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Effects of Radionuclides in Aquatic Lives of Nigerian Coastal Rivers: A Review

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ABSTRACT

The Nigerian Coastal waters have a spectrum of radionuclide emanating from primordial existence of radiating particles such as uranium-238, thorium-232, potassium-40, and Ra-228. These naturally occurring radioactive elements are unstable. However, radioactive emissions such as such as 137Cs, 131I and 90Sr can also be produced artificially. There are basically three types of radioactive emissions namely: alpha, beta and gamma particles. Radioactive elements possess nucleus which are made up of certain number of protons and neutrons. These undergo nuclear disintegration to achieve more stable nuclides. Following the exploration and exploitation of crude oil particularly in the Niger Delta region, radionuclides have been copiously released into the Nigerian coastal Rivers. The vagaries of these substances have impacted adversely on the survival of its aquatic fauna and flora. Ionizing particles cause biological damages such as cell death, cancer, membrane and DNA destruction, oxidative stresses, destruction of aquatic organisms and of aquatic trophic chains and webs.

Keywords: *Radionuclide, effects, coastal rivers, aquatic life*

INTRODUCTION

Radioactivity is the sudden emission of radiations by charged particles into the environment. It is caused by the disintegration of unstable nuclides with varying protons, neutrons into stable nuclides (Balakrishina *et al*., 2007). Radionuclides are ubiquitous in the environment in varying amounts (Olomo, 1990; Linsalata, 1994; Ciezkowski and Przylibski, 1997; Cochran, 1999; Chau, *et al.*, 2001; Hakonson-Hayes *et al.*, 2002). However, activities connected with harnessing of geological resources can also cause the concentration of natural radio nuclides. This can be seen during cases of minerals, oil and gas exploration, and the production of phosphate fertilizer. These processes have to a large extent increased the concentrations of naturally occurring radioactive isotopes in the environment (Tayibi *et al*., 2009).These humanly and technologically enhanced activities also enhances the rediatribution of radioactive isotopes in the environment by both physical and biogeochemical processes (McDonald, 1996).

Radioactive emissions are broadly employed globally most especially in agriculture, nuclear weapon testing, medicine and industries etc., (Larmash 1983). However, radionuclides exist naturally in diverse concentrations. Some of the naturally occurring radioactive emissions include: 238U (T1/2 = 4.468 × 109 y) and 232Th (T1/2 = 1.405 × 1010 y), potassium-40 (40K), radium-226 (226Ra), polonium-210 (210Po), and lead-210 (210Pb), (Ademola and Ehiedu, 2010; Babatunde *et al*., 2015). An increased level of radionuclides (e.g. uranium, thorium) and their associated particles have been reportedly present in areas that are deeply enshrined with natural radioactivity as well as anthropogenic activities. However, Wagner (2010) reported that there are three major sources of ionizing radiation: natural radio nuclides, cosmic radiation and artificial radio nuclides. Natural radio nuclides, e.g. uranium, thorium and their daughters, were formed at Earth´s origin. Cosmic radiation originates outside the Earth. Since the beginning of the atomic era, a number of radio nuclides have been produced by man and released into the environment.

Natural radio nuclides occur in different concentrations across the various components of the earth (Khandaker *et al*., 2015). Contrarily, anthropogenic activities have also immensely contributed to the artificial radionuclides in the aquatic ecosystems. Some of these activities include the release of radioactive wastes from extractive industries, burning of fossil fuel, production of radionuclides for medical and industrial applications, offshore oil and gas exploration, operation of power plants, and nuclear accident catalyzes the degree of radioactivity in aquatic ecosystem (Khandaker *et al.*, 2015). Studies have revealed that primordially existing radioactive isotopes such as thorium, uranium and potassium decay series in water bodies generates indications of these pollutants in the aquatic ecosystem (Khandaker *et al.*, 2015). Animals also easily transfer these radionuclides to man when consumed (Hong *et al.,* 2001). Naturally occurring radionuclides in the environment are complemented by the artificially generated particles that are being harnessed during various industrial, medical, and nuclear explosion fallouts etc (Larmash 1983).

The existence of radonuclides in any environment is directly or indirectly linked to either natural or artificial sources. The artificial sources chiefly exist as a result medical and industrial operations. In the coastal regions of Nigeria, the major industrial outfit is the oil exploration. Away from medical exposure, the petroleum industry is the biggest importer and consumer of radioactive substances. The uses of radioactive materials in the industry stretches across both upstream and downstream operations which include pipeline leakages, drilling operations, well-logging, automated ionizing radiation gauge, radiography and application of radiotracers in oil well management (Olatunde, 2011).

In Nigeria, evaluation of the radionuclides in the coastal rivers is a recent development and is pivoted around the distribution of natural radioactive isotopes in sediments, soils, surface water and other aquatic consumables around oil and gas producing areas, mining areas and important inland water bodies (Jibiri *et al.*, 2007). There are scanty documentations on the trend of radioactivity in the coastal rivers of Nigeria. Some of the available information includes Dublin-Green, 1988; Ajayi, 2008; Ademola and Ehiedu, 2010; Omale *et al.,* 2014. The Niger Delta region reportedly produces over 90% of Nigeria's foreign exchange and incomes through oil and gas exports. However, it is being heavily impacted with pockets of environmental pollution, such as heavy metal and petroleum contamination as a result of oil and gas exploration and exploitation, industrialization and urban development; these have collectively affects its ecological status over the years (Akpomuvie, 2011).

Structure and Nature of Atom, Isotope and Radiations

Atoms are is smallest particles of matter. An atom is primarily made up of a nucleus having protons and neutrons, surrounded by electrons (Goel, 2010). The nucleus houses the total mass of an atom while the electrons are generally weightless. The proton is generally referred to as the atomic number of any element in nature. However, isotopes are elements that have similar atomic number but different mass numbers. Examples of elements which are isotopes in nature are carbon – 12 and carbon – 14 Chlorine=35 and chlorine 37, isotopes of an element possess similar chemical reaction as their stable atoms because of their similarity in atomic number or number protons (Goel, 2011). Relatively, radioactive isotopes have a large number neutrons and unstable nucleus which tries to become stable by releasing radiations of various kinds this causes a breakdown of the original atoms by the process of nuclear fission thus the formation of radionuclide This is measured by the high life i.e. the time taken for 50% of the total atoms to decay (Goel, 2011).

TYPES OF RADIATIONS

Radio-nuclides presumably possess similar chemical properties as their stable isotopes, except for their difference in mass (Santschi and Honeyman, 1989). However, there three types of radiation, namely:

- Alpha(α) radiation
- Beta (β) radiation
- Gamma(γ) radiation

Alpha (A) Radiation

These are radiations that are made up of two protons and two neutrons which are combined in the form of a particle (Goel, 2011). They are positively charged helium atoms (or nucleus of a helium atom) with a mass number of 4.

Alpha radiation (α) has a positive charge, short range and only penetrates organisms from their outside to a small degree. Internal alpha radiation may cause damage. Alpha particles are characterized by high energy loss in relation to transport distance, and therefore give high ionization density along the paths the particle is moving. Alpha particles have high linear energy transfer (LET) and therefore have greater potential to damage cells and tissue structure in living organisms than types of radiation with low LET (Goel, 2011).

Alpha particle emission is associated with a reduction of mass member by 4 and atomic number by 2. e.g. Radium – 226 is transformed into radon – 222 by an alpha particle emulsion.

$$^{226}_{88}\mathrm{Ra} \qquad ^{22}_{86}\mathrm{Rn} + \; ^{4}_{2}\alpha + \gamma$$

They have a weak penetration power. However, they are very deleterious when released by ingested reactivation emitters. This is because they cause a strong ionization in biological molecules. They also move slowly. Alpha particles can also be stopped by thin materials (Pandey, 2010)

Beta (B) Radiation

Beta radiations are basically made up of electrons as the particles are emitted when a neutron is transformed into a proton by releasing negatively charged particles (i.e. electron causes an increase in atomic number by one with no increase or decrease in its mass number (Norse, 2006). Beta radiation (β) consists of free electrons with high velocity and energy; has a greater range than alpha particles and can penetrate skin. However, it has a much lower LET than alpha radiation. (Norse, 2006). Radioactive elements are not degraded in the environment and will emit radiation regardless of which other chemical components are being formed by them. Radioactive nuclide possesses the chemical properties characteristic for each individual element, and the fate of an individual nuclide will thus be determined by the element chemical properties (IAEA, 2008).

E.g. shuntium-90 and Xeron – 139 are transformed into Yttrium – 90 and Cesium – 139 respectively following the release of a par beta particle

$$^{90}_{38}\mathrm{Sr} \longrightarrow \; ^{90}_{39}\gamma + \beta$$

$$^{139}_{54}\mathrm{Xe} \longrightarrow \; ^{139}_{55}\mathrm{Cs} + \beta + \gamma$$

Beta radiations are also negatively charged but of higher penetrating power than alpha rays (Abowei and Sikoki, 2005). They possess a lower ionization than alpha particles due to their lower mass.

Gamma (ϒ) Radiation

Gamma radiations are possess no mass (Goel, 2010). They are electromagnetic and are transmitted at the speed of tight. They have the highest penetrating power of all the radioactive radiations (Abowei & Sikoki 2005). Gamma radiations are usually accompanied is usually release of alpha and particles. They have a small wave length of range 10-11 to 10-17cm. hence these have a greater energy into penetrating power. Their gamma radiation has a high tendency of ionization and is seriously destructive to biological materials.

Entry Routes of Radioactive Particles to the Aquatic Ecosystem

Radioactive pollutants enter the aquatic ecosystem through five principal paths; they food, non-food particles, gills, oral consumption of water and the skin (Heath, 1991). In the aquatic environment, radionuclides are transported and taken up by biota in a similar way to their stable element analogues. If stable and radioactive isotopes of a particular element have the same chemical form, they are thought to be indistinguishable to organisms (Sazykina 2003). Furthermore, industrial anomalies such as mishandling of equipment, improper discharge, loss and theft, radioactive materials of natural and artificial origins may find their ways into the terrestrial and the aquatic environment of the coastal localities and pollute mainly the networks of rivers and creeks. Additionally, some natural pathways such as erosion run-off and rainfall also enhance a huge influx of large amount of these radioactive substances into the aquatic environment which may be detrimental to the aquatic biota and man at the later end (Olatunde, 2011).

Due to their radioactive properties, many nuclides have important applications as indicators of the time- scales of various oceanic processes, such as water mixing and sediment accumulation. Interaction of dissolved material with sediments is an important factor in influencing the pathways of radioactive nuclides in estuarine and coastal waters. Because of the often complex patterns of transport, deposition and re-suspension of sediments and the process of sorption and description which may occur, settled sediments may frequently remove a considerable fraction of some nuclides, causing a reduction in concentration in solution and reducing availability to many organisms. But these are circumstances where associations with particulate material may increase uptake in some food chains, (Li, 1971). Relatively, benthic algae highly accumulate radionuclides due to the absorptive nature of their coating which protect them from physical damage and desiccations. Active transport and direct exchange of radionuclide with water occur in order to maintain homeostatic concentration of a number of radionuclides in tissue (Ademola and Ehiedu, 2010).

The Nigerian Coastal Areas

Nigeria is bordered to the North by the Republics of Niger and Chad, to the West by the Republic of Benin, to the East by the Republic of Cameroon and to the South by the Atlantic Ocean (Dublin Green *et al.*, 1999). It has a coastline of approximately 853km facing the Atlantic Ocean. This coastline lies between latitude 4° 10’ to 6o 20’N and longitude 2° 45’ to 8° 35’ E. The terrestrial portion of this zone is about 28,000 km^2 in area, while the surface area of the continental shelf is 46,300km^2 (Nwilo and Badejo, 2011). The Nigerian coast (Fig.1) is composed of four distinct geomorphology units namely the Barrier-Lagoon Complex; the Mud Coast; the Arcuate Niger Delta and the Strand Coast (Nwilo and Badejo, 2011).

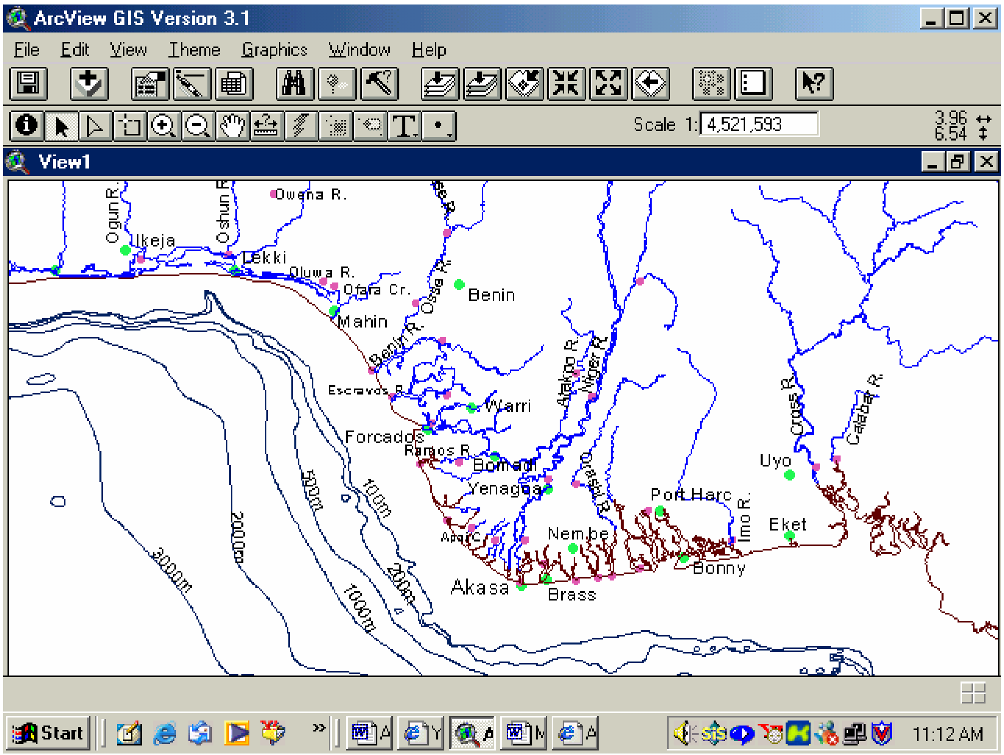

Figure 1. *Map of Nigerian Coastal Areas*

Source: *Nwilo and Badejo (2011).*

Effects of Radionuclides on Aquatic Lives in Nigerian Coastal Rivers

Ionizing radiation causes myriads of biological damage in aquatic biota (Table 1). It may occur by cells dying or developing into cancer cells, but also by damaging DNA; these eventually affects the future generations (Parret, 1998). The potency of radioactive emission is a function of the amount of energy that it is absorbed by the organism and depends on which radionuclide, the type of radioactivity, its chemical form, the route of exposure and the organism’s biochemistry (Polikarpov, 1998). The uptake and concentrations of natural radionuclide is much larger between different species and trophic levels in the food chain than between different geographic regions (Aarkrog, 1997).

Gamma radiation also interacts with water molecules, leading to the formation of radicals that cause damage to cellular membranes (Aquino, 2012). In human cell lines, an increase of reactive oxygen species (ROS) upon gamma irradiated treatments leads to decreased caell viability (Dal- Pizzol *et al.*, 2003). Gamma rays also cause Oxidative stress-induced defense mechanisms in diverse organisms such as plants, fish, polychaetes, and zooplankton (Rhee *et al.*, 2012). In aquatic vertebrates, a primary defense mechanism is antioxidant enzymes. In the killifish, *Kryptolebias marmoratus* embryo, hatching inhibition and development impairment is associated with an increase of ROS and antioxidant enzymatic activities (Rhee *et al*., 2012). This suggests that gamma radiation induces strong oxidative stresses. *K. marmoratus* can operate a global antioxidant defense system to cope with cellular stresses induced by gamma irradiation.

Table 1. *Effects of Radionuclides on Aquatic Biota and Humans*

Radionuclide	Effect	Target Organ/Organisms	Source
226Ra and 228Ra	Radiotoxicity and oversensitivity of organisms/man	Body organs	UNSCEAR (1993)
210Po	acute radiation syndrome and burns, induction of cancer	Liver, Kidney and other body organs	USEPA (2011).
226Ra and 228Ra,	heart disease, reduction in cognitive ability, radiation-induced thyroiditis, radiation burns, acute and chronic radiation syndromes	Body organs	USEPA (2011).
210Po	Death, failure of bone marrow, destroy kidneys and liver	Bone marrows, kidney and other organs	Edwards and Lloyd, (1996); Harrison *et al*. (2007)
Radium-226 and lead-210, polonium-210, α particles.	Deformed spleen, kidney, liver, and the lymph nodes, lung cancer	Lungs, bones, spleen, lymph nodes etc.	Yoon *et al*. (2010); Zaga *et al*. (2011)
Uranium-238,	Disruption of aquatic trophic links	Plankton and benthos	Aarkrog (1997)
Potassium-40	Malfunctions of cellular functions in living organisms	Benthos	Aquino (2012)
Thorium-232,	Sudden death of organisms	Plankton, benthos and fish	Rhee *et al*. (2012).

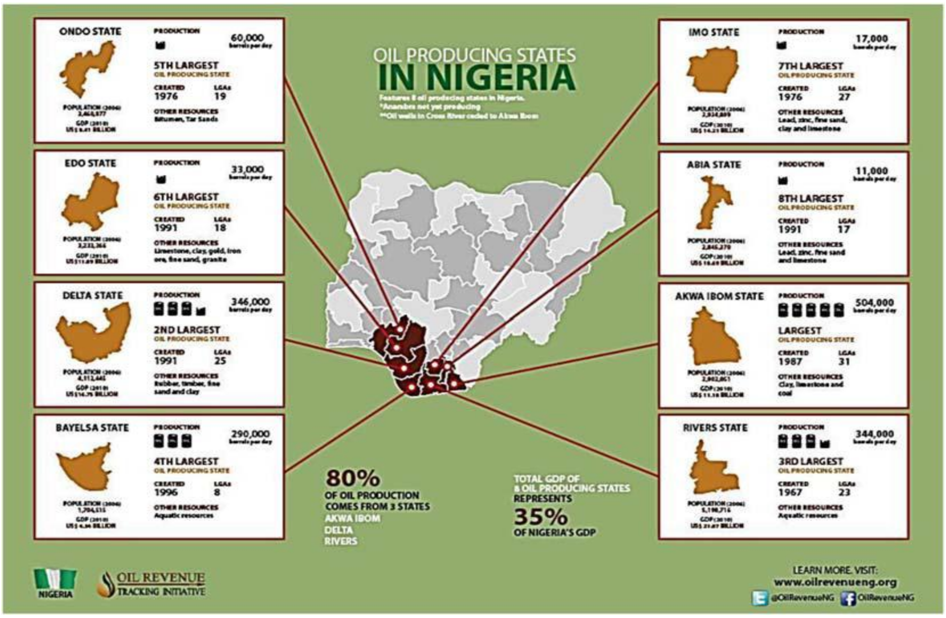

Figure 2. *Nigeria's oil-producing states*

Source: *Oluwaseyi et al. (2018)*

INTERACTION BETWEEN OIL EXPLORATION AND EXPLOITATION AND RADIOACTIVE EMISSION IN NIGERIAN COASTAL STATES

Oil production is the arrow-head of industrial activities in the Niger Delta region of Nigeria (Fig. 2). This takes place on virtually daily basis (Odiete, 1999). It has also constituted the region as one of the most polluted localities in the world (UNDP, 2006; Zabbey, 2009; Kadafa, 2012). An estimated volume of about 2000 m^3 of oil is allegedly reported as annual oil effluent discharged into the Niger Delta environment

(Anderson, 2005). The amount of crude oil spillage in the Niger Delta (Fig. 3) between 1976 and 2010 is estimated to be about three million barrels (Amnesty International, 2011). During the process of spillage, exploration and exploitation, certain radionuclides are being released into the environment which at the long run finds their ways to the aquatic ecosystems of the region (Personal communication).

Certain radionuclides including Uranium and Thorium can be found freely in nature in the earth's crust. However, quite a number of them are emitted during the process of crude oil exploration via artificial bombardments, or simply put, natural transmutation. These artificial radiations can also be released into the environment as byproducts or waste products of geothermal energy production (Vincent-Akpu *et al.*, 2018). Naturally occurring elements

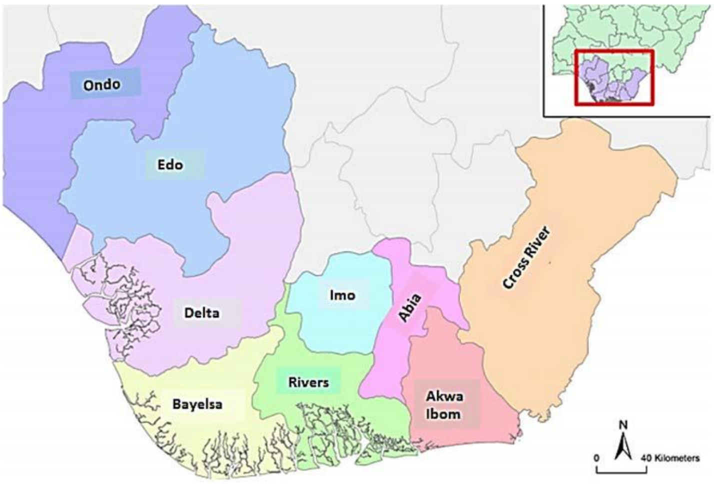

Figure 3. *Map of the Niger Delta States of Nigeria*

Source: *Sylvester et al. (2018)*

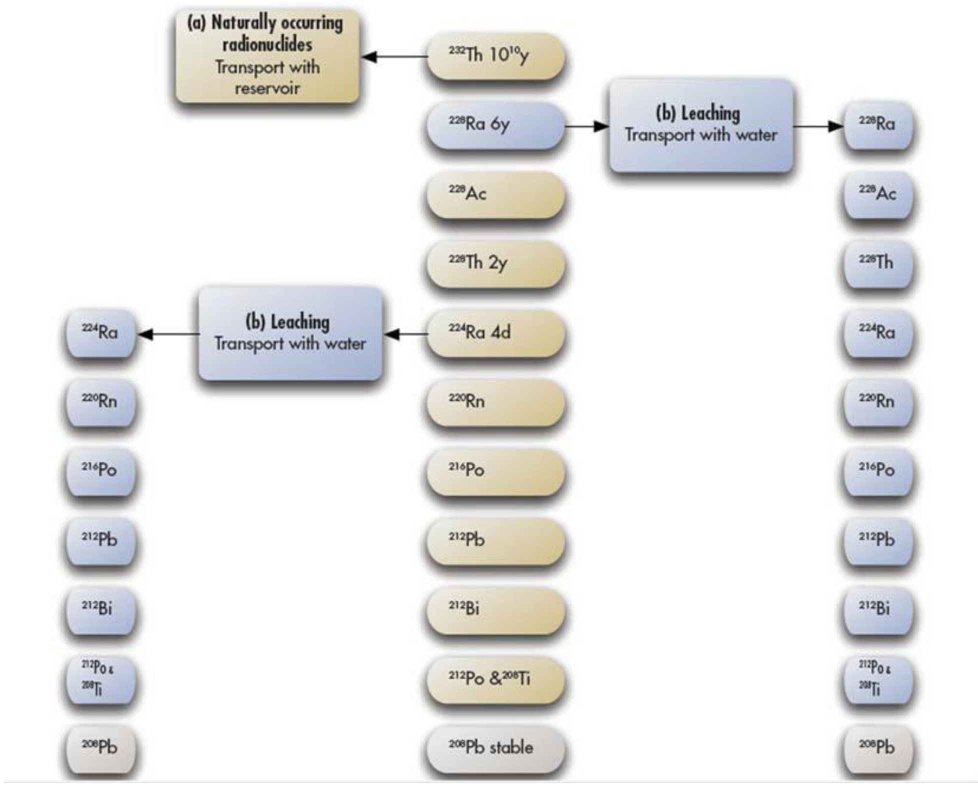

Figure 4. *Thorium-232 decay series showing radionuclides associated with oil and gas production.*

Source: *Vincent-Akpu et al. (2018).*

such as Radium-226 flow alongside crude oil waste, drilling fluids, wellheads and pipes during the process of crude oil drilling. In the process, the same equipment is used from one site to the other which eventually enhances the dispersion of radionuclides.

These radioactive elements further undergo decay series which eventually emit various breeds of radionuclides in our ecosystem. For example, the disintegration of Uranium and Thorium (Fig.4) emits Radium-226, Lead-210, and Radon-222, which accompanies the transportation process of oil and gas products in their recovery process (Vincent-Akpu *et al.*, 2018).

CONCLUSION

Radionuclide inconvertible and non-biodegradable radiations that constitute huge threat to aquatic lives in Nigerian coastal waters because of the diverse range of damages they cause on the aquatic biota. These damages are biomagnified and eventually more destructive to man on consumption of these aquatic potentials. They emanate from natural sources which are supplemented and complemented by anthropogenic activities hence efforts should be made to curtail their entrance to our water bodies in order to check their impacts on aquatic organisms and humans.

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