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17th INAUGURAL LECTURE

TOPIC:

THE MENACE OF ENVIRONMENTAL POLLUTION: SUSTAINABILITY AND PATHWAY TO EDEN

by

PROFESSOR G. O. OLUTONA
Professor of Analytical and Environmental Chemistry

DATE: THURSDAY, 14 NOVEMBER, 2024 | TIME: 2:00PM
VENUE: RED HALL, COLLEGE OF HEALTH SCIENCES (COHES), BOWEN UNIVERSITY, IWO.

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PROFESSOR G. O. OLUTONA

NCE (SACOED), B.Sc. (Ed) (UNIBUJA), M.Sc. (UNIPORT),
M. Div. (Th)(NBTS), M.Phil. & PhD (OAU)
Professor of Analytical and Environmental Chemistry
Bowen University, Iwo, Nigeria

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On Thursday, 14 November, 2024

The Menace of Environmental Pollution:
Sustainability and Pathway to Eden.

Protocol

The Vice-Chancellor,
The Deputy Vice-Chancellor,
The Registrar,
The Bursar,
The Librarian,
The Chaplain,
Chairman Committee of Provosts and Academic Directors,
Provost, College of Agriculture, Engineering and Science
Other College Provosts and Deputy Provosts,
Distinguished Professors, and members of Senate, Head of Programmes,
Members of Staff,
My Lords, Spiritual and Temporal,
Gentlemen of the Press,
Distinguished Guests,
My Family Members,
Ladies and Gentlemen.

Preamble

All glory and thanks be to God Almighty for granting me the privilege and opportunity to deliver the 17th lecture in the Bowen University inaugural lecture series on behalf of the Industrial Chemistry Programme within the College of Agriculture, Engineering, and Science. Today's event is particularly significant as it marks the first inaugural lecture delivered by the Analytical and Environmental Chemistry Unit, as well as the first from the Chemistry and Industrial Chemistry Programme of this esteemed institution.

Mr Vice-Chancellor, Sir, my academic journey has been both challenging and guided by divine providence. It was challenging in that when I gained admission to Ilora Baptist Grammar School in 1978 for my secondary education, my father was transferred to

Iseyin. This made it difficult for him to closely monitor my academics, despite my remarkable brilliance during my primary education. Throughout my secondary education, I was overly playful, and a passionate football and basketball enthusiast. This greatly contributed to my failure in the 1983 West African Examination Council (WAEC) Examination, where I managed only two passes – in Mathematics and Christian Religious Knowledge – out of eight subjects.

My father, however, re-enrolled me the following year, paying one hundred and one naira (N101:00) for the examination. In the 1984 WAEC, I secured three credits and five passes, which enabled me to apply to St. Andrew's College of Education in 1985, where I studied Biology and Chemistry, graduating in 1988. During my time at the College of Education, my father insisted that I delay retaking the WAEC until 1989, ensuring that I could meet the University requirements of 5–6 credit passes.

Between 1989 and December 1991, I worked as a casual labourer at Folawiyo Farms Ltd., Ilora, eventually rising to the rank of Assistant Supervisor (Stores). In January 1992, I gained direct entry into the University of Abuja to pursue a four-year degree programme. As part of the university's second intake, we were not permitted to join the second-year class, resulting in my spending seven years completing my Bachelor's Degree in Science Education.

During the 1991/92 session, 9,000 candidates applied for admission, but only 300 were accepted, with ten candidates chosen from each of the thirty states, including the FCT. It was through the assistance of the late Dr Oladebo of Apomu, Osun State—whom I had helped purchase pineapples during my time at Folawiyo Farms Ltd., Ilora—that I secured my place in the university. In fact, I was the first person to gain admission from the old Oyo State.

In November 1995, I was posted to Rivers State for my National Youth Service Corps (NYSC). This occurred just four days after the death of Ken Saro-Wiwa. Before my departure to Rivers State, a brother from my fellowship, Pekerebia Douglas, approached me and said, "I heard you were posted to Rivers State; I will introduce you to my mother. My younger brother attends Demonstration

Secondary School, Ndele, which is where you will be camped. He will take you to my mother's house."
When I visited his brother, Omiebi Douglas, at his school, I met a man who had come to register his ward, Mr Aderemi Oluokun. He greeted me with, "Ajuwaya, where are you from?" I replied, "Oyo State." He then gave me his contact details and invited me to visit him at his workplace, Eleme Petrochemicals.
After completing my service year, Mr Aderemi Oluokun encouraged me not to rush back home but to apply for a Master's degree. Following his advice, I enrolled in an M.Sc. Programme in Chemistry, specialising in Environmental Chemistry, at the University of Port Harcourt. Mr Aderemi Oluokun was generous enough to pay for my tuition.
I stayed with both of these families during my early years in Port Harcourt. They welcomed me as one of their own, and have continued to do so to this day.
Mr Vice-Chancellor, my encounter with these families was nothing short of divine. Mrs Catherine Douglas and Mr Aderemi Oluokun were, to me, God-sent, akin to Joseph as described in Psalm 105:17: "And he sent a man before them—Joseph, sold as a slave."
The call to ministry brought me to Iwo in 2004, when I applied to the Nigerian Baptist Theological Seminary. However, I was unsuccessful at the interview stage, which ultimately led to my relocation from Port Harcourt to Iwo. In March 2005, I joined the Student Affairs unit of Bowen University as an Administrative Officer II. I resumed my theological training part-time in 2007 while also attempting to secure a position as academic staff in the Department of Chemistry, though without success.
In August 2007, during the regularisation of staff appointments, I was converted to academic staff and took up the position of Assistant Lecturer in the Department of Chemistry on 1 October 2007. This conversion compelled me to pursue a PhD in Chemistry.

Introduction

The inaugural lecture offers newly-promoted or appointed professors the opportunity to inform their colleagues within the

university, as well as the general public, about their research careers to date, and to provide updates on their current and future research directions. The lecture serves to highlight the importance of research and its implications for the discipline. Moreover, it is a public event, and both the title and content should be accessible to interested members of the wider community". Edinburgh University. https://www.ed.ac.uk/education/about-us/people/inaugural-lectures
This occasion allows a professor to share with colleagues and the world an illuminating overview of the research and contributions to knowledge in the field of expertise.

Mr Vice-Chancellor, I was officially pronounced a full Professor of Analytical and Environmental Chemistry on Wednesday, 17th February 2023, although the promotion was backdated to 1st January 2021. I therefore consider it a privilege to deliver the 17th inaugural lecture at this esteemed institution. Mr Vice-Chancellor, Sir, Colleagues, and Distinguished Guests, I am honoured to present an overview of my research and contributions to knowledge in the field of Analytical and Environmental Chemistry, with a focus on the key areas of "***Environmental sustainability, Environmental Monitoring and Management".***

Mr. Vice-Chancellor, Sir, the core of my research and today's lecture is deeply rooted in the Holy Scriptures. The biblical perspective underpinning my work can be found in the book of Isaiah: "*The earth is defiled by its people; they have disobeyed the laws, violated the statutes and broken the everlasting covenant. Therefore, a curse consumes the earth; its people must bear their guilt. Therefore, the earth's inhabitants are burned up, and very few are left*" (Isaiah 24:5-6, NIV).

The aforementioned scriptural passage states that because we humans have disobeyed God's instructions and violated laws, statutes, and covenants, the ecosystem has been destroyed, and the earth's inhabitants have suffered as a result. Instead of caring for our world, we have pursued a self-serving monopoly over the planet's resources, with detrimental effects on the environment. Humanity will inevitably bear the consequences of these actions. Isaiah delivers a severe indictment and condemnation of the people of his time for their destruction of the environment. Though written thousands of years ago, these words resonate with a haunting familiarity today. Why have we not heeded Isaiah's warnings? Why did we fail to learn from him?

We are fully aware that the extent of environmental and climatic damage today is far greater than in Isaiah's time. This passage offers little in the way of hope, yet from God's relationship with humanity, we know that He will never abandon us. There is always an opportunity for repentance and to change our ways. The question remains: are we ready to turn around?

In the beginning, God created heaven and earth (Gen. 1:1). In verse 31 of Genesis Chapter 1, God saw that everything He had made was very good. The environment, lovingly created by God and entrusted to our care, has now become the subject of pollution, driven by mankind's unrelenting pursuit of new knowledge.

Chemistry, as a science, could be likened to being Janus-faced. Janus, the ancient Roman god of beginnings and transitions, is depicted as having two heads facing in opposite directions, symbolically looking to both the past and the future. Chemistry is life—what aspect of life is not touched by Chemistry? Chemists are great designers. Chemistry has provided mankind with countless beneficial by-products, yet it is also a source of pollution and industrial hazards. It can be harnessed to build or to destroy life.

One example of man's exploration of knowledge in agriculture is the use of pesticides to control weeds. Pesticides have greatly optimised crop production and reduced stress for farmers. However, their use has contaminated almost all food crops, agricultural soil, and water with harmful chemical residues, which are passed on to both humans and animals. Using pesticides is akin to signing a pact with the devil. Many farmers, particularly in Africa, struggle to survive without relying on agrochemical products.

Definition of Terminologies

Pollution: The Organisation for Economic Co-operation and Development (OECD) defines pollution as the introduction, by humans, either directly or indirectly, of substances or energy into the environment, resulting in harmful effects that may endanger human health, damage living resources, or interfere with amenities or other legitimate uses of the environment.

Environmental Pollution: This refers to the undesirable alteration of the environment, primarily as a result of human activities, through the direct or indirect effects of changes in energy patterns, radiation levels, chemical composition, and the physical constitution and abundance of organisms.

Environmental Management: This is defined as a system that integrates processes for summarising, monitoring, reporting, developing, and implementing environmental policies. The goal of promoting an environmental management system is to ensure the health of the planet for future generations, while also working to preserve all forms of life. Advocates of environmental management have a statutory duty to protect the environment for both present and future generations, as enshrined in the Constitution's Bill of Rights, which stipulates the following:

"Everyone has the right:

i) to an environment that is not harmful to their health and well-being;

ii) to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that:

a) prevent pollution and ecological degradation;

b) promote conservation; and

c) secure ecologically sustainable development and use of natural resources while promoting justifiable economic and social development".

Environmental Monitoring: This refers to the process of measuring or collecting environmental data. It involves observing or checking the progress or quality of something over a period of time. Assessment is the systematic gathering of data as part of an evaluation. Therefore, environmental monitoring and assessment is the process of observing and checking the quality of the environment over time, while systematically collecting data for evaluation at any given moment. The data obtained are compared with internationally accepted limits to draw logical inferences and conclusions regarding health and environmental risks.

Sustainability: ***The Food and Agriculture Organization of the United Nations (FAO)*** defines **sustainable development** as "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry, and fisheries sectors) conserves land, water, and plant and animal genetic resources; is environmentally non-degrading; technologically appropriate; economically viable; and socially acceptable."

The Food and Agricultural Organization (FAO) define the following concept as follows:

Food refers to any substance, whether processed, semi-processed, or raw, that is intended for human consumption. This includes drinks, chewing gum, and any substance used in the manufacture, preparation, or treatment of "food," but excludes cosmetics, tobacco, and substances used solely as drugs (FAO, accessed 23/02/2024).

A contaminant refers to any substance not intentionally added to food or feed for food-producing animals, which is present in such food or feed as a result of production processes (including activities in crop husbandry, animal husbandry, and veterinary medicine), manufacture, processing, preparation, treatment, packing, packaging, transport, or storage of such food or feed, or as a result of environmental contamination. The term does not include insect fragments, rodent hairs, or other extraneous matter.

A pesticide refers to any substance intended for preventing, destroying, attracting, repelling, or controlling any pest, including unwanted species of plants or animals, during the production, storage, transport, distribution, and processing of food, agricultural commodities, or animal feeds, or which may be administered to animals for the control of ectoparasites. The term includes substances intended for use as plant growth regulators, defoliants, desiccants, fruit-thinning agents, or sprouting inhibitors, as well as substances applied to crops either before or after harvest to protect them from deterioration during storage and transport. The term typically excludes fertilisers, plant and animal nutrients, food additives, and animal drugs.

Pesticide Residue refers to any specified substance present in food, agricultural commodities, or animal feed as a result of the use of a pesticide. The term includes any derivatives of a pesticide, such as conversion products, metabolites, reaction products, and impurities considered to be of toxicological significance.

Mr. Vice-Chancellor, Sir, my research journey has focused on three specific areas of Analytical and Environmental Chemistry:

i) Water Quality
ii) Emerging Organic Contaminants (EOCs)
iii) Food Chemistry, particularly in relation to heavy metals and certain Emerging Organic Contaminants.

Water: A Basic Human Need

Water has consistently been one of the most essential commodities on earth owing to its indispensable roles for agricultural and household uses; industrial, tourism and cultural activities; as well as serving as a medium for numerous biochemical and physicochemical reactions (Oyekunle et al. 2012). Water is vital for survival, yet 2.1 billion people still lack access to safe water each day. This means that millions of disadvantaged families worldwide are without clean water for cooking, drinking, or bathing. Every year, 3.4 million people die due to limited and contaminated water supplies. More than 80% of water-deprived households rely on women to collect water. Every day, millions of women and children spend three to six hours fetching water from distant, contaminated sources. The time spent walking the average 3.7 miles to collect clean water could otherwise be used for work, family care, or education. At any given moment, half of the hospital beds worldwide are occupied by patients with illnesses linked to a lack of access to clean water (WHO, 2024).

Dissolved minerals were once the primary concern regarding the quality of groundwater. However, with the development of reliable techniques for detecting chemicals at minuscule concentrations, and increasing awareness of the potentially hazardous risks to public health and the environment, trace organics and heavy metals have come under heightened scrutiny. Poor sanitation and unsafe water supplies account for 3.7% of global diseases, with the majority occurring in developing countries.

Mr. Vice-Chancellor Sir, the first area of research core competence is water quality, encompassing surface water, groundwater and portable drinking water, in and around Iwo and its environs.

My research on water quality revealed that both the groundwater and surface water consumed by the inhabitants of Iwo and surrounding areas are contaminated with persistent organic pollutants, which act as endocrine disruptors.

Surface Water

Surface water is influenced by the surrounding environment and various factors such as land use, farming, fishing activities, settlement patterns, and industrial operations near the water body (Suriawiria, 2003). Benthic macroinvertebrates are crucial bioindicators of water quality, providing valuable insights into the past, present, and future health of a water body. The distribution, life cycle, capacity for accumulation, and sedentary nature of macroinvertebrates are essential tools for assessing the health of freshwater ecosystems (Mir et al., 2021). Akindele and Olutona (2015) investigated the assemblage of benthic macroinvertebrates in relation to selected environmental variables in two headwater streams of the Aiba reservoir. A total of 23 taxa were recorded. Nitrate and phosphate exhibited inverse relationships ($p < 0.05$) with bioindicators of good water quality, while dissolved oxygen (DO) showed inverse relationships ($p < 0.05$) with bioindicators of poor water quality. The streams were of poor biological quality, and diversity indices indicated they were polluted and unstable in habitat structure. The Ori Stream, a tributary of the River Oba in Iwo, was also studied, and its limnological analysis revealed that the upper stream was the most polluted, with biological indicators pointing to poor water quality (Akindele et al., 2015).

The health status of two headwater streams of Aiba reservoir based on their benthic and micro invertebrate faunae and some environmental variables (Akindele and Olutona 2015) (Figure 1). A total of 23 taxa were recorded in the study. Nitrate and phosphate indicate an indirect relationship ($p < 0.05$) with bioindicators of good water quality, while dissolved oxygen (DO) showed an indirect relationship ($p < 0.05$) with bioindicators of poor water quality. The streams were of poor biological water quality, and diversity indices revealed that they were polluted and unstable in habitat. Zooplankton and physico-chemistry of the two headwater streams were assessed over an annual hydrological cycle. The concentration of total solid (TS) and total suspended solids (TSS) of the two streams were unusually high in the dry seasons for typical inland waters of Nigeria and showed a decrease from upper reach to lower reach (inlet). Dissolved oxygen, nitrate, and phosphate recorded their higher concentrations at the inlet. A total of 37 species were recorded comprising 5 species of protozoa, 14 species of rotifer, 10 species of Copepoda, 4 species of ostracoda, and 4 species of insects Phosphate levels and the zooplankton community fauna of the two streams indicated a polluted freshwater system with an unstable habitat structure (Akindele and Olutona 2014).

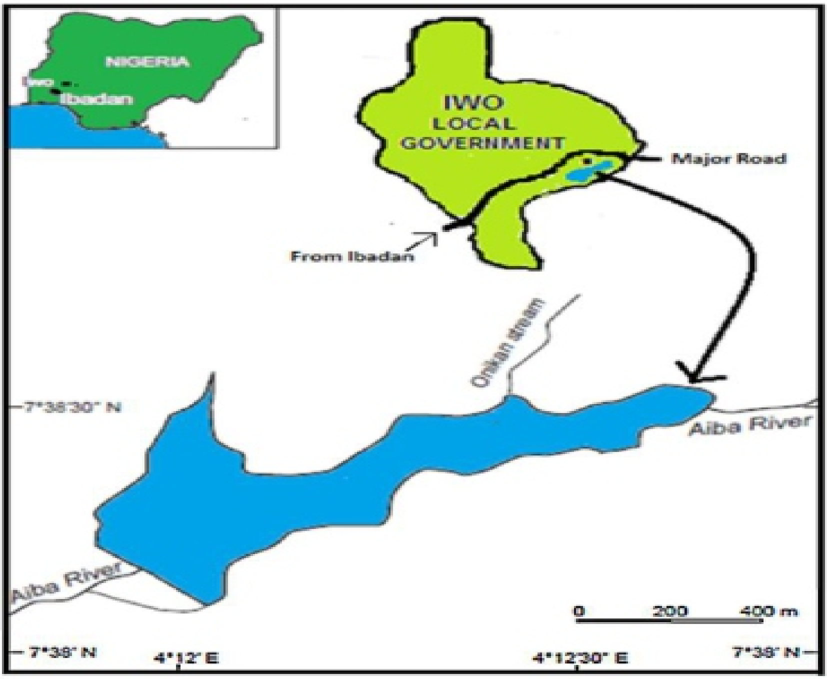


Fig. 1. Map showing location of Aiba Reservoir, Iwo, Nigeria.

(Source: Atobatele and Olutona, 2017)

Phthalate esters (PAEs) are polymer additives used as plasticizers in industries and non-plasticizers such as adhesive, mosquito repellant, cosmetics, food packaging materials etc. Globally, in 2017, PAEs accounted for sixty-five percent of plasticizers consumption and between 2017 and 2022, the total global consumption increased at annual mean rate of 1.3% (Markit, 2018). The additive nature of this contaminant makes them exist freely and not chemically bound to polymer chain, hence, they can migrate, drain off or evaporate into the environment. Human beings are exposed to PAEs via oral, inhalation, ingestion, dietary prenatal, and dermal absorption (Wang et al 2020). Phthalates are classified as carcinogenic and endocrine disruptors for humans with diverse health implications such as early puberty in female, genital defect,

Station	DEP	DBP	DMP	DPP	Σ_4PEs
St1 Ori	ND	ND	74.8±45	ND	75
St 2 Agogo	ND	ND	1980±62	ND	1980
St 3 Osadep	505±74	ND	1440±570	ND	1945
St 4 Technical	ND	6.43±3.10	81.4±48	21.3±13	109
St 5 Oba	ND	ND	1110±560	6.35±9.0	1116
Mean	101±16	1.29±1.3	938±780	5.53±6.5	

(Source: Olutona and Dawodu, 2016)

Table 2: Level (µg/g) of Phthalate esters (PAEs) in Sediment from Ori stream

Station	DEP	DBP	DMP	DPP	Σ_4PEs
St 1 Ori	21.2±19	110±59	12.9±8.3	18.0±1.1	162
St 2 Agogo	10.8±5.3	213±130	11.7±6.5	27.2±16	360
St 3 Osadep	2.45±3.5	86.1±9.9	28.5±20	24.1±13	141
St 4 Technical	25.5±7.5	54.3±10	118±13	51.1±3.1	249
St 5 Oba	3.50±2.9	295±160	ND	55.2±46	354
Mean	12.7±15	152±140	34.2±28	35.1±26	

(Source: Olutona and Dawodu, 2016)

The increasing demand for food production has led to the excessive use of pesticides and fertilisers, which eventually enter surface water bodies through runoff, thereby reducing the quality of surface water. Reservoirs play a significant role in the life of a community, as they supply water for domestic use, irrigation, fisheries, and aquaculture (Akindele and Olutona, 2015).

Olutona et al. (2014) assessed the levels of organochlorine pesticide residues in water and sediment of Aiba reservoir in Iwo (Southwestern Nigeria). The presence of all the three categories of OCPs (chlorinated benzene/cyclohexane, dichlorodiphenylethane and cyclodienes) was evident in all the locations. Analyses shows the presence of endosulfan I, endosulfan III, and methoxychlor in 62.5% of the samples; β- BHC, heptachlor and endrin ketone in 50% of the samples; α-BHC, δ- BHC, pp-DDT, aldrin, endosulfan II, dieldrin and endrin aldehyde in 37.5% of the samples; and pp-DDE, pp-DDD, heptachlor-epox, endrin and γ -Chlordane in 25% of the samples. The γ-BHC was not detected in all the locations. The study revealed the presence of OCPs congeners and mean levels higher than the recommended limit for drinking water. Cancer has been associated with the use of organochlorine pesticides compounds most especially DDT. Endosulfan has been associated with decrease in sperm count up to 39% and damaging effect on sperm morphology and spermagonial cells (Cable and Doherty, 1999).

This scientific advancement has led to the production and use of several flame retardants, broadly classified into three major groups namely: brominated flame retardants (BFRs), phosphorous-based flame retardants and inorganic flame retardants (usually magnesium and aluminum hydroxides) (Minnesota Pollution Control Agency, 2008). One of the most commonly used BFRs (Figure 2) is Poly brominated diphenyl ethers. Polybrominated diphenyl ethers (PDBEs) is one of the emerging organic contaminants (EOC) that have been extensively used in chemical industries mainly as additive flame retardants in polymers resins and plastics, and to a lesser extent, adhesives, sealants and coatings (Figures 3 & 4). It is also used in the manufacturing of combustible materials such as paints, computer and mobile accessories, plastics and thermosetting products such as electrical and electronic appliances, television sets, interior decoration in cars and airplanes, textile materials (Dewit, 2002; Frederksen et al. 2009). Additive flame retardants are physically combined with the materials being treated rather than chemically bonded as in reactive flame retardants, thus they are more susceptible, to a certain extent, to migration and loss from the polymer matrix (Environment Canada, 2004).

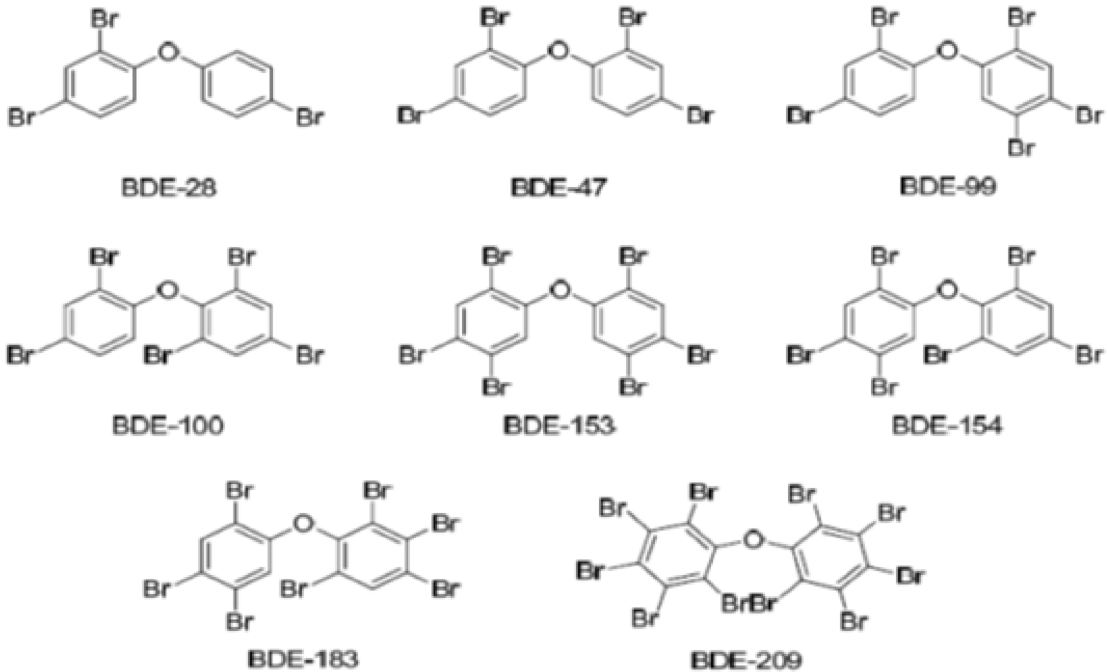


Figure 2: Structure of Eight Most abundant PBDE Congeners (EFSA, 2011)

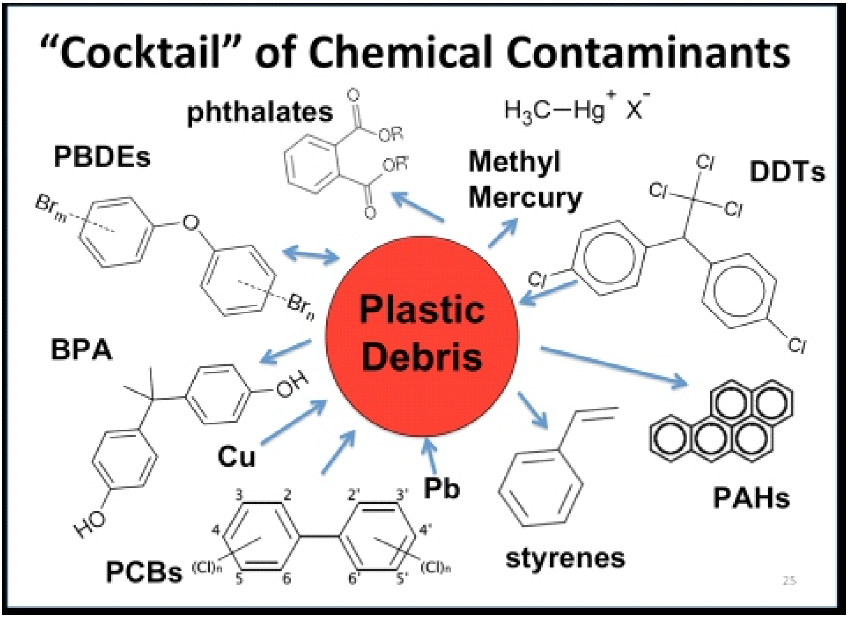


Figure 3: Cocktail of chemical contaminants (Rochman et al. 2015)

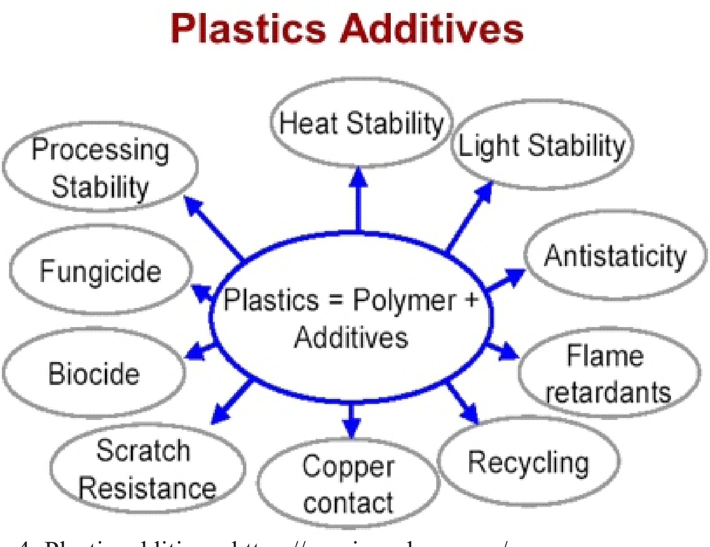
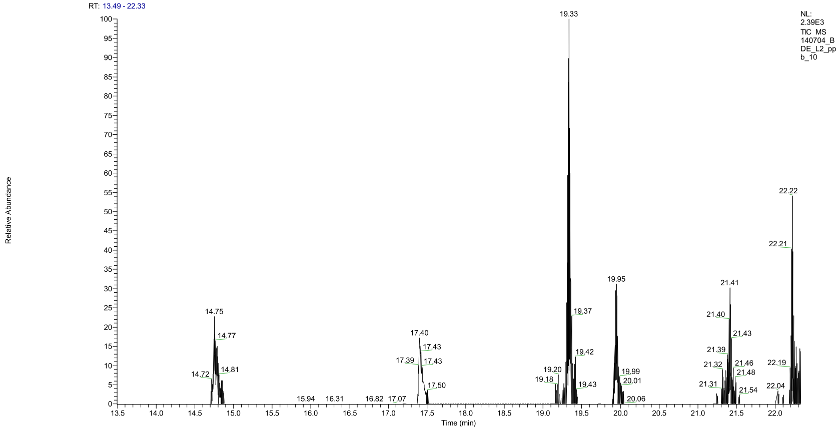
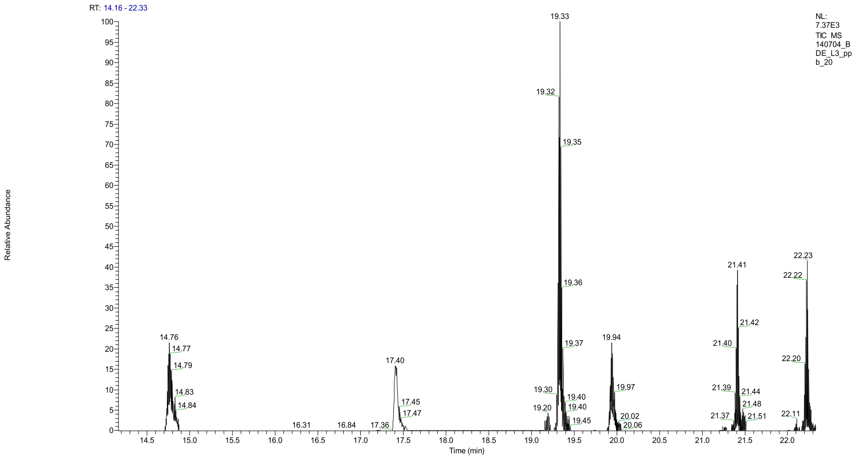


Figure 4: Plastic additives. https://sunrisecolour.com/what-are-plastic-additives-l-en?l=en

Asunle stream has its sources about 250 m uphill from Obafemi Awolowo University dumpsite. The stream runs via a distance of about ten kilometer traversing three villages (Ogunfowokan et al. (2013). Olutona et al. (2017) carried out a study on levels of PBDEs in water from Asunle stream, Ile-Ife. The concentrations of PBDE congeners at the six locations along the water course revealed the occurrence of these contaminants at varying concentrations in all the six locations (Figure 5); that PBDEs were mobile and capable of long-range transport over a long distance. Spatially, the mean levels of the total PBDEs ranged between 0.03 and 0.31 ng/mL (Table 3) This study addresses a knowledge gap by providing data on the contamination status of PBDEs in a water body, an important contribution regarding environmental matters on new emerging contaminants. The detection of PBDEs at all locations of the Asunle stream showed that this pollutant is ubiquitous. The PBDEs levels recorded in this study, though relatively low, are of urgent concern because of the potential health impacts of PBDEs on villagers who depend on this stream for water supply for drinking, cooking, and other purposes. Hence, there is a need to put in place effective control methods that could mitigate the leaching of PBDEs from the dumpsite into the environmental compartments nearby. If unchecked, possible further and future accumulations of these contaminants in the water body could lead to serious health effects on the inhabitants of the communities that depend on this stream for their consumption and many other households uses. Toxicological studies revealed that PBDEs are endocrine disruptors chemical compounds. Endocrine disruptors are capable of interfering the synthesis, secretion, binding, transport, action or elimination of natural hormone responsible for development, fertility and maintenance of homeostasis in human body (Kavlock et al.1996). The PBDEs have been found to be carcinogenic (Ikonomou et al. (2002); capable of affecting thyroid hormones (Lana et al. 2010).

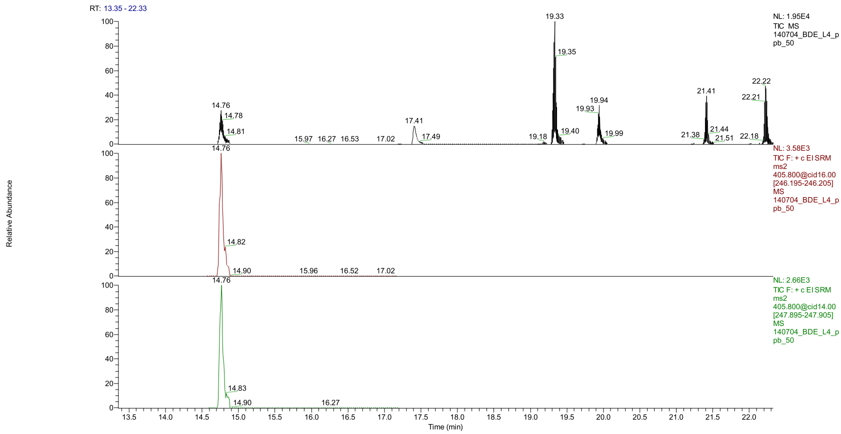


(a) Calibration using 10 ng/mL PBDE

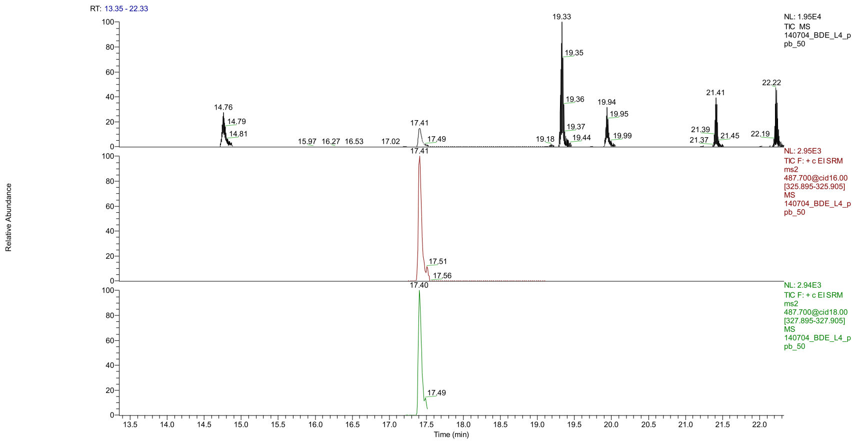


(b) Calibration using 20 ng/mL PBDE Congeners

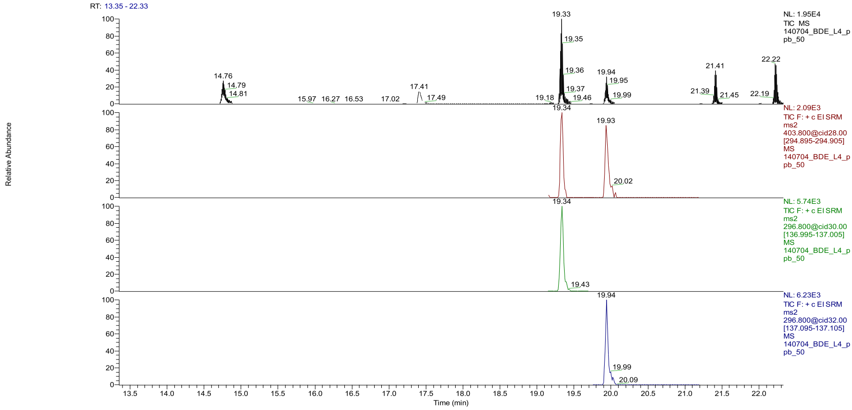
BDE 28


RT: 13.35 - 22.33
NL: 1.95E4
TIC MS
140704_BDE_L4_pb_50
NL: 3.58E3
TIC F: + c EI SRM ms2 405.800@cid16.00 [246.195-246.205] MS 140704_BDE_L4_pb_50
NL: 2.66E3
TIC F: + c EI SRM ms2 405.800@cid14.00 [247.895-247.905] MS 140704_BDE_L4_pb_50
Relative Abundance
Time (min)

BDE 47


RT: 13.35 - 22.33
NL: 1.95E4
TIC MS
140704_BDE_L4_pb_50
NL: 2.95E3
TIC F: + c EI SRM ms2 487.700@cid16.00 [325.895-325.905] MS 140704_BDE_L4_pb_50
NL: 2.94E3
TIC F: + c EI SRM ms2 487.700@cid18.00 [327.895-327.905] MS 140704_BDE_L4_pb_50
Relative Abundance
Time (min)

BDE 100 and BDE 99



BDE 153 and BDE 154

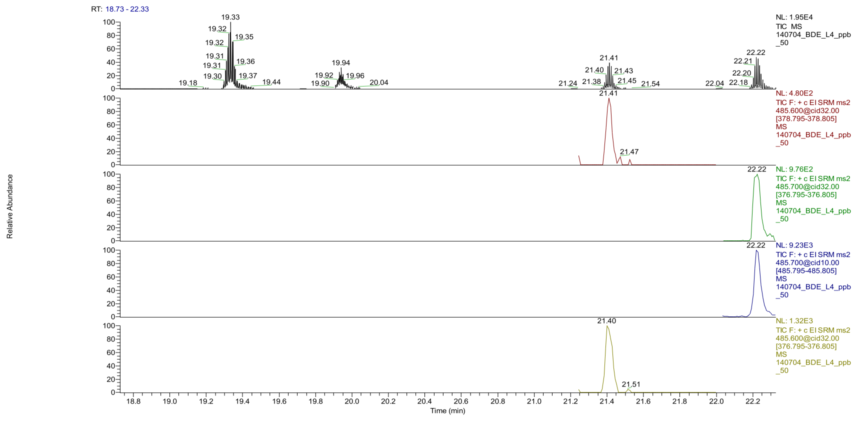


Figure 5: Chromatograms of PBDE Congeners mixed Standards (10 and 20 ng/mL) and Targeted PBDE Congeners

Table 3: Concentration of PBDEs in six Locations of the Asunle Stream

Location	BDE28	BDE47	BDE99	BDE100	BDE153	BDE154	Σ_6PBDEs
0	0.01 ± 0.03	0.02 ± 0.02	0.02 ± 0.04	0.01 ± 0.03	1.31 ± 3.05	0.03 ± 0.04	0.23
1	0.05 ± 0.04	0.02 ± 0.01	0.03 ± 0.04	0.04 ± 0.05	1.65 ± 2.64	0.04 ± 0.04	0.31
2	0.02 ± 0.03	0.03 ± 0.02	0.03 ± 0.02	0.05 ± 0.06	0.24 ± 0.21	0.03 ± 0.02	0.07
3	0.04 ± 0.05	0.02 ± 0.03	0.04 ± 0.03	0.04 ± 0.03	0.20 ± 0.41	0.05 ± 0.03	0.07
4	0.02 ± 0.04	0.02 ± 0.01	0.01 ± 0.01	0.01 ± 0.03	0.06 ± 0.07	0.05 ± 0.03	0.03
5	0.01 ± 0.03	0.02 ± 0.02	0.04 ± 0.03	0.03 ± 0.05	0.18 ± 0.31	0.02 ± 0.03	0.05

(Source: Olutona et al 2017)

Heavy metals are naturally occurring elements with atomic numbers greater than twenty and an elemental density exceeding 5 g cm^{-3} (Ali and Khan, 2017). They can exhibit two contrasting characteristics: in small quantities, they are nutritionally essential for maintaining human metabolism, but at higher concentrations, they can be poisonous or toxic. Arsenic (As) is a ubiquitous metalloid and is particularly notorious for its toxicity, posing serious risks to human health. It has been classified as carcinogenic to humans. The status of arsenic in the Aiba reservoir was assessed by Atobatele and Olutona (2015) to determine its levels and distribution in water, sediment, and fish. The mean levels detected were 1.50 ± 0.22 ppb in reservoir water and 2.0 ± 0.17 ppb in sediment, both of which are below the WHO recommended limit of 0.01 mg/L (10 ppb). The distribution of arsenic in water shows significant spatial and temporal heterogeneity, while that in sediment displays temporal homogeneity.

Groundwater

Groundwater contamination occurs when urban waste materials, mainly domestic garbage, are disposed of without appropriate measures imposing high risks to the underground water resources. Alagbe et al (2019) carried out a study of the impact of waste disposal on the groundwater resources around refuse dumpsite at Oke-Odo, Iwo using Very Low Frequency Electromagnetic method (VLF-EM) and Vertical Electrical Sounding (VES) of the

Schlumberger array. The results of the VLF-EM and VES revealed the presence of the contaminant plumes which are detected as conductive anomalies mainly of dissolved salts from organic matter. The geoelectric section generated from the VLF-EM and VES data revealed that the polluted region had resistivity values as low as 12.0 Ωm and 40.5 Ωm, and a very shallow depth of 3.0 m and 4.0 m to the anomalous sources (contaminant plume). This study further revealed that the hand dug wells (3-5 m depth) were contaminated with nitrate, phosphate, sulphate arsenic, iron, copper, lead and zinc. However, the results of the hydro-geochemical analysis when compared to standard guidelines of the World Health Organization (WHO) to ascertain their quality and it was shown that the quality of the water in the study area fell below the standard. The quality of groundwater in 15 randomly selected rural communities in Oriire, Surulere, and Ogo-Oluwa Local Government Areas of Ogbomosho, Oyo State was assessed. The waters were found to be contaminated with EC, nitrate, phosphate, and coliform (Ogunbode et al. 2016). The presence of coliform could be attributed to the closeness of wells to pit latrines, septic tanks and refuse dumps. The infiltration of chemical fertilizer as runoff could be attributed to the presence of nitrate and phosphate in these wells. Nitrate in water can be hazardous to infants that drinks these contaminated water as it restricts the amount of oxygen that reach the brain causing methaemoglobinaemia also called “blue baby” syndrome and digestive track cancer (Alagbe et al. 2019).

A similar assessment of trace metals contaminants and VLF_EM study of groundwater samples obtained from shallow wells in different parts of Iwo revealed that Mn, Fe, Cu, Pb, Cr, and Cd were either equal or exceeded permissible limits while few were below standard limits. The VLF-EM showed that the metals found their way into these wells through fractures and joints that characterized the study areas (Olutona et al. 2014).

Polycyclic aromatic hydrocarbons (PAHs) are multi-ringed aromatic organic compounds that have been demonstrated to be carcinogenic and mutagenic and are derived from both natural processes of biogenic precursor and anthropogenic processes of incomplete combustion of organic matter and emission of non-combustion petrogenic process. The study of PAHs in groundwater obtained from Edun-Abon, Moro, Yakoyo, and Ipetu-modu of Ife North Central LGA by Adekunle et al. (2017) revealed the presence of PAHs and higher concentrations were recorded in the wet season compared to the dry season. The study concluded that the groundwater in these communities was contaminated with light PAHs and the total PAHs in these areas exceeded the maximum permissible limit of 10 μgL^{-1} recommended by WHO for the safety of groundwater.

Tap Water

The characteristics and quality of drinking water from four different sources (borehole, tap, well, and stream water) in five major towns covering three senatorial districts (Iwo, Osun West; Oshogbo, Osun Central; Ile-Ife, Osun East, Ejigbo, (Osun West; and Ilesa Osun East) in Osun state were analyzed in order to determine their portability status. The result compared favorably with WHO, 2008 and Nigeria Standards for Drinking Water Quality (NSDWQ) except for temperature which was slightly higher than ambient temperature. The pH was also slightly above the specified limits of 6.5-8.5 indicating the alkaline nature of the water samples. This implies that the water samples may enhance the growth of microorganisms, hence increase in the problems related to taste, odour, colour, and corrosion (Odebunmi et al. 2014).

Aquatic Organisms (Fish)

Aquatic organisms are capable of bioaccumulation of heavy metals either through direct ingestion of food and water or through some organs of the organisms such as lungs, gills or skin. Non-essential metals are toxic even at trace levels, and persistent. Atobatele and Olutona (2015) assessed the concentrations of Cd, Pb and Hg in gills, kidney, liver and muscle of eleven species of fish inhabited at Aiba reservoir. The level of toxic non-essential metals in fish ranged from 0.001 to 0.100 ppm (Cd), 0.000–0.067 ppm (Hg) and 0.001–0.125 ppm (Pb) (Table 4). The order of distribution of toxic trace non-essential metals within fish organs is Kidney > Liver > Gill ≥ Intestine ≥ Muscle (Fig 6). This study demonstrates the contamination and bioaccumulation of fish species with toxic metals that are carcinogenic and act as endocrine disruptors to human health.

Table 4: Total mean values and Kruskal-Wallis One-Way analysis of Cd, Hg and Pb of 11 fish Species from Aiba Reservoir

Fish species	Cd (ppm)Mean ± SE	Hg (ppm)Mean ± SE	Pb (ppm)Mean ± SE
Marcusenius senegalensis	0.007 ± 0.001	0.005 ± 0.001	0.005 ± 0.001
Labeo senegalensis	0.020 ± 0.001	0.008 ± 0.004	0.020 ± 0.008
Hepsetus odoe	0.007 ± 0.001	0.005 ± 0.001	0.007 ± 0.001
Chrysichthys auratus	0.006 ± 0.001	0.004 ± 0.001	0.005 ± 0.001
Chrysichthys nigrodigitatus	0.004 ± 0.001	0.002 ± 0.000	0.005 ± 0.001
Clarias ebriensis	0.013 ± 0.005	0.008 ± 0.003	0.009 ± 0.003
Clarias macromystax	0.008 ± 0.003	0.006 ± 0.003	0.008 ± 0.003
Channa obscura	0.012 ± 0.004	0.008 ± 0.003	0.014 ± 0.006
Tilapia zillii	0.013 ± 0.006	0.007 ± 0.004	0.024 ± 0.011
Sarotherodon galilaeus	0.009 ± 0.003	0.004 ± 0.002	0.021 ± 0.009
Oreochromis niloticus	0.022 ± 0.008	0.011 ± 0.005	0.021 ± 0.008
Total			
Mean ± SE (ppm)	0.012 ± 0.002	0.006 ± 0.001	0.010 ± 0.001
Range (ppm)	0.001–0.125	0.000–0.067	0.001–0.100
Species number (*S*)	11	11	11
Sample number (*n*)	168	168	168
(df = 10)	6.25	12.59	7.67
P-value	0.794	0.247	0.794

(Source: Atobatele and Olutona 2015)

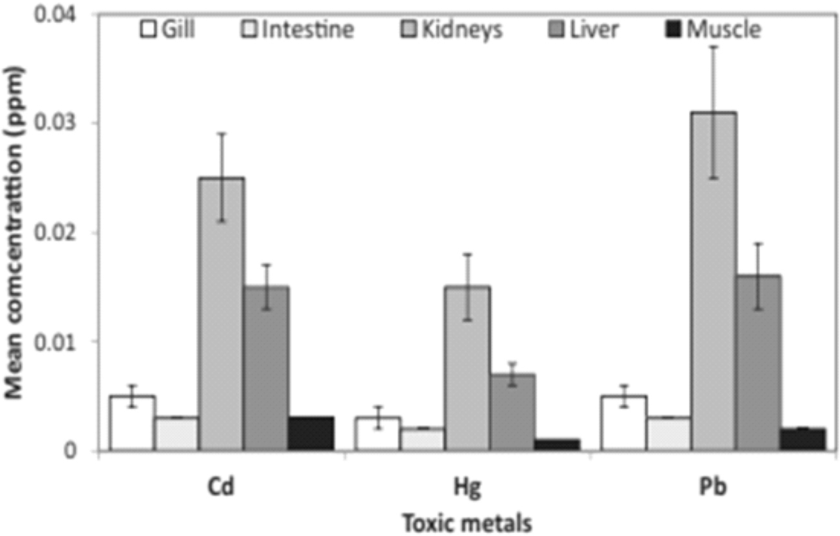
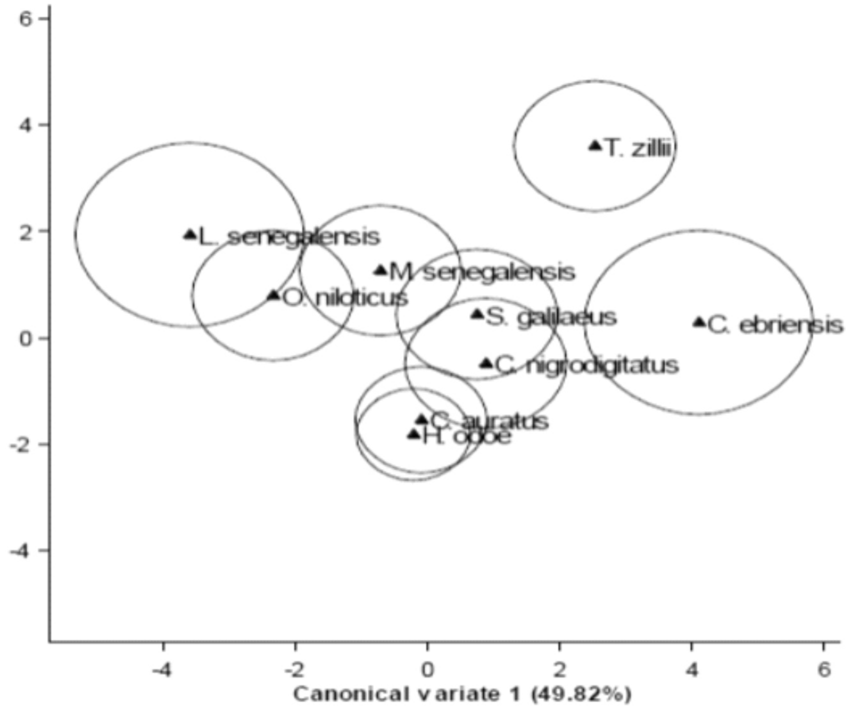


Figure 6: Mean values of Cd, Hg and Pb accumulating in the five organs of the fish species (Source: Atobatele and Olutona 2015)

In another study by Atobatele and Olutona (2015) in their study of arsenic in fish and its organs obtained from Aiba reservoir. The mean As levels for fish kidney (15.72 ±4.14 ppb), and liver (12.04 ± 2.73 ppb) were significantly higher than the levels in fish gills (2.03 ± 0.34 ppb) and muscle (1.46 ±0.13 ppb). The first and the second canonical Variate showed 49.82% and 34.75% between species variation respectively (Figure 7). Their findings suggest that fish at the lower level of the food web have higher level of As compared to those at the higher trophic status. The current low level of As in the abiotic component of the reservoir suggest that their contamination was from anthropogenic origin rather than natural origin.



(Source: Atobatele and Olutona 2015)

Figure 7: Canonical Variate analysis plot of arsenic levels in sample organs of fish against sampled species with 95% confidence levels about means.

Olafisoye et al. (2013) carried out a study on the levels of Pb, Cd and Zn in some fish species consumed in Southwestern, Nigeria. Catfish (*Clarias gariepinus*), Tilapia (*Oreochromis niloticus*) Atlantic mackerel (*Scomber scombrus*) and Roughearscad (decapterus) are prominent fish species that have dominated the Nigerian market. The levels of Cadmium (Cd) in all the fish samples were between 0.03 mg/g in catfish species and 0.09 mg/g in Tilapia fish species. Safe limit for the consumption of Cd in fish is 0.2 mg/kg. Cadmium is a non-essential element in foods and natural waters and it accumulates principally in the kidney and liver. The concentration of zinc was found high in catfish species while low concentration of zinc was observed in the sample of Tilapia fish species. The content of zinc in the fish species ranges from 0.43 to 0.77 mg/g, which is within safe limits. Pb was not detected in all the four species study. High level of Pb and Cd in food substances are associated with various diseases such as cardiovascular, central nervous system, liver and kidney diseases.

Beverages and other Food related substances

Following water, tea is the most widely consumed beverage in the world. Tea contains some beneficial elements such as Ca, Zn, Phosphorus, and Iron. However, the concentration of some of these elements are higher than would naturally occur. The concentrations of seven trace elements in some tea (black, green, and oolong tea) commonly consumed in Ibadan were analyzed by Dawodu et al. (2013). The mean (%) proximate analysis was as follows: Nitrogen (3.01±0.08), protein (18.85±1.87), fat (4.63 ±0.09), Ash (10.79±1.42), and moisture content (8.40±0.11). The mean (%) elemental value was as follows: Ca (1.91-7.99), K (0.90-2.91), Mg (0.33-0.63), Cu (7.36 -10.93), Fe (180.38-320.04), Mn (104.78-117.85), and Zn (21.17-40.00).

Bromate and trace metals concentrations were determined in bread loaves from nine outlets and bakeries within Ile-Ife metropolis by Oyekunle et al. (2014) with intent of determining their safety for human consumption. This study revealed. Bromate levels in the analyzed bread samples ranged from 2.051 ± 0.011 µg/g to 66.224 ± 0.014 µg/g (Table 5) while the trace metal levels were of the order: 0.03–0.10 µg/g Co = 0.03–0.10 µg/g Pb < 0.23–0.46 µg/g Cu < 2.23–6.63 µg/g Zn < 25.83–75.53 µg/g Mn. The results of trace metals analysis showed that bread samples contained Co, Cu, Mn, Pb and Zn at levels that were at wide variance with those specified by such bodies as NAFDAC or WHO. Particularly, the Pb content of the bread was greater than the 0.025 mg/kg body weight set as the Provisionally Tolerable Weekly Intake for humans This study implied that many bread bakers around Ile-Ife had not fully complied with the bromate-free rule stipulated by NAFDAC contrary to the “bromate free” inscribed on the labels of the bread.

The bread samples contained both essential and toxic trace metals to levels that could threaten the health of consumers over prolonged regular consumption. Bromate helps the bread to rise in an oven and improve its texture. Toxicological effect of consumption of potassium bromate can lead to cancer effect; degradation of Vitamins E, A1, A2, B1, B2, and niacin present in bread; abdominal pain, kidney failure, ocular and bronchial ailments, hearing impairment, damage to central nervous system (Atkins, 1993; Robert and Williams 1996).

Table 5: Bromate Levels in Bread from Outlets within Ile-Ife Metropolis

Bromate levels (µg/g)* in the bread samples.

Sample code	Manufacturer's specification	$[BrO_3^-]$ by Crystal Violet oxidation	$[BrO_3^-]$ by Congo Red oxidation
A	Bromate free	28.025 ± 0.005	36.012 ± 0.007
B	Bromate free	3.129 ± 0.024	10.029 ± 0.007
C	Bromate free	41.336 ± 0.009	66.224 ± 0.014
D	Bromate free	2.051 ± 0.011	22.356 ± 0.008
E	Bromate free	7.667 ± 0.012	21.397 ± 0.017
F	Bromate free	4.205 ± 0.012	24.461 ± 0.004
G	Bromate free	10.313 ± 0.012	26.258 ± 0.043
H	Bromate free	6.333 ± 0.023	23.326 ± 0.011
I	Bromate free	20.296 ± 0.022	40.231 ± 0.012

(Source: Oyekunle et al 2014)

The levels and health risk assessment of Polycyclic aromatic hydrocarbons (PAHs) and trace metals in five selected brands of sausage roll sold in Nigeria markets were studied by Olutona et al (2022). The levels of Σ 16 PAHs in sausage samples were in the range of 12.5-36.2 µg/g. Benzo (a) pyrene was predominant in all the samples investigated and their concentrations were above 0.001 µg/g limit in processed cereal-based food products as stipulated by the European Commission Regulation. The brands of sausages were mainly polluted with 4- and 5-ring PAHs. The order of increase of PAHs in brands of sausage roll was: SB > YM > GA > BG > RT. The trace metals concentrations (mg/kg) ranged as follows: Zn (1.01-71.0), Cu (ND-8.12), and Cr (ND-16.4). Cd was not detected in all the samples analyzed. Pb ranged from 2.34-13.0 mg/kg infringing the safe limit for cereals and cereal-based food products of 0.3 mg/kg and 0.05 mg/kg as stipulated by the FAO/WHO and European Commission, respectively. PAHs especially Benzo (a) pyrene can cause cancer and an allergic reaction to both human and animal skin. The estimated dietary daily intakes (EDI) of BaP and EFSA indicators for the occurrence of PAHs in foods like PAH2, PAH4, PAH8, in addition to Σ 16 PAHs and Σ BaPeq from consumption of different brands of sausage rolls were much lower in adults relative to youths and school children. It should be known however that a school child that ingests the exact amount of sausage rolls as an adult for each day would of course be at higher risk of exposure to carcinogenic PAHs due to his/her small body weight and a lower rate of metabolism. The margin of exposure (MOE) values lower than 10,000 show serious health effects for consumers and require an immediate response. MOE values higher than 10,000 show no serious health concerns to consumers by the contaminants (ATSDR, 1995). The MOE values of BaP, PAH2, PAH4, and PAH8 for school children, youths, and adults are displayed in Table 6. The calculated margin of exposure from the ingestion of all the sausage roll samples for all categories based on suitable indicators for PAHs occurrence was lower than 10,000, thus signifying severe health concerns. Consumers of these food products require abrupt attention because they are at greater risk of exposure to carcinogenic PAHs

Table 6: The Margin of Exposure (MOE) for ingestion for 80 g of Sausage Roll for School Children (35 kg), Youths (65 kg), and Adults (70 kg)

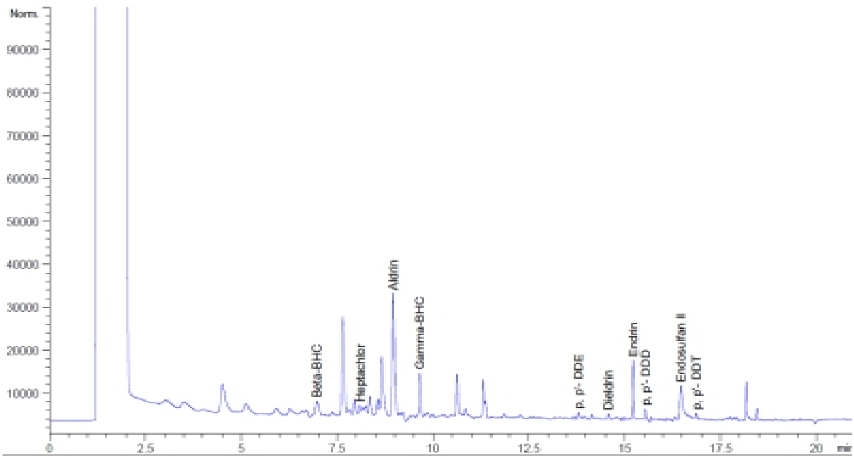
Sausage Sample	Margin of Exposure			
	BaP	PAH2	PAH4	PAH8
	SCHOOL CHILD			
BG	16.5	40.2	17.1	16.5
GA	29.4	48.6	24.8	12.0
SB	25.9	26.8	14.5	8.40
RT	23.7	26.1	38.9	56.0
YM	16.2	22.1	8.27	10.0
	YOUTH			
BG	30.7	74.6	31.8	30.6
GA	54.7	90.4	46.2	22.4
SB	48.3	49.7	26.8	15.6
RT	25.2	48.4	72.2	104
YM	30.0	41.1	15.3	18.6
	ADULT			
BG	33.2	80.6	34.1	32.9
GA	58.8	97.1	49.8	24.1
SB	51.9	53.5	28.8	16.8
RT	47.6	52.1	77.6	112
YM	32.4	44.3	16.5	20.0

(Source Olutona et al 2022)

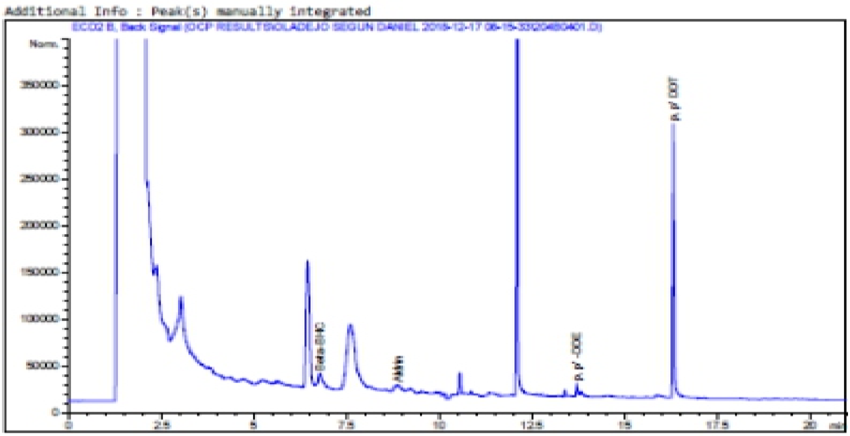
Food safety is fundamental to a healthy and sustainable system. The establishment of pesticide residue standards plays a crucial role in improving food safety and agricultural development globally. Mr. Vice-Chancellor Sir, a visit to Guffanti mission field, Niger State triggered my study on pesticide residue in food substances. During one of my visits, I discovered that farmers in the savannah vegetation belt of Northern Nigeria engaged in the use of agro-chemicals more than their Southern counterparts. My focus was on the commonly grown food crops like Sorghum, Millet and Melon. Sorghum or Millet are used in replacement of wheat in production of malt drink and beer products; while melon is used in preparation of kulikuli and donkwa. Brewer dried grain (BDG) and Groundnut cake (GNC) by products of brewery waste were part of poultry feed formulations. Organochlorine pesticides (OCPs) residue in commercial malt drinks commonly sold in Nigeria market were explored. The study revealed the presence of eleven (11) compounds out of 17 priority chlorinated hydrocarbons considered carcinogenic by USEPA (Olutona and Livingstone, 2018) at varying concentrations in all the five brands examined (Figure 8a). The presence of heavy metals revealed the presence of Pb, Cr and Ni were above the maximum allowed limit specified by World Health Organization/USEPA. Similar study was carried out for beer products by Olutona and Oladejo, (2018 Unpublished). The findings demonstrated that every OCP detected in the examined beer drinks exceeded the MRLs (Figure 8 b & c). According to the results of the trace metal analysis, Cu, Mn, Pb, and Zn were found in samples at concentrations above the drinking water limits established by the World Health Organization (WHO) and United States Environmental Protection Agency (USEPA), while Cr and Cd were below the detection limit in all samples. A warning to the beer drinkers to take heed to the warning of the book of Proverbs 31:6-7 *"Let beer be for those who are perishing, wine for those who are in anguish! 7Let them drink and forget their poverty and remember their misery no more"*.

The migration of pesticides into the food chain was facilitated by their use, most especially in finished products such as beer. Water-soluble pesticide residues are assimilated by the added yeast's biotic metabolism, conveyed to the final product, or destroyed during fermentation by abiotic processes from the neighboring reducing environment. In reality, the malt cycle, high water dilution, and filtration procedures produce beer with essentially undetectable residues.

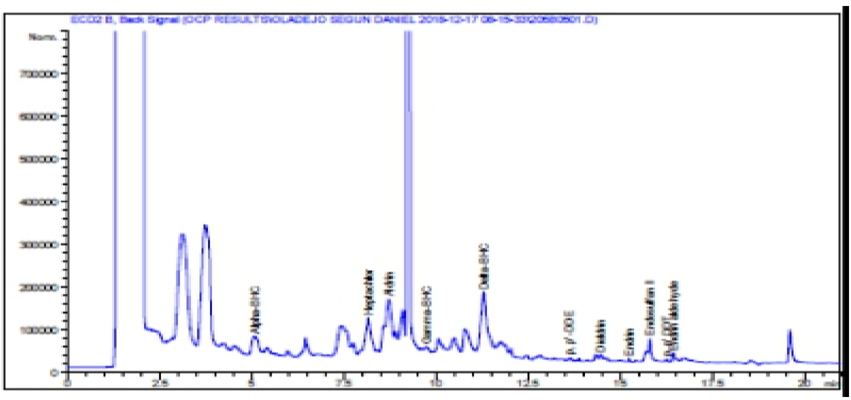
Additionally, OCPs have been linked to immune system dysfunction (Kolpin and al., 1998), endocrine disruption (Ize et al., 2007), human breast disease (Garabrant et al. 1992), liver malignancies, testicular tumors, and infertility (Bouman, 2004), as well as reduced sperm counts in humans (Cocco et al., 1997). According to Colborn and Smolen (1996), potassium influences the metabolism of xenobiotics and steroid hormones through the membranes of nerve fibers. Long-term exposure to dieldrin and aldrin may cause chronic seizures (Belta et al., 2006). Epidemiological research also suggested an etiological link between exposure to organochlorine pesticides and Parkinson's disease (Fleming et al., 1994). The risk brought on by endosulfan is really concerning. Endosulfan is more persistent in the environment for longer periods of time and bioaccumulates in plants and animals, which contaminates human food intake (Briz et al., 2011). It has been proven to have higher acute inhalation toxicity than cutaneous toxicity and to primarily damage the central nervous system. Endosulfan has a very high rate of intestinal absorption (USEPA, 2010). Up to 25 million employees in underdeveloped nations may experience minor pesticide poisoning each year, according to a research (Jeyaratnam, 1990).



(a} Malt drink (Source Olutona Livingstone, 2018)



(b) Beer Product (Source Olutona and Oladejo, 2018)



(c) Beer product (Source Olutona and Oladejo, 2018)

Figure 8 (a -c) Chromatograms of the representative of some malt and beer products analyzed in this study.

Poultry farming is an essential practice to produce high protein-rich foods such as meat and eggs in Nigeria and. It equally serves as a source of revenue to both small and large-scale farmers in Nigeria. Olutona et al (2019) further explored the presence of trace metals and OCPs in poultry feed obtained from three feed mills in Iwo. The mean values of OCPs ranged from 0.34 ng/kg to 14.8 ng/kg in broilers and 0.07 ng/kg to 1.74 ng/kg in layers mash. In broilers feed, aldrin, endosulfan I and endrin, exceeded the Maximum Residue Limits (MRL) for Animal Feed for OCPs, while in layers mash, aldrin and endrin aldehyde exceeded the MRL limits. The levels of Cu Zn and Pb in broiler and layers mash obtained in this study were far below the maximum recommended concentrations as stipulated by European Union for animal feed. These results indicated the presence of OCPs in poultry feeds which could bioaccumulate and eventually lead to the contamination of table eggs and table meats as a result of these toxic materials.

Our study on potential toxic metals (PTMs) in soil and vegetables (*Corchorus olitorus*, *Amarathus viridis*, and *Celosia argentea*) from Ori Eru, Bowen, and Feesu farmlands adjoining major roads in Iwo was carried out by Olutona et al. (2017). The study revealed that the levels of PTMs in vegetables were significantly higher than the control site. The calculated chronic daily intake (CDI) for carcinogenic risks were below the minimal risk level while non-carcinogenic risks level for adult were higher than those of the children. The targeted hazard quotient (THQ) for both the children and adults were above 1.0 stipulated by USEPA as safety limit indicating that regular consumption of these vegetables over a prolong period of time could expose the consumers to significant health risk such as, cardiovascular diseases, cancers, Alzheimer's disease, arthritis, diabetes, fatigue and memory loss.

Olutona and Aderemi (2019) carried out Organochlorine pesticide residue and heavy metals in leguminous food crops from selected markets in Ibadan, Nigeria (Figure 9). Cowpea Oje had the highest level of OCPs with dieldrin (20.14 ± 0.28), aldrin (7.81 ± 0.13), γ-benzene hexachloride (0.24 ± 0.11), pp-DDE (1.23 ± 0.16), endrin (1.82 ± 0.14), endosulfan II (16.90 ± 0.00), pp-DDT (1.82 ± 0.78), endrin CHO (12.89 ± 0.14), and endosulfan (13.49 ± 0.13), whereas Beans Bodija had the lowest value of OCPs with dieldrin (0.99 ± 0.0), endosulfan II (1.02 ± 0.01), and endrin CHO (1.66 ± 0.12), which are all above the maximum residue limits. For the potentially toxic metals, lead was only found in Cowpea Bodija and was below detection limit in other markets. Metals such as Zn, Fe, Cu, and Cr were also detected in the samples. This study showed that the food samples had significant concentrations of the pesticide residue, the three classes of OCPs were identified, and the pesticide residues were more in cowpea than in beans. Also, the research showed that the samples from Oje market have higher concentration than others and the values obtained generally were greater than MRLs. It also showed that the levels of the heavy metals were above the recommended daily intake.

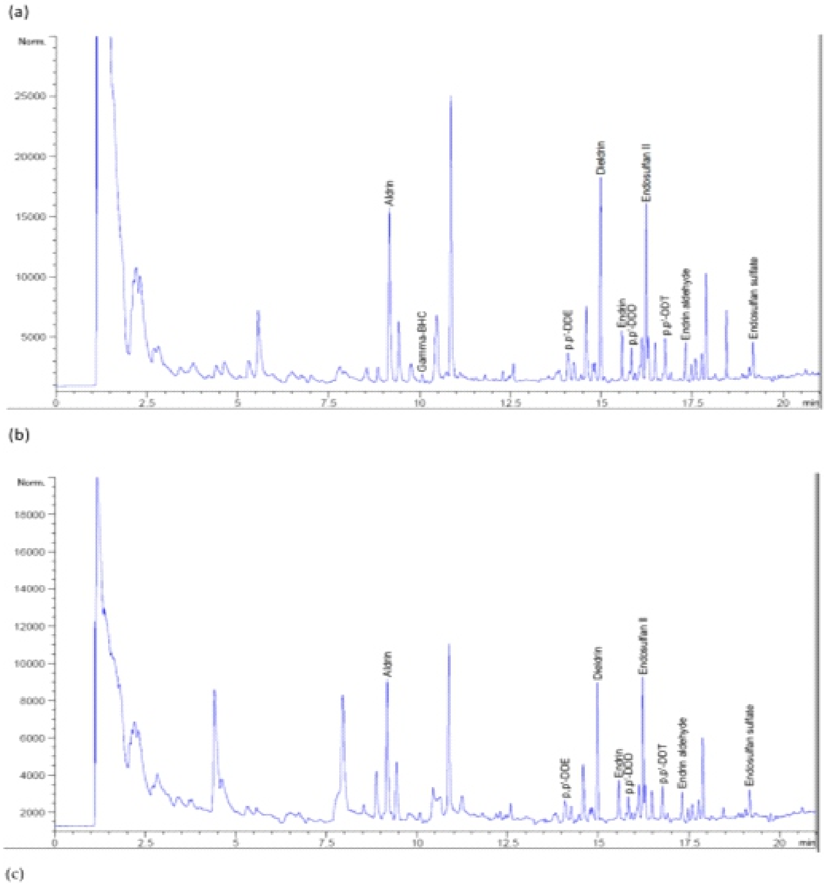


Figure 9: Representative Organochlorine Pesticide (OCPs) Chromatogram of Cowpea (b) and Bean (c) Samples Analyzed. (Source: Olutona and Aderemi, 2019)

Melon (*Colocynthis citrillus* L.), an herbaceous annual vegetable belonging to the family Cucurbitaceae is an important vegetable globally. The oil and the seed are very rich in protein, oil, minerals, vitamins and good source of energy. Olutona and Daniel (2019) carried out an investigation on Organochlorine Pesticides Residues and Trace Metals in Melon. The comparative study was carried out in four different towns: Borgu, Morkwa, Suleja and Bida, all in

Niger State, and Saki, Oyo State Nigeria. The overall metal content per site of the studied elements in the selected sites was determined and it was in the following decreasing order: Mokwa > Bida > Suleja > Borgu > Saki. The mean metal concentrations were in the following decreasing order: Pb > Zn > Ni > Co > Cd. With exceptions of locations where Ni and Pb were below detection limit, the concentrations of Pb, Cd and Ni in other locations were above WHO/FAO recommended limit. Concentrations of Zn and Co were below WHO/FAO limits. Out of 17 isomers of OCPs analyzed only five isomers were detected. The overall OCPs content per site of the studied elements in the selected sites was determined and it was in the decreasing order: Bida > Borgu > Saki > Suleja. OCP was not detected in melon samples obtained from Mokwa. With exception of endosulfan II, endrin aldehyde, heptachlor, DDE and λ –BHC were above their respective maximum residual limit.

Olutona et al (2021) carried out a study on OCPs and trace metals in vegetables (cabbage, onion, garlic, ginger and carrot) obtained from Iwo market. Trace metals analysis revealed that Cd and Cr and were not detected in all the samples, while Pb, Cu, Mn and Zn were above WHO/ FAO limit for food samples (Table 7). Residues of organochlorine were detected in all the vegetable samples except onions. Fifteen isomers of OCPs were detected at varying concentrations. The total burden of OCPs (Table 8) in the samples was in the following order: Ginger> Carrot> Cabbage> Garlic. Total metal burden of the vegetables in decreasing order of Cabbage > Garlic > Carrot > Onion > Ginger. Human exposure to accumulated concentration of OCPs and heavy metals in food via food consumption can be related to several neurological developmental disorder, infertility, reproductive and immune system disorders.

Table 7: Mean values (μg/g) of trace metals in vegetables

Sample	Pb	Cu	Zn	Mn	Cr	Cd	Total metal burden
Carrot	14.8±1.8	13.7±2.8	72.3±3.1	38.3±4.3	<0.005	<0.0028	139
Onion	10.1±1.4	4.7±1.7	56.7±5.2	11.9±1.6	<0.005	<0.0028	83.4
Cabbage	11.2±2.8	1.5±0.1	67.5±2.8	106±4.2	<0.005	<0.0028	186
Garlic	14.0±2.9	20.4±1.4	112±4.2	19.9±2.8	<0.005	<0.0028	166
Ginger	13.9±4.2	6.2±1.4	20.0±4.2	35.6±5.7	<0.005	<0.0028	75.7
WHO/FAO	2.00	10.00	40.00	–	2.3	0.02	–

Table 8: Mean values (μg/g) of cyclodiens, dichlorodiphenylethene, and hexachlorocyclohexanes isomers (Source: Olutona et al. 2021)

OCPs	Carrot	Onion	Cabbage	Garlic	Ginger	MRL
Aldrin	<DL	<DL	3.3±0.1	<DL	44.2±2.8	0.05
Endrin	0.03±0.02	<DL	0.02±0.0	0.2±0.02	<DL	0.01
Dieldrin	<DL	<DL	2.1±0.03	0.03±0.01	<DL	0.02
Endrin aldehyde	4.9±0.03	<DL	0.2±0.2	0.9±0.00	<DL	0.01
α-Endosulfan	<DL	<DL	0.9±0.13	3.9±0.14	<DL	0.10
β-Endosulfan	4.3±1.4	<DL	2.6±0.1	0.03±0.01	<DL	0.10
Endosulfan sulphate	0.02±0.01	<DL	0.2±0.1	0.04±0.02	<DL	0.10
Heptachlor	<DL	<DL	<DL	<DL	2.7±0.13	0.02
Heptachlor epoxide	<DL	<DL	0.09±0.01	0.14±0.02	<DL	0.02

DL Detection limit

OCPs	Carrot	Onion	Cabbage	Garlic	Ginger	MRL
Methoxychlor	0.70±0.1	<DL	2.40±0.3	0.05±0.01	<DL	0.01
p.p'-DDT	0.22±0.01	<DL	0.01±0.1	0.32±0.3	<DL	0.05
p.p'-DDD	<DL	<DL	<DL	0.01±0.01	<DL	0.05
p.p'-DDE	3.98±0.1	<DL	1.70±0.1	0.44±0.3	<DL	0.05

DL Detection limit

OCPs	Carrot	Onion	Cabbage	Garlic	Ginger	MRL
α-BHC	<DL	<DL	<DL	<DL	0.95±0.02	0.05
β-BHC	<DL	<DL	<DL	<DL	<DL	0.05
δ-BHC	<DL	<DL	0.14±0.1	<DL	<DL	0.05
λ-BHC	<DL	<DL	<DL	<DL	<DL	0.05

(Source: Olutona et al. 2021)

Dietary Intake and Risk Assessment of Heavy Metals from Selected Biscuit Brands in Nigeria were carried out by Arigbede et al (2019). Biscuits are commonly consumed by all age groups particularly children in Nigeria. However, this food item may be contaminated with heavy metals picked up from the ingredients, production and packaging methods. The observed mean concentrations of trace metals were ND-12.5 mg/kg Mn, 5.64-157 mg/kg Zn, ND-46.4 mg/kg Cr, 99.4-296 mg/kg Fe, 3.11-92.0 mg/kg Pb. Cu and Cd were not detected in all the biscuit samples. It was observed that Cr and Pb were higher than Food and Agricultural Organization/ World Health Organization (FAO/WHO) safe limit for cereals and cereal-based food products. The estimated dietary daily intake values of Cr and Pb surpassed their permissible intake limits, while the intakes of beneficial nutritive metals, such as Zn and Fe, from the ingestion of these food products were quite low and contributed insignificantly to the dietary requirements of Zn and Fe. The overall estimated target hazard quotient (ΣTHQ) values for the heavy metals were high suggesting possible health concern for infants, school children and adults who consume these products consistently on a daily basis over a long period of time.

Mr. Vice-Chancellor Sir, Food and beverages industry is the largest of all sectors covered by the Manufacturers Association of Nigeria (MAN). Food and beverage industries constitutes various sub-sectors such as brewery, soft drink, flour-mill, cereal and bakery products, dairy products, animal feeds (livestock and fishery), meat and meat products, tea and coffee, sugar and sugar confectioneries, margarine, edible oils, root and tubers, fruits and vegetables, spices and flavors. Food raw materials can be divided into four major classes: Unprocessed agricultural products: which are usually in their natural state e.g. cassava, yam, grains, fruits, vegetables etc.; Semi-processed agricultural products: in form of dry-cocoa beans, dry sugar, pasteurized milk, grain flour, cocoa mass, malted grains etc. Finished products: - of a particular industry can serve as material or ingredient for another industry e.g. refined granulated sugar, starch, Ascorbic acid, flavor etc.; Bye-product or effluent: of an industry can serve as input for another industry e.g. molasses can be used for the production of alcohol and yeast, while biscuit dust can be used for the production of animal feed. Food raw materials, whether primary agricultural produce, secondary or tertiary raw materials are obtained from the soil. It is therefore necessary to pay attention to Nigerian soil. Soil is the major sink of these pollutants. The potentially toxic metals of farmland in major parts of Iwo were studied by Olutona et al (2017). Their findings showed that the levels of PTMs in farmland of Feesu and Ori-Eru were significantly higher (at $P < 0.05$) than the value obtained at Bowen farmland with Feesu farmland having the major exposure to metals. The metal enrichment of these sites was attributed to anthropogenic activities such as vehicular emission and uncontrolled dumping of metal-containing scraps and used items along the vicinity of these farmland. Table 9 presents the carcinogenic and non-carcinogenic health risks of metals in farmland soils. The chronic daily intake (CDI) values for non-carcinogenic (oral) exposure in children were much lower than the values obtained for adults. This also suggests that the adult who engaged in farming activities on the soils of the sites studied were more vulnerable to metal-induced hazards than children.

Table 9: Carcinogenic and Non-Carcinogenic Health Risks of Metals in Farmland Soil

Site	Human Classification	CDI Non-Carcinogenic Adult x 10^6			CDI Carcinogenic		
		Pb	Cu	Zn	Pb	Cu	Zn
Ori-Eeru	Adult	30.9	22.5	70.3	0.003	0.002	0.006
	Child	28.8	20.9	65.6			
Feesu	Adult	26.6	13.7	102	0.002	0.001	0.009
	Child	24.4	12.8	95.1			
Bowen	Adult	7.7	5.7	51.9	0.0007	0.0005	0.005
	Child	7.2	5.3	48.4			

(Source: Olutona et al. 2017)

Drug

Mr. Vice-Chancellor Sir, In November 2021, the Federal Government of Nigeria through the Directorate of technical Aid Corps seconded me to Kampala international University, Uganda. I taught in the School of Pharmacy of their western campus. One of the researches conducted while there was on heavy metals in over-the-counter pediatric drugs locally produced in Uganda. The results of our findings revealed the presence of Pb and Cd. The average values (µg/mL) found were as follows: antihistamine (Cd, 0.89±0.122; Pb, 7.01±10.0); cold and flu (Cd, 0.89±0.073; Pb, 1.69±0.718); cough expectorant (Cd, 0.14±0.0196; Pb, 1.55±1.332); and antipyretics and analgesic (Cd, 0.16±0.774; Pb, 1.76±1.123). Antihistamines and medications for the cold and flu were not detectable in sample codes (A1 and B1), respectively. In every sample examined, manganese levels were below the non-detectable threshold. The different coefficient of variation (CV) values found in this investigation demonstrated that the metals in pediatric medications came from a wide variety of sources. According to total metal content, each brand of pediatric medication contains Antihistamine (56%), Antipyretic and analgesic (15%), Cold and flu (15%), and Cough expectorant (14%). Pretentious that these medications are given to children in doses of 10 mL three times per day, the amount of Pb and Cd they may consume would be significantly higher than the permissible daily exposure (PDE) recommended by the United States Pharmacopoeia (USP), International Conference on Harmonization (ICH), and European Medicine Agency (EMEA) (Olutona and Mulungi, 2022)

Soil/ Sediment

Most of the studies on heavy metal pollution usually centered on soil, sediment, food and water specifically total concentration and speciation studies. Sediment are sand, soil and mineral elements usually washed away from land as runoff owing to precipitation into the river body. Both soil and sediment act as a sink to pollutant such as heavy metals, persistent trace organic and inorganic pollutants. These pollutants affect water body at high concentrations. A study of heavy metals concentration in topsoil of Obafemi Awolowo University, Ile-Ife using ICP-OES revealed the presence of actinide, rare-earth metals and some other elements which had not been reported in previous studies. The presence of elements at this dumpsite could be attributed to erratic anthropogenic activities taking place at the university community. The levels of the heavy metals present in the soil revealed that the elements were contaminated at varying degree and could cause health hazard (Olutona et al. 2020).

Urban roadside soil is also recipient of heavy metals and trace organic pollutants from various sources such as industrial effluent, vehicular emission, fossil fuel burning, roadside mechanics, bus terminals, roadside traders etc. A chemical speciation study of five trace metals of major roadside topsoil of nine major roads in Iwo was carried out by Olutona et al. (2012). The study revealed that total metal concentration (μg/g) were in the following order: Fe (173±11.64) > Mn (104.5±10) > Zn (51.6 ±2.6) > Pb (0.89±0.06) > Cd (0.41±0.03). Speciation study showed that most of Mn and Fe were associated with Mn-oxide bound followed by organic matter; Zn associated with organic natter followed by exchangeable fraction while Pb and Cd showed similar pattern for all fractions. The physicochemical parameter showed that that the soil was alkaline in nature. The mobility factor for the five metals were Fe (42.88±1.54); Zn (44.28 ±1.54); Mn (41.7±2.45); Pb (44.67±1.57); and Cd (43.88±3.21). Geo-accumulation index showed that the roadside soil was practically unpolluted with Mn, Zn and Pb but moderately to heavily polluted with Cd.

A study of effect of organic-based *Gliricidia* biochar (GB), bamboo biochar (BB), maize crop residue biochar (MB), *Chromolena odorata* compost (COC), *Panicum pubescens* compost (PPC), activated charcoal and poultry manure (PM) were studied on Cd and Pb polluted soil in Olodo village in Egbeda LGA of Oyo by Odekunle et al. (2018). The study showed that all amendment increased selected chemical properties in the post-harvested contaminated soil with PM having the greatest increase with respect to soil pH, total nitrogen, phosphorus, calcium, magnesium and extractable cation exchange capacity (ECEC). The study further concluded that the use of organic amendments as soil conditioner is a promising, cost-effective way of improving health of contaminated soils.

The distribution of OCPs in bottom sediment of Aiba reservoir for all the four locations revealed the presence of OCPs. Despite the evidence of presence of all the three categories of OCPs in all the locations, endosulfan III was not detected in all locations. Analyses show the presence of α-BHC, β-BHC, γ -BHC, δ-BHC and heptachlor in 100% of the samples; γ -Chlordane in 87.5% of the samples; endrin ketone in 75% of the samples; pp-DDD, endosulfan I and endrin in 62.5% of the samples; pp-DDE, pp-DDT, heptachlor-epox and aldrin in 50% of the samples; α-Chlodane, dieldrin, endosulfan II and methoxychlor in 25% of the samples; and endrin aldehyde in 12.5% of the samples (Olutona et al. 2014). The values obtained for various OCPs compounds both in water and sediment in this study were above the stipulated guideline values to chemicals from agricultural activities to the area of health significance in drinking water by WHO.

Olutona et al (2016) assessed the levels of PBDEs in bed sediment of Asunle stream along three traverse communities. Their findings showed that the overall mean concentrations of the total PBDEs ranged from 1.80 to 9.46 ng/g. The results showed that the concentrations of the PBDEs were slightly higher during the wet season than those during the dry season (Table 10). In all the studied locations, BDE28, BDE47, BDE99, BDE100, BDE153, and BDE154 were detected in all the sediment samples at concentrations that ranged from 0.73 to 10.43 ng/g. Results of this study indicated that BDE153 was the major pollutant of the Asunle stream sediments. Their findings further revealed that local demands of polymer products and electronics are increasing within the university community, thus, there is the tendency for used polymer and electrical and electronic wastes at the dumpsite to accumulate, and hence, levels of BFR concentrations may continue to increase. This will inadvertently lead to increased contamination of Asunle water body with BFR. Hence, the rural dwellers using the water and the aquatic habitat within the stream vicinity might be negatively impacted.

Table 10: Monthly variation of PBDEs (ng/g) in bed sediment of Asunle stream

	BDE28	BDE47	BDE99	BDE100	BDE153	BDE154	Σ_6PBDEs
Nov	0.59 ± 0.61	0.21 ± 0.36	0.82 ± 0.70	1.23 ± 0.97	37.48 ± 48.97	0.83 ± 1.18	6.86
Dec	0.58 ± 0.64	0.14 ± 0.22	0.84 ± 0.66	1.24 ± 1.03	17.29 ± 22.06	0.66 ± 0.71	3.46
Jan	0.58 ± 0.64	0.35 ± 0.29*	0.91 ± 0.77	1.37 ± 0.25	6.57 ± 6.89	1.00 ± 0.60	1.80
Feb	0.66 ± 0.73	0.63 ± 0.19*	1.32 ± 0.36	0.96 ± 1.05	17.25 ± 20.52	0.51 ± 0.85	3.56
May	0.45 ± 0.71	0.24 ± 0.38	0.73 ± 0.62	0.52 ± 0.82	10.25 ± 20.38	0.17 ± 0.41	2.06
Jun	0.85 ± 0.67	0.48 ± 0.12*	1.21 ± 0.18	1.58 ± 0.86	17.06 ± 19.53	0.84 ± 0.95	3.67
Jul	0.65 ± 0.72	0.21 ± 0.33	0.86 ± 0.70	1.16 ± 1.35	29.19 ± 39.41	0.74 ± 0.95	5.47
Aug	0.59 ± 0.64	0.31 ± 0.39*	1.28 ± 0.30	1.29 ± 1.00	52.69 ± 110.82	0.62 ± 0.48	9.46

*Mean values are significantly different at $p < 0.05$

(Source: Olutona et al. 2017)

The health risk assessment of heavy metals in bed sediment of Asunle stream was also conducted using ICP-OES and reported by Olutona (2023). The potential health risk assessment was calculated for a lifetime exposure (ingestion) based on the United State Environmental Protection Agency (USEPA) models to determine the carcinogenic and non-carcinogenic risks for children and adults. The range of values (mg/kg) of heavy metals in bed sediment were: Fe (2850 – 7260), Mn (58 – 209), Co (0.7 – 33), Ti (21.6 – 67), Ba (1.61 – 9.81), Zn (7.5 – 79), Cu (5.6 – 25), As (8 – 137), Al (273 – 2160), Y (24 – 49), and Sr (0.10 – 5.3). As and Sr, values were below the background values for typical soil. The health risk assessment of heavy metals in the bed sediments revealed that carcinogenic risk was almost insignificant while the non-carcinogenic risk was significant since their values were above the recommended minimal risk level. The results also revealed that children are more vulnerable to hazards than adults (Tables 10 & 11). The chronic hazard quotient index for exposure to these metals through ingestion exceeded the acceptable USEPA value of 1.0 (Table 12).

Table 10: CDI for Non- Carcinogenic Risk (oral) for Children in Sediment of Asunle Stream (x 10^6 mg/kg/day)

	Fe	Mn	Co	Ti	Ba	Zn	Cu	As	Al	Y	Sr
Nov	3610	69.05	1.91	22.1	-	50.38	9.06	14.28	1290	-	2.59
Dec	51240	112	0.75	32.95	2.92	70.84	18.76	8.61	1690	-	3.93
Jan	7000	127	2.97	32.1	6.09	80.66	14.68	15.65	2210	25.02	5.37
Feb	7420	127	2.97	32.1	6.09	80.66	14.68	15.65	2210	25.02	0.28
May	5080	98.1	26.1	60.23	7.90	12.65	24.59	116.71	1460	-	0.45
Jun	5080	126	21.2	28.43	3.18	16.69	13.56	46.95	1020	-	0.10
July	3390	76.1	31.9	25.47	1.65	8.75	5.75	63.38	717	-	-
Aug	2910	59.1	34.2	27.96	-	7.69	12.86	139.83	279	-	3.30

(Source: Olutona, 2023)

Table 11: CDI for Non-Carcinogenic Risk (oral) for Adult in Sediment of Asunle Stream (x10^6 mg/kg/day)

	Fe	Mn	Co	Ti	Ba	Zn	Cu	As	Al	Y	Sr
Nov	3060	58.69	1.62	18.75	-	42.83	7.71	12.14	1100	-	2.19
Dec	4460	95.81	0.634	28.02	2.48	60.22	15.95	7.31	1430	-	3.34
Jan	5950	108.11	215.3	27.26	5.18	68.56	12.47	13.30	1880	21.27	4.56
Feb	6300	182.05	4.38	58.09	8.52	27.02	21.43	2898	930	42.38	2.35
May	4320	83.36	22.14	51.20	6.72	10.75	20.90	99.20	1240	-	0.38
Jun	4320	107.34	18.05	24.16	2.70	14.19	11.53	39.90	8.66	-	0.09
July	2880	64.67	27.09	21.65	1.39	7.44	4.89	53.88	609	-	-
Aug	2480	50.22	29.07	23.76	-	6.54	10.93	118.86	237	-	2.81

(Source: Olutona, 2023)

Table 12: Total Chronic Hazard Quotient Index (x 10^6) of the Heavy metals of Sediment of Asunle Stream

	Minimum Value		Maximum Value		Mean Value	
	Child	Adult	Child	Adult	Child	Adult
Mn	1284.35	1091.75	2765.00	3957.61	2161.96	2038.72
Co	37.30	3.70	1709.50	10766.00	762.16	1989.28
Ba	0.00	0.00	39.50	42.60	17.39	16.87
Zn	384.50	327.00	8345.00	3430.00	2990.81	1484.94
Cu	143.75	122.25	614.75	535.75	175441.70	330.66
As	28700.00	24366.67	466100.00	9660000.00	175441.70	1351079.00

(Source: Olutona, 2023)

The levels of PBDEs in dumpsite soil of OAU was analyzed using GC-MS/MS by Olutona et al. (2019). The mean values and range (ng/g) of PBDEs were: BDE 28 (0.79±0.72; Nd-1.65); BDE 47 (0.36±0.34, Nd-0.84); BDE 99 (0.85±0.59, Nd-1.74); BDE 100 (1.04±0.98, Nd-2.48); BDE153 (13.8±29.2, Nd-106); and BDE 154 (0.74±0.98, Nd-3.19). Total burden of the PBDEs in 0-15 cm soil layer were higher than those in the 15-30 cm layer. The results of this study indicated that the levels of PBDEs were higher in the dumpsite soil samples during wet season which portend high risk to human and the environment. PBDEs were detected in all the soil samples in the study area. This study showed elevated PBDE concentrations in top soil. The mobility of these contaminants through the soil strata as well as leaching through the underlying soil was also established. The seasonal variability of these contaminants in different matrices showed that higher levels were generally found during the wet seasons. The occurrence of PBDEs to the observed levels in the dumpsite could be attributed to the fact that the dumpsite has been the central and major solid waste management center since the inception of the University more than five decades ago. In addition to the age of the dumpsite, other factors such as frequency of precipitation, temperature, moisture content, various degradation periods owing to waste type are capable of influencing the quality and quantity of degradation and leaching of PBDEs from the residential, academic and health wastes that have been generated annually owing to increasing population size of the University community from time to time. The combination of these factors plays a critical role in the pattern of results observed.

Current Research

Mr Vice-Chancellor Sir, our current research focuses on the occurrence, environmental impact, and fate of pharmaceutical compounds in groundwater and surface waters, specifically in Nigeria and Uganda. This is a comparative study between the two African nations. Pharmaceutical active compounds are among the emerging contaminants. Our preliminary reports have revealed contamination of groundwater and surface water at varying concentrations, which can pose health hazards for those consuming this water (Sanusi et al, 2024a,b). Furthermore, our ongoing investigation centres on developing biodegradable anticorrosive and antimicrobial coating systems that incorporate hybrid nanoparticles. A significant aspect of this work is the use of triglyceride oil derived from castor seeds as a renewable oil base for synthesising polyurethane, polyesteramide, and polyetheramide. Ricinus communis L., known as the castor oil plant, belongs to the Euphorbiaceae (spurge) family. Castor seed oil (CSO) is a non-edible, non-volatile, and non-drying triglyceride that can be used to formulate various urethane coatings without requiring modifications.

Figure 10: Castor Oil Plant, Castor Oil Seed and Dehulled Castor Bean

Future Research

Mr. Vice-Chancellor Sir, my future research focuses on the Sustainable Development Goals (SDGs) 3 and 6. I aim to make a stronger and more positive impact on the global community in these two areas, specifically regarding per- and polyfluoroalkyl substances (PFAS) and plastic pollution. These two issues are emerging organic contaminants that pose a serious threat to the global community. Our investigations will centre on water, soil, sediment, and aquatic and marine habitats.

Plastic pollution has become a significant issue in Nigeria. Both urban and rural areas are littered with single-use plastic containers (Figure 11a). These wastes threaten the ecosystem, marine life, and public health (Figures 11b & c). The Punch Newspaper, on June 13, 2024, highlighted the need for Nigeria to tackle plastic pollution. As of today, humans have produced over 8.3 billion metric tons of plastic, and every piece of plastic ever made still exists somewhere in the world. The average decomposition time for these products (Figure 12) ranges from 20 years for plastic bags to 600 years for fishing lines (UNEP, 2020).

Figure 11a: Single-Use Plastics

Figure 11b: Plastic Waste Pollution (Luis Acosta/AFP/Getty. The Guardian Photograph)

Figure 11c: Aquatic and Marine Habitats ingesting Microplastics (Sources: National Geographic and Max Paoli)

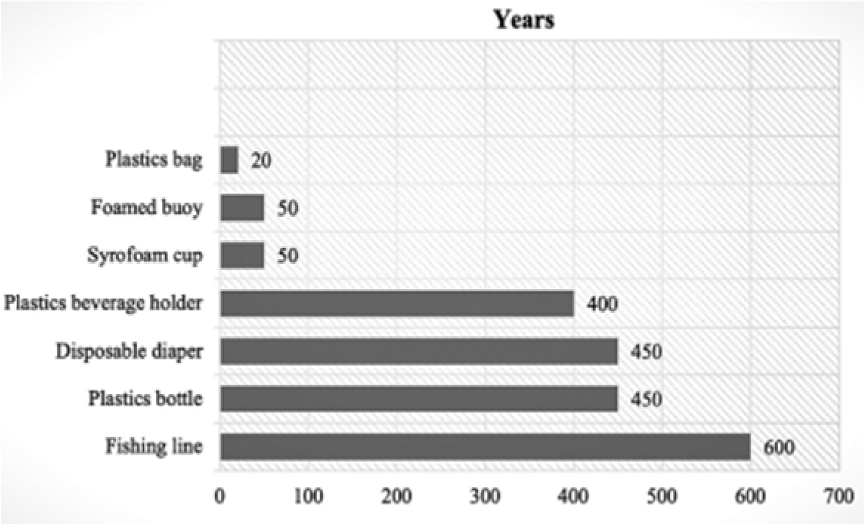


Figure 12: Average Decomposition Time of (Plastic Products) Marine Debris (UNEP, 2020)

The PFAS are frequently utilized as intermediates or additives in the synthesis of fluorine compounds in the production of consumer, biomedical, and industrial goods such as food packaging, nonstick coatings, surfactants, cooking utensils, fire retardants, etc. PFAS are otherwise known as "forever chemicals" because of their persistent nature in the environment (Dhore and Murthy, 2021), and toxic and endocrine disruptors. PFAS are non-degradable; this attribute could be due to the perflorination C-F bond being of improved strength and the strongest bond in organic chemistry and well as high electronegativity of fluorine (Cousins et al. 2020) PFAS have demonstrated several environmental and human health vulnerabilities (Cousins et al. 2020). PFAS are non-degradable; this attribute could be due to the perflorination C-F bond being of improved strength and the strongest bond in organic chemistry and well as high electronegativity of fluorine (Cousins et al. 2020). Also, PFAS have demonstrated several environmental and human health vulnerabilities (Cousins et al. 2020).

Conclusions

In view of the evidence presented in this lecture, it is clear that much of the groundwater and surface water in this nation is polluted and not fit for human consumption without adequate treatment. Most of the processed food and drinks produced and sold locally in Nigeria are contaminated with various chemical substances (both inorganic and organic) that act as endocrine disruptors. The indiscriminate use of banned agrochemicals still persists in Nigeria today. Inefficient management and oversight by the regulatory body is a significant factor contributing to food contamination.

Recommendations

1. The use of biochar as a replacement for fertiliser. Biochar is a by-product of biomass pyrolysis, highly rich in aromatic structures that enhance soil humus. It plays a crucial role in increasing soil carbon storage, improving nutrient retention and availability, and maintaining the balance of soil ecosystems. Biochar replenishes the soil and has the potential to mitigate climate change.
2. The practice of organic farming should be encouraged in Nigeria, as it discourages the use of synthetic fertilisers and pesticides, aiming to minimise their environmental effects and reduce food contamination from pesticides and high levels of nitrates.
3. The Federal Government should implement relevant regulatory measures to control the importation and use of priority pollutant chemicals and products containing them.
4. Regulatory government agencies should develop an inventory of chemicals, including those whose production and use have been banned or restricted in other countries. Similarly, a comprehensive inventory of waste generation, types, and opportunities for reuse or recycling should be established and maintained for national planning and research purposes.
5. Like other developed nations such as China, Japan, and the United States of America, the Federal Government of

Nigeria should encourage private industries to allocate a certain percentage of their annual budget for research and development. This would enhance the research output of universities and other institutions of higher learning.

6. Collaborative and strategic partnership between industry (town) and academia (gown) are highly essential for the growth of research and development in Nigeria. Every industry should be encouraged to allocate a portion of their annual budget for research and development initiatives.

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