42 ±0.67	0.38 ±0.09	0.61 ±0.08	0.48 ±0.34	4.28 ±1.34	3.88 ±1.17	1.38 ±0.41	0.72 ±0.16	13.74 ±1.96	16.98 ±0.12	3.22 ±0.33	0.23 ±0.01	0.67 ±0.14
Awujale	2.38 ±0.44	3.26 ±0.94	0.17 ±0.05	0.22 ±0.02	0.23 ±0.03	0.24 ±0.07	12.08 ±1.29	3.23 ±0.31	0.64 ±0.19	0.80 ±0.28	0.97 ±0.59	6.72 ±3.44	7.79 ±7.22	2.24 ±0.54	0.20 ±0.48	26.32 ±22.86	21.27 ±12.24	6.74 ±2.67	0.48 ±0.34	1.14 ±0.31
Fidipute	1.23 ±0.26	3.53 ±1.93	0.17 ±0.02	0.15 ±0.08	0.17 ±0.05	0.17 ±0.09	10.85 ±7.28	2.16 ±0.32	0.26 ±0.01	0.50 ±0.09	0.80 ±0.12	2.75 ±1.00	3.26 ±0.30	0.87 ±0.19	0.72 ±0.49	46.32 ±16.85	20.00 ±9.39	7.80 ±2.09	0.20 ±0.01	0.90 ±0.23
Ita Osun	1.75 ±0.43	3.03 ±0.48	0.18 ±0.14	0.16 ±0.14	0.18 ±0.03	0.19 ±0.07	6.10 ±4.49	2.42 ±0.38	0.37 ±0.04	0.52 ±0.19	0.63 ±0.02	3.99 ±0.23	4.69 ±1.10	1.31 ±0.36	0.79 ±0.39	12.54 ±3.56	20.69 ±2.91	3.07 ±2.34	0.29 ±0.00	0.50 ±0.21
Molipa	1.34 ±0.25	3.00 ±3.32	0.13 ±0.01	0.14 ±0.04	0.17 ±0.03	0.15 ±0.02	7.78 ±3.73	1.87 ±0.12	0.32 ±0.19	1.14 ±0.55	0.38 ±0.09	3.39 ±0.68	3.79 ±0.61	1.11 ±0.28	0.59 ±0.14	15.39 ±0.64	15.75 ±4.71	4.06 ±1.96	0.02 ±1.01	0.79 ±0.17
Oyingbo	1.43 ±0.14	2.48 ±3.15	0.13 ±0.01	0.13 ±0.04	0.15 ±0.05	0.16 ±0.05	10.91 ±0.85	2.00 ±0.23	0.31 ±0.06	0.36 ±0.25	0.36 ±0.16	3.18 ±0.17	3.98 ±1.17	1.06 ±0.05	0.58 ±0.11	17.05 ±1.13	15.27 ±1.89	4.15 ±1.33	0.23 ±0.06	0.93 ±0.04
Sabo	1.04 ±0.39	1.74 ±1.82	0.09 ±0.01	0.09 ±0.01	0.11 ±0.01	0.12 ±0.04	4.73 ±2.74	1.49 ±0.62	0.25 ±0.06	0.23 ±0.08	0.27 ±0.05	2.46 ±0.18	2.89 ±0.62	0.85 ±0.14	0.42 ±0.22	9.47 ±0.44	10.09 ±1.24	2.24 ±0.97	0.18 ±0.05	0.40 ±0.13
ABEOKUTA (27.0-33.0)m																				
Ake	2.61 ±0.49	4.69 ±0.17	0.27 ±0.09	0.27 ±0.04	0.30 ±0.04	0.31 ±0.07	12.02 ±2.86	8.05 ±0.85	0.70 ±0.44	0.88 ±0.67	1.33 ±1.38	7.94 ±6.43	7.45 ±1.13	2.47 ±0.32	1.17 ±0.40	25.16 ±0.04	31.34 ±28.75	6.55 ±0.47	0.46 ±0.07	1.11 ±0.25
Ibara	0.96 ±0.16	1.76 ±1.25	0.09 ±0.02	0.10 ±0.03	0.12 ±0.01	0.12 ±0.04	4.98 ±2.18	1.46 ±0.01	0.25 ±0.04	0.24 ±0.10	0.27 ±0.10	2.63 ±0.64	3.14 ±1.64	0.91 ±0.09	0.37 ±0.03	9.96 ±2.99	11.63 ±0.00	2.54 ±0.77	0.19 ±0.07	0.46 ±0.10
DUG WELL WATER																				
(15.6-19.2)m																				
Elega	1.26 ±0.25	2.05 ±1.07	0.11 ±0.00	0.12 ±0.01	0.15 ±0.07	0.13 ±0.01	5.52 ±1.08	1.79 ±0.49	0.29 ±0.00	0.31 ±0.17	0.32 ±0.04	3.09 ±0.52	3.49 ±0.14	0.99 ±0.38	0.50 ±0.19	11.23 ±4.97	13.79 ±2.74	2.84 ±0.31	0.21 ±0.09	0.52 ±0.13
Ijaiye	ND	3.89 ±5.29	0.19 ±0.00	0.19 ±0.05	0.22 ±0.07	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Ita Osun	1.44 ±0.77	2.85 ±0.63	0.13 ±0.00	0.15 ±0.03	0.17 ±0.41	0.17 ±0.00	6.44 ±1.54	2.18 ±0.50	0.34 ±0.03	0.66 ±0.22	0.64 ±0.28	3.62 ±1.04	4.18 ±0.18	1.20 ±0.49	0.58 ±0.12	13.48 ±2.10	17.34 ±3.97	3.42 ±0.06	0.26 ±0.01	0.57 ±0.29
Kenta	2.14 ±0.12	1.97 ±2.75	0.09 ±0.00	0.10 ±0.03	0.10 ±0.01	0.11 ±0.03	4.58 ±1.27	1.48 ±0.13	0.25 ±0.00	0.24 ±0.12	0.27 ±0.11	2.65 ±0.35	2.91 ±1.09	0.80 ±0.34	0.34 ±0.07	9.60 ±2.86	10.93 ±0.77	2.30 ±0.17	0.18 ±0.07	0.42 ±0.05
Tenco	1.20 ±0.07	3.71 ±0.05	0.19 ±0.00	0.16 ±0.05	0.17 ±0.00	0.18 ±0.07	10.42 ±1.74	2.31 ±0.90	ND	0.41 ±0.20	31.14 ±6.23	ND	5.55 ±1.08	ND	0.35 ±0.10	18.99 ±2.70	20.19 ±2.64	4.90 ±2.03	0.34 ±0.07	0.89 ±0.31
IDIROKO (34.5-36.0)m																				
Alagbon	2.26 ±0.13	3.21 ±0.81	0.17 ±0.08	0.21 ±0.03	0.23 ±0.05	0.22 ±0.03	11.26 ±4.09	2.84 ±0.72	0.59 ±0.06	0.61 ±0.10	0.82 ±0.08	6.26 ±0.26	7.05 ±2.11	2.05 ±0.24	0.70 ±0.60	24.34 ±2.37	19.75 ±12.98	6.31 ±0.07	0.43 ±0.02	1.06 ±0.76
Alapara	1.66 ±0.13	2.8 ±0.60	0.13 ±0.02	0.14 ±0.07	0.16 ±0.03	0.16 ±0.05	8.15 ±6.48	2.12 ±0.15	0.41 ±0.07	0.45 ±0.02	0.95 ±0.15	4.37 ±1.09	5.00 ±2.10	1.46 ±0.09	0.59 ±0.38	16.28 ±4.35	15.49 ±9.37	4.09 ±3.33	0.31 ±0.16	0.67 ±0.57
Elekune	1.60 ±0.22	3.31 ±4.00	0.15 ±0.04	0.15 ±0.01	0.17 ±0.01	0.18 ±0.03	7.16 ±1.44	1.93 ±0.46	0.38 ±0.07	0.44 ±0.35	0.46 ±0.16	3.85 ±3.85	4.48 ±0.34	1.24 ±0.33	0.60 ±0.02	15.45 ±3.41	14.06 ±6.43	3.67 ±0.22	0.28 ±0.09	0.60 ±0.06
Isaga	1.21 ±0.15	2.00 ±1.76	0.11 ±0.01	0.11 ±0.05	0.12 ±0.06	0.13 ±0.02	5.43 ±0.40	1.67 ±0.21	0.30 ±0.07	0.28 ±0.02	0.35 ±0.23	3.06 ±3.06	3.51 ±0.14	1.01 ±0.14	0.47 ±0.01	11.32 ±1.38	12.05 ±0.42	2.64 ±0.90	0.21 ±0.01	0.47 ±0.14
Penpe	1.29 ±0.11	2.18 ±6.61	0.12 ±0.05	0.12 ±0.01	0.15 ±0.03	0.14 ±0.09	13.23 ±2.84	1.65 ±0.17	0.30 ±0.02	0.28 ±0.01	0.32 ±0.02	2.77 ±2.83	3.44 ±0.06	0.99 ±0.13	0.48 ±0.03	13.47 ±3.88	14.12 ±3.44	3.26 ±0.12	0.21 ±0.00	0.80 ±0.04
Sabo	2.02 ±0.67	3.45 ±1.15	0.20 ±0.03	0.21 ±0.03	0.22 ±0.03	0.22 ±0.01	8.75 ±1.43	2.93 ±0.00	0.49 ±0.09	0.48 ±0.12	0.57 ±0.23	5.08 ±1.48	5.73 ±0.02	1.62 ±0.30	1.02± 0.34	17.92 ±1.05	22.60 ±2.34	4.79 ±1.62	0.34 ±0.07	0.88 ±0.14
	^{88}Y	^{192}Ir	^{131}I	^{144}Ce	^{192}Ir															
Ijaiye	0.22 ±0.01	0.33 ±0.08	6.48 ±0.06	1.97 ±0.35	0.29 ±0.05															

ND = Not Detected

Table 4.3: Activity Concentrations (Bq l^{-1}) of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac in the well water samples

Locations	^{40}K	^{214}Bi	^{214}Pb	^{226}Ra	^{228}Ac
Abeokuta Rd.	3.28±0.10	0.61±0.08	0.48±0.34	3.88±1.17	0.72±0.16
Awujale	3.26±0.94	0.80±0.28	0.97±0.59	7.79±7.22	0.20±0.48
Fidipote	3.53±1.93	0.50±0.09	0.80±0.12	3.26±0.30	0.72±0.49
Ita Osun	3.03±0.48	0.52±0.19	0.63±0.02	4.69±1.10	0.79±0.39
Molipa	3.00±3.32	1.14±0.55	0.38±0.09	3.79±0.61	0.59±0.14
Oyingbo	2.48±3.15	0.36±0.25	0.36±0.16	3.98±1.17	0.58±0.11
Saboij	1.74±1.82	0.23±0.08	0.27±0.05	2.89±0.62	0.42±0.22
Ake	4.69±0.17	0.88±0.67	1.33±1.38	7.45±1.13	1.17±0.40
Ibara	1.76±1.25	0.24±0.10	0.27±0.10	3.14±1.64	0.37±0.03
Elega	2.05±1.07	0.31±0.17	0.32±0.04	3.49±0.14	0.50±0.19
Ijaiye	3.89±5.29	ND	ND	ND	ND
Ita Osin	2.85±0.63	0.66±0.22	0.64±0.28	4.18±0.18	0.58±0.12
Kenta	1.97±2.75	0.24±0.12	0.27±0.11	2.91±1.09	0.34±0.07
Totoro	3.71±0.05	0.41±0.20	31.14±6.23	5.55±1.08	0.75±0.10
Alagbon	3.21±0.81	0.61±0.10	0.82±0.08	7.05±2.11	0.70±0.60
Alapara	2.80±0.60	0.45±0.02	0.95±0.15	5.00±2.10	0.59±0.38
Elekute	3.31±4.00	0.44±0.35	0.46±0.16	4.48±0.34	0.60±0.02
Isaga	2.00±1.76	0.28±0.02	0.35±0.23	3.51±0.14	0.47±0.01
Penpe	2.18±6.61	0.28±0.01	0.32±0.02	3.44±0.06	0.48±0.03
Saboab	3.45±1.15	0.48±0.12	0.57±0.23	5.73±0.02	1.02±0.34
Minimum	1.74±1.82	0.23±0.08	0.27±0.05	2.89±0.62	0.20±0.48
Maximum	4.69±0.17	1.14±0.55	31.14±6.23	7.79±7.22	1.17±0.40
Average	2.98±1.90	2.21±0.18	2.10±0.53	4.47±1.13	0.62±0.24

ND = Not Detected

The activity concentrations of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac ranged from 1.74±1.82 to 4.69±0.17, 0.23±0.08 to 1.14±0.55, 0.27±0.05 to 31.14±6.23, 2.89±0.62 to 7.79±7.22 and 0.20±0.48 to 1.17±0.40 Bq l^{-1} respectively. While the mean values are; 2.98±1.90, 2.21±0.18, 2.10±0.53, 4.47±1.13 and 0.62±0.24 Bq l^{-1} respectively. Activity concentrations of; ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac were not detected above background level in Ijaiye sample. The table shows that ^{226}Ra has the highest mean activity concentration value (4.47±1.13 Bq l^{-1}), while ^{228}Ac had the least value (0.62±0.24 Bq l^{-1}).

Table 4.4: Comparison of measured activity concentrations (Bq l^{-1}) of ^{226}Ra in well waters of Ogun State with other countries.

Country	^{226}Ra	
	Min	**Max**
USA	4×10^{-4}	1.8×10^{-3}
China	2×10^{-4}	0.12
Finland	1×10^{-2}	49
France	7×10^{-3}	0.7
Germany	1×10^{-3}	1.8
Italy	2×10^{-4}	1.2
Romania	7×10^{-4}	0.021
Switzerland	0	1.5
Spain	2×10^{-2}	4
UK	0	0.18
Nigeria (This study)	2.89	7.79

Data for other countries was obtained from UNSCEAR 2000 report.

Table 4.4 shows that the activity concentration of ^{226}Ra (7.79 Bq l^{-1}) in the measured well waters of Ogun State is higher than that reported by other countries with the exception of Finland with a maximum activity concentration of 49 Bq l^{-1}.

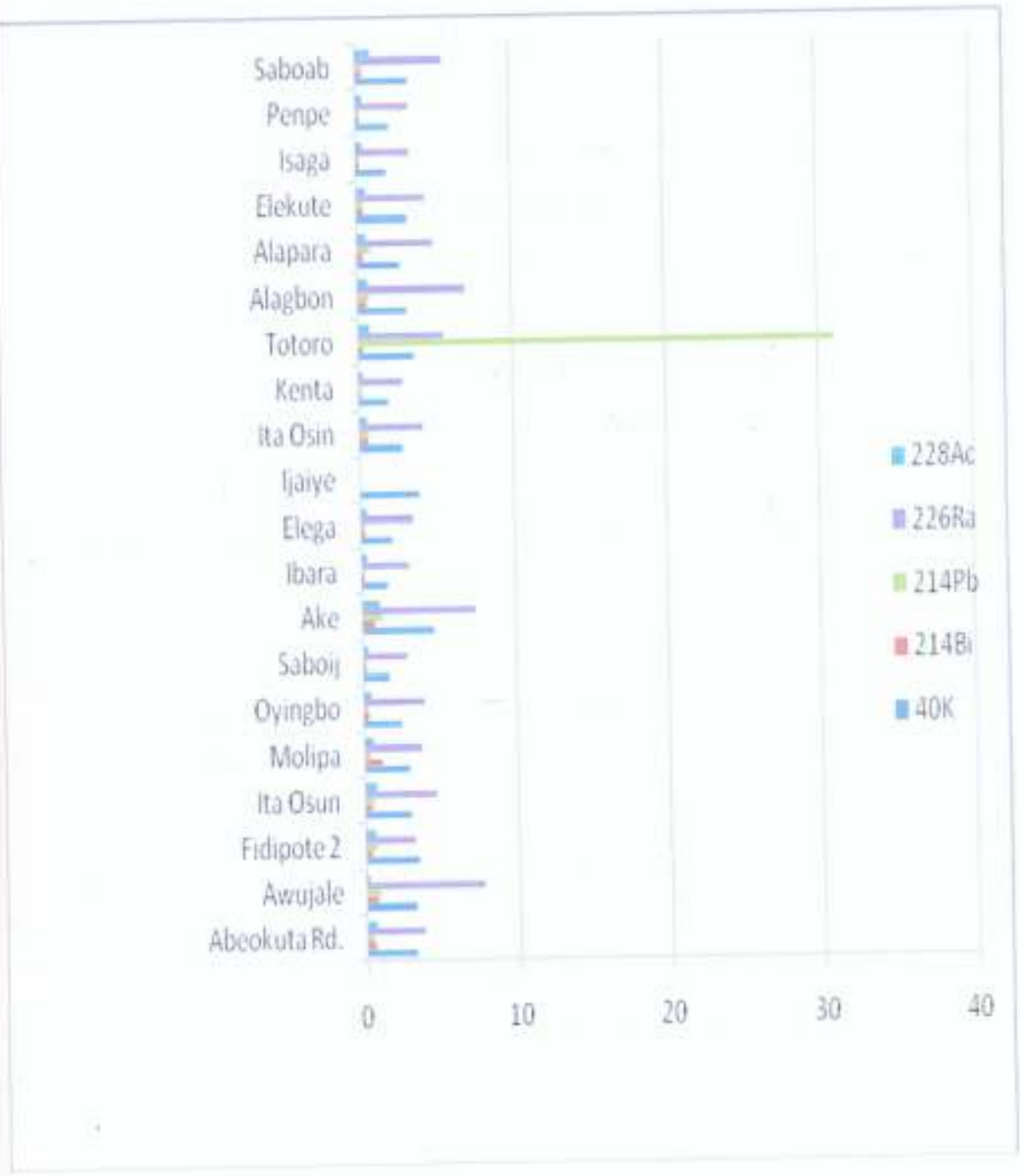

Figure 4.2: Bar chart showing the measured activity concentrations (Bq l^{-1}) of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac in drilled and dug well waters of Ogun State.

Figure 4.2 show that ^{226}Ra had the highest activity concentration in all the samples with the exception of the sample from Totoro (where ^{214}Pb had the highest value) and Ijaiye where ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac were not detected. The high level of ^{226}Ra in the measured well water samples is attributable to the high level of chloride (Cl^{-1}) content in the samples (Table 4.1), since radium is most rich in Cl-rich reducing ground water (Tanner, 1964).

Table 4.5: Activity concentrations (Bq l^{-1}) of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac in Abeokuta well water samples

Locations	Type of well	^{40}K	^{214}Bi	^{214}Pb	^{226}Ra	^{228}Ac
Ake	Drilled	4.69±0.17	0.88±0.67	1.33±1.38	7.45±1.13	1.17±0.40
Ibara	Drilled	1.76±1.25	0.24±0.10	0.27±0.10	3.14±1.64	0.37±0.03
Elega	Dug	2.05±1.07	0.31±0.17	0.32±0.04	3.49±0.14	0.50±0.19
Ijaiye	Dug	3.89±5.29	ND	ND	ND	ND
Ita osin	Dug	2.85±0.63	0.66±0.22	0.64±0.28	4.18±0.18	0.58±0.12
Kenta	Dug	1.97±2.75	0.24±0.12	0.27±0.11	2.91±1.09	0.34±0.07
Totoro	Dug	3.71±0.05	0.41±0.20	31.14±6.23	5.55±1.08	0.75±0.10
Mean		2.99±1.60	0.39±0.25	4.85±1.36	3.82±0.88	0.53±0.15

Table 4.5 shows that ^{214}Bi (0.39 ± 0.25 Bq l^{-1}) has the least value in Abeokuta well water samples while ^{214}Pb (4.85±1.36Bq l^{-1}) has the highest activity concentration. However, radionuclides belonging to the decay series of ^{238}U (^{214}Bi, ^{214}Pb, and ^{226}Ra) and ^{232}Th (^{228}Ac) was not detected in the sample from Ijaiye rather ^{88}Y, ^{103}Ru, ^{131}I, ^{144}Ce and ^{192}Ir were detected in it. The high content of ^{214}Pb in Abeokuta may be due to the presence of uranium-bearing minerals in the granite rock underlying the area (Oshin and Rahaman, 1985).

Table 4.6: Activity concentrations (Bq l^{-1}) of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac in Ijebu Ode well water samples

Location	Type of Well	^{40}K	^{214}Bi	^{214}Pb	^{226}Ra	^{228}Ac
Abeokuta Rd	Drilled	3.28±0.10	0.61±0.08	0.48±0.34	3.88±1.17	0.72±0.16
Awujale	"	3.26±0.94	0.80±0.28	0.97±0.59	7.79±7.22	0.20±0.48
Fidipote 2	"	3.53±1.93	0.50±0.09	0.80±0.12	3.26±0.30	0.72±0.49
Ita Osun	"	3.03±0.48	0.52±0.19	0.63±0.02	4.69±1.10	0.79±0.39
Molipa	"	3.00±3.32	1.14±0.55	0.38±0.09	3.79±0.61	0.59±0.14
Oyingbo	"	2.48±3.15	0.36±0.25	0.36±0.16	3.98±1.17	0.58±0.11
Sabo	"	1.74±1.82	0.23±0.08	0.27±0.05	2.89±0.62	0.42±0.22
Mean		2.90±1.73	0.59±0.20	0.56±0.20	4.33±1.56	0.57±0.31

The activity concentrations of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac,ranged from 1.74±1.82 to 3.53±1.93, 0.23±0.08 to 1.14±0.55, 0.27±0.05 to 0.97±0.59, 2.89±0.62 to 7.79±7.22 and 0.20±0.48 to 0.79±0.39 Bq l^{-1} respectively in Table 4.6. Hence, ^{226}Ra (4.33±1.56 Bq l^{-1}) has the highest activity while ^{214}Pb (0.56±0.20 Bq l^{-1}) has the least activity.

Table 4.7: Activity concentrations (Bq l^{-1}) of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac in Idiroko well water samples

Locations	Type of Well	^{40}K	^{214}Bi	^{214}Pb	^{226}Ra	^{228}Ac
Alagbon	Dug	3.21±0.81	0.61±0.10	0.82±0.08	7.05±2.11	0.70±0.60
Alapara	"	2.80±0.60	0.45±0.02	0.95±0.15	5.00±2.10	0.59±0.38
Elekute	"	3.31±4.00	0.44±0.35	0.46±0.16	4.48±0.34	0.60±0.02
Isaga	"	2.00±1.76	0.28±0.02	0.35±0.23	3.51±0.14	0.47±0.01
Penpe	"	2.18±6.61	0.28±0.01	0.32±0.02	3.44±0.06	0.48±0.03
Sabo	"	3.45±1.15	0.48±0.12	0.57±0.23	5.73±0.02	1.02±0.34
Mean		2.83±2.49	0.42±0.10	0.57±0.15	4.86±0.80	0.64±0.23

Table 4.7 shows that ^{214}Bi (0.42±0.10 Bq l^{-1}) has the least activity while ^{226}Ra (4.86±0.80 Bq l^{-1}) has the highest activity. The varying activity concentrations of ^{214}Bi, ^{214}Pb and ^{226}Ra (all belonging to ^{238}U decay series) in Idiroko imply that parent and daughter radionuclides in well water are not usually found together in similar amounts (Gilkeson et al. 1983).

Figure 4.3: Bar Chart showing the activity concentrations (Bq l^{-1}) of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac in the three selected cities

Figure 4.3 show that Abeokuta has the highest activity concentration of ^{40}K while Idiroko has the least value. Also, Abeokuta has the highest value of ^{214}Pb while Ijebu Ode and Idiroko have the same concentrations. The concentration of ^{214}Bi is highest in Ijebu Ode and least in Abeokuta. Idiroko has the highest activity concentrations of ^{226}Ra and ^{228}Ac while Abeokuta has the least values of ^{226}Ra and ^{228}Ac. In summary, Abeokuta is most rich in ^{40}K and ^{214}Pb; Idiroko is most rich in ^{226}Ra and ^{228}Ac while Ijebu Ode is most rich in ^{214}Bi. Thus, a high concentration of one radionuclide in well water at a specific site does not necessarily imply that similar concentrations of other radionuclides in the same decay series are present (Gilkeson et al. 1983).

4.3 Specifications of the wells

All the wells samples have cylindrical shape. Hence,

Volume of water in well = $\pi r^2 h$

Where, π = 3.142

r = radius of ring for dug well or radius of hole for drilled well

h = height of water in the well

Inner diameter of ring = 0.78m

Inner radius of ring = 0.39m

Diameter of hole = 15cm = 0.15m

Radius of hole = 0.075m

Table 4.8: Specifications of wells

Locations	Type of Well	Depth of well (m)	Level of water in the well (m)	Volume of water in the well (m^3)
Ijebu Ode	Drilled	48.0 – 54.0	12.0	0.21
Abeokuta	"	27.0 – 33.0	12.0	0.21
"	Dug	4.5 – 14.4	3.6	1.72
Idiroko	"	9.0 – 15.0	3.2	1.53

Table 4.8 shows that Abeokuta dug wells have the largest volume of water, followed by Idiroko dug wells while Ijebu Ode and Abeokuta drilled wells have the same volume of water.

Conclusively, dug wells are said to have larger volume of water than drilled wells, this is due to the fact that the radius of dug wells are greater than that of drilled well.

Table 4.9: Dose Conversion Factor E_D, for members of the public (IAEA, 1996).

Category	Radionuclides	Dose Conversion Factor E_D (Sv Bq^{-1})		
		Ages (2-7) y	Ages (12-17) y	Ages (>17y)
Natural Uranium series	^{238}U	8.0×10^{-8}	6.7×10^{-8}	4.5×10^{-8}
	^{226}Ra	6.2×10^{-7}	1.5×10^{-6}	2.8×10^{-7}
	^{214}Bi	3.6×10^{-10}	1.4×10^{-10}	1.1×10^{-10}
	^{214}Pb	5.2×10^{-10}	2.0×10^{-10}	1.4×10^{-10}
NATURAL Thorium series	^{232}Th	3.5×10^{-7}	2.5×10^{-7}	2.3×10^{-7}
	^{228}Ra	3.4×10^{-6}	5.3×10^{-6}	6.9×10^{-7}
	^{228}Ac	1.4×10^{-9}	5.3×10^{-10}	4.3×10^{-10}
Other radionuclide	^{40}K	2.1×10^{-8}	7.6×10^{-9}	6.2×10^{-9}

Table 4.10: Annual water consumption values, I_F (IAEA, 1996)

Age group (y)	Water consumption (l y^{-1})
0-1	200
1-2	260
2-7	300
7-12	350
12-17	600
>17	730

Table 4.11: Annual effective dose due to the intake of natural radionuclides (μSv y^{-1}) of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac for ages (2-7) y.

Locations	^{40}K	^{214}Bi	^{214}Pb	^{226}Ra	^{228}Ac	Total dose
Abeokuta Rd.	20.66±0.63	0.07±0.01	0.07±0.05	721.68±217.62	0.03±0.07	746.19±218.38
Awujale	20.54±5.92	0.09±0.03	0.15±0.09	1448.94±1342.92	0.08±0.20	1469.80±1349.16
Fidipote	22.24±12.16	0.05±0.01	0.12±0.02	606.36±55.80	0.30±0.21	629.07±68.20
Ita Osun	19.09±3.02	0.06±0.02	0.10±0.00	872.34±204.60	0.33±0.16	891.92±207.80
Molipa	18.90±20.92	0.12±0.06	0.06±0.01	704.94±113.46	0.25±0.06	724.27±134.51
Oyingbo	15.62±19.85	0.04±0.03	0.06±0.02	740.28±217.62	0.24±0.05	756.24±237.57
Sabosj	10.96±11.47	0.02±0.01	0.04±0.01	537.54±115.32	0.18±0.09	548.74±126.90
Ake	29.55±1.07	0.10±0.07	0.21±0.22	1385.70±210.18	0.49±0.17	1416.05±211.71
Ibara	11.09±7.89	0.03±0.01	0.04±0.02	584.04±305.04	0.16±0.01	595.36±305.08
Elega	12.91±6.74	0.03±0.02	0.05±0.01	649.14±26.04	0.21±0.08	662.34±32.89
Ijaiye	24.51±33.33	-	-	-	-	24.51±33.33
Ita Osin	17.96±3.97	0.07±0.02	0.10±0.04	777.48±33.48	0.24±0.05	802.40±66.92
Kenta	12.41±17.33	0.03±0.01	0.04±0.02	541.26±202.74	0.14±0.03	559.43±206.77
Totoro	23.37±0.32	0.04±0.02	4.86±0.97	1032.30±200.88	0.32±0.04	1049.93±219.24
Alagbon	20.22±5.10	0.07±0.01	0.13±0.01	1311.30±392.46	0.29±0.25	1335.16±393.05
Alapara	20.85±25.20	0.05±0.00	0.15±0.02	930.00±390.60	0.25±0.16	950.67±395.88
Elekute	12.60±11.09	0.05±0.04	0.07±0.02	833.28±63.24	0.25±0.01	854.50±88.51
Isaga	13.73±41.64	0.03±0.00	0.05±0.04	652.86±26.04	0.20±0.00	665.74±37.17
Penpe	12.73±4.22	0.03±0.00	0.05±0.00	639.84±11.16	0.20±0.01	653.85±52.81
Saboab	21.74±7.25	0.05±0.01	0.09±0.04	1065.98±3.72	0.43±0.14	1079.28±3.92
Average	18.25±11.96	0.05±0.02	0.32±0.08	801.77±206.65	0.23±0.09	821.93±219.49

Table 4.12: Annual effective dose due to the intake of natural radionuclides (μSv y^{-1}) of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac for ages (12-17) y.

Locations	^{40}K	^{214}Bi	^{214}Pb	^{226}Ra	^{228}Ac	Total dose
Abeokuta Rd.	14.96±0.46	0.05±0.01	0.06±0.04	3492.00±1053.00	0.23±0.05	3507.30±1053.56
Awujale	14.87±4.29	0.07±0.02	0.12±0.07	7011.00±6498.00	0.06±0.15	7026.12±6502.53
Fidipote	16.10±8.80	0.04±0.01	0.10±0.01	2934.00±270.00	0.23±0.16	2950.47±278.98
Ita Osun	13.82±2.19	0.08±0.00	0.08±0.00	4221.00±990.00	0.25±0.12	4235.19 ±992.33
Molipa	13.68±15.14	0.05±0.01	0.05±0.01	3411.00±549.00	0.19±0.04	3425.02±564.24
Oyingbo	11.31±14.36	0.03±0.02	0.04±0.02	3582.00±1053.00	0.18±0.03	3593.56±1067.43
Saboij	7.93±8.30	0.02±0.01	0.03±0.01	2601.00±558.00	0.13±0.07	2609.11±566.39
Ake	21.39±0.78	0.07±0.06	0.16±0.17	6705.00±1017.00	0.37±0.13	6726.99±1018.14
Ibara	8.03±5.70	0.02±0.01	0.03±0.01	2826.00±1476.00	0.12±0.01	2834.20±1481.73
Elega	9.35±4.88	0.03±0.01	0.04±0.00	3141.00±126.00	0.16±0.06	3150.58±130.95
Ijaiye	17.74±24.12	-	-	-	-	17.74±24.12
Ita Osin	13.00±2.87	0.06±0.02	0.08±0.03	3762.00±162.00	0.18±0.04	3775.32±164.96
Kenta	8.98±12.54	0.02±0.01	0.03±0.01	2619.00±981.00	0.11±0.02	2628.14±993.58
Totoro	16.92±0.23	0.03±0.02	3.74±0.75	4995.00±972.00	0.24±0.03	5015.93±973.08
Alagbon	14.64±3.69	0.05±0.01	0.10±0.01	6345.00±1899.00	0.22±0.19	6360.01±1902.90
Alapara	12.77±2.74	0.04±0.00	0.11±0.02	4500.00±1890.00	0.19±0.12	4513.11±1892.88
Elekute	15.09±18.24	0.04±0.03	0.06±0.02	4032.00±306.00	0.19±0.12	4047.38±324.30
Isaga	9.12±8.03	0.02±0.00	0.04±0.03	3159.00±162.00	0.15±0.00	3168.33±170.06
Pempe	9.94±30.14	0.02±0.00	0.04±0.00	3096.00±54.00	0.15±0.01	3106.20±84.15
Saboab	15.73±5.24	0.04±0.01	0.07±0.03	5157.00±18.00	0.32±0.11	5173.16±23.39
Average	13.27±8.64	0.04±0.01	0.25±0.06	3879.45±1001.70	0.18±0.07	3893.20±1010.49

Table 4.13: Annual effective dose due to the intake of natural radionuclides (μSv y^{-1}) of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac for ages >17y.

Locations	^{40}K	^{214}Bi	^{214}Pb	^{226}Ra	^{228}Ac	Total dose
Abeokuta Rd.	17.28±0.45	0.05±0.01	0.05±0.03	793.07±239.15	0.23±0.05	810.68±239.69
Awujale	14.75±4.25	0.06±0.02	0.10±0.06	1592.28±1475.77	0.06±0.15	1607.25±1480.25
Fidipote	15.98±8.74	0.04±0.01	0.08±0.01	666.34±61.32	0.23±0.15	682.67±70.23
Ita Osun	13.71±2.17	0.04±0.02	0.06±0.00	958.64±224.64	0.25±0.12	972.70±227.15
Molipa	13.58±15.03	0.09±0.04	0.04±0.01	774.68±124.68	0.19±0.04	788.58±139.80
Oyingbo	11.22±14.26	0.03±0.02	0.04±0.02	813.51±239.15	0.18±0.03	824.98±253.48
Saboij	7.74±8.24	0.02±0.01	0.03±0.01	590.72±126.73	0.13±0.07	598.64±135.06
Ake	21.23 ±0.77	0.07±0.05	0.14±0.14	1522.78±230.97	0.37±0.13	1544.59±232.06
Ibara	7.97±5.66	0.02±0.01	0.03±0.01	641.82±335.22	0.12±0.01	649.96±340.91
Elega	9.28±4.84	0.02±0.01	0.03±0.00	713.36±28.62	0.17±0.06	722.86±33.53
Ijaiye	17.61±23.94	-	-	-	-	17.61±23.94
Ita Osin	12.90±2.85	0.05±0.02	0.07±0.03	854.39±36.79	0.18±0.04	867.59±39.73
Kenta	8.92±12.45	0.02±0.01	0.03±0.01	594.80±222.80	0.11±0.02	603.88±235.29
Totoro	16.79±0.23	0.03±0.02	3.18±0.64	1134.42±220.75	0.24±0.03	1154.66±221.67
Alagbon	14.53±3.67	0.05±0.01	0.08±0.01	1441.02±431.28	0.22±0.19	1455.90±435.16
Alapara	12.67±2.72	0.04±0.00	0.10±0.02	1022.00±429.24	0.19±0.12	1035.00±432.00
Elekute	14.98±18.10	0.04±0.03	0.05±0.02	915.71±69.50	0.19±0.01	930.97±87.66
Isaga	9.05±7.97	0.02±0.00	0.04±0.02	717.44±28.62	0.15±0.00	726.70±36.61
Penpe	9.87±29.92	0.02±0.00	0.03±0.00	703.14±12.26	0.15±0.01	713.21±42.19
Saboab	15.61±5.20	0.04±0.01	0.06±0.02	1171.21±4.09	0.32±0.11	1187.24±9.43
Average	13.28±8.57	0.04±0.02	0.21±0.05	881.07±227.08	0.18±0.07	894.78±235.79

4.4 Annual effective dose results

The results of the calculated age-dependent annual effective dose are summarized in Table 4.11, 4.12 and 4.13 for ages 2-7, 12-17 and >17y respectively. The results show that ^{226}Ra contributed the highest value to the annual effective doses for the three age groups. It contributed 801.77±206.65 (97.5% of total dose); 3879.45±1001.70 (99.6% of total dose) and 881.07±227.08 (98.5% of total dose) for ages 2-7, 12-17 and >17y respectively. The high value of ^{226}Ra is due to its conversion factor (Table 4.9) and also to its high activity concentrations in the measured well water samples (Table 4.3)

Table 4.14: Total annual effective dose (mSv y^{-1}) for ages; 2-7, 12-17 and >17y

Locations	City	Ages (2-7) y	Ages (12-17) y	Ages >17y
Abeokuta Rd.	Ijebu Ode	0.76	3.51	0.81
Awujale	"	1.47	7.03	1.61
Fidipote	"	0.63	2.95	0.68
Ita Osun	"	0.89	4.24	0.97
Molipa	"	0.72	3.43	0.79
Oyingbo	"	0.76	3.59	0.82
Saboij	"	0.55	2.61	0.60
Ake	Abeokuta	1.42	6.73	1.54
Ibara	"	0.60	2.83	0.65
Elega	"	0.66	3.15	0.72
Ijaiye	"	0.02	0.02	0.02
Ita Osun	"	0.80	3.78	0.87
Kenta	"	0.55	2.63	0.60
Totoro	"	1.05	5.02	1.15
Alagbon	Idiroko	1.33	6.36	1.46
Alapara	"	0.95	4.51	1.04
Elekute	"	0.85	4.05	0.93
Isaga	"	0.67	3.17	0.73
Penpe	"	0.65	3.11	0.71
Saboab	"	1.08	5.17	1.19
Average		0.82	3.89	0.89

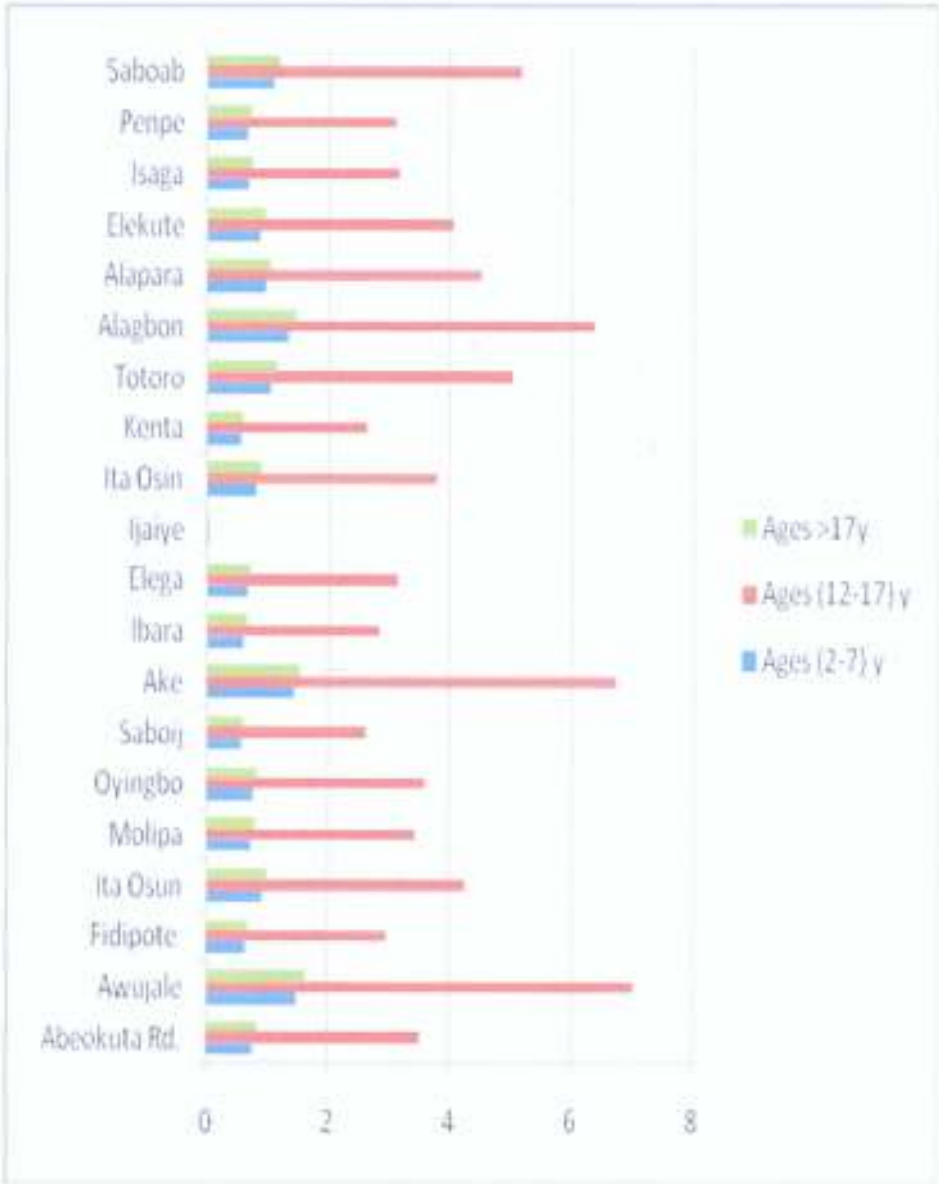

Figure 4.4: Bar chart showing the total annual effective doses (mSv y^{-1}) for ages; 2-7, 12-17 and >17y

The bar chart of Figure 4.4 shows that the age group 12-17y has the highest total annual effective doses while age group >17y has the least doses. Also, Table 4.14 shows that the total annual effective doses for the three age groups with mean values 0.82, 3.89 and 0.89 mSv y^{-1} exceeded the 0.1 mSv y^{-1} limit set by the WHO in all samples except Ijaiye.

Table 4.15: Committed effective dose (Sv) for ages; 2-7, 12-17 and >17y

Locations	City	Ages (2-7) yrs	Ages (12-17) y	Ages >17y
Abeokuta Rd.	Ijebu Ode	0.038	0.176	0.041
Awujale	"	0.074	0.352	0.081
Fidipote	"	0.032	0.148	0.034
Ita Osun	"	0.045	0.212	0.049
Molipa	"	0.036	0.172	0.040
Oyingbo	"	0.038	0.180	0.041
Saboij	"	0.028	0.131	0.030
Ake	Abeokuta	0.071	0.337	0.077
Ibara	"	0.030	0.142	0.033
Elega	"	0.033	0.158	0.036
Ijaiye	"	0.001	0.001	0.001
Ita Osin	"	0.040	0.189	0.044
Kenta	"	0.028	0.132	0.030
Totoro	"	0.053	0.251	0.058
Alagbon	Idiroko	0.067	0.318	0.073
Alapara	"	0.048	0.226	0.052
Elekute	"	0.043	0.203	0.047
Isaga	"	0.034	0.159	0.037
Penpe	"	0.033	0.156	0.036
Saboab	"	0.054	0.259	0.060
Average		0.041	0.195	0.045

The committed effective dose for the three age groups is shown in Table 4.15. It ranged from 0.001 to 0.074 Sv; 0.001 to 0.352 Sv and 0.001 to 0.077 Sv for ages 2-7, 12- 17 and >17y respectively, with a mean of 0.041, 0.195 and 0.045 Sv for ages 2-7; 12-17 and >17y respectively.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Natural radioactivity was measured in the drilled and dug well water of Ogun State using gamma ray spectroscopy. Natural occurring radionuclides of ^{40}K (non-decay series), ^{214}Bi, ^{214}Pb and ^{226}Ra of the ^{238}U decay series and ^{228}Ac of the ^{232}Th decay series were detected in all samples except Ijaiye.

The mean activity concentration of ^{226}Ra with a mean value 4.47 Bq l^{-1} exceeded the values recommended by WHO (1993) current guidelines and United States Environmental Protection Agency (USEPA) (USEPA, 2000) which are; 1Bq l^{-1} and 0.185Bq l^{-1} respectively.

The total dose due to the ingestion of natural radionuclides of ^{40}K, ^{214}Bi, ^{214}Pb, ^{226}Ra and ^{228}Ac for ages 2-7yrs, 12-17yrs and adults are found to be above 0.1mSv y^{-1} of WHO recommended limit for radiological safe drinking water in all samples except Ijaiye.

This study also established the high activity concentration of ^{214}Pb in Totoro, Abeokuta.

5.2 RECOMMENDATIONS

It is recommended that all drinking waters (bottled and sachet inclusive) in Nigeria should be tested for radiological safety before drinking because research had shown that all water sources contains radionuclides (Zapecza and Szabo, 1986) and these radionuclides no matter how minute in drinking water when ingested, are harmful (UNSCEAR, 2000).

It was also suggested that these wells should be treated to remove radium to reduce the chances of people drinking from these wells from being prone to cancer and other radiation-induced diseases. It is also necessary to survey sources of drinking water in other states of the federation.

REFERENCES

Ayayi, M.A, Allen, V.O. and Olatunji, G.O.(2001): Publication of resources and management services of Ogun State. 01:1-3.

Ajayi O.S. and Owolabi, T.P. (2007): Determination of drinking water private dug wells Akure, Southwestern Radiation protection Dosimetry 128:477-484.

Alam, M.N., Chowdhry, M.I., Kamal, M., Ghose, S., Islam, M.N. and Awaruddin, M., (1999). Radiological assessment of drinking water of the Chittagong region of Bangladesh. Radiat. Prot. Dosim. 82: 207-214.

Al-Masri, M.S. and Blackburn, R. (1995). Application of Cerenkov Radiation for the Assay of Radium-226 in Natural Water. Sci. Total Environ. 173: 53-59.

Alvarado, J.S., Orlandini, K.A. and Erickson, M.D. (1995). Rapid Determination of Radium Isotopes by Alpha Spectrometry. J. Radioanal. Nucl. Chem. 194 (1): 163-172.

Awodugba A.O. and Tchokossa P. (2008). Assessment of Radionuclides Concentrations in Water Supply from Boreholes in Ogbomosoland, Western Nigeria. Indoor and Built Environment, 17(2): 183-186

Baratta, E.J. (1990). "Radon, Radium and Uranium in Drinking Water". In (Cothern, C.R. and Rebers, D.A.. eds.) Radon, Radium and Uranium in Drinking Water Lewis Publishers, Washington DC

Belloni, P., Cavaioli, M., Ingrao, G., Mancini, C., Notaro, M., Santaroni, P., Torri, G. and Vasselli, R. (1995). Optimization and Comparison of Three Different Methods for Determination of ^{222}Rn in Water. Sci. Total Environ.173: 67- 69.

Ben Fredj A., Hizem N., Chelbi M., Ghedira L. (2005). Quantitative Analysis of Gamma-ray Emitters Radioisotopes in Commercialized Bottled Water in Tunisia. Radiation Protection Dosimetry. 117: 410 – 424.

Bennet, B.G., (1993). "World wide Exposures to Ionizing Radiation" in: Proceedings of Asia Congress on Radiation Protection, pp.21 (Beijing 1993).

Bennet, B.G., (1994). "New UNSCEAR Report", Radiological Prot. Bulletin No. 149.

Brinck, W.L., Schliekelman, R.J., Bennett, D.L., (1978). Radium removal efficiencies in water treatment processes: American Water Works Association Journal, 70(1), pp, 31-35.

Cevik U., Damla N., Karahan G., Celebi N. and Kobya I.(2005). Natural Radioactivity in Tap waters of Eastern Black Sea Region of Turkey. Radiation Protection Dosimetry. 118: 88-92.

Corriea, J.A., Weise, S.B., Callahan, R.J. and Strauss, H.W. (1987). The kinetics of Ingested ^{222}Rn in Humans Determined from Measurement with ^{133}Xe. Cooperative Agreement USEPA, Health Effects Research Laboratories. Cincinnati.

Cothern, R.C. Lappenbusch, W. L. and Cotruvo, J.A. (1983). Health Effects Guidance for Uranium in Drinking Water "Health Physics 44: 377-384.

Crawford-Brown, D.J. (1990). Analysis of health Risk from Ingested Radon. Lewis Publishers, Washington DC p 203-212.

Eisenbud, M., (1987). Environmental Radioactivity. Academic Press Orlando.

European Commission Directive,(1998). On the quality of water intended for human consumption, EC Directive 98/83EC. OJL 330, 05/12/98.

Fatima I., Zaidi J.H., Arif M. and Tahir S.N.A.(2006). Measurement of Natural Radioactivity in Bottled Drinking Water in Pakistan and Consequent Dose Estimates. Radiation Protection Dosimetry 123:234-240.

Fisenne, I.M., (1993). "Long Lived Radionuclides in the Environment, in Food and in Human Beings". In: Fifth International Symposium on Natural Radiation Environment, Tutorial sessions,

Fujita, M., Iwamoto, J. and Kondo, M., (1996). Comparative metabolism of cesium and potassium in mammals-interspecies correlation between body weight and equilibrium level. Health Physics 12: 1237-1248.

Gilkeson, R.H., Cartwright, Keros, Cowart, J.B. and Holtzman, R.B. (1983), Hydrogeologic and geochemical studies of selected natural radioisotopes and barium in groundwater in Illinois: Illinois Department of Energy and Natural Resources report

Hahn, N.A., (1984). Radium in Winsconsin Department of Natural Resources report, pp.125.

ICRP (1991). Recommendations of the International Commission on Radiological Protection. Annals of the ICRP-60. Pergamon Press.Oxford. 200pp.

ICRP, (1996). Age dependent dose to members of public from intake of radionuclides ICRP, Publication 72 (Oxford: Pergamon Press).

Institute for Water Quality Studies, (2002). Radioactivity dose calculation and water quality evaluation guideline for domestic water use.

International Atomic Energy Agency (IAEA), (1996). Basic Safety Standards. No. 15

International Commission on Radiation Protection (ICRP), (1976). Reference Man: Anatomical, Physiological, and Metabolic Characteristics. Pergamon Pres, Oxford, UK.

Kathren, R.L., (1984). Radioactivity in the Environment: Sources, Distribution, and Surveillance (Harwood Academic Publishers, Chur, Switzerland)

Langmuir, Donald, (1978). Uranium solution-mineral equilibra at low temperatures with applications to sedimentary ore deposits: Geochimica et Cosmochimica Acta, v 42: 547-569.

Lan, C.Y. and Weng, P.S., (1989). Body K and ^{40}K in Chinese Subjects Measured with a Whole-Body Counter, Health Physics 57: 743-746.

Lowry, J.D. and Lowry, Sylvia, (1987). Techniques and economics of radon removal from water supplies . Conference on radon and the environment, Institute for Environmental Studies, pp. 96-101.

Menetrez, M.Y., and Watson, J.E., (1983). Natural radioactivity in North Carolina ground water supplies: University of North Carolina, Water Resources Research Institute Report 208, pp.30.

Milla, W.A. (1990) Risk Assessment and control Management of Radon in Drinking Water. In : (Cothern, C.R. and Rebers, P. eds.) Radon, Radium and Uranium in Drinking Water. Lewis publishers, Washington D.C pp 27-37.

Milvy, P. and Cothern, C.R. (1990). "Scientific Background for Development of Regulations for Radionuclides in Drinking Water"

Onoja, R.A., (2004). M.Sc. Thesis Titled "Survey of gross alpha and gross beta radioactivity in well water from Zaria area", Centre for Energy Research and Training, Ahmadu Bello University, Zaria. 2004. p 203-212.

Oshin, I.O. and Rahaman, M.A. Uranium favourability studies in Nigeria. J. Afr. Earth Sci. (5), 167-175 (1985).

Porstendorfer, J. (1993). Properties and Behaviour of Radon and Thoron and Their Decay Products in the Air. In: Fifth International Symposium on Natural Radiation Environment, Tutorial sessions, pp. 69-150.

Reid, G.W., Lassovszky, Peter, and Hathaway, Steven, (1985). Treatment, waste management and cost for removal of radioactivity from drinking water: Health Physics, 5: 671-694.

Sabol, J. and Weng, P.S. (1995). Introduction to Radiation Protection Dosimetry. World Scientific Publishing Co. Pte. Ltd.

Solley, W.B., Chasse, E.B., and Mann, W.B., 1983, Estimated use of water in the United States in 1980: U.S. Geological Survey Circular 1001,56 p.

Surbeck, H. (1995). Determination of Natural Radionuclides in Drinking Water: A Tentative Protocol. Sci. Total Environ. 173: 91-99.

Szabo, Zoltan, and Zapecza, O.S., (1987), Relation between natural radionuclide activities and chemical constituents in ground water in the Newark Basin, New Jersey, in Graves, Barbara, ed., Radon in ground water- Hydrogeologic impart and indoor air contamination (Conference on radon, radium, and other radioactivity in ground water –Hyrogeologic impart and application to indoor airborne contamination, Somerset, N.J., April 7-9 1987): Chelsa, Milch., Lewis Publishers Inc., pp. 283-308

Tanner, A.B., (1964). Physical and chemical controls on disribution of radium-226 and radon-222 in ground water near Great salt Lake, Utah, in Adams, J.A.S., and Lowder, W.M., eds., The

natural radiation environment: Chicago, III., University of Chicago Press, pp. 253-278.

Tchokossa P., Olomo J.B., Osibote O.A.(1999). Radioactivity in the community water supplies of Ife-Central and Ife-East local government areas of Osun State, Nigeria. Nuclear Instruments and Method in Physics Research A 422: 784-789.

Turner–Peterson, C.E. (1980). Sedimentology and uranium mineralization in the Triassic-Jurassic Newark Basin, Pennsylvania and New Jersey, in Turner-Peterson, C.E., ed. Uranium in sedimentary rocks - Application of the facies concept to exploration: Denver, Colo., Society of Economic Paleontologists and Mineralogists, Rocky Mountain Section, Short Course Notes,

UNSCEAR, United Nations Scientific Committee on the Effects of Atomic Radiation (1993). Sources and Effects of Ionizing Radiation.

USEPA, United States, Environmental Protection Agency (2000). Setting standards for safe drinking water.

UNSCEAR, (1982). Ionizing Radiation: Sources and Biological Effects.

UNSCEAR, (1988). Sources, Effects and Risks of Ionizing Radiation.

UNSCEAR, (2000) United Nations Scientific Committee on Effects of Atomic Radiation. Sources and effects of ionizing radiation. Report to the General Assembly (NY: UN).

World Health Organization (WHO), (1993). Guidelines for drinking water quality.Vol. 1, Recommendations (Geneva: WHO,1993).

Wrenn, M.E. and Sighn, N. (1987). Uptake of Ingested Uranium. Reports on the Conference of Trace Substances in Environmental Health. University of Missouri, Columbia.

Wrenn, M.E., Durbin, P.W., Howard, B., Lipsztein and Willis D.(1995). Metabolism of Ingested Uranium and Radium. Health Physics 48:601-633.

Wrenn, M.E., Sighn, N.P., Herbert, R., Rallison, M.L. and Burleigh, D.P. (1990). Lewis publishers, Washington D.C pp159.

Zofia Pietrzak-Flis, Iwona Kaminska and Edward Chrzanowski (2004). Uranium Isotopes in Public Drinking Water and Dose Assessment for Man in Poland. Radiation Protection Dosimetry. 113(1): 34-39.