FEDERAL UNIVERSITY OF PETROLEUM RESOURCES,
EFFURUN, DELTA STATE, NIGERIA

6TH INAUGURAL LECTURE

FEDERAL UNIVERSITY OF PETROLEUM RESOURCES, EFFURUN

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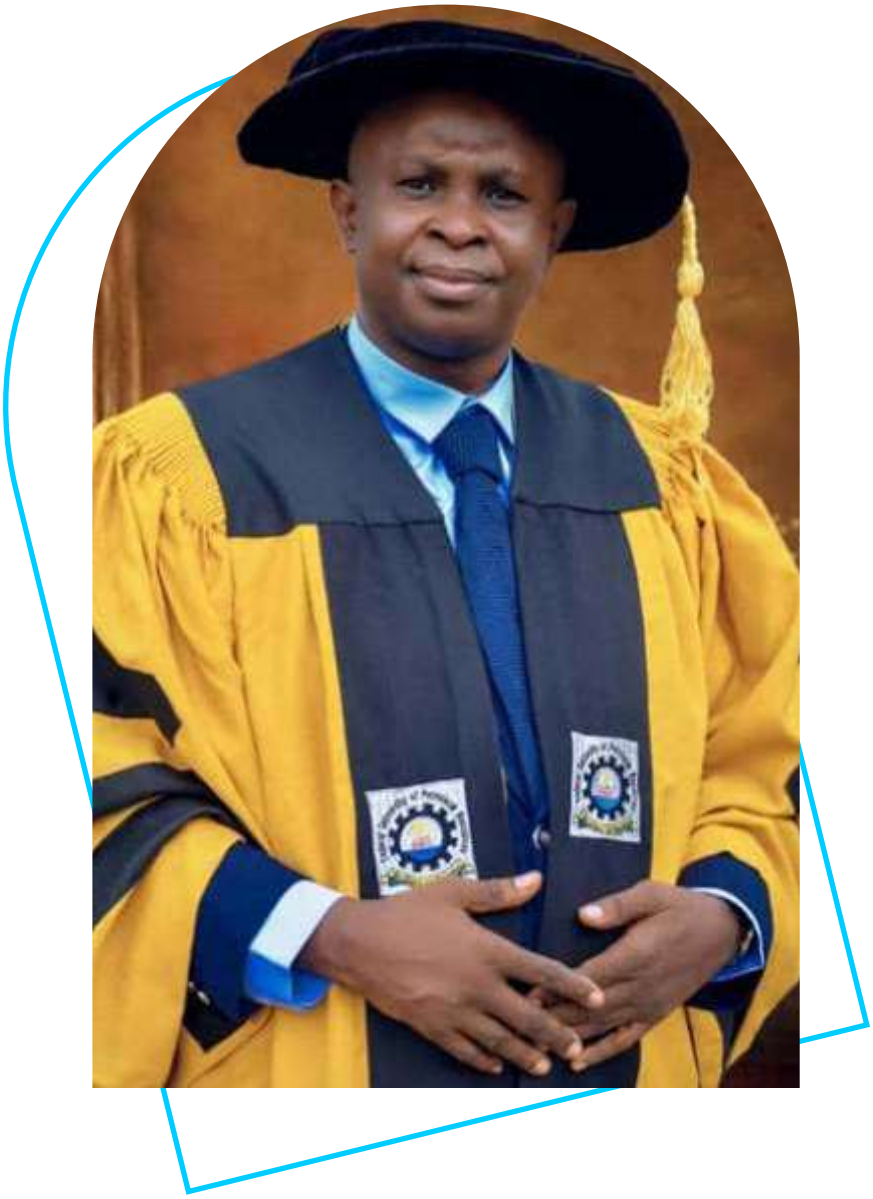

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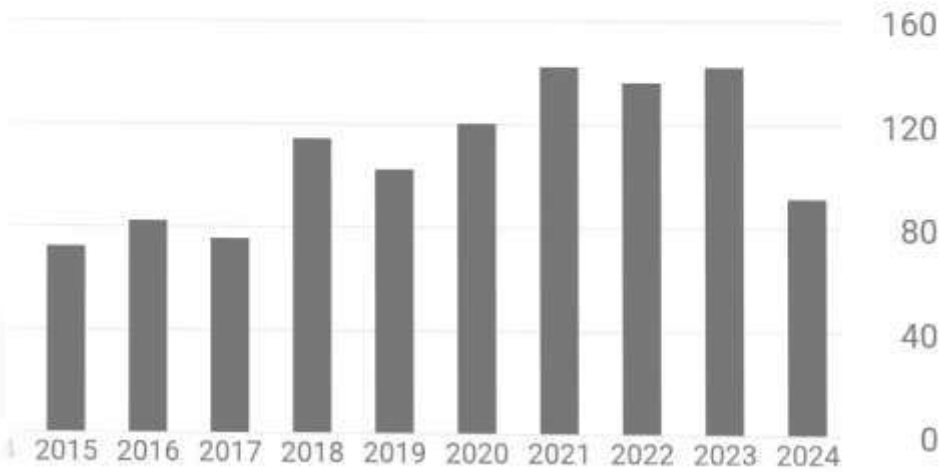

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6th INAUGURAL LECTURE

RADIATION RAIN, RUIN BUT REIGN, -MAN IN THE RING

PROFESSOR EZEKIEL OGHENENYERHOVWO AGBALAGBA

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DEDICATION

The inaugural lecture is dedicated to the Lord God Almighty, from Whom all mercies flow, and to my late father, Pa. Gabriel Onoavwavwa Agbalagba Okpogho.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

PROTOCOL

The Vice Chancellor, FUPRE

The Principal Officers of the University:

Deputy Vice Chancellor (Administration),

Deputy Vice Chancellor (Academic),

The Registrar,

The Bursar,

The University Librarian,

Members of University Governing Council

Deans of Colleges

Professors and All members of FUPRE Senate

Directors of Institutes and Units

Heads of Departments

Royal Fathers and Chiefs Presents

My Lords Spiritual and Temporal

The Town and Gown

Distinguished invited guests

Our Great FUPRITE Staff & Students

Gentlemen of the Press

Ladies and Gentlemen

PREAMBLE

The Fundamental Concept of the Inaugural Lecture Title

Vice Chancellor sir, it is with a great sense of fulfilment, and privilege to stand on this podium in history today, to deliver the Federal University of Petroleum Resources Effurun 6th inaugural lecture.

The choice of the topic of an inaugural lecture is often difficult because of the several research interests of the lecturer having traversed several years.

However, a reflection of the rough road to Physics as a career coupled with the scope of my research activities over the years facilitated my choice of today's lecture title.

I am therefore highly humbled, and honoured to climb this academic alter, joining the roll call of scholars to present my inaugural lecture titled "***Radiation Rain, Ruin but Reign, Man in the Ring''***.

Mr. Vice Chancellor sir, inaugural lecture illuminates the society of the academic trajectory one traversed to reach the professorial rank, my lecture today will not be different from this age long tradition.

As our life is liken to a road of twists and turns, so likewise the pattern our career lives follow.
It leads us to different career path. I wish to share my personal experience to justify these claims.

Mr. Vice chancellor I grew up in a small village called Omavovwe in Agbarha-otor kingdom, I had my primary education partly in the village (Okpaode Primary School Omavovwe) and partly at Ogodo primary school, Sapele., With a distinction from the primary six final examinations, there was great enthusiasm and zeal to proceed to secondary school.

Ibru College Agbarha-tor, was a pride among secondary schools then and I was proud to pass the entrance examination with distinction, thus admitted into JSS 1A without ado (without going to see the son of somebody who known somebody in high places).

At secondary school, I was a very active member of Junior Engineering Technology and Science (JETS) club, we echoed the choice of courses we intend studying at the university at any opportunities or fora that JETS availed us.

I anchored on mechanical engineering for three reasons; one, to be like those engineers I met while going to farm, servicing crude oil wellheads in my village, putting on fine coverall with reflective jackets, two, a friend of my cousin I so admired, who is a Mechanical engineer and was working in one of the drilling rigs as assistant tool pusher, and three, to bear the title of an engineer, as some highfliers in the oil and gas industry then were engineers.

The quest to make a career in the engineering field and most importantly to be a mechanical engineer attracted me to science subjects in the secondary school.

With vigor, I studied hard to ensure I passed the required subjects that will qualify me to study engineering in the university, but with little or no counsel or mentorship.

We the class of 1994, disdained and despised English language partly due to lack of qualified teacher in the school then and partly because the requirement to study Mechanical and other Engineering courses, was five credit passes with a pass in English language. Here comes the life twist, in 1994/1995 I had my O'level results with a pass in English language "I am good to go" I proclaimed.

I enrolled for Joint Admission and Matriculation Board (JAMB) examination same year and the results was fantastic. With confidence I got to University of Benin to inquire of when my admission will be released.

I can still vividly remember the admission officer's response then after assessing my credentials “Young man, you must be an intelligent student but a pass in English language debarred you from been admitted as the condition for admission into Mechanical engineering has changed to include a credit pass in English”. I sort for clarification on the word 'debar' which he replied 'prevent'. At that moment my frustration new no bound. I was later advised by my cousin to pick a pre-degree form of the Delta State University Abraka (DELSU) as alternative which I did to study geology, but the same condition of a credit pass in English language was also applicable in Geology.

The only option left for me that year was to read PHYSICS, which I reluctantly accepted hoping to change course at a later date. In all these, providence was shaping my destiny to a career and profession I now so much loved and cherished.

Mr. Vice Chancellor sir, I stand here with all sense of humility, but with pride, gratitude, and honour for this great gathering and convergence of my Royal and Spiritual fathers, Chiefs, teachers and mentors, mentees, colleagues, peers, comrades, students, family members, friends, town, and gown in one roof to listen to my academic voyage and contributions to knowledge in my chosen career path. Globally, the ivory towers encourage newly elevated staff to the rank of professors to deliver their inaugural lectures, though it has been argued among scholars on the right time to deliver one's inaugural lecture. But I choose to partly align with the opinion of the British Mathematician, Godfrey Harold Hardy (1877-1947) who stated and I quote “It is one of the first duties of a professor, in any subject, to exaggerate a little both the importance of his subject and his own place in it”. In delivery this inaugural lecture, I will dwell on the core and importance of my chosen title, my chosen field of Environmental Radiation, Health and Nuclear Physics and the niche I have carved for myself will be amplified, while I leave the exaggeration for Godfrey Hardy.

Mr. Vice Chancellor Sir, the promotion letter issued to me announcing my elevation to the rank of a professor, specified the area where I should, and I am professing (Environmental Radiation and Health Physics). Thus, in elucidating this audience of my academic journey and trajectory, I seek your kind permission sir, to intermittently speak the language of Physics and Radiation in particular to drive home the intent and purpose of this lecture.

Mr. Vice Chancellor, to irradiate this gathering on the chosen title of my Inaugural lecture “Radiation Rain Ruin but Reign, Man in the Ring” I wish to explain these 5Rs for the Town and Gown to appreciate.

Radiation. Radiation is defined as the energy that emanates from a source, travels through space, and has the potential to penetrate a variety of materials. Simply put, radiation is the propagation or transmission of energy from a source through space. Examples include; the use of remote control in the home, the emission coming from the sun, the radiation from the computer system, the emission from the GSM hand sets and masts, the radiation exposure from the x-ray machine, CT scan machine, the mammogram machine, and the exposure from the emission from gas flare, the emission from radioactive materials and other countless sources.

Rain. Radiation is term omnipresence because it is everywhere on the planet earth, be it terrestrial, water, air (atmosphere), the food we eat, on the clothes we wear and the human body itself. Thus, human beings are continuously exposed to both natural and artificial sources of radiation, and these are classified into ionizing and non-ionizing radiations (UNSCEAR, 2000). The entire universe is encompassed with radiation emission, be it natural or man-made. Figure 1, gives us a glimpse into the abundance (Rain) of radiation in our environment.

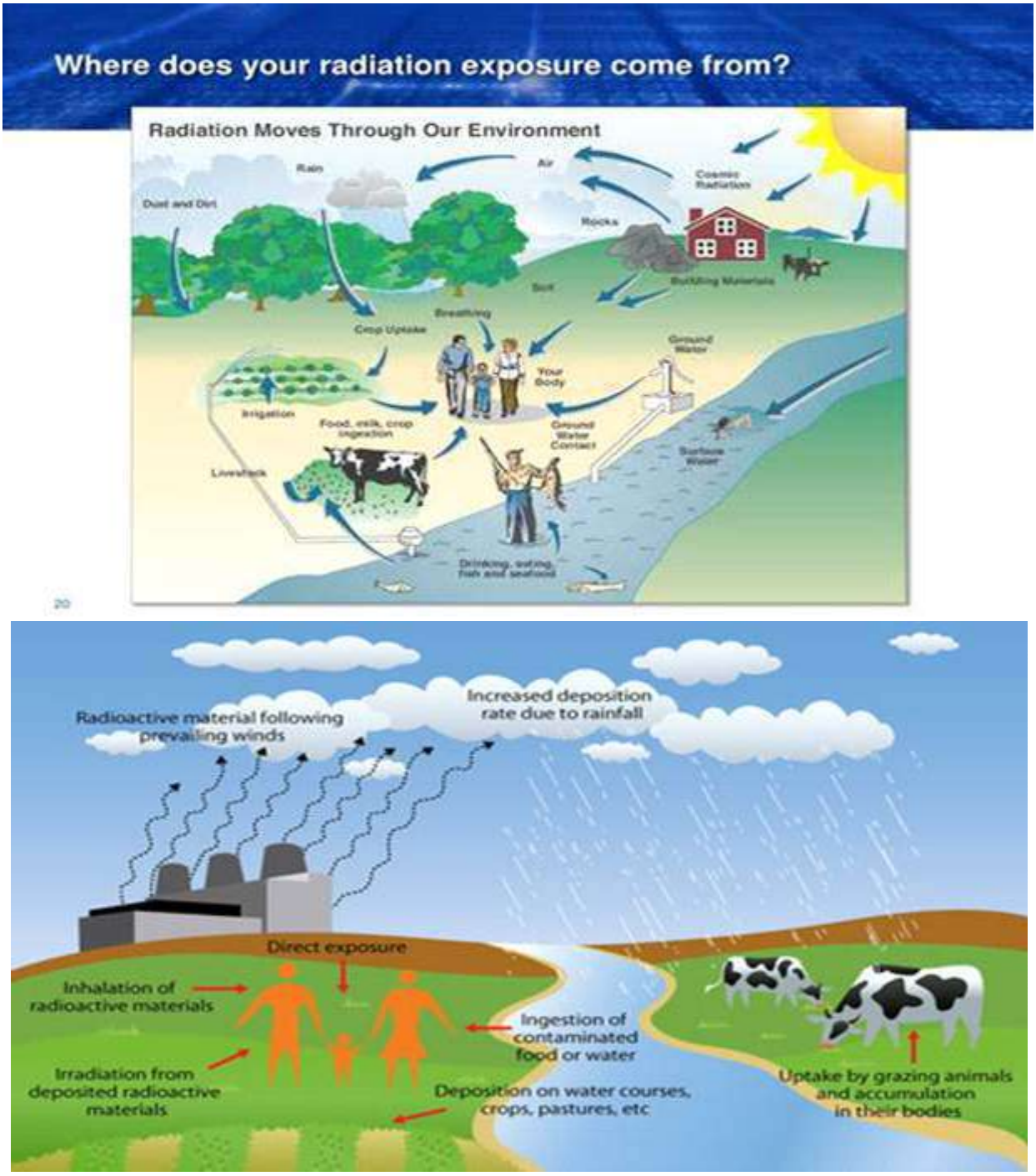


Figure 1: Different Sources of Radiation in the Environment ***(Canadian Nuclear Safety Commission, 2018)***

Ruin: Exposure to non- ionizing radiation is considered less harmful, because its effects are limited to just thermal damages, biological and physiological effects etc., but exposure to ionizing radiation can cause injuries and clinical symptoms which may include a chromosomal transformation, cancer induction, free radical formation, bone necrosis, cataract, and in extreme case death. The misapplication, misuse and accidental discharge of nuclear, radiation and radioactive materials always leads to advance effects on man and the environment when received in high dosage.

The atomic bombings detonated in Hiroshima and Nagasaki in 1945 during the World War II, indicate that the principal long-term effect of radiation exposure is the increase in the frequency of cancer, leukemia, and DNA alteration leading to mutation in residents of these cities, is a special case of reference of radiation ruin. The March 11, 2011, news of the earthquake /tsunami in Japan which caused a high level of devastation to the environment with a consequential

destruction to the power unit of Japan's nuclear facility known as FUKUSHIMA DAIICHI Plant also easily comes to mind. The1988 Koko radioactive waste (toxic) dump which causes Thus, radiation can ruin, and it is therefore proper to say that radiation *Ruin,* but *it reigns;*

Reign: Radiation has proven to be a double-edged sword (potent mutagen and carcinogen) since its discovery by the Physics Nobel prize winner, William Roentgen in 1895, however, at present, radiation is not only indispensable in medical diagnoses and treatment but is widely used in fundamental research and practical applications in various fields of science and technology *(ICRP, 2020, IAEA, 2022, WHO, 2023)*. There are thousands and thousands of areas today where radiation applications play key roles in the revolutionization of the critical sectors of the world economy (reigns). Mr. Vice Chancellor, permit me to mention but a few. In the oil and gas industry, radiation is deployed in non-destructive testing, in well logging, geophysical investigation in oil and gas exploration etc. Radiation and radionuclide applications are gradually replacing the conventional practices in the medical industry. Today radiation and radionuclide applications play key roles in radiotherapy, medical diagnosis, disease treatment and in remote surgery, in fact in the near future, clinical medicine will all be radiation driven. The energy section has its fair share in radiation application specifically in nuclear power plants and Laser. The food industry has extensive apply radiation technology in food preservation and treatment through irradiation, genetic engineering. Other critical areas where radiation finds great application includes, disaster management, military, and general security. It is therefore safe and appropriate to say that radiation ***Reign***s. ***The Bee may sting, but it has the HONEY.***

The ***Ring****.* In all the good, the bad and the ugly radiation throw onto the society and the environment, man is at the epic center *(Ring)* of all radiation episode, thus, ***Man in the Ring.***

Mr. Vice Chancellor sir, distinguished ladies and gentlemen, It is on this firm understanding that I titled this 6th inaugural lecture of Federal University of Petroleum Resources, Effurun **"Radiation Rain, Ruin but Reign, Man in the Ring"**, to elucidate this great audience my role and niche in environmental radiation protection, health, and safety in actualizing the mission and vision of FUPRE in repositioning the oil and gas sector in Nigeria, sub-Sahara Africa and globally, I will now proceed into the core of this lecture.

1. INTRODUCTION

Physics as a branch of science is concerned with the nature, properties of matter and energy with several branches (see figure 2). It is defined as the science that deals with the structure of matter and the interactions between the fundamental constituents of the observable universe *(Einstein's 1926 Britannica essay on space-time).* Mr. Vice Chancellor sir, as the book of Matthew in the first chapter tells us about the genealogy of our Lord Jesus Christ, so has Physics begat Classical Physics, which begat Modern Physics, and it begat Atomic physics which begat Nuclear Physics and Radiation Physics is a progeny of Nuclear Physics and the sixth in the genealogy of Physics. I shall dwell more in the course of this lecture on Radiation Physics, as it affects and relates to the environment, human health and radiation protection.

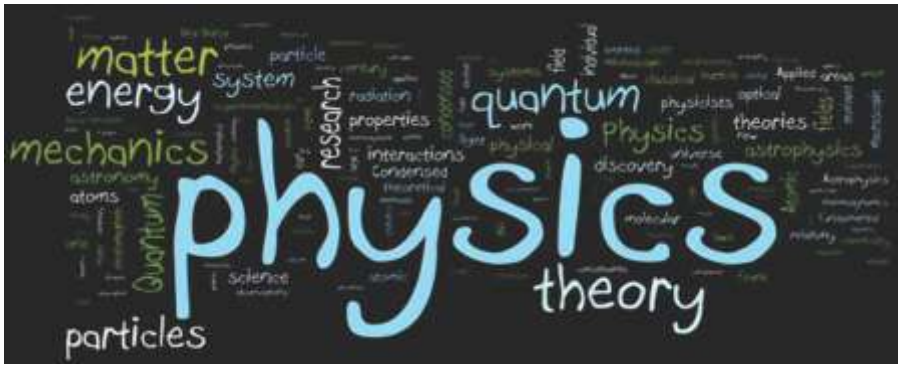


Figure 2: The definition and branches of Physics

1.1 Radiation

The term "radiation" can be defined as energy that is emitted as electromagnetic waves or particles and travels through the atmosphere or a material medium (Avwiri, 2011; Farai, 2014). Since the Big Bang, radiation has been present everywhere in the environment (Dinh *et al.,* 2011). We feel the effects of radiation when we work in the field on a sunlit day, or when we stay by the fire side, this is demonstrated in figure 3.

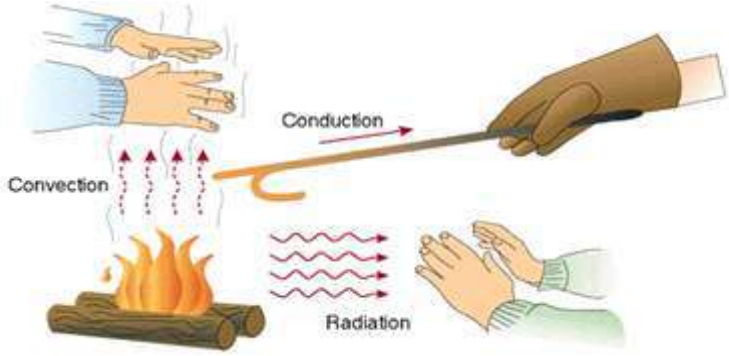


Figure 3: Radiation Demonstrated

According to the International Atomic Energy Agency (IAEA) Report (2022), Radiation is energy that moves from one place to another in a form that can be described as waves or particles. The word "radiation" arises from the phenomenon of waves radiating (i.e., traveling outward in all directions) from a source. This aspect leads to a system of measurements and physical units that apply to all types of radiation. Because such radiation expands as it passes through space, and as its energy is conserved (in vacuum), the intensity of all types of radiation from a point source follows an inverse-square law shown in equation 1, in relation to the distance from its source. Like any ideal law, the inverse-square law approximates a measured radiation intensity (x) to the extent or distance from the source point (d).

$$x \; \alpha \frac{1}{d^2} \qquad (1)$$

Therefore, I will in context of this lecture define ***"Radiation as a natural phenomenon of emission of energy in form of electromagnetic that obey Pauli's exclusive principal, travels through space or medium and impact on man and the environment"***. Radiation is always around us all the time, as such, man is constantly exposed to it. This exposure has influenced our survival, reproduction, and evolution. Radiation is of different forms and they have different properties and effects. The sources of radiation are either ***natural or man-made***. According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), there are four major sources of natural radiation; cosmic radiation, terrestrial radiation and intake of Naturally Occurring Radioactive Materials (NORM) through inhalation and ingestion. Figure 4, shows these natural sources of radiation.

i. **Natural Sources of Radiation**

1. **Cosmic radiation:** cosmic radiation originates from the sun and other celestial events in the universe. Eventually, some ionizing radiations penetrate the earth's atmosphere and become absorbed by humans which results in natural radiation exposure.
2. **Terrestrial radiation:** the composition of the earth's crust is a major source of natural radiation. The main contributors are natural deposits of Uranium, Potassium and Thorium, which in the process of decay releases some amounts of ionizing radiation. Traces of these minerals are also found in building materials.
3. **Inhalation:** most of the variation in exposure to natural radiation results from the inhalation of radioactive gases produced by radioactive minerals found in soil and the bedrock. An example of such radioactive gas is Radon; Radon gas is the largest source of natural radiation exposure, an odourless and colourless radioactive gas produced by the decay of Uranium.
4. **Ingestion:** trace amounts of radioactive minerals are naturally found in food and drinking water. For instance, vegetables are typically cultivated in soil and ground water which contains radioactive minerals. Once ingested, these minerals result in internal exposure to natural radiation. Some of the essential food nutrients like potassium and carbon have radioactive isotopes that contribute significantly to our background radiation dose.

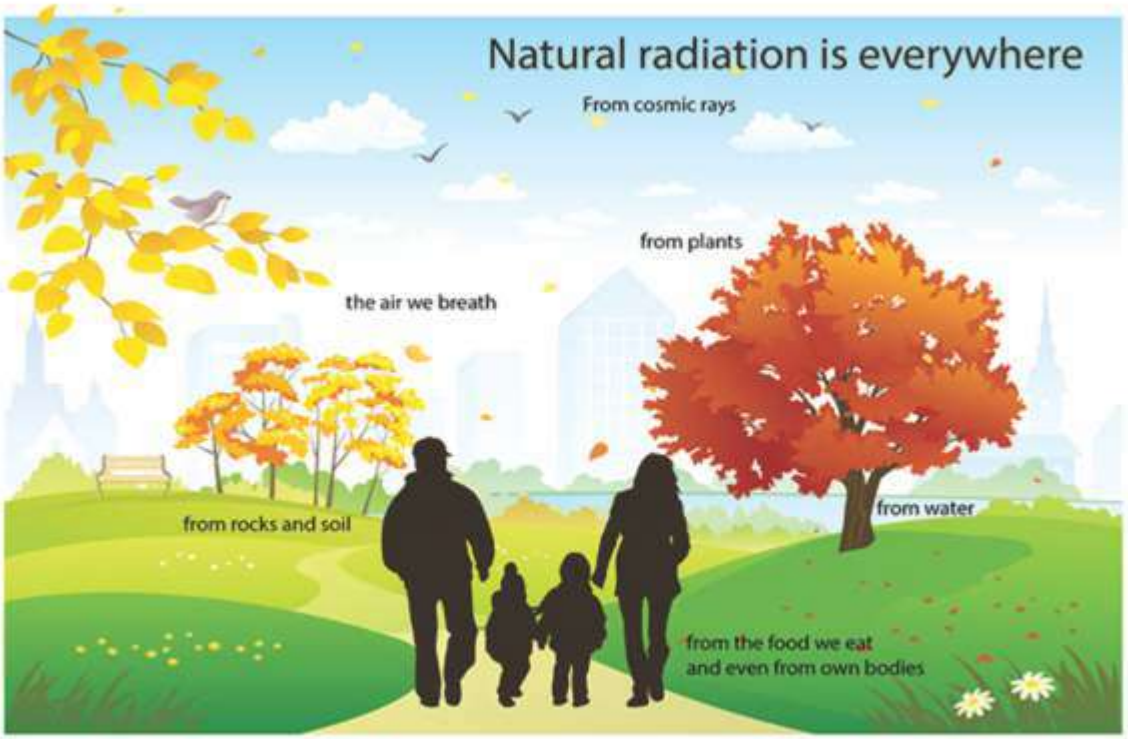


Figure 4: Sources of natural radiation *(UNSCEAR, 2008)*

Exposure to man-made sources of radiation differs for members of the public and Occupationally Exposed Individuals.

ii. Man-made Sources of Radiation

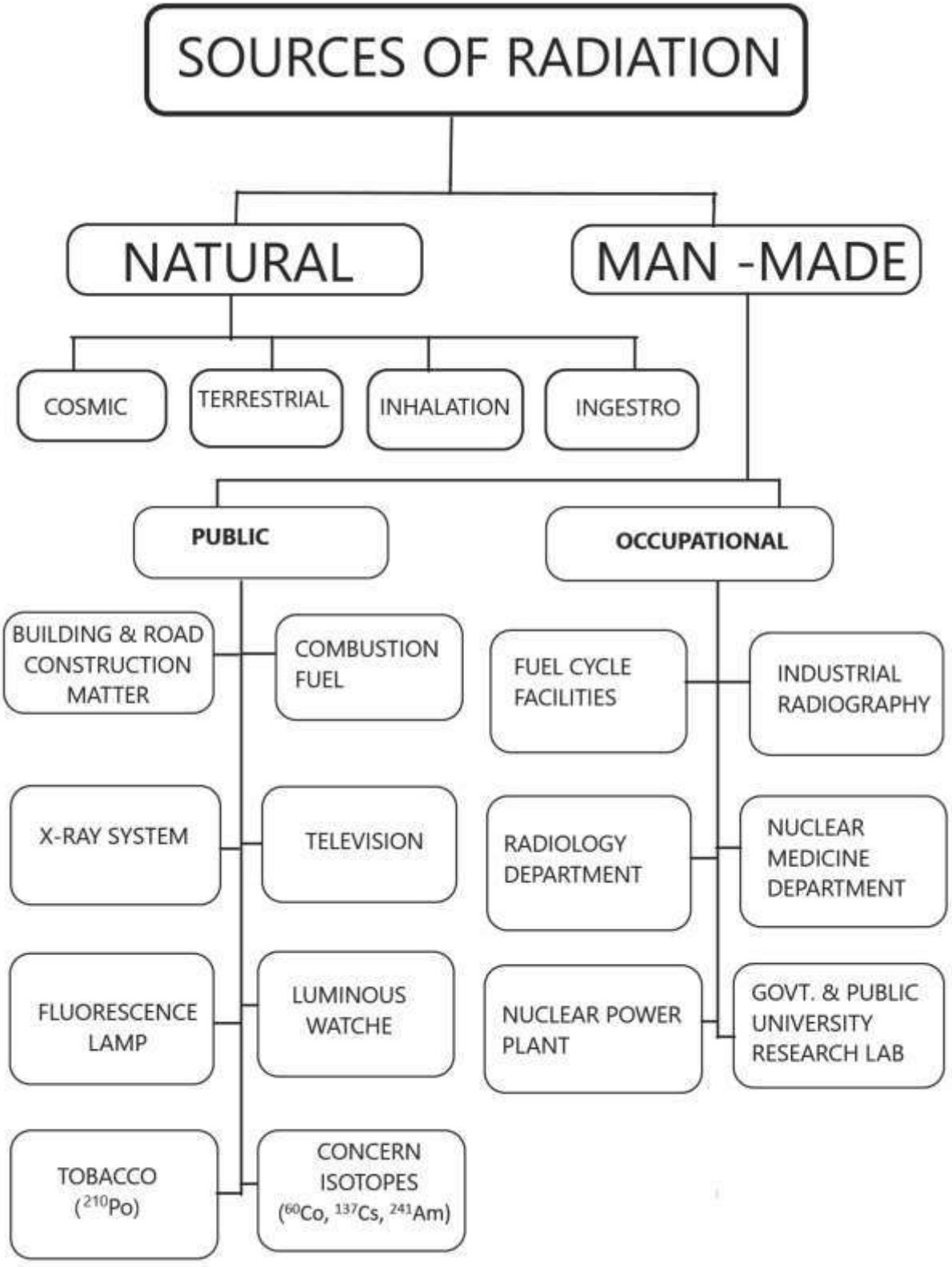
1. **Members of the public:** exposure to medical sources is by far the most significant man-made source of exposure. This involves the use of diagnostic x-rays, Computer Tomography, (CT) scans, nuclear medicine procedures (^{131}I, ^{137}Cs etc.). Other sources of man-made exposure are consumer products which include:
   - building and road construction materials
   - combustible fuels
   - X-ray security systems
   - Televisions
   - Florescent lamp starters
   - Smoke detectors (americium)
   - Luminous watches
   - Lantern mantles (thorium)
   - Tobacco (^{210}Po)
   - Concern isotopes: cobalt (^{60}Co), caesium (^{137}Cs), americium (^{241}Am)
   - Ophthalmic glass used in eyeglasses

To a certain degree, the public is also exposed to radiation from the nuclear fuel cycle, from Uranium mining and milling to disposal of the used fuel. The public also receives minimal exposure from the transportation of radioactive materials and fallout from nuclear weapon testing and reactor accidents (such as the Chernobyl nuclear accident of 1986; Fukushima Daiichi nuclear Plant accident of March 11, 2011).

2. **Occupationally Exposed Individuals:** in general, occupationally exposed individuals work in the following areas:
   - fuel cycle facilities
   - industrial radiography
   - radiology departments
   - nuclear medicine departments
   - radiation oncology departments
   - nuclear power plants.
   - Government and private university research laboratories.

Individuals who work in the aforementioned areas are exposed to varying amounts of radiation depending on their specific jobs and the sources with which they work. The most commonly associated radioisotopes are ^{60}Co, ^{137}Cs and ^{241}Am. Figure 5a shows the over view of the sources of radiation while the pie chart in figure 5b shows the contribution of both natural and artificial sources of radiation.

5a


SOURCES OF RADIATION
NATURAL
MAN -MADE
COSMIC
TERRESTRIAL
INHALATION
INGESTRO
PUBLIC
OCCUPATIONAL
BUILDING & ROAD CONSTRUCTION MATTER
COMBUSTION FUEL
FUEL CYCLE FACILITIES
INDUSTRIAL RADIOGRAPHY
X-RAY SYSTEM
TELEVISION
RADIOLOGY DEPARTMENT
NUCLEAR MEDICINE DEPARTMENT
FLUORESCENCE LAMP
LUMINOUS WATCHE
NUCLEAR POWER PLANT
GOVT. & PUBLIC UNIVERSITY RESEARCH LAB
TOBACCO (^{210}Po)
CONCERN ISOTOPES (^{60}Co, ^{137}Cs, ^{241}Am)

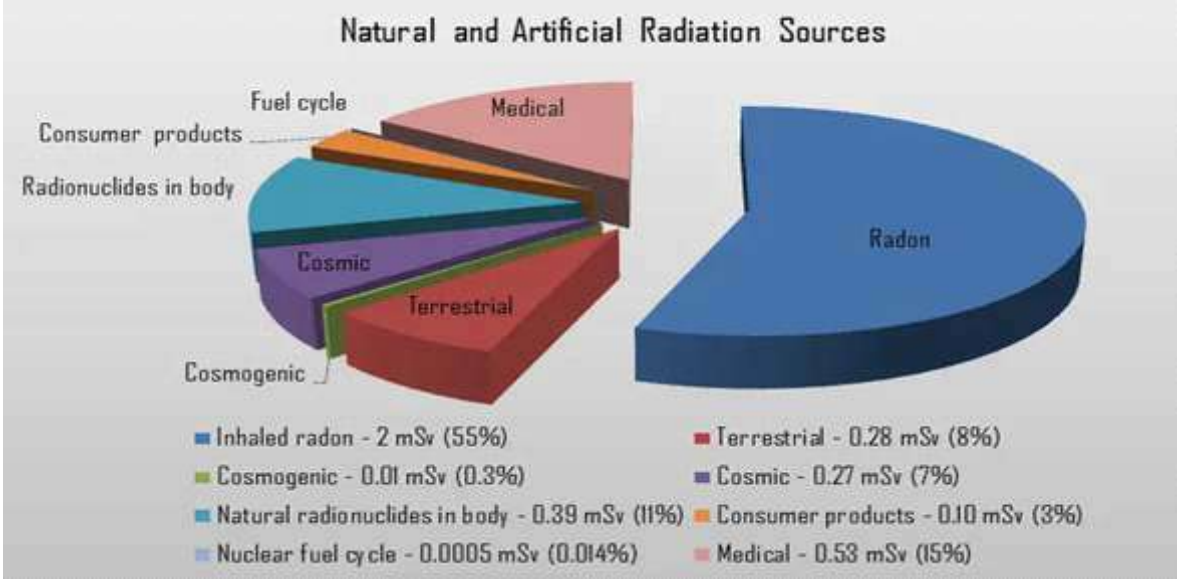


Figure 5b: Sources and contributions of natural and artificial radiation *(UNSCEAR, 2010)*

1.2. Types of Radiation

Radiation is frequently divided into two categories: ionizing and non-ionizing, depending on the energy of the particles that are emitted as shown in figure 6.

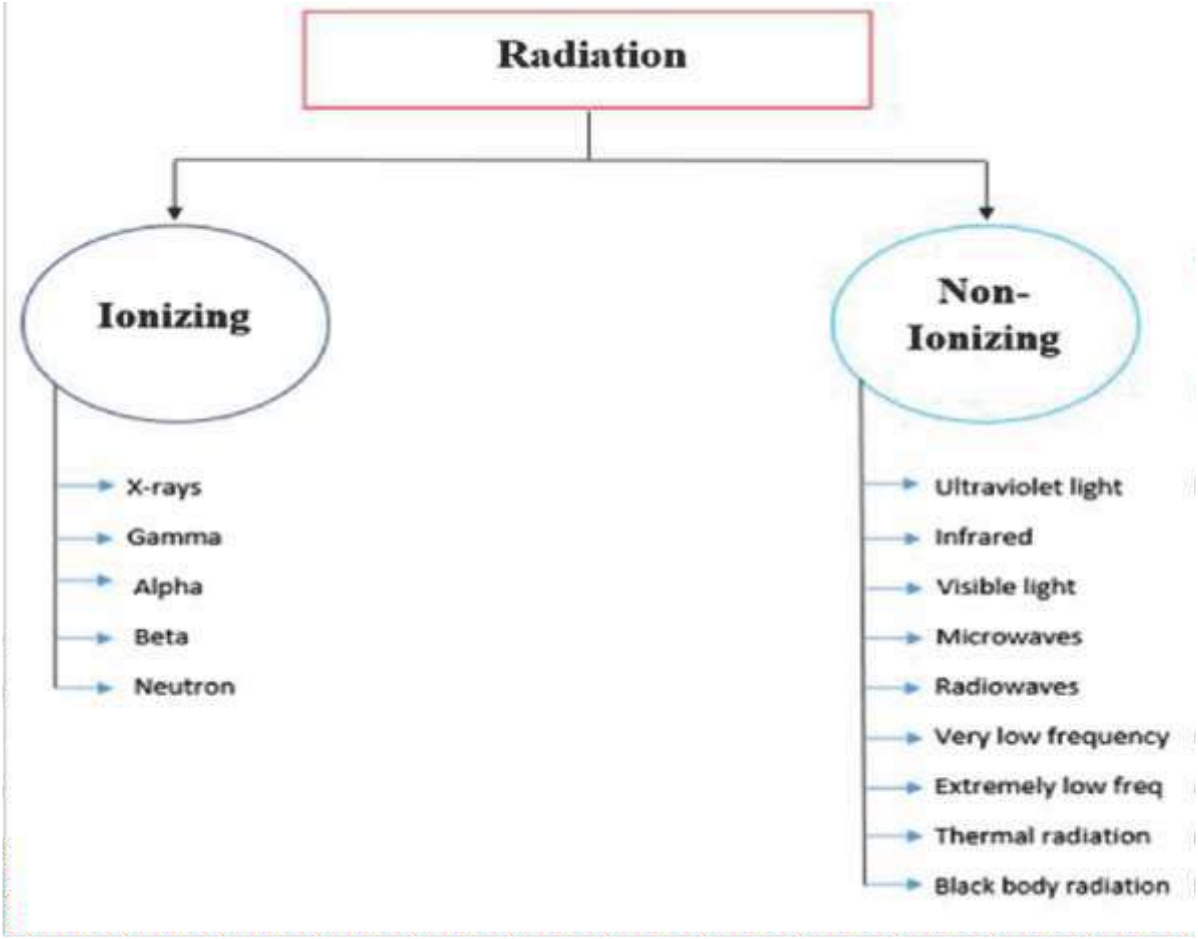


Figure 6: Classification of Radiation

These two types of radiation namely ionizing radiation and non-ionizing radiation, is well descripted by the electromagnetic spectrum. The electromagnetic spectrum comprises both ionizing and non-ionizing radiation as shown in Figure 7a &b.

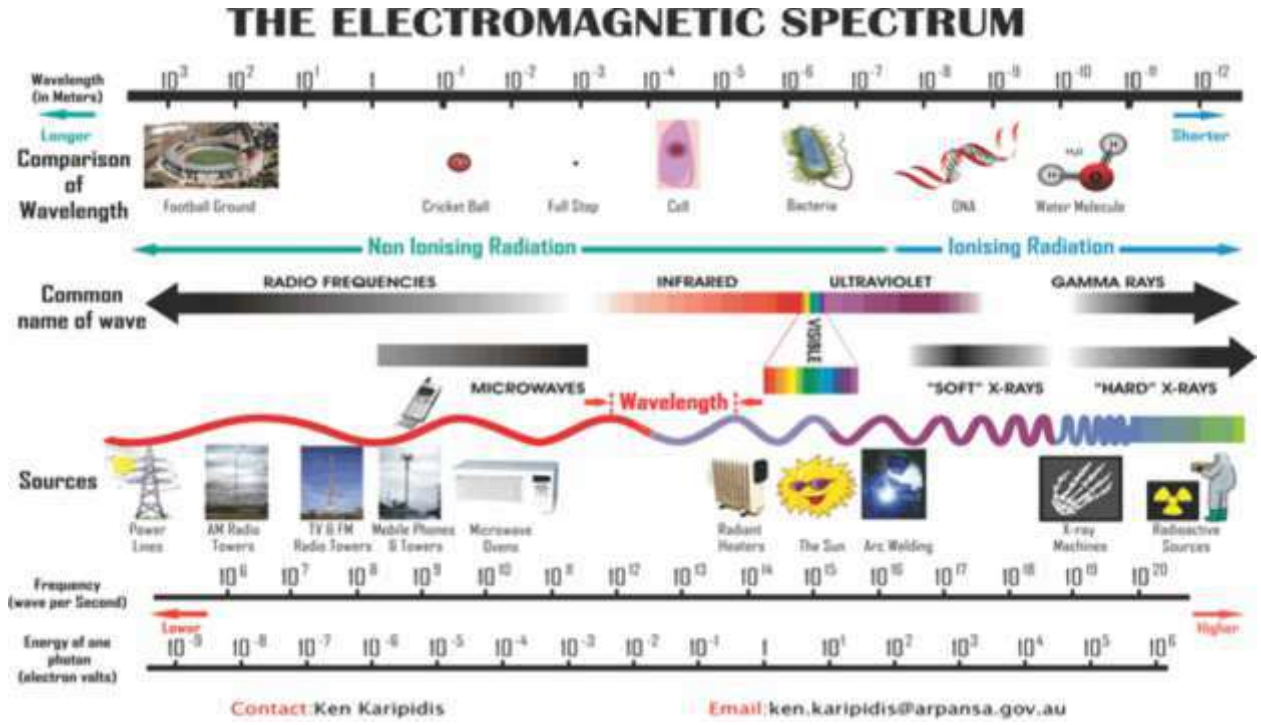


Figure 7(a): Electromagnetic Spectrum Range *(source: Ken Karipidis)*

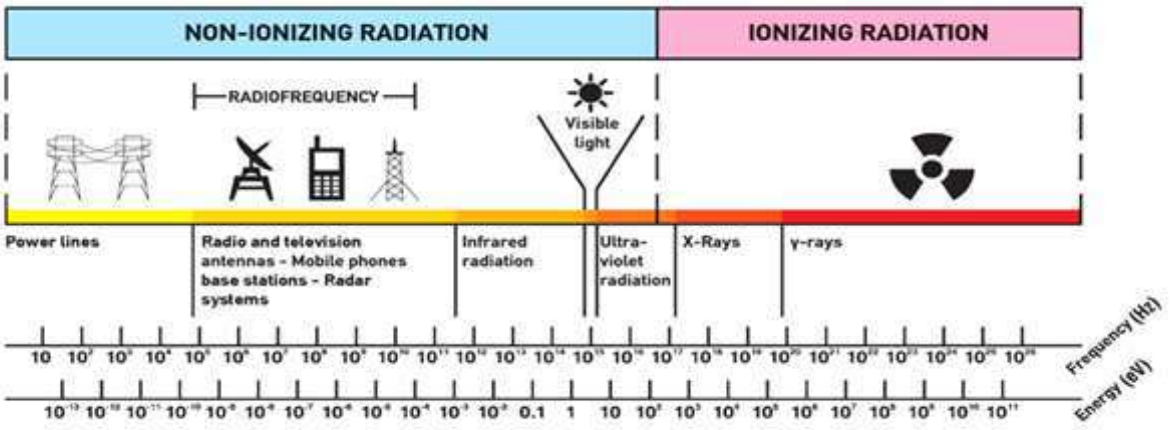


Figure 7(b): Non-ionizing and Ionizing Radiation

1.2.1. Non-Ionizing Radiation

Non-ionizing radiation (NIR) refers to any form of electromagnetic radiation that does not possess required energy to knock off an electron from the atoms or molecules it encounters.

It is a radiative energy that, instead of producing charged ions when passing through matter, has sufficient energy only for excitation. Nevertheless, it is known to cause physiological and biological effects. The NIR spectrum is divided into two main regions, optical radiation, and electromagnetic fields (EMF).

The optical is further sub-divided into ultraviolet, visible, and infra-red. The electromagnetic fields are further divided into radiofrequency (microwave, very high frequency, and low frequency radio wave) as

shown in figure 6(a). The electromagnetic field (EMF) consist of a combination of electric field and magnetic field traveling (propagate) out into space far from their points of generation at the same extremely high speed of about 300,000 km/s. It is produced by the mutual interaction (combination) of electric and magnetic fields which can be considered as having its own existence around a moving charge.

i. **Electric Field:** This is the region or space surrounding a stationary charged body in which another charged body will experience a force.
ii. **Magnetic Field:** This is the region or space surrounding a moving charge (current) in which another moving charge (magnet) will experience a force.

A propagating EMF is composed of oscillating electric and magnetic fields that are perpendicular to each other and mutually perpendicular to the direction of propagation of the wave as shown in figure 8.

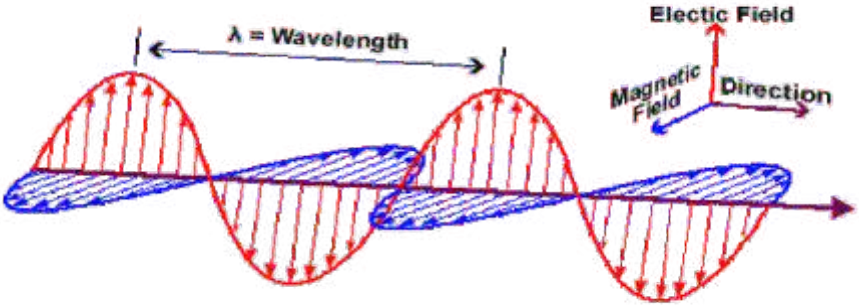


Figure 8: Oscillation Electromagnetic Field *(Farai, 2016)*

Non-Ionizing radiation originates from various sources: Natural origin (such as sunlight or lightning discharges etc.) and man-made as observed in wireless communications, industrial, scientific, and medical applications).

The basics of biological effects seen with NIR relevant to human health include radio waves, microwaves, infrared, visible light, and ultraviolet rays. Sources include GSM (Global System of Mobile Telecommunication) masts and phones, electrical high-tension cables, solar radiation, TVs, remotes etc., as indicated in figure 9.

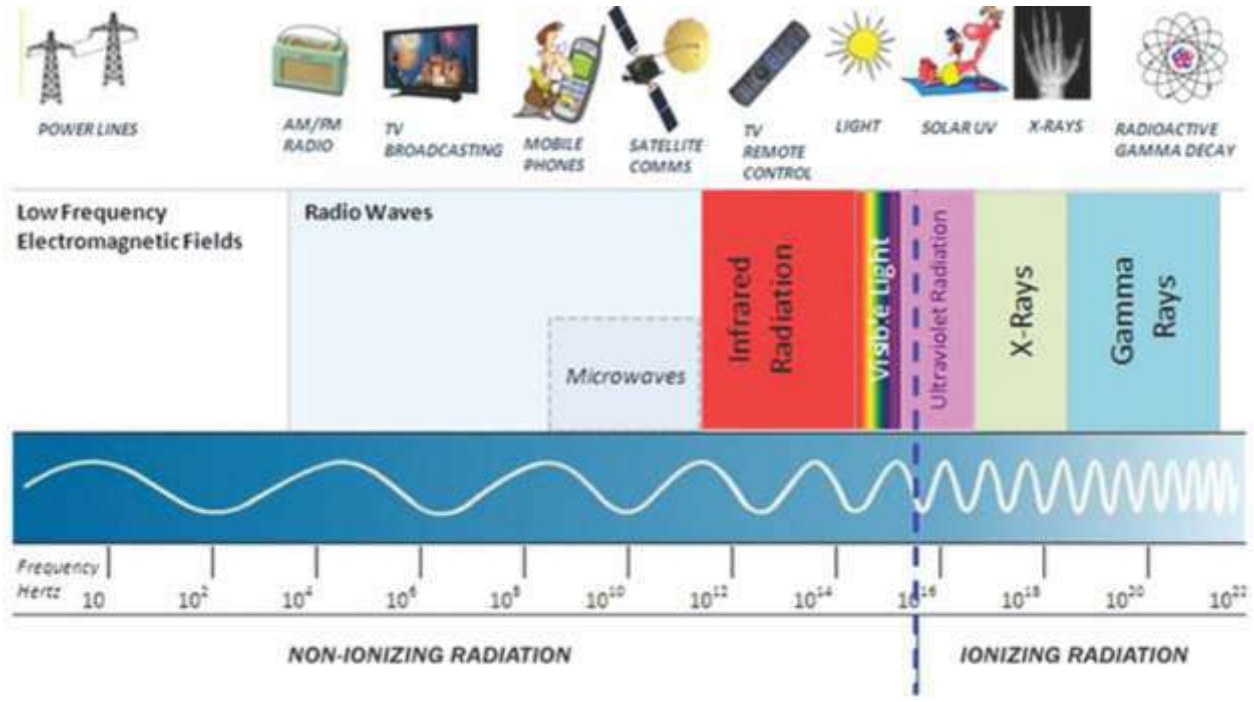


Figure 9: Ionizing and non-ionizing electromagnetic spectrum ***(UNSCEAR 2006; 2020)***

Other sources of NIR are from hot processes such as steelmaking, glassmaking, welding, and also lasers (IR). The application of laser as a coherent light source is increasing rapidly. Medical applications include UV and neonatal phototherapy, surgical and therapy lasers, physiotherapy heat lamps. Electromagnetic fields Microwaves are used in telecommunications, radar/satellite links, mobile phones, microwave ovens, TV transmitters. RF is used in radio communications, visual display units, television sets.

Extremely low-frequency (ELF) electric and magnetic fields (EMFs) surround electrical machinery, home appliances, electric wiring, and high-voltage electrical transmission lines and transformers. Medical applications include microwave hyperthermia, therapeutic and surgical diathermy, and magnetic resonance imaging (MRI).

1.2.1.1. Biological Effects of Non-Ionizing Radiation

We are exposed to low levels of non-ionizing radiation sources daily. Microwave oven which we use to heat food uses infrared radiation. We watch television, listen to radio and talk on cell phones through the use of radio waves. A biological effect occurs when a change can be measured in a biological system after the introduction of some type of stimuli.

However, the observation of a biological effect, in and of itself, does not necessarily suggest the existence of a biological hazard or health effect. A biological effect only becomes a safety hazard when it "causes detectable impairment of the health of the individual or of his or her offspring" (Fernaz, 2012). Biological effects could be physiological, biochemical, or behavioral changes induced in an organism, tissue, or cell. NIRs usually interact with tissue through the generation of heat.

The hazards depend on the ability to penetrate the human body and the absorption characteristics of different tissues (see Table 1). There are still many uncertainties about the severity of effects of both acute and chronic exposure to various types of NIRs. Generally, the public is concerned about the risks from ELF, RF and MW. However, the greatest risk to the public probably arises from natural UV radiation.

Exposure to intense, direct amounts of non-ionizing radiation may result in damage to tissue due to heat. For instance, too much ultraviolet (UV) light from lying out in the sun is known to cause;

- Some type of skin cancers (non-melanoma skin cancer)
- Sunburn
- Premature aging of the skin.
- In addition to these, non-ionizing radiation can produce non-mutagenic effects such as inciting thermal energy in biological tissue that can lead to burns (see Figure 10).

Table1: Biological effects from the various Sources of Non-Ionizing Radiation

	Wavelength/ frequency	Biological Effects
UVC	100 nm	Skin: - Erythema, inc pigmentation
		Eye: - Photokeratitis (inflammation of cornea)
	280 nm	Skin: - Erythema, inc pigmentation
UVB	315 nm	**Skin cancer**
		Eye: - Photochemical cataract
		Photosensitive skin reactions
		Skin: - Erythema, inc pigmentation
UVA	400 nm	**Skin photo-ageing, skin cancer**
		Eye: - photochemical & thermal retinal injury
Visible	780 nm	Eye: - Thermal retinal injury
IRA	1.4 µm	Eye: - Thermal retinal injury, thermal cataract
IRB	3 µm	**Skin burn**
		Eye: - Corneal bum, cataract
IRC	1 mm	**Skin burn**
		Eye: - Corneal bum, cataract
		Heat of body surface
Micro-wave	300 GHz	Heat of body surface,
	1 GHz	Heating with penetration depth of 10mm
		Raised body temperature
	. . . . .	Cumulation of charge on body surface
		Disturbance of nerve & muscle responses
Static	0 Hz	Magnetic field: - vertigo/ nausea
		Electric field: - charge on body surface

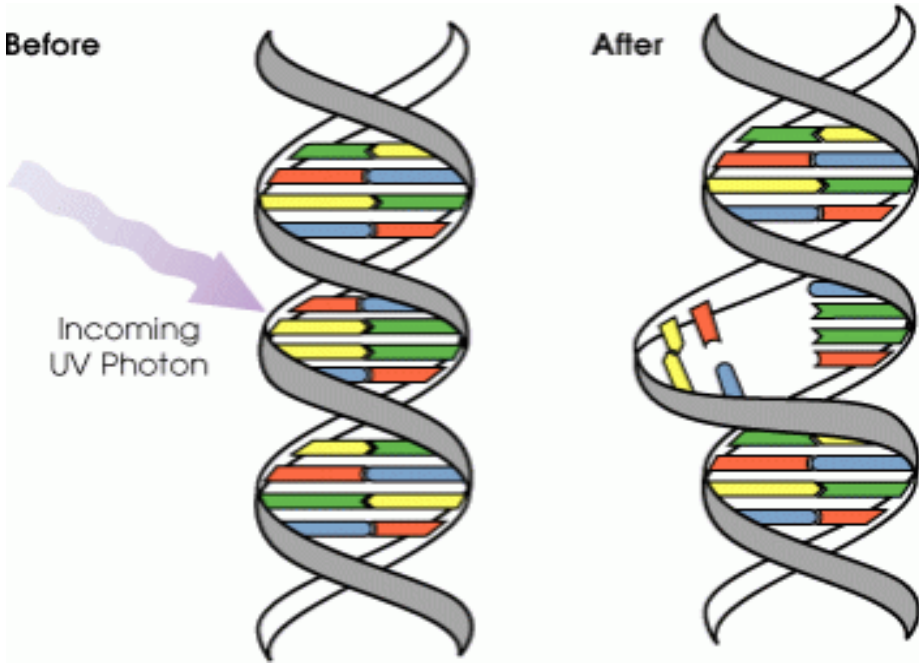


Figure 10: Effect of non-ionizing radiation (UV-photon) *(WHO, 2023)*

1.2.2. Ionizing Radiation

These are radiations with the ability to dislodge electrons from a multi-electron atom, upsetting the electron/proton equilibrium and leaving the atom with a positive charge. Ionizing radiation is emitted by both naturally occurring and artificial radioactive materials. The three major types of ionizing radiations are; alpha(α), beta (β), and gamma(γ) radiations. We shall now discuss these radiations in turns as shown in figure 1

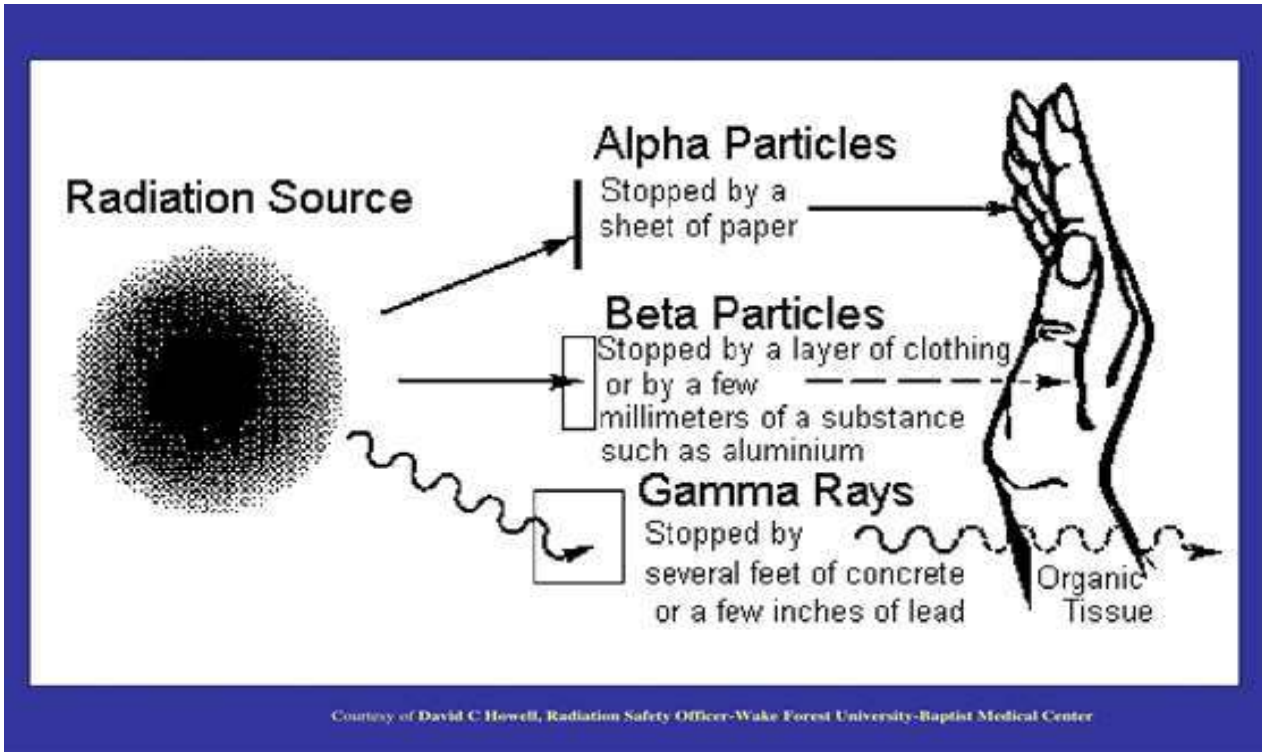


Figure 11: Ionizing radiations penetrating potentials ***(source: David Howell, Radiation safety officer; wake forest University)***

1. **Alpha radiation:** consists of alpha particles (the helium nucleus) which are made up of two protons and neutrons each and they carry a double positive charge as shown in eqn. (2) and figure (12). Radionuclides that emit alpha particles include: Uranium-^{238}U, ^{235}U; Radium- 226Ra, 223Ra, ^{224}Ra (decay products of uranium), Radon-222Rn, 219Rn, ^{220}Rn (decay products of radium), Thorium-230Th, 227Th, and ^{228}Th etc. Alpha particles have a high ionization potential but low penetration ability. They travel only a few centimeters through air and can be stopped by a sheet of paper. Alpha particles have very low capacity to permeate matter due to their comparatively enormous mass and charge. However, when nuclear compounds that emit alpha radiation as shown in equation (2), are ingested or inhaled into the body, the energy of the alpha radiation is fully absorbed into the body's tissues. As a result of this, alpha radiation poses an internal risk.

$$^{A}_{Z}X \rightarrow ^{A-4}_{Z-2}X + \alpha \qquad (2)$$

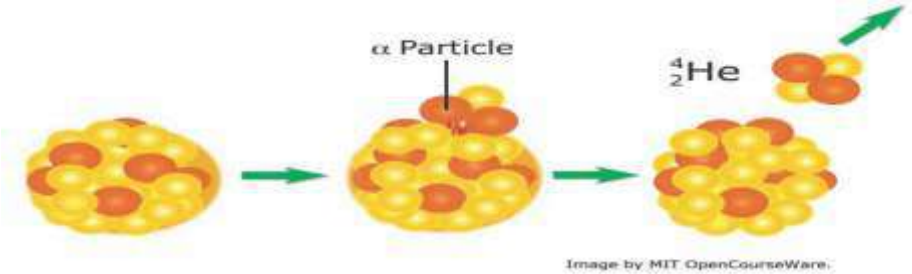


Figure 12: Alpha decay schematics *(Source: MIT OpenCourseware, 2016)*

2. Beta radiation: the beta decay is a radioactive decay in which a proton in a nucleus is converted into a neutron (and vice-versa). Thus, the mass number (A) is constant, but the atomic number (Z) and neutron number (N) changes by 1. In the process, the nucleus emits a beta particle (either an electron or a positron) and quasi-massless particle, the **neutrino.** Beta particles consist of charged particles ejected from the nucleus and they are physically identical to electrons. Some radionuclides that emit beta particles include: Strontium-90 (^{90}Sr), Phosphorus-32 (^{32}P), and Carbon-14 (^{14}C). Typical beta decay is represented by the equation shown below:

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + {}^{0}_{+1}e^{-} + \nu_e \qquad (3)$$

There are three types of beta decay;

i. **β^- decay (or negative beta decay):** the underlying reaction is

$$n \rightarrow p + e^- + \bar{\nu} \qquad (4)$$

This corresponds to the conversion of a proton into a neutron with the emission of an electron and an anti-neutrino.

ii. **β^+ decay (or positive beta decay):** the positive beta reaction is represented as

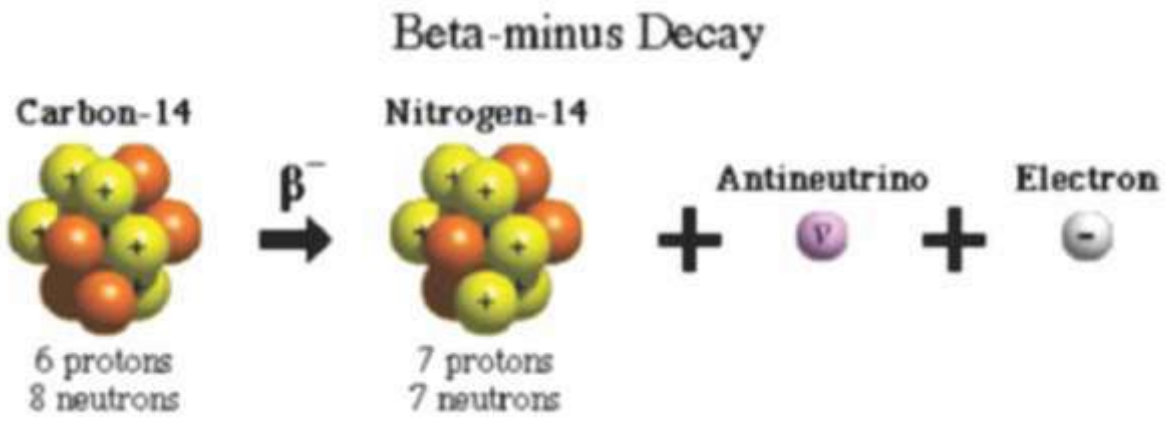
$$p \rightarrow n + e^+ + \nu \qquad (5)$$

Which shows the emission of a positron (the electron anti-particle) and a neutrino.

I. **Electron capture:** this is a process that competes with, or substitutes, the positron emission;

$$p + e^- \rightarrow n + \nu \qquad (6)$$

Beta radiation can be intercepted by sheets of plastic, glass, or metal, can intercept. However, beta radiation with enough energy can pass through the body's outer layer of skin, and deposit its energy within living skin cells. But the ability of beta radiation to reach deeper biological tissues and organs is unlikely. Nuclear compounds that generate beta radiation can also be dangerous when ingested. Beta particles, have a greater penetrating ability and a lesser ionizing power than alpha particles. The schematics for Beta decay are shown in figure 13:



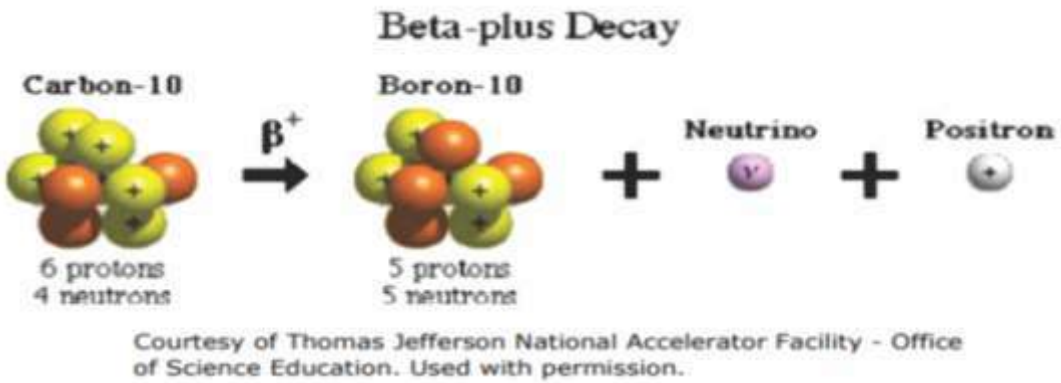


Figure 13: Beta decay schematics *(Source: MIT Open Courseware, 2016)*

1. **Gamma Radiation:** electromagnetic radiation is a photon. Gamma rays are high-energy electromagnetic photons emitted from the nucleus of an unstable, excited atom. They are pure photon energy and can travel great distances at high speed. Gamma rays can be stopped by a thick sheet of lead, steel, or concrete. In gamma decay, the nuclide is unchanged, but it goes from an excited state to a lower energy state. These states are called isomeric states. Some radionuclides that emit gamma rays include: Iodine-131 (^{131}I), Cesium-137 (^{137}Cs), Cobalt-60 (^{60}Co), cobalt-57 (^{57}Co), Gallium-67 (^{67}Ga), and Iridium-192 (^{192}Ir). Gamma rays are often emitted along with alpha or beta particles during radioactive decay as shown in equation (7):

$$ {}^{A}_{Z}X^{*}_{N} \rightarrow {}^{A}_{Z}X_{N} + \gamma \qquad (7) $$

Where the asterisk indicates an excited state. Figure 14a & b show radioactive symbol and the penetration ability of the radiation decay emissions and Table 2. summarizes the properties of the ionizing radiations.

Figure 14a: Radioactive symbol

Where the asterisk indicates an excited state. Figure 14a & b show radioactive symbol and the penetration ability of the radiation decay emissions and Table 2. summarizes the properties of the ionizing radiations.

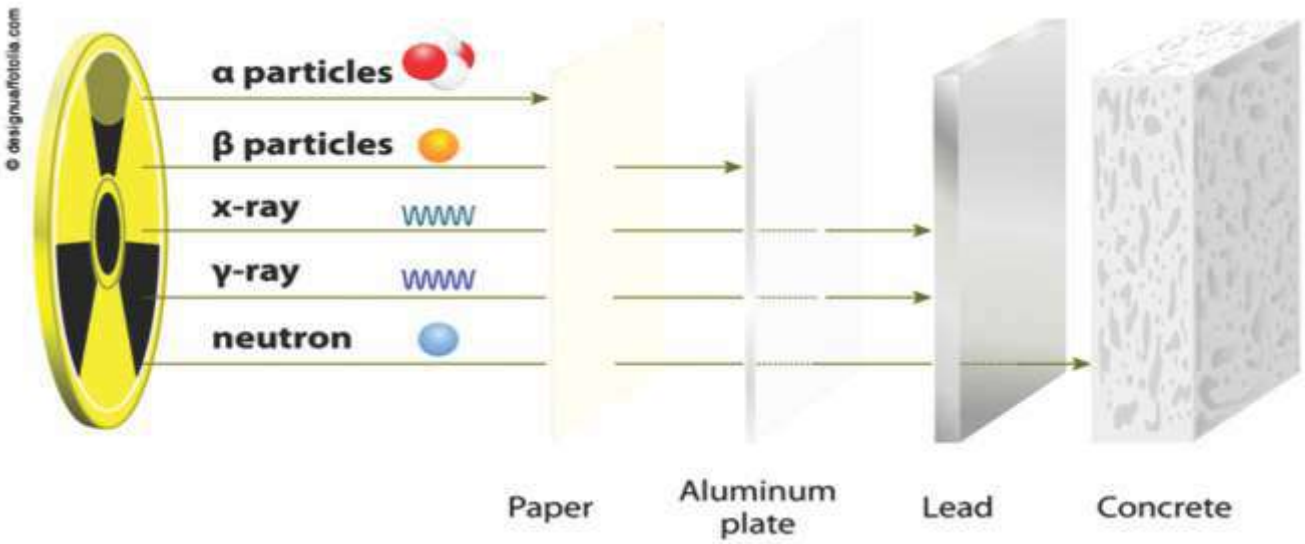


Figure 14b: Penetration ability of the radiation decay emissions ***(Wikipedia, 2020)***

Table 2: Summary of the properties of Ionizing Radiations *(Avwiri, 2011)*

Property	á-particles	â-particles	ã –ray
Nature	Helium Nucleus	Fast electron	Electromagnetic radiation
Charge (c)	3.2×10^{-19}	-2.6×10^{-39}	0
Rest Mass (kg)	6.4×10^{-27}	9.4×10^{-27}	0
Velocity (C)	~ 0.06	~ 0.98	
Energy	~ 6 MeV	~ 5MeV	~ 0.6MeV
Frequency (Hz)	1.4×10^{21}	2.4×10^{20}	1.45×10^{20}
No of Ion Pair/cm	~ 70^{5}	~ 80^{3}	~ 90
Penetration Power (cm)	~ 5	~ 500 of air	~ 4 of lead
Path through Matter	Straight	Tortuous	Straight
Ability to Produce Florescence	Yes (strong)	Yes	Yes (Weak)
Ability to affect photographic plate	Yes	Yes	Yes

1.2.2.1. Applications of Radiation

Although scientists have only known about radiation since the 1890s, they have developed a wide variety of uses for this natural force. Today, to benefit mankind, radiation is used in science, medicine, and industry, as well as for generating electricity. Radiation has useful applications in such areas as agriculture, medicine, space exploration, architect/engineering, industry/manufacturing, government, geology (including mining), ecology, and education. Radiation has been used to diagnose and treat illnesses, kill bacteria and preserve food without chemicals and refrigeration; process sludge for fertilizer and soil conditioner, locate underground natural resources and tell a dry hole from a gusher, make smoke detectors, nonstick frying pans and ice cream, grow stronger crops, Power satellites and provide future electrical needs for space laboratories with people on board, design instruments, techniques, and equipment; measure air pollution, prove the age of works of art and assist in determining their authenticity.

i. Radiation Application in Medicine

X-rays are a type of radiation that can pass through our skin. Our bones are denser than our skin, so when x-rayed, bones and other dense materials cast shadows that can be detected on photographic film. Doctors and dentists use x-rays and CT scanner (Figures 15 & 16) to see structures inside our bodies, these allow them to spot broken bones, dental problems and internal organs problems *(UNSCEAR, 2008).*

Figure 15: X-ray Photographs (Centre for Disease Control, USA 2008)

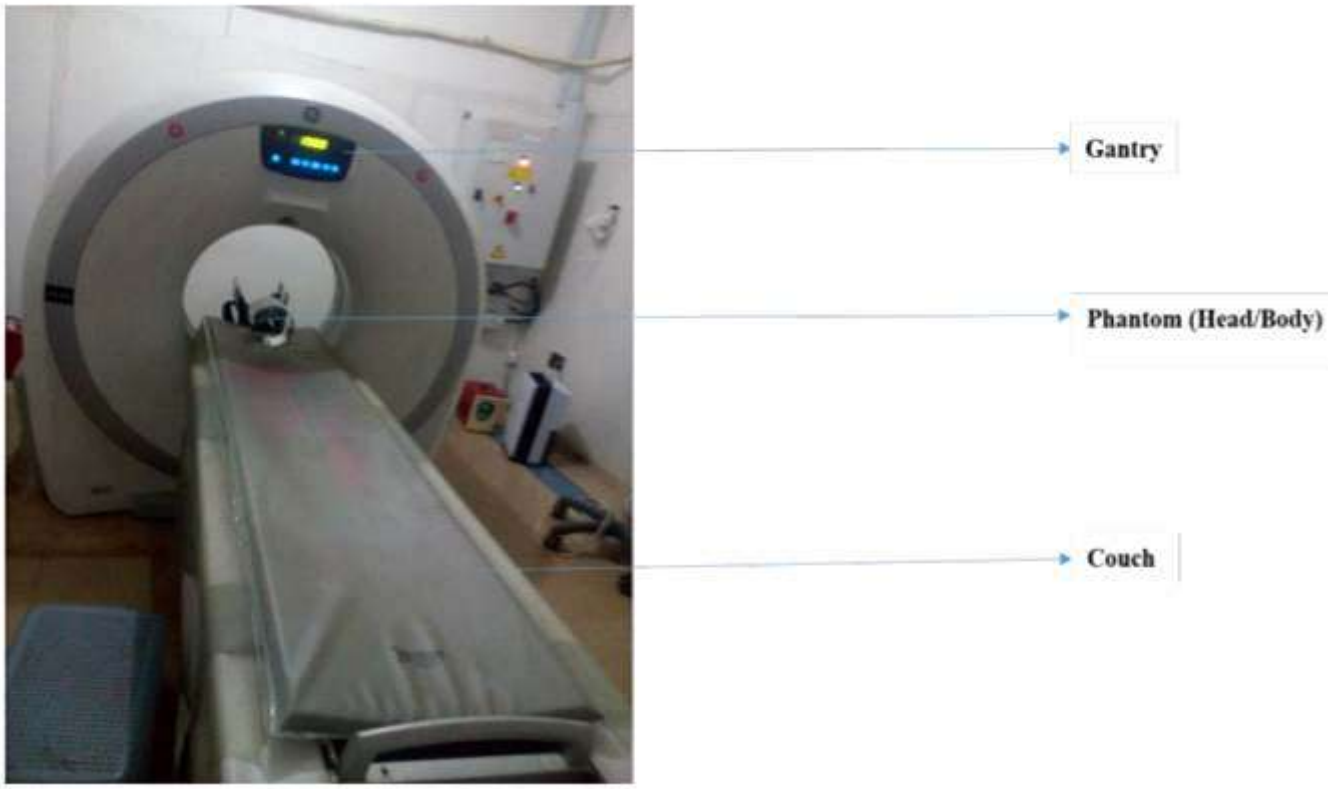


Figure 16: Diagram of a CT scanner *(Tobi, 2021; Mokobia, 2023)*

I. Radiation in Science

Radiation is used in science in many ways. Just as doctors can label substances inside people's bodies, scientists can label substances that pass-through plants, animals, or our world. Scientists use radioactive substances to find the age of ancient objects by a process called **carbon dating (**Figure 17). Carbon is found in all living things, and a small percentage of this carbon is carbon-14. When a plant or animal dies, it no longer takes in new carbon and the carbon-14 it contains begins the process of radioactive decay.

Figure 17: Carbon-14 dating method *(IAEA, 2007)*

I. Radiation in Industry

Radiation finds many applications in the industry. Exposure to some types of radiation (x-rays) can kill germs without harming the items that are being disinfected or making them radioactive. For example, when treated with radiation, foods take much longer to spoil, and medical equipment such as bandages, hypodermic syringes, and surgical instruments don't have to be exposed to toxic chemicals or extreme heat to be sterilized. The agricultural industry makes use of radiation to improve food production. Plant seeds, for example, have been exposed to radiation to bring about new and better types of plants.

Besides making plants stronger, radiation can also be used to control insect populations, thereby decreasing the use of pesticides. Engineers use radioactive substances to measure the thickness of materials and an x-ray process called **radiography (**as shown in Figure 18) is used to find hard-to-detect defects in many types of metals and machines. Radiography is also used to check such things as the flow of oil in sealed engines as well as the rate and way various materials wear out.

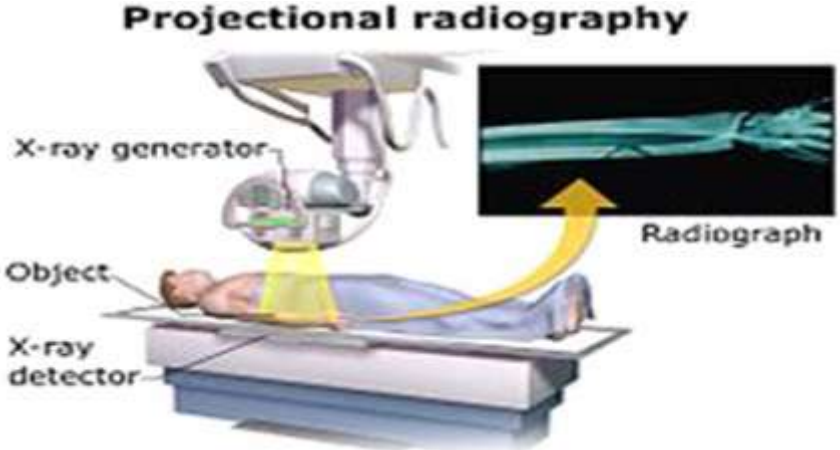


Figure 18: A Radiography Operation *(UNSCEAR, 2008)*

1.2.2.2. Biological Effects of Ionizing Radiation

The response of a person's body, soil, plants, animals, and the environment to changes brought about by radiation energy is known as the biological effect of radiation. The damage to biomolecules in living creatures can substantially impede their normal cellular functioning, taxing their immune systems and possibly resulting in illness or even death. Both somatic and genetic harm to the entire body, including eggs and sperm, can result from radiation exposure. The radiation dose, the cell (somatic and genetic) location within the tissue, has all been found to affect a cell response to radiation differently. Ionizing radiation generally seems to reduce intracellular DNA methylation, according to Guerra *et al.,* (2020), ionizing radiation is known to harm biological components such as proteins, lipids, and nucleic acids.

Biological effects of radiation can either be stochastic or deterministic, with chronic long-term exposure being the main cause of stochastic effects. Acute radiation exposure has deterministic effects, with a radiation threshold dose below which the effect is unlikely to occur.

1.2.2.3. Radiological Effects on Health

The radiological health effects can also be group into deterministic effect and stochastic effect.

A. Deterministic Effects

A deterministic effect is ionizing radiation-induced damage that has a dose threshold and whose severity increases with increasing dose above that threshold. Examples include radiation sickness (vomiting, nausea, and diarrhea), cataracts, hair loss, and radiation burns (reddening of the skin). Acutely high radiation doses that were either given to the entire body or to a specific body part are the cause of all of these side effects. Deterministic effects are also regarded as non-stochastic effect (ICRP, 2018).

B. Stochastic Effects

Stochastic effects are those that happen as a result of a high radiation dose. These effects are increasingly probable as the dose rises. From an artistic perspective, there is no dose below which a stochastic impact cannot occur. The extent of these impacts depends mainly on chance and has little proportion to the dose of radiation they are exposed to. Instead, they are brought on by a single or few cells being damaged. Cancer or genetic changes may be brought on by stochastic events (ICRP, 2018).
Below are some radiological health effects as a result of exposure to radiation in an environment;

1. Cataract: A cataract is a clouding or opacification of the lens capsule, the normally clear lens of the eye, or the lens itself, which blocks light from passing through the lens to the retina. All ages are susceptible to the illness that causes blindness, but older people are disproportionately afflicted. Both the intensity and the bilaterality may change. Daily tasks are unaffected early in the disease's progression, but over time, particularly around the fourth or fifth decade, the cataract grows, becoming completely opaque to light and obstructing daily tasks. Cataracts play a significant role in global blindness (USNRC, 2011). A picture showing how a cataract looks like is depicted in plate 1.

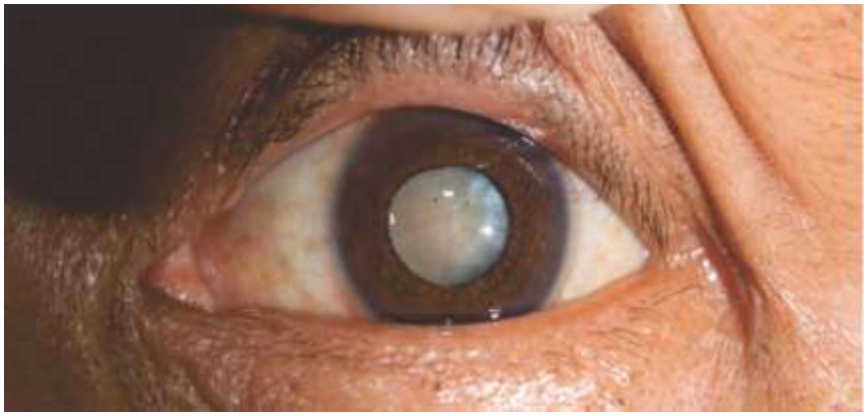


Plate 1: A pictorial description of a cataract in the human eye *(source: Google, 2023)*

2. Erythema: Erythema is an abnormally reddening of the skin or mucous membrane. The main causes include skin damage, an infection, and inflammation. An example of erythema that is not caused by an illness are flushed nerves. Ionizing radiation can cause erythema (USNRC, 2011). Plate 2 shows how erythema looks like.

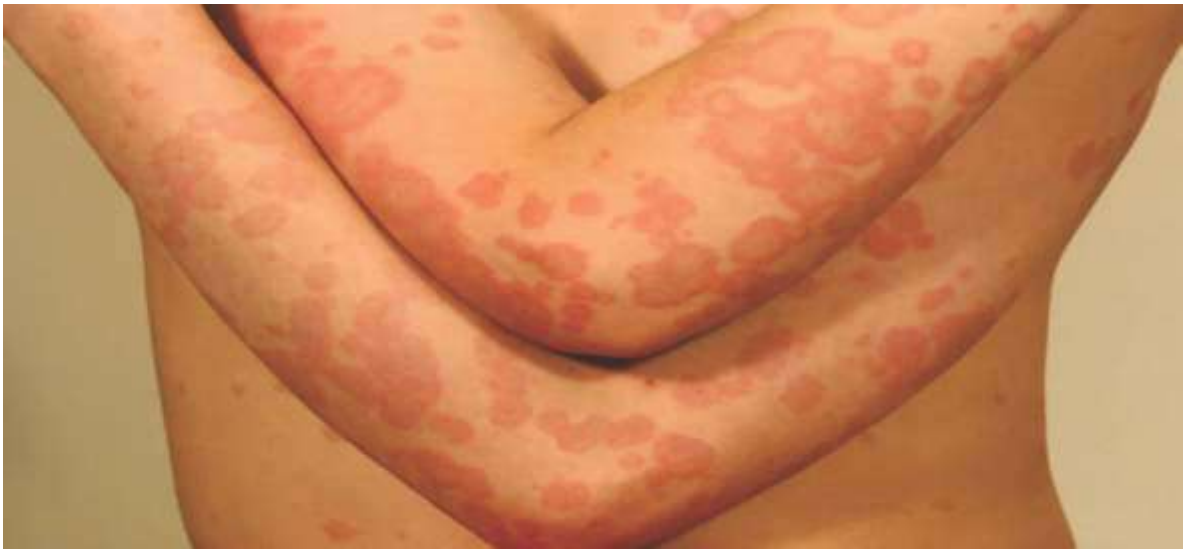
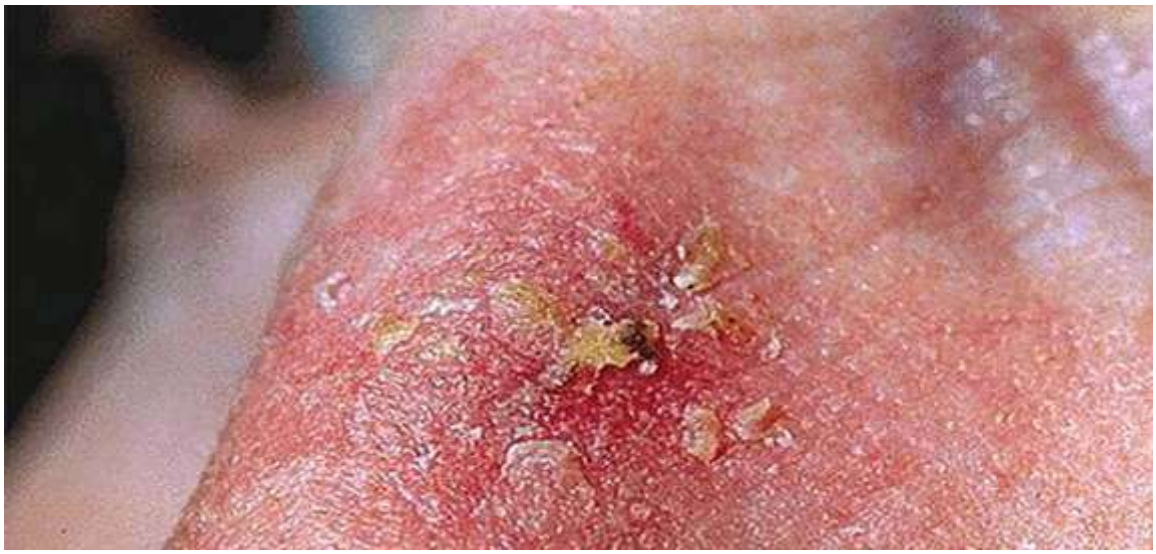


Plate 2: A pictorial representation of erythema caused by ionizing radiation *(source: Google, 2023)*

1. **Cancer:** Cancer is a condition when a few of the body's cells grow out of control and spread to other bodily regions. According to epidemiological studies on people and animals, high radiation exposure levels cause cancer. At low levels, the precise nature of the dose-response relationship is still unknown. Due to the high incidence of naturally occurring cancers, it is still unclear if low doses of radiation cause cancer in people (USNRC, 2011). Plate 3 shows the pictorial description of cancer.



4. Leukemia: Leukemia is a type of cancer that affects the body's blood-forming organs, including the lymphatic system and bone marrow. Different types of leukemia exist, some kinds of leukemia are more common in children. The white blood cells are powerful anti-infection agents, and when your body needs them, they usually multiply and divide in an orderly manner. However, the bone marrow produces an excessive amount of abnormal, defective white blood cells in leukemia patients. Although the actual cause of leukemia is unknown, it is thought that both hereditary and environmental (non-genetic) factors may play a role. Risk factors include smoking, ionizing radiation, petrochemicals (including benzene), previous chemotherapy, and down syndrome (USNRC, 2011). Plate 4 shows the description of leukemia in the blood cell

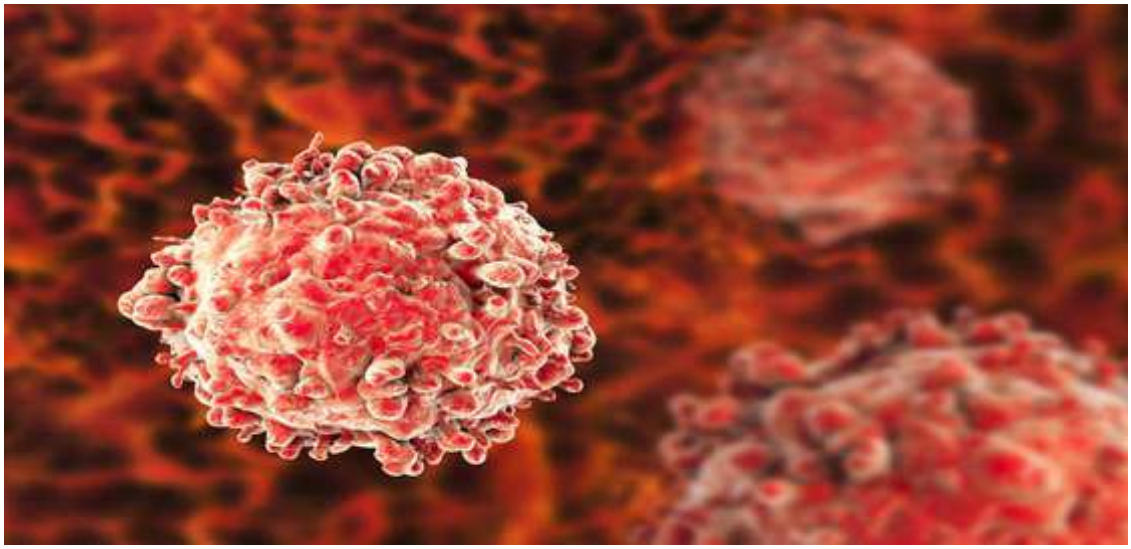


Plate 4: A description of leukemia in the blood cell *(Source: Wikipedia, 2023)*

5. Genetic Effects

Genetic effects occur only when reproductive cells are irradiated by x-ray and other radioactive substances. Radiation affects the estrogen to forestall the effects of menopause and prevent spontaneous absorption in the female reproductive organs, produce a permanent damage to germ plasm which results in genetic mutation that affects the embryo causing miscarriage and sometimes deformity or death (Avwiri, 2011).

6. Atrophy of the Kidney

Atrophy is the wasting or shrinking of a cell, tissue or organ after it has developed completely and achieved its full size. Exposure to radiation can cause the kidney and urinary tract to waste or shrink which leads to fatal loss of renal functions as can be seen in plate 5.

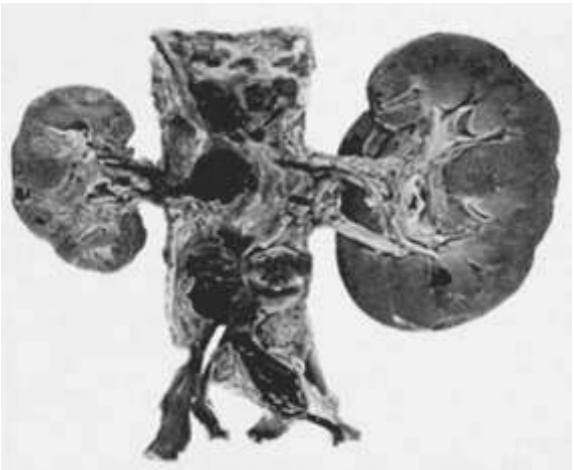


Plate 5: Atrophy of the Kidney

7. Sterility

Sterility is a situation where species are unable to produce offspring. Since the developing germ cells (gonads) are highly radiosensitive, their irradiation may result in sterility as shown in plate 6. In humans, permanent sterilization requires an amount of radiation that is lethal when absorbed by the entire body (Avwiri, 2011).

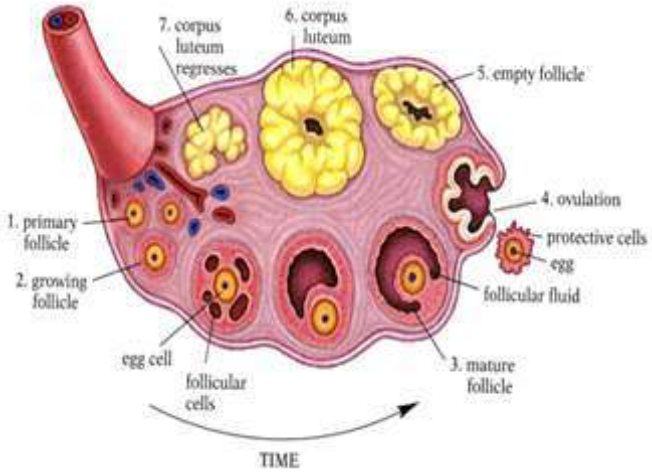


Plate 6: Sterility

1.2.2.4. Assessment of Radiation Doses

Radiation measurements and investigations of radiation effects require various specifications of the radiation field at the point of interest. Only the energy from ionizing radiation that is imparted to (or absorbed by) the human body can cause harm to health.

The doses we receive by our way of life, profession, occupation and social life daily are shown in figure 19

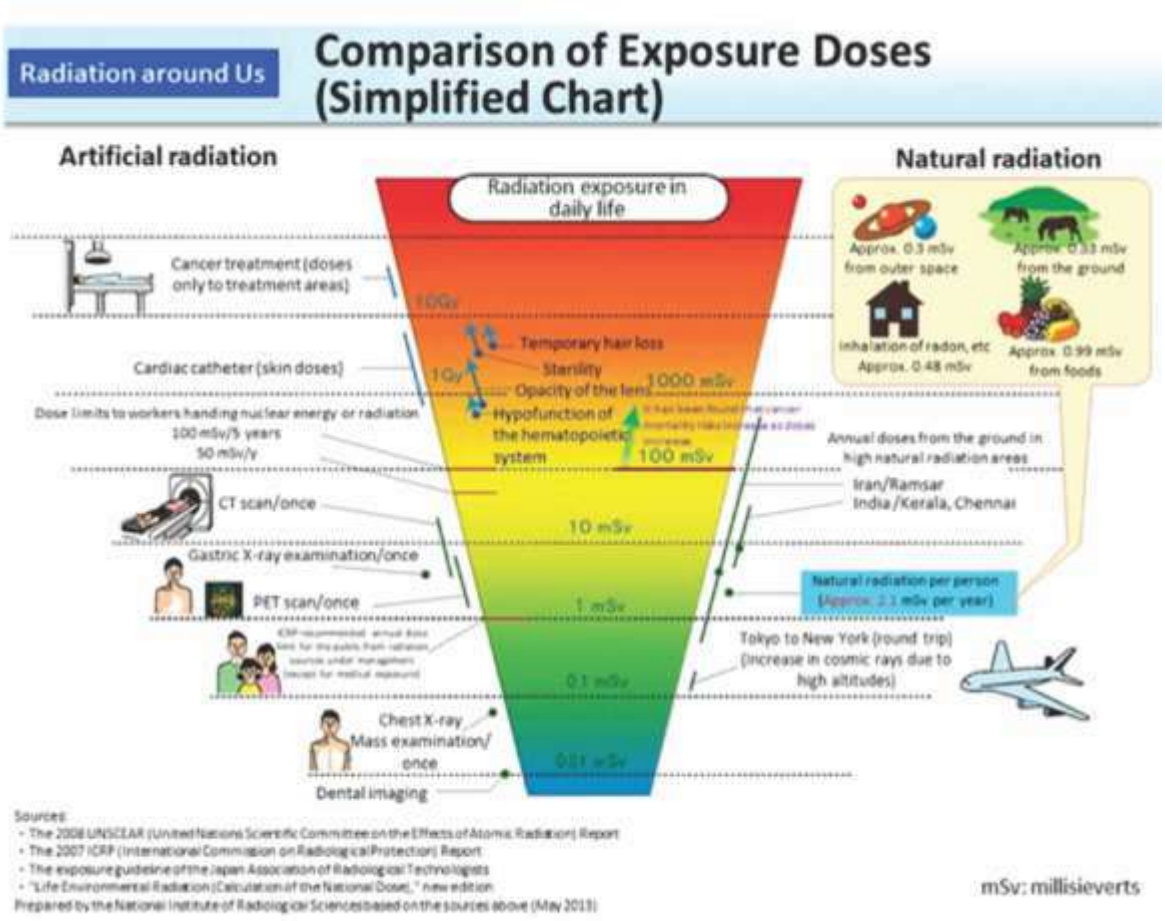


Figure 19: Radiation exposure dose level in daily life *(Source: ICRP, 2018; UNSCEAR, 2020)*

1.2.2.5. Radiation Protection Measures

Radiation protection measure are the guidelines, principles and laws put in place by relevant authorities and regulatory agencies to protect man, plants, soil, atmosphere and the environment at large from the adverse effects emanating from the utilization of radiation in the industries. The goal of radiological protection is to give people an adequate level of protection without unduly limiting the benefits of radiation exposure. Radiation protection aims to prevent harmful deterministic effects and reduce the likelihood of stochastic effects (such as cancer and genetic consequences), and not totally do away with radiation.

When employing dosimetry evaluation, it is needful to reduce anticipated dose and human dose intake for radiological safety. Since excessive radiation exposure to humans can result in radiation sickness, skin burns, and cancer, recommendations and statistics that can be used to quantify the biological impacts on humans and create regulatory and instructional limits have been published (ICRP, 2018). The guiding principle of radiation safety is **ALARA** *(As Low As Reasonably Achievable)* is defined as avoiding exposure to radiation that does not have a direct benefit to you, even if the dose is small.

I. Minimizing Radiation Uptake

Dose refers to how much energy a body takes in. Three factors manage or regulate the dose, or amount of radiation emitted by a source. Radiation exposure can be regulated by a combination of time, distance, and shielding.

a. Time

Spending time close to sources of ionizing radiation is essential to the ionization process since time is defined as the reference by which events may be distinguished. As a result, decreasing the length of exposure lowers the radiation source dose (Avwiri, 2011).

b. Distance

The length of a certain path taken between two points is the distance traveled by an object, so minimize the effects of radiation, one must be distant from the radiation source. The level of radiation intensity (R) rapidly drops. Inverse square law of distance (r), as shown in equation (8). Therefore, the effect is greater the closer the radiation source is (Agbalagba et al., 2024).

$$\frac{I_1}{I_2} = \frac{d_2}{d_1^2} \qquad (8)$$

Where I, is the intensity and d, is the distance.
The equation 8, states that we can determine the intensity at other distances if we know the intensity at one particular distance.

C. Shielding

Source of radiation levels close to a source are frequently reduced through shielding. Shielding is recommended, particularly for historical materials. Neutrons and gamma rays are protected from by lead barriers and water-based concrete. Some radioactive materials are handled or kept in remote areas, huge concrete chambers, or rooms lined with lead. Another option for shield construction is to use a material with a thickness that divides radiation in half (Avwiri, 2011; IAEA, 2023).

2. Radiation Optimization

Putting economic and social wellbeing of man and his environment into considerations, optimization of radiation is an important principle of radiation protection that aims to keep the likelihood of exposure, the number of individuals exposed, and the intensity of each person's personal exposure as low as reasonably practicable (ALARA).

These three basic concepts serve as the foundation for any environmental actions that will lead to an increase in radiation exposure levels.

a. Justification of Practice

Any modification to the radiation exposure scenario should be more advantageous than detrimental. This means that any positive effects on the individual or society should outweigh any bad effects from adding a new radiation source, reducing existing exposure, or reducing the danger of potential exposure (WHO, 2012 BSS).

b. Optimization of Protection

The likelihood of exposures, the number of people exposed, and the amount of each individual dosage should all be kept as low as is practically feasible while keeping in mind societal and economic factors. This recommends that, given the current circumstances, the protection level should be as high as possible, maximizing the margin of benefit over danger. To avoid drastically disparate results from this optimization strategy, there should be controls on the doses or risks that individual can receive from a certain source (dose or risk constraints and reference levels) (WHO, (2012 BSS).

c. The Principle of Application of Dose Limit

To restrict individual dosages, protection optimization is paired with dose constraint and reference level. In order to assess whether dose levels are exceptionally high or low, diagnostic reference levels are utilized in medical diagnosis. To make sure that protection has been optimized, local review should be mentioned (WHO, 2012 BSS).

2. RADIOACTIVITY

The IAEA (2003), defined radioactivity as the spontaneous decay of atomic nuclei that produce energy and emit alpha, beta, or gamma rays, or a combination of any or all of these rays. Henri Becquerel, a French physicist who was researching on uranium compounds, unintentionally discovered radioactivity in 1896.

The spontaneous emission of highly penetrating radiations from heavy elements of atomic weights greater than about 206, occurring in nature, is called natural radioactivity, while radioactivity induced in an element by bombarding it with alpha particles, protons, neutrons, or radiations is called artificial radioactivity. The atoms of radioactive elements emit radiations composed of three different types of particles (rays) alpha, beta and gamma particles (rays), as expressed in Figure 20. No radioactive substance emits both alpha and beta particles simultaneously. Some substances emit alpha particles and some other emits beta particles. However, gamma rays are emitted along with both alpha and beta particles (Weisstein, 2014; WHO, 2023). The activity of a radioactive substance is expressed in terms of Curie, where;

$$1\ curie = 3.70 \times 10^{10}\ {}^{disintegration}/_{second} \qquad (9)$$

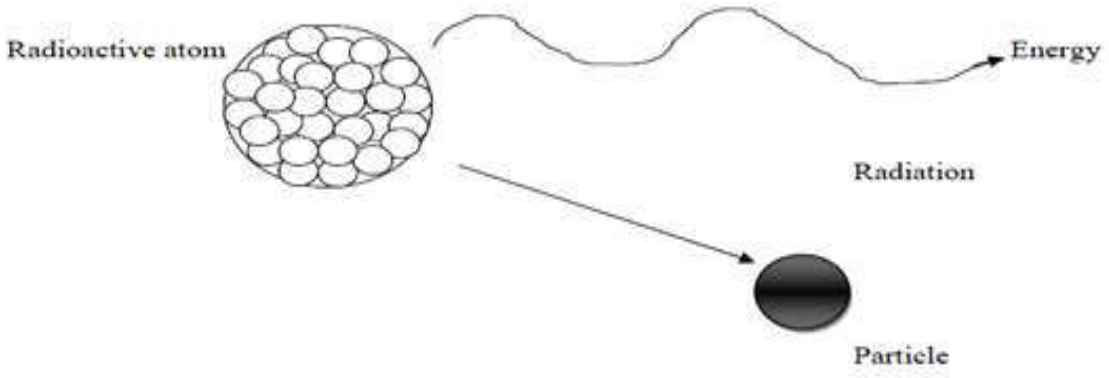


Figure 20: Emission of particle from a radioactive atom

Depending on the element and its atomic number in a certain decay chain, radionuclides' biogeochemical activity is anticipated to differ. For instance, the decay chain of uranium contains isotopes of radium, radon, thorium, and other elements. From an inert gas (radon) to a powerfully adsorptive tetravalent cation (thorium), they differ chemically. For the purpose of determining source terms and calculating dose, it is crucial to comprehend this behavior, this enables us to calculate the concentrations of all other elements in the decay chain from the data of the concentrations of all daughter elements.

Examples of chain disintegrations are the natural decay series of 238U, 234U and 232Th as shown in Figure 21, the two types of radioactive substances are known as natural radionuclides and fabricated radionuclides (artificial) can be distinguished in the hydrosphere and the atmosphere respectively.

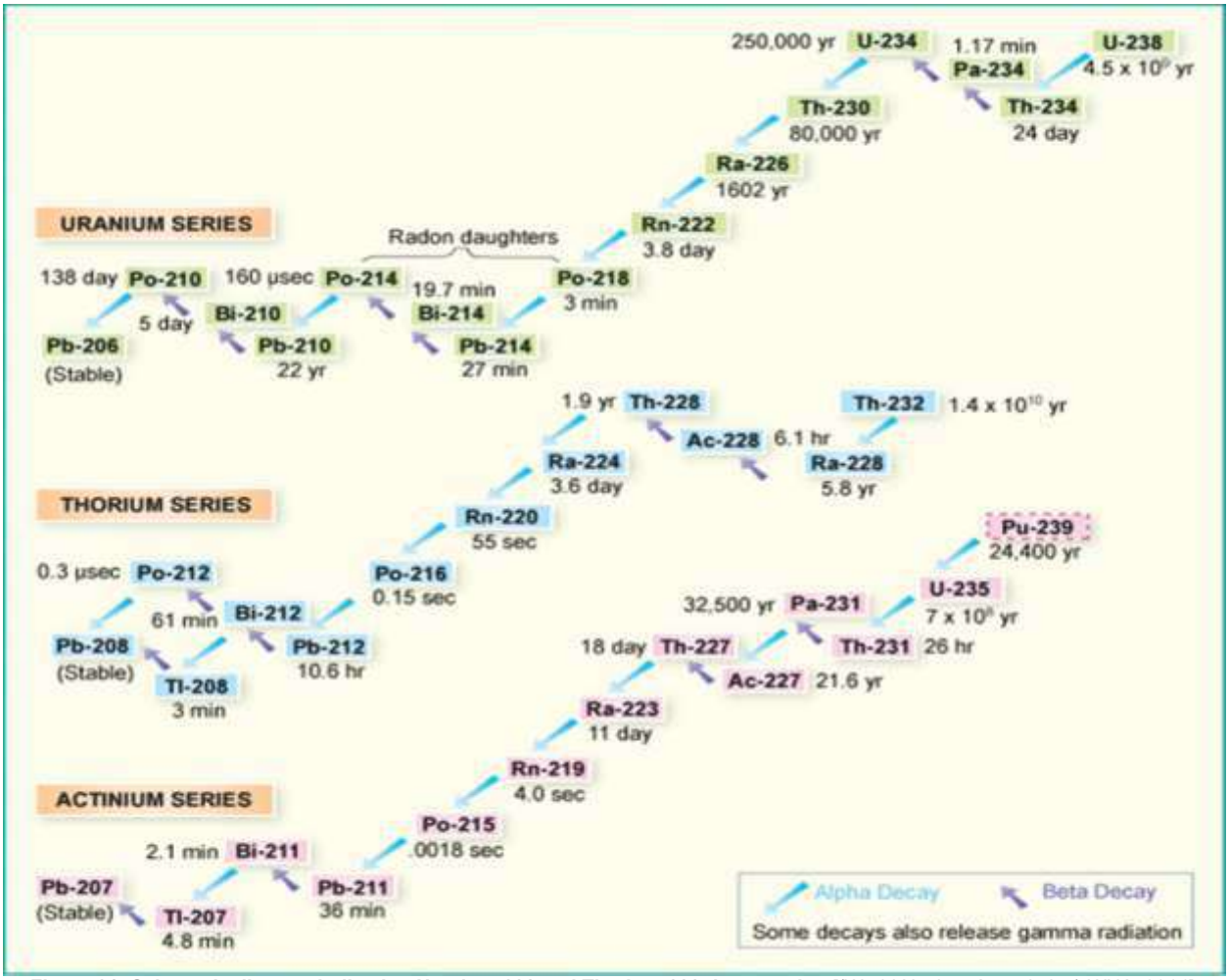


Figure 21: Schematic diagram indicating Uranium-238 and Thorium-232 decay series *[(World Nuclear Association) WNA, 2014]*

2.1. Law Governing Radioactive Decay

The random breakdown of an unstable nucleus into new elements (children or daughters), which are chemically distinct from the decaying element (mother), is known as radioactive decay, often referred to as nuclear de-excitation to the ground state. Until, a stable nuclide is created or continually decay continues. Various methods, including electron capture, particle emission, and gamma ray emission, are used by unstable radionuclides to decay, according to Podgorsak, (2005).

The fundamental principle of radioactive decay is predicated on the notion that the parent nuclei decaying into daughter nuclei is solely a statistical process. The likelihood of decay does not alter over time in atomic nuclei, which is a fundamental property of these particles.

The mathematical formulation of this law is:

$$-dN = \lambda N.\, dt \qquad (10)$$

and

$$\lambda = \left(-\frac{dN/dt}{N}\right) \qquad (11)$$

If N is the total number of radioactive nuclei, then $-dN/dt$ represents the reduction (negative value) of this number per unit of time and, consequently, the probability of nucleus decay per unit of time. For each nuclide's individual decay mode, this decay constant is unique.

The quantity of decays per unit of time is known as radioactivity or decay rate

$$A = -\frac{dN}{dt} = \lambda N \quad (12)$$

Applying boundary conditions with the initial values of t=0 and N=N_0 while integrating this relationship results in.

$$\ln\left(\frac{N}{N_0}\right) = -\lambda t \quad (13)$$

Consequently, the exponential decay equation is

$$N = N_0 e^{-\lambda t} \quad (14)$$

or using

$$A = A_0 e^{-\lambda t} \quad (15)$$

The period when A_0 became A (i.e., the material's age) is:

$$T = \left(\frac{1}{\lambda}\right) \ln\left(\frac{A}{A_0}\right) \quad (16)$$

The link between equations 14 and 15 shows the rate of reduction over time in both the original radioactivity ($\mathbf{A_0}$) and the number of radionuclei($\mathbf{N_0}$).

2.2. Half-life

The half-life, which may be defined as the amount of time it takes for a radioactive isotope to decay in half, is a significant and practical component of radioactive decay. Microseconds to billions of years are included. An individual radioisotope's half-life is independent of both the environment and the isotope's starting concentration. When describing the level of radionuclide instability or decay rate, the half-life $T_{1/2}$) as shown in equation 17 is sometimes used instead of the decay constant (λ) as shown in equation 18. This period has passed after half of the radioactivity (i.e., half of the nucleus) has decayed (www.princeton.edu).

$$T_{1/2} = \left(-1/\lambda\right) \ln(1/2) \quad (17)$$

From which:

$$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{T_{1/2}} \quad (18)$$

2.3. Series of Radioactive Decay

When radioactive decay occurs in light elements with Z=N, daughter nuclei can also be radioactive if the radionuclide is far from the stability line of the nuclide chart. This happens spontaneously when heavy uranium and thorium decay series nuclides are present. Here, several radioactive decay products come after the initial disintegration of 238U or 232Th.

The radioactive decay equation discussed in this work describes how the parent nucleus degrades.

$$A_1 = -\frac{dN_1}{dt} = \lambda_1 N_1 \quad (19)$$

And

$$N_1 = N_0 e^{-\lambda t} \quad (20)$$

Two processes—radioactive decay and radioactive growth caused by parent nucleus decay—affect the number of daughter cores:

$$\frac{dN_2}{dt} = -\lambda_2 N_2 + \lambda_1 N_1 \quad (22)$$

2.4. Radioactive Equilibrium

Radioactive equilibrium in nuclear physics refers to a situation in which radionuclides degrade at a rate equal to that at which they are created. The nucleus that is decomposing is generally referred to as the parent nucleus, and it survives the incident as a daughter nucleus. Daughter nuclei may be radioactive or stable. If the material is radioactive, it breaks down into daughter nuclei. As a result, every radioactive parent nucleus has the ability to start a chain of decays, and every decay byproduct has a unique decay constant.

According to the law of radioactive equilibrium, the progeny uranium-238's activity must be equal to that of the progenitor nucleus. A ton of 12.4 million becquerels. The mass of any offspring present is proportionate to the ratio of the half-lives as a result of this law of equilibrium. They all have far shorter durations (4.47 billion years) than uranium-238, and as a result, much smaller masses. There are two different kinds of balances in addition to (no balance), which will be elaborated below (Podgorsak, 2005).

2.4.1. Secular Equilibrium

When the parent nuclide's half-life is infinitely longer than the daughter nuclide's half-life, there is this type of interaction between the two nuclides (Figure 22 shows the secular equilibrium of a daughter and parent radionuclide). An illustration is the connection between the long-lived uranium and thorium isotopes 238U, 235U and 232Th and the byproducts of their disintegration.

$$\lambda_1 \ll \lambda_2 \quad (23)$$

Where;$\boldsymbol{\lambda_1}$ = daughter nuclide $\boldsymbol{\lambda_2}$ = parent nuclide

Equation 22 precisely defines the parent activity in time.

$$A_2 = A_1^0\left(e^{-\lambda_1 t} - e^{-\lambda_2 t}\right) \quad (24)$$

or whenλ_1 = 0,

$$A_2 = A_1^0\left(1 - e^{-\lambda_2 t}\right) \quad (25)$$

To illustrate the rise in daughter activity over time, we first assume $A_2 = 0$. Finally, the daughter activity reaches the final state (at $t \infty$ with $\lambda_2 t \to \infty$)).

$$A_2 = A_1^0\left(e^{-\lambda_2 t}\right) = A_1 \qquad (26)$$

In other words, activities for both parents and daughters are the same as shown in Figure 22.

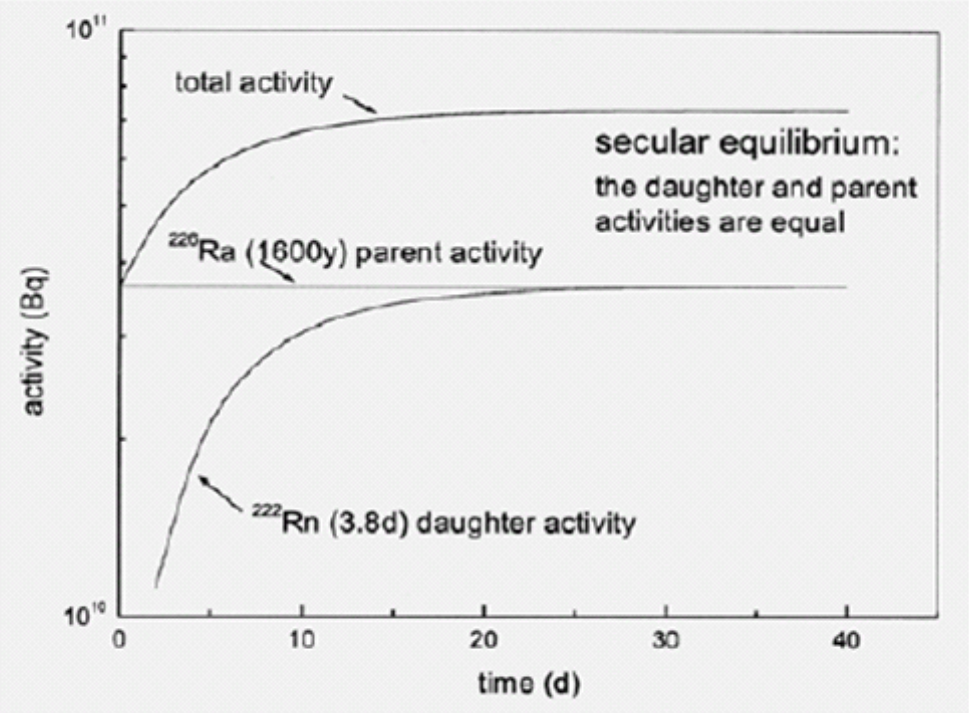


Figure 22: A conceptual image of the secular equilibrium *(source: USNRC, 2011)*

2.4.2. Transient Equilibrium

The half-life of the parent isotope in this case is longer than that of the daughter isotope, but it is finite. Figure 23 represents a transient equilibrium between a daughter and parent radionuclide.

$$\boldsymbol{\lambda_1 < \lambda_2} \qquad \textbf{(27)}$$

The daughter nuclide is currently growing up with zero activities and zero hours. When enough time has elapsed, a stable state is established where it is anticipated that her daughter's activity will be higher than that of her parents.

$$\mathbf{A_2 = \frac{\lambda_2}{\lambda_2 - \lambda_1} A_1^0\left(e^{-\lambda_2 t}\right) = \frac{\lambda_2}{\lambda_2 - \lambda_1} A_1} \qquad \textbf{(28)}$$

Given that;

$\boldsymbol{\lambda_1}$ is the daughter nuclide

$\boldsymbol{\lambda_2}$ is the parent nuclide and

t is the time taken for the nuclide to obtain a stable state.

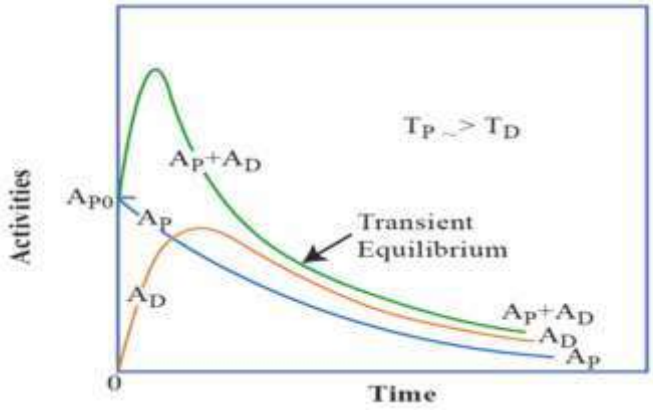


Figure 23: Diagrammatic representation of a transient equilibrium between a parent and its daughter radionuclide (source: Research gate, 2023)

2.5. Types and Sources of Radioactivity in the Environment

External irradiation from radionuclides is naturally present in the environment or released from man-made practices or events. They are usually an important component of the exposure of human populations. When radionuclides are released into the environment, they persist until they are lost through radioactive decay, causing radiation exposures into the future. These exposures lead to gamma radiation exposure arising from the decay of radionuclides at locations outside the human body. These deposited radionuclides are transported in air, water, and soil through various mechanisms, and the measurements of radionuclide transfers from past releases have been used to study and infer large-scale atmospheric and hydrological movements on the earth (Agbalagba et al., 2013; 2014; 2019 & 2023).

In addition, radioactive materials, either particles or gases, may be transported at great distances by local and large-scale air movements. The time-periods that the materials remain airborne depend on the latitude, time of year, and height of injection into the atmosphere. The depletion processes include gravitational settlement and dry impaction, incorporation into raindrops and washout by falling precipitation (UNSCEAR, 2008). The physical and chemical characteristics of the materials themselves, such as particle size, chemical and physical forms, may influence the removal rates. Also, radioactive material released to the aquatic environment is transported and dispersed by advective and turbulent processes occurring in the water body. Methods for modelling hydrological transport have been developed and applied, usually for specific categories of water bodies: lakes, rivers, estuaries, coastal seas and oceans (UNSCEAR, 2000).

2.5.1 Terrestrial Radioactivity

Naturally occurring radionuclides of terrestrial origin (also called primordial radionuclides) are present in various degrees in all media in the environment, including the human body itself. Only those radionuclides with half-lives comparable to the age of the earth, and their decay products, exist in significant quantities in these materials. Many radionuclides occur naturally in terrestrial soils and rocks, and in building materials derived from soils and rocks. Upon decay, these radionuclides produce an external radiation field to which all human beings are exposed. Irradiation of the human body from external sources is mainly by gamma radiation from radionuclides in the 238U and 232Th series and from 40K (UNSCEAR, 2000, 2020; Agbalagba et al., 2019). And the most important processes for the transfer of radionuclides through the terrestrial environment are illustrated in Figure 24, and discussed in the subsections below.

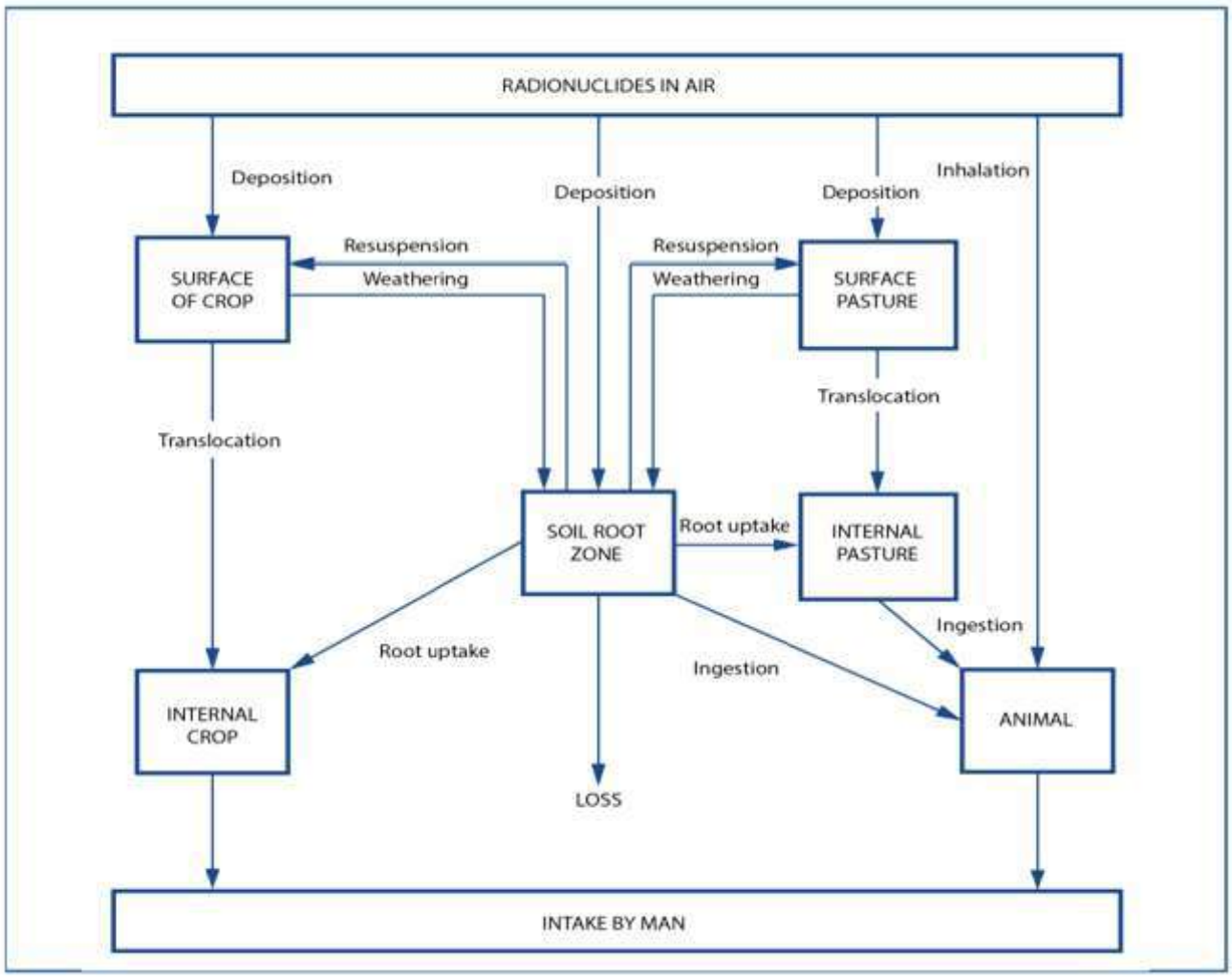


Figure 24: The transfer of radionuclides in the terrestrial environment

2.5.1.1. Soil Contamination Pathway

The earth's soil lithology plays a very important role in the estimation and determination of the source of radionuclides in the subsurface water aquifers. The emission of radiation from naturally occurring radionuclides in rock formations and soil are sources of pollution in the environment if allowed to build up naturally or by anthropogenic activities (Agbalagba et al., 2013; 2014; 2019 & 2023). Radionuclides are initially deposited on the upper surface of the soil, but they quickly weather into the first centimeter of soil, especially if they are deposited via rainfall. This weathering effect and also the fact that the soil surface is not a smooth plane (soil roughness) reduce the radiation field at the generally used reference height of 1 m above the soil surface. Other mechanisms, such as plowing and countermeasures, can reduce the exposure rate (UNSCEAR, 2020).

2.5.1.2 External Outdoor Exposures

External exposures outdoors arise from terrestrial radionuclides present at trace levels in all soils. The specific levels are related to the types of rock from which the soils originate. Higher radiation levels are associated with igneous rocks, such as granite, and lower levels with sedimentary rocks. There are exceptions, however, as some shales and phosphate rocks have a relatively high content of radionuclides.

2.5.1.3 Indoors Exposure

Indoor exposure to gamma rays, is mainly determined by the materials of building construction, and is inherently greater than outdoor exposure, if earth materials have been used, then the source geometry changes from half-space to a more surrounding configuration indoors. When the duration of occupancy is taken into account, indoor exposure becomes even more significant. Buildings constructed of wood add little to indoor exposures, which may then be comparable to outdoor exposures. However, surveys of absorbed dose rates in air inside dwellings are not as complete as outdoor surveys.

2.5.2. Plant Radioactivity Contamination Pathway

Plants (vegetation) are the primary recipients of radioactive contamination to the food chain following atmospheric releases of radionuclides. Plants (vegetation) may be subject to direct and indirect contamination. The direct contamination of terrestrial vegetation refers to the deposition of radioactive materials from the atmosphere onto the above-ground parts of plants. Indirect contamination refers to the sorption of radionuclides from the soil by the root system of plants. The secondary recipients of food chain contamination are animals that consume plants or other animals. Both plant and animal products enter the diet of humans (UNSCEAR, 2000, 2020; IAEA, 2020).

2.5.3. Animal Radioactivity Contamination Pathway

Several important pathways for the transfer of radionuclides to the diet of humans involve animal food chains, including milk and eggs from living animals and meat or flesh from animals and fish. Depending on the radionuclide and the metabolism in the organism, the concentrations may be enhanced or reduced compared with the earlier steps of the food chain. Some parts of the animal are not consumed, e.g., bones, shells, skin and feathers, and this prevents the transfer from animal products of bone-seeking radionuclides such as Strontium (90Sr) and Plutonium (238Pu).

2.5.4 Water (Aquatic) Radioactivity Contamination Pathway

The consumption of foods and water by individuals varies widely around the world, depending on climate, food availability and cultural dietary preferences. Radioactive contamination of the aquatic environment may result in ingestion doses by three pathways: drinking of freshwater from both surface and ground sources, consumption of biota living in the water, typically fish, and consumption of terrestrial foods that have been contaminated by the use of freshwater for irrigation, by the application of sediments as soil conditioners, or by the application of aquatic plants as fertilizer. Water consumed by animals may also form a pathway for the transfer of radionuclides to the human diet. Shoreline deposits of contaminated sediments can contribute to external exposures. The study on water analysis will follow and respect the WHO guidelines and procedures as shown in figure 25.

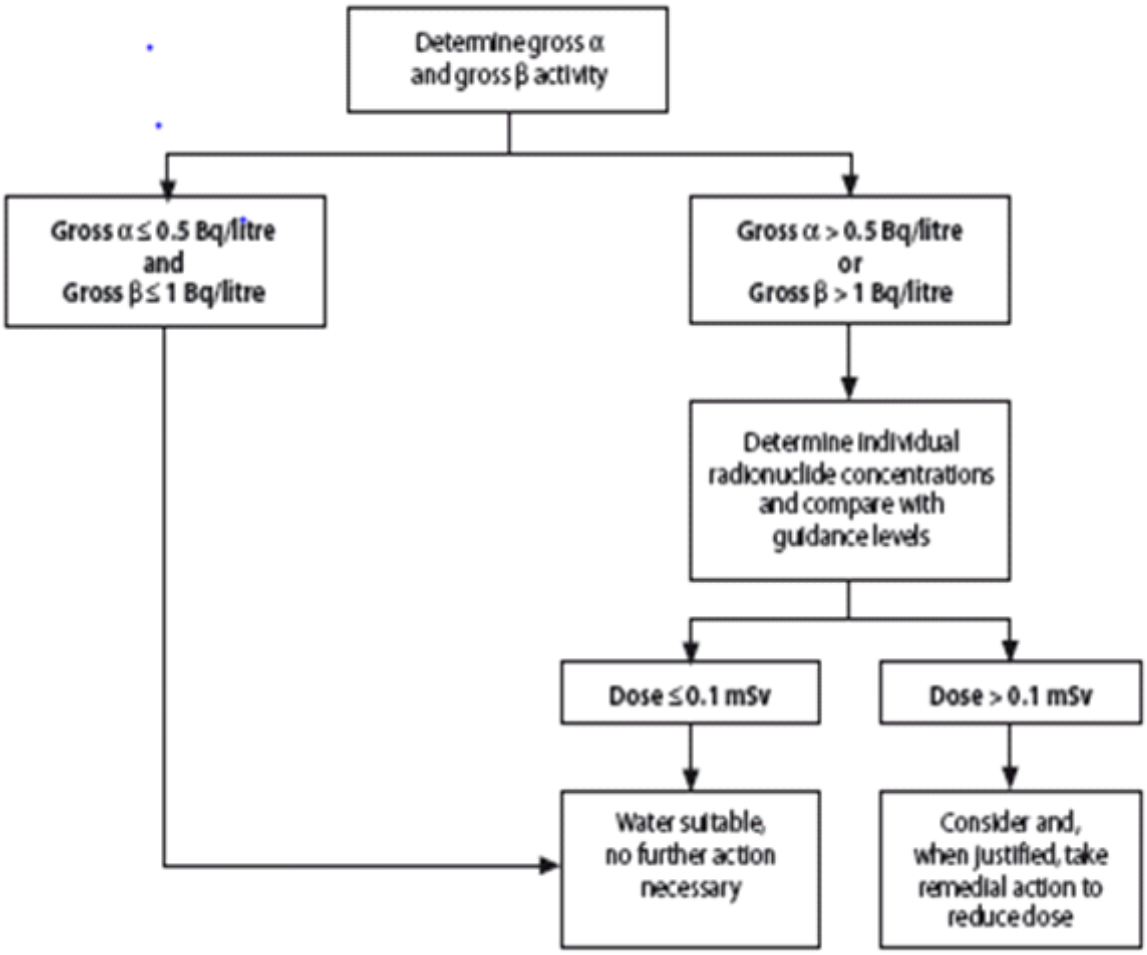


Fig 25: Procedures for screening of drinking-water supplies

Table 3: Different Ranges of Water Quality *(WHO 2018)*

Class /Colour	*Dose range; mSv/a*	*Health Effects and Typical Exposure Scenarios*	*Intervention Decision Time Frames*
Class 0 (Blue - Ideal water quality)	0.01 – 0.10	• There are no observable health effects. • This is the range of exposure from ideal quality water sources. • Most treated water falls in this water quality range. • Additional doses that result from human activities that fall within this range are difficult or impossible to determine and/or to distinguish from variations in background doses with sufficient confidence.	Intervention not applicable for this class of water.
Class 1 (Green - Good water quality)	> 0.10 – 1	• There are no observable health effects. • It is the range of exposure from some natural and untreated water sources (e.g. ground water / wells) as well as water sources that could be influenced by mining and mineral processing activities. • A dose between 0.2 to 0.8 mSv/a is the typical worldwide range of ingestion radiation dose resulting from water as well as food. • A dose equal to 1 mSv/a corresponds to the regulatory public dose limit for human activities involving radioactive material.	No intervention is required although ALARA principles apply.
Class 2 (Yellow - Marginal water quality)	> 1 – 10	• A small increase in fatal cancer risk associated with this dose range. • Probably only a small number of natural water sources of this quality exist, resulting from exceptional geological conditions. • Abnormal operating conditions at some nuclear certified mineral and mining processes may result in a dose in this range when a person drinks the untreated water. Intervention will most likely be required to improve the quality of water that is released into the public domain. • The total natural background radiation from all exposure pathways, not only water, falls in this range.	Intervention considerations within 2 years.
Class 3 (Red - Poor water quality)	> 10 – 100	• Health effects are statistically detectable in very large population groups. • This range represents excessive exposure. • It is highly unlikely to find water of this poor quality in the natural environment.	Intervention is required in less than 1 year.
Class 4 (Purple - Unacceptable water quality)	> 100	• Health effects may be clinically detectable and a significant increase in the fatal cancer risk (greater than one in a thousand). • A dose greater than 100 mSv can usually only occur during a major accident at a nuclear facility. These facilities have to demonstrate that such an accident cannot happen with a frequency of more than once in a million years.	Immediate intervention is required.

If the RDL of 0.1mSv/year is being exceeded on aggregate from Table 3, then the options available to the competent authority to reduce the dose should be examined. Where remedial measures are contemplated, any strategy considered should first be justified (in the sense that it achieves a net benefit) and then optimized in accordance with the recommendations of ICRP (2018) in order to produce the maximum net benefit.

1.6. Radon and Decay Products

Radon and its short-lived decay products in the atmosphere are the most important contributors to human

exposure from natural sources. While the health risks associated with high radon exposures in underground mines have been known for a long time, relatively little attention was paid to environmental radon exposures until the 1970s, when some scientists began to realize that indoor radon exposures could be quite high, in some cases comparable to the exposures experienced by many underground miners. Since then, the flood of information on radon has continued unabated.

It is well known that inhalation of the short-lived decay products of Radon (^{222}Rn), and to a lesser extent the decay products as displayed in Figure 26, and their subsequent deposition along the walls of the various airways of the bronchial tree provide the main pathway for radiation exposure of the lungs.

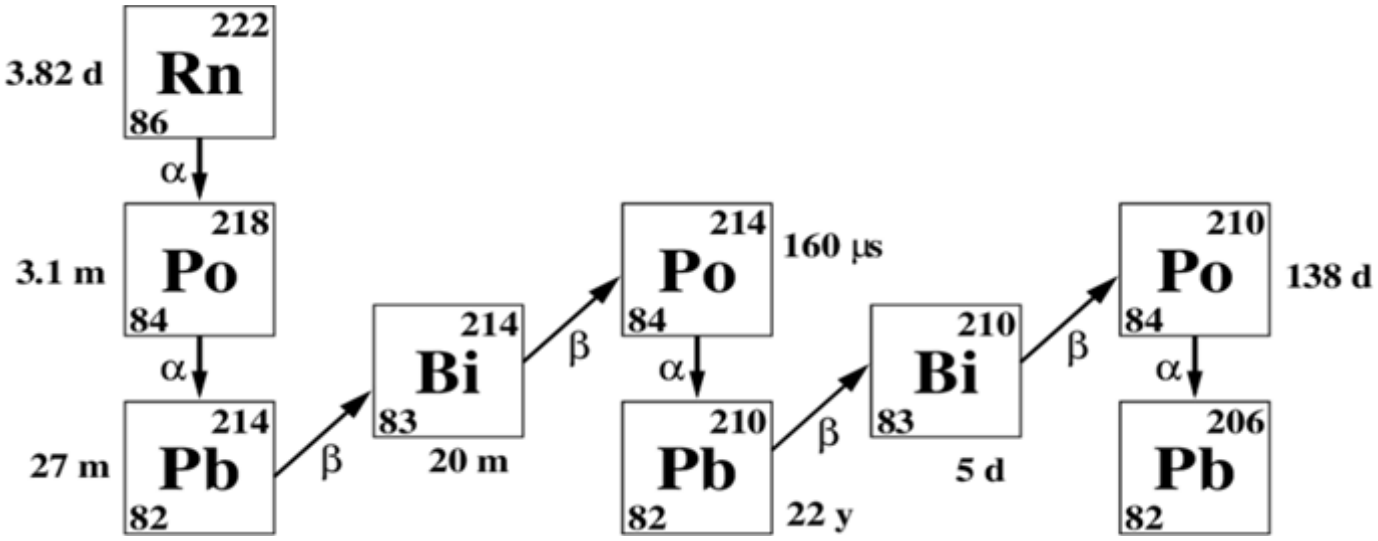


Figure 26: Radon (222Rn) decay chain

2.7. Radiation and Nuclear Regulatory Agencies

Creating a regulatory agency or organization is the main duty of governments at the national and international levels. Governments should take special precautions to protect the public and personnel exposed to radiation at work from excessive radiation exposure. In addition to the Enablement Act, Nigeria has a number of subsidiaries of the two main agencies in charge of radiation shielding the environment (Avwiri, 2011).
There are different radiation regulatory agencies at the international and national level shouldered with the responsibilities of protecting our foods, water, plants and animals from over exposure to radiation of any form. Some regulatory bodies are mentioned below;

i. NAFDAC- National Agency for Food and Drugs Administration and Control
ii. NIRPR- National Institute of Radiation Protection and Research
iii. AERB- Atomic Energy Regulatory Board
iv. IARC- International Agency for Research on Cancer
v. IACRS- Inter Agency Committee on Radiation Safety
vi. IAEA- International Atomic Energy Agency
vii. ICRP- International Commission on Radiation Protection
viii. IRPA- International Radiation Protection Association
ix. NIRPR- National Institute of Radiation Protection and Research (Nigeria)
x. NNRA- Nigeria Nuclear Regulatory Authority
xi. UNSCEAR-United Nations Scientific Committee on Effect of Atomic Radiation
xii. USEPA- United States Environmental Protection Agency
xiv. USNRC- United State Nuclear Regulatory Commission
xv. WHO- World Health Organization

Certain radioactive materials must be used under strict controls and monitoring to safeguard the environment and the public's health due to their potential for harm. To that end, the following governmental entities in Nigeria are jointly in charge of licensing and regulating the use and handling of these materials:

1.Nigerian Nuclear Regulatory Agency (NNRA):

The government organization in charge of enforcing nuclear safety and radiation protection regulations in Nigeria is the Nigerian Nuclear Regulatory Authority (NNRA). It was created in accordance with the Nuclear Act of 1995, and it started functioning in 2001 (Nnodim, 2018). The fundamental duties assigned to this agency are: to regulate radiological protection and nuclear safety in order to ensure the safety and security of radioactive sources and nuclear materials, as well as to enable Nigeria to comply with its international obligations regarding the peaceful uses of nuclear technology (www.nnra.gov.ng, 2023).

2. Nigerian Atomic Energy Commission (NAEC)

The Nigerian Atomic Energy Commission (NAEC) was established in 1976 with the responsibility to, among other things, building and maintaining nuclear installations for the purpose of generating electricity, conducting research on issues relating to the peaceful use of atomic energy, and educating and training people in those areas (www.nigatom.gov.ng, 2023). A management structure was created in order to enable the Commission to carry out its mandate to pursue a sustainable national nuclear technology program. This core mandate is defined by the operational goal and policy objectives, which are established as follows:

I. To create the methods and technical tools necessary to efficiently discover, utilize, and harness atomic energy for beneficial societal and economic growth.

ii. The establishment of a world-class institution for the advancement and responsible use of nuclear technology for the benefit of national advancement in accordance with international best practices.

iii. Creating a long-lasting framework that is infused with the core components of a high safety culture is necessary for the peaceful use of nuclear science and technology for Nigeria's socioeconomic development.

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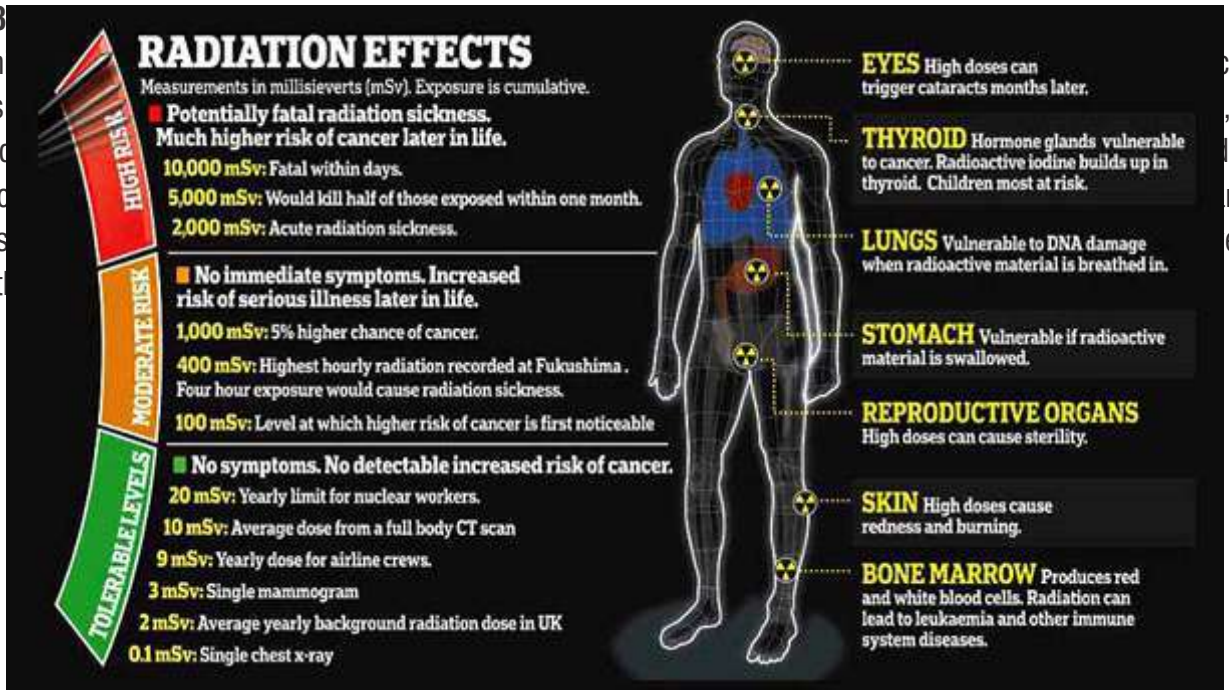


Figure 27: Radiation Doses and their Effects on critical Human Organs and Tissues (Farai, 2014)

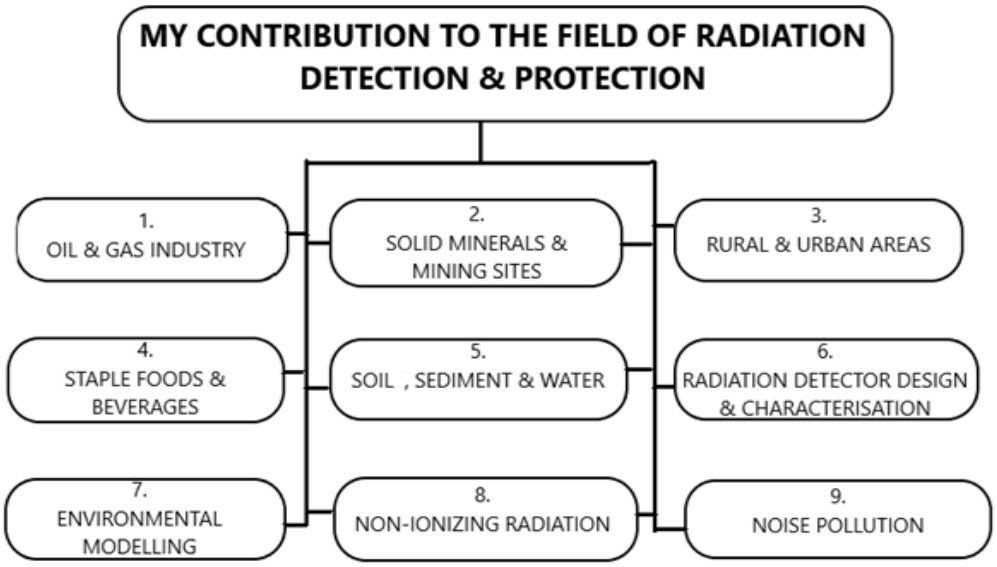
3. MY CONTRIBUTIONS IN RADIATION DETECTION AND PROTECTION

Radiation protection of man and the environment is key to the actualization of good and healthy living and sustainable environment. This has been amplified by the Goal 11 (make cities and human settlements inclusive, safe, resilient, and sustainable) and Goal 15 (take urgent action to combat climate change and its impacts) of the United Nations Sustainable Development Goals (SDGs). Human and environmental radiation protection are critical and pivotal to achieving the overall objectives of these SDGs.

The safety and sustainability of the human settlements and cities to combat and mitigate the effects of environmental degradation and climate change globally has been on the front burner for almost three decades by stakeholders and researchers. But it appeals that time is running against all members' countries signatory to the United Nation convention on the Sustainable Development Goals to meet these two important goals. One of the greatest threats to the realization of this SDGs is man's activities in our environment.

The emission of harmful gases and radiations due to man's perturbation of the ecosystem is becoming more visible and taking alarming dimension in spite of the many advocacy groups and campaign against climate change. I have over the last two decades dedicated myself and research life in unveiling the good, the bad and the ugly of radiation in our environment with the exploited Niger Delta in focus.

Mr. Vice Chancellor Sir, haven gotten the firm conviction that I will advance my career in Federal University of Petroleum Resources Effurun, Delta State the very day it was pronounced established on 17th March 2007 and three years before I was employed as lecturer in FUPRE, I tailored most of my research work to suit the vision, mission and philosophy of the University. In Radiation Protection research, we have three layers upon which research procedure follows. You identify a researchable environment where radiation and radioactivity contamination are probable, first you undertake the *insitu* assessment of the area or environment, upon established radiation elevation, gross alpha and beta activity concentration assessment will then be carried out on water, soil and/or sediment of the area. The final stage of every assessment of a radiation contaminated or polluted environment is the evaluation of the specific activity concentration of the water, soil, sediment, flora and fauna of the environment. Sir, I would have followed same pattern to showcase my research trajectory, but for ease of presentation and sake of time, I shall take this great audience through the various sector of the society where I have impacted with my research as shown, which includes:



3.1. Radiation Detection and Protection in the Oil and Gas Industry

Agbalagba, Avwiri, and Eyinnaya, (2007) studied the terrestrial radiation around **oil and gas facilities in Ughelli region** of Nigeria and reported a range of 12.00 ± 0.l μRh^{-1} (5.33 ± 0.35μSv/wk) to 22.00 ± 2.l μRh^{-1} (9.79±0.16 μSv/wk) in the oil fields and 09.00 ± 1.0 to 11.00 ± 0.5 μRh^{-1} in the host communities. Tables 4 and 5 shows the BIR level results obtained in two of the oil and gas field in the study area. The study concluded that though the radiation values are within international standards for occupational workers, the background ionizing radiation levels exceeded the normal and ambient background level for the public. Also, the significant difference between the values of the premise of the oil facilities and the host community suggests radiation pollution of the company's immediate environment.

Table 4: Kokori Oil and Gas Field Background Radiation Level

Table 4: Kokori Oil and Gas Field Background Radiation Level

S/N	SAMPLED AREA	GEOGRAPHICAL LOCATION	RADIATION LEVEL mRh^{-1} RAD 50	RAD 100	AVE. RAD VALUE mRh^{-1}	EQ. DOSE $mSv\dot{y}^{1}$
1	Manifold	NO5' 38.624' E006 04.321'	0.017	0.025	0.021±0.008	1.8±0.7
2.	Flow station Gate	NO5' 38.641' E006' 04'224'	0.018	0.020	0.019±0.009	1.06±0.8
3	Natural Gas compressc (NGC) station	NO5' 38.638' E006' 04.215'	0.018	0.022	0.021±0.010	1.7±0.8
4	L & S Tangle flow crude pipe	N05'38.601 E00604.226'	0.016	0.014	0.015±0.007	1.3±0.6
5	Control valve (crude)	N05' 39.012' E006. 04.171	0.018	0.020	0.019±0.007	1.6±0.6
6	Flare knockout drum	N05'39.016' E00604 66'	0.017	0.020	0.019± 0.006	1.6±0.5
7	Flare stock site	N05'39.108' E00500.801'	0.017	0.015	0.016±0.006	1.4±0.5
8	Well 13, 34 & 35	N05" 38.844' E006" 04.030'	0.020	0.023	0.022±0.011	1.8±0.9
9	Flare control valve	N05" 39.112' E006 04.192'	0.016	0.014	0.015±0.008	1.3±0.7
10	***Erhioke Community***	***N05 38.602' E006" 04.227'***	***0.014***	***0.013***	***0.014±0.004***	***1.2±0.3***
	MEAN FIELD LEVEL				**0.018±0.007**	**1.50.6**

Table 5: Eriemu Oil and Gas Field Background Radiation Level.

S/N	SAMPLED AREA	GEOGRAPHICAL LOCATION	RADIATION LEVEL mRh^{-1} RAD 50	RAD 100	AVE. RAD. VALUE mRh^{-1}	EQ. DOSE $mSv\dot{y}^{1}$
1	Field logistic base (FLB)	NO5' 32.770' E006 02.716'	0.022	0.016	0.019±0.009	1.6±0.8
2.	Well 3	NO5' 31.264' E006' 03 501	0.014	0.019	0.017±0.007	1.4±0.6
3	Pegging manifold	NO5' 31.550' E006' 03.430'	0.016	0.013	0.015±0.004	1.2±0.3
4	N.G.C Station	N05' 31.211' E006 03.428'	0.019	0.017	0.018±0.008	1.5±0.7
5	Flow station Gate	N05' 31.218' E006. 03.488'	0.012	0.014	0.013±0.005	1.1±0.4
6	GasVent (knockout drum)	N05' 31.488' E006 03.498'	0.017	0.018	0.015± 0.007	1.3±0.6
7	Flare stack site	N05' 31.305' E006 03.519'	0.013	0.019	0.016±0.006	1.4±0.5
8	L & S Tango Crude flow pipe	N05" 31.246' E006" 03.473'	0.013	0.016	0.015±0.005	1.2±0.4
9	Well 13 & 19	N05" 32 .181' E006' 02.251'	0.018	0.020	0.019±0.007	1.6±0.6
10	*Gana Agbarhotor community*	*N05 38.578' E006" 03.75'*	*0.017*	*0.014*	*0.016±0.007*	*1.3±0.6*
MEAN FIELD LEVEL					**0.016±0.006**	**1.4±0.5**

Agbalagba et al., (2008), estimated the occupational radiation profile of oil and gas facilities during and off – production periods in Ughelli oil field. The ionization radiation profile of 30 locations of oil and gas facilities in Ughelli oil and gas industrial area. The study area where samples were taken are shown in plates 7 to 11. Mean radiation levels during production periods range from 15.50± 1.65 µR/h (0.026±0.003 mSv/wk) to 19.14±3.16 µR/h (0.32±0.005 mS/wk) and from 13.38±1.69 µR/h (0.023±0.003mSv/wk) to 16.29±2.60µR/h (0.027±0.004mSv/wk) during the off-production periods, these results from the different oil fields are present in Table 6. The highest level of 26.00±0.5.1 µR/h (0.044±0.009 mSv/wk) was recorded at the Kokori oil field during production. It was observed that the radiation levels of these oil facilities and work environments were higher during production periods compared to off-production periods as shown in figure 28. Furthermore, the values for both periods are all within the occupational safe radiation limit of 0.02 mSv/wk as recommended by the UNSCEAR, but the exposure rates are far above the standard background level of 13.0 µR/hr indicating a measure of radiation health hazard in these locations. We concluded that the elevated levels indicated a measure of radiation health hazard on the field workers and suggested regular monitoring, reduction of on-duty period and reduction in radionuclide bearing input materials as precautionary measures.

Table6. Mean Exposure Rates in the Oil Fields.

		Mean radiation levels (µR/h)			
Field Code	Surveyed oil anc gas field	Off -Production	Production period	Mean Deviation (%)	Mean dose equivalent rate (µSv/wk)
ADF	Afusere oil field	13.38 ±1.69	15.50±1.65	**7.34**	**6.43**±0.75
EOF	Eremu oil field	16.29±2.60	19.14±3.16	**8.04**	**7.88**±1.29
KOF	Kokori oil field	13.57±1.80	18.43±2.68	**15.19**	**7.12**±0.99
UOF	Ughelli oil field	15.50±2.53	18.50±2.68	**8.82**	**7.57**±1.16

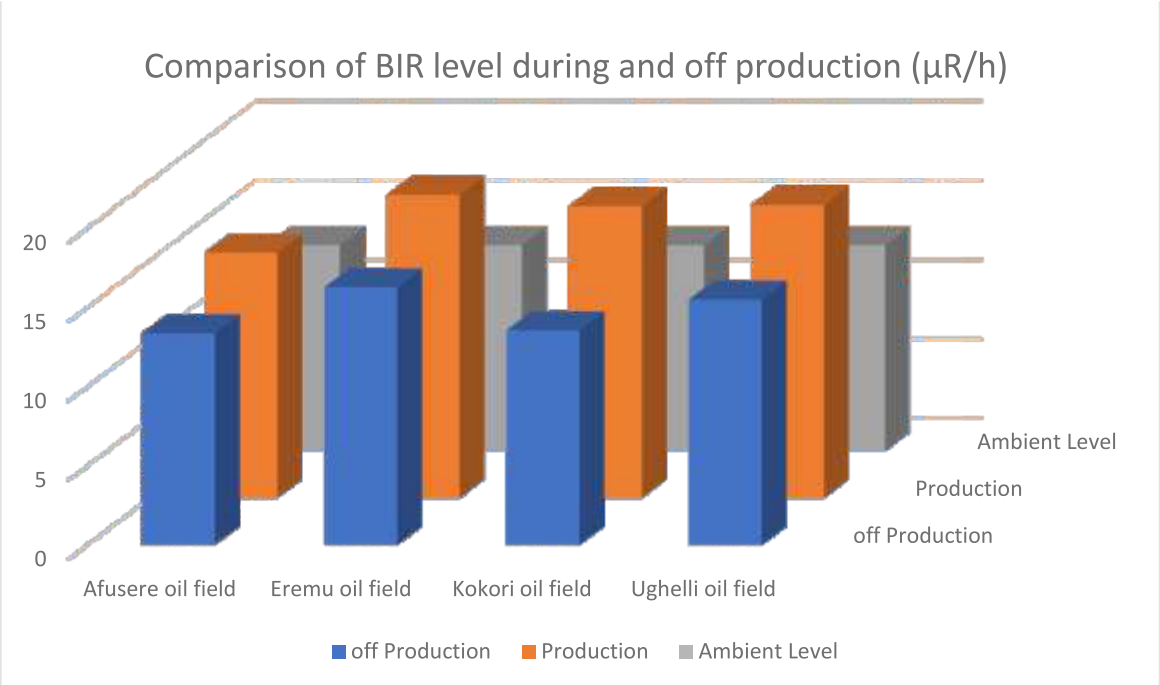


Fig. 28: Comparison of mean radiation levels (μRh^{-1}) in the fields with standard background level

Plate7: Three Oil field wells in one location with lima and serial

Plate 8: Flare Knockout Vessel (gas vent)

Plate 9: **Flare Stack Site**

Plate 10: Gas flare impact on the surrounding vegetation

Plate 11: Flow Station

Agbalagba and Meindinyo, 2010. Examined the radiological impact of oil spilled environment: A case study of the Eriemu well 13 and 19 oil spillages in Ughelli region of delta state, Nigeria. A six years of radiation impact assessment in an oil spillage environment and the host communities in Ughelli region of delta state have been conducted. Measurements were made in 20 sites, 6 host communities and a control sample spread across the affected area. Measured average location values ranged between 0.010 mRh^{-1} (0.532 mSv y^{-1}) to 0.019 mRh^{-1}(1.010 mSv y^{-1}). The yearly exposure rate ranged between 0.013±0.006 mRh^{-1}(0.692±0.080 $mSvy^{-1}$) to 0.016±0.005 mRh^{-1} (0.851±0.100 mSv y^{-1}) in the oil spillage area. The host communities' values ranged between 0.011 mRh^{-1}(0.585 mSv y^{-1}) to 0.015 mRh^{-1}(0.798 mSv y^{-1}) with an average value of 0.010 mRh^{-1}(0.532 mSv y^{-1}) recorded at the control sample. The radiation levels within these oil spillage areas and the host communities were of 55% and 33.3% respectively above the normal background level of 0.013 mRh^{-1}. The average equivalent dose rate obtained was higher than the 0.478 ηSv/y normal background level but was within the safe limit of 0.05 Svy^{-1} recommended by ICRP and NCRP. These values obtained will not pose any immediate radiological health hazard to the host communities and workers within this environment.

Agbalagba and Meindinyo, 2012. studied the radioactivity concentration and heavy metal assessment of soil and water, in and around Imirigin oil field, Bayelsa state, Nigeria. In situ measurement was conducted for pH and electrical conductivity, heavy metal analysis was carried out using Atomic Absorption Spectrophotometer (AAS) and gross alpha and beta activity concentration was by using gas filled proportional counter. Average value for pH and E.C. is 6.5±0.2 and 46.8±1.0 µs/cm respectively for soil and 6.4±0.5 and 406.1±5.2 µs/cm respectively for water. The mean values obtained for ASS analysis for soil are 11.9±1.0, 3.3±0.4, 1.7±0.7, 8.1±0.5, 42.5±1.9, 3.3±0.5, 8.0±0.6, 0.08±0.02 and 79.5±2.2 mg/kg. For Ca, Mg, Zn, Ni, Fe, Cd, Pb, Hg and Cr respectively for water, mean value obtained are 8.3±0.5, 4.2±0.4, 1.6±0.4, 1.5±0.3, 1.3±0.2, 0. 0.06±0.004, 0.07±0.003, 0.05±0.01 and ND mg/l for Ca, Mg, Na, K, Fe, Pb, Cd, Hg and AS respectively. Gross alpha and beta activities

mean concentrations for soil are 0.53±0.02 Bq/g and 29.29±0.17 Bq/g respectively, and 4.02±0.01 Bq/l and 54.23±1.76 Bq/l respectively for water. The results show that the level of the various metals obtained differs from location to location. Values obtained in soil were within reported values in the Niger Delta region except Iron level. Heavy metals such as Ca, Fe and Cd exceed the WHO limits for drinking water. The mean values for alpha and beta activity in soil are above reported values in similar environment while mean values obtained in water samples are above WHO recommended maximum permissible limit for drinking water. These values obtained show that drinking water from sampled locations may pose some long-term health hazards to the public users though soil from the area is still safe as construction material for buildings.

Agbalagba et al., 2012, Studied the γ-Spectroscopy of natural radioactivity and assessed the radiation hazard indices in soil samples from oil fields environment of Delta State, Nigeria. The activity concentration of the samples ranges from 19.2 5.6 Bqkg 1 to 94.2 7.7 Bqkg 1 with mean value of 41.0 5.0 Bqkg 1 for 226Ra, 17.13.0 Bqkg 1 to 47.5 5.3 Bqkg 1 with mean value of 29.7 4 Bqkg 1 for 232Th and 107.0 10.2 Bqkg 1 to 712.4 38.9 Bqkg 1 with a mean value of 412.5 20.0 Bqkg 1 for 40K as presented in Table 7. These values obtained are well within the world range and values reported elsewhere in other countries, but are little above some countries reported average values and some part of Nigeria. The study also examined some radiation hazard indices, the mean values obtained are, 98.5 12.3 Bq.kg 1, 0.8 Bqkg 1, 54.6 hGyh 1, 0.07 mSvy 1, 0.3 and 0.4 for Radium equivalent activity (Raeq), Representative level index (Ig), Absorbed Dose rates (D), Annual Effective Dose Rates (Eff Dose), External Hazard Index (Hex) and Internal Hazard Index (Hin) respectively as shown in Table 8. The study concluded that the calculated hazard indices to estimate the potential radiological health risk in soil and the dose rate associated with them were well below their permissible limit. But, oil workers in the fields and host communities were cautioned against excess and long-term exposure to avoid future accumulative dose of these radiations from sludge and sediment of the study area.

Table7: Specific activity of ^{226}Ra, ^{232}Th and ^{40}K andradium equivalent activity (Bqkg^{-1}) in soil, sediment/sludge samples from oil fields environment of Delta state

S/N	Sample Code	Location Description	Activity Concentration Bqkg^{-1}(±SD)			Ra_{eq} Bqkg^{-1}
			^{226}Ra	^{232}Th	^{40}K	
1	SUZP1	Uzere village soil	19.2±5.6	12.3±2.4	107.0±10.2	45.1±9.9
2	SUZP2	Uzere E&W field soil	38.4±6.6	4 4.2±8.5	497.2±27.3	139.9±20.9
3	SUZP3	Sludge from flow station	37.4±6.4	28.2±4.4	261.4±26.4	97.9±14.7
	[1]UZERE FIELD SOIL AVERAGE VALUE		**31.7±6.2**	**28.3±5.1**	**288.6±21.3**	**94.3±15.2**
4	S0LP1	Olomoro village soil	27.2±5.4	18.7±4.5	172.0±12.8	67.2±12.8
5	SOLP2	Oleh/ Olomoro field soil	42.4±5.3	16.2±3.3	328.6±20	90.9±11.5
6	SOLP3	Oleh/ Olomoro flow station soil	22.4±2.7	16.3±1.4	220.6±9.3	62.8±5.4
	[2]OLEH/ OL FIELD SOIL AVE.VALUE		**30.7±4.5**	**17.1±3**	**240.4±14**	**73.61±9.9**
7	SOWP1	Oweh village soil	20.3±4.4	15.9±2.2	263.4±12.7	63.3±8.5
8	SOWP2	Oweh field soil	32.1±6.3	27.6±4	509.6±18.7	110.8±13.5
9	SOWP3	Oweh flare stack site sediment	58.4±5.3	47.7±5.1	591.4±33.6	172.2±15.2
	[3]OWEH FIELD SOIL AVERAGE VALUE		**36.9±5.4**	**30.4±3.8**	**454.8±21.7**	**115.4±14.1**
10	SEVP1	Evwreni village soil sample	23.5±2.6	16.2±2.4	432.2±24.6	80±8
11	SEVP2	Evwreni field soil sample	40.2±5.2	32.3±4.5	552.1±16.4	128±12.8
12	SEVP3	Sludge from Evwreni oil waste pit	71.3±8.9	38.1±5.2	694.3±24.1	179.3±18.2
	[4]EVWRENI FIELD SOIL AVE. VALUE		**45±5.6**	**28.9±4**	**559.6±21.7**	**129.1±13**
13	SERP1	Gana village soil sample	24.3±2.3	29.5±4.3	272.7±9.7	87.4±9.3
14	SERP2	Eriemu field soil sample	62.7±6.4	41.8±5.3	504.2±26.7	161.4±16.1
15	SERP3	Eriemu oil field sludge sample	94.2±7.7	71.2±6.3	712.4±38.9	250.9±19.7
	[5]ERIEMU FIELD SOIL AVE. VALUE		**60.4±5.6**	**47.5±5.3**	**496.5±25.1**	**166.6±15**
16	SKOP1	Erhoike village soil sample	76.5±6.2	49.9±4.7	493.2±16.2	185.8±14.2
17	SKOP2	Kokori flare stack soil sample	34.1±5.2	26.3±3	614.1±30.2	119±11.8
18	SKOP3	Kokori field oil spilled soil	81.3±7.5	42.6±5.1	684±28.2	194.9±17
	[6]KOKORI FIELD SOIL AVE. VALUE		**64±6.3**	**39.6±4.3**	**597.1±24.9**	**166.6±14.3**
19	SAFP1	Emeragha village soil sample	28.1±3.6	18.6±2.3	394.2±17.5	85.1±8.3
20	SAFP2	Afiesere field soil sample	32.7±3.5	27.2±3	288.4±12.4	93.9±8.7

21	SAFP3	Afiesere flare stack sediment	36.3±4.4	20.4±4.1	312.4±20.3	89.6±11.8
	[7]AFIESERE FIELD SOIL AVE. VALUE		**32.4±3.8**	**22.1±3.2**	**331.7±16.7**	**89.5±9.6**
22	SUEP1	Village soil sample [Eruemukohwarien]	29.4±3.8	24.3±3.8	279.2±12.6	85.7±10.2
23	SUEP2	Ughelli east field soil sample	37.4±4.8	22.9±3.2	471.2±16.3	106.5±10.6
24	SUEP3	Ughelli east flare stack sediment	37.7±4.2	29.6±3.3	570.1±21.8	124±10.6
	[8]UGHELLI EAST FIELD SOIL AVE. VALUE		**34.9±4.3**	**25.6±3.4**	**440.2± 16.9**	**105.4±10.4**
25	SUWP1	Ekakpamre village soil sample	44.7±5.2	31.1±2.8	381.1±18.2	118.5±10.6
26	SUW P2	Ughelli west oil field soil sample	38.9±4.2	39.3±4.7	508.2±18.7	134.3±12.4
27	SUWP3	Ughelli west oil field sediment	54.5±6.2	33.3±5.6	462.1±21.2	137.6±15.8
	[9]UGHELLI WEST FIELD SOIL AVE. VALUE		**46±5.2**	**34.6±4.4**	**450.5±19.4**	**130.2±12.9**
28	SOTP1	Otujeremi soil sample	24.2±2.6	16.2±2.1	204.1±13.8	63.1±6.7
29	SOTP2	Otorogu oil field soil sample	31.6±4.1	18.5±2.7	234.4±17.6	76.1±9.3
30	SOTP3	Otorogu oil field sediment sample	28.1±2.7	34.4±4.4	360±22.1	105.1±10.7
	[10]OTOROGU FIELD SOIL AVE. VALUE		**28±3.1**	**23±3.1**	**266.2±17.9**	**81.4±8.9**
MEAN FIELD SOIL VALUE			**41**±5	**29.7±4**	**412.54±20**	**98.5±12.3**
Worldwide Background Soil Standard			**10-50**	**10- 50**	**100- 700**	≤ 370
31	CONTROL	Edjeba village soil sample	19.3±1.4	8.5±1.6	214.6±12.7	48±4.7

Table 8: Statistical summary of calculated radiation hazard indices of soil, sediment/sludge samples from oil fields environment of Delta state

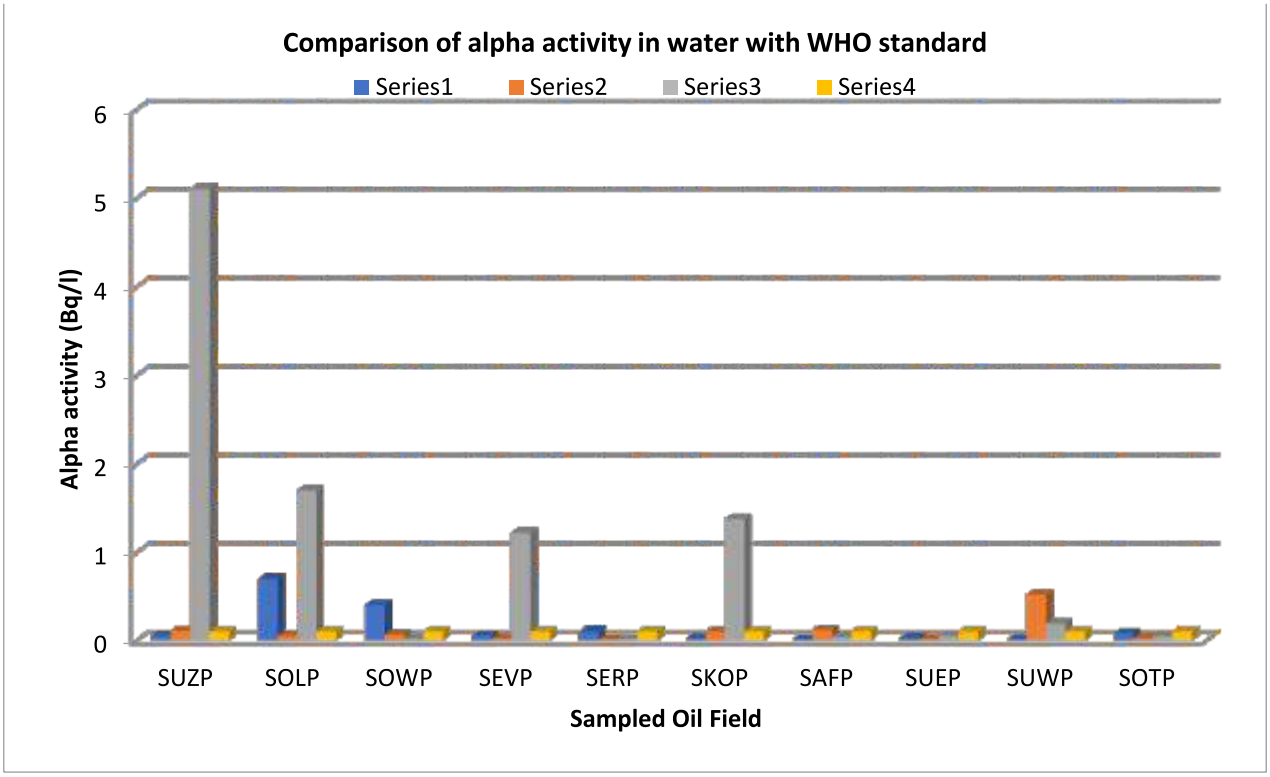
Oil field	Sample Size	Iγ (Bqkg^{-1}) Mean Range	D (ηGy.h^{-1}) Mean Range	E_{ff} Dose (mSvy^{-1}) Mean Range	Hazard index	
					H_{ex} Mean Range	H_{in} Mean Range
Uzere E& W	3	0.7(0.3- 1.0)	44.2(21- 65.9)	0.05(0.03- 0.08)	0.3(0.1- 0.4)	0.3(0.2- 0.5)
Oleh/ Olomo.	3	0.5 (0.5- 0.7)	34.8(31.3 - 43.4)	0.04(0.04 0.05)	0.2(0.2- 0.3)	0.3(0.2- 0.4)
Oweh	3	0.9 (0.5- 1.3)	54.9(30.2- 81.3)	0.07(0.04 0.1)	0.4(0.2- 0.5)	0.4(0.2- 0.6)
Evwreni	3	1.0(0.6- 1.3)	62.1(39- 85.6)	0.08(0.05- 0.1)	0.4(0.2- 0.5)	0.5(0.3- 0.7)
Eriemu	3	1.2 (0.6- 1.8)	78.1(40.9117.5)	0.1(0.05- 0.2)	0.5(0.2- 0.7)	0.6(0.3- 0.9)
Kokori	3	1.2 (0.9- 1.4)	79.1(57.7- 92.5)	0.1(0.07- 0.1)	0.5(0.3- 0.5)	0.6(0.4- 0.8)
Afiesere	3	0.7(0.6- 0.7)	42.5(41- 44.1)	0.05(0.05- 0.06)	0.2(0.2- 0.3)	0.3(0.3- 0.3)
Ughelli East	3	0.8 (0.6- 0.9)	50.4(40.3- 59.6)	0.06(0.05- 0.07)	0.3(0.3- 0.4)	0.4(0.3- 0.5)
Ughelli West	3	1.0 (0.9- 1.0)	61.5(55.9- 65.1)	0.08(0.07- 0.08)	0.4(0.3- 0.4)	0.5(0.4- 0.5)
Otorogu	3	0.6 (0.5- 0.8)	38.3(29.8- 49.4)	0.05(0.04 0-06)	0.2(0.2- 0.3)	0.3(0.2- 0.4)
MEAN VALUE		**0.8 (0.3- 1.8)**	**54.6(21- 117.5)**	**0.07(0.03- 0.2)**	**0.3(0.1- 0.7)**	**0.4(0.2- 0.9)**
ControlSample		**0.4**	**23.1**	**0.03**	**0.1**	**0.2**
Standard		≤ 1	**{60 (18- 93)}**	**1.0**	≤ 1	≤ 1

Agbalagba and Avwiri, (2012), determinate the Gross α and β Activity Concentration and estimated the Adults and Infants dose intake in surface and ground water of ten oil fields environment in Western Niger Delta of Nigeria. This study examined the gross α and β activity in thirty (river/stream, well and tap) water samples collected from ten oil fields environment in Western Niger Delta region of Nigeria. Table 9 present the results of the analyzed gross alpha and beta activities concentrations obtained. Gross alpha activity concentration ranged from 0.01±0.002 to 0.7±0.01 (0.15±0.003) Bql^{-1}, 0.01±0.003 to 0.5±0.01 (0.1±0.003) $Bql^{-1}$and 0.02±0.001 to 35.1±1.1 (4.1±0.1) Bql^{-1} while beta activity concentration ranged from 1.1±0.04 to 13.2±0.1 (6.0±0.1) Bql^{-1}, 0.7±0.1 to 54.7±1.3 (8.9±0.2) Bql^{-1} and 0.7±0.03 to 151.2±1.8 (40.1±0.9) Bql^{-1} for well, tap and river waters respectively. The obtained results showed that average natural activity concentrations of α- and β-emitting radionuclides in the water samples are slightly above the WHO recommended limit except alpha activity in tap water samples. For all samples the gross β activities were higher than the corresponding gross α activities. The mean effective equivalent dose intake per year due to alpha activity in the water samples for adults and infants are: 76.4±1.8 and 20.9±55μSvy^{-1}, 54.6±1.3 and 14.9±0.4 μSvy^{-1}, and 2118±70 and 584±19.2μSvy^{-1} in well, tap, and river water samples respectively. The comparison of the gross alpha and gross beta activity with WHO recommended limits are presented in figures 29 and 30 respectively. The results obtained for dose intake are below the WHO recommended reference level of 0.1mSvy^{-1}, except for Uzere river water sample.

This reveals that the water sources examined especially from river waters are contaminated radiologically. We therefore recommended that alternative water supply should be provided for people drinking or consuming the river waters, meanwhile well and tap waters should be treated for radioactivity before consumption.

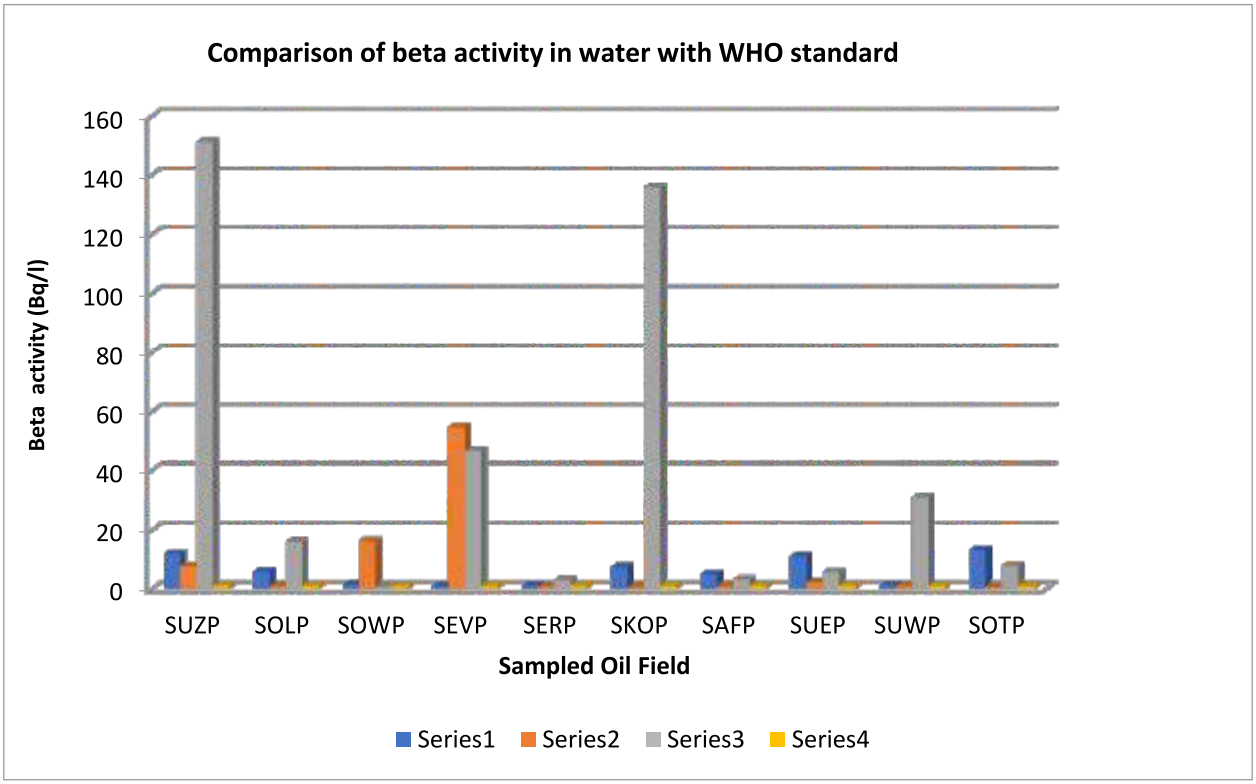
Table 9: Evaluatedeffective equivalent dose intake for the different age group from gross alpha activity in the studied well, tap and river water

S/N	Oil Field	Committed Effective Dose(m$Svyr^{-1}$) due to Intake of Water for various Age Group											
		Well Water				Tap Water				River Water			
		Infant ≤ 1	Childre n 1-12	Teenager 12-17	Adult >17	Infant ≤ 1	Childre n 1-12	Teenager 12-17	Adult >17	Infant ≤ 1	Children 1-12	Teenager 12-17	Adult >17
1	Uzere W &East	4.37	2.37	7.81	1.27	7.86	2.04	6.95	1.21	26.61	6.51	23.72	3.83
2	Olomoro/ Oleh	7.42	4.33	14.42	2.19	8.95	3.54	6.64	0.95	28.05	7.64	21.86	3.13
3	Oweh	23.95	13.17	46.15	6.75	46.72	6.02	34.28	4.98	50.94	11.90	38.16	5.40
4	Evwreni	21.37	16.70	52.13	7.09	43.48	10.24	33.50	4.74	49.88	4.44	20.52	6.16
5	Eriemu	41.13	10.04	31.57	4.94	83.00	18.80	62.44	9.39	204.50	48.20	101.39	28.85
6	Kokori	58.25	13.58	49.16	7.37	20.87	4.96	16.80	2.51	40.13	9.50	32.24	4.81
7	Afiesere	34.06	8.24	29.82	4.72	27.42	6.54	22.41	3.39	46.98	11.25	39.72	6.13
8	Ughelli East	38.33	9.13	31.56	4.78	28.12	6.57	22.00	3.21	89.69	20.74	77.07	11.45
9	Ughelli West	3.27	0.84	2.58	0.41	38.34	8.93	29.37	4.19	125.00	29.56	102.11	14.85
10	Otorogu	38.08	9.03	31.24	4.64	37.51	8.76	28.69	4.16	20.64	10.43	35.97	3.86
Average Value (m$Svyr^{1}$)		27.02±	8.74±2.1 1	29.64±6.8 3	4.42± 0.66	34.23± 7.30	7.64±1.0 2	26.31±5.7 6	3.87± 0.47	67.94±9. 24	16.02±2.2 8	49.28±7.8 2	8.85± 1.46
Control Value (m$Svyr^{1}$)		15.68	0.15	5.97	1.86	5.02	1.21	4.16	0.65	19.21	4.58	15.26	2.29



Series1: *Well water;* ***Series2****: Tap water;* ***Series3****: River water;* ***Series4****: WHO standard*

Fig 29: Comparison of Gross alpha activity in Well water, Tap water and River water with *WHO (2003) Maximum Limit of 0.1Bql*



Series1: *Well water;* ***Series2****: Tap water;* ***Series3****: River water;* ***Series4****: WHO standard 2003*

Fig 30: Comparison of Gross Beta activity in Well water, Tap water and River water with WHO (2003) Maximum Limit of 1.0Bql

Agbalagba et al., 2013. Evaluated the Naturally Occurring Radioactivity Materials (NORM) of Soil and Sediments in Oil and Gas Wells in Western Niger Delta Region of Nigeria (see figure 31). The research work presents an analytical approach to natural radioactivity assessment in soil and sediment in 15 oil fields and three oil mineral leases (30, 58 and 61) in Delta and River States. Concentrations of natural radionuclides (226Ra, 232Th and 40K) were determined using gamma spectroscopy. The mean activity concentration of ^{226}Ra, ^{232}Th and ^{40}K for OML30 is (40.2 ± 5.1, 29.9 ± 4.2 and 361.5 ± 20.0) Bq kg-1, respectively; the corresponding values obtained for OML58 is (20.9 ± 2.8, 19.4 ± 2.5 and 260.0 ± 14.1) Bq kg-1, respectively. While the mean activity concentration of 226Ra, 232Th and 40K for OML61 is 29.3 ± 3.5, 21.6 ± 2.6 and 262.1 ± 14.6 Bq kg^{-1}, respectively. These values obtained show enhanced NORMs, but are well within the world range and values reported in some regions and countries of the world, and are slightly above control values, values obtained in Southwestern region of Nigeria and some countries reported average values. The study also examined some radiation hazard indices, the mean values obtained are 86.6 ± 9.3 Bq kg^{-1} , 0.6 Bq kg^{-1}, 40.8 gGy h^{-1} , 0.05 mSv y^{-1} , 0.2 and 0.3 for radium equivalent activity (Raeq), representative level index (Iγ), absorbed dose rates (D), annual effective dose rates (Eff dose), external hazard index (Hex) and internal hazard index (Hin), respectively. These calculated hazard indices to estimate the potential radiological health risk in soil and sediment are well below their permissible limits. A comparison of the activity's concentrations in the three OMLs as shown in figures 32-34, indicated that activity concentration of NORMs in the fields are highest in OML30. The soil and sediments from the study area provide no elevated activity concentration for excessive radiation exposure of the inhabitants, thus, can be used as construction materials without posing any radiological threat or harm to the public users. However, oil-field workers and host community residents are cautioned against excess exposure to avoid future accumulative dose of these radiations from sludge and sediment of this area.

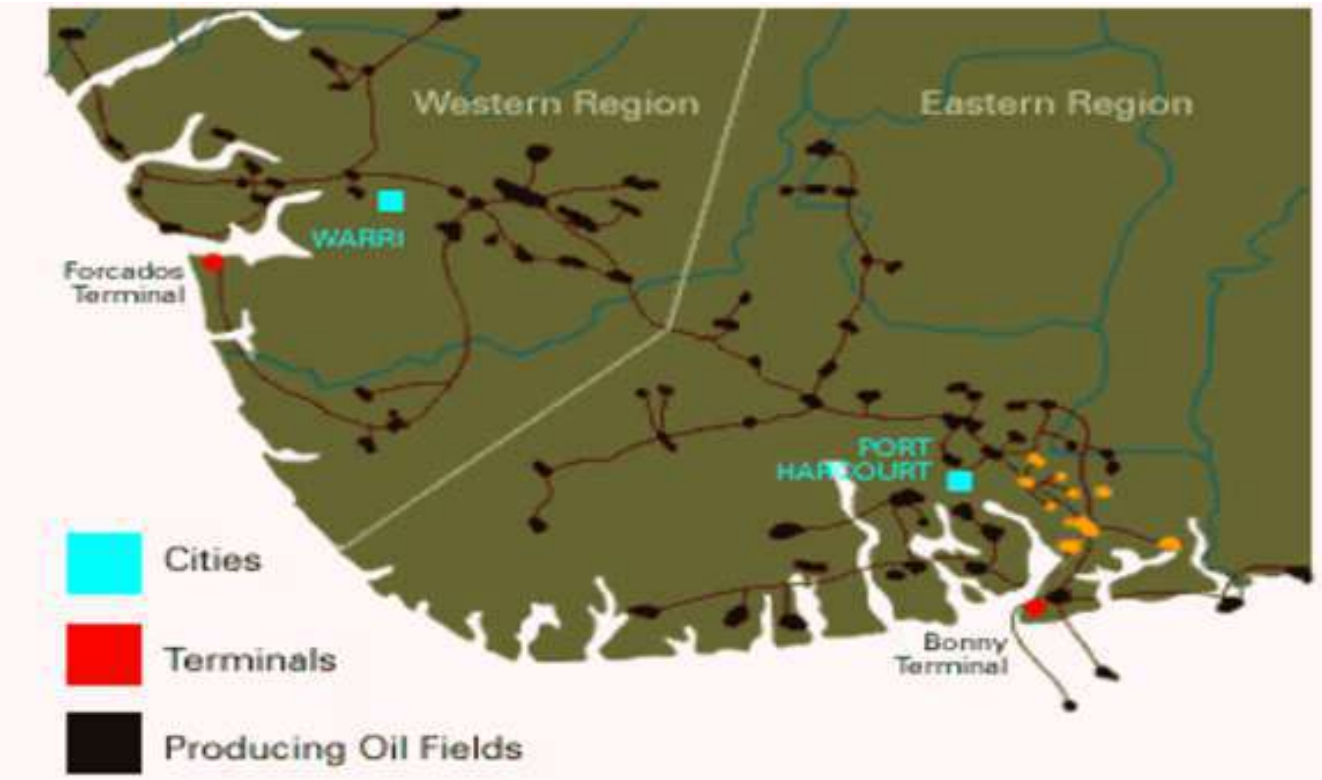


Fig 31: A map showing sampled are and the network of pipes in the studied area.

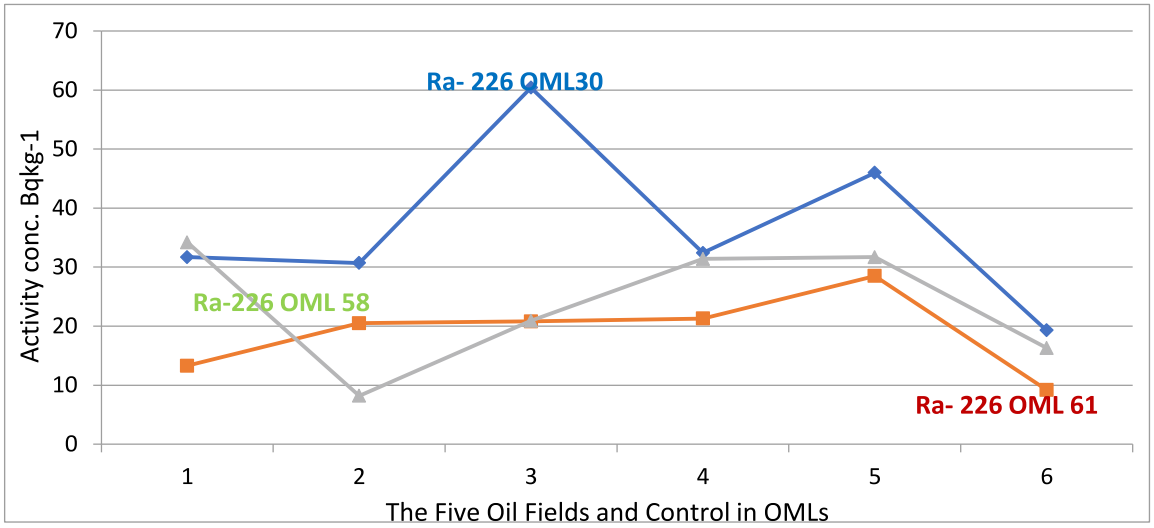


Fig 32: Comparison of Ra-226 average values in the three OMLs

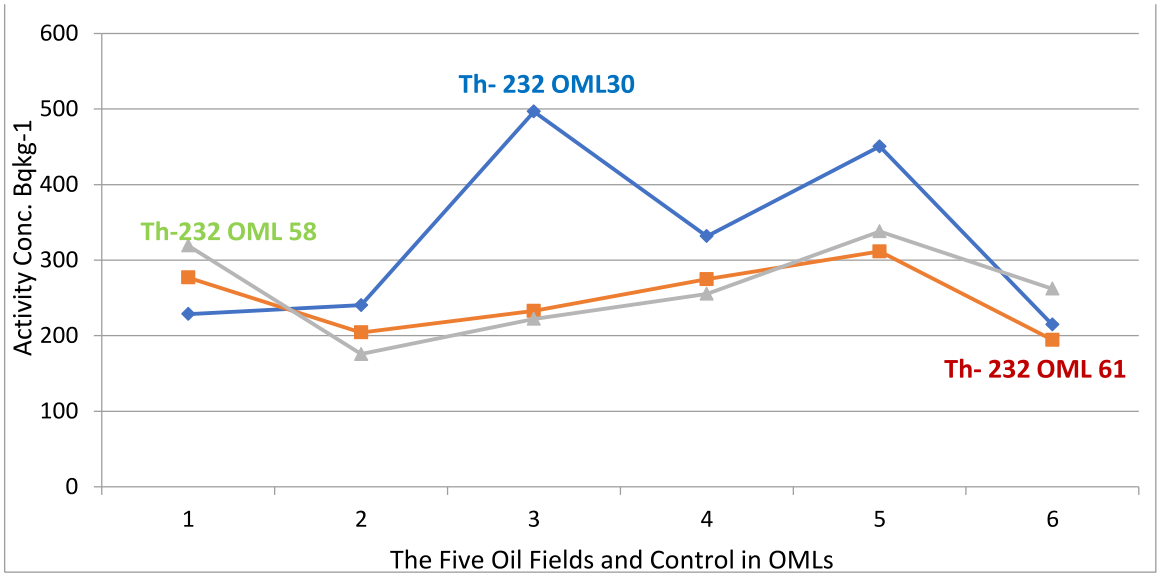


Fig 33: *Comparison of Th-232 average values in the three OMLs*

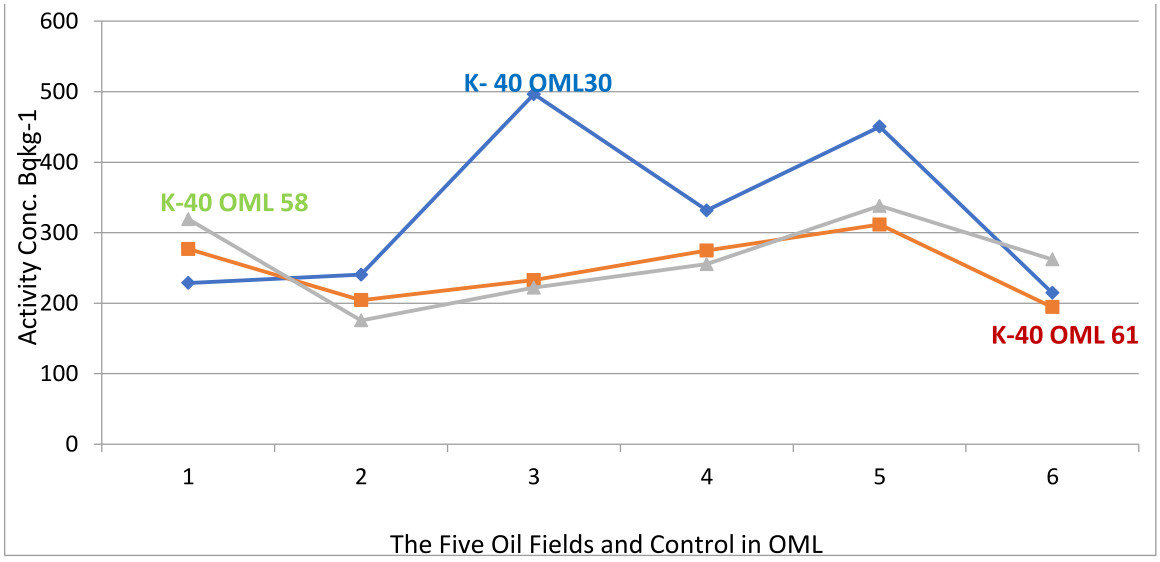


Fig 34: *Comparison of K- 40 average values in the three OMLs*

Agbalagba et al., (2013). Studied present the activity concentration and radiological impact assessment of ^{226}Ra, ^{228}Ra and ^{40}K in drinking waters (hand dug wells, boreholes and river waters) from (OML) 30, 58 and 61 oil fields and host communities in Niger Delta region of Nigeria. Fifty-four water samples from the three sources of drinking water supply were collected within the oil fields and host communities and three water samples from a control site. The results from Table 10 show average activity concentrations of ^{226}Ra, ^{228}Ra and ^{40}K as 8.9 1.0, 8.1 0.9 and 39.8 3.3 respectively for hand dug wells, 4.4 0.8, 4.6 0.5 and 28.5 3.0 for borehole water and 8.2 1.0, 6.7 0.7 and 32.1 3.5 for river water respectively, while the estimated committed effective dose values for the different water sources is presented in Table 11. The ^{226}Ra, ^{228}Ra and ^{40}K average values are well above the WHO permissible levels of 1.0, 0.1 and 10 BqL^{-1} respectively and also above the control values. Although the hazard indices calculated are still within their tolerable levels, the estimated committed effective dose due to intake of the sampled water for all the four age groups considered are far above the ICPR 0.1 mSvy-^{1} maximum permissible limit. The result indicates some level of water pollution in the studied area.

Table 10: Activity concentrations of ^{226}Ra, ^{238}Ra and ^{40}K (Bq L^{-1}) in well, tap and river water samples from OML30, 58 and 61 oil fields environment

		Water sample activity concentration (BqL^{1})								
	Oil mineral lease	Host Comm. Hand dug well water			Host Comm. Borehole water			Field river water		
S/N	(OML)	226Ra	228Ra	40K	226Ra	228Ra	40K	226Ra	228Ra	40K
1	30 Range	2.7-15.2	2.7-12.2	16.7-52.4	0.7-7.4	1.5-7.2	12.1-32.5	4.3-28.4	4.4-18.3	17.2-56.3
	Mean	8.4 0.9	7.3 0.7	29.9 2.6	4.5 0.6	5.1 0.4	20.9 2.0	11.3 1.2	8.5 0.7	32.4 3.7
2	58 Range	5.2-13.7	3.1-15.2	27.7-50.1	0.8-7.4	0.9-10.1	20.3-564	2.6-9.4	2.6-9.4	21.8-50.0
	Mean	8.3 1.0	8.6 1.1	39.6 3.3	3.8 0.8	4.9 0.6	35.7 4.1	5.5 0.8	5.4 0.7	36.9 3.8
3	61 Range	5.5-16.3	4.5-11.3	40.6-67.3	0.7-7.2	0.5-6.5	18.2-39.8	4.6-14.4	3.1-10.2	10.3-46.4
	Mean	10.1 1.1	8.3 1.0	50.0 3.9	4.7 0.9	4.0 0.4	28.8 3.0	7.7 0.9	6.1 0.8	27.1 2.9
Average		8.9 1.0	8.1 0.9	39.8 3.3	4.3 0.8	4.6 0.5	28.5 3.0	8.2 1.0	6.7 0.7	32.1 3.5
Control		2.7 0.2	2.4 0.3	19.4 1.9	1.3 0.2	0.7 0.1	6.3 1.1	3.6 0.4	2.9 0.6	21.0 1.7
WHO, 2008 Standard		**1.0**	**0.1**	**10.0**	**1.0**	**0.1**	**10.0**	**1.0**	**0.1**	**10.0**

Table 11: Estimated committed effective dose (mSvy^{-1}) for different age group

S/N		Committed effective dose (mSvy-^{1}) due to intake of water for various age group											
	Oil mineral lease (OML)	Hand dug well water Infant	1	Childrer 1-12	Teenage 12-17	Adult > 17	Borehole water Infant 1	Childrer 1-12	Teenager 12-17	Adult > 17	River water Infant	1	Children 1-12	Teenager 12-17	Adult > 17
1	OML30	47.5		11.2	37.6	5.6	32.0	7.5	24.7	3.5	56.6		13.2	45.4	7.2
2	OML58	54.7		5.1	42.6	6.2	30.5	7.2	23.5	3.2	34.7		8.2	27.1	4.5
3	OML61	54.7		13.0	43.5	6.4	26.3	6.2	20.8	3.1	40.3		9.5	32.2	4.8
Average		52.3		9.8	41.2	6.1	29.6	7.0	23.0	3.3	43.9		10.3	34.9	5.5
ICRP 1997 Standard		0.1		0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1		0.1	0.1	0.1

Avwiri, Esi and **Agbalagba** 2013, examined the gamma spectroscopy analysis of produced water from selected flow stations in delta state, Nigeria.

Twenty- one produced water samples from seven flow stations waste pit were collected within the oil fields using standard methods. The obtained results show that the average specific activity concentrations for the radionuclides ^{40}K, ^{226}Ra and ^{228}Ra are 48.78±13.67Bql^{-1}, 6.04±2.48Bql^{-1} and 5.18±2.14Bql^{-1} respectively. These obtained values are higher than the WHO, 2008 recommended standard limit of 10Bql^{-1}, 1.0Bql^{-1} and 0.1Bql^{-1} for ^{40}K, ^{226}Ra and ^{228}Ra respectively. Estimated radium equivalent had average activity concentration of 14.36± 5.55Bql^{-1} while the average absorbed dose rate of 6.68mSvy^{-1} was found to be higher than the UNSCEAR 2000 acceptable standard of 1.5mSvy^{-1}. The estimated committed effective dose due to intake of the sampled water for all the produced water considered were far above the ICRP 0.1 mSvyr^{-1} maximum permissible limit. The result indicates

some level of radioactive water pollution in the studies water samples.
Esi, **Agbalagba** and Avwiri, 2018, Impact of produced water discharge on the gross alpha and gross beta activity concentrations and radiological health risk on drinking water sources in coastal areas of Nigeria. The Gross alpha and gross beta activity concentrations in drinking water samples from the coastal areas of Nigeria were investigated using an MPC-2000-DP model proportional counter.
The result of mean gross alpha activity concentrations values obtained as shown in Table 12, ranged from 0.02 ± 0.00 Bq l^{-1} to 1.37 ± 0.01 Bq l^{-1} with an average value of 0.38 ± 0.03 Bq l^{-1} while the mean gross beta activity concentrations values ranged from 0.41 ± 0.04 Bq l^{-1} to 7.32 ± 0.33 Bq l^{-1} with an average value of 2.96 ± 0.41 Bq l^{-1}.

These revealed that the gross alpha and gross beta activity levels obtained in the drinking water were above the recommended permissible limit of 0.1 and 1.0 Bq l^{-1}, respectively as shown in the contour maps in figure 35 and 36 respectively, and that of the control values. These high values obtained were attributed to anthropogenic activities (oil and gas activities) in the study area. The anthropogenic activities of discharging produced water into water bodies of these 15 communities studied has contaminated the drinking water radiologically, which might pose significant radiation health threat to both human system and the environment. Further study on the specific activity to identify the radionuclide of concern was recommended.

Table 12: Estimated AEDE intake for infants, children and adults from gross alpha and beta activity concentration results for sampled waters

		Alpha annual effective dose equivalent			Beta annual effective doseæquivalent			Total annual effective dose equivalent		
		AEDE			AEDE			AEDE		
S/N	Communities	infants (mSvy^{-1})	children (mSvy^{-1})	adults (mSvy^{-1})	infants (mSvy^{-1})	children (mSvy^{-1})	Adults (mSvy^{-1})	infants (mSvy^{-1})	children (mSvy^{-1})	adults (mSvy^{-1})
1	Burutu	0.03	0.05	0.10	0.63	1.16	2.31	0.66	1.21	2.41
2	Yeye	0.05	0.10	0.19	0.35	0.64	1.28	0.40	0.73	1.47
3	Ogulagha	0.02	0.04	0.08	1.05	1.91	3.82	1.07	1.95	3.90
4	Forcados	0.11	0.20	0.39	0.20	0.36	0.72	0.31	0.56	1.12
5	Odimodi	0.11	0.20	0.39	0.65	1.19	2.38	0.76	1.39	2.78
6	Okenrenkoko	0.04	0.06	0.13	0.28	0.51	1.01	0.31	0.57	1.14
7	Kunukunuma	0.02	0.04	0.08	0.06	0.12	0.23	0.09	0.16	0.32
8	Benikurukuru	0.05	0.11	0.20	0.79	1.45	2.90	0.85	1.56	3.10
9	Oporoza	0.02	0.04	0.08	0.44	0.80	1.59	0.46	0.84	1.66
10	OkpeleAma	0.07	0.13	0.25	0.68	1.24	2.47	0.75	1.36	2.72
11	Koko	0.05	0.10	0.20	0.21	0.38	0.75	0.26	0.47	0.95
12	Abigborodo	0.01	0.01	0.01	0.06	0.11	0.21	0.06	0.11	0.22
13	Tebu	0.01	0.01	0.01	0.17	0.31	0.62	0.17	0.32	0.63
14	Tisum	0.03	0.06	0.12	0.21	0.38	0.75	0.24	0.44	0.88
15	Kolokolo	0.20	0.36	0.72	0.78	1.07	2.13	0.98	1.42	2.85
Mean Values		**0.05**	**0.10**	**0.20**	**0.44**	**0.77**	**1.55**	**0.49**	**0.87**	**1.74**

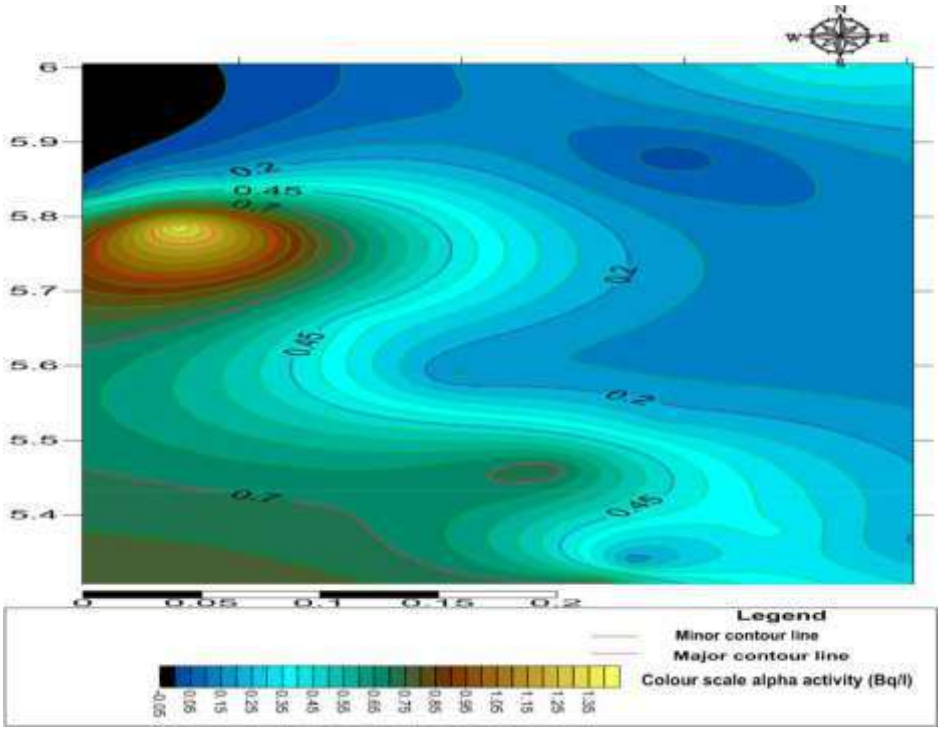


Figure 35: Contour map of gross alpha activity concentrations for sampled water

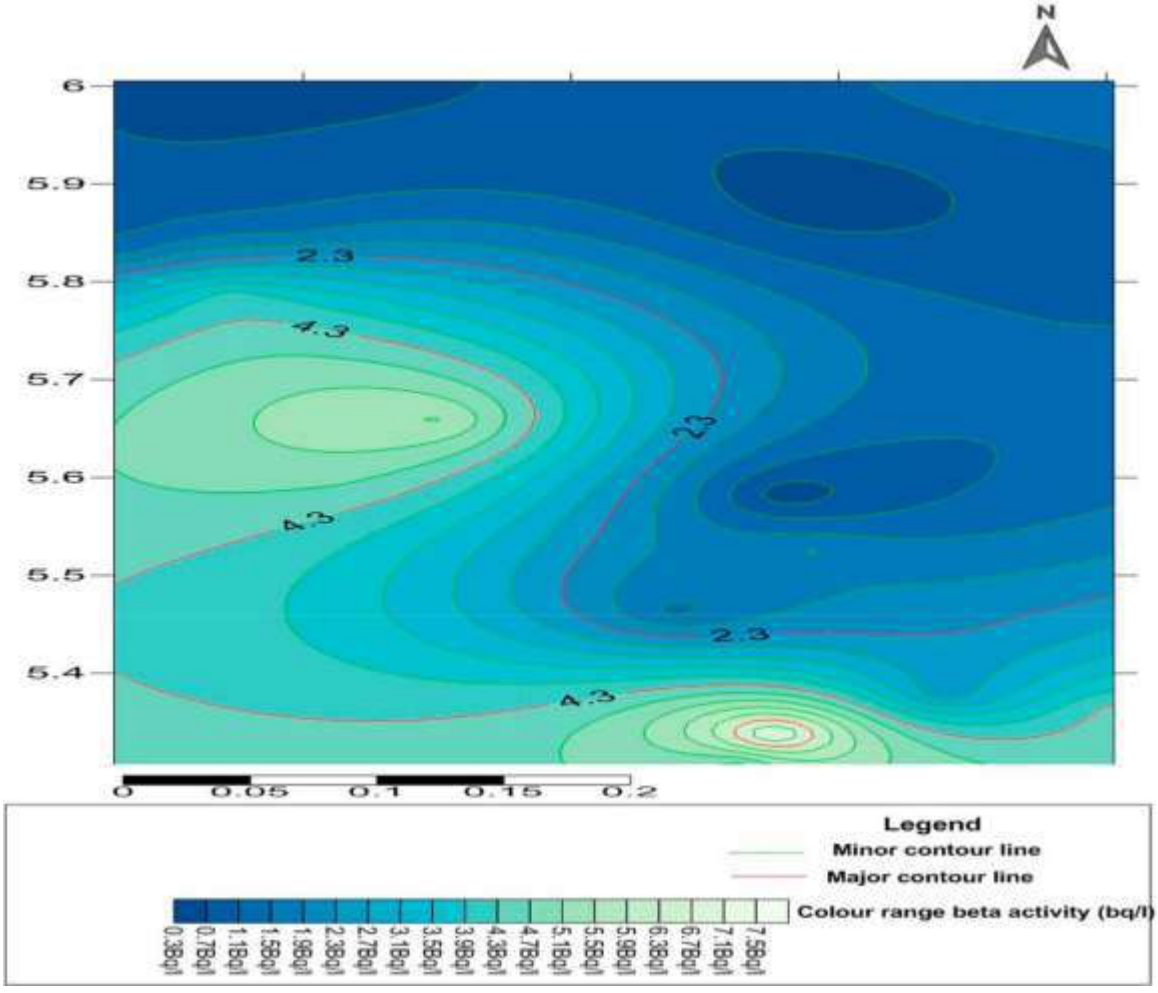


Figure 36: Contour map of gross beta activity concentrations for sampled water

In 2023, Agbalagba and Esi, carried out the Occupational and Public Risk Assessment of NORMs in Soil of the Coastal Niger Delta Region of Nigeria after Six Decades of Hydrocarbon Exploitation. The radiological risks on oil field workers and residents of host communities associated with exposure from radioactivity in soil from oil and gas producing coastal areas of Nigeria were assayed after sixty years of exploration activities in the area. The obtained mean activity concentration of the three natural radionuclides of ^{40}K, ^{238}U and ^{232}Th are 1586.82±17.97, 27.26±8.38 and 37.67±9.55 $Bqkg^{-1}$ respectively and as presented in figures 37-39. The estimated mean radium equivalent for the host communities and the control sample values as shown in Table 13, are 203.31±23.56 $Bqkg^{-1}$ and 20.17±2.54 $Bqkg^{-1}$ respectively. The radiation risk estimates from three exposure routes; external, inhalation and ingestion are shown in the percentage contribution of total effective dose in soil samples is presented in figure 41. The measured activity concentrations are higher than the corresponding global average values.

The estimated total effective dose received are reported in Table 14, which ranged from 0.21 to 14.8 $mSvy^{-1}$. The values of each of the total effective dose estimated in the different communities exceeded the 1.0 $mSvy^{-1}$ permissible limit for the general public as shown in figure 40. The estimate dose equivalent obtained for external exposure is 4.27 μSvy^{-1} which represents 89.0% of the permissible limit for the general public. These results obtained shows that both residents and oil field workers are significantly exposed to radiation from the soil which may be of radiological health concern.

Table 13: MeasuredAverage Activity Concentration of ^{40}K, ^{238}U, ^{232}Th and the estimated Radium equivalent activity (Raeq) ($Bq\,kg^{-1}$) results in soil samples

S/N	Communities	Average Activity ($Bqkg^{-1}$)			
		^{40}K	^{238}U	^{232}Th	Raeq
1	Burutu	1031.58±62.14	24.44±5.40	28.63±2.78	144.81
2	Yeye	535.32±97.90	48.87±22.02	60.60±16.80	176.75
3	Ogulagha	2187.86±25.53	54.42±12.07	32.33±3.17	269.12
4	Forcados	1428.18±33.39	45.10±20.35	38.75±9.06	210.48
5	Odimodi	5566.18±304.74	30.93±7.38	87.22±8.04	584.25
6	Okerenkoko	608.81±40.81	BDL	12.9±1.27	65.33
7	Kunukunuma	1095.14±66.89	2.85±0.68	18.76±1.89	114.00
8	Benikurukuru	770.52±49.71	36.50±8.10	11.21±1.21	111.86
9	Oporoza	1201.81±72.90	0.16±0.04	5.92± 0.61	101.16
10	OkpeleAma	4255.73±123.26	4.11±1.09	99.60±19.81	474.23
11	Koko	40.70±5.81	3.02±0.77	15.82±1.55	28.78
12	Abigborodo	904.15±64.84	51.54±12.41	41.64±13.29	180.70
13	Tebu	466.01±32.73	47.59±21.42	62.67±5.84	173.09
14	Tisum	3634.31±52.42	42.04±9.90	44.07±17.38	384.90
15	Kolokolo	76.03±6.15	17.35±4.04	4.88±0.55	30.18
	Mean	1586.82±17.97	27.26±8.38	37.67±9.55	203.31
	Control	36.54±7.11	12.19±0.43	3.61±1.09	20.17
World Permissible Limit *(UNSCEAR, 2000)*		**400**	**35**	**30**	**≤ 370**

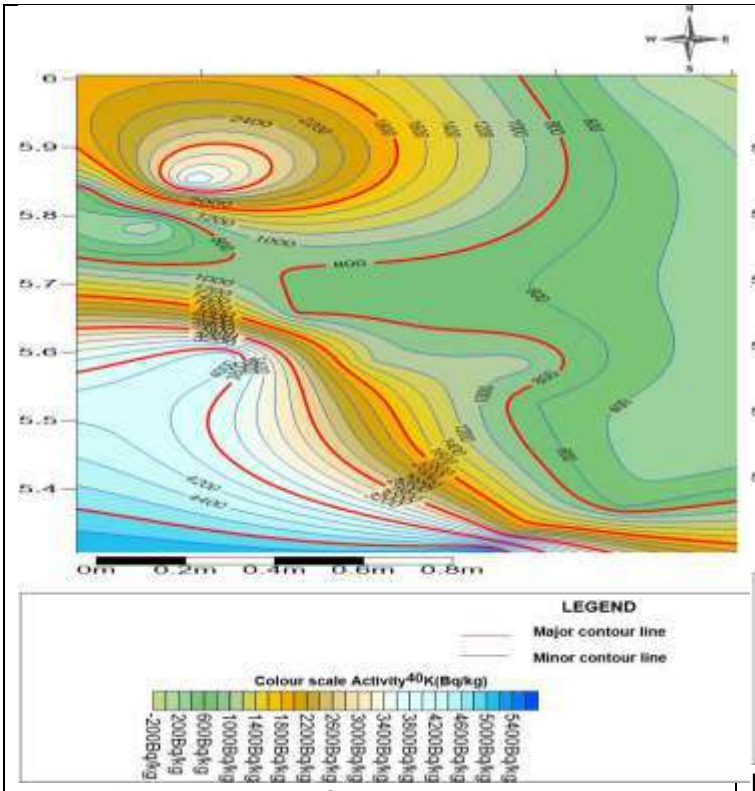


Figure37. Mean specific activity concentration resu ^{40}K (Bq/kg) for soil

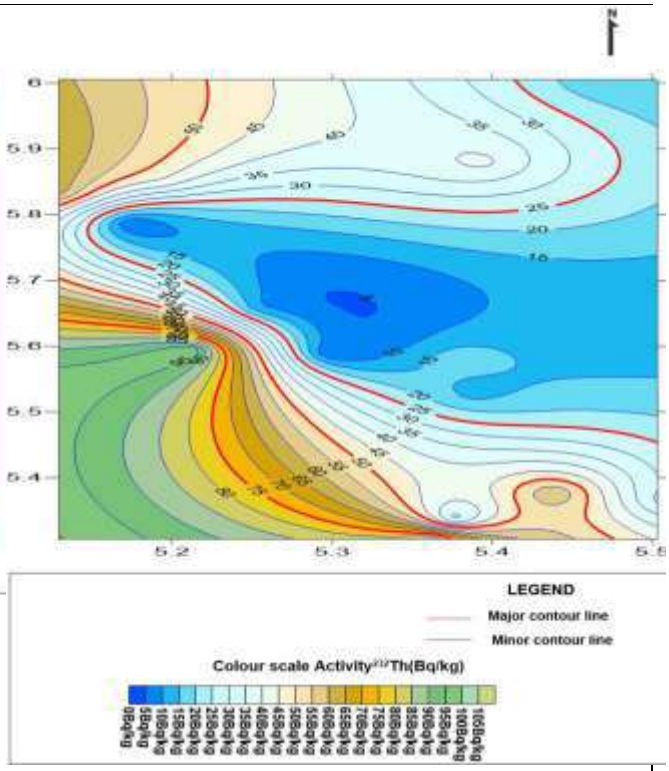


Fig.38: Mean specific activity concentration results ^{232}Th (Bq/kg)for soil

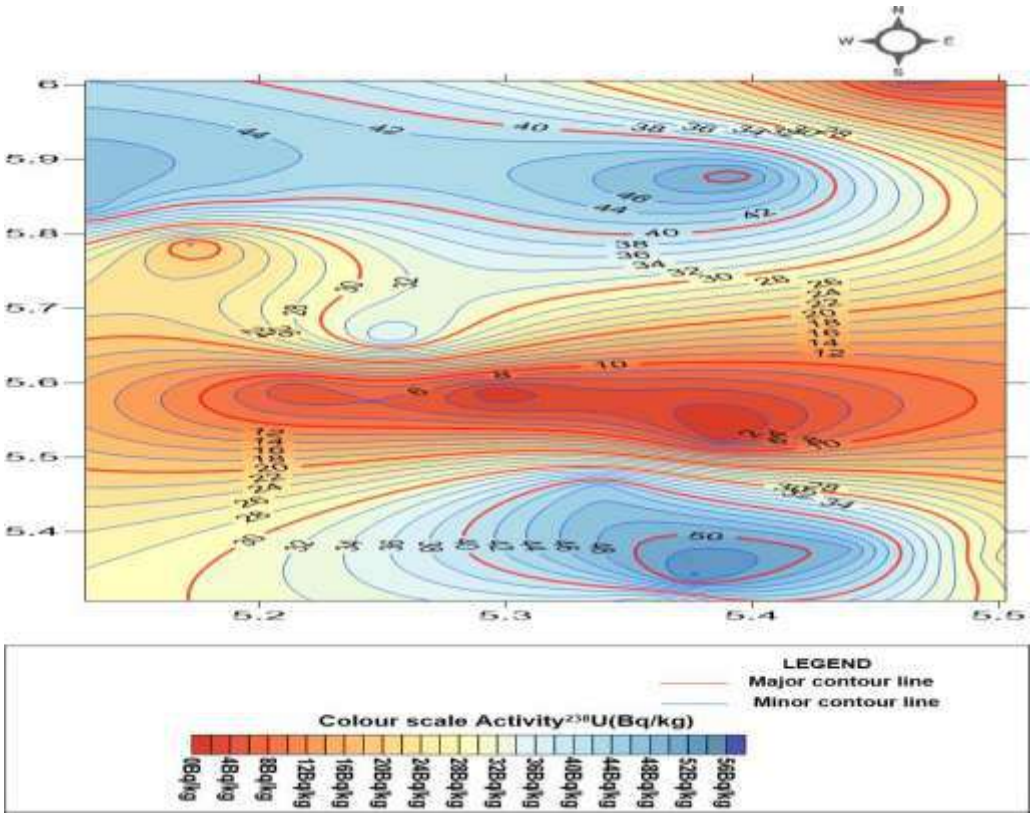


Fig. 39: Mean specific activity concentration results ^{238}U (Bq/kg)for soil

Table 14: Calculated effective dose in soil samples from the three exposure routes due to radionuclide activity.

S/N	Communities	Effective Dose (μSvy^{-1})			Total Effective Dose ($mSv\ y^{-1}$)
		D_{ext}	D_{inh}	D_{ing}	
1	Burutu	2.9097	0.2892	0.0977	3.2966
2	Yeye	2.2288	0.4238	0.1517	2.8043
3	Ogulagha	6.2223	0.6298	0.1796	7.0317
4	Forcados	4.2521	0.4841	0.1500	4.8862
5	Odimodi	13.6953	0.8033	0.3118	14.8103
6	Okerenkoko	1.4308	0.0630	0.0331	1.5269
7	Kunukunuma	2.6303	0.1341	0.0586	2.8230
8	Benikurukuru	2.5356	0.3507	0.0873	2.9736
9	Oporoza	2.8275	0.1237	0.0440	2.9951
10	Okpele-Ama	10.0832	0.4722	0.2472	10.8026
11	Koko	0.1557	0.0282	0.0229	0.2068
12	Abigborodo	3.1485	0.4792	0.1460	3.7736
13	Tebu	2.0405	0.4075	0.1500	2.5980
14	Tisum	9.3757	0.6856	0.2200	10.2813
15	Kolokolo	0.5232	0.1372	0.0320	0.6925
	Mean	4.2706	0.3674	0.1288	4.7668
	Min	0.1557	0.0282	0.0229	0.2068
	Max	13.6953	0.8033	0.3118	14.8103

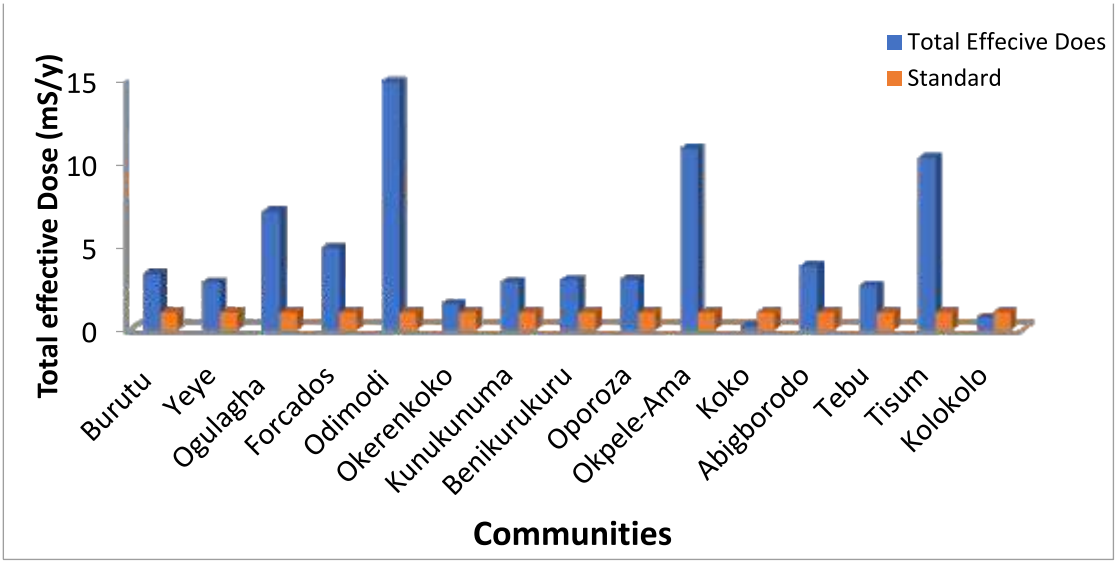


Fig. 40: Comparison of total effective dose of soil samples ($mSvy^{-1}$) with st communities.

Community	Solid Minerals	Mean BIR Levels (mR/hr	Equivalent Dose Rate (mSv/yr)
Ogugu	Limestone	0.016 ± 0.005	1.37 ± 0.04
Enugu-Ekulu	Clay	0.020 ± 0.003	1.64 ± 0.24
Awgu	Bitumen	0.019 ± 0.007	1.56 ± 0.05
Awkuke	Ironstone	0.020 ± 0.00	1.64 ± 0.09
Ama-echi	Silica	0.019 ± 0.002	1.58 ± 0.19
Uzo-uwani	Kaolin	0.014 ± 0.008	1.16 ± 0.05

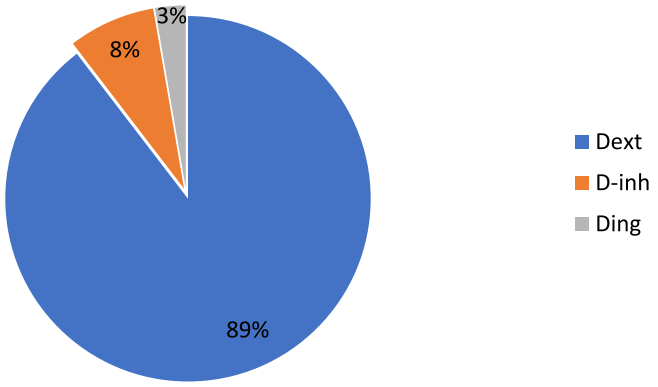


Fig. 41: Percentage contribution of total effective dose in soil samples.

3.2. Radiation Detection and Protection in Solid Mineral and Mining Sites

Accurate and precise knowledge of radioactivity concentration and radiation indices in solid mineral, mining environment and workplace is a protection guide to miners, mining field operators and for government policy. In 2012, Agbalagba, Osanibi and Avwiri, carried out the GIS mapping of background ionizing radiation (BIR) assessment of solid mineral mining sites in Enugu State, Nigeria. They reported that the measured BIR levels obtained ranged from 0.012 mR/hr in Nkpologwu silica mining site to 0.028 mR/hr in clay mining site in Enugu-Ekulu with an average value of 0.018 ± 0.004 mR/hr, while the corresponding calculated equivalent dose rate ranged from 1.0 mSv/yr to 2.35 mSv/yr with a mean value of 1.51 ± 0.04 mSv/yr.

The result obtained indicates that the average exposure level of the studied area is 38.5% higher than the international tolerable limit for the public. Table 15 shows the average gamma radiation results obtained in the various sites examined while figure 42 presents the GIS map of the radiation distribution within the mining sites. The result obtained revealed that silica, ironstone and clay minerals each contributes about (14%) radiation to the Enugu environment BIR, with kaolin being the least contributor (10%) as shown in Figure 43. This suggests the possibility of the presence of radionuclide in the solid minerals mined in Enugu state.

Table 15: Measured average BIR levels and the computed Equivalent dose rate for different solid mineral mining sites

Community	Solid Minerals	Mean BIR Levels (mR/hr	Equivalent Dose Rate (mSv/yr)
Ogugu	Limestone	0.016 ± 0.005	1.37 ± 0.04
Enugu-Ekulu	Clay	0.020 ± 0.003	1.64 ± 0.24
Awgu	Bitumen	0.019 ± 0.007	1.56 ± 0.05
Awkuke	Ironstone	0.020 ± 0.00	1.64 ± 0.09
Ama-echi	Silica	0.019 ± 0.002	1.58 ± 0.19
Uzo-uwani	Kaolin	0.014 ± 0.008	1.16 ± 0.05
Enugu North	Gypsum	0.017 ± 0.002	1.37 ± 0.17
Nsude	Glass sand	0.015 ± 0.001	1.28 ± 0.09
Average		**0.018 ± 0.004**	**1.51 ± 0.04**

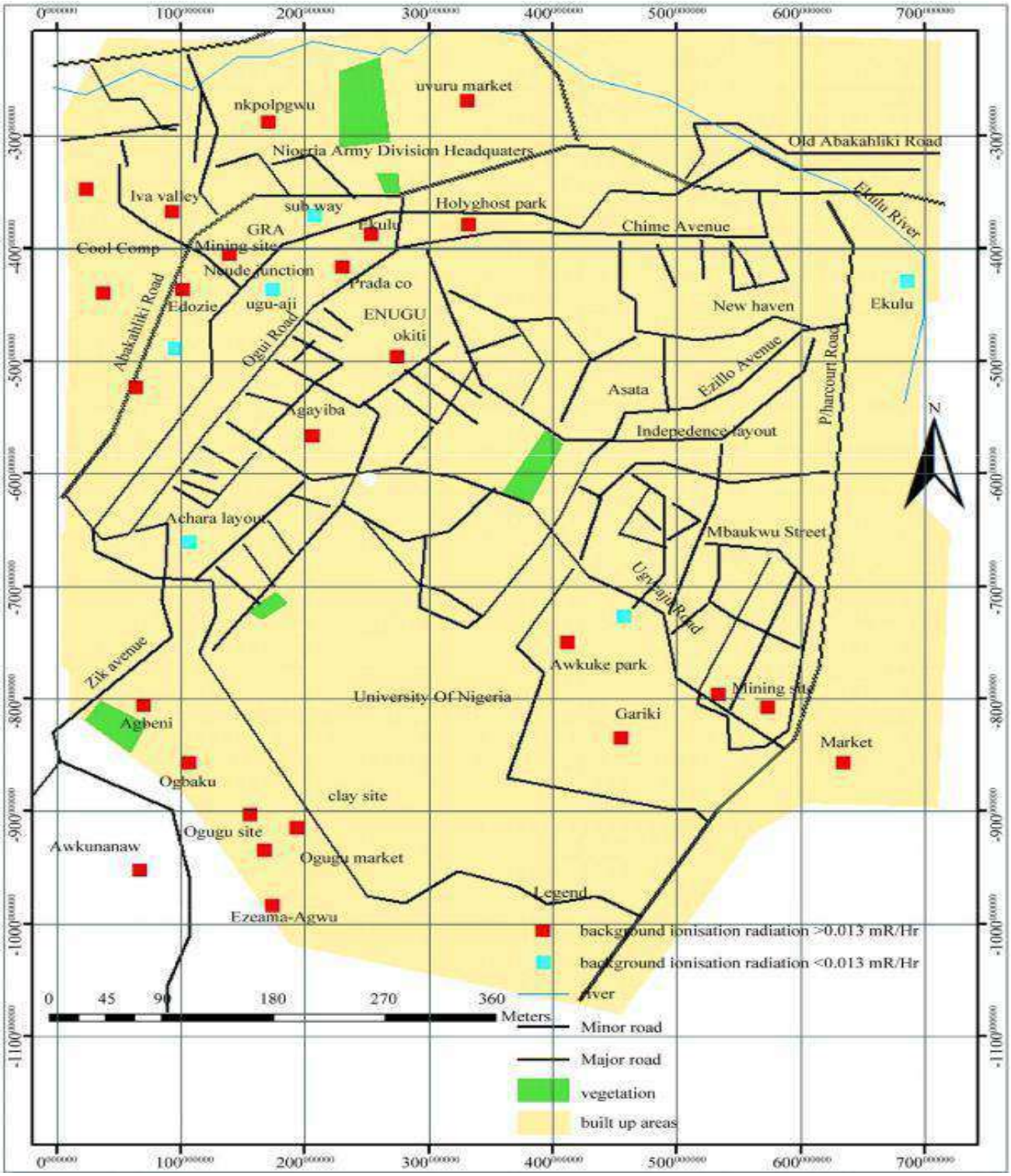


Figure 46: GIS mapping of BIR levels in some solid mineral producing areas of Enugu state

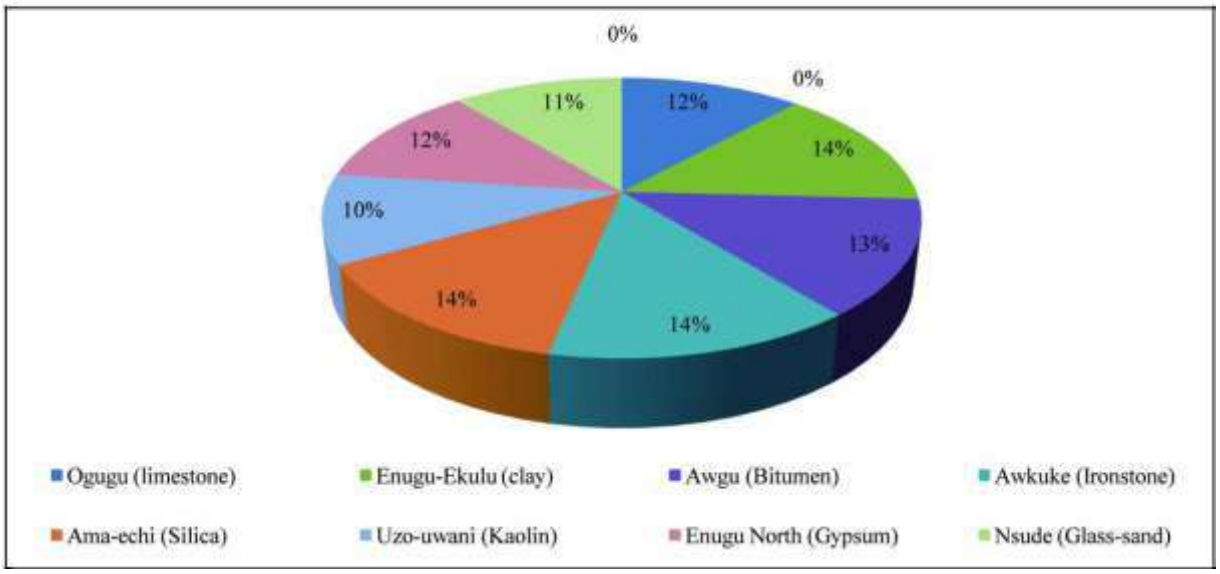


Figure47: Percentage contributions of the various solid mineral to the total background ionizing radiation

Agbalagba et al., 2014, undertake a comparative assessment of natural radionuclide content of cement brands (grey Ordinary Portland Cement (OPC) and 5 brands of white cement) used within Nigeria and some countries in the World**.** The results obtained show an average value of ^{226}Ra, ^{232}Th, and ^{40}K for OPC as 30.210.4Bqkg^{-1}, 24.67.1Bqkg^{-1}, and 251.327.6Bqkg^{-1} respectively and the average values for the white cement is 41.916.7Bqkg^{-1}, 30.19.4Bqkg^{-1} and 340.237.7Bqkg^{-1} respectively. The total average content of ^{226}Ra, ^{232}Th, and ^{40}K for all the cement brand samples are 36.113.6Bqkg^{-1}, 27.48.3Bqkg^{-1}, and 295.832.7Bqkg^{-1} respectively, which is presented in Table 16. These values obtained were lower when compared to the world average values of (^{226}Ra- 50 Bqkg^{-1}, ^{232}Th-50 Bqkg^{-1} and ^{40}K-500 Bqkg^{-1}) for building materials. The estimated radium equivalent activities (Raeq), representative index (Iγ), average absorbed γ–dose rate (D), the annual effective dose rate (AEDE), annual gonadal dose equivalent **(**AGDE) external and internal hazard indices and the Excess life cancer risk (ELCR) were below the recommended safe limit and are comparable with results from similar studies conducted in other countries as presented in Table 17 and figure 44. A comparison of the average activity values obtained in Nigeria cement and other countries of the world show that those countries with history of high radionuclide solid minerals have activity concentration far above that of Nigerian cement, while these values agreed with those obtained in other countries as shown in Table18. Figure 45 present the percentage contributions of each of the three natural radionuclides to the overall activity concentration in the studied samples.

Table 16: Specific activities concentration of various Nigerian Portland and white cement brands

Cement Brand	Sample Size	Cement Colour	^{226}Ra (Bqkg^{-1}) Range	^{226}Ra (Bqkg^{-1}) Mean	^{232}Th (Bqkg^{-1}) Range	^{232}Th (Bqkg^{-1}) Mean	^{40}K (Bqkg^{-1}) Range	^{40}K (Bqkg^{-1}) Mean	Raeq (Bqkg^{-1})
Ashaka	6	Gray	19.1-26.7	23.3±9.6	17.3-23.0	20.7±6.9	216.0-233.4	227.1±30.6	70.4±21.8
Atlas	6	Gray	28.4-44.2	39.5±14.6	15.6-21.1	19.4±8.3	250.2-261.3	254.8±32.3	86.9±28.9
Bua	6	Gray	42.0-50.2	44.7±12.5	29.0-35.6	32.5±11.0	266.1-282.2	275.3±27.7	112.4±30.4
Burham	6	Gray	33.3-42.5	38.5±11.7	26.2-34.1	30.5±10.6	389.0-421.9	401.9±38.1	113.1±29.8
Dangote (Obajana)	6	Gray	18.6-24.2	22.6±6.7	13.5-18.6	19.3±7.1	208.1-215.5	211.2±28.3	66.6±19.3
Dangote (Ibese)	6	Gray	20.8-29.2	25.6±6.3	16.4-20.6	18.1±5.6	206.5-210.0	208.3±25.2	67.5±16.2
Eagle	6	Gray	29.8-35.4	31.1±8.4	22.6-29.4	26.0±9.0	209.5-217.3	213.4±27.9	84.7±23.4
Elephant	6	Gray	21.1-34.1	28.8±7.2	18.6-24.2	20.1±8.6	212.6-220.1	217.1±27.6	74.3±21.6
Ibeto	6	Gray	32.9-40.7	36.4±11.6	23.9-30.4	27.4±9.0	281.1-298.8	289.4±34.4	97.9±27.1
Madewell	6	Gray	36.4-43.3	38.9±12.3	21.3-34.6	29.3±9.8	211.8-222.1	217.6±29.1	97.6±28.6
Sokoto	6	Gray	25.5-30.3	26.6±7.9	17.0-24.2	21.3±7.8	198.2-209.8	205.9±24.3	72.9±20.9
Unicem	6	Gray	39.4-46.0	43.3±13.4	26.2-33.7	30.1±9.4	288.4-297.5	293.7±34.0	109.0±29.5
Sub-Average of Gray Cement			**18.6-50.2**	**30.2±10.4**	**13.5-35.6**	**24.6±7.1**	**198.2-421.9**	**251.8±27.6**	**84.7±22.7**
ABS	6	White	37.1-42.8	40.2±12.9	22.2-30.4	27.4±9.5	301.2-324.9	318.6±36.9	103.9±29.3
JK	6	White	46.3-51.8	49.5±14.7	24.9-34.1	29.6±8.2	339.5-349.0	342.4±37.8	118.2±29.3
Maggen roi	6	White	45.6-47.2	46.7±14.6	26.0-34.3	30.7±8.8	440.4-463.9	452.9±43.5	125.5±32.8
Moulders	6	White	34.0-40.0	37.5±10.9	28.2-35.1	32.8±10.4	277.1-285.5	283.8±35.6	106.3±28.5
Rak white	6	White	31.5-38.4	35.5±11.3	24.6-32.1	29.8±9.7	294.2-308.0	303.5±34.8	101.5±27.9
Sub-Average of White Cement			**31.5-51.8**	**41.9±16.7**	**22.2-35.1**	**30.1±9.4**	**301.2-463.9**	**340.2±37.7**	**111.1±33.0**
Aver. Age	**102**		**18.6-51.8**	**36.1±13.6**	**13.5-35.6**	**27.4±8.3**	**198.2-463.9**	**295.8±32.7**	**98.1±28.0**

Table 17: Estimated radiation hazard indices of Nigerian cement

S/N	Cement Brand	Cement Origin	Iγ (Bqkg^{-1})	D (ηGy.h^{-1})	AEDE (mSvy^{-1})	AGDE (mSvy^{-1})	Hazard index H_{ex}	Hazard index H_{in}	*ELCR* x 10^{-3}	Raeq (Bqkg^{-1})
1	Ashaka	Nigeria	0.5	33.1	0.04	0.17	0.19	0.25	0.14	70.4±21.8
2	Atlas	Nigeria	0.6	40.9	0.05	0.28	0.23	0.34	0.18	86.9±28.9
3	Bua	Nigeria	0.8	52.3	0.06	0.36	0.30	0.42	0.21	112.4±30.4
4	Burham	Imported	0.8	53.5	0.07	0.37	0.28	0.41	0.25	113.1±29.8
5	Dangote (Obajana)	Nigeria	0.5	31.2	0.04	0.22	0.18	0.27	0.14	66.6±19.3
6	Dangote (Ibese)	Nigeria	0.5	31.7	0.04	0.22	0.18	0.25	0.14	67.5±16.2
7	Eagle	Nigeria	0.6	39.4	0.05	0.27	0.23	0.31	0.18	84.7±23.4
8	Elephant	Nigeria	0.5	34.8	0.04	0.24	0.20	0.28	0.14	74.3±21.6
9	Ibeto	Nigeria	0.7	45.9	0.06	0.32	0.26	0.36	0.21	97.9±27.1
10	Madewell	Nigeria	0.6	45.2	0.06	0.24	0.26	0.36	0.21	97.6±28.6
11	Sokoto	Nigeria	0.5	34.1	0.04	0.24	0.20	0.27	0.14	72.9±20.9
12	Unicem	Nigeria	0.8	50.9	0.06	0.35	0.29	0.41	0.21	109.0±29.5
13	ABS	Imported	0.8	48.9	0.06	0.34	0.28	0.39	0.21	103.9±29.3
14	JK	Imported	0.9	55.5	0.07	0.38	0.32	0.45	0.25	118.2±29.3
15	Maggen roi	Imported	0.9	59.5	0.07	0.42	0.34	0.47	0.25	125.5±32.8
16	Moulders	Imported	0.8	49.5	0.06	0.31	0.29	0.39	0.21	106.3±28.5
17	Rak white	Imported	0.7	47.5	0.06	0.33	0.27	0.37	0.21	101.5±27.9
	Average		0.7	45.1	0.06	0.31	0.26	0.36	0.21	98.1±24.6
	World Standard		≤ 1.0	{60 (18-93)}	1.0	0.36	≤ 1.0	≤ 1.0	0.29	370.0

Table 18: Comparison of mean radium equivalent Ra_{eq} (Bq kg^{-1}) in Nigeria brands of cements with reported values in others countries of the world

Country	Ra_{eq} (Bq kg^{-1})	References
Ghana	90.1	[Kpeglo et al., 2011]
Malaysia	188	[Ibrahim, 1999]
Zambia	79	[Hayambu et al., 1995]
South Korea	80.8	[Lee et al., 2001]
China	127.7	[Xinwei, 2004]
Greece	221.6	[Papaefthymiou et al., 2008]
India	580.1	[Sonkawade et al., 2008]
Egypt	291.9	[Ahmed,2005]
Lebanon	93.8	[Kobeissiet al., 2008]
Turkey	246.1	[Baykaraet al., 2011]
Nigeria	96.4	Present work

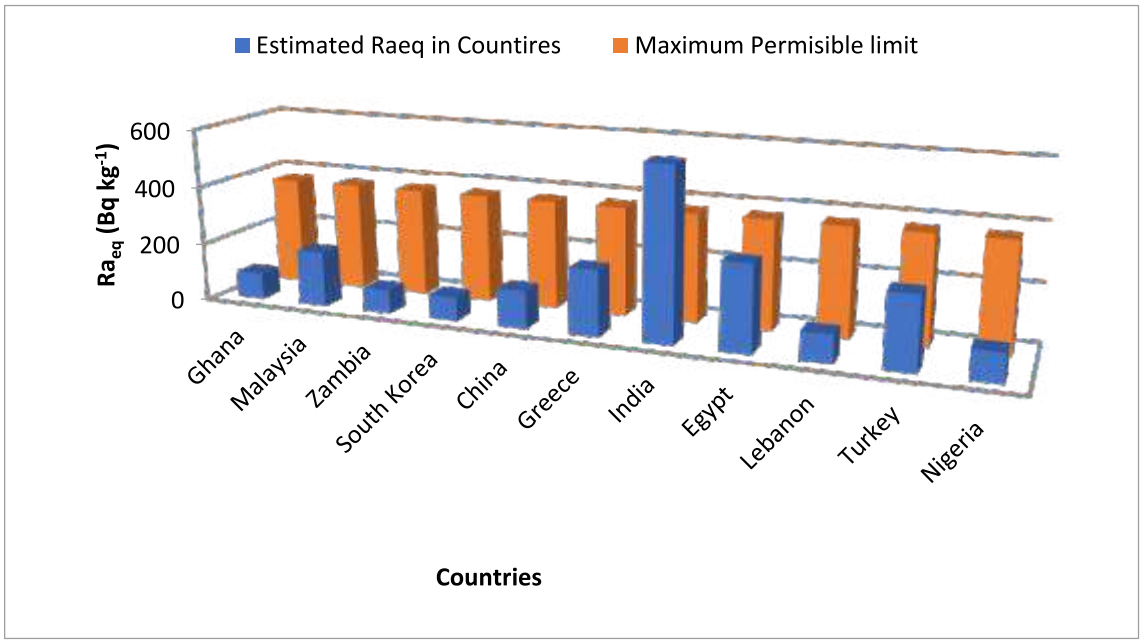


Fig 44 : A comparison of various countries cement estimated radium equivalent with Nigeria (present study)

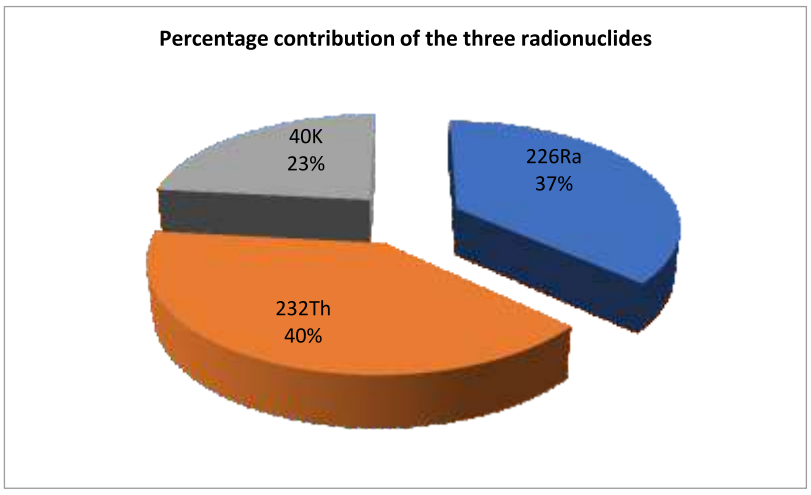


Figure45: Percentage contribution of the three naturally occurring radionuclides in the cement samples

Agbalagba et al., 2016, examined the excess lifetime cancer risk from measured background ionizing radiation levels for one calendar year in active coal mines of Bunker and Okpara mining sites environment in Enugu state. The results of the average BIR levels values measured ranged from 0.009 mRh^{-1} (0.76 $mSvy^{-1}$) in Enugu new market (Bunker) mine site to 0.039 mRh^{-1} (2.52 $mSvy^{-1}$) in Okpara mine site with overall mean value of 0.017 ± 0.007 mRh^{-1} (1.39 ± 0.60 $mSvy^{-1}$). The study revealed that of the 8 sampling locations and 3840 exposure measurements made, 74.1 % exceeded the world ambient standard levels of 0.013 mRh^{-1} (1.0 $mSvy^{-1}$) recommended by UNSCEAR as shown in Figures 46 and 47. The reported results may not constitute any immediate health risk to the residents and coal miners in the study area. The calculated Excess Lifetime Cancer Risk values indicates that the chance of developing cancer by residents and workers in the mine sites of the study area is low and the effective dose for adult organs investigated is insignificant (see figure 48), to cause any health-related sicknesses or damage to the investigated organs from the present exposure rate.

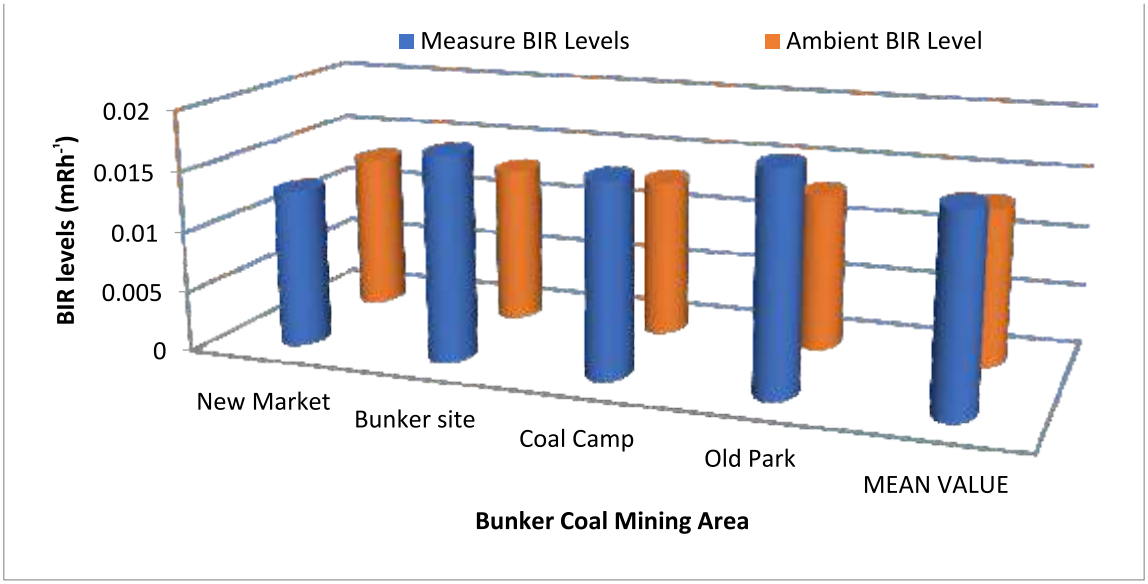


Figure46: Comparison of Measured BIR levels Bunker Mining Site with Ambient Level

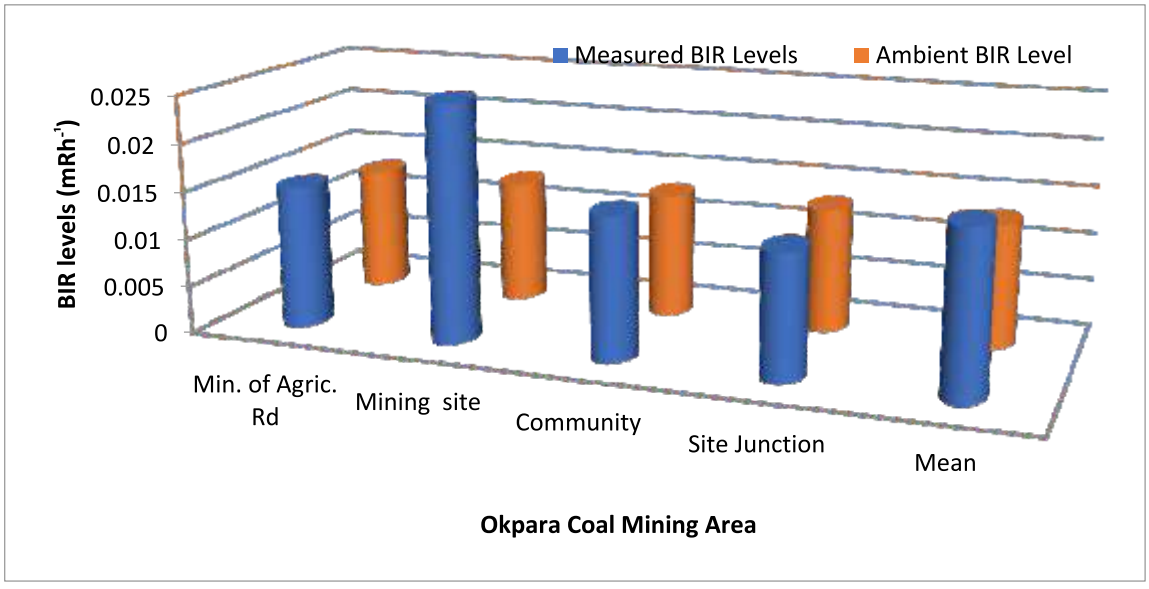


Figure47: Comparison of Measured BIR levels Okpara Mining Site with Ambient Level

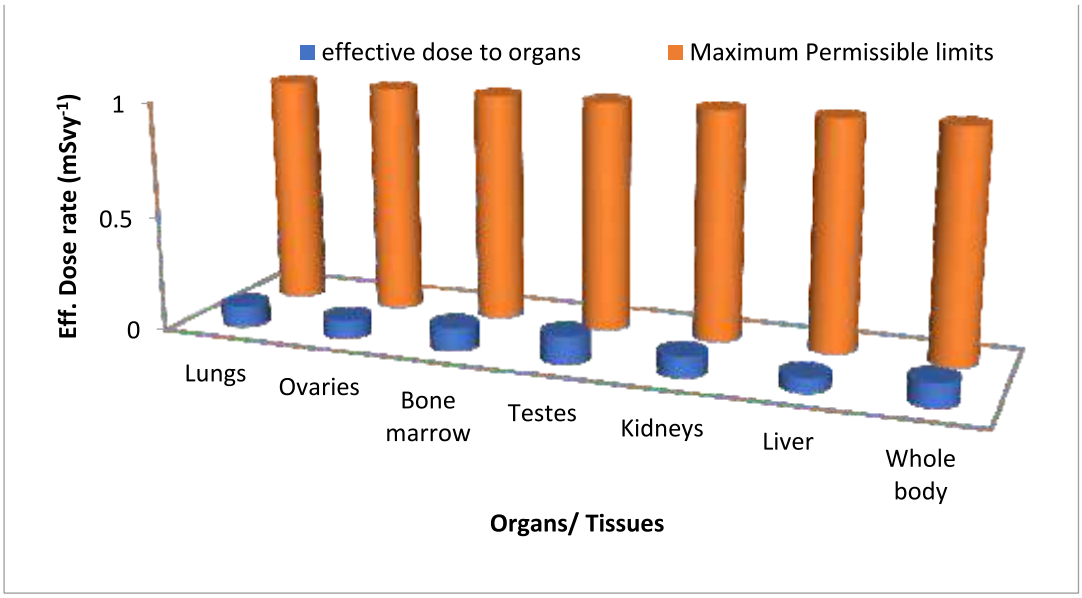


Figure 46: Comparison of Measured BIR levels Bunker Mining Site with Ambient Level

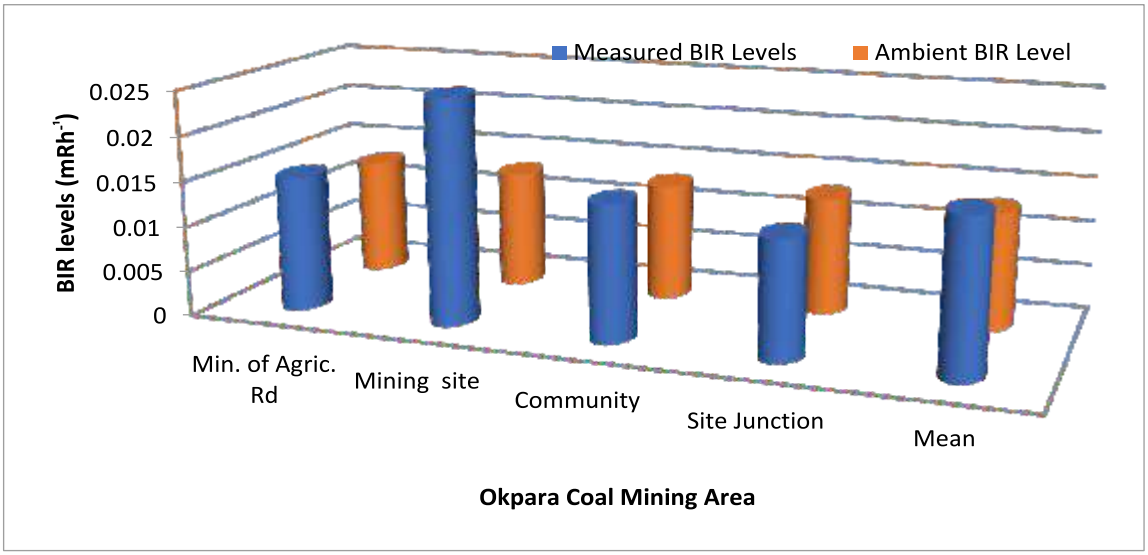


Figure47: Comparison of Measured BIR levels Okpara Mining Site with Ambient Level

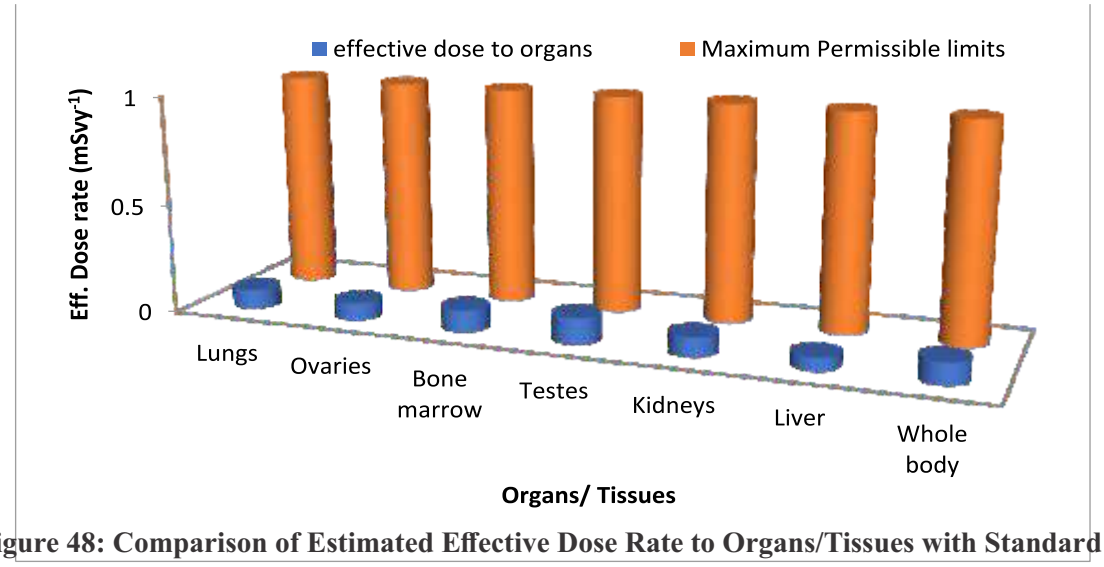


Figure 48: Comparison of Estimated Effective Dose Rate to Organs/Tissues with Standard Maximum

Permissible Limit in the Study Area

Osimobi, Avwiri, and **Agbalagba,** 2018, investigated the radiometric and radiogenic heat of natural radioactivity in soil around solid minerals, mining environment in south-eastern Nigeria. We evaluated the radionuclides activity concentrations in soil around solid mineral mining sites and processing areas of Enugu in South-Eastern Nigeria using sodium iodide [Na(TI)] gamma spectroscopy. Ten solid mineral mining sites which includes limestone, ironstone, glass sand, bitumen, silica, gypsum, kaolin, clay and two coal, were selected for the study (see figure 49 & 50). Four soil samples and a control sample were collected from each of the selected site's environment for analyses. The obtained results of the gamma spectroscopy analyses show mean concentration values of 33.2 Bq $kg^{-1}$for 226Ra, 100.7 Bq kg^{-1} for 40K and 77.7 Bq kg^{-1} for 232Th as shown in Table 19. The mean activity concentration obtained for ^{226}Ra and ^{40}K were within the WHO and worldwide acceptable limits but the 232Th mean value was above the UNSEAR permissible level of 30 Bq kg^{-1} recommended for the public. The estimated radiological risk parameter results have shown average values of 67.5 ηGy h^{-1} for the Absorbed Dose Rate (DR), 82.8 μ Sv y for the Annual Effective Dose Equivalent (AEDE), 151.4 Bq kg^{-1} for the Radium Equivalent (Ra_eq) and 457.1 mSv y^{-1} for the Annual Gonadal Equivalent Dose (AGED) which is high compared to the allowable WHO value of 300 mSvy $^{-1}$ and that of the control value of 177.7 mSv y $^{-1}$.

The average Excess Life Cancer Risk (ELCR) value obtained was 289.6 x10-6 and the control value 112.9 $x10^{-6}$. The average External Hazard Index (Hex), Internal Hazard Index (Hin), Representative Gamma index ($I\gamma$), and Activity Utilization Index (AUI) obtained are 0.4, 0.5, 1.1 and 1.3, respectively. The Radiogenic Heat produced which is associated with the radionuclide in terms of the quantity of heat Q (pW kg^{-1}) generated ranged from 248.4 pW kg^{-1} in Awkuke (ironstone mine) to 608.5 pW kg^{-1} in Ama-echi (Silica mine) with an average heat value of 415.8 pW k^{-1} over the entire study area. The obtained result of the Neutron Gamma Spectroscopy for lithology [clay] identification shows a mixed clay lithology type amongst the mining sites. The overall results of the gamma analysis were found to be higher when compared to previously reported values from similar mineral mining areas, which is an indication of radiological contamination. Proper and effective monitoring of radiation dose to workers and settlers for radiological health related sicknesses from accumulative dose was recommended.

The radiogenic heat assessment was conducted using the radiogenic heat analysis model and the results are presented in Table 20. First the radioactivity concentrations of the measured natural radionuclides in Bq kg^{-1}were converted to ppm for easy estimation of the radiogenic heat Q, produced in the rock materials and the radiogenic heat generated A per m3 of rock. The values of the radiogenic heat produced ranged from 248.4 pW kg^{-1} in Awkuke, where ironstones are mined, to 608.5 pW kg^{-1} in Ama-Echi, where Silica are mined, with an average value of 415.8 pW kg^{-1} in the study area. The values of radiogenic heat generated ranged from 0.4 W m-3 in Awgu where Bitumen is mined to 1.9 W m-3 in Ama-echi where silica is mined with a mean value of 1.0 W m-3. The comparison of the three natural radionuclides values obtained in the study area with the control and the WHO recommended permissible limits are shown in figure 51. Figure 52 shows the radiogenic heat generation curve for the study-area. The result indicates that if we consider the entire study area as a power generating station: at 30% efficiency of radiogenic heat generation, about 150 pW kg^{-1} of heat energy will be generated, while at 50% efficiency of radiogenic heat generation, 250 pW kg^{-1} of heat energy will be generated from the rock materials, and at 100% efficiency, about 600 pW kg-1 of heat energy will be produced. The results show that silica or silica rich rocks have the tendency of producing more heat than the other solid mineral rocks found in the study area of Enugu, Nigeria. Table 21 compare the results of the activity concentration of the laboratory measured values with reported values from Nigeria and other parts of the world in literature.

Figure 53 presents the thorium/potassium activity ratio analysis. The result of the lithology (clay) identification obtained from the plot of ^{232}Th against ^{40}K shows a mixed clay lithology type in the study area. This is evident as several clay units were identified in the shallow sections of the geology of the studied area. The clay being mixed also shows that the area has different clay types, and thus, heterogeneous clay rich zone.

Figure49: Samples of the solid minerals collected within the sampling sites

Figure50: Selectedsoil samples collection sites within solid mineral mining sites

Table 19: Activities (Bq kg^{-1}) of ^{40}K, ^{226}Ra, ^{232}Th from solid mineral mining soils in south eastern Nigeria

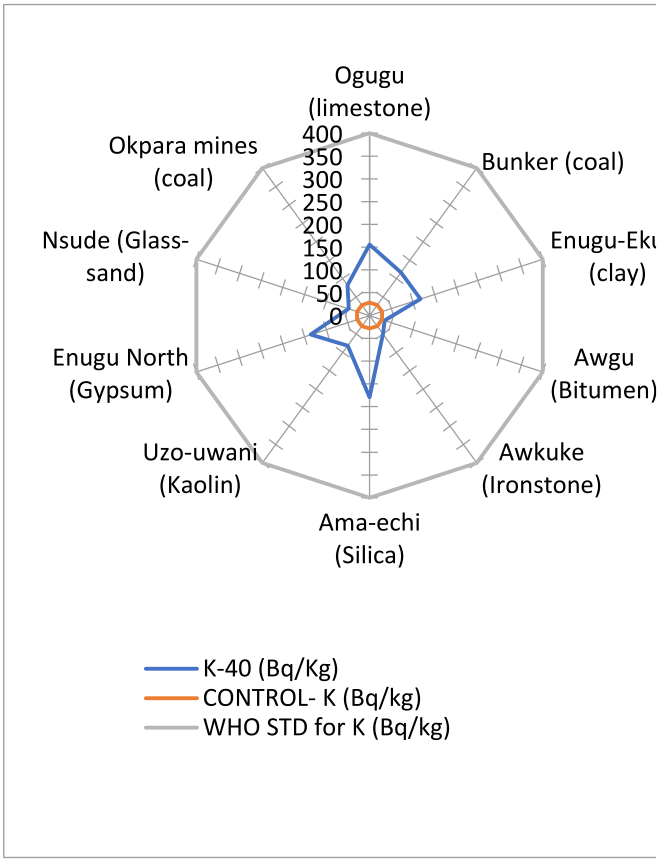
S/N	Site geographical location	Mining Location	Mineral found	^{40}K (Bq kg^{-1}) Mean (Range)	^{226}Ra (Bq kg^{-1}) Mean (Range)	^{232}Th (Bq kg^{-1}) Mean (Range)
1	N06°09′56" E007°29′07"	Ogugu	Limestone	155.7 (20.4-322.7)	30.6 (16.7-46.7)	48.9 (27.2-72.2)
2	N06°25′47" E007°28′00"	Bunker	Coal	117.0 (67.8-242.1)	36.4 (28.1-44.7)	70.0 (61.6-83.5)
3	N06°09′56" E007°29′07"	Enugu-Ekulu	Clay	117.3 (46.2-275.6)	35.2 (14.6-49.4)	59.1 (34.5-86.9)
4	N06°05′27" E007°26′34"	Awgu	Bitumen	34.8 (18.9-61.0)	32.7 (22.2-37.5)	69.4 (50.7-93.2)
5	N06°22′45" E007°27′52"	Akwuke	Ironstone	54.3 (28.5-82.6)	20.5 (8.0-32.8)	48.0 (25.9-67.6)
6	N06°28′08" E007°27′03"	Ama-Echi	Silica	179.2 (137.6-311.8)	52.6 (33.7-76.0)	97.7 (70.9-117.4)
7	N06°45′44" E007°16′17"	Uzo-Uwani	Kaoline	81.6 (35.5-149.1)	31.8 (36.8-76.0)	70.0 (56.2-93.0)
8	N06°31′05" E007°26′34"	Enugu North	Gypsum	136.0 (85.2-163.9)	49.5 (44.3-55.7)	67.3 (42.1-92.6)
9	N06°24′34" E007°28′52"	Nsude	Glass-sand	48.0 (19.9-72.0)	19.9 (13.2-28.9)	193.1 (72.2-618.9)
10	N06°23′53" E007°27′15"	Okpara	Coal	82.6 (22.7-180.7)	22.5 (16.4-29.0)	53.3 (39.6-67.4)
Overall Mean Value				**100.7±8.2**	**33.2±3.3**	**77.7±6.1**
Control (Mean)				28.6	19.6	25.9
Global Recommended Value (UNSEAR 2000)				**400**	**35**	**30**

Table 20: Radiogenic heat concentration and estimated heat generated in the study area

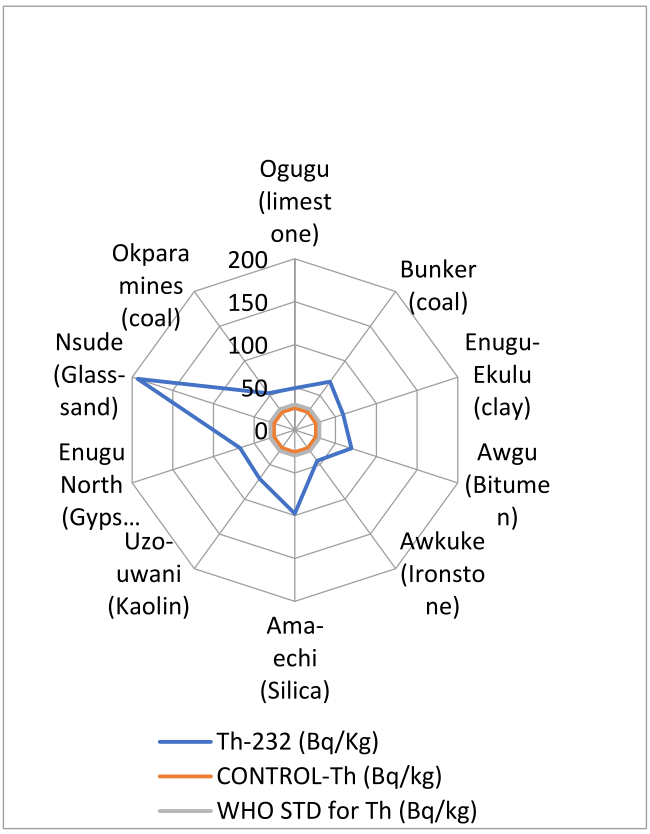
Communities (Mineral)	Mineral rock densities "ρ" (kg m^{-3})	^{226}Ra (PPM)	^{232}Th (PPM)	^{40}K (PPM)	Q (pWkg^{-1})	A (pW m^{-3}) =$Q x \rho$	A (μW m^{-3})
Ogugu (limestone)	2500	2.4	4.0	12.6	337.4	843592	0.8
Bunker (coal)	1200	2.9	5.7	9.5	425.4	510473	0.5
Enugu-Ekulu (clay)	2700	2.9	4.8	9.5	394.1	1064151	1.1
Awgu (Bitumen)	1010	2.6	5.6	2.8	395.7	399691	0.4
Awkuke (Ironstone)	2650	1.6	3.6	4.1	248.4	658209	0.7
Ama-echi (Silica)	3190	4.3	7.9	14.5	608.4	1940909	1.9
Uzo-uwani (Kaolin)	2590	2.6	5.7	6.6	390.4	1011026	1.0
Enugu North (Gypsum)	2310	4.0	5.4	11.0	520.9	1203340	1.2
Nsude (Glass-sand)	2580	1.6	15.6	3.9	553.6	1428260	1.4
Okpara mines (coal)	1500	1.8	4.3	6.7	283.8	425784	0.4

Table 21: Comparison of radionuclide concentrations in the studied soil with other published results

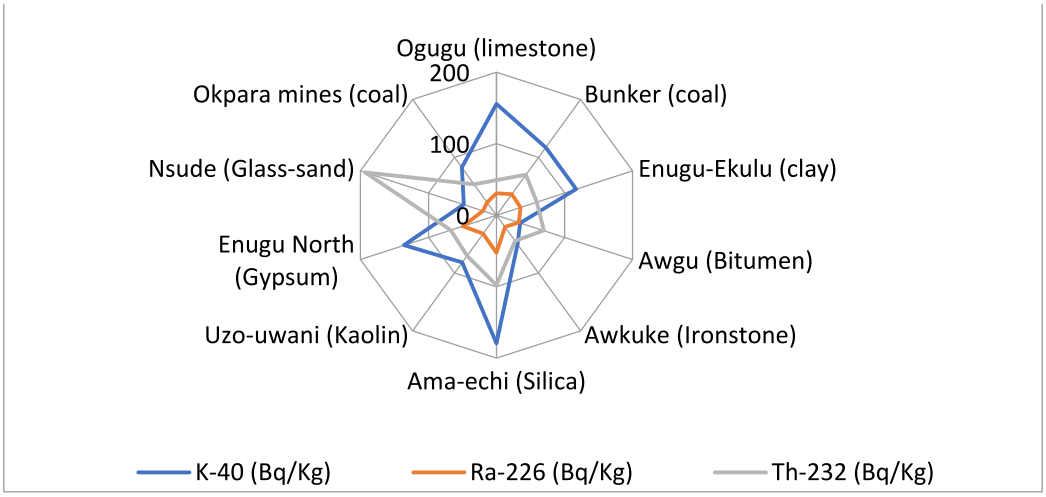
Country	^{226}Ra (Bq kg^{-1})	^{232}Th (Bq kg^{-1})	^{40}K (Bq kg^{-1})	Reference
South-East, Nigeria	**33.16**	**77.680**	**100.65**	**Present work**
South-West, Nigeria	55.3	26.4	505.1	Ademola et al. (2014)
South-Western Nigeria	39.8	17.7	384.2	Ademola and Obed (2012)
West, Nigeria	12.1	60.1	426.5	Innocent et al. (2013)
Ghana	13.6	24.2	162.1	Faanu et al. (2011)
Algeria	41	27	422	Amrani and Tahtat (2001)
Egypt	78	33	337	El Afifi et al. (2006)
China	26	49	440	Wang et al. (2011)
China (Yangtze)	13.7-52.3	26-71.9	392-898	Wang et al. (2017)
Slovenia	63	77	800	Kovácset al. (2013)
Spain	12.1	15	188	González-Fernández et al. (2012)
Turkey	37.4	27.2	431	Kam and Bozkurt (2007)
Thailand	22.3	21.4	1145	Kessaratikoon et al. (2013)
Jordan	42.5	26.7	291	Al-Hamarneh and Awadallah (2009)
Greece	25	21	355	Anagnostakiset al. (1996)
Malaysia	51	22	189	Muhammad et al. (2012)
USA	33.7	31.9	300	Hannan et al. (2015)
World Recommended	35	30	400	UNSCEAR (2000)



(a)



(b)



(c)

Figure 51: Comparison; (a) measured ^{40}K activity, control value and WHO (2008) standard value; (b) measured ^{232}Th activity from the study area with the control and the WHO (2008) recommended

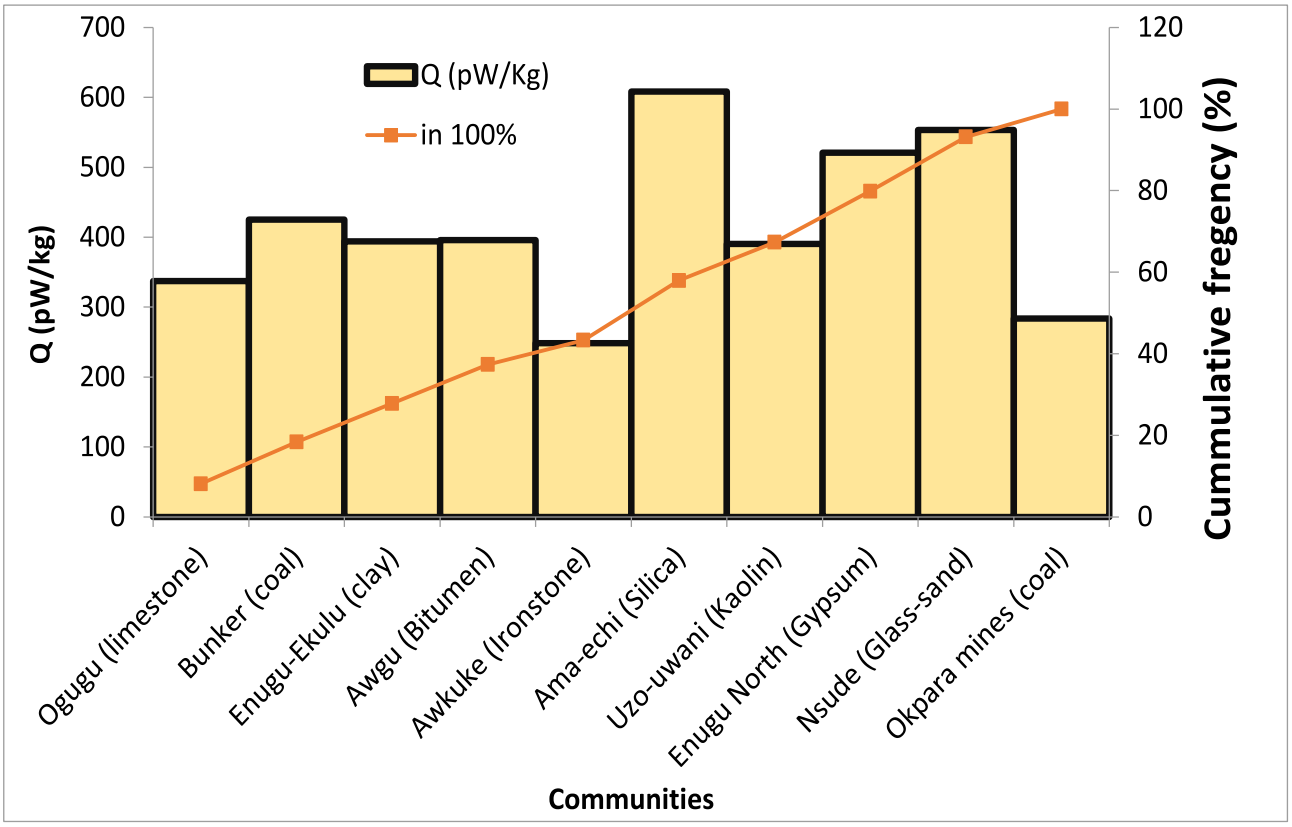


Figure 52: Heat produced Q (pW kg^{-1}) from the study areavalue; and (c) measured ^{40}K, ^{226}Ra and ^{232}Th activities from the study area against each other

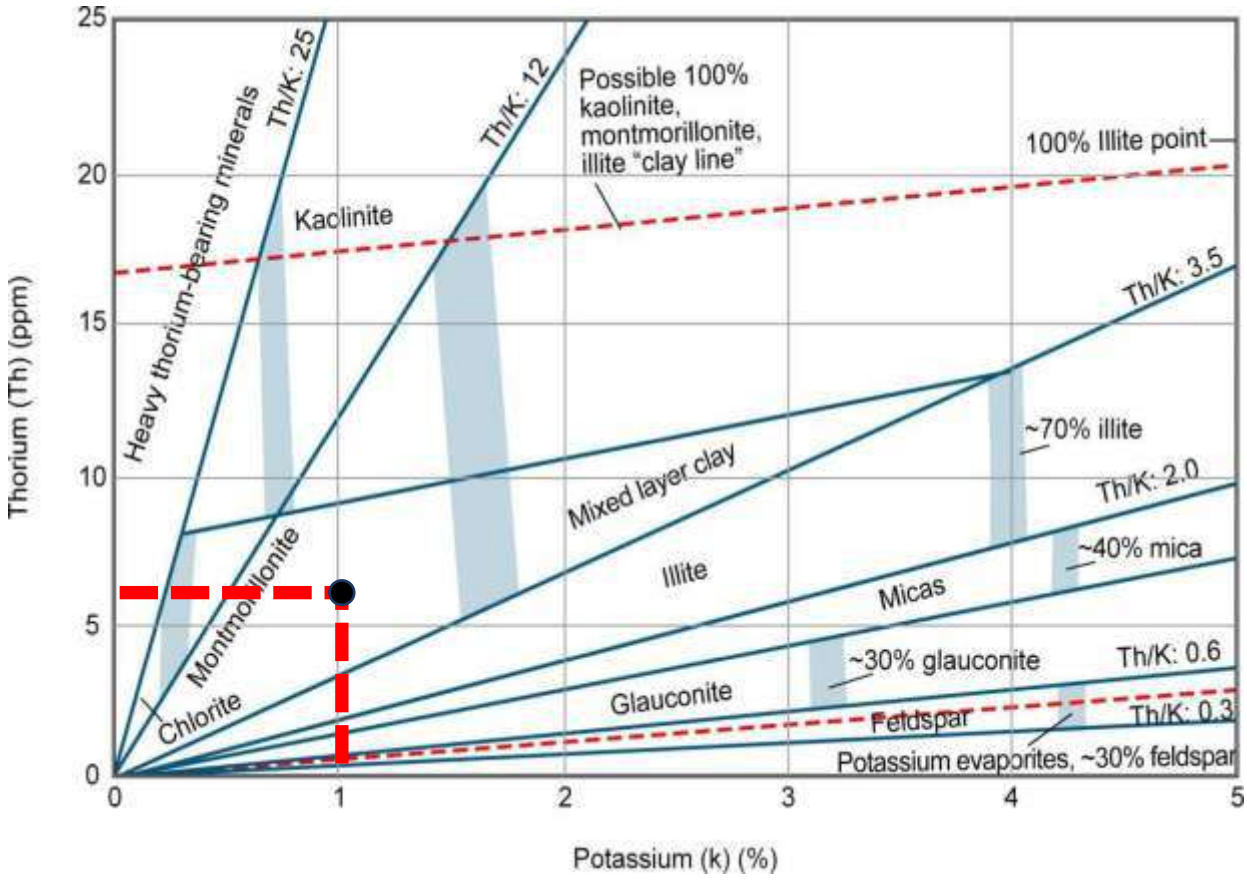


Figure 53: ^{232}Th against ^{40}K (source: PetroWiki 2015)

Agbalagba et al., 2021, assessed solid mineral to soil radioactivity contamination index in selected mining sites and their radiological risk indices to the public**.** The results of the activity concentration values for ^{40}K, ^{226}Ra and ^{232}Th are 100.22 Bq kg^{-1}, 33.15 Bq kg^{-1} and 77.31 Bq kg^{-1} respectively. ^{226}Ra and ^{40}K activities were within the United Nation Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) acceptable permissible limit but the ^{232}Th mean value was above the permissible limit of 30 Bq kg^{-1} for the public as shown in Table 22. In comparison, ^{40}K, ^{226}Ra and ^{232}Th soil samples mean activity concentrations were higher than the control soil samples values by 48.6%, 43.7% and 62.3% respectively. The statistical analysis of the results of radionuclides and the radiological risk indices are indicated in figure 54, while figure 55 shows the sequential chart distribution of the three natural radionuclides investigated with the radiological risk parameters examined.

The research concluded that the exceeding of the world recommended permissible limit of some of the radiation hazard index parameter estimated and gamma analysis be higher compared to previously reported values from similar mineral mining environment is an indication of a radiologically contaminated environment by the solid minerals mining and processing. We therefore recommended that proper kitting of workers and discouragement of settlers living around these mining sites to reduce the radiation effects on people and the environment.

Table 22: Soil Activity Concentration (Bq kg^{-1}) of ^{40}K, ^{226}Ra, ^{232}Th around Solid Mineral mining Areas in South-Eastern Nigeria

S/N	Geographical location	Mining State	Mineral found	^{40}K (Bq kg^{-1}) Mean (Range)	^{226}Ra (Bq kg^{-1}) Mean (Range)	^{232}Th (Bq kg^{-1}) Mean (Range)
1	N06°22′45" E007°27′52"	Ebonyi	Ironstone	54.26 (32.45-80.58)	20.45 (7.29-30.66)	48.18 (25.88-67.61)
2	N06°45′44" E007°16′17"	Imo	Kaoline	81.65 (37.46-142.42)	31.83 (18.19-40.72)	71.08 (54.33-91.64)
3	N06°28′08" E007°27′03"	Abia	Silica	179.15 (127.08-289.79)	52.64 (36.61-71.01)	97.68 (72.04-112.45)
4	N06°05′27" E007°26′34"	Enugu	Bitumen	34.80 (21.93-60.46)	32.66(21.25-40.41)	68.79 (48.74-91.00)
5	N06°25′47" E007°28′00"	Enugu	Coal 1	117.03 (64.11-238.10)	36.37 (26.09-43.73)	69.94 (60.87-80.04)
6	N06°09′56" E007°29′07"	Imo	Clay	117.34 (34.84-275.58)	35.23 (17.55-46.40)	58.91 (36.25-84.87)
7	N06°31′05" E007°26′34"	Enugu	Gypsum	136.0 (87.40-161.82)	49.46 (41.24-53.65)	67.25 (42.08-90.54)
8	N06°23′53" E007°27′15"	Abia	Coal 2	82.58 (25.67-174.22)	22.47 (15.38-27.12)	55.31 (37.99-64.36)
9	N06°24′34" E007°28′52"	Ebonyi	Limestone	155.68 (23.73-313.74)	30.66(18.73-48.26)	48.78 (29.70-70.41)
10	N06°24′54" E007°27′45"	Anambra	Glass - sand	48.02 (21.00-70.10)	19.85 (14.19-28.90)	189.11 (74.18-588.93)
Overall Mean Value				**100.22±8.20**	**33.15±3.31**	**77.31 ±6.10**
Control (Mean)				28.60	19.63	25.92
Global Recommended Value (UNSEAR 2010)				**400**	**35**	**30**

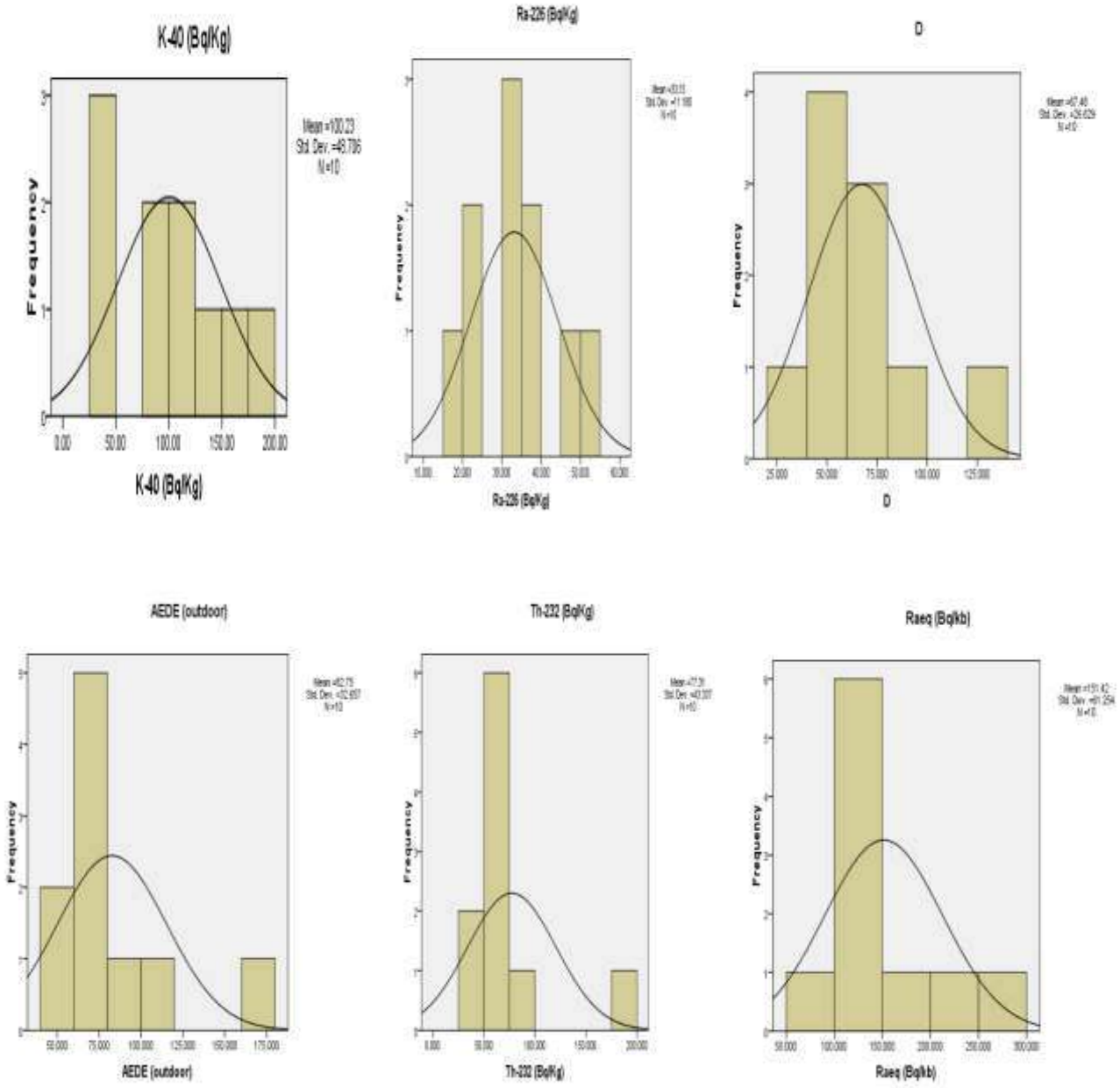


Figure54: Histogram and Skewness plot of some Radiation parameters.

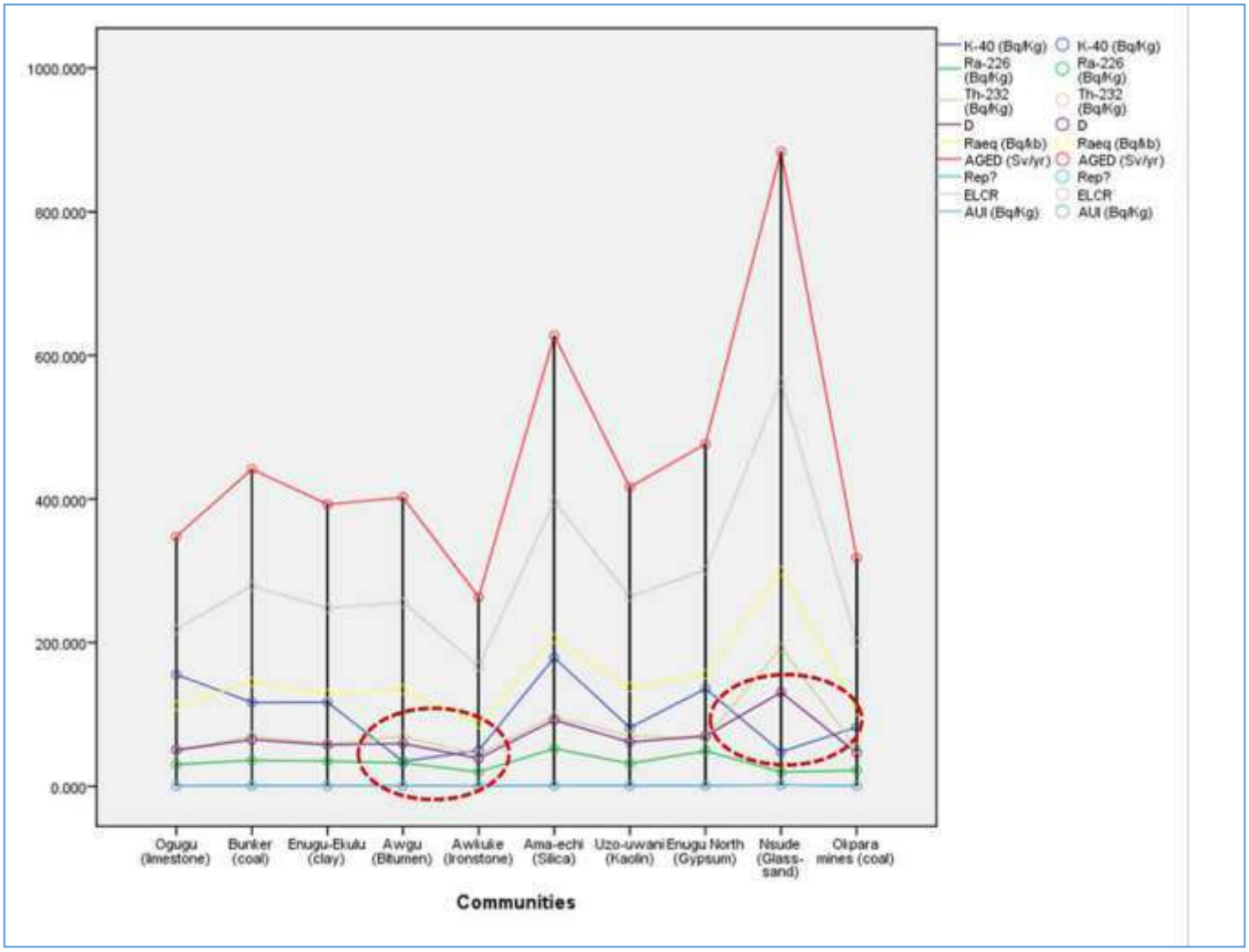


Figure55: Sequence Chart of the Statistical Analysis

3.3. Radiation Detection and Protection in Nigeria Rural and Urban Cities

In my quest to monitor, assess and unravel the impacts of radiation and radioactivity in our environment and to proffer mitigative measures, we made substantive inroad into establishing baseline data on radiation and natural radionuclides in many of our cities in the Niger Delta region of Nigeria. I wish to use this medium to avail this audience some of these landmark research findings.

Agbalagba et al., 2016. On the GIS mapping of Impact of Industrial activities on the Terrestrial Background Ionizing Radiation Levels of Ughelli Metropolis and Its Environs, Nigeria. The study assessed the effects of industrial activities and effluents on the external background ionizing radiation (BIR) levels of Ughelli metropolis and its environs. The monitoring of the terrestrial BIR levels was carried out for two years (from May 2013 to June 2015) in 21 locations within the city and 21 other major villages/towns in Ughelli North local government area of Delta state. Measured exposure rate in Ughelli metropolis revealed a mean value of 15.20±2.80μRh^{-1}(1.28±0.23 ηGyh^{-1} respectively. The mean annual effective dose equivalent (AEDE) is 0.16±0.03 mSvy^{-1}, while the mean excess life cancer risk (ELCR) is (0.56±0.11) x 10-3 mSvy^{-1}. GIS maps of the study area revealing the BIR distribution, higher radiation levels were recorded in areas/communities where there are industrial activities and oil and gas facilities. The overall results of the measured exposure rates and the estimated radiological indices show that 73.5% of the sampled location exceeded their permissible limits as shown in figures 57 and 58. The mean equivalent dose rate obtained is higher than the safe exposure limit of 1.0 mSv^{-1}

recommended by UNSCEAR and the mean radiation exposure levels in the study area is well above the normal background radiation level of 13.00 μRh^{-1} which shows that the studied area is radiologically contaminated. Though these values obtained may not cause immediate health hazard but there is the likelihood of long-term accumulating health side-effects on the residents of some of these locations and communities sampled and recommend the follows as interim measures:

i. Government and the operators of facilities should device mean of reducing radionuclide input and output to prevent increase in BIR,
ii. Asphalt processing plant and oil and gas facilities identified as potential sources of enhancing BIR levels should be relocated away from residential area,
iii. There should be a regular monitoring of radiation levels in these environments by the operating companies, friend of the environment and government agencies responsible for the (radiation) safety of the environment,
iv. Further research work on the levels of contamination of the soil, water and sediment of these flash points (high BIR levels) should be carried out, and
v. Research on the radiation dispersion and transportation mechanism and modeling should be conducted.

S/N	Sample Site	Geographical location	Average exposure rate (μRh^{-1})	Equivalent Dose rate (µSv/week)	Equivalent Dose rate ($mSvy^{-1}$)	Absorbed Dose Rate (ηGyh^{-1})	Annual Effective Dose Equivalent ($mSvy^{-1}$)	Excess Life Cancer Risk $x10^{-3}$

Table 23: Background Ionizing Radiation Levels (BIR) Ughelli Metropolis

S/N	Sample Site	Geographical location	Average exposure rate (μRh^{-1})	Equivalent Dose rate (µSv/week)	Equivalent Dose rate ($mSvy^{-1}$)	Absorbed Dose Rate (ηGyh^{-1})	Annual Effective Dose Equivalent ($mSvy^{-1}$)	Excess Life Cancer Risk $x10^{-3}$
1	IG Global micro financebank	N05^0 29.839" E006^{0}00.696"	14.00±3.00	6.23±1.34	1.18±0.25	121.80	0.15	0.53
2	Agbarha junction	N05^0 28.967" E006^{0}01.116"	11.00±1.50	4.90±0.67	0.93±0.13	95.70	0.12	0.42
3	Ughelli stadium	N05^0 28.776" E006^{0}01.141"	16.10±3.50	7.12±1.56	1.35±0.29	140.07	0.17	0.60
4	Ughelli Kingdom Ovie palace	N05^0 28.861" E006^{0}00.918"	14.00±2.80	6.23±1.25	1.18±0.24	121.80	0.15	0.53
5	Ughelli centre mosque	N05^0 29.077" E006^{0}00.691"	14.00±3.00	6.23±1.34	1.18±0.25	121.80	0.15	0.53
6	SPDCLogistic Centre	N05^0 29.315" E006^{0}00.375"	22.00±4.40	9.79±1.96	1.85±0.37	191.40	0.23	0.81
7	Uloho Avenue Junction	N05^0 29.463" E006^{0}00.106"	13.00±2.00	5.79±0.89	1.09±0.17	113.10	0.14	0.49
8	Postoffice Junction	N05^{0}29.611" E005^{0}59.788"	14.00±3.20	6.23±1.42	1.18±0.27	121.80	0.15	0.53
9	Ughelli RefusedWaste dump site	N05^{0}29.354" E005^{0}59.724"	15.00±3.00	6.68±1.34	1.26±0.25	130.50	0.16	0.56
10	Deltastate UrbanWater BoardUghelli	N05^0 29.470" E005^{0}59.516"	07.00±1.00	3.12±0.45	0.59±0.08	60.90	0.07	0.25
11	Ughelli High court II premises	N05^0 29.456" E005^{0}59.431"	11.00±1.20	4.90±0.53	0.93±0.10	95.70	0.12	0.42
12	Ughelli North L.G.A secretarial	N05^0 29.291" E005^{0}59.341"	14.00±2.40	6.23±1.07	1.18±0.20	121.80	0.15	0.53
13	Ughelli General Hospital yard	N05^0 29.530" E005^{0}59.016"	15.00±2.70	6.68±1.20	1.26±0.23	130.50	0.16	0.56
14	All SaintAnglic anCathedral Ighwreko	N05^0 29.609" E005^{0}59.589"	09.00±1.70	4.01±0.76	0.76± 0.14	78.30	0.10	0.35
15	Ughelli centre Market	N05^{0}29.837" E005^{0}59.364"	20.00±3.90	8.90±1.78	1.68±0.33	174.00	0.21	0.74
16	Omotor street Junction	N05^0 29.983" E005^{0}59.384"	16.00±3.00	7.12±1.34	1.35±0.25	139.20	0.17	0.60
17	St. Theresa Grammar Sch.	N05^0 30.201" E005^{0}59.030"	12.00±2.20	5.32±0.98	0.99±0.19	104.40	0.13	0.46
18	SetracoNig Ltd camp Site Ughelli	N05^0 30.441" E005^{0}59.697"	28.00±4.60	12.46±2.05	2.35±0.39	243.60	0.30	1.05
19	Afiesere Junction Ughelli	N05^0 30.050" E006^{0}00.320"	25.00±4.00	11.13±1.78	2.1±0.34	217.50	0.27	0.95
20	Agofuremotor park Ughelli	N05^0 29.018" E006^{0}01.105"	11.00±2.30	4.90±1.02	0.92±0.19	95.70	0.12	0.42
21	Otovwodo Centre Motor park	N05^0 28.773" E006^{0}01.144"	18.00±3.30	8.01±1.46	1.51±0.28	156.60	0.19	0.67
	MEAN		**15.20±2.80**	**6.76±1.25**	**1.28**±0.24	**132.16±24.36**	**0.16±0.03**	**0.56±0.10**

Table 24: Backgroundonizing Radiation (BIR) Levels of major Communities in Ughelli North L.G.A

S/N	Location (Community)	Geographical location	Average exposure rate(μRh^{-1})	Equivalent Dose (μSv/week)	Equivalent Dose rate ($mSvy^{-1}$)	Absorbed DoseRate (ηGyh^{-1})	Annual Effective Dose Equivalent ($mSvy^{-1}$)	Excess Life Cancer Risk x 10^{-3}
1	Orogun	N05^0 35.046 " E006^{0}05.207 "	13.00±2.40	5.79±1.07	1.09±0.20	113.10	0.14	0.49
2	AgbarhaOtor	N05^0 32.207 " E006^{0}04.571 "	12.00±3.00	5.34±1.34	0.99±0.25	104.40	0.13	0.46
3	Omavovwe	N05^0 32.810 " E006^{0}03.196 "	16.00±3.40	7.12±1.51	1.35±0.29	139.20	0.17	0.60
4	Gana	N05^0 31.505 " E006^{0}03.041 "	18.00±3.60	8.01±1.60	1.51±0.30	156.60	0.19	0.67
5	Saniko-Owevwe	N05^0 31.103 " E006^{0}02.828 "	16.00±2.80	7.12±1.25	1.35±0.24	139.20	0.17	0.60
6	Uduere	N05^0 30.344 " E006^{0}01.116 "	11.00±1.40	4.90±0.62	0.93±0.12	95.70	0.12	0.42
7	Otogor	N05^0 27.212 " E006^{0}01.746 "	13.00±2.70	5.79±1.20	1.09±0.23	113.10	0.14	0.49
8	Edjekota	N05^0 26.488 " E006^0.01.177"	11.00±1.90	4.90±0.85	0.93±0.16	95.70	0.12	0.42
9	Evwreni	No5^0 24.135 " E006^{0}03.967 "	21.00±3.60	9.35±1.60	1.77±0.30	182.70	0.22	0.77
10	Uwheru	N05^0 23.221 " E006^{0}04.327 "	14.00±2.20	6.23±0.98	1.18±0.19	121.80	0.15	0.53
11	Oteri-Ughelli	N05^0 29.554 " E005^{0}58.326 "	15.00±3.10	6.68±1.38	1.26±0.26	130.50	0.16	0.56
12	Ekiugbo	N05^0 30.587 " E005^{0}58.653 "	23.00±4.10	10.24±1.82	1.93±0.34	200.10	0.25	0.88
13	Eruemukohwoarien	N05^0 29.530 " E006^{0}59.016 "	17.00±3.00	7.57±1.34	1.43±0.25	147.90	0.18	0.63
14	Agbarho	N05^0 35.825 " E006^{0}59.589 "	16.00±2.50	7.12±1.11	1.35±0.21	139.20	0.17	0.60
15	Emekpa	N05^0 35.837 " E005^{0}54.148 "	10.00±2.00	4.45±0.89	0.84±0.17	87.00	0.11	0.39
16	Ighwrekpokpo	N05^0 30.200 " E006^{0}00.950 "	10.00±1.60	4.45±0.71	0.84±0.13	87.00	0.11	0.39
17	Afiesere	N05^0 31.601 " E006^{0}00.796 "	15.00±2.70	6.68±1.20	1.26±0.23	130.50	0.16	0.56
18	Emeragha	N05^0 32.582 " E006^{0}01.530 "	21.00±3.30	9.35±1.47	1.77±0.28	182.70	0.22	0.77
19	Ofuoma	N05^0 33.115 " E006^{0}01.320 "	17.00±3.10	7.57±1.38	1.43±0.26	147.90	0.18	0.63
20	Awirhe	N05^0 37.664 " E006^{0}03.712 "	14.00±2.30	6.23±1.02	1.18±0.20	121.80	0.15	0.53
21	Odovie	N05^0 34.667 " E006^{0}02.001 "	16.00±2.40	7.12±1.07	1.35±0.20	139.20	0.17	0.60
	MEAN		**15.19±2.70**	**6.76±1.20**	**1.28±0.23**	**132.15± 23.50**	**0.16±0.03**	**0.56±0.11**

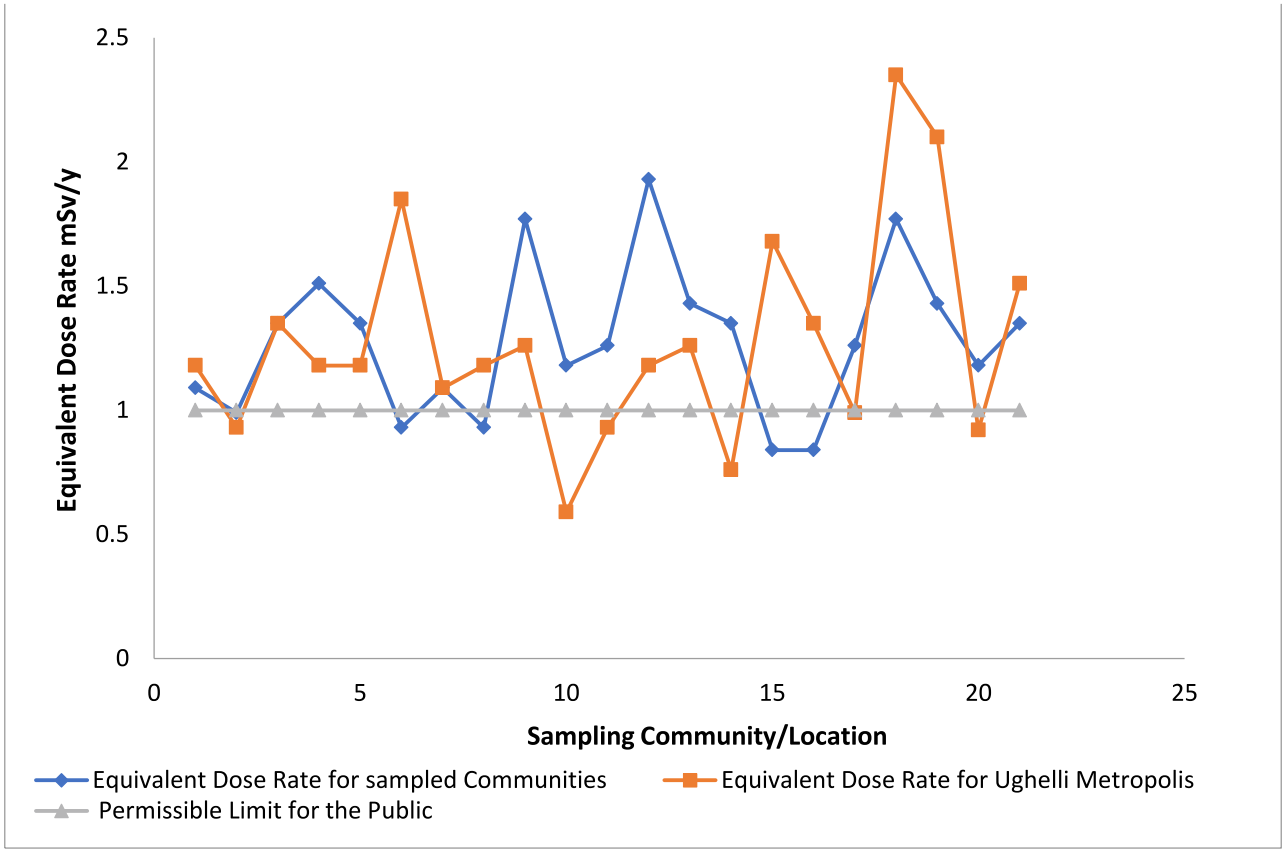


Fig.56: Comparison of the Equivalent Dose Rate in Sampled Communities and Ughelli Metropolis with Permissible Limit

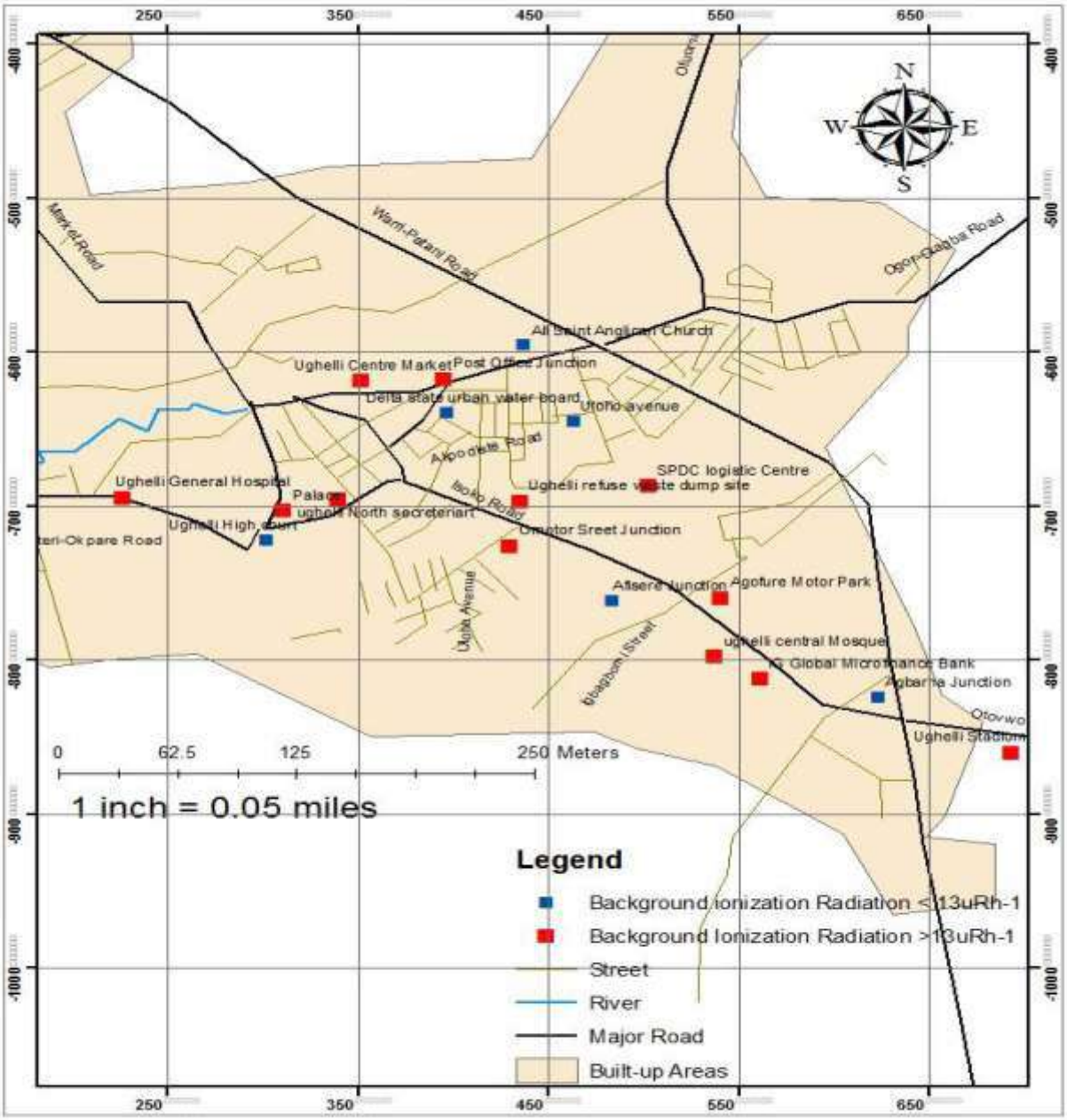


Figure 57: GIS map of Ughelli metropolis showing the BIR distribution with levels within and above Global Ambient level

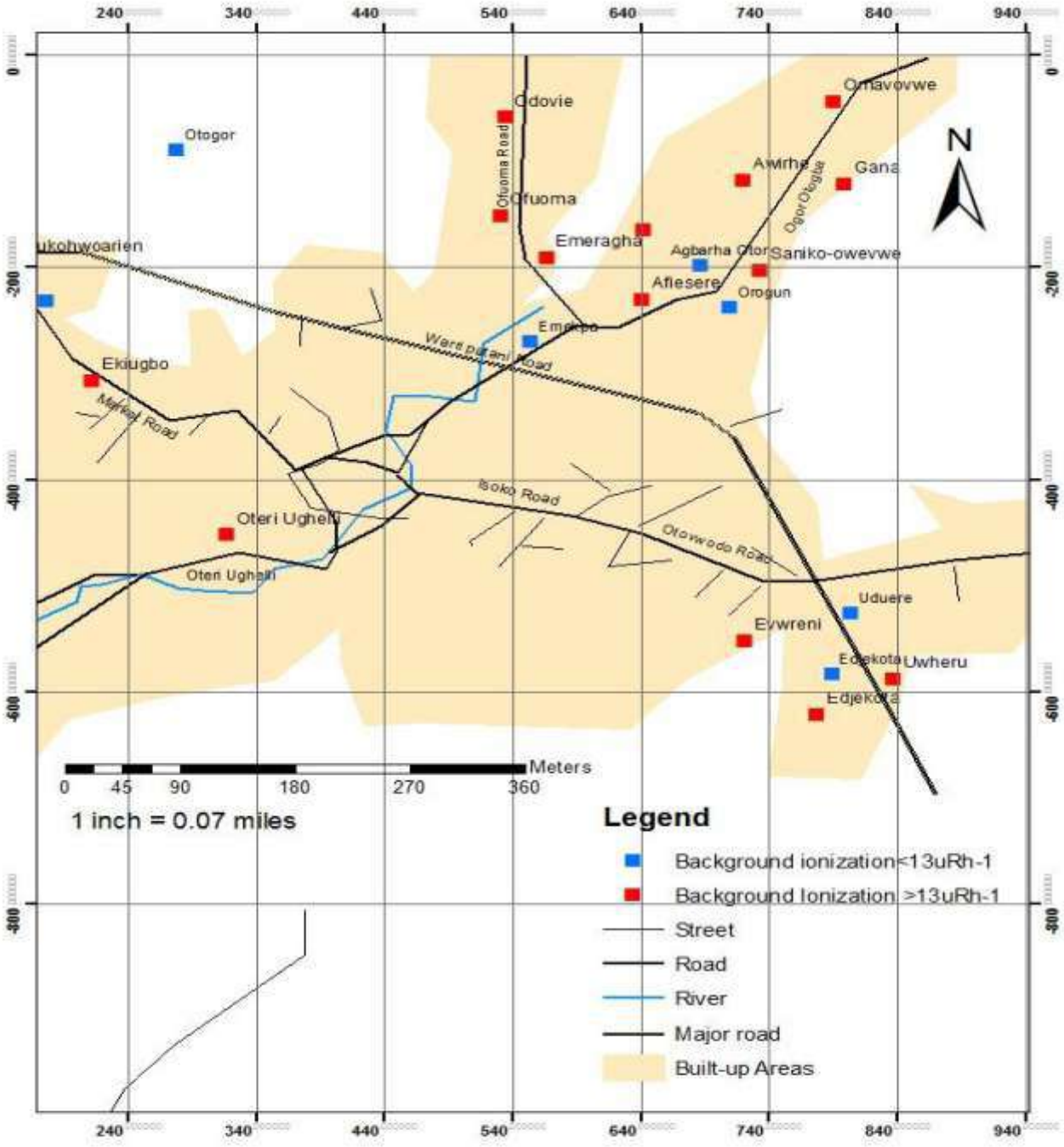


Figure 58: GIS map of Ughelli Environs showing the BIR distribution with levels within and above Global Ambient level

On the assessment of excess lifetime cancer risk from gamma radiation levels in Effurun and Warri city of Delta State, Agbalagba 2017, study the terrestrial BIR levels to estimate the excess lifetime cancer risk in Effurun and Warri. The monitoring of the terrestrial BIR levels was carried out between May 2014 and June 2015 by delineated the city into eight zones. Measured average exposure rate ranges from 0.006 mRh^{-1}(0.51$mSvy^{-1}$) to 0.029 mRh^{-1}(2.49 $mSvy^{-1}$) with overall mean value of 0.016±0.006 mRh^{-1}(1.37±0.47 $mSvy^{-1}$). The estimated mean outdoor absorbed dose rate for the zones ranged from 121.90±25.32 ηGyh) in Ajamogha zone to 190.16±51.60 ηGyh^{-1}) in the industrial zone with a mean value of 141.30±31.31 ηGyh^{-1}). The mean annual effective dose equivalent (AEDE) calculated is 0.17±0.04 $mSvy^{-1}$), while the mean excess life cancer risk (ELCR) is (0.61±0.14) x10-3 $mSvy^{-1}$. The results obtained and the evaluated radiological risk indices are summarized in Table 25. The dosage to organs received shows that testes have the highest dose of 0.11mSvy-1, while liver have the lowest dose values of 0.06 $mSvy^{-1}$. The GIS map of the study area as presented in figure 58, revealed that of the 94 sampling locations, 64 sampling sites exposure levels representing 68.1%, exceeded the World ambient standard levels of 0.013mRh^{-1} (1.0$mSvy^{-1}$ recommended by UNSCEAR 2000 and these values obtained were higher compare to values reported in previous literatures reviewed. Figures 60 and 61 show the correlation of the obtained absorbed dose rate in Enerhe zone 1 with the values obtained in East-West/ Sapele road and the correlation of the values obtained in Enerhe zone 1 with values of the absorbed dose rate estimated in the Industrial zone of Warri city. The correlation expression obtained is $y = -0.299x + 159.15$ with a regression value of $R^2 = 0.0303$ for the Enerhe/ East-West/Sapele road correlation, while the correlation of the Enerhe zone with the Industrial zone expression obtained is y=-0.6304x+281.05,$R^2 = 0.0994$. This shows that there is not strong correlation between the different zones examine from their regression values which indicates that the sources of the BIR levels from which the absorbed doses were calculated varies in the zones. The research concluded that the overall values obtained may not constitute any immediate health risk to the resident of Warri city.

Table 25: Summary of the BIR Exposure rate and the Estimated Hazard Indices in Warri City

Mapped Area	Mean BIR Exposure Rate (mRh^{-1})	Mean Equivalent Dose Rate ($mSvy^{-1}$)	Absorbed Dose Rate (ηGyh^{-1})	Annual Effective Dose Equivalent ($mSvy^{-1}$)	Excess Life Cancer Risk (μSvy^{-1})
Enerhen Zone **(1)**	0.015±0.006	1.28±0.50	130.50±25.00	0.16±0.03	0.56±0.10
Ajamoga Zone **(2)**	0.014±0.005	1.17±0.40	121.90±25.32	0.15±0.03	0.52±0.10
WaterResources Zone **(3)**	0.018±0.006	1.51±0.50	156.60±28.30	0.19±0.04	0.67±0.14
Effurun Zone **(4)**	0.018±0.007	1.52±0.60	157.47±29.20	0.19±0.04	0.68±0.14
Jeddo Zone **(5)**	0.015±0.006	1.27±0.51	130.50±28.23	0.16±0.04	0.56±0.14
PTI Zone **(6)**	0.014±0.005	1.19±0.40	122.59±30.20	0.15±0.04	0.53±0.14
East-West/Sapele Road Zone **(7)**	0.014±0.004	1.18±0.34	120.65±32.60	0.15±0.04	0.52±0.14
Industrial Zone **(8)**	0.022± 0.006	1.84±0.50	190.16± 51.60	0.20±0.06	0.81±0.21
TOTAL MEAN	**0.016±0.006**	**1.37± 0.47**	**141.30±31.31**	**0.17±0.04**	**0.61±0.14**
World Standard	**0.013**	**1.00**	**59.00**	**0.07**	**0.29$mSvy^{-1}$**

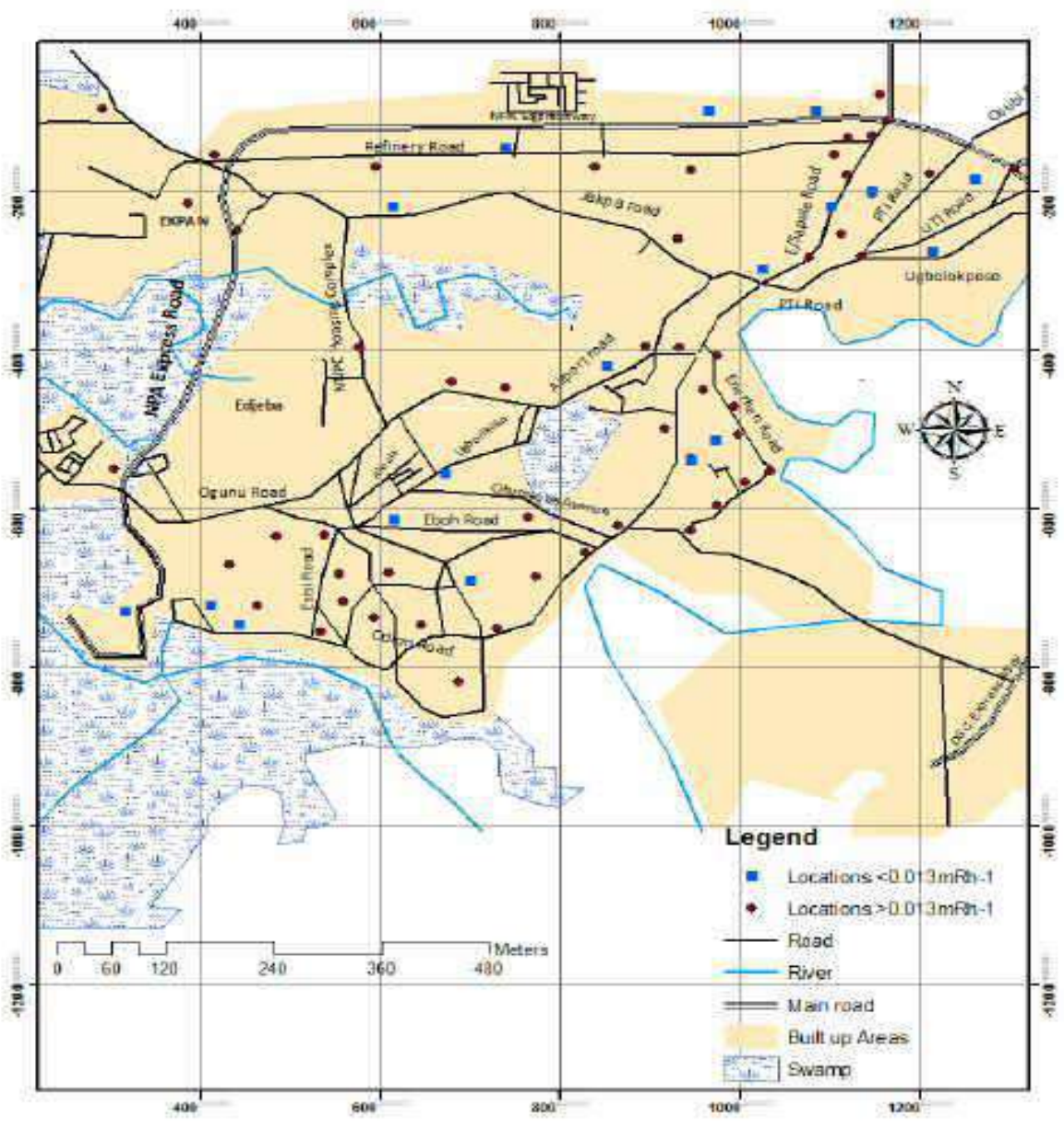


Figure 59: GIS map of Effurun and Wari metropolis showing the BIR distribution with levels within and above recommended permissible level

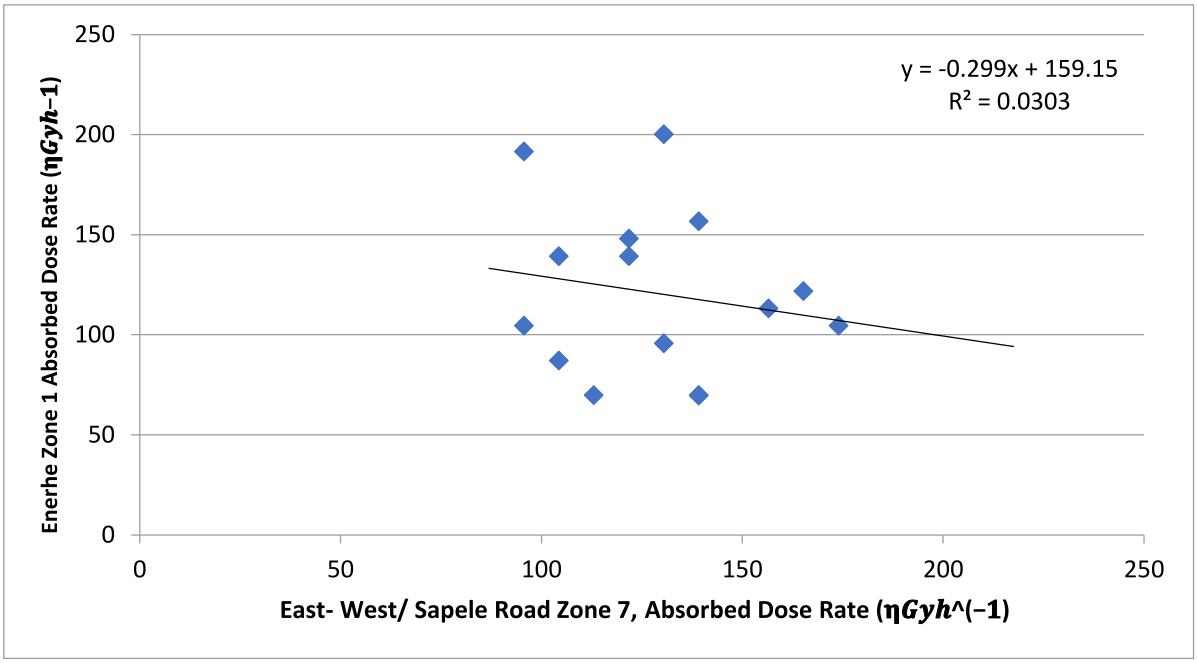


Figure 60: A correlation value of the absorbed dose rates in Enerhe zone 1 and East West/ Sapele road zone 7 in Warri City

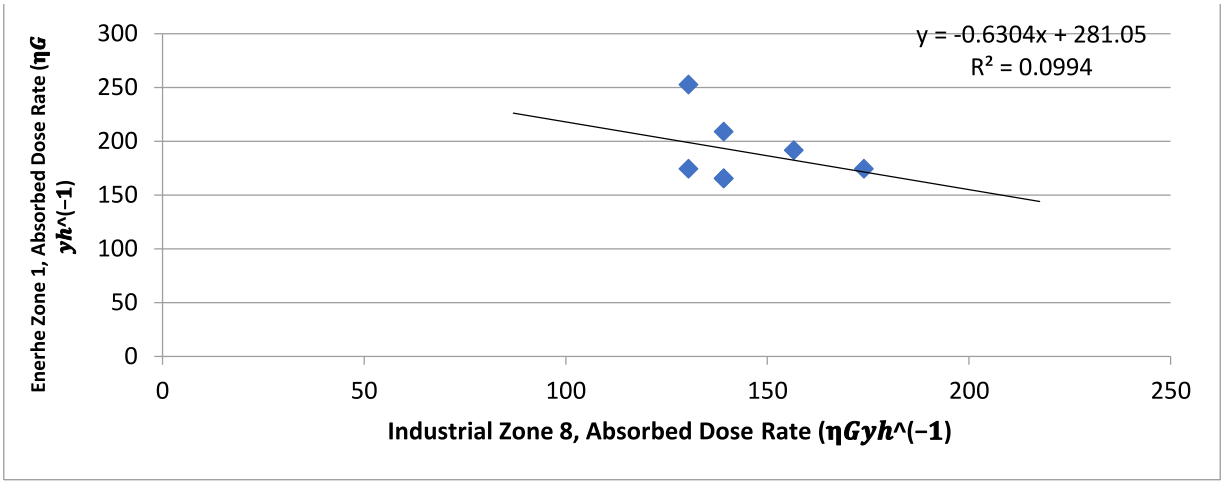


Figure 61: A correlation value of the absorbed dose rates in Enerhe zone 1 and Industrial zone 8 in Warri City

Ononugbo, Avwiri and Agbalagba, 2017, Investigated the radioactive pollution and excess lifetime cancer risk due to gamma exposure of soil and ground water around open landfills in Rivers State, Nigeria. The mean specific activity concentration of ^{238}U, ^{232}Th and ^{40}K for soil samples were 48.44± 4.08 Bqkg , 39.68±2.48 Bqkg and 416.48±11.23 Bqkg in Aluu landfill and 22.99± 1.04 Bqkg $^{-1}$, 12.94± 0.84 Bqkg and 169.11±5.46 Bqkg^{-1} in the Rumuolumeni landfill respectively, while in water they were 10.58± 1.09 Bql $^{-1}$, 10.30±1.02 Bql $^{-1}$ and 173. 78±21.32 Bql $^{-1}$ in Aluu landfill and 11.01±3.44 Bql^{-1} , 16.26± 3.77 Bql^{-1} and 225.88± 36.10 Bql^{-1} in Rumuolumeni landfill respectively and as presented in Tables 26 and 27. The mean activity concentration of ^{238}U, ^{232}Th and ^{40}K around Aluu landfill were higher than the permissible values. The study concluded that activity concentration of ^{238}U, ^{232}Th and ^{40}K in soil and ground water samples were high and Excess lifetime cancer risk calculated for all the samples analyzed were higher than the safe limits, therefore long-term radiation exposure of the residents around Aluu and Rumuolumeni landfill will pose significant health threat,

thus the ground water from these study areas should be treated for radionuclide before ingestion to minimize the radiation risk. Thus, the area has been radiologically polluted by the radioactive waste dumps in both landfills. We therefore recommend that domestic wastes be sorted out and appropriate disposal option be adopted to help safeguard the lives of the people residing close to the landfills and their environment. Also, boreholes in the area should incorporate ion exchange of reverse osmosis technology in order to eliminate the radionuclides from the water before consumption.

Table 26: Location of the sampling points and the Activity concentration of ^{238}U, ^{232}Th and ^{40}K in Soil Samples (Bqkg^{-1})

		Activity Concentration (Bqkg^{-1})		
S/N	**Sample Code**	**^{40}K**	**^{238}U**	**^{232}Th**
1.	SALU1	470.06±89.51	38.08 ± 13.32	21.75± 7.86
2.	SALU2	390.86± 78.75	41.36± 14.56	40.94± 12.08
3.	SALU3	497.41±91.83	33.19± 9.31	44.65± 11.87
4.	SALU4	457.35± 102.0	44.68± 16.20	38.96± 10.69
5.	SALU5	379.86± 72.28	43.20± 11.31	39.84± 10.02
6.	SALU6	420.9± 68.37	47.74± 12.37	40.81± 13.03
7.	SALU7	298.69± 53.74	51.32± 18.06	45.72± 20.11
8.	SALU8	347.57±97.37	39.78± 10.41	37.24± 9.20
9.	SALU9	603.77± 129.3	37.53± 8.95	41.95±16.89
10.	SALU10	342.52± 81.13	51.21± 16.40	45.67± 20.03
11.	SALU11	467.48± 117.4	47.73± 12.32	39.89± 17.18
12.	SALU12	316.69± 99.84	43.62± 15.18	38.77± 14.97
13.	SREP1	197.88± 87.51	33.23± 12.36	25.54± 8.79
14.	SREP2	156.49± 49.26	29.31±9.12	16.21±5.81
15.	SREP3	174.46± 53.32	22.55± 7.38	9.56± 3.10
16.	SREP4	162.72± 42.85	19.87± 8.29	7.98± 2.34
17.	SREP5	110.85± 36.84	23.53± 6.88	8.95± 3.01
18.	SREP6	168.76±45.37	21.98±9.02	7.62±2.71
19.	SREP7	130.44±29.74	17.09± 6.34	15.14± 4.17
20.	SREP8	159.86± 46.89	19.14 ±8.49	13.84± 3.19
21.	SREP9	260.55± 72.47	20.19± 7.03	11.59± 4.01
Mean		**310.25±68.30**	**34.59**± 11.12	**27.27± 7.89**
Standard		**400**	**35**	**30**

Table 27: Location of the sampling points and the Activity concentration of ^{238}U, ^{232}Th and ^{40}K in Water Samples

		Activity Concentration (Bql^{-1})		
S/N	**Sample Code**	^{40}K	^{238}U	^{232}Th
1.	WALU1	125.30 ± 29.35	14.25 ± 5.66	17.27± 5.34
2.	WALU2	246.38± 68.75	16.79± 7.15	12.65± 3.09
3.	WALU3	245.73± 57.32	10.58±4.12	9.07± 2.87
4.	WALU4	179.18± 7.85	7.85± 3.53	10.99± 3.65
5.	WALU5	120.82±33.62	9.07± 2.87	8.52± 2.87
6.	WALU6	141.98±45.30	8.10± 4.11	7.53± 2.19
7.	WALU7	211.95± 68.48	9.96± 3.21	8.46± 3.16
8.	WALU8	118.91± 42.52	8.02± 3.11	7.92±3.10
9.	WREP1	118.74± 31.93	13.50± 3.19	18.72± 6.82
10.	WREP2	246.01± 91.12	12.03±4.21	15.70±5.93
11.	WREP3	244.77± 69.46	14.23± 5.13	21.62± 7.32
12.	WREP4	222.98±46.39	11.48± 3.17	14.24± 6.07
13.	WREP5	226.60±50.01	8.61± 2.34	22.30± 8.11
14.	WREP6	137.41± 37.62	7.86±3.09	14.02±4.21
15.	WREP7	226.60±74.92	9.25± 2.18	17.28± 6.09
16.	WREP8	217.16± 46.58	8.99±3.29	13.02± 4.21
17.	WREP9	392.66± 97.23	13.15± 4.11	9.46± 3.21
Mean		**170.19±55.28**	**10.81± 3.67**	**13.49±4.60**
WHO, 2011 standard		**10**	**10.0**	**1.0**

Agbalagba and Anekwe, 2021. Examined the radiometric mapping of terrestrial gamma radiation and evaluation of radiological health risk on the residents in Nigeria State commercial (Agbor) and capital (Asaba) cities. The two monitored cities and environs were delineated into five zones. Measured zones mean outdoor background ionizing radiation (BIR) levels in Asaba ranged from 0.012±0.003 mRh^{-1} (1.01±0.27 $mSvy^{-1}$) to 0.023±0.009 mRh^{-1} (1.96±0.82 $mSvy^{-1}$) with total mean value of 0.018±0.006 mRh^{-1} (1.52±0.49 $mSvy^{-1}$), as presented in Table 28. Table 29 present Agbor, zones mean outdoor BIR levels, which ranged from 0.012±0.004 mRh^{-1} (1.01±0.35 $mSvy^{-1}$) to 0.019±0.004 mRh^{-1} (1.58±0.37 $mSvy^{-1}$) with total mean value of 0.016±0.004 mRh^{-1} (1.38±0.38 $mSvy^{-1}$). The mean outdoor absorbed dose rate for Asaba and Agbor are 158.34±50.44 $nGyh^{-1}$. and 141.52±29.58 $nGyh^{-1}$ respectively. The mean annual effective dose equivalent (AEDE) for the two cities are 0.19±0.05 and 0.16±0.05 $mSvy^{-1}$ respectively, while the mean excess lifetime cancer risk (ELCR) are (0.69±0.21 and 0.64±0.17) x10-3 $mSvy^{-1}$ respectively. The estimated effective dosage to organs received shows that testes have the highest dose of 0.10$mSvy^{-1}$, with liver receiving the lowest dose of 0.06$mSvy^{-1}$ as shown in Table 30. The study revealed that of the 100 sampling locations, 76 sampling sites outdoor radiation levels (76%) exceeded the World ambient standard levels of 0.013 mRh^{-1} (1.0 $mSvy^{-1}$) as shown in the contour GIS maps in figure 62 and 63. The overall results obtained shows elevation of BIR levels and all the estimated risk parameters except ELCR and effective doses to organs, above recommended limit for the public. Figures 64 and 65 show the comparison of the mean absorbed dose rate estimated in Asaba and Agbor` and the respective international recommended and permissible limits for the public. They show elevation of the BIR levels above the ambient levels, while all the estimated risk parameters are well above their recommended permissible levels for the general public except for the excess lifetime cancer risk that is below its recommended permissible limits (Azionu, et al., 2019). These observed and reported elevation of the measured and computed values above their ambient and recommended permissible limits is a potential radiological pollution, Nonetheless, it does not establish any immediate health risk to the residents of the study area, especially to the various human organs as shown in figure 66.

Table 28: Summary of Measured BIR levels and estimated Radiological Risk Parameters in Asabametropolis and its environs.

Mapped Area	Mean BIR Exposure rate (mRh^{-1})	Mean equivalent dose rate (EDR) ($mSvy^{-1}$)	Absorbed dose rate (ADR) ($ŋGyh^{-1}$)	Annual effective dose equivalent (AEDE)($mSvy^{-1}$)	Excess lifetime cancer risk (ELCR) x 10^{-3}
Zone1	0.012±0.003	1.01 ±0.27	104.40 ±27.90	0.13 ±0.03	0.45 ±0.12
Zone 2	0.018±0.002	1.53 ± 0.21	159.10±21.16	0.19 ±0.03	0.68 ±0.09
Zone 3	0.018±0.005	1.53 ±0.43	159.10 ±24.80	0.19 ±0.06	0.68 ±0.12
Zone 4	0.023±0.009	1.96 ±0.82	203.80 ±35.40	0.24 ±0.06	0.87 ±0.17
Zone 5	0.019±0.009	1.59 ±0.21	165.30 ±32.96	0.20 ±0.05	0.70 ±0.31
Total Mean	**0.018±0.006**	**1.52 ±0.49**	**158.34 ±50.44**	**0.19 ±0.05**	**0.69 ±0.21**
World Recommended limit (ICRP, 2008)	**0.013**	**1.00**	**59.00**	**0.07**	**0.29**

Table 29: Summary of Measured BIR levels and estimated Radiological Risk Parameters in Agbor metropolis and its environs

Mapped area	Mean BIR exposure rate (mRh^{-1})	Mean equivalent dose rate (EDR) ($mSvy^{-1}$)	Absorbed dose rate (ADR) ($nGyh^{-1}$)	Annual effective dose equivalent (AEDE) ($mSvy^{-1}$)	Excess lifetime cancer risk (ELCR) x10^{-3}
Zone1	0.018±0.003	1.50±0.24	152.90±24.98	0.18±0.03	0.85±0.11
Zone 2	0.018±0.004	1.63±0.38	160.30±31.50	0.19±0.05	0.68±0.18
Zone 3	0.019±0.004	1.58±0.37	164.06±37.90	0.20±0.05	0.70±0.16
Zone 4	0.012±0.004	1.01±0.35	105.27±26.80	0.12±0.04	0.45±0.16
Zone 5	0.014±0.006	1.20±0.55	125.06±26.54	0.13±0.07	0.53±0.24
Total Mean	**0.016±0.004**	**1.38±0.38**	**141.52±29.58**	**0.16±0.05**	**0.64±0.17**
World Recommended limit	**0.013**	**1.00**	**59.00**	**0.07**	**0.29**

Table 30: Comparison of estimated Effective dose rate to different organs and tissues and ICRP recommendation

Organs	Lung	Ovary	Bone marrow	Testes	Kidney	Liver	Whole Body
ICRP 1996, UNSCEAR, 2000 Recommendation	0.64	0.58	0.69	0.82	0.62	0.42	0.68
$D_{organ}(mSvy^{-1})$	0.08	0.07	0.09	0.10	0.08	0.06	0.09

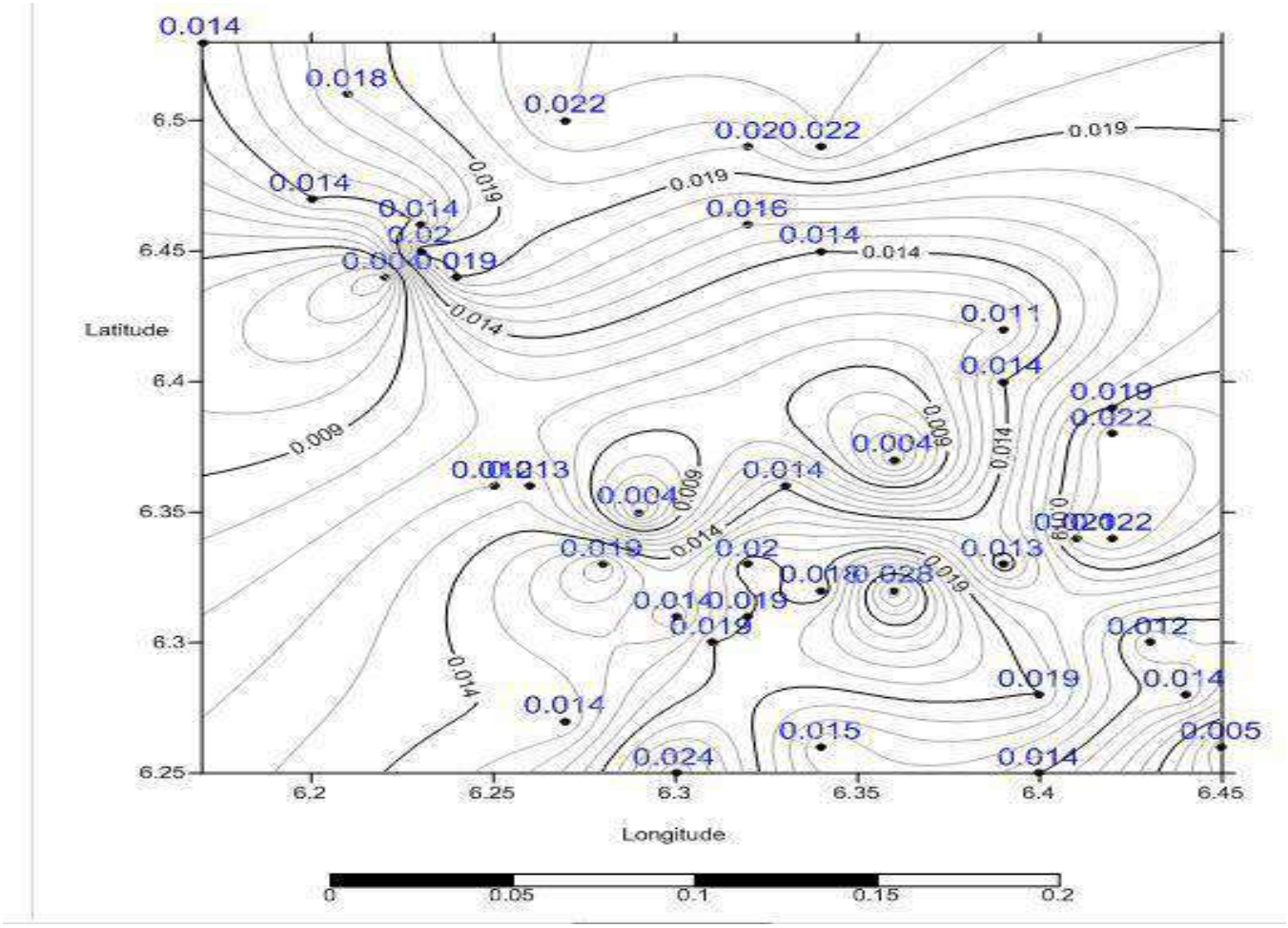


Figure 62: GIS contour map of Asaba showing sampled points with BIR exposure levels

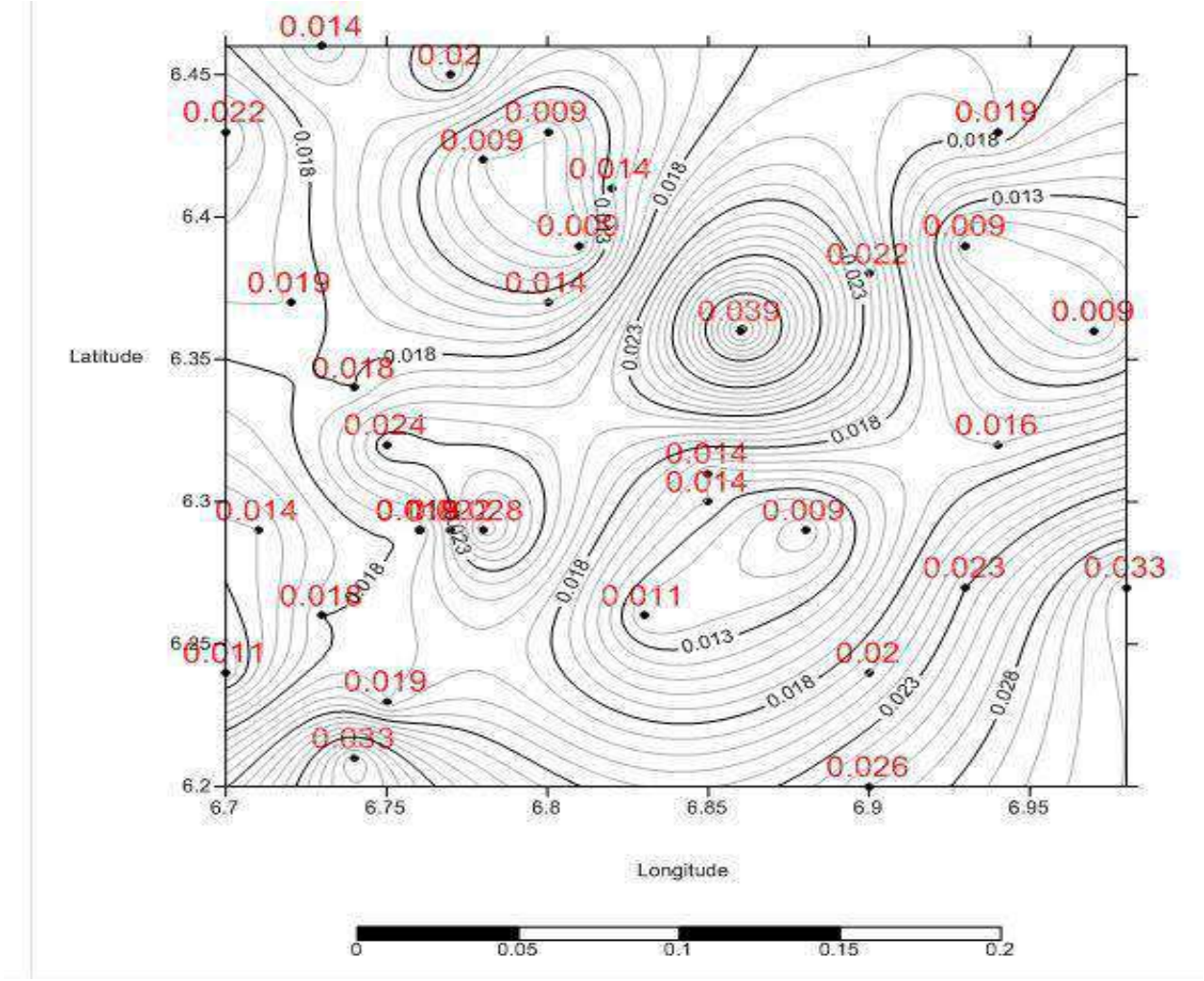


Figure 63: GIS contour map of Agbor showing sampled points with BIR exposure levels

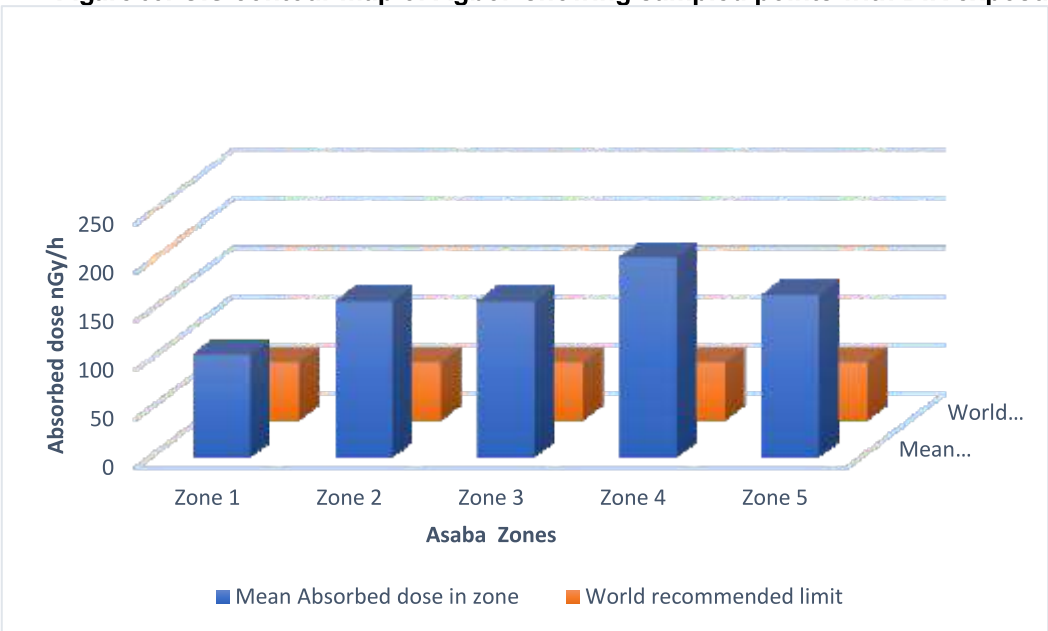


Figure 64: Comparison of the measured absorbed dose rate with global recommended limit for the public in Asaba

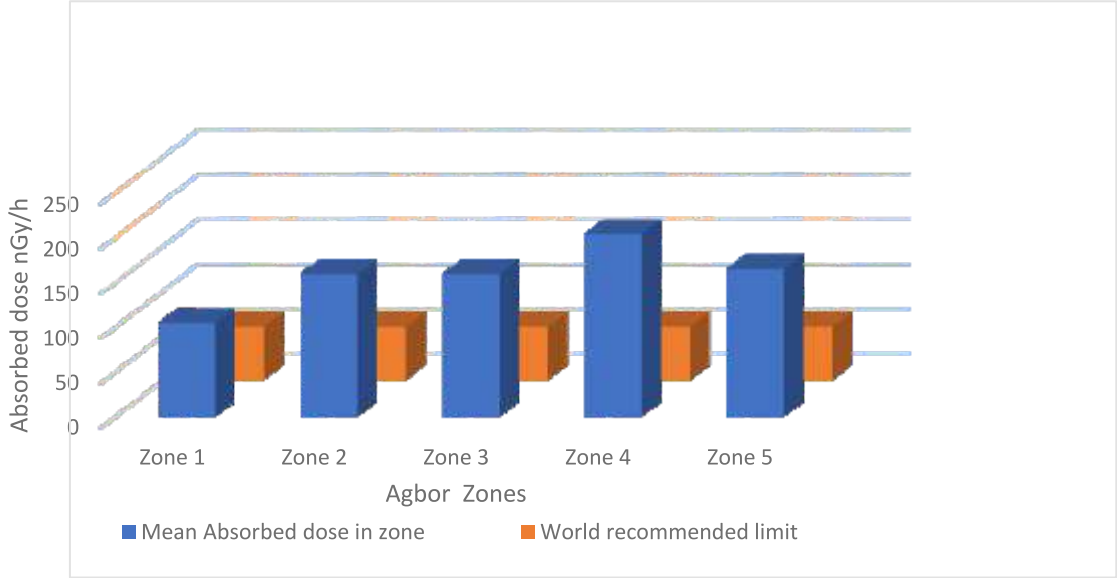


Figure 65: Comparison of the measured absorbed dose rate with global recommended limit for the public in Agbor

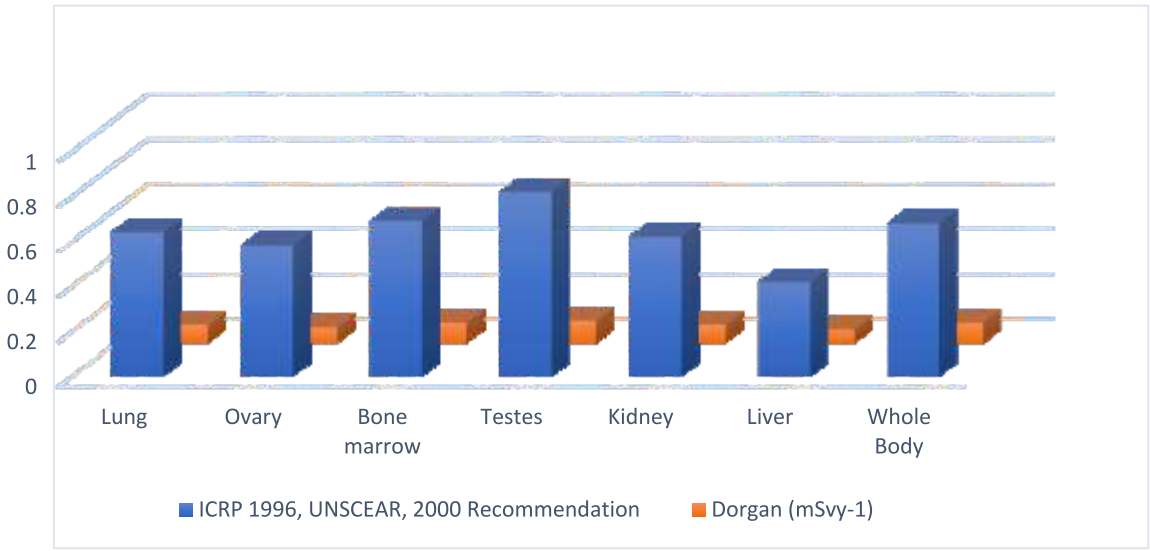


Figure 66: Comparison of the estimated dose rate to organs and tissues with global recommended permissible limit

Agbalagba and Okorodudu, 2024, did a forensic GIS γ-radiation mapping and associated radiological health risk assessment of the premier cities of Sapele, Oghara and Koko; South-South Nigeria. In Sapele with four zones, the measured average gamma radiation levels ranged from 0.011±0.003 mRh^{-1} to 0.014±0.005 mRh^{-1}, while in Oghara metropolis with five zones, the average gamma radiation levels ranged from 0.013±0.002 mRh^{-1} to 0.026±0.009 mRh^{-1} and for Koko with four zones, the values obtained ranged from 0.018±0.003 mRh^{-1}(1.54±0.11$mSvy^{-1}$) to 0.023±0.008 mRh^{-1} respectively, with overall mean value of 0.017±0.006 mRh^{-1}(1.43±0.51$mSvy^{-1}$). The mean absorbed gamma dose rate for three cities of Sapele, Oghara and Koko are 106.50±22.33 $nGyh^{-1}$, 167.28±22.59 $nGyh^{-1}$ and 176.80±24.74 ηGyh^{-1} respectively. The mean annual effective dose rate (AEDR) for the three cities is 0.13±0.03$mSvy^{-1}$, 0.20±0.07$mSvy^{-1}$ and 0.22±0.06$mSvy^{-1}$ $mSvy^{-1}$ respectively, while the mean excess lifetime cancer risk (ELCR) values are (0.47, 0.72 and 0.77) x10-3 respectively. These results are presented in Table 31 and the GIS maps of the three cities are shown in figures 67-69. Figures 70-73 show the comparison of the measured BIR, calculated equivalent dose, absorbed dose rate and the doses to human organs to their world permissible limits in the all the zones examined. The results obtained in the cities indicate that the BIR levels, and corresponding estimated health risk parameters are in the order of Koko > Oghara > Sapele. The estimated effective dosage to organs shows that liver receiving

the least dose of 0.07mSvy^{-1} (11%) while testes got the highest dose of 0.12 mSvy $^{-1}$(19%), as shown in figure 74. The overall results obtained show that all the thirteen zones' BIR levels and their estimated risk parameters exceeded their recommended limits for the public and were also higher than reported values in previous studies reviewed. The reported significant elevation of the obtained background ionizing radiation (BIR) values may not necessarily establish any immediate likelihood of radiological health risk, but call for caution on possible accumulative radiation effects in future on the residents of the study area. It was therefore recommended that a detailed specific radioactivity concentration assessment be conducted on soil and water of the study area, while a periodic terrestrial background gamma radiation evaluation be conducted for radiation protection.

Table 31: Summary of the BIR Exposure Rate and the Estimated Radiological Hazard Indices of the study Areas of Sapele, Oghara and Koko

S/N	Mapped Area	CODE	BIR Levels (mRh^{-1})	Equivalent Dose (mSvy^{-1})	Absorbed Dose (nGyh^{-1})	AED (mSvy^{-1})	ELCR (x10^{-3})
1	***Ogodo-Sapele***	Zone A	0.012±0.005	1.01±0.42	104.40±23.50	0.13±0.03	0.46
2	Abere- Sapele	Zone B	0.014±0.005	1.18±0.42	121.80± 24.00	0.15±0.04	0.54
3	**Major Bowen-Sapele**	Zone C	0.011±0.003	0.93±0.25	95.71±19.10	0.12±0.02	0.42
4	**Amukpe - Sapele**	Zone D	0.012±0.004	1.00±0.31	104.50±22.70	0.13±0.03	0.46
5	**Oghareki**	Zone E	0.019±0.008	1.61 ±0.24	166.5±14.88	0.20 ±0.08	0.71
6	**Oghara Market**	Zone F	0.015± 0.008	1.29±0.09	132.98±18.70	0.16±0.09	0.57
7	Western Delta University Zone	Zone G	0.013±0.002	1.06± 0.44	109.37± 530	0.13± 0.05	0.47
8	Otefe Zone	Zone H	0.018±0.009	1.59±0.26	200.10±46.27	0.25±0.06	0.86
9	Ovade zone	Zone I	0.026±0.009	2.20±0.46	227.44±17.80	0.28±0.08	0.98
10	Ajagbodudu	Zone J	0.023±0.008	1.93±0.46	200.10±44.28	0.25±0.06	0.86
11	Korode	Zone K	0.020±0.007	1.91±0.53	188.91±21.52	0.23±0.07	0.81
12	Nana	Zone L	0.018± 0.007	1.54±0.56	159.10±17.66	0.20±0.07	0.68
13	Ologbo Zone	ZoneM	0.018±0.003	1.54±0.11	159.08±15.49	0.20±0.04	0.54
Total mean			**0.017±0.006**	**1.43±0.51**	**147.91±23.17**	**0.18±0.06**	**0.63x10^{3}**
World average value (UNSCEAR, 2008)			**0.013**	**1.00**	**59.00**	**0.07**	**0.29x10^{3}**

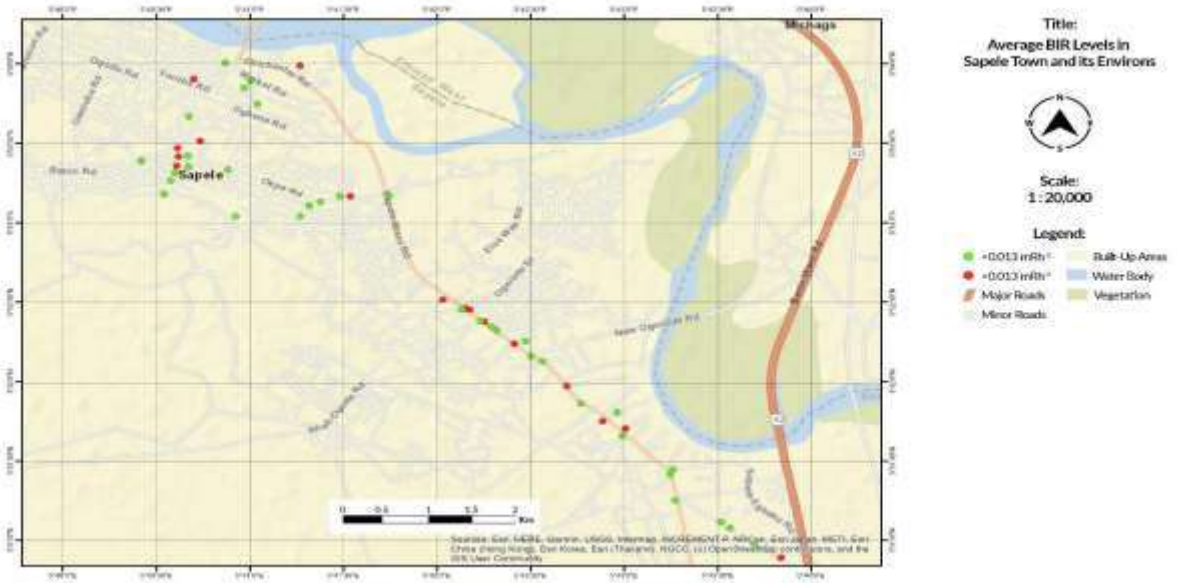


Figure 67: GIS map of the BIR levels showing areas within and above permissible limits in Sapele town

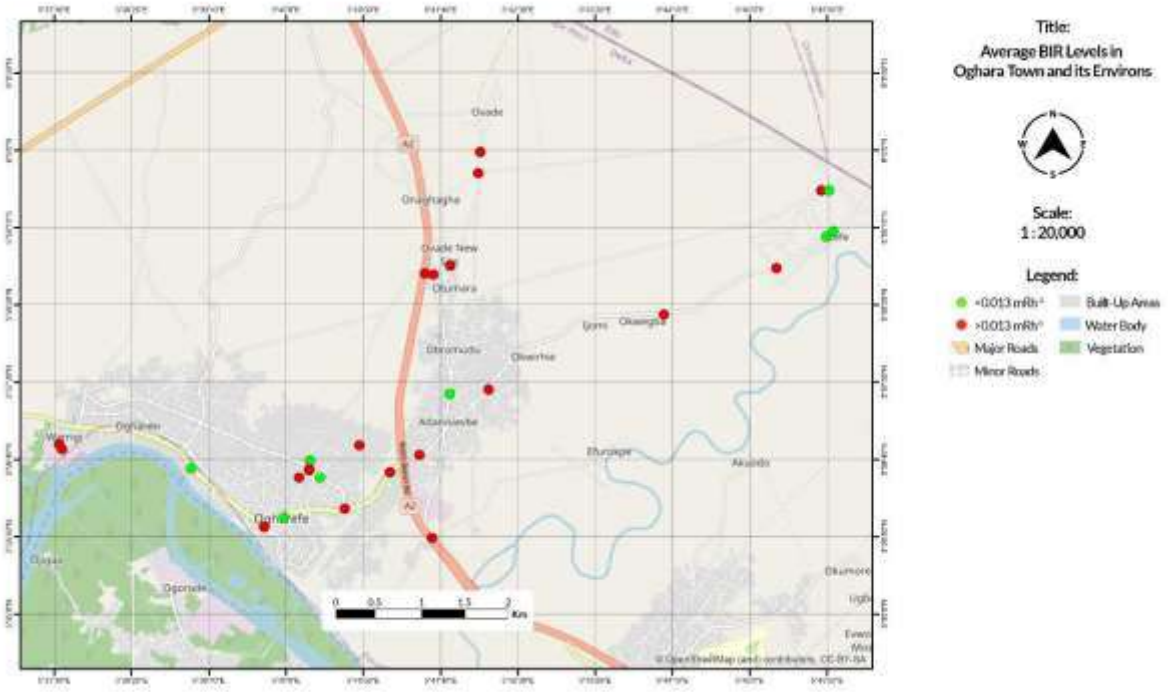


Figure 68: GIS map of the BIR levels showing areas within and above permissible limits in Oghara town

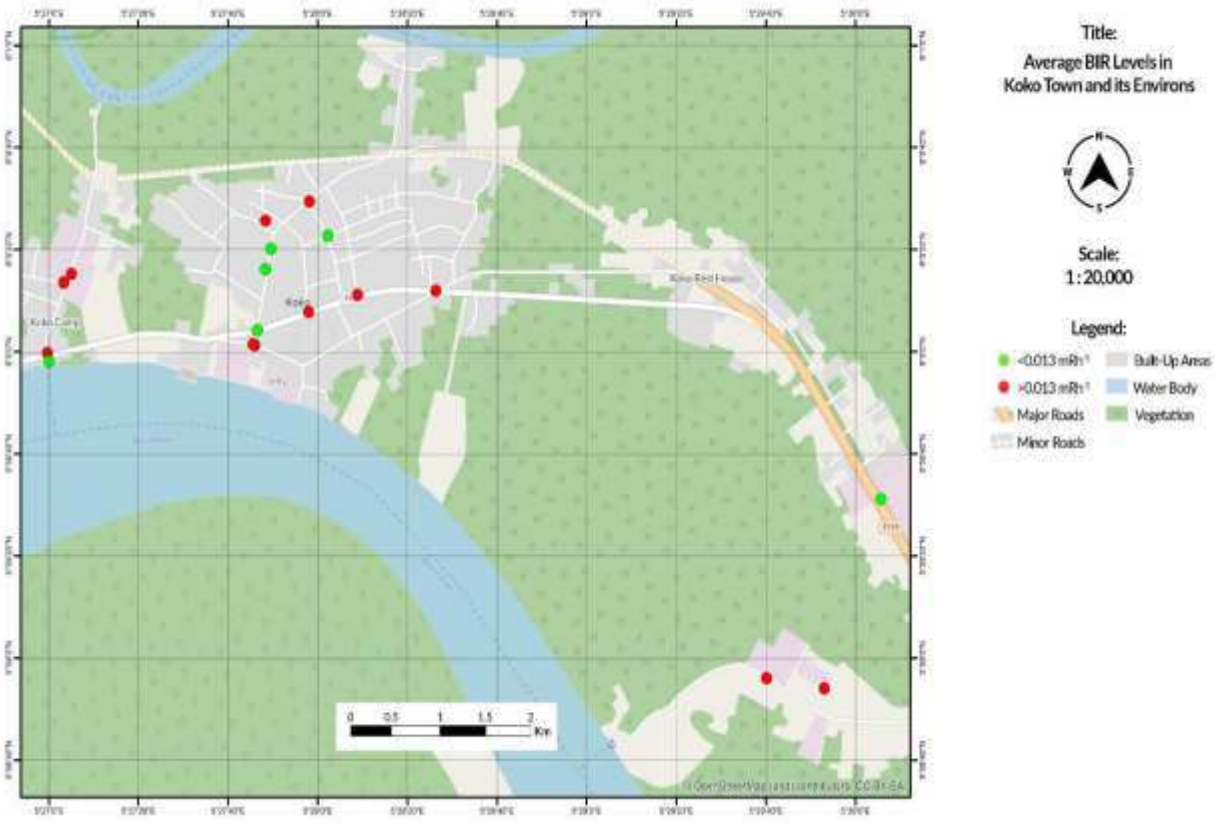


Figure 69: GIS map of the BIR levels showing areas within and above permissible limits in Koko town

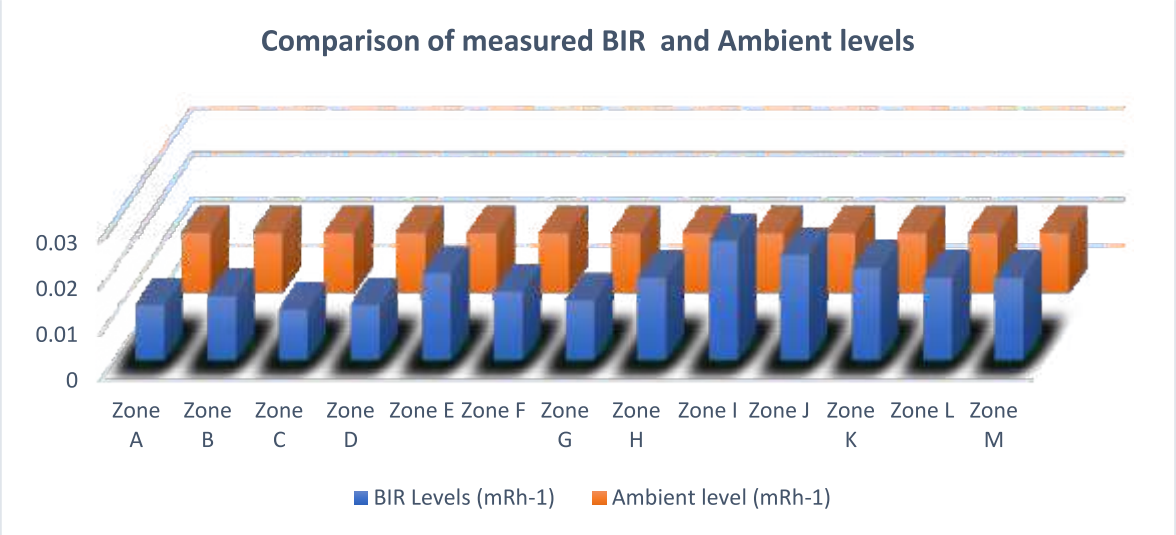


Figure70: Comparison of the measured BIR levels and World Ambient level

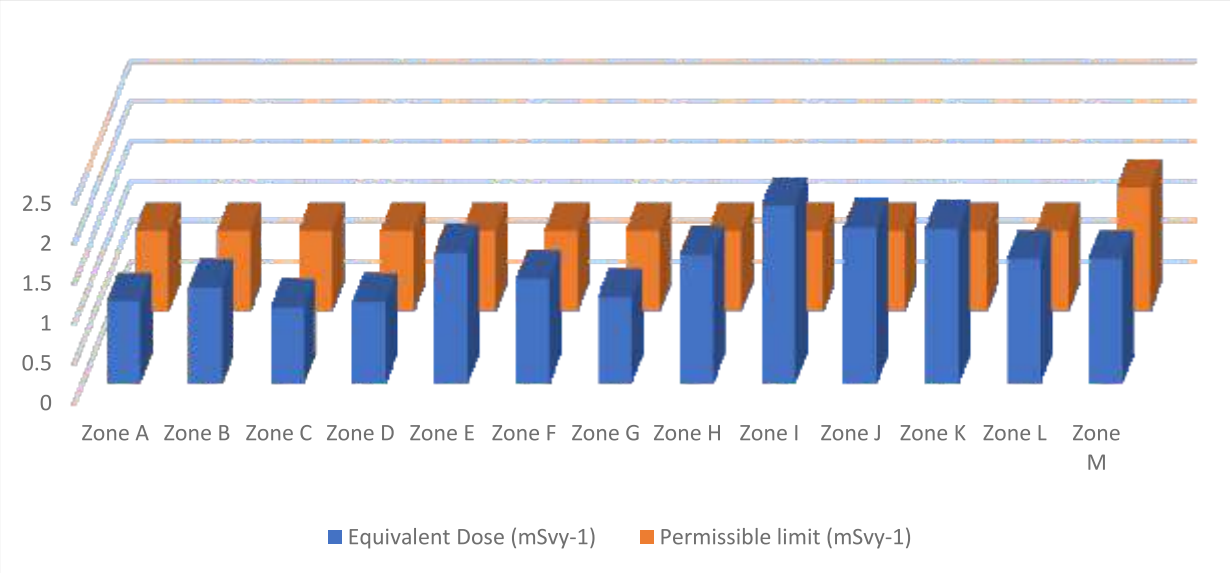


Figure71: Comparison of Evaluated Equivalent Dose with World average limit for the Public

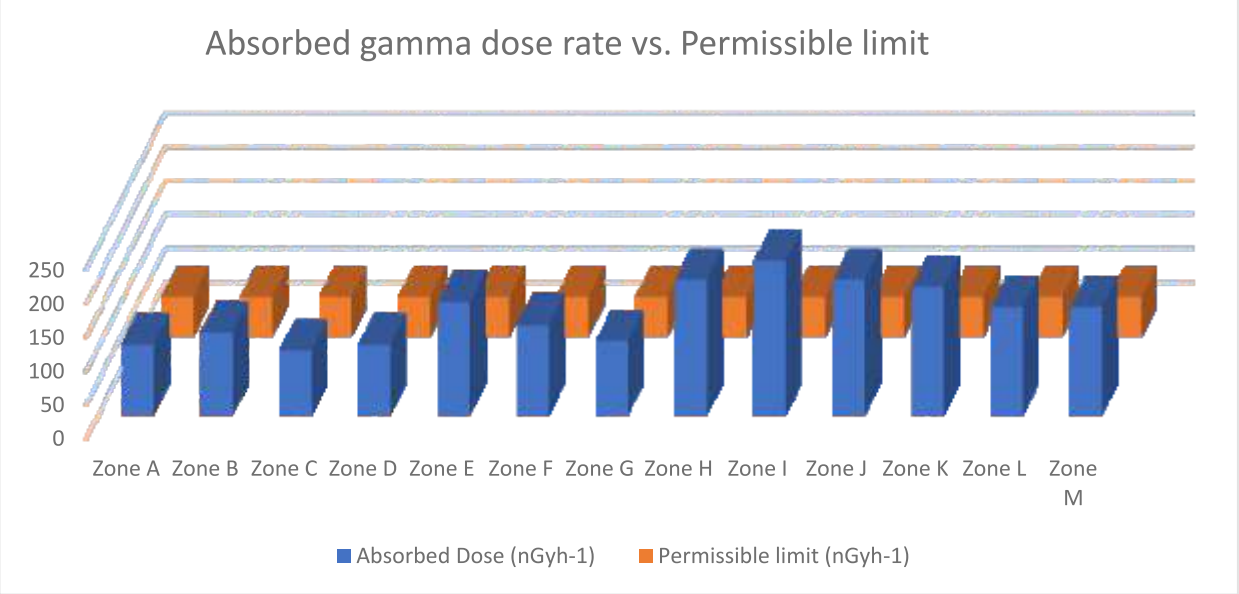


Figure72: Comparison of the Absorbed Gamma Dose Rate with the World average limit for the Public

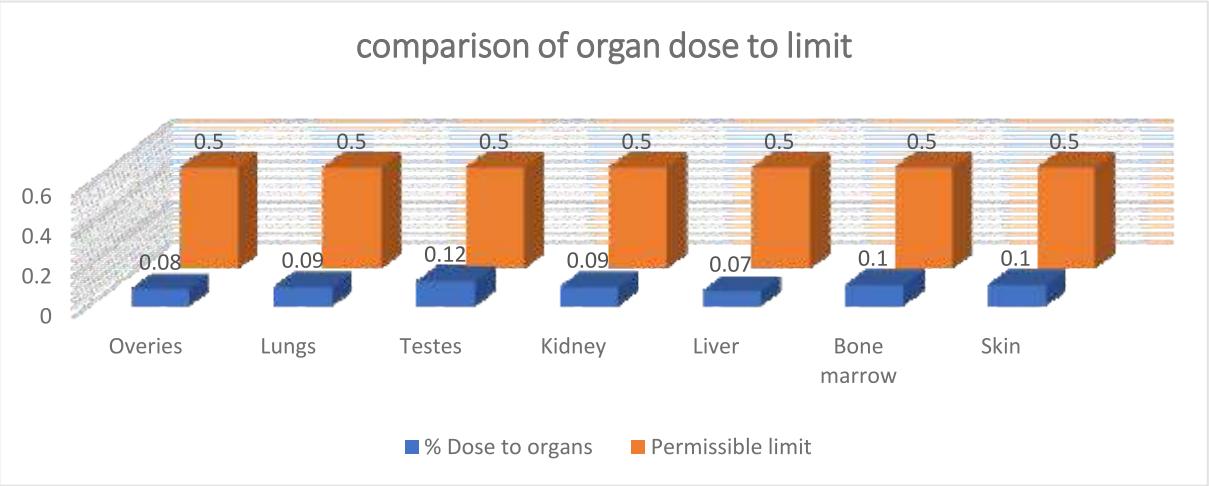


Figure73: Comparison of the Dose to Examined Organs with World average limit for the Public

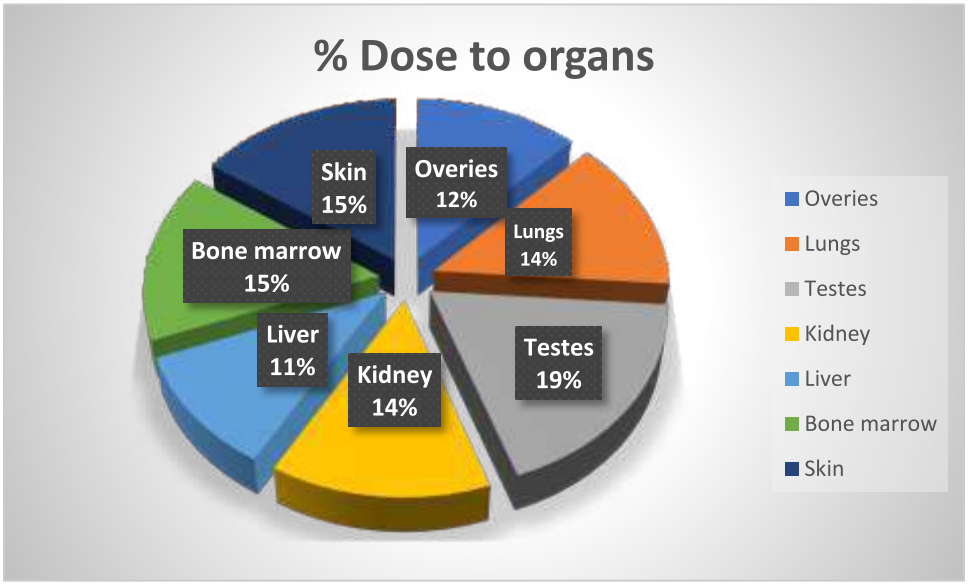


Figure74: Estimated Percentage Equivalent Dose to the Examined Organs

3.4. Radiation Detection and Protection in Soil, Sediment and Water

Much has been researched and opined about our environment as it affects man; soil, sediment and water are the environmental indicators for the evaluation of environmental sustainability. Radiation and radionuclide present in the environment indicate contamination and pollution of same when it is above permissible limits. It is of great important therefore, that the radiation and radionuclide status of the environment be known and monitored periodically for its ambient maintenance and human health protection. In light of this, Agbalagba and Onoja 2011, investigated natural radioactivity status of soil, sediment and water samples of Niger Delta (Biseni) flood plain lakes, Nigeria. This plan is strategic to people of Bayelsa because it serves as reserve lake for crocodile conservation and a tourism attraction site. The activity profile of radionuclides shows low activity across the study area. The mean activity level of the natural radionuclides ^{226}Ra, ^{232}Th and ^{40}K is 20 ± 3, 20 ± 3 and 180 ± 50 Bq kg^{-1}, respectively. These values are well within values reported elsewhere in the country and in other countries with similar environments. The study also examined some radiation hazard indices. The mean values obtained are, 76 ± 14 Bq kg^{-1}, 30 ± 5.5 nGyh^{-1}, 37 ± 6.8 mSv y^{-1}, 0.17 and 0.23 for Radium Equivalent Activity (Raeq), Absorbed Dose Rates (D), Annual Effective Dose Rates (Eff Dose), External Hazard Index (Hex) and Internal Hazard Index (Hin) respectively. All the health hazard indices obtained were well below their recommended limits. The findings shows that the soil, sediments and water samples examined are radiologically safe and will not pose any health risk to both the aquatic life and human living within and around the lake.

Avwiri, Osimobi and Agbalagba, 2012, on the evaluation of radiation hazard indices and excess lifetime cancer risk due to natural radioactivity in soil profile of Udi and Ezeagu local government areas of Enugu state, Nigeria. Soil samples were collected at 20meters interval down the borehole (well) within depths of about 200m and 140m for Well 1 (Amagu-Umuene) and well 2 (Ogulogu-Olo) respectively. The average values of ^{40}K, ^{226}Ra and ^{232}Th obtained is 57.17Bqkg^{-1}, 13.71Bqkg^{-1} and 10.49Bqkg^{-1} respectively for well 1 and 59.77Bqkg^{-1}, 11.49Bqkg^{-1} and 8.83Bqkg^{-1} respectively for well 2. The findings revealed that the values obtained when compared with their corresponding world permissible values, were found to be below the permissible limits for such environment. We concluded that radiation exposure to the drillers and residents in the study areas will pose no significant health threat thus the soil/ sediment of this area can be use as building material and recommended that these results should form a baseline data for soil vertical depth profile in the studied area.

3.5. Radiation Detection and Protection in Staple Foods and Beverages

In our utmost quest and concern for the quality and compliance to standard of food we consume and the increasing cases of sickness induce by radiation and radioactive propelled diseases, we undertake different research investigation into the radioactive content in some of our staple foods and general food consume in this Nigeria, I will highlight some of these research work and our key findings.

If cow milk starts testing positive to high level of radioactive elements, it is an indicative of radioactive contamination of the entire food supply (Ethan Huff, 2011). If these high content of radionuclides in the milk are ingested, they will be concentrated and accumulated in certain parts or organs of the body, for example ^{238}U and ^{226}Ra accumulates in human kidney and lungs, ^{232}Th in liver, skeleton tissue and lungs and 40K in muscles (Tawalbeh et al., 2012). Agbalagba et al., 2016, undertook the cost-benefit analysis approach to risk assessment of natural radioactivity in powdered and liquid milk products consumed in Nigeria. The paper presented important facts on food safety in milks consumed in Nigeria which is in agreement with NAFDAC plan to actualize its objective regarding the safety of food in Nigeria. The activity concentrations of the three naturally occurring radionuclides ^{226}Ra, ^{232}Th and ^{40}K were measured in 10 brands of the powdered milks and 11 brands of liquid milks. The results obtained show that the mean activity concentration of ^{40}K in the powder and liquid samples are 468.0±72.7Bqkg^{-1} and 317.6±58.5Bqkg^{-1} respectively. The mean values for ^{226}Ra for powder and liquid milk were 19.2±7.2Bqkg^{-1} and 16.6±6.3Bqkg^{-1} respectively, while for ^{232}Th it is 12.1±4.8Bqkg^{-1} and 10.6±4.3Bqkg-$^{-1}$ 1respectively. The average value of 40K in the powder milk was found to be slightly above the standard value set by UNSCEAR for foodstuffs. The values of the calculated hazard indices and the radium equivalent of all milk samples were within the permissible limit set by UNSCEAR and other international regulatory bodies. However, the consumption of powder and liquid milk by infants and children at the rate of 14 to 15kg/year from this analysis may result in radiation dose to vital organs above standard values. The summary of the results obtained are presented in Table 32.

Table 32: Summary of Risk Analysis of Radiation Dose from Milk Products

Age Group	Annual Effective Dose E_D (μSv)		Committed Effective Dose C_D (mSvy^{-1})		Collective effective Dose Equivalent S_E (man-Sv)		Total Health Detriment (G) (man)		Mean THD (G) (man)	Total Cost of Detriment man-Sv $million
	Powdered milk	Liquid milk	Powdered milk	Liquid milk	Powdered milk	Liquid milk	Powdered milk	Liquid milk		
Infant (0-1yr)	1607.3	1345.4	80.4	67.3	5,551.5	4,640.9	91.6	76.6	168	10.2
Children (7-12yrs)	962.0	822.5	48.1	41.1	9,305.8	7,950.3	153.5	131.2	285	17.3
Adult (>17yrs)	186.5	181.1	09.3	9.1	6,023.1	5,840.7	99.4	96.4	196	11.9

The cost-benefit analysis shows a low collective effective dose equivalent with a mean radiological index ratio of 1:30,839 for infants, 1:50,909 for children and 1:247,145 for adults. The computed values of the total cost of health detriment of consuming these examined milk products revealed that children age group has the highest cost health detriment per-caput dose with estimated total cost of health detriment of US $17.256 million, followed by adults with estimated cost implication of US $11.864 million while infants is the least with estimated cost implication of US $10.192 million. The overall results show that the powdered and liquid milks consumed in Nigeria are radiologically safe and may not cause any immediate radiation health hazard to consumers of the examined milk brands while optimizing radiation protection using cost-benefit analysis is recommended.

Agbalagba and Agbalagba, 2021, carried out the assessment of radioactivity concentrations and its' health detriment of imported canned food products in Nigeria. The study x-ray natural (^{238}U, ^{232}Th and ^{40}K) and artificial (^{210}Pb and ^{60}Co) occurring radioactivity content in 22 brands of imported canned food products in Nigeria categorized into staple foodstuffs, beef and seafood was investigated using a High purity Germanium detector (HPGe).

Table 33: Specific Activity Concentration of the different canned food products

S/N	Staple Foodstuffs	Radioactivity Concentration (Bqkg^{-1})					
		Country	^{238}U	^{232}Th	^{40}K	^{210}Pb	^{60}Co
1	Trio golden sweet corn	Thailand	16.99±3.00	7.44±3.32	59.91±17.63	5.96±0.31	ND
2	Trio Green Peas	China	13.91±3.02	9.73±3.99	37.62±11.11	8.19±0.43	1.86±0.84
3	Trio mushroom	China	19.92±5.93	8.72±3.86	36.50±10.80	3.08±0.22	1.11±0.58
4	Macedonia Vegetable	Greece	16.83±6.07	20.71±6.13	42.11±12.39	5.62±0.29	1.63±0.63
5	Tomato puree	South Africa	16.43±3.14	14.34±5.00	90.14±26.31	6.32±0.73	2.16±0.90
6	Sweet Kernel corn	Thailand	BDL	3.68±1.08	39.53±11.62	ND	ND
7	Braii relish tomato	South Africa	13.56±5.82	13.99±4.50	70.95±20.66	ND	ND
8	KOO vegies	South Africa	16.33±7.49	21.36±6.12	38.29±11.27	ND	ND
9	KOO baked beans	South Africa	BDL	4.89±2.72	50.29±14.86	ND	ND
10	Foodtown sweet corn	USA	22.41±5.96	11.32±4.41	45.10±13.23	ND	ND
11	Heinz baked beans	UK	BDL	19.67±9.72	55.87±16.46	ND	ND
Total	Activity Conc.		**135.68±40.43**	**135.85±50.85**	**566.31±166.34**	**29.17±1.98**	**6.76±2.95**
Mean	Activity Conc.		**12.33±3.68**	**12.35±4.62**	**51.48±15.12**	**2.65±0.18**	**0.61±0.27**
Beef Food Products		**Country**	^{238}U	^{232}Th	^{40}K	^{210}Pb	^{60}Co
1	Zwan Hotdog sausage	Holland	12.15±3.26	10.32±4.41	46.90±13.81	6.63±0.41	0.95±0.66
2	Minced beef delight	Lebanon	15.85±3.24	13.03±5.07	55.87±16.41	0.05±0.01	BDL
3	Montex Luncheon beef	Italy	15.11±5.72	7.28±3.48	35.49±10.54	BDL	0.99±0.51
4	Ailaaghazah beef hotdog	Lebanon	1.09±0.49	22.23±5.77	64.61±18.88	ND	ND
5	Cattleman corn beef	South Africa	20.99±9.35	6.38±2.69	72.23±21.07	ND	ND
6	CSB sausage	NA	21.24±6.67	25.48±7.54	27.02±8.07	ND	ND
Total	Activity Conc.		**86.43±28.73**	**84.72±28.96**	**302.62±88.78**	**6.68±0.42**	**1.94±1.17**
Mean	Activity Conc.		**14.41±4.79**	**14.12±4.83**	**50.44±14.80**	**1.11±0.07**	**0.32±0.20**
Seafood Products		Country	^{238}U	^{232}Th	^{40}K	^{210}Pb	^{60}Co
1	Milo sardine	Morocco	20.57±5.80	18.78±5.68	54.76±16.10	5.86±0.65	ND
2	Mackerel Geisha	China	23.84±6.79	7.57±3.61	63.63±18.68	BDL	ND
3	Skipper (fish)	Lebanon	27.92±7.86	19.69±6.95	49.90±14.72	ND	ND
4	White Tuna		BDL	18.20±5.56	80.88±23.58	ND	ND
5	Trio Tuna chunks	Thailand	17.42±8.11	16.98±5.59	59.06±17.28	ND	ND
Total	Activity Conc.		**89.75±28.56**	**81.22±27.39**	**308.23±90.36**	**5.86±0.65**	**NIL**
Mean	Activity Conc.		**17.95±5.71**	**16.24±5.48**	**61.65±18.07**	**1.172±0.13**	**NIL**

The results obtained as contained in Table 33 for staple foodstuffs shows a mean activity concentration of 12.33±3.68, 12.35±4.62, 51.48±15.12, 2.65±0.18 and 0.61±0.27 Bq kg^{-1} for ^{238}U, ^{232}Th, ^{40}K, ^{210}Pb and ^{60}Co respectively, while for beef food products, it is 14.41±4.79, 14.12±4.83, 50.44±14.80, 1.11± 0.07 and 0.32±0.20 Bq kg^{-1} respectively, and for seafood products it is 17.95±5.71, 16.24±5.48, 61.65±18.07, 1.17±0.13 and ND Bq kg^{-1} respectively. The overall results indicate that the natural radioactivities in the three categories of canned foodstuffs examined are well below the UNSCEAR and

other International regulatory bodies recommended permissible limits. The presence of ^{210}Pb and ^{60}Co in some samples potent some degree of heavy meter contamination of those foodstuffs. All the five radiological risk parameters evaluated are well below International recommended permissible levels. The computed effective dose rate to essential organs and tissues indicates highest dose of 0.2 mSvy^{-1} is well below the recommended permissible level of 1mSvy^{-1}for the public. The calculated collective effective dose equivalent revealed that 97,463,16 of the total population are exposed to radiation from ingestion of the canned foods with adults most impacted. The total health detriment indicates radiological risk ratio of 1:2238 for infants, 1:2583 for children and 1:4238 for adults. The estimated total cost of health detriment shows that the benefit of consuming the imported canned food products outweigh the health detriment associated with the consumption of the food.

The use of organic and inorganic fertilizers in agricultural practices has continued to make major impact on the levels of natural radionuclides in cultivated soil. These practices have resulted in the transfer and accumulation of radionuclides in food chain above tolerable limit, thus posing threat to human organs and tissues. Ugbede, Osahon and **Agbalagba**, 2021, examined the radiological risk assessment of ^{238}U, ^{232}Th and ^{40}K in soil and their uptake by rice cultivated in College of Agricultural Sciences (CAS) campus of Ebonyi State University. Topsoil soil samples were collected before planting (BP), after planting (AP) and during harvesting (DH) stages and were analyzed for the activity concentrations of the radionuclides using NaI(TI) detector. The activity concentrations of the radionuclides in the soil during the harvesting stage are of significant magnitude than the other stages which follows the order of DH>BP>AP for ^{232}Th and DH>AP>BP for both ^{238}U and ^{40}K. The weighted average activity concentrations of the radionuclides in the rice indicated the order ^{40}K >^{232}Th>^{238}U, which are within bearable limits of UNSCEAR and therefore radiologically safe for consumption. The radionuclides transfer factors indicated higher values for ^{40}K in this order of ^{40}K >^{238}U>^{232}Th, implying higher tendencies of ^{40}K uptake by the rice plant. The evaluated soil radiological hazard indices predicted a radiological risk to exposed farmers only during harvesting.

3.6. Research in Other Areas of Environmental Physics (Environmental Modelling)

In the quest to unearth the mystery of radiation in our environment, we extended our research to other areas in the environment, notably the effects of radiation on the pattern of our building. **Agbalagba,** and Nenuwe, 2018 examined the absorb dose rate conversion factor for outdoor and indoor exposure in typical Nigerian mud houses. The study presents the findings of the absorbed dose rate conversion factors computed for external and internal exposure from sources of ionizing radiations in soil/floors and walls of a typical Nigeria mud houses. Two types of mud houses were considered in the study, calculations were based on the point-kernel build-up factor method

We consider a homogeneous distribution of γ-rays emitters in a medium of constant density ρ_m(gcm^{-3}), the dose rate conversion factor CF_D (r,

$$(CFD\ (r,\epsilon) = \frac{k.\rho m.P(\epsilon)}{4TT}.\frac{\boldsymbol{\mu}}{\rho}(\epsilon)a.\left[\int_v^{\infty}\frac{1}{r2}.\beta(\mu m\epsilon.r_m).exp(-\mu a\epsilon.r_a).exp(-\mu m\epsilon.r_m).dv\right] \quad (29)$$

Where P(ϵ) is the emission probability (s^{-1}Bq^{-1}) of γ-rays with energy E per disintegration of the gamma emitter, μaϵ is the linear attenuation coefficient in air (cm^{-1}), μmϵ is the linear attenuation coefficient in the medium (cm^{-1}), μ/ρ (ϵ)a is the mass energy absorption coefficient in air (cm2g^{-1}), r is the total distance from the source to the receptor (cm), rm is the distance travelled in the medium (cm), ra is the distance travelled in air (cm), β(μmϵ.rm) is the dose build-up factor for the medium, v is the volume of the medium (cm3) and the proportionality constant k =5.04 x 10-3 GygMeV^{-1}sy-1cm3Bq^{-1} (Chen, 1991). Dorschel et al, 1996 build-up factor was used in this calculation i.e.

$$\beta(\mu m\epsilon, r_m) = Ai\ exp\ (\propto_1 \mu m\epsilon.r_m) + (1 - A_i)exp\ (-\propto_2 \mu m\epsilon.r_m) \quad (30)$$

Where P(ϵ) is the emission probability ($s_{-1}Bq_1$) of γ-rays with energy E per disintegration of the gamma emitter, μaϵ is the linear attenuation coefficient in air (cm_{-1}), μmϵ is the linear attenuation coefficient in the medium (cm_{-1}), $\frac{\mu}{\rho}$(ϵ)a is the mass energy absorption coefficient in air ($cm2g_{-1}$), r is the total distance from the source to the receptor (cm), rm is the distance travelled in the medium (cm), ra is the distance travelled in air (cm), β(μmϵ.rm) is the dose build-up factor for the medium, v is the volume of the medium (cm3) and the proportionality constant k =5.04 x 10-3 $GygMeV_{-1}sy_{-1}cm3Bq_{-1}$ (Chen, 1991). Dorschel et al, 1996 build-up factor was used in this calculation i.e. Substituting

$$\beta(\mu m\epsilon, r_m) = Ai\ exp\ (\propto_1 \mu m\epsilon . r_m) + (1 - A_i) exp\ (-\propto_2 \mu m\epsilon . r_m) \qquad (30)$$

The parameters A_i, $\propto_1$ and $-\propto_2$ are not available for soil, but published data for concrete are considered to be a reasonable approximation (Dorsche et al., 1996). The mass energy absorption and attenuation coefficients were obtained from the computations of Hubell, 1982 and ICRU, 1994. CF_D is computed for two different exposure geometries. The outdoor exposure geometry was modeled with a point receptor in air at a height h above a semi-infinite volume of soil (earth floor) containing uniformly distributed gamma emitters. The CF_D was obtained by integrating contributions from volume elements dv_2 with co-ordinations from volume element dv_2 with co-ordinates (r_2, θ_2, φ_2) over the entire soil volume. Substituting $dv_2 = r_2^2 \sin\theta_2 dr_2 d\theta_2 d\varphi_2$, $r_m = r_2 - {}^{h}/_{\cos\theta_2}$, $r_\alpha = {}^{h}/_{\cos\theta_2}$,

The build- up factor and integration limits: ${}^{h}/_{\cos\theta_2}$ to $\propto$ for r_2, 0 to $for\ \varphi_2$, and 0 to ${}^{\tau\tau}/_{2}$ for θ_2 unto equation (30) and integratig over r_2 and φ_2 given as.

$$CF_D(\epsilon) = \frac{k.\rho m.P(\epsilon).\epsilon.}{2}\frac{\mu}{\rho} C\epsilon D_\alpha . \frac{1}{\mu\alpha\epsilon} . \left[\frac{A_1}{1+\propto_1} + \frac{1-A}{1+\propto_2}\right].$$

$$\int_0^{\tau\tau/2} \exp\left(-\mu\alpha\epsilon \frac{h}{\cos\theta_2}\right) . \sin\theta_2 . d\theta_2 \qquad (31)$$

Equation (31) was integrated analytically or numerically to obtained $_DCF$ for the outdoor exposure.

The first building considered for the indoor external exposure in the study is a one room building with cylindrical earth wall (mud) and conical thatched roof as shown in Plate 9. The house is modeled with a vertical annular cylinder of radius R, thickness L and height 2h closed at the lower end (floor) by a solid of infinite depth. The volume element in the wall dv_3 is described in terms of spherical coordinates (r_3, θ_3, φ_3) and Cartesian coordinates (x_1, z_1). It was assumed that both wall and the earth soil (floor) beneath the building are of the same homogeneous materials, the CF_D at height h above the ground along the axis of the cylinder is the sum of contributions from the two media given by.

$$CF_D(\epsilon) = \frac{k.\rho m.p(\epsilon).\epsilon.}{4\tau\tau}\frac{\mu}{\rho}(\epsilon)a\{2I_1 + I_2\} \qquad (32)$$

Where I_1 and I_2 are integrals over the volume elements in the wall and the floor respectively given by:

$$I_1 = \int_{\varphi_1=0}^{2\tau\tau}\int_{Z_1=0}^{h}\int_{x_1=R}^{R+L} \frac{1}{(x_1^2 + z_1^2)} . exp\left(-\mu_{\alpha\epsilon}\frac{R}{x_1}r_1\right) . exp - \mu m\epsilon$$

$$\left(1-\frac{R}{x_1}\right) r_1.\ \beta\left[\mu m\epsilon, \left(1-\frac{R}{x_1}\right) r_1\right].x_1.dx_1.dz_1.d\varphi_1 \qquad (33)$$

and

$$I_2 = \int_{\varphi_{2=0}}^{2\tau\tau} \int_{r_{2=\frac{h}{\cos\theta_2}}}^{\propto} \int_{\theta_{2=0}}^{tan^{-1}\left(\frac{R}{h}\right)} exp\left(\mu\alpha\epsilon, \frac{h}{\cos\theta_2}\right).exp\left[\mu m\epsilon\left(r_2 - \frac{h}{\cos\theta_2}\right)\right].\beta\left(\mu m\epsilon, r_2\frac{h}{\cos\theta_2}\right).\sin\theta_2.d\theta_2.dr_2.d\varphi_2 \qquad (34)$$

The second building considered in the study is also a single room building with cylindrical earth wall (mud) and a dome mud roof as presented in Plate 10. It was modeled with a vertical annular cylinder of radius R thickness L and height h, closed at the lower end (earth floor) by a solid of infinite thickness and at the top by a hemispherical shell of thickness T. Assuming the walls of the roof and the earth soil beneath the building are all of the same homogeneous materials, the CF_D along the axis at height h above the ground is the sum of contributions from the three media given by;

$$CF_D(\epsilon) = \frac{k.\rho m.P(\epsilon).\epsilon.\mu}{4\tau\tau}(\epsilon)a\{I_1 + I_2 + I_3\} \qquad (35)$$

Where I_3 is the integral of volume element dv_3 with coordinates $(r_3, \theta_3, \varphi_3)$ over the volume of the hemispherical roof, while I_1 and I_2 are given by equations (33) and (34) respectively.

$$I_3 = \int_{r_{3=R}}^{R+T} \int_{\varphi_{3=0}}^{2\tau\tau} \int_{\theta_{3=0}}^{\tau\tau} exp(-\mu_{m\epsilon}R).exp[-\mu_{m\epsilon}(r_3 - R)].\beta\left(\mu_{m,\epsilon,} - R\right)\sin\theta_3 d\theta_3 d\varphi_3 dr_3 \qquad (36)$$

Table 34: Dose rate conversion factors for outdoor and indoor external exposure (CF_D) of natural radionuclide

Natural Radionuclide	Conversation factor CF_D (nGyh^{-1} per Bgkg^{-1})			
	UNSCEAR standard	Present work	Present work indoor	
	Outdoor	Outdoor	Indoor[1]	Indoor[2]
^{226}Ra	0.461	0.401	0.442	0.647
^{232}Th	0.623	0.563	0.573	0.799
^{40}K	0.0414	0.0397	0.0423	0.0679

[1]Houses with thatched roof. [2]Houses with mud dome roof

Plate12: A picture showing a mud house with thatched roof.

Plate 13: A picture showing a mud house with mud dome roof

The result of the indoor dose rate in air per unit activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil of infinite depth are 0.442, 0.573 and 0.0423Gyh^{-1} per Bqkg^{-1} for mud walls with conical thatched roof building respectively, and 0.647, 0.799 and 0.0676nGyh^{-1} per Bqkg^{-1} for mud walls with dome mud roof house respectively. The outdoor dose rate in air per unit activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in soil of infinite depth were found to be 0.401, 0.563 and 0.0397 Gyh^{-1} per Bqkg^{-1} respectively. The calculated outdoor dose rates results agreed satisfactorily with results of previous calculations that were based on similar assumptions while the indoor exposure values are higher and differ from one building design and material to another. The study recommends that external dose assessment should be based on conversion factors that take into consideration local (mud) building designs in their calculations.

3.7. Radiation Detector Design and Characterization

In my expedition to know more about the reliability and durability of the materials and equipment use as radiation and radionuclide detectors, we formed a research collaboration with colleagues at Alabama A &M State University, Nonproliferation and National Security, Brookhaven National Laboratory, Upton and Savannah River National Laboratory, Science and Technology Directorate, Aiken, all in the United States of America. The collaboration is to design and characterize detectors for optimal performance, for durability and reliability. This collaboration is yielding positive results with over ten impactful and result oriented publications in international reputable journals and still fostering stronger. Table 35 presents the summary of some of the output of these research collaboration.

in international reputable journals and still fostering stronger. Table 35 presents the summary of some of the output of these research collaboration

Table 35: Radiation and radionuclide detectors design, characterization and performance evaluation

S/N	Authors	Research Title / Publisher	Results obtained	Findings
1	**Agbalagba E.O.,** Drabo M.L., Egarievwe S.U., Roy U.N., Davis A. H., Mordecai B. I., Alexander P.L.,& J Ralph B. J, 2021.	Characterization of CdZnTeSe Nuclear Detector Chemically Etched in Bromine Methanol. *Materials Science and Applications 12: 363-373*	Semiconductor nuclear radiation detectors made from tertiary and quaternary compounds of cadmium telluride (CdTe) can operate at room temperature without cryogenic cooling. Chemical etching is often used to smoothen wafer surfaces during detector fabrication. This paper presents the characterization of CdZnTeSe that is chemically etched using bromine methanol solution. Infrared imaging shows that the wafer has no sub-grain boundary networks that often limit detector performance. The current-voltage(I-V) characterization experiment gave a resistivity of 4.6 × 1010 Ω-cm for the sample. The I-V curve was linear in the ±10 to ±50 volts range. An energy resolution of 7.2% was recorded at 100 V for the 59.6-keV gamma line of 241Am.	We were able to characterized a CZTS nuclear detector that is chemically etched using bromine methanol solution. The infrared transmission imaging result showed that the CZTS crystal has no grain boundary network, and it is mostly free of Te inclusions. This implies that the CZTS matrix does not have defects that could adversely affect the transport of charge carriers. The current-voltage curve is linear in the ±10 to ±50 volts range and gave a resistivity of
2	Drabo Mebougna L. Egarievwe, A.A., **Agbalagba E.O.,** Lagle R.M., Egarievwe S.U., Roy U.N., & Ralph B. J, 2021.	Surface composition studies of CdZnTe material using x-ray photoelectron spectroscopy. *International Journal of Modern Engineering 21(2):40-44*	High-resistivity zinc cadmium telluride (CdZnTe) semiconductor is a very popular material for room-temperature nuclear detection applications. High electronic noise is detrimental to the energy resolution of the detector device. X-ray photoelectron spectroscopy (XPS) technique was used for determining dominant surface composition of a CdZnTe wafer. The experiments involved loading CdZnTe wafers into the XPS machine and recording the peaks of the binding energies of elements and compounds present on the surfaces. The XPS results showed the presence of Zn, Te, O, Cd, C, Cl, Si, and TeO2. These results are important in the engineering of CdZnTe radiation detection devices.	The XPS results showed the presence of Zn, Te, O, Cd, C, Cl, Si, and TeO2. The XPS scans focused on the binding energies in the regions of Cd, Zn, and Te showed that these elements were significantly present, as expected. The XPS scan for Te also showed TeO2 peaks, which is an indication of the formation of TeO2 on the surfaces of the CdZnTe wafers. Future studies to investigate the near-surface compositional variation by using high-speed ions to remove very thin surface layers of the CdZnTe wafer was recommended.

3	Egarievwe U. Stephen, Utpal N. Roy, **Agbalagba E.O.**, Benicia A. Harrison, Carmella A. Goree, Emmanuel K. Savage & Ralph B. J., 2020.	Optimizing CdZnTeSe Frisch-grid nuclear detector for gamma-ray spectroscopy. *IEEE Access 8:137530-137539*	Wide bandgap semiconductor materials capable of detecting X-rays and gamma-rays at room temperature without cryogenic cooling have great advantages that include portability and wide area deployment in nuclear and radiological threat defense, medical imaging, spectroscopy, and astrophysics. A Frisch-Grid configuration helps to solve this problem. This research is focused on optimizing the Frisch-grid configuration for a CZTS detector. The CZTS was grown by traveling heater method. Infrared images of the CZTS matrix largely showed the absence of tellurium inclusions.	The findings from the resistivity of the CZTS obtained from a current-voltage plot is of the order of $10^{10}\Omega$.cm. The charge-transport characterized by measuring the electron mobility-lifetime product is $4.7x10^{-3}$ cm^2/V. Detector resolution was measured for various Frisch-ring widths. For a 4.8 × 4.9 × 9.7 mm3 detector, the best Frisch-ring widths were found to be 3-4 mm. A detector resolution of 1.35% full-width-at-half-maximum was obtained for the 3-mm width at −2300 V
4	Adams1, I.A, Stephen U. Egarievwe U.S., **Agbalagba E.O.**, Gul R., Hossain A, Roy N.U., & James B.R., 2019.	Study of Chemical Etching and Chemo-Mechanical Polishing on CdZnTe Nuclear Detectors. *Journal of Materials Science and Chemical Engineering 7: 33-41 DOI: 10.4236/msce.2019.7800 5*	Chemical etching and chemo-mechanical polishing are processes used to smoothen CdZnTe wafer during detector device fabrication. These processes reduce surface damages left after polishing the wafers. In this paper, we compare the effects of etching and chemo-mechanical polishing on CdZnTe nuclear detectors, using a solution of hydrogen bromide in hydrogen peroxide and ethylene glycol mixture. X-ray photoelectron spectroscopy (XPS) was used to monitor TeO2 on the wafer surfaces. Current-voltage and detector-response measurements were made to study the electrical properties and energy resolution.	XPS results showed that the chemical etching process resulted in the formation of more TeO2 on the detector surfaces compared to chemo-mechanical polishing. The electrical resistivity of the detector is of the order of 10^{10} Ω-cm. The chemo-mechanical polishing process increased the leakage current more that chemical etching. For freshly treated surfaces, the etching process is more detrimental to the energy resolution compared to chemo
5	S. U. Egarievwe, U. N. Roy**, E. O. Agbalagba**, K. L. Dunning, O. K. Okobiah, M. B. Israel, M. L. Drabo, & R. B. James, 2019. "(NSS/MIC), pp. 1-3. IEEE, 2019	Characterization of CdMnTe Planar Nuclear Detectors Grown by Vertical Bridgman Technique." In 2019 IEEE Nuclear Science Symposium and Medical Imaging Conference	Cadmium manganese telluride (CdMnTe) crystals are expected to be homogenous in structure due to the segregation coefficient of Mn in CdTe, which is about 1.0. This could translate in the growth of large-volume CdMnTe crystals free of defects that currently limit X-ray	We presented recent results for a planar detector fabricated from a CMT ingot grown by the Bridgman technique. The development of the CMT took three systematic growth runs that initially focused on reducing Te inclusions, dislocations, and

			and gamma-ray detection efficiencies. The present characterization experiments show results on CdMnTe planar detectors grown by the vertical Bridgman technique. The CdMnTe crystal used in the experiments was mostly free of tellurium inclusions and high angle grain boundaries.	sub-grain boundary networks that often plague CdTebased semiconductors. These problems and related defects were greatly reduced by the second growth run and detector-grade CMT was obtained in the third growth run. One of the reasons for the quick success is the compositional uniformity exhibited by CdMnTe due to the segregation coefficient of Mn in CdTe matrix being ~1.0. Crystal growth expertise and knowledge from studies on optimization of the ampoule carbon-coating in CZT, where the optimum coating was found to be 0.2 μm, also contributed to our success. Future studies will focus on chemical passivation of CMT surfaces
6	A. L. Adams, M. L. Drabo, S. U. Egarievwe, **E. O. Agbalagba** J. O. Jow, Alexander A. Egarievwe, Utpal N. Roy, & Ralph B.J,. 2016.	"Batch annealing of CdMnTe wafers for nuclear detector applications." In 2016 IEEE Nuclear Science Symposium, Medical Imaging Conference and Room-Temperature Semiconductor Detector Workshop (NSS/MIC/RTSD), pp. 1-3. IEEE.	Post-growth annealing is used to eliminate performance-limiting Te inclusions and related defects from cadmium manganese telluride (CdMnTe) wafers for nuclear detector applications, which could cause problems in applications that require large-volume detectors, where they trap charges that are generated by nuclear radiation. We carried carried out batch annealing of three CdMnTe wafers in different ampoules at the same temperature of 720 °C using a three-zone furnace. The experiment compared annealing in tellurium (Te) vapor, cadmium (Cd) vapor, and a mixture of cadmium and tellurium (Cd-Te) vapors. For the samples annealed in Te and Cd-Te vapors, it appears that Te deposited on their surfaces. This limited the imaging of the inside of the wafer since Te is opaque to infrared light. The infrared imaging of the matrix of the wafer annealed in Cd showed that the sizes of tellurium inclusions were reduced.	The batch annealing of three CdMnTe wafers in different ampoules with Te vapor, Cd vapor and Cd-Te vapors enabled us to anneal the samples under the same temperature and pressure. However, the samples annealed in Te and Cd-Te vapors had Te deposited on their surfaces. The most probable cause for this is the sudden cooling of the ampoules after annealing at very high temperature of 720 °C. The observed reduction of the sizes of Te inclusions in the CdMnTe wafer annealed in Cd vapor resulted from the combination of Cd with excess Te to form CdTe crystalline material and the diffusion of Te to produce smaller sizes for Te inclusions. In future

				experiments, we plan to use lower annealing temperature and slower cooling rate for the ampoules after annealing. We also plan to study the change in the resistivity of the CdZnTe wafers in relation to annealing period.

3.8. Environmental Monitoring and Assessment for Noise and Non-ionizing Radiation

I will not end this inaugural lecture without making mention on my research imprint in non-ionizing radiation assessment and monitoring and noise pollution in our society. Non- ionizing radiation as earlier defined and discussed are less lethal compare to ionizing radiation, however their effects on man from the omni-directional radiation and man's exposure to it is now becoming a great concern to researchers and radiation experts. The already established physiological and biological effects of non-ionizing radiation is something that should be of concern. Some research bodies and organizations are questioning previous results findings exculpating non-ionizing radiation sources from the deleterious effects, most crucially from accumulative effects. They have published clinical reports that have linked some radiation related sicknesses to non-ionizing radiation. However, I will restrict my lecture here to my contributions to the data base of non-ionizing radiation research not to contradict Physics laws, and theories and global radiation recommended permissible limits until proven otherwise. Table 36 present some of my noble research work in this direction and notable findings.

Table 36: Environmental monitoring and assessment for noise and non-ionizing radiation

S/N	Authors	Research Title/ Publisher	Summary	Findings
1	Chiedu S.N., **Agbalagba E.O.**, & Avwiri G.O., 2021.	Noise Pollution Assessment of Selected Junctions in Warri Metropolis and Its Environs. *International Journal of Innovative Environmental Studies Research* 9(4), 27-39	This research work presents the characteristics of noise levels in some strategic locations within Warri and its environs. An MS6701 Digital Sound Level Meter of range 30-130 dBA, and a Geographical Positioning System (GPS) was employed to measure the noise level at 40 strategic locations (T-junctions) and ascertain the location coordinates within the study area for six days (morning and evening periods). The results obtained were validated using the Microsoft Excel, SPSS, and QGIS software and the output was used in generating a noise map of the study area. The n-percent exceedance level (L10 and L90), The Analysis of the empirical results revealed that the noise levels of the study area was relatively high with value range of 67 dBA to 85.01 dBA	The values of noise levels measured at the selected junctions which range from 66.10 dBA – 88 dBA with NESREA and WHO standards (55 dBA), indicates that the measured values were above the standard limits for residential areas but within limits for commercial areas except for a few locations. With the level of traffic noise measured, there is need for the redesigning of Warri city and its environs to re-classify the areas

			for the morning and 66.10 dBA and 88 dBA for the evening period. The results obtained were validated using the Microsoft Excel, SPSS, and QGIS software and the output was used in generating a noise map of the study area. The n-percent exceedance level (L10 and L90), Traffic Noise Index (TNI) and the Noise Climate (NC) values were calculated for both morning and evening periods.	that should be designated as residential/schools, commercial and industrial to avoid noise pollution impacts that may be detrimental (hearing impairment) to residence and reading and learning inhibition of pupils of schools close to these junctions.
2	Avwiri G.O., & **Agbalagba E.O.,** 2015.	Examining the EMF exposure effects of GSM mast antennas and high-tension electric cables on the environment of Delta Park of University of Port Harcourt, Rivers State. *Journal of Multidisciplinary Engineering Science and Technology 2(11): 2936- 2939* Germany	The radiofrequency field strengt measurement in the study was aimed a determining the level of non-ionizing radiation (emf) that may have impact the Delta Park environment and residence as a result of the cluster of GSM ba stations (mast) in the campus and th high-tension overhead cables th crisscross the area. An *insitu* measurement of power density w conducted over the entire Delta Pa using a radiofrequency (RF) field strength meter and the SARS values comput The values obtained ranged betwe 0.31288µ/cm^2 (0.683x10^{-5}w/kg) to 0.29 µ/cm^2 (6.64 x 10^{-5}w/kg) with a mean value of 0.13 x 10^{-5}mw/cm^2 (2.89x10^{-5} w/kg).	The impact of the radio frequency (RF) radiation from GSM masts and high-tension cables on the residents of Delta Park, University of Port Harcourt has been conducted. The following conclusions was reached. (i)The investigation revealed that the radiation level of the GSM mast and the high-tension cables combined is low and well below international permissible limit for the public. (ii)These values of radiation obtained will not cause any significant biological or physiological health side effects on the resident of Delta Park. But caution must be taken against further installation of more GSM mast as this may result in RF field radiation build-up,

				which may have some further (long term) biological and physiological effects on the public and the residents of the area. (iii)The Delta Park's environment therefore meets all the international guidelines on non-ionizing radiation.
3	Avwiri, G.O., Avwiri, E., & **Agbalagba, E.O.,** 2009.	Investigation on the RF Radiation Power Density Delivery of inactive and active call operations of some makes and models of GSM mobile phone in Nigeria. ***Scientia Africana*** *International Journal of Pure and Applied Science 8(1): 75-80,*	The radio frequency power density delivery of active and inactive call operations of selected GSM handsets and their radiation impact on the users were investigated using a rediofrquency field strength meter. Thirty-one different models were used for the investigation. The measuring meter was place 1cm away from the handset during calls and off call period. The results obtained from the inactive call operation mode ranged from 0.012$\mu W cm^{-2}$ in Nokia 3120 to 0.060$\mu W cm^{-2}$ in Sony Ericsson w610i. The active call operation mode values range from 1.30 $\mu W cm^{-2}$(0.286 $mW kg^{-1}$) in Nokia 6260 to 19.20$\mu W cm^{-2}$(4.224 $mW kg^{-1}$) in Samsung SGH700. The results of the comparison of the inactive and active mode operation of the GSM handsets show a variation range of 1.4% to 35.6%	The values results obtained in the assessment of the radiation performance of the different GSM handsets during call (active) and off call (inactive) operational mode of the sets are well within the permissible limit for the public on the use of GSM handsets as given by ICNIRP for the safe use of the products. The paper however recommended caution against the use of the phone for a longer time to avoid a build up to avoid accumulative effects on the users.
4	**Agbalagba, E.O.**, Diemuodeke, E.O & Momoh, O.L.Y., 2009.	Radiofrequency impact of GSM mast antenna on the Background Non-ionizing Radiation (BnIR) levelsof Yenagoa City, Bayelsa State Nigeria. *Nigeria. Journal of Space Research6: 63-74*	The study examined the impact of the scattered GSM mast clusters in Yenagoa on the residence of the city. An-situ measurement of the power densities twenty functional stations and the estimation of transmission frequency using Radiofrequency (RF) field strength meter. The results of the power density value obtained ranged from 0.151$\mu W cm^{-2}$(33.22 $\mu W kg^{-1}$) to 1.1694$\mu W cm^{-2}$(372.68 $\mu W kg^{-1}$), while the estimated transmission frequency values ranged from 105.83MHz to 2136.7MHz which shows a wide deferential	The values obtained show that the GSM mast installed inYenagoa are all well below the International permissible limits for the public.But violate the NCC guideline on Mast and Base station proximity to residential building, which the researcher reported that can cause havoc on incident of mechanical failure

4. ACKNOWLEDGEMENT

Psalm 127:1 “Except the Lord build the house, they labour in vain that build it: [and] except the Lord keep the city the watchman waketh but in vain” (KJV). Thus, I owe all I am today and all I will ever become tomorrow if Christ tarry to the mercies of God. I attribute all honour and glory to the all knowing and Almighty God.

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Mr. Vice Chancellor sir, I have a rare privilege to be bless with my immediate family whose love and cooperation is a reflection of my productivity in my job description. I thank my children Joan, Joel and Joyce for their love and understanding.

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5. CONCLUSION AND RECOMMENDATION

5.1. Conclusion

Mr. Vice Chancellor sir, from this one-hour lecture, my esteemed audience will convincingly agree with me that radiation abound in our environment, from the cosmic, to terrestrial, to the food we eat, the air we inhale, to the drugs we take, to the medical facilities we submit ourselves to, for examination, to the workplace and to the occupation we engaged in. Thus, I can safely conclude that radiation rain. The abuse or misuse of this raining radiation in our environment can and have cause irreparable damage to many in our society, like cancer, erythema, leukemia, cataract, skin burn, organ failure, nausea and vomiting, weakness etc., it will be proper therefore to affirm that radiation can ruin. However, we cannot make any meaningful development in the present technological era, if we must avoid the use of radiation aided equipment, materials and facilities. The advancement in the medical industry today has resulted in 45% treatment of sickness and diseases is driven by radiation and radioactive ladened equipment and it is projected that by the year 2050, it will be 80% driven. The scanners at the air and sea ports are radioactive material, the food preservation industry and agricultural revolution we are witnessing today is currently driven by radiation, genetically modified organisms (GMOs) are all radiation induced products. The world powers, military last joker in any warfare is the nuclear missile (radiation), thus my audience again will agree with me that radiation reigns, while man will continue to be at the epic center (ring) of the radiation rain.

Vice Chancellor Sir, at the 79th in the series of inaugural lectures of the University of Port Harcourt delivered by erudite Prof. Gregory O. Avwiri and titled "Radiation: The Good, the Bad and the Ugly in our Environment" (Avwiri, 2011), the lecture admonished that the safety of our environment (man, flora and fauna) is a collective responsibility of all. Twenty years down the road of my academic research journey, I have come to the same conclusion and agree with him absolutely (scripta manet).

Sir, my research work in Physics all these years are largely on Environmental radiation and health Physics, with the Niger Delta people and environment in focus. I have encountered the good, the bad and the ugly of our environment from my research expedition in radiation. But as a founding member of Nigeria Society of Radiation Protection (NSRP) and affiliate member of the International Radiation Protection Association (IRPA), whose aim is to inculcate radiation safety culture and awareness on citizenry. I have jealously tailored most of my research works to fulfil the objectives of my profession and professional affiliations.

My research voyage from this lecture have been on radiation and radionuclides assessment in; the oil and gas facilities, host communities, on workers and their deleterious impact, radiation mapping in all the major cities and some rural communities in Delta state and part of Edo state, radiation and radionuclides in soil, water, sediments and sludge. I have also in the course of the lecture revealed the indebt investigations on radiation burden in solid mineral and within their mining environment, works on the impact of radionuclide contamination of the food chain on the quality of foodstuffs we consume and its radiological health implication on man with other environmental research in noise GSM mast, and cell phones.

Mr. Vice Chancellor sir, I have empirically come to the following conclusion from the intense and concerted research efforts in radiation detection and protection around the Niger Delta Region and beyond;

The radiation burden occasioned by the activities of crude oil exploration and exploitation companies within and around oil facilities in the Niger Delt region is on the redline. Urgent measures to avoid near future radiological health hazards on the field workers and the host communities need to be taken.

The radiation status of our major cities, metropolis, towns and villages are being influenced by various radiation induced activities, but their current levels are still within tolerable limits. Therefore, serious radiation awareness campaign and advocacy is needed to create the desired consciousness for radiation optimization for minimum dose uptake.

The solid mineral mining environments have been found to be radiologically contaminated due to minerals that are naturally ladened with radioactive materials. The mining environments are therefore not radiologically safe to build permanent residential buildings. Government needs to come up with building policy in solid mineral mining environment/ area to protect citizens from excessive exposure from radiation and timing optimization and shielding for occupational workers.

Our communities, villages, cities, and metropolis soil and sediments are found to be radiologically safe for use as building and construction material in all our studies, but areas with spark values need to be closely monitored.

Soil to crop transfer factor studies have shown that the uptake of radionuclides by crop from our arable soil. Therefore, the high NORM presents in some of our staple food samples is traceable to application of fertilizers, cultivation of legacy radioactive dump sites and cosmic ray.

Major staple food products and beverages in Nigeria market contain some degree of radioactive material but the level is worrisome in imported food stuff. NAFDAC need to have closer radioactivity content monitoring and regulation on imported food stuff.

The radiation effects from GSM masts, base stations and GSM phone have been found to be thermal, and physiological as against the cancer effects proponent in some quarters.

5.2. Recommendation

In these two decades of my intense research works, we have use environmental radiation assessment and monitoring as an indicator to monitor climate change, and to caution and canvass for greener environment in the Niger Delta. In the process, the level of capacity building has been boasted with the supervision of twelve Masters' degree students, five PhD students as at today. Putting it differently, the mentored have become a mentor, this is the beauty of academics. However, sir, a constant monitoring of all the environmental indicators for greener and safer environment for ambient and better world order can only be achieved through conscientious and regular monitoring of radiation in our environment. For an indebt radiation monitoring of the Niger Delta environment and Nigeria as a nation, government need to as a matter of urgency deliberately invest in radiation research and fund education adequately. No matter how beautiful and innovating scientific research findings may be, if government and the private sector do not play their role as regulator and end users of such findings, most of our ground-breaking research results will only continue to rot on the shelves. Government must therefore provide the enabling encouragement and compel the already established companies and multinationals to channel resources toward R & D in the country, as obtainable in develop countries of the world.

My Vice Chancellor Sir, may I use this opportunity at this peak of my lecture to call for the establishment of a Centre of Excellence for Radiation Protection and Research in Federal University of Petroleum Resources Effurun. This Centre when established will serve as a Central Laboratory for radiation research and hub for analysis of samples for the oil and gas industry and allied industry which hitherto are been ferry to Zaria, Ibadan and Ife for such analysis. It will also guarantee the integrity of our sample which we do send to these existing centers. Thus, if established will on the short, medium and long term reposition our research laboratories for in-depth research, fulfil the mission of the University to service the oil and gas industry and will be a third stream of income to the University.

Mr. Vice Chancellor Sir, haven in my research quest, transverse the atmosphere, the terrestrial

environment, the hydrosphere and the lithosphere for radiation and nuclear safety and protection, it is my firm conviction to draw this curtain by saying that I have carve a niche for myself in environmental radiation, health and nuclear Physics, with utmost feeling in me that I have contributed to knowledge by solving societal problem in my chosen field and my Professorial promotion was not in error.

I thank you all for coming.

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