BIOACCUMULATION OF NATURALLY OCCURING RADIONUCLIDES IN RICE AND SWEET POTATOE SAMPLES CULTIVATED IN SELECTED FARMLANDS OF KEBBI STATE, NIGERIA

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DEPARTMENT OF PHYSICS

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A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGERIA IN PARTIAL FULFILMENT OF THE REQUIMENTS FOR THE AWARD OF THE DEGREE OFMASTER OF TECHNOLOGY IN APPLIED NUCLEAR PHYSICS

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ABSTRACT

This study details the bioaccumulation of natural radionuclides in rice and sweet potatoes samples acquired from selected farmlands of Kebbi State. Ten (10) samples of rice and five (5) samples of sweet potatoes were collected from (15) different farmlands in Kebbi State and analyzed by means of Gamma-rays spectroscopy using Nal(Tl) detector. Activity concentration for ^{238}U,$^{232}Th$and^{40}K, in soil sample from the rice farms ranged from, 10.19±0.5-19.56±1.98, 13.58±0.43-32.77±3.02 and 205.32±4.73-512.25±36.51Bqkg^{-1}respectively,with mean values of 14.42±1.31, 20.11±2.28 and 336.90±17.11Bqkg^{-1} accordingly. Similarly, the range of activity for soils from the sweet potatoes farms varies from 5.76±1.09-15.41±2.36, 9.28±1.34-24.28±2.34 and 220.55±7.773-431.32±22.65Bqkg^{-1} respectively, with the average values of 12.32±1.7, 17.43±1.95 and 309.17±13.42Bqkg^{-1}in accordingly for^{238}U,$^{232}Th$and^{40}K.These values were found to be lower than the world average values of, 30, 35and 400Bq kg^{-1} respectively for ^{238}U,$^{232}Th$and^{40}K in soil, provided by the United Nations Scientific Committee on the Effects of Atomic Radiation. Furthermore, the activity concentration of in rice samples ranged from 0.95±0.02-3.96±0.63, 4.73±0.15-8.65±0.77 and 60.77±1.09-125.59±2.72Bqkg^{-1}, with the mean value of 2.81±0.21, 6.22±0.42 and 84.27±1.69Bqkg^{-1}respectively. Similarly, the range of activity in sweet potatoes sample varies from 0.18±0.03-1.79±0.09, 1.01±0.14-5.29±0.41and 81.55±0.15-203.48±2.22Bqkg^{-1}respectively, with the average value of 0.93±0.06, 3.89±0.27 and 116.92±1.32Bqkg^{-1} respectively. The mean transfer factor (TF) for^{238}U,$^{232}Th$and^{40}K in rice samples were 0.18, 0.33and 0.26respectively; while in sweet potatoes samples valueof TFfor^{238}U,$^{232}Th$and^{40}K were 0.59, 0.19 and 0.32respectively. The computed TFof natural radionuclides in the crops were found to be lower than unity which signifies that the bioaccumulation of ^{238}U,$^{232}Th$and^{40}K is insignificant. The crops considered could be thus not constitutes a source of radiotoxicity to consumers.

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LIST OF ABBREVIATIONS

AED	:	Annual effective does
CEC	:	Cation exchange capacity
DNA	:	Deoxyribonucleic acid
D_R	:	Absorb dose rate
EC	:	European community
HPGe	:	High purity germanium
$I_ɣ$	:	Gamma index
IAEA	:	International atomic energy agency
ICRP	:	International commission for radiation protection
MDA	:	Minimum detectable activity
Nal(TL)	:	Sodium iodide detector
NCRP	:	National council on radiation protection and measurements
NORM	:	Naturally occurring radionuclides
NPC	:	National population commission
PS	:	Potatoes-soil
RS	:	Rice-soil
SP	:	Soil-potatoes
SR	:	Soil-rice
SSA	:	Sub-Saharan Africa
TF	:	Transfer factor
UNSCEAR	:	The United Nations scientific committee on the effects of atomic radiation

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study

Human environment is filled with both natural and artificial radionuclides that continuously disintegrate to release nuclear particles (α- and β-particles) together with neutral gamma radiation and lighter particles (neutrinos). The internal and external radiation exposure of human is the consequence of the release of these nuclear particles into the environment. The natural radionuclides, Uranium (^{238}U) and Thorium (^{232}Th) including their decay products and non-series Potassium (^{40}K) are distributed by geological and geochemical processes in the soils that originated from the earth crust (Mlwilo *et al.,* 2007). About 96.1% of the total radiation dose received annually by the world population which comes from natural background radiation source is huge compared to radiation dose from man-made sources that accounts for 3.9% (Shiva *et al.,* 2008). The natural sources are from terrestrial (primordial) and extra-terrestrial (cosmic) origins. The internal exposure of human is mainly associated with food consumption (Chen *et al.,* 2005).

Natural radionuclides are ubiquitously present in the environment; even humans carry naturally occurring radioactive materials within their bodies (Hutchison and Hutchison, 1997). Natural radioactivity and its corresponding gamma radiation exposure demonstrate geological dependence. Such materials exist at varying levels in different regions worldwide (Almayahi *et al.,* 2012; Dragovic *et al.,* 2014; Mazor, 1992; Vera *et al.,* 2003). Primordial isotopes of ^{226}Ra, ^{232}Th, and ^{40}K are the main sources of external radiation on earth. These radionuclides, along with essential nutrients, may be absorbed from the soil via plant roots and transported to other parts of the plant. The presence of radioactivity in the edible parts of crops causes human internal exposure (Pulhani *et al.*, 2005). Primordial radionuclides in the soil are transported to food crops through plant-root uptake. The uptake of radionuclides from soil to plant is characterized by the transfer factor (Yassine *et al*., 2003). The transfer of radionuclides from soil to plant system referred to as transfer factor (TF) is an assessment model commonly utilized in a soil-plant activity concentration ratio. It gives the level of bioaccumulation of specific radionuclide in materials such as crops. Various studies on natural radionuclides transfer or pathway mechanisms to plant have been reported in the literature (Marko and Smodis, 2011; Yassine *et al.,* 2003; Vera Tome *et al.,* 2003; Shtangeeva, 2003). Till today the transfer factor remains the useful tool to scientists for predicting the radionuclide concentration in agricultural crops and estimating dose impact to human as reported by IAEA (IAEA, 1994).

In order to quantify the transport process of radionuclides from soil to plants, the term plant/soil concentration ratio has been introduced, often referred to as transfer/ bioaccumulation factor (TF) (Mortverdt, 1992). The transfer factor (TF) is defined as a parameter used to evaluate the transport of radionuclides and other elements of interest through the food chain. Sheppard *et al*. (1989) defined it as a factor that describes the amount of an element which is expected to be from the substrate to enter the plant in terms of balance. Knowledge of transfer factors can theoretically allow the calculation of radionuclide activity in plant and animal products on the basis of the measured activity in the soil.

In soil, each radioactive element follows complex dynamics in which a part of its concentration is transported into the soil solution, while another part gradually becomes strongly bound to the particles of the soil. The portion of these radionuclides, which is in the soil solution, can be incorporated via the root into the plants. In some cases, this is facilitated by their chemical similarity with other elements that the plant normally uses for its growth (Manigandan and Manikandan, 2009).

Rice remains a vital component of the Nigerian diet and its importation makes an important share of Nigerian agricultural imports (Ogundele and Okoruwa, 2006). The consumption of traditional cereals, mainly sorghum and millet, has fallen by 12 kg per capita, and their share in cereals used as food dropped from 61% in the early 1970s to 49% in the early 1990s. In contrast, the share of rice in cereals consumed grew from 15% to 26% over the same period (Akpokodje *et al.,* 2002; Ogundele and Okoruwa, 2006). The average yield of upland and low land rainfed rice in Nigeria is 1.8 $t.ha^{-1}$, while that of the irrigation system is 3.0 $t.ha^{-1}$ (Pcu, 2002). This is very low7 when compared to 3.0 $t.ha^{-1}$ from upland and lowland systems and 7.0 $t.ha^{-1}$ from irrigation systems in Côte d'Ivoire and Senegal (Ogundele and Okoruwa, 2006; Warda and Niser, 2001).

Potato (*Solanum tuberosum L.*) belongs to the tuber crops and there are two main types – Irish potato (*Solanum tuberosum*) and sweet potato (*Ipoema batata*) which is raised through Vines, whereas the former are raised through tubers. Irish potato was first introduced in Nigeria in the late 19th Century, through missionary activities (Obigbesan, 1976). Nigeria is most populous country in Africa, it is the fourth biggest producer of potato in sub Saharan Africa, with almost as much land under potato as Germany, and potato output has grown sevenfold over the past decade, reaching 843000 tonnes in 2007 (FAO, 2008).

1.2 Statement of the Research Problem

Rice and sweet potatoes are common food crops in Nigeria. They are sources of carbohydrate and are generally consumed by all ages and cultivated across the length of Nigeria. Consequently, the health of the populace is at risk if these food crops are not radiologically safe. The level of radiological risk associated with the consumption of these crops will depend on the level of radiation emitting isotopes in them. This will in turn depend on the level of naturally occurring radionuclide in the farm soils where they were harvested. Furthermore, data on radionuclide transfer factor in Nigeria's crops are very scanty. Thus, it is impossible to ascertain how much of radionuclide is absorbed by human through the food chain. Analysis of crop transfer factor is therefore necessary to ensure public health. It is of paramount importance to ensure the crops are radiologically safe to ensure human health and environmental protection.

1.3 Aim and Objectives of the Study

The aim of this study is to determine the activity levels of ^{238}U, ^{232}Th and ^{40}K in the food crops and farm soils and the associated radiation risks among the population in Kebbi State.

The objectives of this study are to:

i. Determine the activity concentrations of naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) in rice and sweet potatoes in the selected farmlands.
ii. Determine the activity concentrations of these radionuclides in soil samples from the selected farmlands.
iii. Estimate the effective dose due to the ingestion of the crops grown in these areas.
iv. Evaluate the associated soil-to-food transfer factors.

1.4 Justification for the Study

All types of food including rice and potatoes have a detectable amount of radioactivity which successively relocates into the human body through the ingestion pathway. More so, the radiation content of food has been firmly linked to the activity of the soil where the food was cultivated (Marko and Smodis, 2011; Yassine *et al.*, 2003; Vera Tome *et al.*, 2003; Shtangeeva, 2003). Rice and potato are amongst the commonly cultivated and most consumed foods in Kebbi State. Consequently, consumers of these foods are prone to ingesting significant doses of radiation if the soil contains high activity radionuclide. Hence, there is the need to investigate the accumulated dose to humans due to the natural radioactivity in rice and sweet potato cultivated in Kebbi State, Nigeria.

1.5 Scope of the Study

The study was conducted at selected farmlands in Makera, Kalgo, B/Kebbi, Bunza,Yauri, Kardi, Gwandu, Yamama, Argungu and Alieru of Kebbi State, Nigeria. Rice and sweet potatoe are the selected plants to be evaluated alongside their corresponding soil samples for bioaccumulation of radionuclides ^{40}K, ^{223}U and ^{232}Th, using a NaI (Tl) detector.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Radioactivity

Naturally occurring radioactive materials (NORMs) have been part and parcel of the world since creation. The planet and its atmosphere, the living and the non-living species on earth with the global environment that surrounds them, contains different species of NORM at varying degrees. According to Eisenbud and Gesell (1997), majority of the natural radionuclides that now exist were produced when the matter that formed the universe came into existence several billion years ago; thus life on earth has developed under the ubiquitous presence of environmental radiation. The major constituents of NORMs are uranium (^{238}U), thorium (^{232}Th) and their respective decay daughter radionuclides, together with potassium (^{40}K). These long-lived radionuclides contain some decay daughters with long lives, together with ^{222}Rn in their progeny (IAEA, 2002).

Natural radioactivity is distributed extensively in human environment. It can be found in different geological formations such as water, air, plants, rocks and soils (Ibrahiem *et al.,* 1993; Malanca *et al.,* 1996).

2.2 Sources of Radiation in the Environment

The natural sources of radiation are either terrestrial (primordial radionuclides) or extra-terrestrial (cosmic rays) and cosmogenic radioactivity. These sources are briefly discussed below.

2.2.1 Primordial radioactivity

Radiation from the primordial sources constitutes about 85% of the natural background radiation exposure received by individuals in the environment (IAEA 1996, Obed *et al.*, 2005). About 70 out of 340 naturally occurring nuclides on earth are radioactive thus man is continually exposed to radiation due to natural radioactivity in the terrestrial environment (Olomo, 2006). The specific activity levels of terrestrial sources of radiation are related to the composition of each lithological area and to the content of the rock from which the soils originate (Akhtar *et al.*, 2004 and Tahir *et al.*, 2005).

2.2.2 Cosmogenic radioactivity

The highly energetic cosmic rays with energies in the range between 102 MeV and 1014 MeV continually bombard the earth from the outer space. Cosmic radiation consists of a mixture of protons (87%), alpha-particles (11%), electrons (1%) and a trace of heavier nuclei (1%) (Sabol and Weng, 1995; Adams and Allday, 2000). The mechanism for the production of the cosmic rays is not known but the origin of the rays is deep in the interstellar space. Cosmic rays according to Jibiri (2000) and Farai and Jibiri (2000) and Farai *et al.*, (2006), are the major sources of ionizing in the atmosphere from altitude 70 km to 1 km, below which the ionizing effect is comparable to that from airborne and terrestrial radiation. The interaction of cosmic rays with atoms and molecules of the upper atmosphere results in the production of ^{14}C, ^{7}Be and ^{3}H, referred to as cosmogenic radionuclides. The contribution of cosmic rays to the environmental radiation exposure is about 15% of the natural background radiation.

2.3 Gamma-ray Spectrometry

The evaluation of environmental radioactivity including the monitoring, and assessment of the radiation environment is achieved mainly through the gamma ray spectrometry technique. Gamma ray surveys over the years have enjoyed numerous applications in several fields of science. Of particular interest to this research is its application in estimating, and assessing the terrestrial radiation dose to human population due to ingestion of food crops.

Gamma ray spectrometers use the direct proportionality between the energy of an incoming gamma ray, and the pulse amplitude at the output of the detector. Radiation with the highest penetrating potential, from both natural and anthropogenic sources are the gamma-rays. Their detection is a function of their interaction with the medium such that all or most part of their energy is transferred to an electron in the absorbing medium. Gamma-ray detector therefore, must act as a conversion medium for the incident gamma rays to have a high interaction probability to produce fast electrons, and also function as a conventional detector for these secondary electrons (Knoll, 2010).

Two basic detectors are commonly employed in gamma-ray spectrometric technique: thallium-doped sodium-iodide (NaI (Tl)), and high purity germanium (HPGe), which is characterized by low impurity concentration, high atomic number, and low ionizing energy required to produce electron-hole pair. Readily available detectors commonly used in radioactivity surveys are the NaI (Tl) scintillation crystals, especially that they can be operated at room temperature. The crystal suffers various excitations by the incident radiation, which is followed by series of de-excitations within the same crystal. This process results in the production of light photons which are captured on the photo-cathode of a photomultiplier tube and eventually released as electrical charge that is amplified along a dynode chain to produce electrical signal which is finally processed (Knoll, 2010).

2.4 Food Radioactivity Pathway to Man

The rate and level of absorption of radioactive elements from soil by plants depends on factors such as the soil type, climate conditions, plant type, and chemical form of the elements. Other factors are time of deposition relative to plant growth cycle and distribution of activity within the soil (Boone *et al.,* 1981). The time of deposition of the radionuclides is likely to have an appreciable effect on root uptake rate, especially during the early period of the plant. The natural radionuclides in the soil enter the food crop through the plant-root uptake and are transferred to the edible parts of the crops via plant roots (Pantelica and Salagean, 1997). In general, the retained radionuclides in soil pass into the root system in the same manner as non-radioactive elements enter the plant roots. In addition, there can be direct deposition on above ground parts with subsequent translocation to the edible parts of the food crop. The process of radionuclides entrance into food crops include direct deposition on to the leaves or exposed parts of the plants that are eaten by human being or other animals; persistent in soil layers from where they are taken up into growing plants through the roots; re-suspension as dust from the soil or any other exposed surfaces and being washed from the surface or deeper ground layers into water sources that are used for irrigation. The radionuclides enter human body system through ingestion of foodstuffs. In view of the potentially dangerous effects of radioactive isotopes contained in foods, no effort should be spared in their quantitative determination in all the identifiable pathways.

2.5 Food Crops Grown in Nigeria

Nigeria enjoys warm tropical climate with relatively warm temperatures throughout the year or two seasons. The rainy season lasts from mid-March to November in the south and from May to October in the north; and the dry season which occupies the rest of the year (Oyenuga, 1967). Most parts of the country experience rich soil and good rainfall that encourage good production of food crops. The types of food crops grown in Nigeria are grouped into cereal, roots tubers, vegetables, legume and spices (Maziya *et al.*, 2004). Cereals and tubers that constitute the most important food basket in Nigeria (Arogunjo *et al.,* 2004) are grown in almost all the part of the country. A large percentage of the total diet for both medium and low income consumers is hinged on cereals and tubers. The food crops grown in different parts of Nigeria are:

i. Cereals including maize, millet, Guinea corn and rice are largely produced in many states like Kebbi, Benue, Kogi, Enugu, Anambra, Imo, Abia, Jos-Plateau, and Ogun in Nigeria.

ii. Tubers including yam, cassava and potatoes are produced in some states of the country like Benue, Kebbi, Kogi, Anambra, Imo, Ogun, Delta and Edo.

iii. Pulses including cowpea, groundnuts, soya beans, different variety of beans are largely produced in the northern parts of the country.

iv. Vegetables including tomatoes, okra, spinach, bitter leaf, water leaf and onion are grown in almost all part of the country but onions are grown in large quantity in the north.

v. Fruits including citrus fruits, like sweet orange, tangerine, and lemon, mango, pineapple and cashew are grown in different part of the country.

When food crops are grown on soils which contain radioactive elements, the crops absorb these radioactive elements along with other nutrients and through plant root uptake when the food crops are consumed, the radionuclides further enter human thereby causing internal radiation exposure.

2.6 Radioactivity Measurements in Food Crops

Natural radioactivity originates from radionuclides found in the earth crust. Majority of the radionuclides are present as decay of ^{232}Th and ^{238}U, distributed by natural geological and geochemical processes, in addition to non-series naturally occurring radionuclides such as ^{40}K radionuclide (Olomo, 1990; Mlwilo *et al.,* 2007). The realization of the presence of radionuclides in food crop with its health implications has prompted some authors to carry out radioactivity measurements in different food crops across the world. Pantelica and Salagean (1997) reported that the radionuclides in soils enter food crops through plant-root uptake. It has also been reported that about one-eighth of the mean annual effective dose due to natural sources is caused by intake of foods (UNSCEAR, 2000; Hernandez *et al.,* 2004). The presence of natural radionuclides in food crops has raised concerns and worries among scientists worldwide. This concern prompted different authors (Takagi *et al.,* 1994; Min-Seok, 2008; Akhter *et al.,* 2003) to investigate radioactivity levels in various food items. In Nigeria, the presence of radioactivity in the environment posed anxiety of possible retention of the radionuclides in food crops. Following this fear of elevated levels of radionuclides in food crops, Olomo (1990) carried out measurements of the natural radioactivity in some Nigeria foodstuffs including cereals and tubers.

The measurements showed that the activity concentrations of ^{40}K, ^{238}U and ^{232}Th were significantly low. The economic and social needs in exploiting natural resources have prompted some countries in the world to embark on industrial mining and milling activities. The uncontrolled mining and milling activities have led to a number of environmental problems including land degradation, soil erosion, deformation and alteration of surface drainage. Besides the waste products resulting from the activities may modify the radioactivity levels in the soils that are used for agricultural purposes. As a result, the radioactivity levels in the foods grown on such soils may be augmented through the plant- root uptake. The great interest expressed worldwide over the naturally occurring background radiation in foodstuffs from mining environments led to the performance of extensive work by some authors (Mc Donald *et al.,* 1999; Mlwilo *et al.*, 2007; Jibiri and Agomuo, 2007; Arogunjo *et al.*, 2009). For instance, Jibiri and Agomuo (2007) carried out radioactivity measurements in some staple food crops, including cassava, maize, Guinea corn and potatoes collected directly from farmlands in Jos where series of mining had taken place, while Arogunjo *et al.* (2009) determined the uranium and thorium in soils, mineral sands water and food samples collected from Jos.

Application of fertilizers on the agricultural farm is one of the sources of technologically enhanced natural radiation which contributes greatly to radioactivity levels in the soils (Schmidt, 1993). The most common radionuclides in fertilizers and soils are ^{40}K, ^{226}Ra, and ^{232}Th. The levels of enhancement of radioactivity due to applied fertilizers in agricultural farms depend on the type and frequencies of application. Phosphate fertilizers are known to contain relatively high levels of uranium while potassium fertilizers are very rich in elemental potassium that contains about 0.0118% as ^{40}K. The anxiety over radiological enhancement and possible elevated radioactivity in food crops grown on farm lands where fertilizers are applied have been investigated (Mortevedt 1992; Bolca *et al.,* 2007). The elevations of radioactivity levels due to application of fertilizers on the farms where food samples were collected and analyzed by the authors were found to be insignificant.

Some areas on the globe including Guarapari in Brazil, Yangjian in China, Ramsar in Iran, Kerala and Tamil Nadu areas in India are known with high background radiation while the high radioactivity scenario in Nigeria has been documented (Jibiri, 2001). The population growth and movement, industrial development and food security have resulted into pressure to use agricultural lands that contain relatively high radioactivity level. The realization of high background radiation levels and the fear of enhanced radioactivity levels in food crops grown in these areas necessitated measurements of radioactivity in different foodstuffs by some authors (Mistry *et al.,* 1970; Avadhani *et al.,* 2001; Samavat *et al.,* 2006; Shanthi *et al.,* 2009). The radionuclide contents in the food crops analyzed were very low including those from high background radiation areas.

The application of ionizing radiation in research for energy development results in the possible release of radionuclides into the environment if not appropriately handled. In Nigeria, two research centres established for purpose of research training and developments are creating fears of possible leakage of ionizing radiation into the environment. The fear of elevated radioactivity in the environment of Obafemi Awolowo University where a Tandem linear accelerator is operational at the Centre for Energy Research and Development, prompted Akinloye and Olomo (2000) to determine the natural radioactivity in some tubers cultivated in farmlands within Obafemi Awolowo University, Ile-Ife. Akinloye *et al.* (2000) determined the meat and poultry consumption contribution to the natural radionuclide intake of the inhabitants of Obafemi Awolowo University, Ile-Ife, Nigeria. The radioactivity levels in both meat and poultry products were low despite the fact that the samples used for the measurements were collected from the site where a nuclear accelerator is operational.

The use of ionizing radiation in development of nuclear technology and the associated nuclear leakages or accidents and nuclear weapon tests, have led to the radioactive contamination of soils and foods in various countries of the world. A variety of radionuclides of artificial radioactivity results mainly from nuclear weapon testing, major nuclear power accidents and illicit disposal of radioactive wastes. The Chernobyl nuclear reactor fire disaster on 26 April, 1986 has motivated the needs to develop monitoring techniques for radioactive contaminations in the environment particularly in foodstuffs. After the Chernobyl, the accumulation of ^{137}Cs mostly in mushrooms was reported in Europe (Haselwandter *et al.*, 1988). This report was motivated by the fear of possible elevation of radionuclides in various other food crops in different parts of the world. As a result, the foodstuff intervention levels were set by the European Community (EC) which was adopted in many countries including USSR (Willen and Teunis, 1992). The EC set the maximum permissible radiocaesium levels applicable to imported milk and baby food as 370 Bq/kg and 600 Bq/kg for all other food items. The realization of release of radiocaesium into the environment after the Chernobyl reactor accident and awareness of the maximum dose level in foods prompted various authors (Copper *et al.,* 2003; Shiraishi *et al.,* 1999; Yu and Mao, 1999; Gaso *et al.,* 2000; Badran *et al.,* 2003) to investigate the radioactivity in different food crops in different parts of the world. For instance, Yu and Gao (1999) determined the concentration level of ^{137}Cs in potatoes from Hong Kong; Shiraishi *et al.* (1999) investigated stable and radiocaesium on dietary intakes in Japan; Gaso *et al.* (2000) determined ^{137}Cs element in edible mushroom from Mexico and Badran *et al.* (2003) investigated the levels of ^{137}Cs and ^{40}K in edible parts of some vegetables consumed in Egypt. The activity concentrations in all the food analyzed were low.

In Nigeria the fear of possible elevated radioactivity in foods had led to the investigation of internal radiation dose as a component of radiation health burden. Few months after Chernobyl reactor accident, a pioneering work on the measurements of activity concentrations of ^{137}Cs in imported milk from European countries was carried out by Farai (1993). The work reported activity concentration of ^{137}Cs ranging from 0.5 to 5.1Bq/kg in eleven widely consumed imported milk products from countries in Europe. Similar radioactivity measurement was carried out for milk products imported into and consumed in Nigeria ten years after Chernobyl nuclear power-plant accident (Osibote *et al.*, 1999). No artificial radionuclide was detected in the milk products. About twenty years being two-third of the ^{137}Cs half-life (32.2 yrs.) after the Chernobyl nuclear reactor accident that led to the release of radioisotopes into the environment.

2.7 Radioactive Contamination of Soils

It is a well-known fact that a number of natural radioactive elements such as uranium, thorium, radium and potassium occurs in the soil. Thus the soils and also the crops harvested are somehow radioactive. A general review of the amounts of fallout which have reached the surface of the earth (Garcia *at el.*, 1995)

As a consequence, the radioactivity of the earth has increased and nowadays these artificial radioactive elements can be found in the soil, water and food items of man and animal. The increase in radioactivity of the soil is small compared to the radioactivity from naturally occurring radioactive nuclides, where the quantities of radioactive nuclides which have entered the soil are so small that no cases of solubility product of any compound reached.

2.8 Radioactive Contamination of Plants

2.8.1 Direct contamination of plants

When the so-called fallout or waste reaches the surface of the earth, it will pass the crop before it reaches the soil. i.e., direct contamination can take place where by radioactive material "sticks" to the surface of the crops.

2.8.2 Indirect contamination of the plants

With regard to the contamination of the crop via absorption of radioactive nuclides through the roots, three major factors may be distinguished besides the root pattern as follows:

a- The availability for the plant of the nuclide after its reaction with the soil materials, this availability will be low for ^{137}Cs, because of the strong fixation by the soil, it will be rather, higher for ^{90}Sr, being only moderately strongly absorbed by the soil.

b- The capacity of the roots to take particular elements. This capacity is high for Sr^{90} and ^{137}Cs. Both have similar characteristics as calcium, and potassium respectively which are taken up by the plants in considerable quantities.

c- The possibility of transport of these elements from roots to the aboveground parts and to the tuber. The transport possibilities of strontium and cesium are large as the transport of calcium and potassium is also large (Jacobson and Overstreet, 1998).

2.9 Factors Influencing the Behaviour of Radionuclides in Soil

The concentration of naturally occurring radio nuclides in soil depends on the rock type from which the soil is formed (NCRP, 1975). The soil can be contaminated by radio nuclides deposition either from what originally discharged into the atmosphere, or from direct discharge of waste to land or water ways. The amount of radio nuclides in the soil depends on its organic matter content, soil to water ratio, site characteristics, rate and amount of rainfall and soil drainage (NCRP, 1950)

Moreover, the behaviour of radio nuclides in soil is affected by different biochemical processes (John and Robert, 1983).

2.10 Biological Effect of Radiation

When ionizing radiation transverses any medium, it releases all or part of its energies to the electrons in the medium thereby causing ionization. The effect of radiation and the subsequent health effects if it interacts with any biological entity are due to physical and chemical changes that result from the ionization. The basic building blocks of human body are the cells that form tissues and organs. A unit cell in human body consists of a nucleus, which is surrounded by about 70% colourless fluid called cytoplasm that contains variety of compounds like salts, carbohydrates, fats, amino acids and proteins. A cell is injured when exposed to radiation which eventually interacts with other non-irradiated cells and thereby causing damage to the entire biological entity. The injury incurred by the cell as a result of exposure to ionizing radiation may lead to molecular changes and formation of chemical species or radicals (H+ and OH-) which have deleterious effects on the chromosomes materials of the cells. The OH- and H+ attack Deoxyribonucleic Acid (DNA) causing the breakage of the molecules and the rupturing of the molecular bonds. The breakage of the DNA molecules ends up to a sudden random change in genetic code, and as a consequence causes genetic mutation. Such mutated cells may be repaired in a process called DNA degeneracy. Mutated cells that are not properly repaired may die through apoptosis or survive as viable but transferred from a parent to an offspring.

The water content in the cell experiences ionization and excitation within 10-16 second when radiation transfers energy to a biological medium. The resulting ions interact with other water molecule and cause a number of new products like OH-, H+ and strong oxidizing agent H_2O_2 (hydrogen peroxide). Figure 2.1 shows the chains of event that could take place after a cell is exposed to ionizing radiation. The biological effect of radiation actually depends on the dose, type of radiation and the radiosensitivity of the cell. The biological effects of radiation can be broadly categorized into stochastic and deterministic effects. Stochastic effects include malignant and hereditary diseases for which the probability of an effect occurring rather than its severity is considered to be directly proportional to the effective dose level.

In stochastic effects, any radiation dose no matter how small is capable of initiating an effect. Genetic mutations are examples that can result from stochastic effects. A gene mutation occurs when the Deoxyribonucleic Acid (DNA) is altered. In 1927, Mueller discovered the mutagenic properties of ionizing radiation and reported that radiation can cause alteration to the genetic information contained in a germ cell. Genetic mutation caused by radiation exposure can be transferred from a parent to an offspring. If the mutant gamete is successfully fertilized and the zygote (fertilized ovum) develops into a live offspring, then the mutation is carried into the progeny. Radiogenic cancer is a stochastic effect of ionizing radiation and the risk of incurring cancer from radiation exposure depends on factors like, the dose administered over time, the age, sex and genetic background of the exposed person. In recent time, cancer has assumed greater importance in the health agenda throughout the world and it has been observed that exposure to ionizing radiation increases the risk of incurring cancers (Farai, 1993; Brenner *et al.,* 2003).

Deterministic effect of radiation is predictable and its severity is an inevitable consequence of exceeding a given threshold radiation dose. In other word the severity of the deterministic effect is a function of radiation dose. Examples of deterministic effects are non-malignant skin damage (erythema), and haematological effects (changes in the composition of the blood). Somatic effect is deterministic and may be observed when an individual is irradiated. The damage due to somatic effect is only limited to the exposed individual, and in essence the individual suffers and dies with the damage. Somatic effects may take a longer time to develop and become evident after ionizing radiation had been administered either acutely or over an extended period. This is referred to as delayed somatic effect. Another delayed somatic effect is cataract which affects the opacity of the lens of the eye. A radiogenic cataract is a deterministic effect because there is a practical threshold of ionizing radiation dose below which cataract is not produced or manifested; and its severity, when it occurs, is related to the magnitude of the radiation dose and the time over which it is administered.

Radiation exposure

$\downarrow$

Ionization

$\downarrow$

Free radicals
(chemical changes)

$\downarrow$

Molecular Changes
(DNA, RNA, Enzymes)

$\downarrow$

Sub-cellular damage
(Nuclei Chromosomes, Membranes)

$\downarrow$

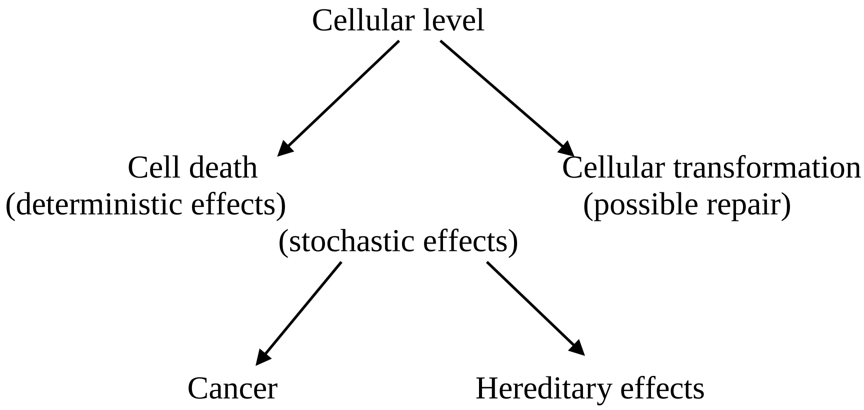

Figure 2.1 Chains of events in a cell after exposure to ionizing radiation.

2.11 Factors Affecting the Transfer of Radionuclides from the Environment to Plants

2.11.1 The plants

It is clear that the difference in physical and chemical characteristics in different plant species have a large effect on the accumulation of radionuclides in plant (Cawse, 1982). Arkhipove *et al*. (1975) reported that maximum and minimum values of ^{85}Sr accumulation by a variety of grain crops and legumes from the same soil differed by a factor of 85, and in 170 varieties of root and vegetable crops by a factor of 350. At this point, it is worth mentioning that the type of plant growing in a contaminated ecosystem will have a greater influence on the total intake by the plant than re-suspension or direct deposition of radioactive materials from the atmosphere, especially contamination of a particulate field. Higher levels of activity are more likely in plants with a hairy leaf surface and a hairy convoluted fruiting inflorescence, as well as in plants with broad open leaves (Cawse, 1982). Further analyses proved that maize leaves from the plants that are 1–2 m above ground had nearly twice the plutonium contamination present in lower leaves, indicating the importance of direct atmospheric deposition rather than soil re-suspension (Adriano *et al.*, 1980). TF values for ^{137}Cs in apples were six times lower than those derived for lettuce, carrot and string bean under the same experimental conditions (Delmas, 1973).

Studies of interception and deposition of ozone on peach orchard and soybean crop indicated that fruit tree constituted a far more effective sink for gaseous pollutants than herbaceous crops (Georgiadis, 1995). The authors emphasized on the structural and architectural characteristics, and the biological activity of the vegetative surfaces of the two crops. They are greatly dissimilar and give rise to a 3-fold higher deposition velocity of ozone in fruit trees than in herbaceous crop (Georgiadis, 1995). Actually, foliar retention also depends on the presence and development of hair, trichomes, waxes and cuticle on the leaf surface. Sawidis's studies in 1988 showed that after Chernobyl deposition, hairy leaves of fruit-bearing trees were found to have more radioactivite (Carini, 1999). Foliar contamination can be removed by radioactive decay, volatilisation, leaching by rain, other weathering effects, death and loss of plant part, and of course, washing prior to human consumption (Eisenbud, 1997).

2.11.2 Distribution of radionuclides in plant

When the radionuclides enter the transpiration stream they are not distributed uniformly, but tend to concentrate in certain organs of the plant. The plants take up the nutrient ions, in accordance to their requirement. They are transported to specific tissues based on the function of the element in plant metabolism, and it gets reflected in its higher concentration in a particular part when compared with others. Radionuclides can also be picked up along with nutrients that may have similar chemical behavior as the essential nutrient. The distribution of uranium and thorium in different parts of the wheat plant showed the decreasing trend as root > shoot and husk > grains and root > husk and shoot > grains, respectively (Pulhani, 2005).

2.11.3 Root of plants

Root mainly affects plant uptake in its relation to the leach rate through the soil of a particular radionuclide (Cawse, 1982). Some of the radionuclides have a relatively high leach rate, but this does not necessarily mean that there is less chance of uptake, as there are some plants with deep roots The slow migration of radiocaesium in the soil profile represents a different potential source of contamination for plants with different root penetration in soil. It was suggested that the low root uptake of cesium found in fruit trees in northern Greece during the period 1987–1990 was due to the depth distribution of the root system. In contrast, fruit trees planted after 1986 were suggested to have been contaminated through root uptake because their roots were near the ground surface (Antonopoulos-Domis, 1991). Spread of roots in fruit trees is generally much greater than that of the branches. An indirect demonstration of the extension of the whole root system and of the implications for uptake processes is provided by experiments with applications of potassium in bearing groves of coconuts at Bikini Atoll. Potassium applications lowered the concentrations of ^{137}Cs in drinking-nut meat, and this effect was increased when the treatment width was expanded from 8.5 to 17 m on either side of the row; however, the reduction was not proportional to the percentage of root area treated (Robison, 1992).

2.12 The Soil

The media in which a plant is grown has a particularly large effect on the uptake of any nuclide. Most of the consumed foods by human beings are grown on land and, except for elements like carbon and oxygen, which may be obtained from the atmosphere, it is the soil that nourishes the terrestrial ecosystem and supplies human food (Eisenbud, 1997). The concentration of chemical elements in the soil solution depends on soil moisture, pH, cation exchange capacity (CEC), redox potential, quantity of organic matter, microbial activity and fertilizer application. Mass flow and diffusion of chemical elements into plants depend on soil structure and porosity (Carini, 2001).

2.12.1 Soil characteristics

Soil consists of a complex mixture of minerals and organic matter, in addition to water and air. The size of the soil particles ranges from clay particles of sub-micron diameter to sand particles with dimensions of around 2 mm. The surface soil consists of a topsoil layer (about 0.5 m thick) that is rich in organic matter. Below surface soil lies the sub-soil layer (about 0.3 m thick), consisting mainly of inorganic matter. The next level down is the pervious rock layer, before meeting the impervious bedrock. Sand particles are generally chemically inert and because of their large sizes, water travels through them easily. Silt particles, which are smaller in size, offer larger surface areas and can be transported with contaminated water. Clay particles offer the largest surface area per unit mass and thus hinder water flow. Soluble radionuclides can be adsorbed onto the reactive surfaces of fine soil particles. They can also react with organic matter, precipitate, for example as oxides, or undergo ion exchange. Depending on the time that a radionuclide remains in the soil, it can be partitioned into various fractions through these processes. The importance of these processes depends on the radionuclide itself and removal mechanisms, such as root uptake. The movement of the radionuclide through the soil is hence determined, to a large extent, by these partitioning processes (Cooper, 2003). Fruits grown on peat soils characterized by high organic-matter content show higher TFs for caesium and lower TFs for strontium, americium and plutonium, than fruits grown on loamy and sandy soils (Green *et al.*, 1997). Soil type significantly influences radiocaesium transfer to olive and orange trees. TFs were higher for the acid-light soil than for the calcareous-heavy soil. TFs of orange trees were higher than those of olive trees in the acid-light soil (Skarlou, 1999).

2.12.3 Calcium content

The uptake and metabolism of strontium in plants follow a pattern similar to that of calcium (Coughtrey and Thorne, 1983). The ratios of strontium activity to calcium content were calculated in soils and plants. The highest ratios were observed in root crops, followed by grains and finally fruits. The low ratios found for fruits were suggested to reflect a preference of the plant for the absorption of calcium along the entire distance of the roots (Juznic, 1989). The root uptake of calcium depends mainly on the plant requirements and not on the amount of calcium in the soil (Romanov, 1995). As it concerns plant requirements, the uptake of strontium is generally inversely related to the amount of exchangeable calcium in the soil. The larger the exchangeable calcium pool, the lower the Sr/Ca ratio and thus, the lower the uptake of strontium (Carini, 2001).

2.12.4 Migration of radionuclides in soil

Vertical migration of radionuclides down the soil column could arise from various transport mechanisms including convection, dispersion, diffusion and biological mixing. High root uptake of radionuclides in plants is correlated with high vertical migration, because in both processes the radionuclides are relatively mobile. Typically, the rate of movement of radionuclides will thus vary with soil type and physio-chemical form (EGE, 1994).

2.12.5 Agricultural practices

Management practices such as ploughing, liming, fertilization and irrigation greatly affect radionuclide uptake. Agricultural practices have a major impact on radionuclide behavior. Depending on the type of soil tillage and on the tools used, a mechanical redistribution of radionuclides in the soil may occur. On arable soils, radionuclides are distributed fairly uniformly along the whole depth of the tilled layer. It has been shown that the major mechanism for contamination of soybeans and wheat grown in soil that is superficially contaminated with plutonium is re-suspension due to mechanical harvesting (McLeod *et al.,* 1980).

2.13 Sweet Potato Cultivation

Sweet potato has numerous potential benefits and uses. It requires fewer inputs and less labour than other crops such as cereals, more productive, and adaptable to marginal growing conditions (e.g., drought and poor soil) (Oswald *et al.,* 2009). Sweet potato is an important food and feed crop in sub-Sahara Africa (SSA) and ranks fourth after maize, bananas, and cassava (Fao, 2015). It serves as cash crop and is one of the most popular food crops which serve as food security promoting root crop in sub-Sahara Africa specifically, and the world at large. The importance of the crop in national and household food security coupled with health and livelihoods of poor farming households in Nigeria cannot be overemphasized. In Kwara State, the crop plays particularly important role in cultural practices of the peoples' traditions at the beginning of harvest (Agbo, 1992). Despite the numerous potential uses and benefits of sweet potato in Nigeria, the production of the crop is below the nation's potential. Sweet potato has a yield potential of 20–50 tonnes per hectare wet weight in the tropics (Caliskan *et al*., 2007). Farmers in South Africa however produce below 10 tonnes per hectare wet weight on the average (FAO, 2009). The low yields in Nigeria were due to quality of planting materials (vines), high labour costs, biotic and abiotic constraints. As opined by Fawole, the low productivity recorded in sweet potatoes farms is traceable to inefficiency in resource use (Fawole, 2007).

2.13.1 Soil types for sweet potatoes harvesting

A well-drained sandy loam is preferred and heavy clay soils should be avoided as they can retard root development, resulting in growth cracks and poor root shape. Lighter soils are more easily washed from the roots at harvest time. Wet season green manure cropping with sterile forage sorghum is recommended and should be thoroughly incorporated and decomposed by planting time. Soil pH should be adjusted to about 6.0 by applying lime or dolomite. Rates of 240 kg and 400 kg/ha respectively will raise the pH by 0.1 of a unit. The soil should be deep ripped and then disk cultivated to break up any large 4 clods and provide enough loose soil for hilling of beds. A yearly soil test is recommended to assess soil properties, pH and nutrient levels before ground preparation (Edmond and Ammerman, 1971).

2.13.2 Nutrients need in potatoes

Potassium is the most important element for storage root development, and so in many places sweet potato will benefit from extra potassium. This can be provided using ash, as ash is rich in potassium. However, it is not only the amount of potassium that is important, but also the ratio between the potassium and nitrogen to be supplied. The best bulking of storage roots occurs when the nitrogen and potassium are present in the soil at a ratio of about 1:3. Applying potassium during the second half of the crop's growth cycle helps promote development of a strong skin (Osullivan *et al*., 1997 and Susan *et al., 2006*).

Nitrogen is one of the nutrients most commonly taken up by sweet potato (Echer *et al.,* 2009) and its supply, by either green manure or mineral fertilizer, is essential to promote plant growth and development. The Nitrogen also has an important role in dry matter accumulation and the uptake of Phosphorous and potassium, as well as in the formation and enlargement of the sweet potato storage roots (Villordon and Clark, 2014; Duan *et al.,* 2018). Furthermore, Nitrogen is one of the most important factors affecting shoot morphogenesis and the root yield of sweet potato (Ning *et al.,* 2015; Duan *et al.,* 2018) and since it influences the accumulation and distribution of dry matter in the plant (Lebot, 2009), Nitrogen application increases plant growth and, consequently, the plant's demand for other nutrients (Fargeria, 2006).

2.14 Natural Radionuclides in Food Crops

One of the three goals of the United Nations for sustainable food security is to ensure that all people have access to sufficient, nutritionally adequate and safe food (Jibiri *et al.,* 2007). Natural radioactive elements are transferred and cycled through natural processes and between the various environmental compartments by entering into ecosystems and food chains. Vegetables may be subjected to direct and indirect contamination of uranium series radionuclide. Use of fertilizers leads to elevation of uranium series nuclides in vegetables. Naturally Occurring Radionuclides (NORM) of Thorium and Uranium are significant contribution of ingestion dose and are present in the biotic systems of plants, animals, soil, water and air.

Distribution of those radionuclides in different parts of the plant depends on the chemical characteristics and several parameters of the plant and soil (Shanthi *et al.,* 2009). Olomo (1990) studies on natural radioactivity in some Nigeria foodstuffs examined, varies and concluded that the major factor that may be responsible include, application of fertilizer, soil type and irrigation pattern. Arogunjo *et al.* (2004) studied the level of natural radionuclide in some Nigerian cereals and tubers using HpGe detector and reported average concentration of ^{40}K, ^{238}U and ^{232}Th as 130+8.12Bqkg^{-1}, 11.5+3.86Bqkg^{-1}, and 6.78+2.13Bqkg^{-1} respectively, while ^{137}Cs was not detected in any of the food stuffs analyzed. Eyebiokin, *et al.* (2005) studied the activity concentrations and absorbed dose equivalent of commonly consumed vegetables in Ondo state using Nal (TI) detector and reported that mean effective dose equivalent for Akure, Idanre and Agbabu were 0.59mSvy^{-1} 0.73mSvy^{-1} and 0.64mSvy^{-1} respectively. They concluded that the values obtained were lower than the UNSCEAR (1993) recommended value for normal background. Ojo and Ojo, (2007) on the radiological study of brackish and fresh water food samples in Lagos and Ondo States, reported that the average concentration of 50.92+7.04Bqkg^{-1} ^{238}U and 24.60+6.47Bqkg^{-1} ^{232}Th were found to be higher in brackish water while ^{40}K (738.94+84.81Bqkg^{-1}) was found to be higher in food samples got from fresh water.

Mlwilo *et al.* (2007) study on radioactivity levels of staple foodstuffs and dose estimates for most of the Tanzanian population revealed that the average activity concentration of ^{40}K, ^{232}Th and ^{238}U in maize were 48.79+0.11, 4.08+0.01 and 13.23+0.10BqKg^{-1} respectively and in rice 3.82+0.02, 5.02+0.02 and 24.67+0.03. BqKg^{-1} respectively .He concluded that the relatively high average concentrations of the radionuclides in maize compared to rice may be attributed to the extensive use of phosphate fertilizers in maize production in Tanzania and that the total annual committed effective doses due to total ^{232}Th and ^{238}U intakes as a result of consumption of staple foodstuff for infants, children and adults were 0.16, 0.29 and 0.36msvyr^{-1} respectively, which are lower than the annual dose guideline for the general public. Activity concentrations of ^{226}Ra, ^{228}Th, ^{40}K in different food crops from a high background radiation area in Bitsichi, Jos Plateau, Nigeria were studied by Jibiri *et al.* (2007). The activity concentration in the food crops ranged below detection limit (BDL) to 684.5BqKg^{-1} for ^{40}K from BDL to 83.5BqKg^{-1} for ^{225}Ra, and from BDL to 89.8BqKg^{-1} for ^{228}Th. It was further revealed that activity concentrations of these radio nuclides were found to be lower in cereals than in tubers and vegetables. The average external gamma dose rates were found to vary across the farms from 0.50+0.01, to 1.47+0.04uSrh^{-1}. Because of the past mining activities in the area, it was found that the soil radioactivity has been modified and the concentration level of the investigated natural radionuclides in the food crops has been enhanced but however, the values obtained suggested that the dose from intake of these radionuclides by the food crops is low and that harmful health effects are not expected.

Shanthi *et al.* (2009) carried out a study to evaluate the radioactivity concentration in the food crops grown in high-level natural radioactive area (HLBRA) in South–West, India. The calculated daily intakes of these radionuclides isotope (^{226}Ra, ^{228}Ra, ^{228}Th and ^{40}K) using concentrations in south Indian foods and daily consumptions of these foods were fund to be ^{226}Ra, 0.001-1.87, ^{228}Ra, 0.0023-1.26, ^{228}Th,0.01-14.09, ^{40}K, 0.46-49.39 Bq/day. It was concluded that the daily internal dose resulting from ingestion of radionuclides in food was 4.92uSv/day and the annual dose was 1.79mSvyr^{-1}.

In view of the potentially dangerous effects of radioactive substances, no effort should be spared in their quantitative determination in all the identifiable pathways.

2.15 Effective Dose due to Ingestion of Foodstuffs

Effective dose is a useful concept in the radioactivity measurement that enables the radiation doses from different types of radiation and the doses by different organs to be added. It is based on the risks of radiation induced health effects and the use of International Commission on Radiological Protection (ICRP) metabolic model provides relevant conversion factors that permit the calculation of effective doses from the total activity concentrations of the radionuclides measured in food items (ICRP, 2007). The estimation of the radiation induced health effects associated with intake of radionuclides in the body is proportional to the total dose delivered by the radionuclides on accumulation in the various body organs. The radiation dose delivered when food is taken also known as effective dose is obtained by measuring how much is the activity concentration (Bq kg^{-1}) of the radionuclide in the food; multiplying it by how much food is consumed over a period of time (kg d^{-1} or kg y^{-1}) and then by a dose conversion physical factor ($SvBq^{-1}$) which gives an indication of how much dose is caused by a unit radioactivity in the given body organ.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Sample Site

The sample sites are selected farmlands in Kebbi State, Nigeria. Kebbi State lies in North-western Nigeria, located on 11°30′ N, 4° 0′ E with its capital in Birnin Kebbi. The state is bordered by Sokoto State to the north and east, Niger State to the south, Dosso Region in the Republic of Niger to the Northwest and the Republic of Benin to the West. Kebbi has a total land area of 37,698,685 km^2 and an estimated population of 4,629,880 (NPC, 2006; 2017). Figure 3.1 shows the map of Kebbi State, indicating the sample points.

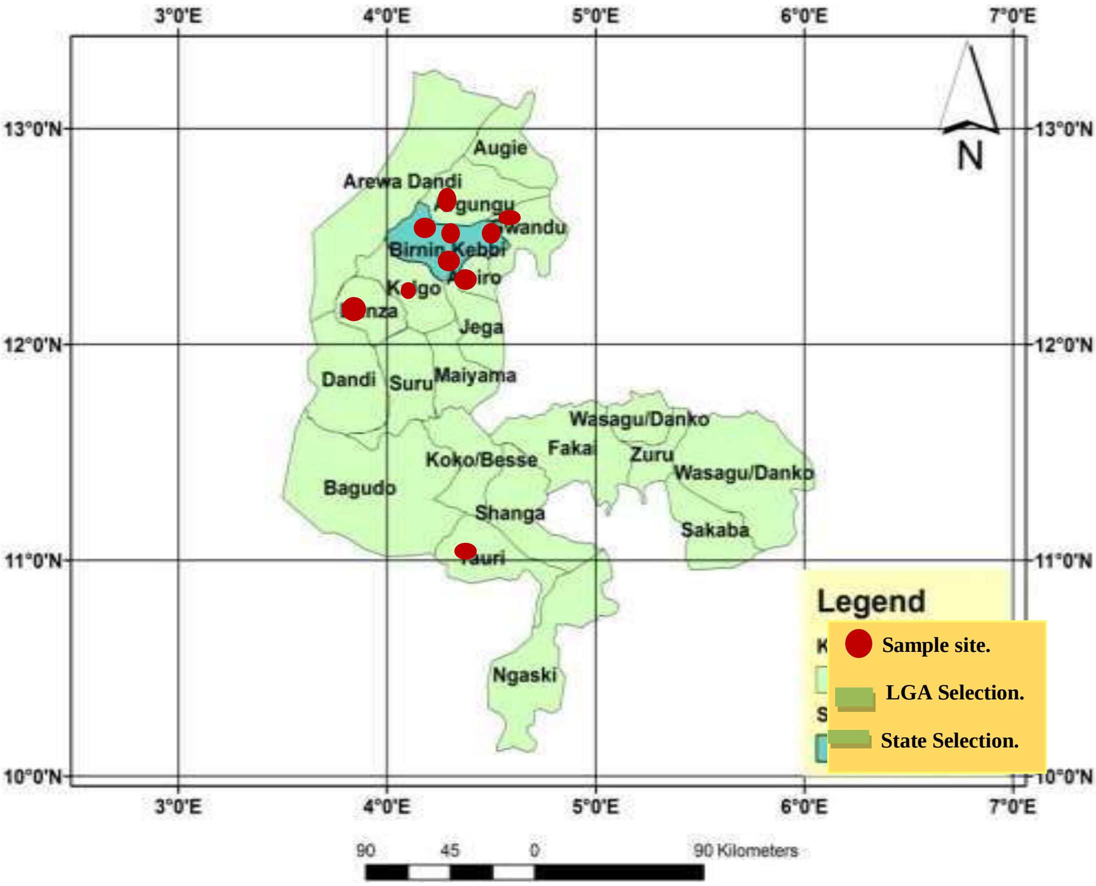

Figure: 3.1: Kebbi State showing the sample site.

The state is endowed with high soil fertility, vast farmlands and economically operable rivers sheltered by suitable tropical climate (Blench, 2020). Thus, making it an agriculturally viable environment.

The local government areas covered are Makera, Kalgo, B/Kebbi, Bunza,Yauri, Kardi, Gwandu, Yamama, Argungu and Alieru. Plate I shows the rice farm in kebbi while Plate II Shows the potatoes farm.

Plate I: Rice Farm in Birnin Kebbi

Plate II: Potato Farm.

3.2 Sample Collection

Rice and sweet potatoes crops and their corresponding soils were collected in fifteen (15) different farmlands scattered across ten (10) towns (Makera, Kalgo, B/Kebbi, Bunza,Yauri, Kardi, Gwandu, Yamama, Argungu and Alieru) in Kebbi State.

3.2.1 Soil sample collection

Approximately 0.50 kg of soil samples were collected from the selected farmlands. Ten (10) surface-soil samples were collected from the rice farms and five were collected from the sweet potatoes farmlands at 0.18 m depth. At the point of collection, the samples were rid-off debris, then packaged in polyethylene bags and labelled with the sample codes (SR1 to SR10) for rice soil and (SP1 to SP5) for sweet potatoes soil. The location parameters for the soil samples collected from the rice and potato farmlands are shown in Tables 3.1 and 3.2 respectively.

Table 3.1: Sample collection points on the rice farmlands

Sample Code	Sample Site	Latitude	Longitude	Elevation (m)
SR1	Birnin Kebbi	12°29′23”N	4°09”56”E	697
SR1	Bunza	12°13′08”N	4°01”35”E	688
SR3	Kalgo	12°17′47”N	4°11′07”E	690
SR4	Alieru	12°17′53″N	4°28′17″E	699
SR5	Argungu	12°46′07”N	4°30′05”E	717
SR6	Yauri	10°48′31”N	4°43′52”E	643
SR7	Kardi	12°25′57”N	4°16′10”E	714
SR8	Gwandu	12°27′25”N	4°37′30”E	731
SR9	Makera	12°29′48″N	4°08′11″E	698
SR10	Dukku	12°28′47″N	4°09′42″E	698

Table 3.2: Sample collection points in the Potato Farmlands

Sample Code	Sample Site	Latitude	Longitude	Elevation (m)
SP1	Makera	12°30′36″N	4°11′41″E	699

SP2	Kalgo	12°19′17”N	4′11”46”E	691
SP3	B/kebbi	12°28′36”N	4°11′18”E	701
SP4	Bunza	12°13′19.4”N	4°92′91.18”E	656
SP5	Kardi	12°25′54“N	4°16′04”E	715

3.2.2 Rice sample collection

Point of samples collected with their longitude and latitude are shown in Tables 3.1 and 3.2. All the locations selected for plants and soil samples collection were on agriculture land. The rice samples were collected during the harvesting season. Ten rice samples were harvested from the selected farmlands. The rice was carefully washed to remove any external contamination and dried. The dry rice samples were then packaged in well labeled polythene bags. The packaged samples were transported to the lab for further preparation and analysis.

3.2.3 Sweet potatoes sample collection

Five sweet potatoes samples were harvested at a depth of 0.18 m using a hoe to dig the crop underground, the sweet potatoes samples were then packaged in well labeled polythene bags with the sample codes (PS1 to PS5). The packaged samples were then transported to the lab for further preparation and analysis.

3.3 Sample Preparation

3.3.1 Preparation of soil samples

The soil samples were air-dried to drain their moisture content. The moisture-free samples were grinded using agate mortar and pestle shown in Plate III (a) and sieved using the sieve shown in Plate III (b) to attain fine sample with proper surface area to volume ratio. Then the samples were packaged in air-tight plastic containers that were double-sealed with a masking adhesive tape as shown in Plate IV (a) and Plate IV (b).

Plate III: Sample preparation materials (a) Mortar and pestle (b) 500µm sieve

Plate IV: Packaged Samples (a) potatoes and soil samples (b) rice and soil samples

3.3.2 Preparation of rice samples

The grains of the rice sample were threshed separately during sample preparation. The samples were separately air dried for one week at room temperature and grinded to a powder form using mortar and pestle. Then they were sieved and packaged into well labeled Plastic containers, doubled sealed using a masking tape to avoid any peripheral contamination as portrayed in Plate IV.

3.3.3 Preparation of sweet potato samples

The potato samples were also washed with water to remove any contamination. Then they were peeled (Plate V). The edible part were cut into small pieces and dried at room temperature, before pulverization into powder form using pestle and mortar. The pulverized samples were sieved and packaged into well Plastic containers.

Plate V: Peeled sweet potatoes sample

All the prepared samples sealed in the Plastic containers were then stored for a period of 30 days to allow for long-lived radionuclides and their short-lived progenies to reach secular radioactive balance prior to gamma ray measurement (Agbalagba and Onoja, 2011).

3.4 Gamma Spectrometric Analysis

The gamma spectrometry system employed consist of a 3" x 3" NaI(Tl) detector supplied by Princeton Gamma Tech., USA. The detector is housed in a cylindrical lead shield to reduce the effect of background radiation. The detector was coupled to Gamma spectrometry (model GS-2000 Pro) multichannel analyzer and further linked to a computer for display. Data acquisition and analysis of gamma-ray spectra were achieved using Theremino software.

In order to derive a qualitative and quantitative relationship between the peak position in the spectrum and the corresponding gamma-ray energy, the NaI(Tl) spectrometry system was calibrated. Energy calibration of the detector was carried out using the RSS8 gamma source set traceable to Spectrum Techniques LLC, USA. It was accomplished by measuring the spectra of point sources emitting gamma-rays of precisely known energies (Cs^{-137} and Co^{-60}). The efficiency calibration of the detector was also carried out using a reference source consisting of known radionuclide activities: ^{40}K (578.4 $Bqkg^{-1}$), ^{238}U (20.9 $Bqkg^{-1}$) and ^{232}Th (10.47 $Bqkg^{-1}$). The standard sources are designed for the determination of natural radionuclides in environmental matrices. The source was prepared in a container that has the same geometry as the sample and counted for a period of 36000s. The full energy peak efficiency was employed as it relates the peak area in the spectrum to the amount of radioactivity present. It is denoted by **ε** and expressed by

$$\varepsilon = \frac{C_{net}}{A \times P_{\gamma} \times m \times T} \tag{3.1}$$

Where C_{net} is the net peak count for each radionuclide present in the source, A is the activity concentration of the radionuclide present in the source, P_{γ} is the absolute gamma ray emission probability of the radionuclide of interest and T is the acquisition time (Ibeanu, 1999).

3.4.1 Counting procedure

Prior to the sample measurement, an empty container was counted for 36000s so as to determine the background gamma-ray distribution count. The sealed samples after attaining a state of secular equilibrium were each placed on the detector one after the other for analysis. Each sample was counted for the same period of time as that of the empty container. The characteristics of the radionuclides used in determining the most prominent radionuclides identified in the samples are: 1460.0 keV (^{40}K), 1764.5 keV of ^{214}Bi (^{238}U), and 2614.7 keV of ^{208}Tl (^{232}Th). The activity concentration A (Bqkg^{-1}) of each identified radionuclide in the sample was estimated using:

$$A = \frac{C_{net}}{P_{\gamma} \times \varepsilon \times m \times t} \quad (3.2)$$

where C_{net} is the net peak count for each radionuclide present in the sample after subtracting the background count from the gross count, $P\gamma$ is the absolute gamma ray emission probability of the identified radionuclide, ε is the obtained full energy peak efficiency for each identified radionuclide, m is sample mass and t is the counting time.

The detection capabilities associated with measuring and analyzing radioactivity levels vary according to the instrumentation and analytical techniques. It is, therefore, necessary to determine the detection limits of the radionuclides that are statistically significant for the measurement. The minimum detectable activities (MDA) for each radionuclide detected were calculated using:

$$\text{MDA} = \frac{2.71 + 4.66(\sigma)}{P\gamma \times \varepsilon \times t \times m} \quad (3.3)$$

where σ is the standard deviation of the background collected during time t over the energy range of interest, Pγ, ε, m and t are as already defined.

3.5 Evaluation of Radiological Dose and Risk Parameters

As part of radiological impact assessment of natural radionuclides in the environment, radiation dose and risk parameters are usually calculated. This will reveal if natural radionuclides concentration and radiation dose are within safe limits or otherwise.

3.5.1 Absorbed dose rate (D)

The absorbed dose rate (D) in air associated with the activity concentration of ^{238}U ^{232}Th and ^{40}K present in the soil sample was evaluated using equation 3.5 (UNSCEAR, 2000, Abba *et al*., 2018):

$$D(\text{nGy}h^{-1}) = \sum_{i=1}^{3} A_i\, C_i \tag{3.4}$$

where, A_i is the measured activity concentrations ($Bqkg^{-1}$) of ^{238}U, ^{232}Th and ^{40}K and C_i are their conversion factor to dose rate given as 0.462, 0.604 and 0.0417 $nGyh^{-1}$ per $Bqkg^{-1}$ respectively (UNSCEAR, 2000; Abba *et al*., 2018).

3.5.2 External absorbed dose rates and outdoor effective dose

The absorbed dose rates (D) due to gamma radiations in air at 1m above the ground surface for the uniform distribution of the naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) were calculated based on guidelines provided by UNSCEAR (2000).

To estimate the mean annual effective dose rates which is sometimes referred to as Outdoor annual effective dose equivalent, the conversion coefficient from absorbed dose in air to effective dose (0.7 $SvGy^{-1}$) and outdoor occupancy factor (0.2) proposed by UNSCEAR (2000) were used. Therefore, the mean annual effective dose rate ($mSvy^{-1}$) was calculated by the following formula:

$$D_{eff}.\ (\mu Svy^{-1}) = \text{Dose rate } (nGyh^{-1}) \times 24h \times 3600 \times 0.2 \times 0.7\ Sv/Gy \times 10^{-3}\ Sv/Gy \tag{3.5}$$

3.5.3 Radium equivalent activity

Radium equivalent activity (Ra_{eq}) is the sum of the weighted activities of ^{226}Ra, ^{232}Th and ^{40}K based on the estimation that 10 $Bqkg^{-1}$of ^{226}Ra, 7 $Bqkg^{-1}$of ^{232}Th and 130 $Bqkg^{-1}$ of ^{40}K will deliver an equal or the same gamma dose rate (Ademola, 2008a, b; Shiva

Prasad *et al.*, 2008). According to Diab *et al*. (2008), this index is mathematically defined by UNSCEAR (2000) as:

$$Ra_{eq} = A_U + 1.43A_{Th} + 0.077A_K \tag{3.6}$$

where A_{Ra}, A_{Th} and A_K are activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, respectively.

3.5.4 Soil to plant transfer of radionuclides

Absorption of radionuclides from soils into plants is usually quantified in terms of the transfer (or concentration) factor, which is defined as the ratio of the radioactivity per unit dry weight of plant to the radioactivity per dry weight of soil in the rooting zone (Harb *et al.,* 2007). Transfer factor (TF) is defined as the ratio of radionuclide concentrations in vegetation and soil. The soil to plant transfer factors were determined according to the relation (IAEA, 1994):

$$TF = \frac{\text{Activity concentration of radionuclides in plant Bq/kg }-1\text{dry crops}}{\text{Activity concentration of radionuclides in soil Bq/kg }-1\text{dry soil}} \tag{3.7}$$

The dry weight was preferred because the amount of radioactivity per kilogram dry weight is much less variable than the amount per unit fresh weight. It reduces uncertainties (IAEA, 1994).

3.6 Instrumentation

3.6.1 Sodium iodide thallium NaI(Tl) gamma spectroscopy

In this study, the activity concentration of radionuclides in the rice and sweet potatoes sample was analysed using NaI(Tl) scintillation detector supplied by United State of America (USA) as seen in Plate V. It was coupled through an amplifier base to a GS-2000-Pro plus Multichannel analyser used for samples analysis. The detector was enclosed in a 10 cm thick cylindrical lead shield to reduce the background radiation from various natural radiation sources and to isolate it from other radiation sources used in nearby surroundings. Each of the samples was mounted on the detector surface and each counted for 36,000 seconds. The configuration and the geometry were maintained throughout the analysis. A computer-based multichannel analyzer (MCA GS-2000-Pro) was used for the acquisition and analysis of gamma spectra using comparative method of analysis. The activity concentration was expressed in Bq/kg. ^{232}Th concentration in the rice and sweet potatoes samples was determined by the 2614.7 KeV gamma lines of ^{208}TI while the ^{238}Th concentrations were determined by the 1764.5 KeV gamma lines of ^{214}Bi. The activity concentration of ^{40}K was determined from its characteristic gamma line 1460.0 KeV.

Plate V: Laboratory Setup of the detector

Plate VI: RSS8 Gamma Source Set

3.6.1 Energy calibration of sodium iodide detector

In order to appropriately identify different peaks in the spectrum, the Sodium Iodide detector (Plate V and Plate VI) was calibrated for its energy and efficiency.

Standard energy sources with recognized gamma-ray energies and activities that are broadly different from those to be measured in the unknown spectrum, supplied by the RSS8 Gamma Source Set (Plate VI), Spectrum Techniques, LLC, USA, were used for the energy calibration of the detector. These standard calibration sources used for the calibration are shown in Table 3.3. The sources were counted 36,000 seconds to obtain a well-defined photopeak whereas the gain of the system was adjusted so that the photopeak of ^{137}Cs was about one-third the full scale. This ensured that the range of all radio-nuclides of interest was covered. The channel number that corresponds to the centroid of each Full Energy Peak (FEP) on the MCA was noted and recorded, and the slope and intercept calculations were automatically done by the computer system. The recorded values were used to obtain the calibration curve shown in Figure 3.2.

The energy calibration curve assures a precise comparison of the known full energy peaks (FEP) of the standard with the unknown FEP in the samples.

Table 3.3: Data for energy calibration of NaI(Tl) detector

Radionuclide	Energy (keV)	Channel Number
^{137}Cs	662	236
^{60}Co	1173	408
^{60}Co	1332	461

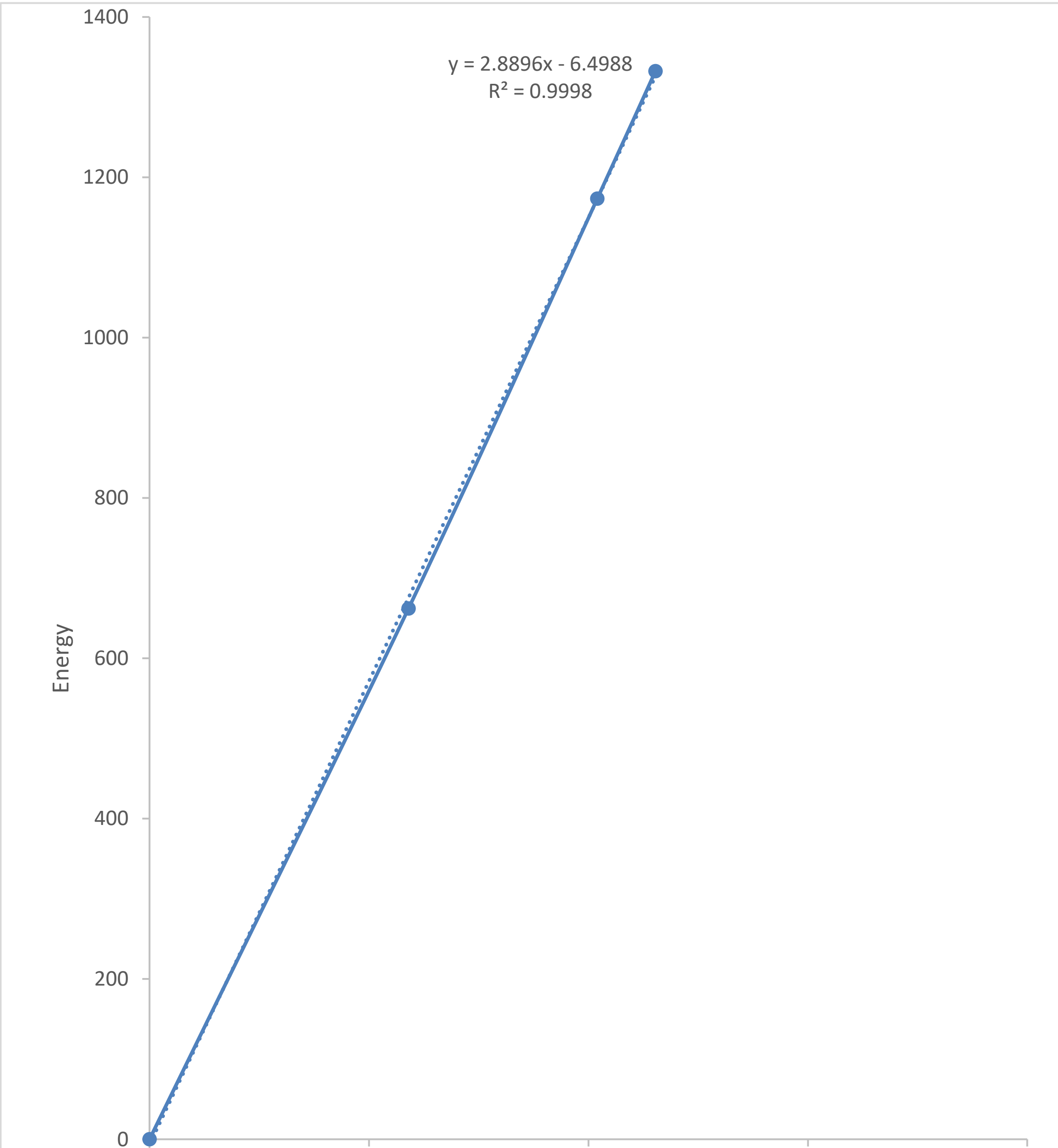

Figure 3.2: Energy caliberation curve of the source (Ibeanu, 1999).

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Activity Concentrations of Natural Radionuclides in Rice and Soil from Rice Farmlands and in Potatoes and Soil from Potatoes Farmlands.

Activity concentration of ^{238}U, ^{232}Th and ^{40}K in the rice and soil samples from the rice farmlands are presented in Table 4.1 and 4.2 respectively. Similarly, the specific activities of soil and potatoes samples from the potatoes farmlands are presented in Table 4.3 and 4.4.

From Table 4.1, the minimum activity concentration of 0.95±0.02 for ^{238}U was seen at Kardi farm, while the maximum value of 3.96±0.63 Bq kg^{-1}for ^{238}U was acquired at Makera farm with mean value of 2.81±0.21. Similarly, the minimum activity concentration of 4.73±0.15 Bq kg^{-1} for ^{235}Th was seen at Argungu farm, while the maximum activity concentration of 8.65±65 Bq kg^{-1} for ^{232}Th was obtained at B/kebbi farm with mean values of 6.22±0.42 Bq kg^{-1}. The minimum activity concentration of 60.77±1.09 Bq kg^{-1}for ^{40}K was seen at Kalgo farm, while the maximum value of 125.59±2.72 Bqkg^{-1} for ^{40}K was obtained at Gwandu farm with mean value of 84.27±1.69 Bq kg^{-1}. These results agreed with the previous study from Saeed *et al*. (2011), which reported the average concentration in Malaysia between the range of 18.33 Bq kg^{-1} to 25.10Bq kg^{-1} for ^{238}U, 35.49 Bq kg^{-1} to 64.97 Bq kg^{-1} for ^{232}Th and 64.802 Bq kg^{-1} to 109.929 Bq kg^{-1} for ^{40}K and was comparatively lower than the present study, though different location.

Ilemona *et al.* (2016) measured the mean activity concentrations of 41.15±5.41 and 10.36±1.72 Bq kg^{-1} in rice sample for ^{40}K and ^{232}Th respectively and their results were comparatively lower than the present study. Similarly, Reza and Fatemeh (2015) obtained activity concentration of 107.24±4.28 and 15.24±1.68 Bq kg^{-1} in rice samples for ^{40}K and ^{232}Th respectively in Iran, which indicated lower value than the present study. More also, Jose *et al.* (2015) measured the average concentration of 63.9±14 and 16.7±4 Bq kg^{-1} for ^{40}K and ^{232}Th respectively in Kerala, which was comparatively lower than the present study. This indicates that the results obtained from this present study are environmentally safe and friendly to the people living around the study area.

Table 4.1: Activity concentration (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in rice samples

Sample ID	**Site**	**Activity concentration (Bq kg^{-1})**		
		^{238}U	**^{232}Th**	**^{40}K**
RS1	B/kebbi	2.73±0.02	8.65±0.16	92.10±1.84
RS1	Bunza	3.10±0.13	6.33±0.15	101.19±2.72
RS3	Kalgo	1.72±0.18	5.29±0.27	60.77±1.17
RS4	Alieru	1.93±0.06	5.07±0.46	90.99±1.35
RS5	Argungu	1.95±0.08	4.74±0.77	86.22±1.91

RS6	Yauri	3.65±0.35	5.28±0.60	75.27±1.48
RS7	Kardi	0.95±0.63	6.21±0.75	68.16±1.09
RS8	Gwandu	2.96±0.24	19.14±2.39	125.59±2.46
RS9	Makera	3.96±0.06	14.31±2.74	69.83±1.68
RS10	Dukku	3.21±0.03	13.58±2.94	72.53±1.18
Min.		0.95±0.02	4.73±0.15	60.77±1.09
Max.		3.96±0.63	8.65±0.77	125.59±2.72
Mean		2.81±0.21	6.22±0.42	84.27±1.69

Table 4.2 shows the lowest activity concentration of 10.19±0.50 Bq kg^{-1} for ^{238}U was observed at Bunza farm, while the highest activity concentration of 19.56±1.98 for ^{238}U was obtained at Alieru farm with mean value of 14.42±1.31 Bq kg^{-1}. The minimum activity concentration of 13.58±0.43 Bq kg^{-1} for ^{232}Th was obtained at Dukku, while the maximum activity concentration of 32.77±3.02 $Bqkg^{-1}$ for ^{232}Th with mean values of 20.11±2.28 Bq kg^{-1}. The minimum activity concentration of 205.32±4.73 Bq kg^{-1} for ^{40}K at Makera farm, while the maximum concentration of 512.25±36.51 Bq kg^{-1} for ^{40}K was acquired at Gwandu farm with mean value of 336.90±17.11 $Bqkg^{-1}$ The overall mean activity concentration values are found to be lower than the recommended world average of 30, 35 and 400 Bq kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively (UNSCEAR, 2000). With this recommendation, the results obtained for this study is relatively in agreement with international standard and could be concluded that the study area is habitable.

Table 4.2: Activity concentration (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in soil from rice farmlands

Sample ID	Site	Activity concentration (Bq kg^{-1})		
		^{238}U	^{232}Th	^{40}K
SR1	B/kebbi	15.58±1.98	21.28±2.23	256.72±8.33
SR1	Bunza	10.19±0.50	15.08±0.43	409.92±16.16

SR3	Kalgo	13.58±1.09	19.29±1.77	321.66±4.73
SR4	Alieru	19.56±1.21	32.77±2.95	482.66±36.51
SR5	Argungu	14.66±1.23	17.84±3.02	372.38±29.74
SR6	Yauri	14.98±1.17	22.51±2.53	263.56±8.61
SR7	Kardi	13.44±0.92	25.29±1.77	242.50±9.18
SR8	Gwandu	16.9±1.45	19.14±2.39	512.25±29.87
SR9	Makera	12.25±1.56	14.31±2.74	205.32±8.80
SR10	Dukku	13.02±1.94	13.58±2.94	301.85±19.17
Min		10.19±0.50	13.58±0.43	205.32±4.73
Max		19.56±1.98	32.77±3.02	512.25±36.51
Mean		14.42±1.31	20.11±2.28	336.90±17.11

Table 4.3 shows the minimum activity concentration of ^{238}U in potatoes were found to be 0.18±0.03 Bqkg^{-1}, while the maximum activity concentration of 1.79±0.09 Bq kg^{-1} for ^{238}U for Bunza farm with mean values of 0.18±0.03 Bq kg^{-1}. The lowest activity concentration value of 1.01±0.14 Bq kg^{-1} for ^{232}Th were obtained at Kardi farm, while the highest value was 5.29±0.41 Bq kg^{-1}at Kalgo farm with mean value of 3.89±0.27 Bq kg^{-1}. The minimum activity concentrations of 81.55±0.15 for ^{40}K at Birnin Kebbi farm. Similarly, the maximum activity concentration of ^{40}K shows the highest value at 203.48±2.22 Bqkg^{-1} in Kalgo farm, while the mean value of ^{40}K were observed to be 116.92±1.32 Bq kg^{-1} with mean values of 116.92±1.32 Bq kg^{-1}. Similar, study was conducted by Asaduzzaman *et al.,* (2014), where the mean activity concentration of 282 and 17 Bq kg^{-1} in potatoes crops for ^{40}K and ^{232}Th respectively was found beyond the present study. Similarly, Ononugbo *et al.* (2019) obtained the mean activity concentration of 24.83±10.87, 859.41±2.47 and 746.08±0.48 Bq kg^{-1} in tubers crops samples for ^{238}U, ^{232}Th and ^{40}K respectively in Delta State, Nigeria, which is relatively higher than the present study. Van *et al.,* (2020) showed the mean activity concentration of 827and 3.39 Bq kg^{-1}for ^{40}K and ^{232}Th in sweet potatoes crops respectively in

Malaysia. This report indicated higher activity concentration in ^{40}K than the present study and lower activity concentration in ^{238}U and ^{232}Th than the present study. This may be attributed to variations in soil physio-chemical properties of the study areas and different fertilizers application.

Similarly, Van *et al.* (2020) reported the mean activity concentration of 363 and 0.70± 3.32 Bq kg^{-1} for ^{40}K and ^{232}Th in potato respectively in Malaysia. Alausa and Omotosho. (2017) obtained a mean activity concentration of 294.6 ± 137.2 for ^{40}K and of 18.2 ± 13.0 Bq kg^{-1} for ^{232}Th respectively in cassava at Ogun State, which indicated higher activity concentration in ^{40}K and lower activity concentration in ^{232}Th than the present study. Jibril *et al.* (2007) reported that the mean activity concentration of 423.7 ± 30.8 and 35.6 ± 12.3 Bq kg^{-1} in sweet potatoes for ^{40}K and ^{232}Th respectively in in Jos plateau, which was comparatively higher than the present study. This may be attributed to variations in soil physio-chemical properties of the study areas and different fertilizers application. According to Ilori *et al.* (2020), the measured mean activity concentration of 4.62 ± 2.40 and 105.97 ± 48.65 Bqkg^{-1} for ^{232}Th and ^{40}K respectively in South Africa, were comparatively higher than those of the present study.

Table 4.3: Activity concentration (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in sweet potatoes farmlands

		Activity concentration (Bq kg^{-1})		
Sample ID	**Site**	**^{238}U**	**^{232}Th**	**^{40}K**
PS1	Makera	1.2±0.09	4.56±0.14	104±1.99
PS2	Kalgo	0.51±0.07	5.29±0.26	203.48±2.22
PS3	B/kebbi	0.18±0.08	3.94±0.3	81.55±0.15
PS4	Bunza	1.79±0.03	4.69±0.24	102.82±1.25
PS5	Kardi	0.99±0.05	1.01±0.41	92.31±1.01

Min.	0.18±0.03	1.01±0.14	81.55±0.15
Max.	1.79±0.09	5.29±0.41	203.48±2.22
Mean	0.93±0.06	3.89±0.27	116.92±1.32

Table 4.4 shows the minimum activity concentrations of 5.76.55±1.09 for ^{238}U were seen at Kardi farm. The maximum activity concentration of 15.41±2.36 Bq kg^{-1} for ^{238}U was seen at Bunza farm with the mean value of 12.32±1.7 Bq kg^{-1}. The minimum activity concentrations of 9.28±1.34 for ^{232}Th were seen at Kardi farm. Similarly, the maximum activity concentration of 24.28±2.34 Bq kg^{-1} for ^{232}Th was seen at B/kebbi farm with mean values of 17.43±1.95 Bq kg^{-1}. The lowest activity concentration of 431.32±22.65 Bq kg^{-1} for ^{40}K were obtained at Kardi farm, and the highest activity concentration value of 220.55 Bq kg^{-1} for ^{40}K was obtained at Kalgo farm with mean value of 309.17±13.42 Bq kg^{-1}.This study revealed that the overall mean of the activity concentrations of the measured radionuclides (^{238}U, ^{232}Th and ^{40}K) shown in Table 4.4 were found to be 12.32, 17.43 Bq kg^{-1} and 309.17 respectively which were below the acceptable limits of 30, 35 and 400 Bq kg^{-1} respectively (UNSCEAR, 2000).

Table 4.4: Activity concentration (Bq kg^{-1}) of ^{238}U, ^{232}Th and ^{40}K in soil from sweet potatoes farmland.

Sample ID	**Site**	**Activity concentration (Bqkg^{-1})**		
		^{238}U	**^{232}Th**	**^{40}K**
SP1	Makera	14.85±1.35	16.85±01.34	232.01±9.78
SP2	Kalgo	10.29±1.26	14.80±2.32	431.32±22.65
SP3	B/kebbi	15.45±2.30	24.28±2.11	380.85±16.25

SP4	Bunza	15.30±2.36	21.96±2.11	281.55±10.72
SP5	Kardi	5.76±1.09	9.28±1.87	220.55±7.73
Min		5.76±1.09	9.28±1.34	220.55±7.73
Max		15.41±2.36	24.28±2.34	431.32±22.65
Mean		12.32±1.7	17.43±1.95	309.17±13.42

4.2 Radiological Interpretation of Rice and Potato from the Study Area

4.2.1 Absorb dose rate

The absorbed dose rate (nGyh^{-1}) in air due to the mean specific activities of ^{238}U, ^{232}Th and ^{40}K (Bq kg^{-1}) in the collected samples was calculated at 1m above the ground surface. It can be calculated using Eq. (3.5) (UNSCEAR, 2000)

4.2.2 Effective dose

Effective dose is a useful concept Effective dose is a useful concept in the radioactivity measurement that enables the radiation doses from different types of radiation and the doses by different organs to be added. It is based on the risks of radiation induced health effects and the use of International Commission on Radiological Protection (ICRP) metabolic model provides relevant conversion factors that permit the calculation of effective doses from the total activity concentrations of the radionuclides measured in food items (ICRP, 2007). The estimation of the radiation induced health effects associated with intake of radionuclides in the body is proportional to the total dose delivered by the radionuclides on accumulation in the various body organs. The radiation dose delivered when food is taken also known as effective dose is obtained by measuring how much is the activity concentration (Bqkg^{-1}) of the radionuclide in the food; multiplying it by how much food is consumed over a period of time (kgd^{-1}/kgy^{-1}) and then by a dose conversion physical factor ($SvBq^{-1}$) which gives an indication of how much dose caused by a unit radioactivity in the given body organ.

4.2.3 Gamma representation index

This is used to estimate the gamma radiation hazard associated with the natural radionuclide in specific investigated samples. The representative gamma index was estimated as shown in Table 4.6 (UNSCEAR, 2000)

$$I_\gamma = \frac{Cu}{150} + \frac{Cth}{100} + \frac{Ck}{1500} \leq 1 \qquad 4.1$$

Where, C_U, C_{Th}, and C_K are the activity concentration of ^{238}U, ^{232}Th and ^{40}K in the soil sample.

Table: 4.5 shows the absorbed dose rate in air was evaluated and their values ranged from 745.68 to 3992.77 $nGyh^{-1}$ with a mean value 1750.01 $nGyh^{-1}$, the external hazard index was evaluated and their values ranged from 0.91 to 0.89 with an average value 0.14, the internal hazard index was evaluated and their values ranged from 0.36 to 0.78 with an average value 0.52 which were all lower than the global limit of 1 $mSvy^{-1}$ (ICRP, 1990).

Table 4.5: External absorbed dose rate (D), Annual effective dose (AED) and representative gamma index (Iγ) for soil from rice farmlands

	Concentration radionuclides (Bq kg^{-1})			D(nGy^{-1})	E out	I_γ
Sample ID	**^{40}K**	**^{238}U**	**^{232}Th**			
SR1	15.58±1.98	21.28±2.23	256.72±8.33	1383.15	0.69	0.49
SR2	10.19±0.5	15.08±0.43	409.92±16.16	1561.65	0.92	0.49
SR3	13.58±1.09	19.29±1.77	321.66±4.73	1569.07	0.92	0.49

SR4	19.56±1.21	32.77±2.95	482.66±36.51	3992.77	0.89	0.78
SR5	14.66±1.23	17.84±3.02	372.38±29.74	1679.99	0.06	0.52
SR6	14.98±1.17	22.51±2.53	263.56±8.61	1501.19	0.84	0.5
SR7	13.44±0.92	25.29±1.77	242.5±9.18	1550.87	0.9	0.5
SR8	16.9±1.45	19.14±2.39	512.25±29.87	2477.24	0.04	0.65
SR9	12.25±1.56	14.31±2.74	205.32±8.8	745.68	0.91	0.36
SR10	13.02±1.94	13.58±2.94	301.85±19.17	1038.45	0.27	0.42
Min	10.19±0.5	13.58±0.43	205.32±4.73	745.68	0.91	0.36
Max	19.56±1.98	32.77±3.02	512.25±36.51	3992.77	0.89	0.78
Mean	14.42±1.31	20.11±2.28	336.9±17.11	1750.01	0.14	0.52

Table: 4.6 shows the absorbed dose rate in air was evaluated and their values ranged from 54.21 to 240 $nGyh^{-1}$ with a mean value 145.53 $nGyh^{-1}$, the external hazard index was evaluated and their values ranged from 0.07 to 0.29 with an average value 0.18, the internal hazard index was also calculated and their values ranged from 0.28 to 0.59 with an average value 0.47 which were lower than the global limit of 1$Msvy^{-1}$ set by (ICRP 1990).

Table 4.6: External absorbed dose rate (D), Annual effective dose (AED) and representative gamma index (Iγ) for soil from sweet potatoes farmlands

sample ID	**concentration of radionuclide(Bq kg^{-1})**			**D(nGyh^{-1})**	**E_{out}**	**Iγ**
	^{238}U	**^{232}Th**	**^{40}K**			
SP1	14.85±1.35	16.85±1.34	232.01±9.76	105.33	0.13	0.42

SP2	10.29±1.26	14.8±2.34	431.32±22.65	165.54	0.20	0.50
SP3	15.41±2.30	24.28±2.11	380.85±16.24	240.02	0.29	0.59
SP4	15.3±2.36	21.96±2.11	281.1±10.72	162.55	0.19	0.51
SP5	5.76±1.09	9.28±1.87	220.55±7.73	54.21	0.07	0.28
Min	5.76±1.09	9.28±1.34	220.55±7.73	54.21	0.07	0.28
Max	15.41±2.36	24.28±2.34	431.32±22.65	240.02	0.29	0.59
Mean	12.32±1.7	17.43±1.95	309.17±13.42	145.53	0.18	0.47

Table 4.7 shows the Transfer factor TF obtained. TF values for ^{238}U, ^{232}Th and ^{40}K were found to have the ranges of 0.01 - 0.32, 0.15 - 0.46 and 0.19 – 0.36 with average values of 0.18, 0.39 and 0.26 respectively, which is below the acceptable limits provided by (UNSCEAR, 2000). Therefore, this result indicates that the radionuclide intake from the consumption of rice grain yet poses no threat to public health. The outcomes of this work will support in establishing a baseline database of TF’s and radioactivity exposure to the general community from consumption of rice or other foodstuff.

Table 4.7: Soil-to-rice transfer factor (TF) of ^{238}U, ^{232}Th and ^{40}K

Sample ID	^{238}U	^{232}Th	^{40}K

RS1	0.18	0.41	0.36
RS2	0.30	0.42	0.25
RS3	0.13	0.27	0.19
RS4	0.09	0.15	0.19
RS5	0.13	0.27	0.23
RS6	0.24	0.23	0.29
RS7	0.15	0.25	0.28
RS8	0.18	0.39	0.25
RS9	0.32	0.46	0.34
RS10	0.25	0.44	0.24
Min	0.01	0.15	0.19
Max	0.32	0.46	0.36
Mean	0.18	0.39	0.26

Table 4.8 shows the transfer factor data for the radionuclides ^{238}U, ^{232}Th and ^{40}K in the sweet potatoes which ranges from 0.01 to 0.09, 0.07 to 0.35 and 0.21 to 0.49 with the mean values of 0.06, 0.19 and 0.32 respectively and were below the recommended limit of unity from (UNESCA, 2000). Therefore, this result indicates that the radionuclide intake from the consumption of rice grain yet poses no threat to public health. The outcomes of this work will support in establishing a baseline database of TF's and radioactivity exposure to the general community from consumption of rice or other foodstuff.

Table 4.8: Soil-to-sweet potatoe transfer factor (TF) of ^{238}U, ^{232}Th and ^{40}K

Sample ID	^{238}U	^{232}Th	^{40}K
PS1	0.08	0.21	0.41
PS2	0.05	0.35	0.49
PS3	0.01	0.20	0.25
PS4	0.09	0.14	0.21
PS5	0.07	0.07	0.25
Min	0.01	0.06	0.21
Max	0.09	0.35	0.49
Mean	0.06	0.19	0.32

The calculated *AEDE* values of rice to soil samples were exhibited in Table 4.9, the calculated values for AEDE ranges from 0.02 to 0.03mSvy^{-1} with the mean values of 0.02 mSvy^{-1}. In comparison to global measured values, these values were all below the assigned worldwide values of 0.42, 0.50 and 0.08 mSvy^{-1} respectively by UNSCEAR. As all measured values were lower than unity (Table 4.9), the locations from which the soil samples were collected were all safe according to the Radiation Protection 112, and such locations can be classified as hazard-free (ICRP, 1990). Accordingly, such places can be used as agricultural lands without posing any significant radiological threat to the population.

Table 4.9: Annual effective dose for ingested radionuclide (AEDi) from rice

Sample ID	^{238}U	^{232}Th	^{40}K	AEDi
RS1	2.73	8.65	92.1	0.03
RS2	3.11	6.33	101.19	0.03
RS3	1.72	5.29	60.77	0.02
RS4	1.93	5.07	90.99	0.02
RS5	1.95	4.73	86.22	0.02
RS6	3.65	5.28	75.27	0.02
RS7	0. 95	6.21	68.16	0.02
RS8	2.96	7.46	125.59	0.03
RS9	3.96	6.62	69.83	0.02
RS10	3.21	5.98	72.53	0.02
Min	1.72	4.73	60.77	0.02
Max	3.96	8.65	125.59	0.03
Mean	2.80	6.162	84.265	0.02

Table 4.10 shows the overall AEDi activity concentrations of radionuclide (^{238}U , ^{232}Th and ^{40}K) in the sweet potatoes crops and the value ranged from 0.18 to 0.44 with the mean value of 0.26. As all measured values were lower than unity (Table 4.10), the locations from which the soil samples were collected were all safe according to the Radiation Protection 112, and such locations can be classified as hazard-free (ICRP, 1990). Accordingly, such places can be used as agricultural lands without posing any significant radiological threat to the population.

Table 4.10: Annual effective dose for ingested radionuclide (AEDi) from sweet potatoes

Sample ID	^{238}U	^{232}Th	^{40}K	AEDi
PS1	1.2	4.56	104.42	0.23
PS2	0.51	5.29	203.48	0.44
PS3	0.18	3.94	81.55	0.18
PS4	1.79	4.69	102.82	0.23
PS5	0.99	1.01	92.31	0.20
Min	0.18	1.01	81.55	0.18
Max	1.79	5.29	203.48	0.44
Mean	0.93	3.89	116.91	0.26

Figure 4.1 shows the plotted result of concentration of ^{238}U, ^{232}Th, ^{40}K in rice sample. As seen in the plots, the activity concentration of ^{40}K was higher compared to ^{232}Th and ^{238}U as the ^{40}K was relatively abundant in the earth crust and also the vast use of fertiliser by the local farmers in other to enhance crop yield.

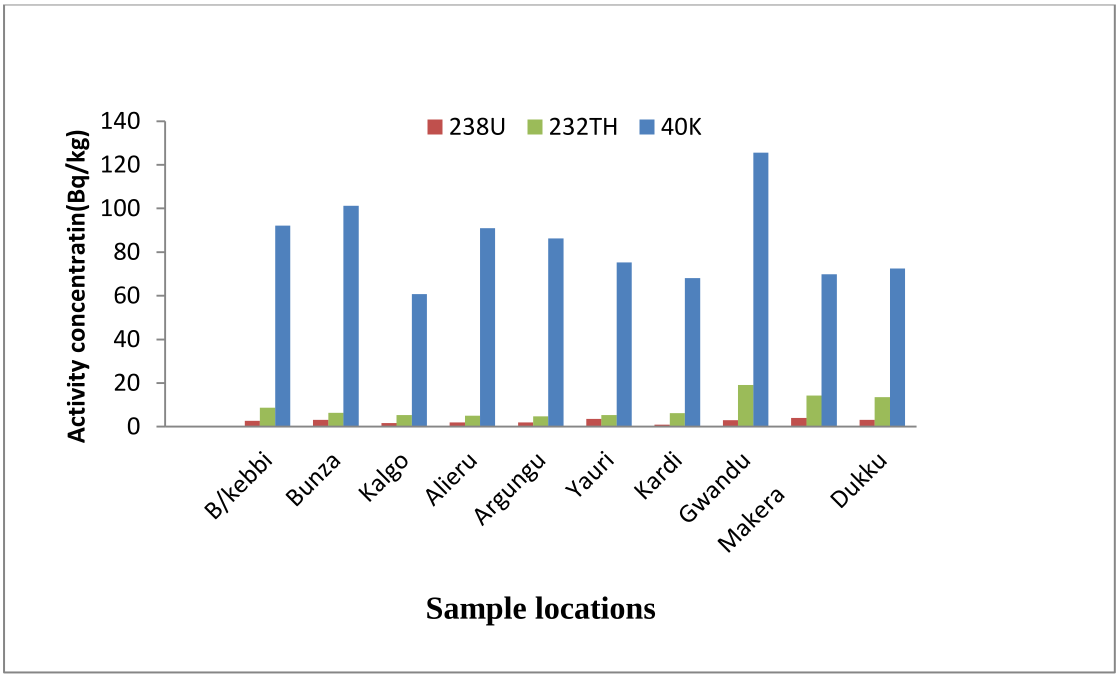

Figure 4.1: Activity concentrations of ^{238}U, ^{232}Th, ^{40}K in rice farmlands.

Figure 4.2 shows the plotted result of concentration of ^{238}U, ^{232}Th, ^{40}K in soil from rice sample. As seen in the plots, the activity concentration of ^{40}K was higher compared to ^{232}Th and ^{238}U as the ^{40}K was relatively abundant in the earth crust and also the vastly use of fertiliser by the local farmers in other to enhance crop yield.

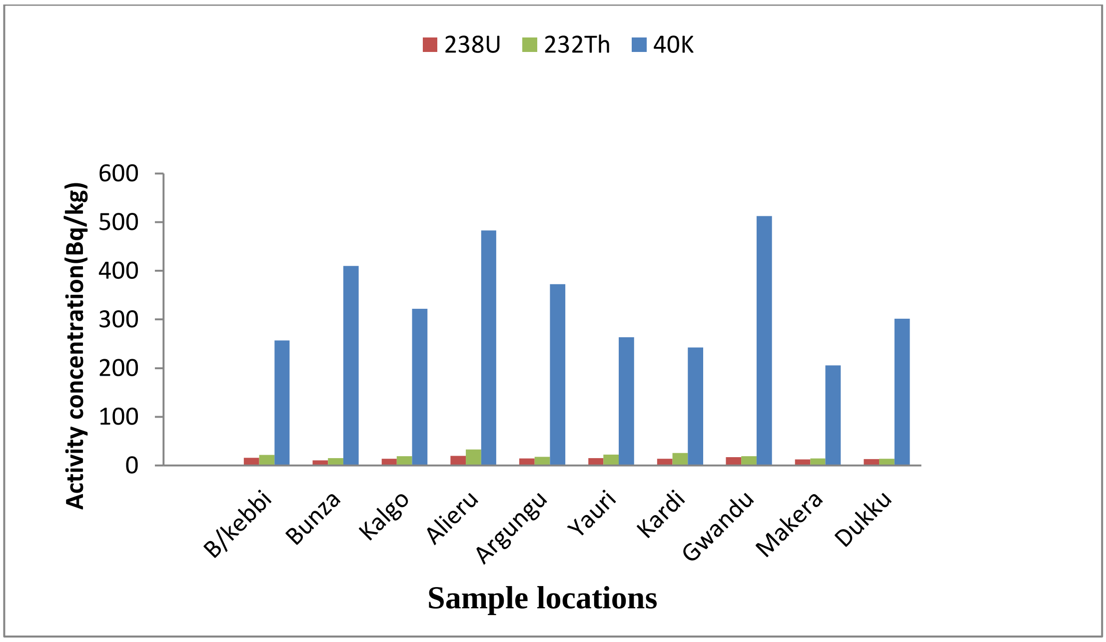

Figure 4.2: Activity concentrations of ^{238}U, ^{232}Th and ^{40}K soil-rice sample

Figure 4.3 shows the plotted result of activity concentration of ^{238}U, ^{232}Th, ^{40}K in sweet potatoes sample as a function of sample measurement. The activity concentration of ^{40}K was higher compared to ^{232}Th and ^{238}U as the ^{40}K was relatively abundant in the earth crust and also the vastly use of fertiliser by the local farmers in other to enhance crop yield.

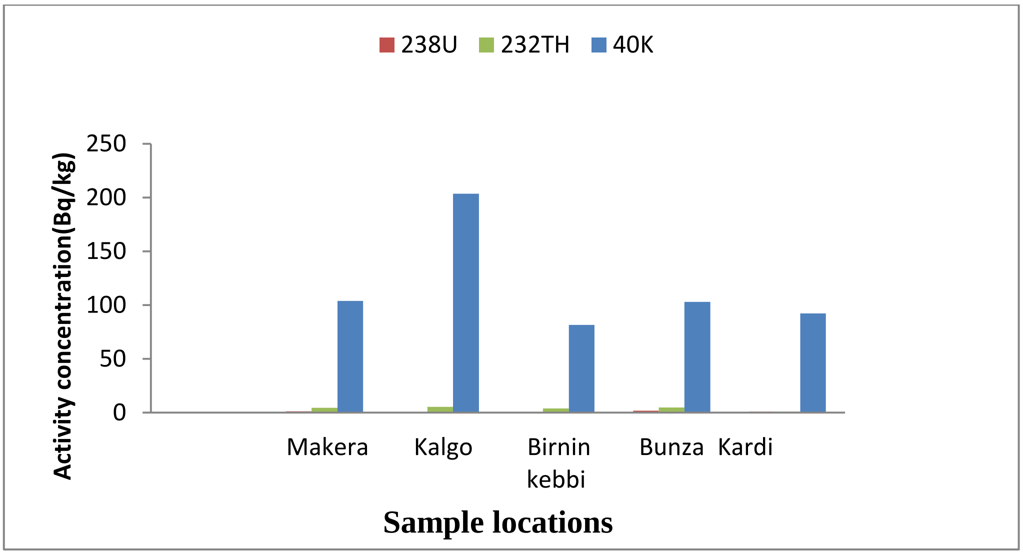

Figure 4.3: Activity concentrations of ^{238}U, ^{232}Th and ^{40}K in sweet potatoe sample.

Figure 4.4 is the plotted result of level of the activity concentration of natural radionuclide in soil from sweet potatoes sample, the plot clearly show the level of concentration of radionuclides which ^{40}K having the highest values in all the selected farmlands than ^{238}U and ^{232}Th, this is due to the use of fertilizer by the farmers to enhance crop yield.

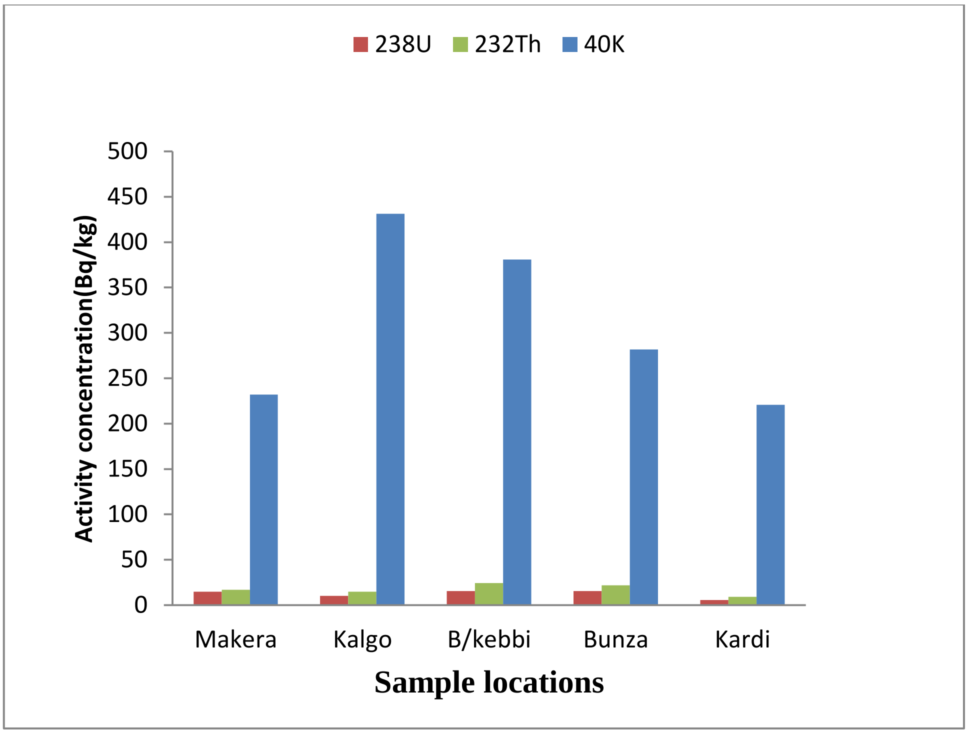

Figure 4.4: Activity concentrations of ^{4238}U , ^{232}Th and ^{40}K in soil for sweet potato sample.

Figure 4.5 is the plotted result transfer factor of natural radionuclides in rice Figure 4.6 shows the transfer factor of natural radionuclides in Rice sample which shows the values were all below the precautionary limit of one set by UNSCR (2000). Therefore, this study indicates that the radionuclides intake from the consumption of rice grain yet poses no threat to public health. The outcomes of this work will support in establishing a baseline database of TF’s and radioactivity exposure to the general community from consumption of rice or other foodstuff.

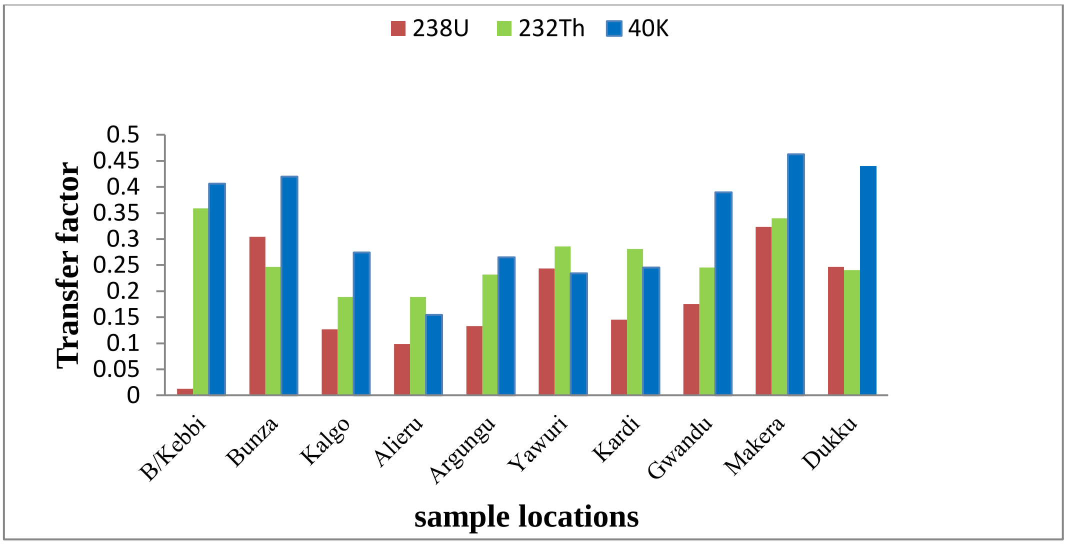

Figure: 4.5: Transfer factor of radionuclides ^{238}U, ^{232}Th and ^{40}K in rice sample.

Figure 4.6 shows the transfer factor of natural radionuclides in sweet potatoes sample which shows the values were all below the precautionary limit of one set by UNSCER (2000). Therefore, this study indicates that the radionuclides intake from the consumption of rice grain yet poses no threat to public health. The outcomes of this work will support in establishing a baseline database of TF's and radioactivity exposure to the general community from consumption of rice or other foodstuff.

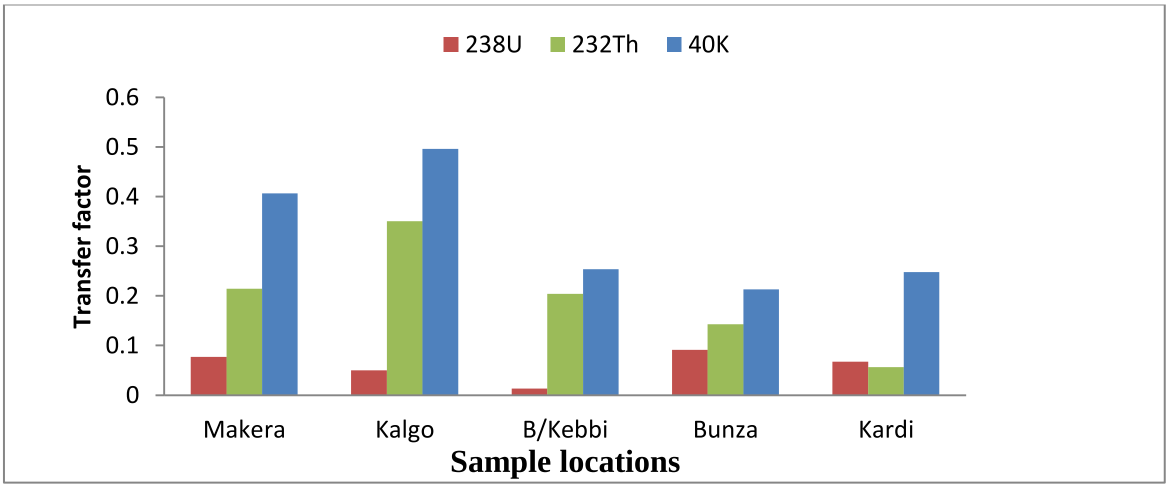

Figure: 4.6: Transfer factor of radionuclides in sweet potato sample

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

This study details the bioaccumulation of natural radionuclide in rice and sweet potatoes samples and the corresponding soil acquired from selected farmlands of Kebbi State, Nigeria. The samples were assessed using gamma-ray spectroscopy technique which employ NaI(Tl) detector. The possible radiological effects due to the ingestion of these crops were also computed. The above results show that mean activity concentration of ^{238}U, ^{232}Th and ^{40}K for soil sample from the rice farms were 14.42±1.31, 20.11±2.28 and 336.90±17.11 Bq kg^{-1} accordingly. Similarly, the average values of ^{238}U, ^{232}Th and ^{40}K for soil sample from sweet potatoes farmlands were 12.32±1.7, 17.43±1.95 and 309.17±13.42 Bqkg^{-1} in sequence. These values were found to be lower than the world average values of, 30, 35 and 400 Bq kg^{-1} respectively for ^{238}U, ^{232}Th and ^{40}K in soil and rocks provided by the United Nations Scientific Committee on the Effects of Atomic Radiation. Also, it was observed that ^{40}K has the highest activity concentration than ^{232}Th and ^{238}U in both crops and the corresponding soil samples. This is because ^{40}K is relatively abundant in the earth crust and also the use of fertilizer by the local farmers in other to enhance crop yield and nutrient absorption form the soil. The mean transfer factor (TF) for ^{238}U, ^{232}Th and ^{40}K in rice samples were 0.18, 0.33 and 0.26 respectively; while in sweet potatoes samples value of TF for ^{238}U, ^{232}Th and ^{40}K were 0.59, 0.19 and 0.32 respectively. The calculated dose was found to be lower than the dose limit (1 mSv/year) from International Atomic Energy Agency standards (IAEA, 2010). Concerning radiological hazards, the results show that the derivable radiological hazard indices e.g. absorbed gamma dose rate, annual effective dose equivalent, external and internal radiation indices predict an inconsequential impact on environment and on human health.

5.3 Recommendations

Sequel to the insignificant level of concentration of radionuclides reported in this research, improve actions towards maintaining a safer level rates in Kebbi State by both farmers and local authorities are urgently vital. These would protect both man and the environment from the dangers associated with exposure to high level of radiation. In line with radiation protection protocol, the following recommendations are hereby put forward:

(i) Evaluation of transfer factor (TF) of other common edible plants in Kebbi State should be carried out in other to have a data base for radiological safe farm produce.

(ii) Research on the effect of farm practice on the evaluated TF should be conducted as well so as to ascertain the input of the practices on radionuclide transfer.

(iii) Culture plants in terms of planting date, fertilizer level, water supply and harvesting dates to conform to best practices and effects on TF should be investigated for other food crops in Nigeria.

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