Assessment of Heavy Metals and Organic Compounds in Water and Leachate from Aba-Eku Municipal Solid Waste Site in Ibadan, Oyo State, Nigeria.

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Certification

This is to certify that **Morolake Oluwatoyosi AFOLABI** with the matriculation number LCU/PG/002246, carried out this research work titled "**Assessment of Heavy Metals and Organic Compounds in Water and Leachate from Aba- Eku Municipal Solid Waste Site in Ibadan, Oyo State, Nigeria..**" in the Department of Biological Sciences, Faculty of Natural & Applied Sciences, Lead City University Ibadan, Oyo State, for the award of Master of Science Degree (MSc) in Environmental Management and Toxicology and this has not been previously submitted.

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(Head of Department)

Dedication

This thesis is dedicated to Almighty God, to my husband and family.

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Even though the above-mentioned institutions and persons have assisted in the process of this research work, I alone stand responsible for the errors, if any, found in the work.

Abstract

Increase in waste generation, resulting from population growth, has led to a burden on global health. Physico-chemical, organic analysis, and leachate pollution index analysis were conducted on the water samples from Aba Eku dumpsite (latitudes 3°35'N and 4°10'N and longitudes 7°2'E and 7°40'E.). Relationships among various parameters were also analysed using correlation coefficients (r) and significance levels (p values). Water samples revealed high concentrations of physico-chemical parameters, heavy metals, also Polyaromatic hydrocarbons (PAHs), and phthalate esters were present. Notably, the dumpsite exhibited highest concentration of naphthalene among all the PAHs. These findings indicate that the landfill site is polluted with PAH and phthalate compounds. Significant relationships among parameters were observed, including a strong negative correlation between pH and both BOD ($r = -0.932$) and dissolved oxygen ($r = -0.912$). Total dissolved solids showed significant positive associations with chloride ($r = 0.977$, $p < 0.05$), total hardness ($r = 0.889$), sulphate ($r = 0.955$, $p < 0.05$), and phosphate ($r = 0.836$). BOD exhibited a strong positive correlation with dissolved oxygen ($r = 0.984$, $p < 0.05$) and NO-3 ($r = 0.742$), while chloride demonstrated significant positive correlations with total hardness ($r = 0.942$), sulphate ($r = 0.994$, $p < 0.01$), and phosphate ($r = 0.796$). Significant differences ($P < 0.001$) were found between leachate and 300m location, leachate and 600m location, as well as leachate and the river location. No significant differences ($P > 0.05$) were detected among other locations. Leachate pollution index (LPI) values of water samples around the dumpsite ranged from 5.558 to 7.683, indicating slight contamination from heavy metals. The pollution from the landfill site, and surface runoff, poses a significant risk to quality of both underground water and river. Urgent remediation, waste management strategies should be implemented to mitigate the pollution.

Keywords: Leachates, Heavy Metals, Leachate Pollution Index, Physicochemical Parameters.

Word Count: 300

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List of Acronyms

Abbreviation	Meaning
AAS	Atomic Absorption Spectroscopy
USEPA	United States Environmental Protection Agency
ANOVA	Analysis of Variance
GC	Gas Chromatography
GC-MS	Gas Chromatography Coupled to Mass Spectrometry
HPLC	High Performance Liquid Chromatography
PAHs	Polycyclic Aromatic Hydrocarbons
LPI	Leachate Pollution Index
MSW	Municipal Solid Waste
PAEs	Phthalate Esters
DEHP	Di (2-ethylhexyl) Phthalate
EPA	Environmental Protection Agency
USA	United States of America
APEs	Alkylphenol Polyethoxylates
PFCs	Perfluorinated Compounds
VOC	Volatile Organic Compounds
PCBs	Polychlorinated Biphenyls
POP	Persistent Organic Pollutants
DDT	Dichlorodiphenyltrichloroethane
PVC	Polyvinyl Chloride
PET	Polyethylene Terephthalate

OECD	Organization for Economic Cooperation and Development
EDCs	Endocrine Disruptive Chemical
SWM	Solid Waste Managements
BPA	Bis-Phenol

Chapter One

Introduction

1.1 Background to the Study

Waste was not a threat before, not until urban populations began to increase rapidly. People's consumption, usage of solid materials that eventually result in magnanimous solid wastes is a result of globalization. Solid wastes are defined as non-liquid or nongaseous products for example of human activities that are unwanted[1]. The generation of Municipal solid waste (MSW) increases in line with the developmental rate of any country. Africa according to research is the least developed region in the world having 38% urbanization. Although compared to many other countries in the world this is low, African countries are experiencing rapid development with a growth rate of four percent per annum[2]. African countries are now faced with huge amounts of MSW which has a direct effect on human health, safety and the environment.

In light of population expansion, fast urbanization, and rising per capita trash creation, waste management is a critical issue in both developed and developing countries[3,4,5]. Methods of disposal that have invariably increased municipal solid waste (MSW) load include sanitary landfill, composting and incineration. According to World Bank Data, in 2016, the municipal solid waste (MSW) generated by the world is about 2.01 billion tons; at a rate of about 0.74kg/capita/day. In 2005, about 262.4 million tones' of MSW was generated at the rate of 4.48 pounds/capita/day in the US[6]. In the metro cities of India, about 3 billion people are responsible for the generation of MSW at the rate of 1.2 kg/capital/day[7]. In East Asia and the Pacific, 777 million people are responsible for waste generation, at the rate of 738,959 tons/day and 0.95 kg/capita/day. Latin America and the Caribbean of about 400million people generate 437545 tons of MSW in a day at the rate

of 1.09 kg/capita/day; about 426 million people in South Asia, are responsible for 192411 tons of MSW in a day at the rate of 0.45 kg/capita/person. MSW generation data for the region, in 2012 also stated that 261 million people are responsible for 169120 tons of MSW per day in Africa at the rate of 0.65 kg/capita/day[8]. In Nigeria, around 196 million people produce 32 million tons of solid municipal waste each year, of which roughly 20%–30% is collected. More than 730412 individuals generate 370706 tons per year in Onitsha, and the commercial center of Lagos generates 370706 tons per year[9].

Nowadays, waste collection, treatment, transportation, storage, and eventual disposal of waste is the major problems of urban areas[10,11,12]. Solid wastes, mounds of rubbish, garbage and sewage are produced every day and, in an attempt, to dispose of these materials, the environment has been carelessly polluted. Consequently, there is relatively poor waste management practices enhanced by indiscriminate dumping of refuse in water bodies and isolated places[13,14].However, a major concern is that there are no adequate infrastructural facilities and appropriate land use planning to match up with the demands posed by the urban growth rate, especially the rural areas in Africa[15,16].

This waste dumped indiscriminately pollute the environment by burning waste outside, thereby contaminating groundwater and surface water through leaching and runoff, harboring disease vectors, etc. Consequentially physical, chemical, and biological activities at municipal dumping grounds lead to the decomposition of trash, the production of leachate, and the release of landfill gases[17].

Leachates are formed when rainwater penetrates the waste at a dumpsite and dissolves the waste through biochemical activities that result in waste decomposition[18,19]. A series of biological and physicochemical transformations occur after waste is dumped in landfills,

and in turn, produces extremely polluted wastewater called leachate. Wastewater (leachate) may pollute nearby groundwater, surface water and as well as topsoil[20].

Leachate composition depends on its type, burying technique, and the area's geology site, climate, dumpsite age, and kind of garbage, and can typically comprise both dissolved and solid waste and suspended substances. Leachates include significant levels of dissolved organics and xenobiotic. Ammonia, heavy metals, inorganic salts, organic chemicals, and other poisonous substances[21,22].

Municipal landfill leachate has 200 organic compounds that have been discovered with up to 35 substances with the potential to cause harm to the environment and human health[23,24,25,26]. Leachates from municipal solid waste are very similar in composition to those from mixed or hazardous landfill. Municipal waste raises the soil's organic matter, pH, cation-exchange capacity, nitrogen content, and other soil properties[27]. However, excessive waste in the soil may raise the level of heavy metals in the groundwater and soil and may have adverse consequences on agriculture, soils, and public health[28,29]. Polycyclic aromatic hydrocarbons (PAHs) are one of the organic compounds found in dumpsite leachates[30,31].

PAHs are environmental contaminants that are comprised of more than two benzene rings. PAHs can bio accumulate in humans through the food chain[27]. PAHs are persistent organic compounds with toxic and carcinogenic capabilities[28,32]. Waste incineration is an important source of parent and halogenated polycyclic aromatic hydrocarbons (PAHs and HPAHs) in urban air. During incineration, PAHs are mainly derived from the incomplete incineration of organic matter in waste[32,33]. PAHs are soluble not easily in water, also attach easily to solid particles. Most types of PAHs in air, water and soil exist most in an

absorption state, they could migrate, under certain conditions, into environmental media, carrying along dust, rainfall and snow[34,35,36].

PAHs found in soil and surface groundwater normally diffuse into the atmosphere, being carried by escaping dust, and invariably causes toxic damage to human and animal body system through the respiratory system and ingestion. It has been verified that most PAHs e.g. BaP, BaA, ANT, are of high carcinogenicity, mutagenicity, genotoxicity and high teratogenicity[37].

As mentioned earlier, Leachate is mostly generated through the penetration of precipitated water into the dumpsites. PAEs (esters of phthalic acids) are easily released from this waste and are found in high concentrations in landfill leachate[38,39]. PAE presence in MSW leachate has been documented in many studies[40,41]. Penetration of leachate to ground and surface water can cause water contamination, rendering it unusable[42].

However, Phthalates, or esters of phthalic acid, are toxic, and ubiquitous environmental pollutants and some of them (e.g. butyl benzyl phthalate, DEHP etc.) are identified as hazardous compounds[43,44,45,46]. DEHP and some other phthalate compounds, according to EPA (USA) on its Toxicity Release Inventory are considered because of their toxicity and the evidence of pervasive human and environmental exposure to them[47]. They are compounds which consist of chemicals that cause adverse environmental or human health effects.

However main concerns of human and wildlife exposure to PAEs are the potential adverse effects on reproduction, fertility issues, the development of newborns, and carcinogenicity[48].

PAEs enter the human body through inhalation, ingestion and dermal absorption[49,50]. Because PAEs can bioaccumulate over long-term exposure, humans are at higher risk following continued consumption of contaminated water or food[5]. PAEs may potentially affect human testicular dysgenesis syndrome, reproductive development and sex reversal. PAEs acting as endocrine disruptors may contribute to many health problems such as hepatomegaly, osteoporosis, and feminization of boys, weight loss, and skin and breast cancer[51,52]. Pharmaceuticals and personal care items, as well as developing pollutants like phthalates, bisphenol-A, and non-ionic surfactants such alkylphenol polyethoxylates (APEs), Perfluorinated compounds (PFCs) and (PPCPs) are now detected typically in environmental matrices and in biota[53,54].

1.2 Statement of the Problem

Unmanaged and improperly managed waste from decades of economic growth requires urgent action at all levels of society[55]. Compounds, many of which are hazardous to human health and the environment, are present in dumpsite leachate and topsoil.

Dumpsite leachate can also seep through the soil into groundwater, percolates and run off into surface water[56].

Dumpsite leachate contains different hazardous substances, some of which threaten the environment and is one of the major concerns of urban areas the world over[57].

1.3 Justification of the Study

- The growing rates MSW generation, is alarming and has constituted a great problem for environmental managers and the government because most of these waste residues are discarded indiscriminately[58].

- The uncontrolled increase in waste generation rate will lead to a rise in environmental challenges if not well managed[59].
- Excessive waste in the soil may increase the heavy metal concentration of the soil and groundwater and may have harmful effects on soils, crops and human health[60,61,62].
- Municipal waste increases the nitrogen, pH, cation-exchange capacity, percentage base saturation and organic matter of soil[63].
- High PAH concentrations in soils and leachate are the result of accumulation from surface run-off, of municipal and industrial waste discharge, and aerial deposition from industrial pipes[64].

Thus, there is a need for public awareness on the harmful effects associated with dumpsite leachates and to discourage people farming and living on dumpsites or close to dumpsites[65].

1.4 Aim and Objectives of the Study

Aim of the Study

The aim of this study was to evaluate the pollution level of Aba-Eku (Ibadan) municipal landfill site by assessing the physico-chemical parameters and persistent organic pollutants in the landfill leachate and underground water.

The specific objectives of this study were to:

I. evaluate the level of heavy metals (Cu, Cr, Cd, Pb, Mn and Fe) in underground water on and around Aba-Eku open dumpsite.

II. evaluate the chemical parameters (pH, TS, COD, BOD, DO, chlorides, total hardness, nitrate, phosphate and ammonia of the leachates and the underground water around the open dumpsite.

III. determine the persistent organic pollutants (Polycyclic Aromatic Hydrocarbons (PAH) and Phthalates Esters (PAE) in leachates and the underground water around the open dumpsite.

IV. analyze and calculate the pollution index of Aba-Eku open dump site in Ibadan

1.5 Research Questions

1. What are the levels of some selected heavy metals present in the leachate and underground water around the dumpsite?
2. What is the pollution index of the open dumpsite?
3. What types of PAH are present in the dumpsite?
4. What are types of phthalates present in the dumpsite?
5. What are the environmental effects of this pollutants?

1.6 Significance of the Study

In Nigeria solid waste are indiscriminately disposed on open space and fallow land usually sited close to residential areas. Solid waste generally finds itself in the landfills and open dumpsites where it poses serious threats to aquatic systems and human health. The disposal of waste poses major environmental and public health problems in cities across the world. These open dumpsites are not properly managed hence, leachates generated from landfills pose a significant health risk to the ecosystem and general population.

Landfill leachates are a complex mixture of components such as dissolved organic matter, inorganic macro-components, heavy metals and a wide range of xenobiotic organic compounds that have the capacity to leach highly toxic substances into soil and underground water[66]. Amongst the many chemical compounds monitored from open dump sites and landfills are Phthalates esters (PAEs), Poly aromatic hydrocarbons (PAHs) and heavy metals that are believed to have some endocrine activity[67,68]. In literature, reports exist on the effects of landfill leachate in environmental matrices.

However, no known reports on:

- Spatial Physico-chemical parameters of the underground water of Aba-Eku landfill dumpsite.
- Leachate pollution index of the underground water of Aba-Eku landfill dumpsite.
- Types and distribution of persistent organic pollutants (phthalate esters and the polycyclic aromatic hydrocarbon of Aba-Eku landfill dumpsite.

Therefore, this study

I. examined the spatial pollution status of the underground and river water of Aba-Ekulandfill leachate
II. determined the leachate pollution index of Aba-Eku landfill site.
III. also assessed the phthalate compound on the dump site.
IV. will generated a baseline for further studies on Aba-Eku landfill site.

1.7 Scope of the Study

The physicochemical parameters (pH, total solids, COD, BOD, DO, chlorides, total hardness, nitrates, sulphates, phosphorus and ammonia), were analyzed along with selected heavy metals (Cu, Cr, Cd, Pb, Mn, Fe) were analyzed from the sampled leachates and underground water samples at spatial distribution with standard methods. The sampling carried out in this study was on and around Aba-Eku municipal dumpsite located at Lagelu Local Government Area, Ibadan Oyo State Nigeria.

1.8 Limitation of the Study

This study assessed the leachate pollution index of the municipal dumpsite, alongside the two groups of organic pollutants e.g. PAEs and PAH. The seasonal variation of the examined parameters was not considered. The management of the dumpsite was exposed and closely monitored us to reduce our access to some locations on the dumpsite. We were only allowed for a single collection.

1.9 Operational Definition of Terms

Dumpsite: An area of land where large amounts of waste materials are disposed or buried under the earth.

Waste: Unwanted or unusable materials, substances or by-products.

Solid Waste: The unwanted or useless solid materials generated from human activities in residential, industrial or commercial areas.

Municipal: Relating to a town or a district or its governing body.

Environment: The natural world in which people, animals and plants live, as a whole or in a particular geographical area especially as affected by human activity.

Pollution: The presence or introduction into the environment of a substance which has harmful or poisonous effects.

Plant: A living thing that grows in the earth and usually has a leaf stem and root.

Hazardous: Risky or dangerous, has potential to cause danger.

Anthropogenic: Originating from human activity.

Endnotes

1 US EPA, OLEM, *Criteria for the Definition of Solid Waste and Solid and Hazardous Waste Exclusions | US EPA. [online] US EPA*.2023. https://www.epa.gov/hw/criteria-definition-solid-waste-and-solid-and-hazardous-waste-exclusions.

2 E. Muzenda; M. Belaid, M. Mollagee, N. Motampane & F. Ntuli, *Reflecting on Waste Management Strategies for South Africa,* **World Congr Eng Comput Sci** 2, 2011, 19-21.

3 N. Ferronato, & V.W. Torretta*, Waste Mismanagement in Developing Countries: A Review of Global Issues*, **Int. J. Environ. Res. Public Health** 16 (6), 2019, 1060.

4 O.M. Ogundele, O.M. Rapheal & A.M. Abiodun, *Effects of Municipal Waste Disposal Methods on Community Health in Ibadan- Nigeria*, **Polytechnica** 1, 2018, 61–72.

5 USEPA, *Advancing Sustainable Materials Management: Assessing Trends in Material Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling in the United States*, 2015.

6 R.A. Ibikunle, I.F. Titiladunayo, B.O. Akinnuli, S.O. Dahunsi & T.M.A. Olayanju, *Estimation of Power Generation from Municipal Solid Wastes: A Case Study of Ilorin Metropolis, Nigeria***, Energy Reports,** 5, 2019, 126–135.

7 W. Fadhullah, N.I.N. Imran, S.N.S. Ismail, M.H. Jaafar, & H. Abdullah, *Household Solid Waste Management Practices and Perceptions among Residents in the East Coast of Malaysia*, **BMC Public Health,** 22(1), 2022.

8 B. Wale, *Energy. Energy Consult Powering Clean Energy Future, Solid Waste management in Nigeria*. 2022. https://www.bioenergyconsult.com/solid-waste-nigeria.

9 United States Environmental Protection Agency (EPA), *National Overview: Facts and Figures about Materials, Waste and Recycling, 2023*. https://www.epa.gov.

10 M.A. Kuddus, E. Tynan, & E. McBryde, *Urbanization: A Problem for the Rich and the Poor?* **Public Health Reviews**, 41(1), 2020.

11 J C.C. Aralu, P.A.C. Okoye, H.O. Abugu, & V.C. Eze, *Pollution and Water Quality Index of Boreholes Within Unlined Waste Dumpsite in Nnewi, Nigeria*, **Discover Water**, 2(1), 2022.

12 G. Chen, Y. Sun, Z. Xu, X. Shan & Z. Chen, *Assessment of Shallow Groundwater Contamination Resulting from a Municipal Solid Waste Landfill—A Case Study in Lianyungang,China,* **Water**, 11, 2019, 2496.

13 O.A. Adewoyin, *Earthworm Diversity and Abundance in Selected Dumpsites and Toxicity of Contaminated Water on Associated Fauna in Ibadan*, Ph.D. Thesis submitted to the Department of Zoology, University of Ibadan, Nigeria, 2016**.**

14 O.A. Adeyemi-Ade; A.T. Anifowoshe & S.I. Abdulkareem, *Ecotoxicological Assessment Of Leachate From Amilegbe Dumpsite, Ilorin, Nigeria Using Clarias Gariepinus* (Burchell 1822)

15 Ankit, L. Saha, V. Kumar, J. Tiwari, Sweta, S. Rawat, J. Singh, & K. Bauddh, *Electronic Waste and Their Leachates Impact on Human Health and Environment: Global Ecological Threat and Management*, **Environmental Technology & Innovation,** 24, 2021, 102049.

16 R. Keyikoglu, O. Karatas, H. Rezania, M. Kobya, J. Cortina, & A. Khataee*, A Review on Treatment of Membrane Concentrates Generated from Landfill Leachate Treatment Processes*, **Separation and Purification Technology**, 259, 2021, 118182–118182.

17 P. Rushbrook P., World Health Organization. Regional Office for Europe & European Centre for Environment and Health, *Guidance on Minimum Approaches for Improvements to Existing Municipal Waste Dumpsites*, **Copenhagen: WHO Regional Office for Europe**. 2021. Available Online: https://apps.who.int/iris/handle/10665/108432

18 C.C. Aralu & P.A.C. Okoye, *Assessment of Heavy Metals Levels in Soil And Vegetables in the Vicinity of Unlined Waste Dumpsite in Nnewi, Anambra State Nigeria,* **Journal of Chemical Society of Nigeria***,* 45(4),2020, 687.

19 L. Lindamulla, N. Nanayakkara, M. Othman, S. Jinadasa, G. Herath, & V. Jegatheesan*, Municipal Solid Waste Landfill Leachate Characteristics and Their Treatment Options in Tropical Countries***, Current Pollution Reports**, 8, 2022, 273–287

20 M. F. Zamri, M. A., Kamaruddin, M. S. Yusoff, & H. A. Aziz, *Semi-Aerobic Stabilized Landfill Leachate Treatment by Ion Exchange Resin: Isotherm and Kinetic Study*, **Appl.Water Sci.**, 7, 2017, 581–590.

21 M.S. Beldean-Galea, J. Vial, D. Thiébaut, & M.V. Coman, *Analysis of Multiclass Organic Pollutant in Municipal Landfill Leachate by Dispersive Liquid-Liquid Microextraction and Comprehensive Two-Dimensional Gas Chromatography Coupled with Mass Spectrometry*, **Environmental Science and Pollution Research**, 27(9), 2020, 9535–9546.

22 A. Pivato & L. Gaspari, *Acute Toxicity Test of Leachates from Traditional and Sustainable Landfills Using Luminescent Bacteria,* **Waste Manag,** 26, 2005, 1148–1155.

23 F. Parvin, & S.M. Tareq, *Impact of Landfill Leachate Contamination on Surface and Groundwater of Bangladesh: A Systematic Review and Possible Public Health Risks Assessment*, **Applied Water Science**, 11(6), 2021.

24 I. Schwarzbauer; S. Heim; S. Brinker & R. Litke, *Occurrence and Alteration of Organic Contaminants in Seepage and Leakage Water from A Waste Deposit Landfill*, **Water Resour.**, 36, 2002, 2275–2287.

25 R. Machado, I. Alves-Pereira, M. Robalo, & R. Ferreira, *Effects of Municipal Solid Waste Compost Supplemented with Inorganic Nitrogen on Physicochemical Soil Characteristics, Plant Growth, Nitrate Content, and Antioxidant Activity in Spinach***, Horticulturae**, 7(3), 2021, 53.

26 P. Kjelsen, M.A. Barlaz; A.P Rooker; A. Baun, A. Ledin & T.H. Christensen, *Present and Long-Term Composition of MSW Landfill Leachate: A Review*, **Crit Rev Environ Sci Technol.,** 32, 2002, 297–336.

27 A. Rashid, B.J. Schutte, A. Ulery, M.K. Deyholos, S. Sanogo, E.A. Lehnhoff, & L. Beck, *Heavy Metal Contamination in Agricultural Soil: Environmental Pollutants Affecting Crop Health*, **Agronomy,** 13(6), 2023, 1521.

28 Mohammad Reza Masjedi, Dobaradaran, S., Hossein Arfaeinia, Mohammad Reza Samaei, Novotny, T.E. and Rashidi, N. (2023). *Polycyclic Aromatic Hydrocarbon (PAH) Leachates from Post-Consumption Waterpipe Tobacco Waste (PWTW) into Aquatic Environment- A Primary Study***, Environmental Pollution,** 327, 2023, 121500–121500.

29 Smith CJ, Hopmans P, Cook FJ. *Accumulation of Cr, Pb, Cu, Ni, Zn and Cd In Soil Following Irrigation with Untreated Effluents in Australia*, **Environ Poll**. 94(3), 1996, 317–323.

30 Q.X. Deng, J.R. Feng, P. Gao, & H.G. Ni, *Combined Effects of Vehicles and Waste Incineration on Urban Air Halogenated and Parent Polycyclic Aromatic Hydrocarbons*, **Environment International,** 171, 2023, 107720–107720.

31 E. Klimiuk & D. Kulikowska, *The Influence of Hydraulic Retention Time and Sludge Age on the Kinetics of Nitrogen Removal from Leachate in SBR*, **Pol. J. Environ. Stud**., 13, 2004, 525.

32 S. Ma, M. Lin, J. Tang, R. Liu, Y. Yang, Y. Yu, G. Li, & T. *An, Occurrence and Fate of Polycyclic Aromatic Hydrocarbons from Electronic Waste Dismantling Activities: A Critical Review From Environmental Pollution To Human Health,* **Journal of Hazardous Materials,** 424, 2022, 127683.

33 A.B. Patel, S. Shaikh, K.R. Jain, C. Desai, & D. Madamwar, *Polycyclic Aromatic Hydrocarbons: Sources, Toxicity, and Remediation Approaches,* **Frontiers in Microbiology**, 11, 2020.

34 K. Hussain, R. Hoque, S. Balachandran, S. Medhi, M. I., Rahman, & F. L, Hussain, *Monitoring and Risk Analysis of PAHs in the Environment,* **Springer eBooks,** 2019, 973–1007.

35 G.R. Sampaio, G.M. Guizellini, S.A. da Silva, A.P. de Almeida, A.C.C. Pinaffi-Langley, M.M. Rogero, A.C. de Camargo, & E.A.F.S. Torres, *Polycyclic Aromatic Hydrocarbons in Foods: Biological Effects, Legislation, Occurrence, Analytical Methods, and Strategies to Reduce their Formation*, **International Journal of Molecular Sciences**, 22(11), 2021, 6010.

36 G.S. Na, C.Y. Liu, Z, Wang, L.K. Ge, X.D. Ma & Z.W. Yao, *Distribution and Characteristics of Pahs in Snow of Fildes Peninsula,* **J. Environ. Sci.**, 23 (9), 2011, 1445–1451.

37 H.I. Abdel-Shafy, A.M. Ibrahim, A.M. Al-Sulaiman, & R.A. Okasha, *Landfill Leachate: Sources, Nature, Organic Composition, and Treatment: An Environmental Overview*, **Ain Shams Engineering Journal,** 2023, 102293.

38 D.W. Gao & Z.D. Wen 2016, *Phthalate Esters in the Environment: A Critical Review of Their Occurrence, Biodegradation, and Removal During Wastewater Treatment Processes*, **Science of the Total Environment,** 541, 2016, 986-1001.

39 H. Liu; Y. Liang, D. Zhang; C. Wang, H. Liang & H. Cai, *Impact of MSW Landfill on the Environmental Contamination of Phthalate Esters*, **Waste Management**, 30, 2010, 1569-1576.

40 H. Chaturvedi, & P. Kaushal, *Survey Findings to Study the Socio-Environmental and Economic Impact of Msw Leachate on Neighboring Residents*, **SSRN Electronic Journal**, 6(1), 2019.

41 K.O.A. Amano, E. Danso-Boateng, E. Adom, D. Kwame Nkansah, E.S. Amoamah, & E. Appiah-Danquah, *Effect of Waste Landfill Site on Surface and Ground Water Drinking Quality*, **Water and Environment Journal,** 35(2), 2020, 715–729.

42 N.D. Baloyi, M. Tekere, K.W. Maphangwa, & V. Masindi, *Insights Into the Prevalence and Impacts of Phthalate Esters in Aquatic Ecosystems,* **Frontiers in Environmental Science,** 9, 2021

43 M. Balali-Mood, K. Naseri, Z. Tahergorabi, M.R. Khazdair, & M. Sadeghi, *Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic***, Frontiers in Pharmacology**, 12(643972), 2021.

44 P.A. Przybylińska & M. Wyszkowski, *Environmental Contamination With Phthalates and Its Impact on Living Organisms*, **Ecol Chem Eng S**., 23(2), 2016, 347-356.

45 C. Chai, H. Cheng, W. Ge, D. Ma & Y. Shi, *Phthalic Acid Esters in Soils from Vegetable Greenhouses in Shandong Peninsula, East China*, **PLoS ONE,** 9(4), 2014, e95701.

46 Regulation (EC) *No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on Classification, Labelling and Packaging of Substances and Mixtures, Amending and Repealing Directives 67/548/EEC and 1999/45/EC, and Amending Regulation (EC) No 1907/2006*,

47 United States Environmental Protection Agency (USEPA), *Toxics Release Inventory Reporting Forms and Instructions.2015*.

48 A. Li, L. Kang, R. Li, S. Wu, K. Liu, & X. Wang, *Modeling di (2-ethylhexyl) Phthalate (DEHP) and Its Metabolism in a Body's Organs and Tissues through Different Intake Pathways into Human Body,* **International Journal of Environmental Research and Public Health,** 19(9), 2022, 5742.

49 C.J. Willson, *Phthalate Toxicity in Rats and Its Relation to Testicular Dysgenesis Syndrome in Humans*, **Toxicologic Pathology**, 49(8), 2021, 1416–1424.

50 N. KloÈ ting; N. Hesselbarth; M. Gericke; A. Kunath; R. Biemann & R. Chakaroun, *Di-(2-Ethylhexyl)-Phthalate (DEHP) Causes Impaired Adipocyte Function and Alters Serum Metabolites*, **PLoS ONE,** 10(12) 2015, e0143190.

51 E.G. Shershneva, *Analysis of Correlation between Waste Accumulation and Countries Welfare Level,* **IOP Conference Series: Earth and Environmental Science**, 988(2), 2022, 022034.

52 B. Sailas; P. Selvanesan; S.J. Moolakkariyil; K. Sunil & M. Eiji, *A Monograph on the Remediation of Hazardous Phthalates,* **Journal of Hazardous Materials**, 298, 2015, 58-72. 4

53 L.W. Yeung, N. Yamashita; S. Taniyasu, P.K. Lam; R.K. Sinha & D.V. Borole, A *Survey of Perfluorinated Compounds in Surface Water and Biota Including Dolphins from the Ganges River and in Other Waterbodies in India*, **Chemosphere,** 76, (1), 2009, 55–62.

54 K.E. Murray, S.M. Thomas & A.A. Bodour, *Prioritizing Research for Trace Pollutants and Emerging Contaminants in the Freshwater Environment.* **Environ Pollut.,** 158, 2010, 3462–71.

55 F. Parvin, & S.M. Tareq, *Impact 0f Landfill Leachate Contamination on Surface and Groundwater of Bangladesh: A Systematic Review and Possible Public Health Risks Assessment,* **Applied Water Science,** 11(6), 2021.

56 A.A. Oketola & S.O. Akpotu 2015 *Assessment of Solid Waste and Dumpsite Leachate and Topsoil*, **Chemistry and Ecology**, 31(2), 2015, 134-146.
57 C. Sridhar, A.O. Coker, O.O. Shittu, T.A. Laniyan, & C.G. Achi, *Phytotechnologies in Wastewater Treatment: A Low-Cost Option for Developing Countries*, **Sustainable Water Engineering**, 2020, Pages 137-164

58 N. Ferronato, & V.W. Torretta, *Waste Mismanagement in Developing Countries: A Review of Global Issues*, **Int. J. Environ. Res. Public Health** 16 (6), 2019, 1060

59 A. Johari; H. Hashim, R. Mat; H. Alias, M.H. Hasshim & M. Rozainee, *Generalization, Formulation and Heat Contents of Simulate DMSW with Moisture Content*, **J. Eng. Sci. Technol**., 7 (6), 2012.

60 C. Nyle & R. Ray, *The Nature and Properties of Soils,* **USA: Prentice Hall. Technology & Engineering (12th ed.),** 1999, 743–785.

61 P. Nyiramigisha, Komariah & Sajidan, *Harmful Impacts of Heavy Metal Contamination in the Soil and Crops Grown Around Dumpsites*, **Reviews in Agricultural Science**, 9(0), 2021, 271–282.

62 A. Alengebawy, S.T. Abdelkhalek, S.R. Qureshi, & M.Q. Wang, *Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications*, **Toxics,** 9(3), 2021, 42.

63 E.R. Sam-Uroupa, & A.E. Ogbeibu, *Effects of Solid Waste Disposal on the Receiving Soil Quality in Benin Metropolis, Nigeria,* **Journal of Applied Sciences and Environmental Management,** 24(2), 2020, 393–401.

64 A.B. Patel, S. Shaikh, K.R. Jain, C. Desai, & D. Madamwar, *Polycyclic Aromatic Hydrocarbons: Sources, Toxicity, and Remediation Approaches,* **Frontiers in Microbiology,** 11, 2020

65 A.A. Oketola & S.O. Akpotu. *Assessment of Solid Waste and Dumpsite Leachate and Topsoil,* **Chemistry and Ecology**, 31(2), 2015, 134-146.

66 A. Siddiqua, J.N. Hahladakis, & W.A.K.A Al-Attiya, *An Overview of the Environmental Pollution and Health Effects Associated With Waste Landfilling and Open Dumping*, **Environmental Science and Pollution Research**, 29, 2022, 58514-58536

67 . G.J. Mosotho, *Determination And Quantification Of Phthalic Acid Esters from the Soil Collected from the Municipal Solid-Waste Dumpsite in Maseru Using A Simple Vortex-Assisted Low-Volume Organic Solvent Extraction*, **J Anal Pharm Res.**;7(5), 2018, 522–528.

68 J. Dueñas-Moreno, A. Mora, P. Cervantes-Avilés, & J. Mahlknecht, *Groundwater Contamination Pathways of Phthalates and Bisphenol A: Origin, Characteristics, Transport, and Fate – A Review,* **Environment International**, 170, 2022, 107550.

Chapter Two

Literature Review

2.1 Solid Waste

Waste is a useless byproduct of human activity that physically contains the same substances as the valuable product[1,2]. According to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal of 1989, Art. 2(1), "'Wastes' are substance or objects, which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law[3]. Waste production tends to increase with rising levels of income, urbanization, and population[4]. Meat, vehicles, electricity, and other consumer products are all being consumed in greater quantities by this increasingly rich population[4].

Waste is any material that is no longer useful or valuable to society. Looking back in time, waste management was first a problem in densely populated areas such as villages and cities[5,6]. Poor waste management leads to sanitary and aesthetic problems. One of the most commonly used waste management practices is disposal of waste to landfills[7]. A landfill constructed with modern practice has environmental disadvantages of waste disposal. Waste in landfills degrades, producing greenhouse gases such as methane[8]. Rainfall and groundwater seepage into the landfill creates leachate, contaminated water. The release of untreated leachate can lead to contamination of groundwater, eutrophication of surrounding waters, or spread of toxic compounds.

In order to manufacture those products, more natural resources are being utilized, and as a result of increased consumption, more trash is being generated. Post-consumer waste affects air, water, human health, and contributes to climate change. Solid waste is defined

as worthless and undesired substances in a solid form that are abandoned by members of society. It is any product or material that has no future use or value for the person or organization that owns it and is being or will be discarded[9].

Solid waste comprises all the wastes arising from human activities that are normally solid, discarded as useless or unwanted by-products of process lines or materials that may be required by law to be disposed off [10, 11,12]. It has become a recurring feature in the urban environment. Municipal solid waste, industrial solid waste, and agricultural solid waste are examples of solid waste classifications[13]. Municipal and industrial solid wastes contain a variety of harmful pathogenic organisms and essential chemical components that have a negative impact on the quality of the land, air, and water as well as on human health.[14,15]

In addition to being an eyesore in the city, it poses health risks and endangers the well-being of both people and animals in the environment. Municipal solid waste sites can be toxic due to the presence of hazardous materials and chemicals. It accumulates on streets and open spaces between houses, causing or contributing to serious health problems. The poorer households suffer most since it is overwhelmingly in the poorer areas of cities that there are no services to collect garbage or the services are very inadequate[16].

2.2 Types of Solid Wastes

Waste can be broadly classified into several categories based on its source, composition, and potential environmental impact. Here are some of the most common classifications of waste:

2.2.1 Municipal Solid Waste (MSW): This refers to the everyday waste produced by households, commercial and institutional establishments, and small businesses. According to the World Bank Group, the rate of global waste generation is approximately 0.74 kg of

waste per capita per day[17]. An uptrend in waste generation was reported, with the global municipal solid waste production at 1.3 billion tonnes in the year 2012 increasing to 2.01 billion tonnes in the year 2016. It is expected to reach 2.59 billion tonnes in 2030. While the world's population continues to rise, the demographic composition of the world's population is changing rapidly. The globe is experiencing extreme levels of urbanization, with the majority of this growth occurring in small & mid cities in low-income nations[18]. Increasing populations, industrialization, and changing consumption patterns result in the generation of increasing amounts of solid waste and its diversification[19].

2.2.2 Hazardous Waste: This includes waste materials that are potentially harmful or dangerous to human health or the environment. Examples include medical waste, chemical waste, and electronic waste.

2.2.3. Industrial Waste: This includes waste materials generated by industries such as manufacturing, construction, and mining. Examples include scrap metal, concrete, and chemical byproducts.

2.2.4. Agricultural Waste: This includes waste materials generated by agricultural activities such as crop and livestock production. Examples include crop residue, animal manure, and agricultural chemicals.

2.2.5 Construction and Demolition Waste: This includes waste materials generated during the construction, renovation, and demolition of buildings and other structures. Examples include wood, concrete, bricks, and metal. The EPA defines this type of waste as "Construction and Demolition (C&D) debris is a type of waste that is not included in municipal solid waste (MSW)". Items typically found in C&D include but are not limited to steel, wood products, drywall and plaster, brick and clay tile, asphalt shingles, concrete,

and asphalt. Generally speaking, construction and demolition waste can be categorized as any components needed to build infrastructures. In 2018, the EPA estimated that the US generated approximately 600 million tons of C&D waste[20]. The waste generated by construction and demolition is often intended to be reused or is sent to the landfill. Examples of reused waste is milled asphalt can be used again for the asphalt mixture or fill dirt can be used to level grade.

2.2.6 Biomedical Waste: This includes waste materials generated by healthcare facilities, such as hospitals, clinics, and laboratories. Examples include used needles, contaminated gloves, and human or animal tissue. This type of waste is typically generated from hospitals, physicians' offices, dental practices, blood banks, veterinary offices, and research facilities. This waste has often been contaminated with bodily fluids from humans or animals. Examples of this type of contamination can include blood, vomit, urine, and other bodily fluids. Concerns started to generate when medical waste was appearing on east coast beaches in the 1980's. This forced congress to pass the Medical Waste Tracking Act. This act was only in effect for approximately 3 years after the EPA concluded the "disease-causing medical waste was greatest at the point of generation and naturally tapers off after that point[21].

2.2.7 Electronic Waste (E-Waste): This includes discarded electronic devices such as computers, phones, and televisions. E-waste can contain hazardous materials such as lead, mercury, and cadmium. Electronic waste, often referred to as "E-Waste" or "E-Scrap," are often thrown away or sent to a recycler. E-Waste continues to end up in landfills across the world. The EPA estimates that in 2009, 2.37 million tons of televisions, computers, cell

phones, printers, scanners, and fax machines were discarded by US consumers. Only 25% of these devices were recycled; the remainder ended up in landfills across the US.

E-Waste contains many elements that can be recycled or re-used. Typically speaking, electronics are encased in a plastic or light metal enclosure. Items such as computer boards, wiring, capacitors, and small motor items are common types of E-waste. Of these items, the internal components include oil, iron, gold, palladium, platinum, and copper. All of which are mined from the earth's core. For these items to be mined, it requires massive amounts of energy to operate the equipment, which emits greenhouse gases into the atmosphere. Donating e-waste to recycling centers or refurbishing this equipment can reduce the greenhouse gases emitted through the mining process. It will also lower the usage of our naturally formed products to ensure future generations will have sufficient natural resources.

2.2.8 Radioactive Waste: This includes waste materials that emit ionizing radiation and can be harmful to human health and the environment. Examples include spent nuclear fuel and nuclear weapons waste. Radioactive waste is produced by industries such as mining, nuclear power generation, defense, medicine, and certain types of scientific research[22,23]. Waste can be classified and categorize based on its nature and potential environmental impact. These classifications help to categorize waste based on its nature and potential environmental impact

2.2.9 Organic Waste: Organic waste refers to waste materials that are biodegradable and originate from living organisms or natural sources. This includes food waste, yard waste, agricultural waste, and other biodegradable materials. Organic waste can be broken down by microorganisms through composting or anaerobic digestion processes.

2.2.10 Inorganic Waste: Inorganic waste refers to waste materials that are non-biodegradable and do not originate from living organisms. This category includes materials such as plastics, metals, glass, ceramics, and synthetic fibers. Inorganic waste can persist in the environment for a long time and may require specialized recycling or disposal methods.

2.2.11 Toxic Waste: Toxic waste, also known as hazardous waste, is waste that poses a threat to human health and the environment due to its chemical, biological, or physical characteristics. Toxic waste includes substances that are corrosive, flammable, reactive, or poisonous. Examples of toxic waste include certain chemicals, pesticides, solvents, batteries, and medical waste. Proper handling, storage, and disposal methods are necessary to prevent harm from toxic waste.

It has been observed that in 1980, on average, a balance of 100 metric tons of solid waste are piled up daily in Benin City[24]. This is because while about 350 metric tons of solid waste are generated daily, the maximum rate of evacuation achievable was only 250 metric tons daily. Uchegwu in his research remarked that big cities like Port Harcourt, Lagos, Kano, etc. in Nigeria produced on average 46 kg of solid waste per person, per day. In 2010 estimated MSW generated in Lagos, Port Harcourt, Ibadan and Warri are 1.23 × 105; 762,143; 996,102 and 174, 372 t/ year respectively[25,26]. On the contrary, Lagos with a population estimate of 21 million has a per capita waste generation of 0.5 kg per day, the city generates more than 10,000 tons of urban waste every day. Ibadan with a projected population of 3,154,487, the quantity of waste generated in Ibadan Metropolis in 2012 is estimated at 634,998.43 t/year and 0.55 kg per capita per day which included provision for street sweeping[27].

The composition of waste varies from one municipality to another and from country to country significantly (Table 2.1). Such variation depends mainly on the lifestyle, economic situation, waste management regulations and industrial structure[28]. However, the average composition of MSW in the United States is approximately 33% paper and cardboard, 13%-yard waste, 13% food waste, 12% plastics, 6% metals, 5% rubber, leather, and textiles, 4% wood, and 14% other materials[28].

Region	Waste Composition(% *w/w*)							
	Organic food	Glass	Metals	Paper	Plastics	Rubber	Wood	Others
East Asia	53	26	3	15	12	<1	2	12
South Asia	57	4	3	10	8	2	1	15
Europe And Central Asia	36	8	3	18.6	11.5	<1	1.6	21
Latin America and Caribbean	52	4	3	13	12	<1	<1	15
Middle East and North Africa	58	3	3	13	12	2	1	8
North America	28	45	9.3	28	12	9	5.6	3.6

Table 2.1: Waste Composition in Different Region.
Sources:[28].

Household or municipal wastes are usually generated from variable sources where different human activities are encountered. The amount of MSW generated varies by region, but on average, an individual in the United States produces about 4.5 pounds of waste per day. This adds up to more than 250 million tons of MSW generated annually in the United States alone[29]. Several studies reported that the municipal solid waste that are generated in developing countries is mainly from households (55–80%), followed by market or commercial areas (10–30%). The later consists of variable quantities generated from industries, streets, institutions and many others[30].

MSW is typically collected by municipalities and waste management companies through curbside collection, drop-off centers, or transfer stations. MSW can be disposed of through a variety of methods, including landfilling, incineration, and composting. Landfilling is the most common method of MSW disposal in the United States, with approximately 52% of MSW being sent to landfills.

This poses a significant hazard to the terrestrial ecosystem and groundwater resources[31]. Pollutants (e.g., nutrients, heavy metals, polycyclic aromatic hydrocarbons, etc.) emanating from dumpsites usually penetrate the lower soil horizons as leachates thereby polluting the groundwater at different degrees[15,32]. Environmental contaminants are those substances which are present in the environment above the permissible limits of concentration, which adversely alters the environment and is toxic to human (Figure 2.1), animal and plant health. Due to industrialization and the overuse of chemical fertilizers, our environment has become contaminated with various types of contaminants[33]. The contaminants include solid, liquidand gaseous substances which are produced by human activity for short-term economic benefits at the cost of long-term ecological benefits for humanity. A wide variety of

contaminants are present in the environment, and they can be broadly categorized as emerging contaminants, endocrine disruptors, carcinogens, mutagens, neurotoxins, and others, and they enter the environment from various point and nonpoint sources[34]. The common sources of contaminants are fossil fuels, industries and industrial accidents, oil spills, mining, ammunition and agents of war etc (figure 2.2). The contaminants may be natural or xenobiotic (man-made) in nature[35].

2.3 Leachates

Leachates consists of the liquid effluent generated from municipal waste consolidation into landfills. This liquid is a cocktail of numerous chemicals that are the result of water passing through the waste and saturating it with organic and inorganic matter. The produced leachate poses significant disposal challenges for landfill operators worldwide due to its potential to contaminate soils, surface water, aquifers and sea water[36]. Leachate can be treated locally or in a municipal wastewater treatment plant. Treatment methods for leachate can be divided into biological and physicochemical methods. Biological techniques use bacteria to reduce the organic matter and nitrogen content of leachate. Physico-chemical techniques are often used as a pre-treatment for biological steps or to remove specific compounds. Examples of biological treatment methods are sequencing batch reactors, moving bed biofilm reactors, and wetlands. Examples of physicochemical techniques are chemical oxidation, precipitation, and absorption. Various treatment methods often produce contaminated sludge that must be treated and disposed

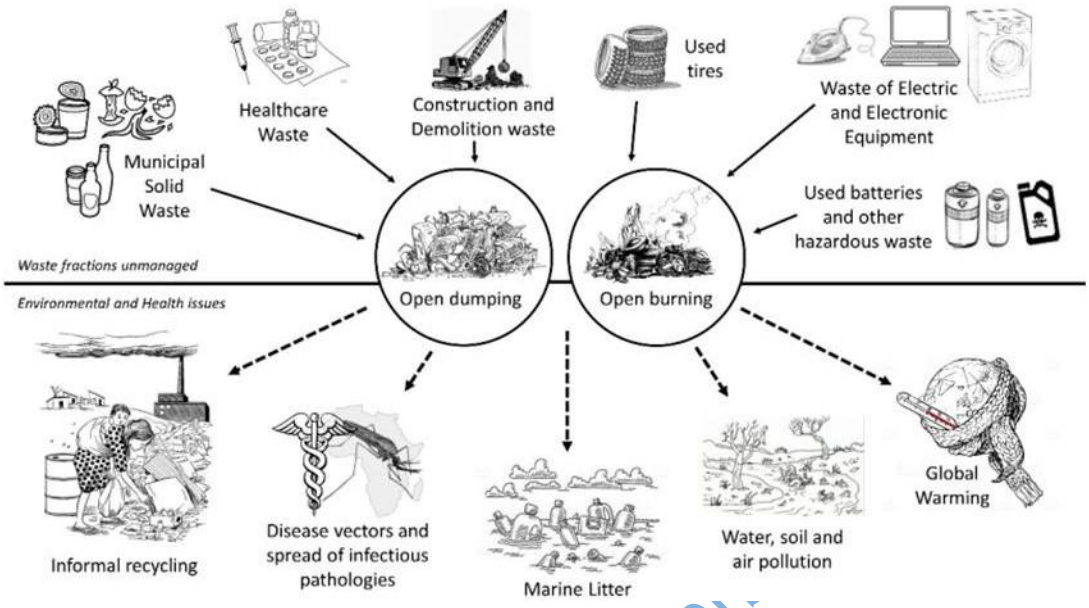


Figure 2.1: Theoretical Framework of the Review: Source of Contaminants Due to Solid Waste.

Source: [4].

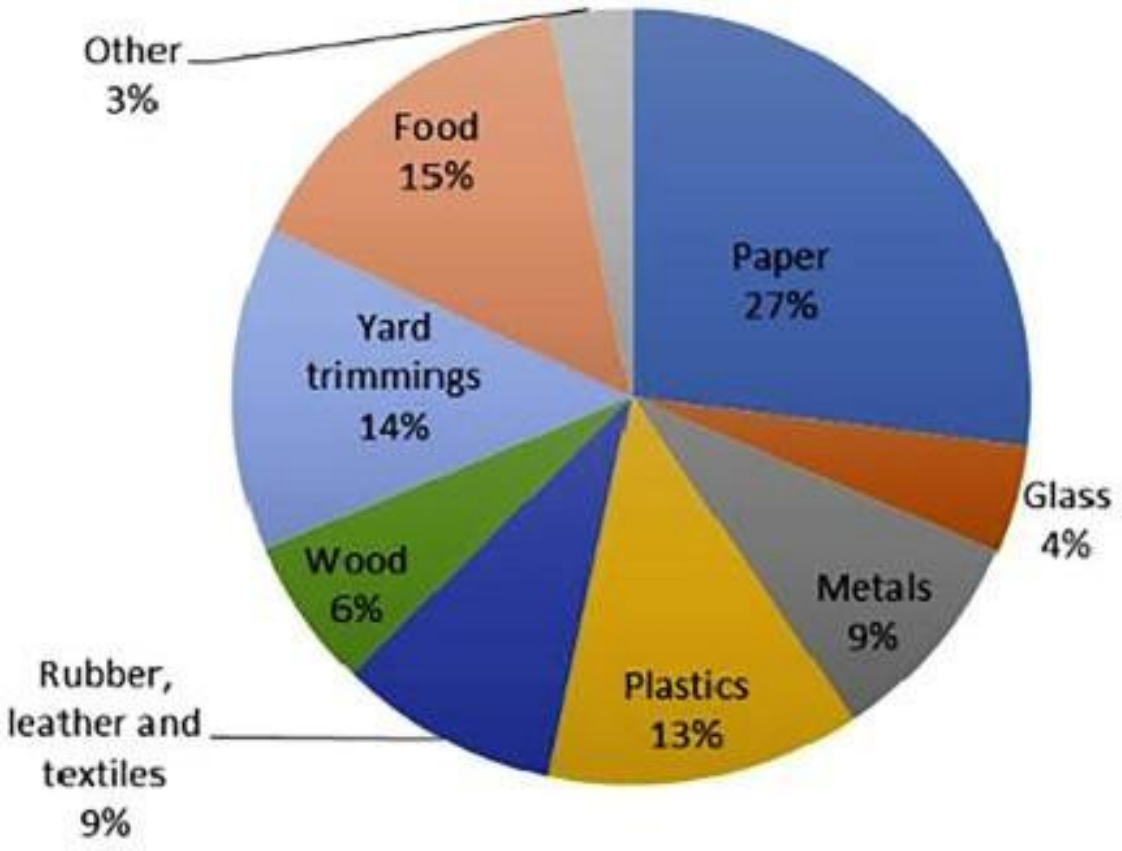


Figure 2.2: Composition and Classification (by material) of MSW Generated by The United States in 2013.

Source: [20].

Generally, it is necessary to reduce the water content of the sludge before it is further treated and finally disposed of[37]. Rapid development and rising populations have boosted garbage generation in the majority of emerging nations. However, there hasn't been much attention paid to the management of waste in these emerging nations, such as Nigeria, where stacks and heaps of this material are carelessly discarded in public places[38]. In most nations around the world, the most popular practice for managing solid waste is landfilling[39,40]. A large portion of these landfills are unclean in the majority of developing nations, including Nigeria and India[41]. In the presence of moisture, biodegradable wastes, which are frequently found in landfills from developing nations, go through a number of biological and chemical processes to produce mounds of decomposed organic matter (landfill soil), which are laden with a mixture of organic pollutants and toxic metals[36,42].

2.4 Sanitary Landfills

One of the most popular and widely approved methods of getting rid of these wastes is sanitary landfilling. This is as a result of its cost-effective and sustainable approach to trash management. For instance, the majority of the materials required for construction are easily accessible and present naturally in most places. The mineral seal or liner is a crucial part of the sanitary landfill because it prevents leachates and contaminants from entering the groundwater or subsoil and contaminating them. Additionally, it stops water from percolating or seeping into the waste. Because of its tropical and subtropical climate, Nigeria benefits from the creation of lateritic soils, which are the result of extensive weathering. As a result, they are the most often used soils for a variety of construction uses

since they are plentiful (easily available) everywhere. There is a wealth of information on the varied geotechnics qualities of different types of soil from around the world[43,44].

Despite the usage of Integrated Municipal Solid Waste Management, landfilling is still the most often used technique of disposing of solid waste by municipal authorities globally. Landfills Leachates are a key cause of environmental worry since they have been linked to changes in ecological equilibrium. Landfills have developed into well-engineered structures with bottom liners and leachate management systems to reduce the migration of this leachate into the environment. This evolution has occurred relatively quickly. Unfortunately, the majority of developing economies, such as those in Africa and Asia, have not kept up with the rate of economic evolution[45].

Given the ongoing expansion in the quantity and diversity of waste entering landfills as a result of urbanization and rapid population growth, it is likely that the surrounding habitat will continue to experience an adverse influence from landfill leachate. Sub-Saharan Africa is of special concern due to the region's high yearly rate of urbanization (approximately 4.1%), insufficient waste treatment infrastructure, and problematic land use planning that plague the area[46].

As a result of in-place waste being solubilized and chemical and biological reactions taking place within the landfill system, leachate contains a variety of chemical elements, the composition of which changes over the course of the landfill's life[47]. Food contamination with heavy metals is another concern for human and animal health. The concentration of heavy metals in water resources, air, and food is assessed with this regard[48].

2.5 Toxic Pollutants

Toxic pollutants encompass a wide range of substances with diverse chemical properties and effects. Examples include heavy metals (lead, mercury, cadmium), volatile organic compounds (VOCs), polychlorinated biphenyls (PCBs), dioxins, pesticides, asbestos, and radioactive materials. Accidental release of these contaminants in the environment leads to evolution of new diseases to human health and as well as mass death of population.

Exposure to toxic pollutants can lead to various adverse health effects, depending on the specific substance and level of exposure. Health impacts can include respiratory problems, neurological disorders, developmental abnormalities, organ damage, reproductive issues, cancer, and even death. Toxic pollutants can have severe consequences for ecosystems and the environment. They can contaminate soil, water bodies, and the atmosphere, leading to habitat degradation, biodiversity loss, bioaccumulation in the food chain, and ecosystem disruption.

Governments and international bodies have implemented regulations and protocols to control and reduce toxic pollutants. These measures involve setting emission standards, establishing safe disposal practices, enforcing pollution control measures, and promoting the use of cleaner technologies. Monitoring programs are in place to measure the presence and levels of toxic pollutants in the environment. This includes air quality monitoring, water quality assessments, and soil testing. Toxicological studies are also conducted to evaluate the potential health risks associated with exposure to specific pollutants. Effective communication about toxic pollutants is crucial to inform the public, raise awareness, and promote responsible behavior. Risk management strategies involve identifying sources,

implementing pollution prevention measures, developing cleanup plans, and promoting sustainable practices to minimize the release and impact of toxic pollutants.

2.6 Types of Toxic Pollutant

Toxic pollutants refer to substances that, when released into the environment, have the potential to cause harm to living organisms. These pollutants can originate from various sources and can have detrimental effects on human health, ecosystems, and the environment as a whole. Here are some examples of toxic pollutants:

Heavy Metals: Heavy metals such as lead, mercury, cadmium, arsenic, and chromium are toxic pollutants that can be released from industrial activities, mining, fossil fuel combustion, and improper waste disposal. They can accumulate in the environment and pose significant risks to human health and ecosystems.

Volatile Organic Compounds (VOCs): VOCs are organic chemicals that readily vaporize at room temperature. They are found in many common products such as solvents, paints, adhesives, and fuels. VOCs contribute to air pollution and can have harmful effects on human health, including respiratory issues and the formation of ground-level ozone.

Polychlorinated Biphenyls (PCBs): PCBs are a group of synthetic organic compounds that were widely used in electrical equipment, coolants, and hydraulic fluids until they were banned due to their toxicity. PCBs are persistent in the environment, can accumulate in organisms, and have been linked to adverse health effects, including developmental and reproductive disorders.

Pesticides: Pesticides are chemical substances used to control pests, insects, and weeds in agriculture and public health. While they serve important purposes, many pesticides are

toxic to humans and non-target organisms. Pesticides can contaminate soil, water, and food sources, posing risks to human health and ecological balance.

Air Toxics: Air toxics, also known as hazardous air pollutants, are a group of substances emitted into the air from various industrial processes, combustion of fuels, and transportation. Examples include benzene, formaldehyde, dioxins, and certain metals. Inhalation of air toxins can lead to respiratory problems, cancer, and other adverse health effects.

Persistent Organic Pollutants (POPs): POPs are organic compounds that are highly resistant to degradation and can persist in the environment for long periods. They include substances such as certain pesticides (e.g., DDT), industrial chemicals (e.g., polychlorinated biphenyls), and unintentional byproducts of combustion and industrial processes (e.g., dioxins). POPs can bioaccumulation in organisms, travel long distances through air and water, and have toxic effects on both humans and wildlife.

Heavy metals are toxic substances that can have adverse effects on human health and the environment. Soil pollution by HMs can negatively affect human health, wildlife, and soil production[49]. Heavy metals, due to their toxicity and stability in the environment and the ease of getting into the food chain, pose a serious threat to organisms living in aquatic ecosystems and, indirectly, also to human health [50,51,52].

Metals, such as Cu, Co, Mn, and Zn, are essential for animals, being involved in cellular metabolism, antioxidant and anti-inflammatory defenses, gene expression, and protein synthesis[53]. Excessive environmental concentrations of these become toxic for animals and plants.

Other metals, such as Cd, Cr, and Pb, are not involved in the metabolic pathways[54,55]. Cd and Pb are accumulated primarily in the kidney and liver, but they may reach high concentrations also in the gills, digestive tract, and spleen[56]. The kidney in particular, but also the liver and gills, can accumulate Cr[55]. here are some common heavy metals and their associated health effects:

Lead (Pb): Neurological Effects: Lead exposure can lead to cognitive and behavioral impairments, especially in children. It can cause developmental delays, decreased IQ, learning disabilities, and behavioral problems. Other Effects: Lead exposure can also affect the kidneys, cardiovascular system, and reproductive system.

Mercury (Hg): Neurological Effects: Mercury exposure, particularly to methyl mercury, can result in neurological damage, affecting cognitive function, memory, attention, and motor skills. It is especially harmful to the developing brains of fetuses and young children. Mercury can also cause kidney damage and affect the respiratory and cardiovascular systems.

Cadmium (Cd): Kidney Damage: Cadmium exposure can lead to kidney damage, including kidney dysfunction and renal failure. Other Effects: Cadmium can also affect the respiratory system, skeletal system, and cardiovascular system.

Arsenic (As): Cancer Risk: Arsenic is a known human carcinogen and exposure to high levels can increase the risk of various cancers, including skin, lung, bladder, and kidney cancers. Arsenic can also cause skin lesions, cardiovascular effects, and neurological effects.

Chromium (Cr): Respiratory Effects: Hexavalent chromium (Cr (VI)) can cause respiratory problems such as asthma and bronchitis. Prolonged exposure to high levels of Cr (VI) has been associated with an increased risk of lung cancer.

These heavy metals can enter the human body through various routes such as inhalation, ingestion, or dermal contact. The health effects can vary depending on the specific metal, dose, duration of exposure, and individual susceptibility. In addition to their impact on human health, heavy metals can also have harmful effects on the environment. They can persist in soil, water, and air, contaminating ecosystems and posing risks to plants, animals, and microorganisms. Heavy metals can disrupt ecological processes, harm biodiversity, and enter the food chain, leading to bioaccumulation and biomagnification.

2.7 Phthalate Esters (PAEs)

Phthalates

Phthalates are a group of chemicals that are commonly used as plasticizers, which means they are added to plastics to make them more flexible and durable. The first commercial plasticizers were synthesized in 1846, and in the late 1920s, di (2-ethylhexyl) phthalate (DEHP) was the first worldwide phthalic acid ester (PAE) introduced[57]. Phthalates are not chemically bonded to materials used in the manufacturing process. They migrate to the surface of the produced goods easily, and then to the environment and living organisms. Phthalates were also found in landfill leachate. The older the landfill, the smaller the amount of leachate, which suggests that phthalates are gradually degraded[58]. However, DEHP was also found in leachate from older landfills, because they were widely used and slowly degraded[59]. Other phthalates were gradually introduced in industrial processes due to the marked development of polyvinyl chloride plastics (PVC) and other polymers, such

as polyethylene terephthalate (PET), polyvinyl acetates, cellulosic, and polyurethanes, which are softened by phthalates. There are many different types of phthalates, and they can be classified into several categories based on their chemical structure and properties.

Examples of Phthalates

- **High-Molecular-Weight Phthalates**: These are phthalates that have a molecular weight greater than 250 daltons. Examples include diisononyl phthalate (DINP), diisodecyl phthalate (DIDP), and di-n-octyl phthalate (DnOP)[60, 61].
- **Low-Molecular-Weight Phthalates**: These are phthalates that have a molecular weight less than 250 daltons. Examples include diethyl phthalate (DEP), dibutyl phthalate (DBP), and diisobutyl phthalate (DIBP)[62].
- **Ortho-Phthalates**: these are phthalates that have a benzene ring attached to two carboxylic groups (ortho position). Examples include DEP, DBP, di-n-octyl phthalate (DnOP).
- **Terephthalates**: these are phthalates that have a benzene ring attached to two carboxylic acid groups (para position). Example include dimethyl terepthalates (DMT), and diethyl terephthalates (DET).
- **Adipates**: these are phthalates that have a linear carbon chain with two carboxylic acid groups, e.g dietyl adipate, and dibutyl adipate.
- **Trimellitates**: These are phthalates that have three carboxylic acid groups Examples include triethyl trimellitate and tri-n-butyl trimellitate. These are phthalates that have three carboxylic acid groups.

Phthalate esters (PAEs) are synthesized by phthalic anhydride and alcohols, also known as phthalic acid esters[63,64]. They are colorless, odorless, flavorless, exist as liquid types at a

large temperature range (25 ℃ − 50 ℃), and are chemically stable[65]. In the 1930 s, di (2-ethylhexyl) phthalate (DEHP) was added to plastic polyvinyl chloride (PVC) to improve flexibility and elasticity.

PAEs were widely used in global amounts up to approximately 5.5 million metric tons per year, through various sources, including household stuff (furnishings, clothing, cosmetics, children's toys, nutritional supplements/food packaging, etc.), building and traffic materials, industrial fields (paints and varnishes, adhesives, lubricants, waxes, cleaning materials, electronics, inks), agricultural activities (insecticides, pesticides, fertilizers, mulch plastic) or others (e.g., pharmaceuticals, medical devices, etc.)[66]. Owing to their growing economic and commercial interest, PEs are by far the most used synthetic organic chemicals in a large variety of products since 1930s[66]. Global production of PEs is estimated at 6 to 8 million tons per annum[67]. As a result, PAEs are found in various environmental matrices, including the atmosphere, lithosphere (soil, sediment), and hydrosphere (surface water, and wastewater, etc.).

Human exposure to PAEs can happen through various pathways (figure 2.3) such as ingestion,inhalation, skin absorption/contact, and intravenous injection. For example, the human body can be easily exposed PAEs by oral exposure (i.e., the ingestion of food, or children's toys); inhalation from air ambient mixed with PAEs; by skin contact with plastic products (i.e., personal care products, paints, clothes or cosmetics, etc.); and intravenous exposure related to medical equipment. Meanwhile, PAEs are a type of endocrine disruptive chemical (EDCs) that can cause substantial harm to the respiratory, reproductive, and endocrine systems of humans. So far, PAE exposure was linked to a variety of health problems, including abnormal reproductive system impacts, asthma, and allergies.

Several PAEs compounds were detected in the environment, such as Diethyl phthalate (DEP), Dimethyl phthalate (DMP), Di(2-ethylhexyl)phthalate (DEHP), Dibutyl phthalate (DBP), Diisobutyl phthalate (DIBP), Butyl benzyl phthalate (BBP), Diisononyl phthalate (DINP), and Dinoctyl phthalate (DnOP)[68] . PAEs are grouped into: high-molecular-weight (HMW) PAEs with 7 to 13 carbon chains and low-molecular-weight (LMW) PAEs with 3 to 6 carbon chains. For example, DEHP (C24H38O4) belongs to the HMW.

2.8 Effects of Phthalate on Human

Overall, the utilization of these millions of tons of phthalates and BPA is related to their wide use in the plastic industry, as well as in medical devices, health care products, dispersants and emulsifying agents, epoxy resins, lubricants, auto parts, food packaging and services, paints, gelling agents, cosmetics, insecticides, and many other households and consumer products[70,71,72]. Despite their many uses and applications, phthalates and BPA have become major environmental concerns due to their genotoxicity, neurotoxicity, cytotoxicity, reproductive toxicity, and endocrine-disrupting effects, which may affect human health from gestation to adulthood.

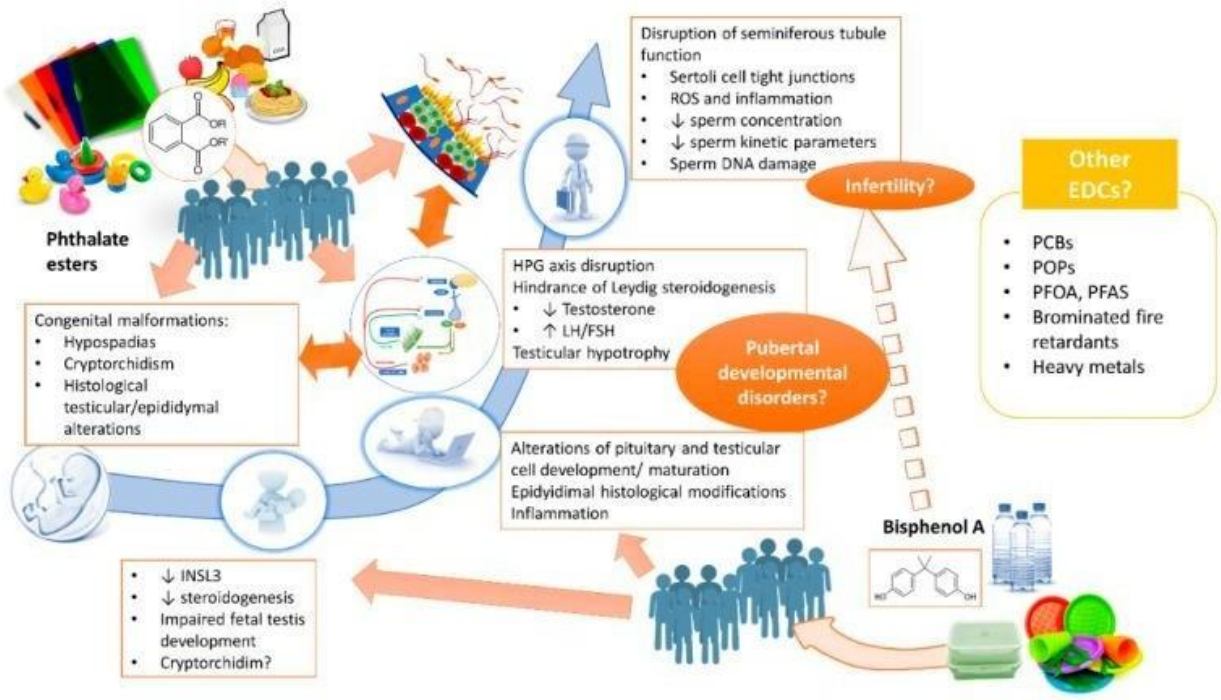


Figure 2.3: **Effects of BPA and Phthalates on the Development and Function of the Male Reproductive Tract.**

Abbreviations: Polychlorinated **B**iphenyls (PCB), Persistent Organic Pollutants (POP), Polyfluoroalkyl Acids (PFAS), Perfluorooctanoic Acid (PFOA)

Source: [69].

Endocrine Disruption: Phthalates can disrupt the endocrine system, interfering with hormone signaling in the body. They have been linked to reproductive and developmental effects, including reduced fertility, impaired sperm quality, and developmental abnormalities in the male reproductive system[73]. Human exposure to these endocrine-disrupting compounds (EDCs) can occur through four major pathways (ingestion, inhalation, intravenous and dermal contact), where the first is the main route of exposure [74]. By examining testicular volume, sperm parameters, and reproductive hormones in a cohort of 216 young men with known prenatal exposure to multiple phthalates' esters, Hart et al. (2018) made an effort to address this flaw. In particular, the authors discovered a positive correlation between maternal monoethyl phthalate (MEP) and adult semen volume, a negative correlation between maternal mono(carboxyisooctyl) phthalate (MCiOP) and adult sperm motility, and a positive correlation between maternal DEHP, DiNP (and their metabolites) and total testosterone[75].

Asthma and Allergies: Some studies suggest a possible association between phthalate exposure and an increased risk of asthma and allergies, although the evidence is not conclusive.

Liver and Kidney Damage: Certain phthalates have been associated with liver and kidney damage, although the extent of the health risks may depend on the specific phthalate compound and the level and duration of exposure[76].

Carcinogenic Potential: Some phthalates, such as di (2-ethylhexyl) phthalate (DEHP), have been classified as possible human carcinogens by international agencies.

2.9 Environmental Effects of Phthalates

Water Contamination: Phthalates can enter the environment through various pathways, including wastewater discharges and leaching from landfills. They can contaminate surface water and groundwater, potentially impacting aquatic ecosystems[77].

Soil and Sediment Contamination: Phthalates can accumulate in soil and sediments, affecting soil quality and potentially entering the food chain through plant uptake[78,79].

Toxicity to Aquatic Organisms: Phthalates can be toxic to aquatic organisms, including fish and invertebrates, with potential effects on growth, reproduction, and behavior.

Persistence and Bioaccumulation: Some phthalates have the potential to persist in the environment and bioaccumulate in organisms, leading to long-term exposure and potential ecological impacts

2.10 Environmental Sources of Phthalate

Indoor Sources:

Consumer Products: Phthalates are commonly used as plasticizers in a variety of consumer products, including vinyl flooring, PVC pipes, flexible plastics, and personal care products (such as cosmetics, lotions, and fragrances), which can serve as sources of phthalate release indoors[80].

Outdoor Sources

Airborne Sources: Phthalates can be released into the outdoor air through volatilization from consumer products, industrial emissions, and exhaust from vehicles. They can also be transported long distances through atmospheric transport[81].

Water Sources:

Wastewater Discharges: Phthalates can enter water bodies through the discharge of domestic and industrial wastewater, which may contain phthalates from various sources, including household products and manufacturing processes[82].

Soil and Sediment Sources:

Landfill Leachate: Landfill leachate, an aqueous by-product of landfilling, is generated as a consequence of precipitation percolation through waste, biochemical processes in wastes cells and the inherent water content of wastes themselves[83]. Phthalates can leach from disposed consumer products in landfills and contaminate surrounding soil and groundwater through leachate, which is the liquid that drains from landfills[84,85].

Food Sources:

Packaging and Processing: Phthalates can migrate from packaging materials into food, especially fatty or acidic foods, during processing, storage, and transportation[86].

2.11 Methods of Analyzing Toxic Pollutants

1. **Chromatography**: Chromatography is a technique that separates the different components of a mixture based on their chemical properties. This technique can be used to separate and analyze individual pollutants in a sample[87].
2. **Mass Spectrometry**: Mass spectrometry is a method of identifying and quantifying molecules based on their mass-to-charge ratio. It can be used to identify specific toxic pollutants in a sample[88].

3. **Atomic Absorption Spectroscopy**: This technique measures the absorption of light by atoms in a sample, which can be used to determine the concentration of specific elements, including toxic pollutants, in the sample[89].

4. **Immunoassays**: Immunoassays use antibodies to detect and quantify specific toxic pollutants in a sample. This technique is often used in environmental monitoring and food safety testing[90].

5. **Microbial Assays**: Microbial assays use bacteria or other microorganisms to detect the presence of toxic pollutants in a sample. These assays are often used to test the toxicity of a sample or to monitor the effectiveness of remediation efforts[91].

6. **Electrochemical Methods**: Electrochemical methods use electrodes to detect and quantify toxic pollutants in a sample. These methods are often used for water quality monitoring and can detect a wide range of pollutants[92].

Along with informal solid waste management (SWM), open dumping sites of SWs mainly have operated in developing countries and pose serious environmental problems[93]. Landfill leachates from municipal solid waste (MSW) sites can be highly toxic to both aquatic organisms and plants.

The European Food Safety Authority (EFSA) has established the maximum daily limit of human intake for some PAEs (DBP 0.01, BBP 0.5, DEHP 0.05, DNP 0.15, DDP 0.15 mg kg−1 per day per body weight) [9]. Since phthalates are loosely incorporated in the polymer structure without covalent bonding, they can be easily separated and migrate constantly to the environment, these pollutants have been shown to be ubiquitous in some environmental compartments the polymers display limited resistance[95,96,97].

Therefore, changes in environmental conditions such as temperature, UV radiation, or contact with liquid compounds (solvents, lipids, etc.) and/or acidic/alkaline environments, could accelerate its release from the polymeric matrix to the different environmental matrices[98]. For example, during the rainy season, runoff coming from dump sites may transport organic pollutants, contaminating receiving water bodies and/or groundwater resources[4].

Adsorption

The mechanisms of adsorption/desorption together with biodegradation have been considered the most influential processes regulating the migration of organic micropollutants to aquifers [99]. Some pollutants have a low potential to migrate to aquifers during the Biological degradation by the indigenous bacterial consortium is an important mechanism that naturally eliminates organic contaminants in the aquifer or during their pathway from the surface to the saturated zone [100].

2.12 Poly Aromatic Hydrocarbons (PAHs)

Over 100 chemical compounds make up the group of compounds known as PAHs, most of which are colorless but occasionally exhibit white or yellow coloring. They may come from artificial or natural sources and are widely distributed (figure 2.4). Volcanic eruptions, open burning, seepage or loss from coal or petroleum deposits are some typical natural sources of PAHs[101, 102]. The anthropogenic sources of PAHs are caused by human activity and are typically linked to thermal breakdown processes involving incomplete burning of organicmaterials.[103,104].

Therefore, the primary anthropogenic sources of PAHs are the processes used in the processing of crude oil, tar sands, bitumen, coal, gas, and the use of refined petroleum

products. Burning of municipal and medical trash, plants, and all forms of biomass are additional sources[105,106]. When storing, transporting, and using crude and refined petroleum products, temperatures between 100 °C and 150 °C are also conducive to the formation of PAHs. These sources are referred to as petrogenic, if they cause low temperature PAH emission. Last but not least, PAHs are created biologically during biomass breakdown and as a result of some microbial activity. Human toxicology and exposure to PAHs in Nigeria.

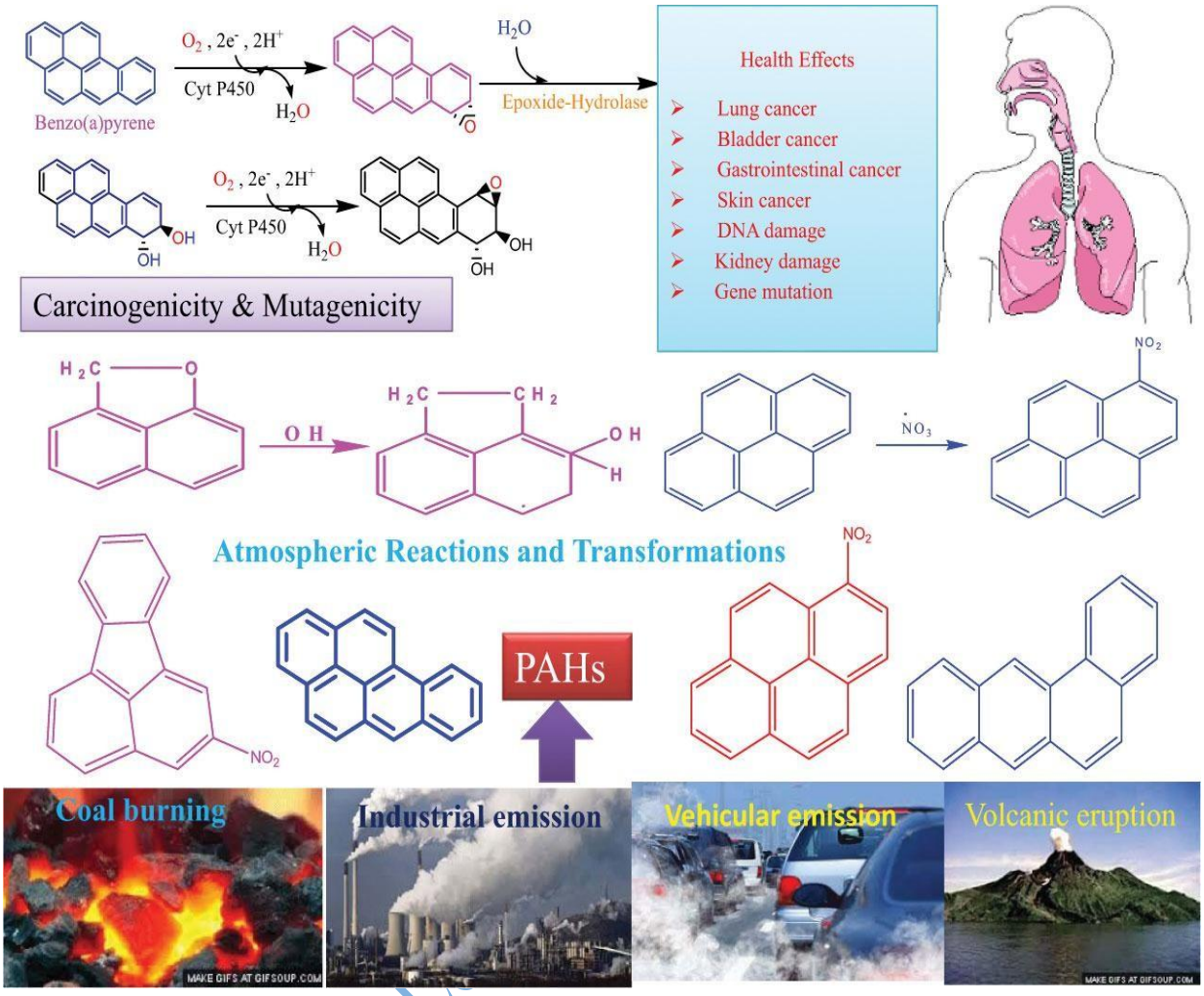


Figure 2.4: Polycyclic Aromatic Hydrocarbons: Sources, Importance and Fate in the Atmospheric Environment.

Source: [107].

Human Toxicology and Exposure to PAHs in Nigeria.

The human body has purportedly been revealed to contain PAHs. Although these kinds of research are not common in Nigeria, many have shown a connection between exposure to PAHs and a variety of physical afflictions and disorders. Carcinogenic PAH concentrations in the blood and urine samples of about 36 children tested in Imo State, Nigeria, ranging from 53.48 to 70.8 g/dL and 94.98-115.04 g/dL were determined[107,108]. In a different investigation, blood samples collected from neurology patients included up to 14 PAHs. Pyrene, fluoranthene, and acenaphthene concentrations were 2.96-236.86 ng/ml, 1.96-11.55 ng/ml, and 11.08-1.81 ng/ml, respectively, in the blood plasma. The numbers obtained were said to be important and related to the patient's health [109].

Because of their toxicity and characteristics including limited water solubility, strong affinity for lipids, and propensity to adsorb to particulate matter, PAHs are of importance because of their persistence in the environment, long-range transit, accumulation in the soil, and hazardous nature. Their conversion into alkylated compounds is another factor contributing to their toxicity. Sixteen of these are currently regulated by the World Health Organization and the United States and are known as priority PAHs. Acenaphthene (ACE), Acenaphthylene (ACY), Anthracene (ANTH), Benzo[a]anthracene (B[a]A), Benzo[a]pyrene (B[a]P), Benzo[b]fluoranthene (B[b]F), Benzo[k]fluoranthene (B[k]F), Benzo[g,h,i]perylene (B[ghi]P), Chrysene (CHRY), Dibenz[a,h]anthracene (D[ah]A), Fluoranthene (FLTH), Fluorene (FLU), Indeno[1,2,3-c,d]pyrene (IND), Phenanthrene (PHEN), Pyrene (PYR) and Naphthalene (NAP)[110] . Through many years of eco-toxicity studies, seven of the PAHs, namely Benzo[b]fluoranthene (B[b]F), Benzo[k]fluoranthene

(B[k]F), Benzo[a]pyrene (B[a]P), Indeno[1,2,3-c,d]pyrene (IND), Benzo[a]anthracene (B[a]A), Chrysene (CHRY), and Dibenz[a,h]anthracene (D[ah]A) have been identified and profiled for potent carcinogens, mutagens and teratogens[101]

2.13 Sources of PAH

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of organic compounds consisting of fused aromatic rings[111]. They are formed during the incomplete combustion of organic materials and are widely distributed in the environment. PAHs are known to be carcinogenic and mutagenic, making them a significant environmental and public health concern. Presented below are the diverse origins of polycyclic aromatic hydrocarbons (PAHs) (figure 2.5).

Combustion of Fossil Fuels

PAHs are majorly produced during the combustion of fossil fuels such as coal, oil, and gasoline. Vehicle emissions, industrial processes, power plants, and residential heating are some of the primary sources of PAHs resulting from the incomplete combustion of these fuels. Studies have shown that vehicle exhaust is a major contributor to urban PAH pollution[112].

Biomass Burning

The burning of biomass, including wood, charcoal, crop residues, and animal dung, releases PAHs into the atmosphere. Agricultural burning practices, deforestation, and cooking using solid fuels in developing countries are significant contributors to PAH emissions.

Industrial Activities

Certain industrial processes such as steel manufacturing, aluminum production, and coke production involve high-temperature operations that release PAHs into the air. PAHs are also found in industrial effluents and wastewater.

Residential Heating and Cooking

In households that rely on solid fuels like wood, coal, or charcoal for cooking and heating, PAH emissions can be substantial. Indoor air pollution from these sources can lead to health problems, especially in developing countries with poor ventilation.

Tobacco Smoke

Cigarette smoke contains numerous harmful compounds, including PAHs. Smokers and individuals exposed to secondhand smoke are at risk of inhaling PAHs and experiencing adverse health effects.

Natural Sources

PAHs can also originate from natural sources such as forest fires and volcanic eruptions. While the contribution from natural sources is relatively small compared to human activities, they can still influence PAH levels in certain regions.

Road Dust and Urban Resuspension

PAHs from vehicle emissions and other sources can settle on road surfaces and become part of road dust. When traffic passes over the roads, these particles can become resuspended in the air, contributing to urban PAH pollution.

2.14 Atmospheric Transformation and Deposition

PAHs can undergo various atmospheric transformations, including reactions with other pollutants, photodegradation, and oxidation. These processes can alter the composition and behavior of PAHs in the atmosphere and can lead to their deposition onto surfaces, including soil and water bodies[101].

2.15 Transport and Fate of PAHs in the Environment

The transport and fate of Polycyclic Aromatic Hydrocarbons (PAHs) in the environment involve various processes that determine their movement, transformation, and ultimate distribution. Understanding these processes is essential for assessing their environmental impact and designing effective mitigation strategies.

Atmospheric Transport

PAHs released into the atmosphere during combustion processes, industrial activities, and natural sources can travel long distances due to their volatility and low water solubility. Once in the air, they can be transported over regional and even global scales before being deposited back to the earth's surface through dry or wet deposition[113].

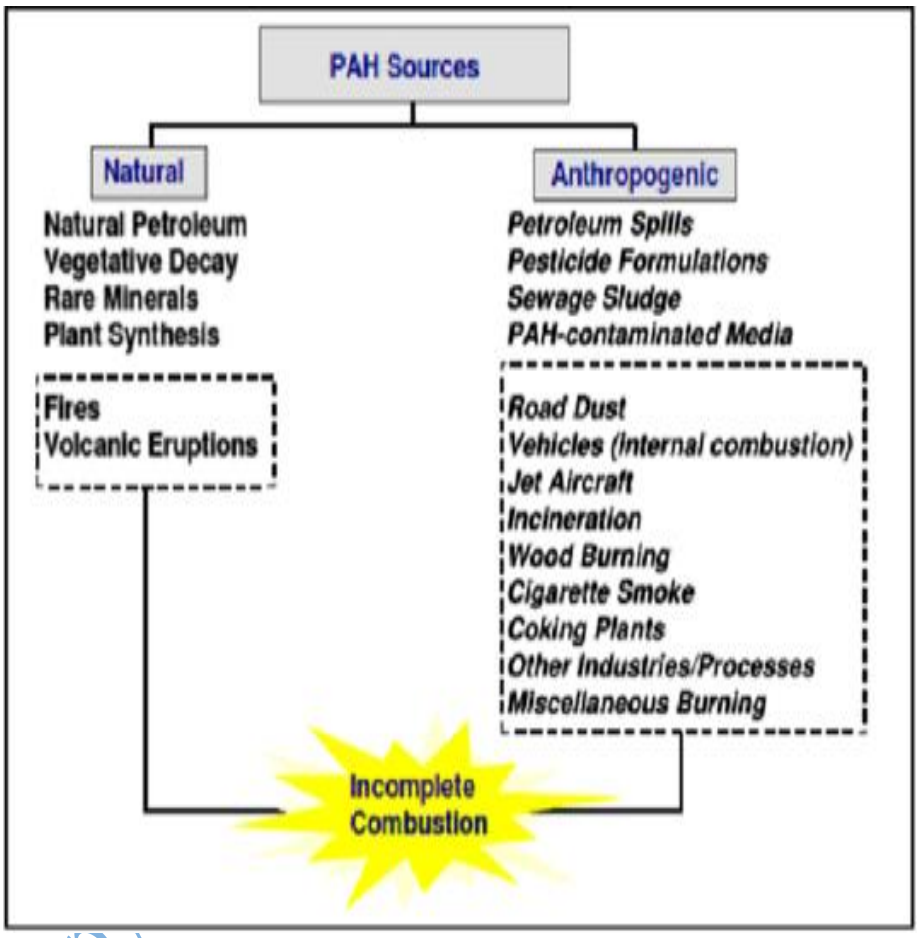


Figure 2.5: Natural and Anthropogenic Sources of Polycyclic Aromatic Hydrocarbons (PAHs).

Source: [101].

Deposition

PAHs can be deposited onto different environmental compartments through both dry and wet processes. Dry deposition occurs when particles settle directly from the atmosphere onto surfaces like soil, vegetation, and water bodies. Wet deposition involves PAHs being scavenged from the atmosphere by rain or snow and subsequently deposited onto surfaces during precipitation events[114].

Soil Interaction

When PAHs are deposited onto soil surfaces, they can bind to soil particles, leading to their sorption and sequestration. The extent of sorption depends on the physicochemical properties of both the PAHs and the soil, such as organic carbon content, pH, and clay mineral composition. Sorbed PAHs may remain in the soil for an extended period, depending on their persistence and susceptibility to microbial degradation.

Water Interaction

PAHs can enter water bodies through direct runoff or via atmospheric deposition during precipitation events. Once in water, they can partition between the dissolved phase and suspended particles. PAHs with higher molecular weight and lower water solubility tend to associate more with particulate matter, leading to their accumulation in sediments.

Bioaccumulation and Biomagnification

PAHs have the potential to bioaccumulate in aquatic organisms, particularly those with a higher lipid content, such as fish. Through the process of biomagnification, PAH concentrations can increase up the food chain, with top predators having the highest levels (figure 2.6).

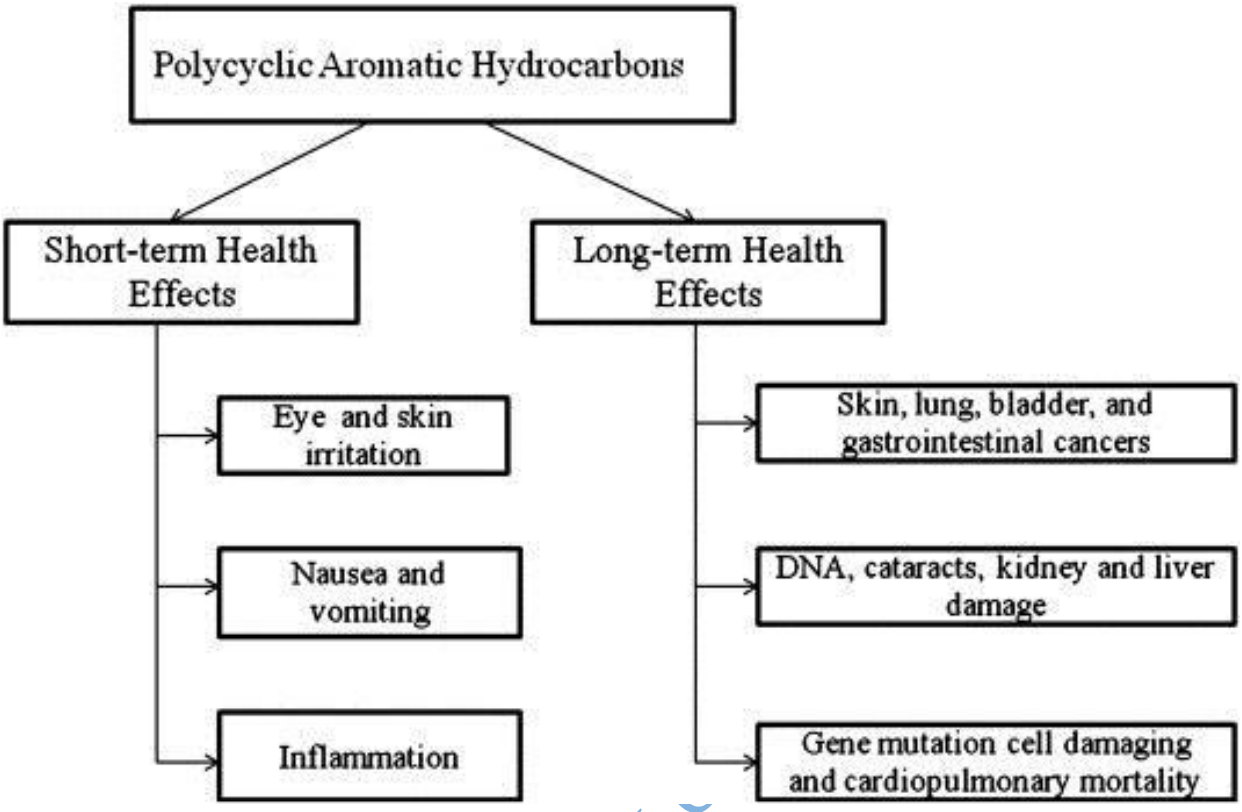


Figure 2.6: Flow Charts showing Short- and Long-Term Health Effects of Exposure to PAHs.

Source:[115].

Photodegradation

PAHs in the atmosphere and on surfaces can undergo photodegradation when exposed to sunlight. This process involves the breaking of chemical bonds due to UV radiation, leading to the formation of less complex and less toxic PAH derivatives. However, some photodegradation products can still be harmful to the environment.

Microbial Degradation

In soil and aquatic environments, certain microorganisms have the ability to metabolize PAHs, breaking them down into simpler and less toxic compounds. Microbial degradation is a crucial natural mechanism for reducing the persistence and potential harmful effects of PAHs in the environment.

2.16 Risk Management Strategies

Remediation and Mitigation Measures

Implementing effective strategies to prevent or mitigate groundwater contamination is essential for minimizing the associated risks. These measures could encompass a range of approaches, such as employing appropriate landfill designs to minimize leachate migration, implementing leachate collection and treatment systems to minimize potential pollutants, and ensuring consistent monitoring of groundwater quality to promptly detect any deviations[116, 117].

In order to effectively address the risks posed by groundwater contamination from municipal solid waste dumpsites, the implementation of robust remediation and mitigation measures becomes paramount. These measures constitute a crucial line of defence against

the potential migration of toxic chemicals and pollutants, safeguarding both human health and the environment[118]. A comprehensive approach involving multiple strategies is necessary to tackle the multifaceted nature of the issue. One of the fundamental approaches involves the careful design and engineering of landfills to minimize the migration of leachate—a significant carrier of contaminants—into the groundwater system. Landfill design elements include impermeable liners, drainage systems, and proper cover materials to inhibit the percolation of leachate. This prevents the downward movement of pollutants, reducing their potential reach within the subsurface [119].

Furthermore, the implementation of leachate collection and treatment systems represents a pivotal strategy in reducing the release of potential pollutants into the environment. By capturing leachate at the source, these systems prevent its uncontrolled migration and facilitate its proper treatment. This not only minimizes the immediate impact on groundwater quality but also mitigates the long-term potential for contaminant migration [120].

To ensure the effectiveness of these measures, consistent and rigorous monitoring of groundwater quality is of utmost importance. Regular assessment of the concentrations of various contaminants allows for the early detection of any deviations from established benchmarks. This proactive approach enables timely responses and adjustments to mitigation strategies, preventing potential risks from escalating and ensuring the ongoing protection of water resources [121].

In essence, remediation and mitigation strategies encompass a multifaceted approach that addresses the entire spectrum of contamination prevention and control. By combining appropriate landfill designs, effective leachate collection and treatment systems, and

vigilant groundwater quality monitoring, the potential risks associated with groundwater contamination can be substantially reduced[122]. These measures collectively contribute to the creation of a sustainable framework for managing and safeguarding water resources in areas affected by municipal solid waste dumpsites.

Long-Term Monitoring

Following the implementation of remediation measures to address groundwater contamination issues, the significance of long-term monitoring cannot be overstated. Continuous and sustained monitoring of groundwater quality serves as a critical mechanism for evaluating the ongoing effectiveness of the employed remediation strategies. This practice helps ensure that the situation remains under control and provides a platform for timely responses to any unanticipated developments that may arise over time.

The complexities of groundwater systems, along with the dynamic nature of contaminant transport, necessitate an extended monitoring period to accurately gauge the success of the implemented measures[123]. The long-term monitoring is pivotal in discerning the gradual changes in contaminant concentrations, groundwater flow patterns, and potential fluctuations in environmental conditions[124]. Such changes might not become apparent in short-term monitoring efforts. Through long-term monitoring, the persistence and trends of contaminants can be better understood. This aids in identifying whether the initially observed reduction in pollutant concentrations, a key goal of remediation, is being sustained over the years. By analysing these trends, practitioners can confirm whether the desired remediation outcomes are being achieved or if further interventions are necessary.

Moreover, long-term monitoring serves as an essential tool for detecting unforeseen issues that might emerge after remediation. The subsurface environment can react unpredictably to remediation actions, potentially leading to shifts in contaminant behaviour or the appearance of previously dormant pollutants. Such occurrences may not become evident immediately but could surface over time[125]. Regular monitoring provides the opportunity to promptly detect and respond to these challenges, thereby preventing potential setbacks and ensuring the continued protection of groundwater resources.

In essence, long-term monitoring encapsulates a proactive approach to environmental management, where the lessons learned from the ongoing evaluation of groundwater quality contribute to the refinement and enhancement of remediation strategies. The insights gained from such monitoring efforts aid in maintaining control over the state of groundwater quality and offer a means to respond effectively to changing conditions[126]. Therefore, it serves as a linchpin in the overarching risk assessment and management framework, ensuring that the commitment to safeguarding the environment and public health remains resolute over time.

2.17 Public Health Effects of Landfill Leachates

The effects of landfill leachate on the environment and public health. The environment is made up of a variety of elements that surround one. It could include the soil, water, and air environments. Leachate from dump sites affects the ecosystem mostly as a consequence of operating landfills below acceptable standards. Due to the fact that dumpsite leachate contains a variety of elements that can have a negative impact on the environment and public health, Nigeria's lack of properly engineered landfills has contributed to the cause of dumpsite leachate effects on those two areas [127]. Soil, groundwater, and surface water

have all been shown to be contaminated by dumpsite leachate. As it may pollute the air with an unpleasant odour, it can also be considered to contaminate the air environment. Pollution from dumpsite leachate may contaminate food goods, plants, animals, or other living things, which might have an impact on people's health [128].

2.17.1. Leachate as a Possible Pathogen Source and its Implications for Human Health

The pathogenicity of leachates from dumpsites can be attributed to the dumpsite's suitability for the growth of various microbial pathogens like *Arthorobacter, Bacillus, E. coli, Klebsiella, Micrococus, Proteus, Serratia, Aspergillus, Fusarium, Mucor, Penicillum, Rhizopus*, and *Saccharomyces*[129]. Direct handling of the garbage may lead to a number of infectious and chronic illnesses in both the waste employees and the general public [130]. As they migrate from one dumpsite to another, scavengers of all ages are exposed to numerous illnesses from the dumpsites. Some people reside fairly near to the landfill. People who live closer to landfill sites experience more health problems than those who live further away, including diarrhoea, abdominal pain, cough, asthma, skin irritation, malaria, respiratory diseases, recurrent flu, eye irritation, body weakness, cholera, tuberculosis, etc[131]. The proximity of a dumpsite near homes and other sensitive locations like a market, a river, or a stream should be deemed unsafe and pose a risk to the public's health that has to be adequately handled. Consumables including fruits, vegetables, sauces, and other food products that are sold nearby are exposed to a variety of diseases from the dumpsite, which poses a major health concern to those who live close to the site[132]. The elderly, small children, and those with impaired immune systems are particularly susceptible to infection, as are sellers, purchasers, and anybody who eats from such goods without cleaning or

preparing them properly. *E. coli, Enterobacter, Bacillus, Salmonella, Aspergillus niger, Aspergillus flavus, Rhizopus, yeast species, Serratia marcescene, Klebsiella aerogenes, Staphylococcus aureus, Alcaligens species,* and *Proteus* species are a few of the pathogens linked to dumpsite leachate. These pathogens may cause a number of disease outbreaks, including typhoid, cholera, diarrhoea, skin rash, etc. by contaminating water, plants, or food supplies.

2.17.2. Heavy Metal Occurrence in Dumpsite Leachate and Human Exposure

Many of these wastes are disposed of in the dump site without adequate or no treatment or management, despite this the presence of heavy metals in waste dumpsites has increased as a result of the indiscriminate disposal of some hazardous waste, such as electronic waste, batteries, construction and demolition wastes. The leachate that is created from such a dumpsite ultimately retains residues of the heavy metals that were present there. Depending on the waste types it originates from and the age of the dumpsite, leachate may include various metals. Out of the 92 naturally occurring elements, around 30 metals and metalloids—Be, B, Li, Al, Ti, V, Cr, Mn, Co, Ni, Cu, As, Se, Sr, Mo, Pd, Ag, Cd, Sn, Sb, Te, Cs, Ba, W, Pt, Au, Hg, Pb, and Bi—are potentially harmful to humans[132]. The health of humans is known to be adversely affected by lead (Pb), cadmium (Cd), mercury (Hg), and arsenic (As), even at low concentrations of intake[133]**.** Consuming plants or water that has been polluted with heavy metals may lead to heavy metal toxicity in humans. For instance, environmental cadmium may persist for decades in soils and sediments. Plants progressively absorb accumulated metals in the food chain, which eventually reaches humans who consume these plants. Due to cadmium's high rate of soil to plant transfer and it was mostly identified in fruits and vegetables. To reduce the risk of hazardous metals

entering the human system, planting vegetables and legumes close to waste sites should be discouraged[134]. If ingested, the high quantity of metal that plants take up from the soil poses a serious danger to human health[135]. Ingestion of other creatures, such as fish and aquatic plants that inhabit an environment polluted by leachates may potentially result in further impacts from leachates. If actions are not taken, pollutants will eventually migrate through soil strata and may contaminate ground water after a certain period of time, which can create serious problems because these metals cannot be degraded [136]. The presence of toxic heavy metal in leachate-contaminated soil indicates that there is appreciable contamination of the soil. Heavy metals, which have been shown to be harmful to human health, are known to cause a number of diseases and health problems, including impaired growth and development, damage to the nervous system, organ damage, and a rise in the incidence of cancer when ingested[137].

2.17.3 Leachate Pollution of Underground Water

The soil is a crucial part of the dumpsite where different types of dirty materials are dumped. Leachate is produced as a consequence of biological, chemical, and physical processes that encourage garbage decomposition inside the landfill. Soil contamination is caused by water flowing first through garbage disposal sites and subsequently through soil. Leachates are known to pollute landfill soil and the area surrounding it[138]. Chemicals, heavy metals, batteries, medications, and other potentially dangerous compounds may be present in leachate. The soil has become a sink for pollution as a result of the migration or movement of leachate. Because heavy metals including lead, copper, zinc, iron, manganese, chromium, and cadmium cannot be biodegraded, they may create major issues when contaminated[139]. Heavy metals alter the microbial population that produces enzymes,

which has an indirect impact on the enzymatic activity of soil. The microbial diversity, population size, and general activity of the soil microbial communities are all altered by the heavy metals[140]**.** Landfill leachate may compromise the quality and safety of soil, contaminate the food supply, and pose long-term health hazards[140]**.** The quality and production of crops may be impacted by the migrations of heavy metal-contaminated leachate to agricultural farmland because they have the potential to degrade the soil and render it unusable for agriculture[141]**.** Even at extremely low concentrations, Pb may disrupt key essential plant functions including photosynthesis, mitosis, and water absorption with toxic signs of dark green leaves[142]**.** High Pb concentrations in soils can reduce soil production.

Leachate soil pollution may also result in the following additional effects:

•Modification of soil composition

•Landscape alteration and discomfort

•Crop/plant influence; abnormal development and growth brought on by harmful substances

•Has an impact on the local economy; is often not appealing to visitors or investors

Contamination of Surface and Ground Waters.

Groundwater and surface water contamination from landfill leachate are the main possible environmental effects. The dumpsite is made up of a variety of waste materials that are being broken down by microorganisms as well as different chemicals, metals, and other materials that make up the dump. When trash migrates into a body of water due to leachate, it becomes a cause of water pollution. Leachate may also mix with the environment and

water bodies due to rainwater flow. Leachate production is linked to precipitation that seeps through the trash dump, which often causes leachate to migrate into the groundwater zone and contaminate it[143]**.** Leachate from solid waste dumps has been documented in many reports as contaminating ground water[144]**.** Different types of contaminants, such as heavy metals, nitrogen species, chlorinated hydrocarbons, phenols, cyanides, and bacteria, among others, may cause ground water contamination from dumpsite leachate[145]**.** Electronic garbage dumped in a landfill emits poisons that seep into the groundwater, contributing to groundwater contamination. Heavy metals may come from electronic trash, and their presence in water bodies can have an impact on both terrestrial and marine life. Human health is therefore impacted, particularly for those who drink directly from the source.

In Chachoengsao, an agricultural region east of Bangkok, the local people have lost their primary water supply as a consequence of e-waste disposal. In order to mine the electronics for precious metal components like copper, silver, and gold, a neighbouring Chinese-run firm began importing Western e-waste goods such shattered PCs, circuit boards, and cables. When it rained, the water travelled through the rubbish pile, into their houses, and into the water system since these things contain extremely poisonous lead, cadmium, and mercury. Both the local government and environmental organisation Earth tested the water in the province, and it was determined that dangerous amounts of iron, manganese, lead, nickel, and sometimes arsenic and cadmium were present. The people also noted that the shallow well had an unpleasant odour, and that certain skin conditions developed when they used the well water[146]**.** The biological balance of the aquatic environment may be severely impacted by surface or ground water pollution, and the variety of aquatic creatures is constrained as contamination levels rise.

An aquatic organism's accumulation of heavy metals may spread through the higher classes of the food chain. Because they are at the top of the food chain, including humans, carnivores get the majority of the heavy metals in their bodies from the aquatic environment via their diet. The concentration and flow of the leachate, as well as the fundamental quality, volume, and sensitivity of the receiving water bodies, are the elements affecting the polluting potential of leachate. Planning and building water resources properly requires evaluating groundwater quality and creating plans to keep aquifers clean[147].

2.17.4 Leachate Air Contamination

Air is a vehicle for the spread of bacteria, fungi, and viruses that may infect people and animals and cause a number of illnesses. Leachate promotes bad odour on the site and in the neighbourhood, contaminating the air as a result of the concentration of microorganisms and other harmful components produced on landfills. The locations' airborne discharges may have a serious negative impact on human health. People who live near to a landfill, garbage workers, and scavengers are vulnerable to ongoing exposure to the numerous pollutants that are prevalent there. Anosmia may be brought on by prolonged pollutant inhalation. It is often unpleasant and unclean to breathe in the foul smell from such a dumpsite. Asthma, stomach discomfort, sneezing, skin irritation, and other health issues might be brought on by it.

2.17.5 Leachate as a Potential Source of Pathogen and Health Implication

Studies has shown that leachate from dumpsite contains large number of pathogenic and opportunistic microorganisms[150,]. It pathogenicity can be linked to the disposal of raw

human faeces and other human waste on the dumpsite which is suitable for the growth of diverse microbial pathogens *like Arthorobacter, bacillus, E. coli, Klebsiella, micrococus, Proteus, serratia, Aspergillus, Fusarium, mucor, Penicillum, Rhizopus and Saccharomyces*[151]**.** Direct handling of the waste can result in various types of infectious and chronic diseases with the waste workers and community at large[152]**.** Scavengers both young and old are open to various infections from the dumpsites as they move from one dumpsite to the other. Some live very close to the dumpsite. A review carried out by Njoku et al., shows that people living closer to landfill sites suffer from several illnesses such as diarrhea, abdominal pain, cough, asthma, skin irritation, malaria, respiratory diseases, recurring flu, eye irritation, body weakness, cholera, tuberculosis etc. more than the people living far away from landfill sites[153]. The location of dumpsite closer to residential buildings and other sensitive areas like market place, river and stream should be considered not safe and a public health threat that needs to be properly addressed. Consumables such as fruits, vegetables, condiments and other food items being sold close by are opened to various pathogens from the dumpsite, will pose serious health risk to human within the dumpsite vicinity due to possible cross contamination of food and fruit items[154]**.** Sellers, buyers and any individuals who consumes from such items without washing or cooking well are at high risk of contamination, especially the aged, young children and immune compromised persons are more vulnerable. Some of the pathogens associated with dumpsite leachate include; *E.coli, Enterobacter, Bacillus, Salmonella, Aspergillus niger, Aspergillus flavus, Rhizopus, yeast species, Serratia marcescene, Klebsiella aerogenes, Staphylococcus aureus, Alcaligens species and Proteus species*. Many outbreaks of disease

such as typhoid, cholera, diarrhea, skin rash etc., may result from these pathogens through contamination in water, plant or food sources.

2.18 Public Health Effects of PAHS

PAHs are taken into account as a category since they have been recognised as being of the highest concern in terms of possible exposure and harmful effects on human health. Due to the extensive distribution of these substances and their importance in terms of toxicology, biological monitoring of exposure to PAHs is of prime interest. However, there are certain differences between how each PAH affects health. In fact, several PAHs are classified as being known, probable, or definitely carcinogenic to humans (Group 1, 2A, or 2B) by the International Agency for Research on Cancer[155]. Benzo[a]pyrene (Group 1), naphthalene, chrysene, benz[a] anthracene, benzo[k]fluoranthene, and benzo[b]fluoranthene (Group 2B) [8] are a few of these[155]**.** Some PAHs are well-known to be teratogens, mutagens, and carcinogens, which puts human health and wellbeing in grave danger. Lung cancer risk is elevated as a result of PAH inhalation exposure, which is the most severe health consequence to be anticipated[156]**.**

2.18.1 Routes of Exposure

Inhaling outdoor and indoor air, consuming foods containing PAHs, smoking cigarettes, or inhaling smoke from open fireplaces are the main ways that people in general are exposed to PAHs[157]**.** More than 40 recognised or suspected human carcinogens are also present in tobacco smoke, along with a range of PAHs such benzo(a)pyrene[157]**.** Some plants, including wheat, rye, and lentils, may produce PAHs or take them up via the soil, water, or

air. Since these substances may leak into water from the land, as well as through industrial effluents and maritime accidental spills during the transport of oil, water may potentially include some PAHs. Additionally, PAHs are found in soil, mostly from airborne dispersion[158]**.** As a result, the majority of individuals regularly come into contact with PAHs. In both industrial and non-occupational situations, there are three main ways to be exposed: by ingestion, inhalation, and skin contact. Workers who breathe exhaust fumes on the job, such as mechanics, street sellers, and drivers of cars, as well as those who work in the mining, metalworking, or oil refining industries, may also be exposed. When more than one exposure route is used at once, it may impact the overall dosage received (for example, cutaneous and inhalation exposures from polluted air) [101]. Direct inhalation, ingesting, or dermal contact with PAHs in the air or surface soil may expose a person to them.

2.18.2. Metabolism Exposure to PAHs is Never to Single PAHs.

It is possible to accurately estimate the hazards of PAHs by understanding the variations that may exist in mixes of PAHs. Therefore, it is essential to comprehend the dynamics of PAHs' solitary metabolism as well as any potential hazardous consequences. This will aid in precisely understanding the effects of PAHs and aid in the development of effective remediation solutions. By observing the disappearance of the parent chemical, studies were conducted comparing the metabolism of the PAHs phenanthrene (PHE), flouranthene (FLA), and benzo (a)pyrene (BAP) in single, binary, and ternary combinations. It was found that the metabolism of PAHs in the binary and ternary mixes was different from that of the single PAH experiment. The metabolism of combinations showed evidence of enzyme competition, which considerably altered the patterns of metabolism for individual

PAHs. The metabolism of mixtures and the potential for adverse effects during mixture metabolism were both observed to be influenced by PAH structure. The metabolism of a single PAH altered more quickly over time than that of a ternary mixture, a binary metabolism, and a ternary mixture metabolism combined [101]. This family of chemicals have a large bioavailability upon ingesting and inhalation because of their high lipophilicity. Scientific studies have shown that practically all internal organs, especially those that are abundant in adipose tissue, contain measurable quantities of PAH. These organs may act as repositories for the hydrocarbons, from which they can be progressively released. Once the PAHs have entered the body, certain enzymes are needed for a multistep metabolic activation process. The mixed-function oxidase system is the primary system of enzymes involved in PAH metabolism. Epoxidation is the first reaction. The next step is the conjugation of PAH epoxides with glutathione, which is recognised as a real detoxification response. Epoxides are transformed into phenols and diols if they are not conjugated with glutathione. However, these PAH metabolites aren't always polar enough to be eliminated. To permit elimination, they must thus be conjugated with sulfuric or glucuronic acids. The majority of PAH metabolites are eliminated in urine and faeces[159].

2.18.3 Short-Term Health Effects (Acute)

The effects of PAHs on human health mostly rely on the duration and mode of exposure, the quantity or concentration of PAHs one is exposed to, as well as the relative toxicity of the PAHs [101]. Numerous additional variables, such as age and subjective variables like pre-existing health condition, might also have an influence on health outcomes. It is unclear if PAHs may have an immediate negative impact on human health. Eye irritation, nausea, vomiting, diarrhoea, and disorientation have been reported as symptoms of occupational

exposure to high levels of pollutant mixes including PAHs[160]**.** However, it is unknown which elements of the combination caused these side effects, and other substances that are often detected alongside PAHs might be to blame for similar symptoms. Combinations of PAHs are also known to irritate and inflame the skin. Naphthalene, benzo(a)pyrene, and anthracene directly irritate the skin. However, it has been shown that anthracene and benzo(a)pyrene may elicit skin sensitization, or an allergic response, in both people and animals [111].

2.18.4 Long-Term Health Effects (Chronic)

Reduced immunological function, cataracts, kidney and liver damage (such as jaundice), breathing issues, asthma-like symptoms, and altered lung function are just a few of the health impacts that may result from long-term or chronic exposure to PAHs. Meanwhile, frequent skin-to-skin contact may cause skin irritation and redness. If breathed or swallowed in high quantities, the particular PAH naphthalene may lead to the destruction of red blood cells. The negative consequences that might happen if Man is exposed to PAHs mostly depend on the exposure route [101,111].

2.18.5. Carcinogenicity

Reduced immunological function, cataracts, kidney and liver damage (such as jaundice), breathing issues, asthma-like symptoms, and altered lung function are just a few of the health impacts that may result from long-term or chronic exposure to PAHs. Meanwhile, frequent skin-to-skin contact may cause skin irritation and redness. If breathed or swallowed in high quantities, the particular PAH naphthalene may lead to the destruction

of red blood cells. The negative consequences that might happen if Man is exposed to PAHs mostly depend on the exposure route [111].

2.18.6. Effects of PAH on the Immune System

It has been reported that the PAHs induce suppress immune reaction in rodents [111]. The precise mechanisms of PAH induced immune-toxicity are still not clear. It was concluded that the immune-suppression may be involved in the mechanisms by which PAH induce cancer. The immune-toxic effects of PAH have been investigated for many years. Whatever the route of exposure, the resulting effects have been considered mostly at the systemic level. However, very few studies have looked for alterations of the local gut immune system. Immuno-suppression is associated with an increased susceptibility of the exposed individuals to the development of cancers or of infectious diseases. It was sated that the immune-potentiation results in an increased secretion of cytokines by immune cells, that leads to inflammation. Under specific circumstances, this may facilitate tumor development, expression of hypersensitivity (allergy, contact hypersensitivity) or auto immunity. Depending on various parameters in the design of the protocol such as route of exposure, end point, high or low level of dosage, model used, immune suppression or immune-potentiation can be observed[161]. Nevertheless, the published reports indicate that the immune-suppression is the most frequent effect reported after exposure to PAH[162]**.** In addition, the literature stated that the immune-potentiation is reported to occur after either atmospheric or topic exposure, or by using in vitro systems[163]**.** In term of the route of exposure, most of literature have used either subcutaneous and intra-peritoneal injection or inhalation[164]**.** Experimental studies were conducted on the immuno-toxicity that resulted from ingestion of PAH in contaminated food after oral intake of a diet contaminated with

PAH. Furthermore, it has been reported that some PAH when taken into the diet may induce DNA adducts in the lungs. In addition, translocations from one organ to another may result in ‘‘at distance” effects.

2.19. Issues with Effective Waste/Leachate Management.

Waste management is a significant issue in developing nations like Nigeria. Even while there are municipal solid waste disposal facilities spread out throughout the states, they are poorly run. The country's failure to manage its waste effectively has exacerbated the leachate impact and pollution, which is very dangerous for the environment and people's health. In Nigeria, the issue of solid waste management is characterised by ineffective collection techniques, inadequate collection system coverage, and poor solid waste disposal[148]**.** The majority of states and cities do not have standard engineered landfills, and the majority of landfills are not designed with a leachate collection/treatment system or an engineered liner, resulting in the free flow and migration of leachate waste from the dumpsite and environmental hazards[149]**.** It is also interesting to note that some issues with improper waste management can be linked to irregular performance of duties by environmental waste workers or agencies. For example, there appears to be no regular clean-up, no apparent routine check on how waste is properly managed in the community or dumpsite, and improper or no allocation of waste dumpsite, all of which contribute to the growth of open dumpsites. Leachate from dump sites may also have negative effects on the ecosystem and the general populace if there aren't enough financial and political restraints for appropriate waste management.

•Inadequate community members' awareness of good health hygiene.

• The careless dumping on landfills of hazardous industrial and medical wastes.

•There is no supposed location for landfills or rubbish disposal.

• The dump site's proximity to a market, a river, and homes.

•The dumpsite is not properly regulated or controlled.

•The treatment of the waste/leachate dumpsite is subpar or non-existent. Although there haven't been many incidents of leachate migration in Nigeria, the issue might become much worse if it isn't seriously investigated and addressed.

Endnotes

1. R. Basu, *Solid Waste Management-A Model Study*, **Sies Journal of Management**, 6, 2009, 20- 24.

2. P.R. White, M. Franke & P. Hindle, *Integrated Solid Waste Management: A Lifecycle Inventory***.** Berlin: Springer, 1995.

3. Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, *Protocol on Liability and Compensation for Damage Resulting from Transboundary Movements of Hazardous Wastes and their Disposal*, 2019.

4. N. Ferronato & Torretta V., *Waste Mismanagement in Developing Countries: A Review of Global Issues,* **International Journal of Environmental Research and Public Health***; 16(6), 2019, 1060.*

5. C. Ludwig, S. Hellweg & S. Stucki, *Municipal Solid Waste Management: Strategies and Technologies for Sustainable Solutions*, **Springer-Verlag, Berlin**, 2003.

6. M. Andersson & H. Säterskog, *Removal of Organic Contaminants, Metals and Sludge Characterisation*, Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering. Chalmers University of Technology Gothenburg, Sweden 2015.

7. R. Chandrappa, & D.B. Das, *Solid Waste Management – Principles and Practice*, **Springer-Verlag**, Berlin, 2012.

8. J.H. Lehr & J. Keeley, *Landfill*, **Water Encyclopedia**, 1, 2005, 695-699.

9. K.A. Kolekara; T. Hazrab & S.N. Chakrabartyc, *A Review on Prediction of Municipal Solid Waste Generation Models. Int. Conf. on Solid Waste Manage. 5IconSWM 2015*, **Procedia Environ. Sci.** 35, 2016, 238 – 244

10. J. Liu, Q, Li, W. Gu & C. Wang, *The Impact of Consumption Patterns on the Generation of Municipal Solid Waste in China: Evidences from Provincial Data*, **Int. J. Environ. Res. Public Health,** 16, 2019, 1717.

11. H. Chen, J, Dou & H, Xu, *Remediation of Cr (VI)-Contaminated Soil With Co-Composting of Three Different Biomass Solid Wastes*, **J. Soils Sediments**, 18, 2018, 897–905.

12. T. Tadesse, *Solid Waste Management. Produced in Collaboration with the Ethiopia Public Health Training Initiative*, The Carter Center, the Ethiopia Ministry of Health, and the Ethiopia Ministry of Education, Gondor University: Gondar, Ethiopia, 2004.

13. Tang, Jinfeng. "*Recovery of Copper and Zinc in Ashes from Municipal Solid Waste Combustion*." (2015).

14. O.M. Ogundele; O.M. Rapheal & A.M. Abiodun, *Effects of Municipal Waste Disposal Methods on Community Health in Ibadan- Nigeria*, **Polytechnica** 1, 2018, 61–72.

15. O.O. Olujimi, O.L. Ajayi & O.U., Oputu, *Toxicity Assessment of Olusosun Andigando Leachates Using the African Catfish (Clariasgariepinus) as Bioindicator Species Part I*, **IFE J. Sci.,** 18 (3), 2016, 693–700

16. MUDC, *Solid Waste Management Manual: With Respect to Urban Plans, Sanitary Landfill Sites and Solid Waste Management Planning: Urban Planning, Sanitation and Beautification Bureau*: Addis Ababa, Ethiopia, 2012.

17. S. Kaza, L. Yao, P. Bhada-Tata & F. VanWoerden, *What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050*. https://openknowledge.worldbank.org/handle/10986/30317

18. X. Sun; J. Li, X. Zhao, B. Zhu & G. Zhang, *A Review on the Management of Municipal Solid Waste Fly Ash in American*, **Procedia Environmental Sciences**, 31, 206, 535–540.

19. M.O. Agwu, *Issues and Challenges of Solid Waste Management Practices in Port-Harcourt City, Nigeria-a Behavioural Perspective*, **Am. J. Soc. Manag. Sci.,** 3, 2012, 83–92

20. United States Environmental Protection Agency, Waste - Non-Harzardous Waste-Municipal Solid Waste, 1200 Pennsylvania Avenue, N.W. Washington,DC 20460,U.S.A. (2013).

21. United States Environmental Protection Agency, Office of Land and Emergency management (US EPA) OLEUM "Medical Waste". 2023. www.epa.gov

22. United States Environmental Protection Agency, Office of Air and Radiation (US EP, OAR) "Radioactive Waste" 2023.www.epa.gov.

23. S.L. Rothwell, *Antinuclear Movement*. **Encyclopedia Britannica**.2023 https://www.britannica.com/topic/anti-nuclear-movement

24. P.O. Sada, *Urbanization and Living Conditions in Nigerian Cities, Research Triangle Institute as Cited by Uwadiegwu and Chukwu, 2013, Strategies for Effective Urban Solid Wate Management*, **European Scientific Journal**, 9(8), 1984, 1857 – 7881 1

25. S.N. Uchegbu, *Environmental Management and Protection*, Spotlite Publishers, Nigeria, 1988.

26. O.S. AmudA; S.A. Adebisi; L.A. Jimoda & A.O. Alade, *Challenges and Possible Panacea to the Municipal Solid Wastes Management in Nigeria*, **J Sustain Dev Stud.,** 1, 2014, 64–70

27. B. Olowe, *Existing Situation of Solid Waste Management in Ibadan*. https://www.academia.edu/12966883/EXISTING...

28. American Society of Mechanical Engineers (ASME), *Waste to Energy, Summary,* 2023, http://www.asme.org

29. A. Omari, B. Kichonge, G. John, K. Njau & P. Mtui, Peter, *Potential of Municipal Solid Waste, as Renewable Energy Source -A Case Study of Arusha, Tanzania*, **International Journal of Renewable Energy Technology Research**, 3, 2014, 1-9.

30. A.B. Nabegu, *An Analysis of Municipal Solid Waste in Kano Metropolis, Nigeria*, **Journal of Human Ecology**, 31(2), 2010, 111–119.

31. S. Mishra, D. Tiwary; A. Ohri & A.K. Agnihotri, *Impact of Municipal Solid Waste Landfill Leachate on Groundwater Quality in Varanasi, India*, **Groundwater for Sustainable Development**, 9, 2019, 100230.

32. Z.O. Ojekunle, M.A. Balogu, A.A. Adeyemi, K.A. Adegoke, A.O Anumah; A.M. Taiwo & S.A. Ganiyu, *Effect of Industrialization on Groundwater Quality in Shagamu and Ota Industrial Areas of Ogun State, Nigeria*. **Heliyon,** 6 (7), 2020, 1-13

33. Savita, Vivek Chopra, Anuradha Sharma, *Environmental Contaminants: Sources and Effects, Evaluation of Environmental Contaminants and Natural Products: A Human Health Perspective* 1(1) 2019.

34. Puspendu Bhunia, *Environmental Toxicants and Hazardous Contaminants: Recent Advances in Technologies for Sustainable Development*, 2017, **Journal of Hazardous, Toxic, and Radioactive Waste** 02017001 214

35. Savita, V.S. Chopra, & A. Sharma, *Environmental Contaminants: Sources and Effects, Evaluation of Environmental Contaminants and Natural Products: A Human Health Perspective*, Bentham Science Publisher, 23, 2019, 1-23.

36. C. Khalil, C. Al Hageh; S. Korfali & R,S, Khnayzer, *Municipal Leachates Health Risks: Chemical and Cytotoxicity Assessment from Regulated and Unregulated Municipal Dumpsites in Lebanon*, **Chemosphere**, 208, 2018, 1–13

37. N.F. Gray, *Water Technology – An Introduction for Environmental Scientists and Engineers*, Butterworth-Heinemann, Oxford, United Kingdom, (Third edition), 2010.

38. S.O. Daramola & B.I. Ilesanmi, *Geotechnical Evaluation of Some Lateritic Soils from Ore, Southwestern Nigeria as Liners in Landfills*, **Current Journal of Applied Science and Technology,** 32(1), 2019, 1-7

39. R.K Annepu, *Sustainable Solid Waste Management in India*, MSc thesis. Department of Earth and Environmental Engineering, Fu Foundation School of Engineering and Applied Science, Columbia University in the City of New York, 2012, 1-189.

40. C.G. Alimba, O.O. Adewumi, O.M. Binuyo & G.C. Odeigah, *Wild Black Rats (Rattus Rattus Linnaeus, 1758) as Zoomonitor of Genotoxicity and Systemic Toxicity Induced by Hazardous Emissions from Abule Egba Unsanitary Landfill, Lagos, Nigeria*, **Environ Sci Pollut Res** 28, 2021, 10603–10621.

41. C. G. Alimba, *DNA and Systemic Damage Induced by Landfill Leachates and Health Impacts of Human Exposure to Landfills in Lagos and Ibadan, Nigeria*, PhD thesis. Department of Zoology, University of Ibadan, Nigeria, 2013, 1-25.

42. D. Abiriga, L.S. Vestgarden, & H. Klempe, *Groundwater Contamination from A Municipal Landfill: Effect of Age, Landfill Closure, and Season on Groundwater Chemistry*, **Sci Total Environ**, 737, 2020, 140307.

43. O.O. Ige, *Note On Liners for Containment of Leachate in Sanitary Landfills to Enhance Sustainable Environment,* **International Journal of Development and Sustainability**, 2(1), 2013, 380-389.

44. G.P. Yal & H. Akgun, *Landfill Site Selection and Landfill Liner Design for Ankara, Turkey*, **Enviromental Earth Sciences**, 70, 2013, 2729-2752.

45. Waste Atlas Report, *World's Fifty Biggest Dumpsites.* 2014. http://www.d-waste.com/Atlasreport2014/Waste-Atlas-report-2014-webEdition.pdf.

46. J. Saghir & J. Santo, *Urbanization in Sub-Saharan Africa: Meeting Challenges by Bridging Stakeholders*, Center for Strategic and International Studies (CSIS), Washington, DC, 2018.

47. S. O. Adesogan & B. O. Omonigho, *Assessment of Leachate Contamination Potential Of Landfills in Ibadan, Nigeria*, **African Journal of Environmental Science and Technology**, 15(5), 2021, 179-187.

48. L. Lu, B. Wang, J. Jiang, Q. Huang, Z. Yu & H. Li, *Heavy Metal Contamination in Herbal Medicine: Determination Comprehensive Risk Assessment*, **Front. Pharmacol**., 11, 2020, 595335.

49. S.M. Ali, A. Pervaiz, B. Afzal, N. Hamid & A. Yasmin, *Open Dumping Of Municipal Solid Waste and Its Hazardous Impacts on Soil and Vegetation Diversity at Waste Dumping Sites of Islamabad City*, **J. King Saud Univ. Sci**., 26 (1), 2014, 59–65.

50. N. Nawrot, E. Wojciechowska, M. Mohsin, S. Kuittinen, A. Pappinen & S. Rezania, *Trace Metal Contamination of Bottom Sediments: A Review of Assessment Measures and Geochemical Background Determination Methods*, **Minerals**, 11, 2021, 872.

51. E.R. Salcedo Sánchez; J.M.E. Martínez; M.M. Morales; O.T. Mendoza & M.V.E. Alberich, *Ecological and Health Risk Assessment of Potential Toxic Elements from a Mining Area (Water and Sediments): The San Juan-Taxco River System, Guerrero, Mexico*, **Water**, 14, 2022, 518, 8

52. M. Tytła, A. Dmochowska, D. Dmochowski & K. Jaworska, *Ecological Risk Assessment of Trace Metals in the Bottom Sediments of the Young Water Reservoir - Bardowskiego Lagoon (Warsaw) Case Study*, **E3S Web Conf**., 44, 2018, 00182.

53. L. Prashanth, K.K. Kattapagari, R.T. Chitturi, V.R. Baddam & L.K. Prasad, *A Review on Role of Essential Trace Elements in Health and Disease,* **JNTR Univ. Health Sci**., 4, 2015, 75–85.

54. C.L. Mieiro, A.C. Duarde, M.E. Pereira & M. Pacheco, *Mercury Accumulation Patterns and Biomedical Endpoints in Wild Fish (Liza aurata): A Multiorgan Approach*, **Ecotox. Environ. Safety,** *74*, 2011, 2225–2232

55. S. Mahboob, S. Kausar, F. Jabeen, S. Sultana, T. Sultana, K.A. Al-Ghanim, B. Hussain, F. Al-Misned & Z. Ahmed, *Effect of Heavy Metals in Liver, Kidney, Gills and Muscles of Cyprinus Carpio and Wallago Attu Inhabited in the Indus*. **Braz. Arch. Biol. Technol.,** *59*, 2016, 1–10.

56. A. Careghini, A.F. Mastorgio, S. Saponaro & E. Sezenna, *Bisphenol A, Nonylphenols, Benzophenones, and Benzotriazoles in Soils, Groundwater, Surface Water, Sediments, and Food: A Review*, **Environ. Sci. Pollut. Res.** 22 (8), 2015, 5711–5741

57. B. Jezieerska & M. Witeska, *Uptake and Accumulation in Fish Living in Polluted Waters. in Soil and Water Pollution Monitoring,Protection and Remediation*; **Springer: Berlin/Heidelberg**, Germany, 69, 2006, 107–114.

58. H. Liu, H. Huang, X. Xiao, Z. Zhao & C. Liu, *Effects of Phthalate Esters (PAEs) on Cell Viability and Nrf2 of HepG2 and 3D-QSAR Studies*, **Toxics**, 9 (6), 2021, 134.

59. S. Jonsson, J. Ejlertsson & B.H. Svensson, *Transformation of Phthalates in Young Landfill Cells*, **Waste Manage**, 23, 2003, 641-651.

60. Y. Kalmykova, K. Björklund, A. Strömvall & L. Blom, *Partitioning Of Polycyclic Aromatic Hydrocarbons, Alkylphenols, Bisphenol A and Phthalates in Landfill Leachates and Stormwater*, **Water Res**., 47, 2013, 1317-1328.

61. O.T. Can; M.M. Tutun & R. Keyikoglu, *Anodic Oxidation of Bisphenol A by Different Dimensionally Stable Electrodes*, **Water Sci. Technol.,** 83 (8), 2021, 1907–1919

62. Xu, D.D., Liu, D.S *The Experiment Study of the Pollution of Phthalate Compounds,* 2014.

63. D.D. Xu & D.S. Liu, *The Experiment Study of the Pollution of Phthalate Compounds and Heavy Metals to Rice in the Film,* **Trans Tech Publ**, 2014, 303–306

64. D. Kashyap & T. Agarwal, *Concentration and Factors Affecting the Distribution of Phthalates in the Air and Dust: A Global Scenario*, **Sci Total Environ.** 635, 2018, 817-827.

65. N.D. Baloyi, M. Tekere, K.W. Maphangwa & V. Masindi, *Insights Into the Prevalence and Impacts of Phthalate Esters in Aquatic Ecosystems*, **Front. Environ. Sci**. 9, 2021, 684190.

66. H. Heo, M.J Choi, J. Park, T. Nam & J. Cho, *Anthropogenic Occurrence of Phthalate Esters in Beach Seawater in the Southeast Coast Region, South Korea*. **Water J.** 12 (122), 2020, 1–13.

67. A. Seyoum & A. Pradhan, *Effect of Phthalates on Development, Reproduction, Fat Metabolism and Lifespan in Daphnia magna*, **Sci. Total Environ.** 654, 2019, 969–977.

68. United States for Environmental Protection Agency USEPA, National Primary Drinking Water Regulations. (NPDWRs). 2023 http://www.epa.gov/ogwdw/consumer/pdf/mcl.pdf.

69. F. Pallotti, M. Pelloni, D. Gianfrilli, A. Lenzi, F. Lombardo, & D. Paoli. *Mechanisms of Testicular Disruption from Exposure to Bisphenol A and Phthalates.* **J Clin Med**, 9(2), 2020, 471.

70. M. Deng, X. Han, J. Ge; X. Liang, B. Du, J. Li & L. Zeng, *Prevalence of Phthalate Alternatives and Monoesters Alongside Traditional Phthalates in Indoor Dust from A Typical E-Waste Recycling Area: Source Elucidation and Co-Exposure Risk*, **J. Hazard. Mater**. 413, 2021, 125322.

71. A.C. Godswill & A.C. Godspel, *Physiological Effects of Plastic Wastes on the Endocrine System Bisphenol A, Phthalates, Bisphenol S, PBDEs, TBBPA),* **Int. J. Bioinform. Computational Biol.**, 4 (2), 2019, 11–29.

72. A. Schwendt, *The Influence of Conventional Phthalate Plasticizers Versus Emerging and Novel Non-Phthalate Plasticizers on Recovery from Cardiac Injury Using a Mouse Model of Surgically Induced Myocardial Infarction. 2020.* Division of Experimental Medicine McGill University, Montreal.

73. H. Wang, S. Tang; X. Zhou, R. Gao, Z. Liu, X. Song & F. Zeng, *Urinary Concentrations of Bisphenol Analogues in the South of China Population and their*

Contribution to the Per Capital Mass Loads in Wastewater, **Environ. Res**., 204, 2022, 112398

74. M.VNotardonato, M.V. Russo & P. Avino, *Phthalates and Bisphenol-A Residues in Water Samples: An Innovative Analytical Approach*, **Rendiconti Lincei. Scienze Fisichee Naturali,** 29 (4), 2018, 831–840

75. R.J. Hart., H. Frederiksen, D.A.Doherty., J.A. Keelan, N.E.Skakkebaek, N.S. Minaee, R. McLachlan, J.P. Newnham, J.E. Dickinson., C.E. Pennell,. *The Possible Impact of Antenatal Exposure to Ubiquitous Phthalates upon Male Reproductive Function at 20 Years of Age*. ***Front. Endocrinol. (Lausanne)***. 2018; 9:288. doi: 10.3389/fendo.2018.00288.

76. R. Hauser, & A.M. Calafat, *Phthalates and Human Health*. **Occup. Environ.Med**., *62*, 2005, 806–818.

77. Y. Qian, X. Jia; T. Ding; M. Yang, B. Yang & J. Li, *Occurrence and Removal of Bisphenol Analogues in Wastewater Treatment Plants and Activated Sludge Bioreactor*, **Sci. Total Environ.** 758, 2021, 143606

78. M. Zielinska, I. Wojnowska-Baryła & A. Cydzik-Kwiatkowska, *Bisphenol A Removal from Water and Wastewater*, **Springer**, 2019.

79. M. Mukhopadhyay, S. Sampath, J. Munoz-Arnanz, B. Jim´enez & P. Chakraborty, *Plasticizers and Bisphenol A in Adyar and Cooum Riverine Sediments, India: Occurrences, Sources and Risk Assessment*, **Environ. Geochem. Health,** 42 (9), 2020, 2789–2802

80. H. Fromme, Phthalates *and Their Metabolites in Indoor Air and Dust*, **Environmental Science & Technology**, 41(18), 2007, 6341-6346.

81. H.M. Shin, *Atmospheric Occurrence and Distribution of Phthalates in Urban and Suburban Residential Environments*, **Atmospheric Environment**, 45(18), 2011, 3132-3139.

82. J. Radjenović, *Phthalate Esters in Wastewater Treatment Plants: Sources, Fate and Removal,* **Science of the Total Environment**, 621, 2018, 753-766.

83. S. Renou, J.G. Givaudan, S. Poulain, F. Dirassouyan & P. Moulin, *Landfill Leachate Treatment: Review and Opportunity*, **Journal of Hazardous Materials**, 150(3), 2008, 468-493.

84. K. Kannan & J.W. Choi, *Phthalate Exposure and Associated Health Risks among School-Age Children Residing Near Plastic Recycling Facilities,* **Environmental Health Perspectives**, 110(7), 2002, 737-739.

85. U. Kotowska, J. Kapelewska, & R. Sawczuk, *Occurrence, Removal, and Environmental Risk of Phthalates in Wastewaters, Landfill Leachates, and Groundwater in Poland*, **Environ. Pollut**. 267, 2020, 115643.

86. R.A. *Rudel, Food Packaging and Bisphenol A And Bis(2-Ethylhexyl) Phthalate Exposure: Findings from a Dietary Intervention*, **Environmental Health Perspectives**, 119(7), 2011, 914-920.

87. P.M. Medeiros, *Gas Chromatography–Mass Spectrometry (GC–MS)*, **Encyclopedia of Earth Sciences Series,** 2018, 530–535.

88. S. Chun, M. Muthu & J. Gopal, *Mass Spectrometry as an Analytical Tool for Detection of Microplastics in the Environment*, **Chemosensors,** 10(12), 2022, 530.

89. R. Lindenmayer, L. Lu, F. Eivazi & Z. Afrasiabi, *Atomic Spectroscopy-Based Analysis of Heavy Metals in Seaweed Species*, **Applied sciences**, 13(8), 2023, 4764–4764.

90. G. Xing, X. Sun, N. Li, X. Li, T. Wu, & F. Wang, *New Advances in Lateral Flow Immunoassay (LFI) Technology for Food Safety Detection*, **Molecules**, 27(19), 2022, 6596.

91. S. González Henao & T. Ghneim-Herrera, *Heavy Metals in Soils and the Remediation Potential of Bacteria Associated with the Plant Microbiome,* **Frontiers in Environmental Science,** 9, 2021.

92. M. S. Islam, K. Sazawa, K. Sugawara & H. Kuramitz, *Electrochemical Biosensor for Evaluation of Environmental Pollutants Toxicity*, **Environments,** 10(4), 2023, 63.

93. G. Alessandra; B. Dicma & M. Garfí, *Waste Disposal in Developing Countries and Emergency Situations*. The Case of Saharawi Refugees Camps.

94. EFSA, V. Silano, J.M.B. Baviera, C. Bolognesi, B.J. Bruüschweiler, A. Chesson, P.S. Cocconcelli, R. Crebelli, D.M. Gott & K. Grobar, *Draft Update of the Risk Assessment Enhanced Bioremediation of RDX and Co-Contaminants Perchlorate and Nitrate Using an Anaerobic Dehalogenating Consortium in A Fractured Rock Aquifer*. **Chemosphere** 133674.

95. H. Wang, H. Liang & D. Gao, *Occurrence and Distribution of Phthalate Esters (PAEs) in Wetland Sediment*s, **J. For. Res**. 28 (6), 2017, 1241–1248.

96. F.L. Chiriac, I. Paun, F Pirvu, V. Iancu & T. Galaon, *Fast and Sensitive LC-MS Detection of Bisphenol A and Butylhydroxyanisole in WWTP Sewage Sludge*. *70*(6), 2019, 2123–2127.

97. J. TrivedI & U. Chhaya, *Bioremediation of Phenolic Pollutant Bisphenol A Using Optimized Reverse Micelles System of Trametes Versicolor Laccase in Non-Aqueous Environment,* **Biotech**, 11(6), 2021, 1–14.

98. P. Sun, X. Liu, M. Zhang, Z. Li, C. Cao, H. Shi, Y. Yang, & Y. Zhao, *Sorption and Leaching Behaviors between Aged Mps and BPA in Water: the Role of BPA Binding Modes Within Plastic Matrix*, **Water Res**. 195, 2021, 116956.

99. W. Dong, W. Xie; X. Su, C. Wen, Z. Cao & Y. Wan, *Micro-Organic Contaminants in Groundwater in China*, **Hydrogeol. J.** 26 (5), 2018, 1351–1369.

100. M.M Lora, E. Vogler, F.E. Gebhardt, D. Graves & J.F. *Grabowski, Enhanced Bioremediation of RDX and Co-Contaminants Perchlorate and Nitrate using an Anaerobic Dehalogenating Consortium in a Fractured Rock Aquifer,* **Chemosphere**, 2022, 133674.

101. H.I. Abdel-Shafy & M.S.M Mansour, *A Review On Polycyclic Aromatic Hydrocarbons: Source, Environmental Impact, Effect on Human Health and Remedia-tion,* **Egypt. J. Pet.** 25, 2016, 107–123.

102. C.M.A. Iwegbue, G.O. Tesi, G. Obi, G.E, Obi-Iyeke, U.A. Igbuku; S. Bice & B.S. Martincigh, *Concentrations, Health Risks and Sources of Polycyclic Aromatic Hydrocarbons in Nigerian Honey,* **Toxicol. Environ. Health Sci.** 8 (1), 2016, 28–42 .

103. S. Barreca, *Determination of Selected Polyaromatic Hydrocarbons by Gas Chromatography-Mass Spectrometryfor the Analysis of Wood to Establish the Cause*

of Sinking of an Old Vessel (Scauri Wreck) by Fire, **Microchemical. J.** 117, 2014, 116–121

104. R. Olawoyin, R.L. Grayson & O.T. Okareh, *Eco-Toxicologicaland Epidemiological Assessment of Human Exposure to Polycyclic Aromatic Hydrocarbons in the Niger Delta, Nigeria,* **Toxicol. Environ. Health. Sci.** 4, 2012, 173–185

105. O.A . Adesina, & J.A . Adeniran, *Level Of Polycyclic Aromatic Hydrocarbon Emission in the Ambient Air and Residual Ash From a Typical Munic- Ipal Solid Waste Open Burning Site in Nigeria,* **Waste Disposal Sustain. Energy**, 2 (2), 2020, 105–111

106. O.A . Adesina, J.A . Sonibare, P.N. Diagboya, J.A. Adeniran & R.O Yusuf, *Spatio-Temporal Distribution of Polycyclic Aromatic Hydrocarbons Close to a Typical Medical Waste Incinerator,* **Environ. Sci. Pollut. Res.** 25 (1), 2018, 274–282

107. A. Lakhani, *Polycyclic Aromatic Hydrocarbons: Sources, Importance and Fate in the Atmospheric Environment*, **Current Organic Chemistry**, 22(11), 2018, 1050–1069.

108. V.A. Wirnkor; V.E. Ngozi; C.M. Ajero, L.K. Charity, O.S.M. Ngozi, Enyoh Christian, E.C. Ebere & A.C. Emeka, *Biomonitoring of Concentrations of Polycyclic Aromatic Hydrocarbons in Blood and Urine of Children at Playgrounds Within Owerri, Imo State, Nigeria,* **Environ. Anal. Health Toxicol.** 34 (4), 2019, e2019011

109. I.O. Olabanji, O.I. Asubiojo, K.M. Adedoyin, A. Akintomide & A.O. Adeniji, *Determination of Polycyclic Aromatic Hydrocarbons in Blood Plasma of Neurol-Ogy Patients,* **J. Toxicol. Environ. Health Sci.** 11 (1), 2019, 1–8

110. J. Yan, L. Wang, P.P. Fu & H. Yu, Photomutagenicity of 16 *Polycyclic Aromatic Hydrocarbons from the Us Epa Priority Pollutant List,* **Mutat. Res.** 557 (1), 2004, 99–108

111. A.B. Patel, S.Shaikh, K.R., Jain; C. Desai & D. Madamwar, *Polycyclic Aromatic Hydrocarbons: Sources, Toxicity, and Remediation Approaches*, **Frontiers in Microbiology**, 11, 2020

112. Z. Li, Q. Feng, J. Dang, Y. Rong; X. Zhu; L. Meng & X. Zhang, *Types and Source Apportionment of Polycyclic Aromatic Hydrocarbons (PAHs) in Soil-Groundwater of a Closed Coking Plant in Shanxi Province, China*. 15(11), 2023, 2002–2002.

113. H.I. Eldos, N, Zouari, S. Saeed & M.A. Al-Ghouti, *Recent Advances in the Treatment of PAHs in the Environment: Application of Nanomaterial-Based Technologies*, **Arabian Journal of Chemistry**, 15(7), 2022, 103918

114. Y. Sheng, C. Yan, M. Nie, M. Jiang, M. Ding, X. Huang & J. and Chen, *The Partitioning Behavior of PAHs between Settled Dust and its Extracted Water Phase: Coefficients and Effects of the Fluorescent Organic Matter*, **Ecotoxicology and environmental safety**, 223, 2021, 112573–112573

115. A.T. Lawal, *Polycyclic Aromatic Hydrocarbons. A Review*, **Cogent Environmental Science,** 3(1), 2017

116. G. Ozbay, M. Jones, M. Gadde, S. Isah & T. Attarwala, *Design and Operation of Effective Landfills with Minimal Effects on the Environment and Human Health,* **Journal of Environmental and Public Health**, 2021, 1–13.

117. N. Akhtar, M.I. Syakir Ishak, S.A. Bhawani & K. Umar, *Various Natural and Anthropogenic Factors Responsible for Water Quality Degradation: A Review*, **Water**, 13(19), 2021, 2660.

118. I. Manisalidis, E. Stavropoulou, A. Stavropoulos & E. Bezirtzoglou, *Environmental and Health Impacts of Air Pollution: A Review*, **Frontiers in public health,** *8*, 2020, 14.

119. S. Mukherjee, S. Mukhopadhyay, M.A. Hashim & B. Sen Gupta, B. *Contemporary Environmental Issues of Landfill Leachate: Assessment and Remedies*, **Critical Reviews in Environmental Science and Technology**, *45*(5), 2014, 472–590.

120. A. Siddiqua, J.N. Hahladakis & W.A.K.A. Al-Attiya, *An Overview of the Environmental Pollution and Health Effects Associated with Waste Landfilling and Open Dumping,* **Environmental Science and Pollution Research,** *29*, 2022

121. J. Laonamsai, V. Pawana, P. Chipthamlong, P. Chomcheawchan, K. Kamdee, B. Kimmany & P. Julphunthon, *Groundwater Quality Variations in Multiple Aquifers: A Comprehensive Evaluation for Public Health and Agricultural Use,* **Geosciences**, 13(7), 2023, 195–195.

122. M. Vaccari, G. Vinti & T. Tudor, *An Analysis of the Risk Posed by Leachate from Dumpsites in Developing Countries*, **Environments,** *5*(9), 2018, 99.

123. H.K. Esfahani, A. Heggie & B. Datta, *Integrated Sequential Groundwater Contaminant Source Characterization and Pareto-Optimal Monitoring Network Design Application for a Contaminated Aquifer Site*, **Journal of Water Resource and Protection,** *14*(07), 2022, 542–570.

124. C.J. Taylor, *Ground-Water-Level Monitoring and the Importance of Long-Term Water-Level Data*, United State Geological Survey Circular 1217. 2001 https://pubs.usgs.gov/circ/circ1217/pdf/circular1217.pdf

125. S. Bala, D. Garg, B.V. Thirumalesh, M. Sharma, K. Sridhar, B.S. Inbaraj & M.Tripathi, *Recent Strategies for Bioremediation of Emerging Pollutants: A Review for a Green and Sustainable Environment*, **Toxics,** 10(8), 2022, 484.

126. V. Kayastha, J. Patel, N. Kathrani, S. Varjani, M. Bilal, P.L. Show, S.H. Kim, S.K. Bontempi, E., Bhatia & X.T. Bui, *New Insights in Factors Affecting Groundwater Quality with Focus on Health Risk Assessment and Remediation Techniques*, **Environmental Research**, 212, 2022, 113171.

127. W.M.P.C., Wijekoon, P.A., Koliyabandara, A., Cooray, S.S., Lam, B.C.L. Athapattu, & M., Vithanage, *Progress and Prospects in Mitigation of Landfill Leachate Pollution: Risk, Pollution Potential, Treatment and Challenges*, **Journal of Hazardous Materials,** 2021, 126627.

128. A., Siddiqua, J.N., Hahladakis, & W.A.K.A, Al-Attiya, *An Overview of the Environmental Pollution and Health Effects Associated with Waste Landfilling and Open Dumping*, **Environ Sci Pollut Res** 29, 2022, 58514–58536.

129. I.A., Simon-Oke, O.O. Oladele, & O.E., Dada, *Microorganisms in Soil and Groundwater of Epe and Laje Solid Waste Dumpsites in Ondo Town, Nigeria,* **Journal of Applied Sciences and Environmental Management,** 27(2), 2023, 217–322.

130. D.I., Kwun Omang, G., Egbe John, S. Alain Inah, & J.,Owan Bisong, *Public Health Implication of Solid Waste Generated by Households in Bekwarra Local Government Area*, **African Health Sciences**, 21(3), 2021, 1467–1473.

131. A.-H.O., Abiola, F.C., Fakolade, B.A., Akodu, A.A., Adejimi, O.A., Oyeleye, G.A. Sodamade, & A.T., Abdulkareem, *Comparison of Respiratory and Skin Disorders between Residents Living Close to and Far from Solous Landfill Site in Lagos State, Nigeria*, **African Journal of Primary Health Care & Family Medicine,** 13(1), 2021, 7.

132. O., Alegbeleye, O.A., Odeyemi, M. Strateva, & D., Stratev, *Microbial Spoilage of Vegetables, Fruits and Cereals,* **Applied Food Research**, 2(1), 2022, 100122.

133. L.Ankit, V.Saha, J. Kumar, S.Tiwari, Sweta,, J. Rawat, J. Singh, & K., Bauddh, *Electronic Waste and their Leachates Impact on Human Health and Environment: Global Ecological Threat and Management*, **Environmental Technology & Innovation,** 24, 2021, 102049.

134. M., Balali-Mood, K., Naseri, Z., Tahergorabi, M.R. Khazdair, & M., Sadeghi, *Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic*, **Frontiers in Pharmacology,** 12, 2021, 643972.

135. F.U., Haider, C., Liqun, J.A., Coulter, S.A., Cheema, J., Wu, R., Zhang, M.Wenjun, & M., Farooq, Cadmium toxicity in plants: Impacts and remediation strategies, **Ecotoxicology and Environmental Safety**, 211, 2021, 111887.

136. A., Alengebawy, S.T., Abdelkhalek, S.R. Qureshi, & M.-Q., Wang, Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications, **Toxics,** 9(3), 2021, 42.

137. S., Mitra, A.J., Chakraborty, A.M., Tareq, T.B., Emran, F., Nainu, A., Khusro, A.M., Idris, M.U., Khandaker, H., Osman, F.A. Alhumaydhi, & J., Simal-Gandara, *Impact of Heavy Metals on the Environment and Human health: Novel Therapeutic Insights to Counter the Toxicity*, **Journal of King Saud University - Science,** 34(3), 2022, 101865.

138. T., Wuave, *Effect of Leachate on Soil in Jos Metropolis, Plateau State Nigeria,* **IOP conference series,** 1142(1), 2023, 012058–012058.

139. C.M., Raffa, F.Chiampo, & S., Shanthakumar*, Remediation of Metal/Metalloid-Polluted Soils: A Short Review*, **Applied Sciences,** 11(9), 2021, 4134.

140. X., Hu, J., Wang, Y., Lv, X., Liu, J., Zhong, X., Cui, M., Zhang, D., Ma, X. Yan, & X., Zhu, *Effects of Heavy Metals/Metalloids and Soil Properties on Microbial Communities in Farmland in the Vicinity of a Metals Smelter*, **Frontiers in Microbiology**, 12, 2021.

141. O.O., Ololade, S., Mavimbela, S.A. Oke, & R., Makhadi*, Impact of Leachate from Northern Landfill Site in Bloemfontein on Water and Soil Quality: Implications for Water and Food Security,* **Sustainability, 11**(15), 2019, 4238.

142. A., Rashid, B.J., Schutte, A., Ulery, M.K., Deyholos, S., Sanogo, E.A. Lehnhoff, & L., Beck, *Heavy Metal Contamination in Agricultural Soil: Environmental Pollutants Affecting Crop Health*, **Agronomy,** 13(6), 2023, 1521.

143. A., Yan, Y., Wang, S.N., Tan, M.L., Mohd Yusof, S., Ghosh, & Z., Chen, *Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land,* **Frontiers in Plant Science,** 11(359), 2020.

144. W.N., Igboama, O.S., Hammed, & J.O., Fatoba, *Review Article on Impact of Groundwater Contamination Due to Dumpsites Using Geophysical and Physiochemical Method*s, **Appl Water Sci 12**, 2022, 130

145. A., Goutam Mukherjee, U., Ramesh Wanjari, M.A., Eladl, M., El-Sherbiny, D.M.A., Elsherbini, A., Sukumar, S., Kannampuzha, M., Ravichandran, K., Renu, B., Vellingiri, S. Kandasamy, & A., Valsala Gopalakrishnan, *Mixed Contaminants: Occurrence, Interactions, Toxicity, Detection, and Remediation*, **Molecules**, 27(8), 2022, 2577.

146. US EPA, *Potential Well Water Contaminants and their Impacts* 2023 https://www.epa.gov/privatewells/potential-well-water-contaminants-and-their-impacts.

147. S., Mor, P. Negi, & R., Khaiwal, *Assessment of Groundwater Pollution by Landfills in India Using Leachate Pollution Index and Estimation of Error*, Environmental Nanotechnology, Monitoring & Management**,** 10, 2018, 467–476.

148. A. O., Nwosu, & H. E., Chukwueloka, *A Review of Solid Waste Management Strategies in Nigeria*, **Journal of Environment and Earth Science** 10(6), 2020, 2224-3216.

149. K.S., Rajoo, D.S., Karam, A. Ismail, & A., Abdu, *Evaluating the Leachate Contamination Impact of Landfills and Open Dumpsites from Developing Countries Using the Proposed Leachate Pollution Index for Developing Countries (LPIDC)*, Environmental Nanotechnology, Monitoring & Management, 2020, 100372.

150. L.A.A., Garcete, J.E.R., Martinez, D.B.V., Barrera, R.C., Bonugli-Santos, & M.R.Z., Passarini, *Biotechnological Potential of Microorganisms from Landfill Leachate: Isolation, Antibiotic Resistance and Leachate Discoloration,* **Anais da Academia Brasileira de Ciências**, 2022, 94(3).

151. Z., Gong, S., Yang, R., Zhang, Y., Wang, X. Wu, & L., Song, *Physiochemical and Biological Characteristics of Fouling on Landfill Leachate Treatment Systems Surface,* **Journal of Environmental Sciences-china,** 135, 2022, 9–71.

152. A. Y., Daniel, I. K., Ekeleme, C. M., Onuigbo, V. O., Ikpeazu, and S. O., Obiekezie, *Review on Effect of Dumpsite Leachate to the Environmental and Public Health Implication*, **GSC Advanced Research and Reviews**, 7(2), 2021, 051–060.

153. V.A., Ndukwe, M.U., Uzoegbu, O.S. Ndukwe, & A.N., Agibe, *Environmental and Health Impact of Solid Waste Disposal in Umuahia and Environs, Southeast, Nigeria,* **Journal of Applied Sciences and Environmental Management,** 23(9), 2019, 1615.

154. P.O., Njoku, J.N. Edokpayi, & J.O., Odiyo, *Health and Environmental Risks of Residents Living Close to a Landfill: A Case Study of Thohoyandou Landfill, Limpopo Province, South Africa,* **International Journal of Environmental Research and Public Health**, 16(12), 2019, 2125.

155. S., Karanth, S., Feng, D., Patra, & A. K., Pradhan, *Linking Microbial Contamination to Food Spoilage and Food Waste: The Role of Smart Packaging, Spoilage Risk Assessments, and Date Labelling,* **Frontiers in microbiology,** *14*, 2023, 1198124.

156. C.W Jameson. *Polycyclic Aromatic Hydrocarbons and Associated Occupational Exposures. In Tumour Site Concordance and Mechanisms of Carcinogenesis.* International Agency for Research on Cancer*;* 2019. (IARC Scientific Publications, No. 165.) Chapter 7. Available from: https://www.ncbi.nlm.nih.gov/books/NBK570325/

157. B., Moorthy, C., Chu, & D. J., Carlin, *Polycyclic Aromatic Hydrocarbons: from Metabolism to Lung Cancer,* **Toxicological Sciences: an official journal of the Society of Toxicology,** *145*(1), 2015, 5–15.

158. A.T., Lawal, *Polycyclic Aromatic Hydrocarbons. A Review,* **Cogent Environmental Science**, 3(1), 2017.

159. M. Honda, and N Suzuki, *Toxicities of Polycyclic Aromatic Hydrocarbons for Aquatic Animals*, **International Journal of Environmental Research and Public Health,** 17(4), 2020, 1363.

160. J., Hwang, C., Xu, P., Grunsted, R.J., Agnew, T.R., Malone, S., Clifton, K. Thompson, & X., Xu, *Urinary Metabolites of Polycyclic Aromatic Hydrocarbons in Firefighters: A Systematic Review and Meta-Analysis*, **International Journal of Environmental Research and Public Health,** 19(14), 2022, 8475.

161. J., Burdon, L.T., Budnik, & X., Baur, *Health Consequences of Exposure to Aircraft Contaminated Air and Fume Events: A Narrative Review and Medical Protocol for the Investigation of Exposed Aircrew and Passengers*. ***Environ Health* 22**, 2023, 43.

162. K., Lumniczky, N., Impens, G., Armengol, S., Candéias, A. G., Georgakilas, S., Hornhardt, O. A., Martin, F., Rödel, & D., Schaue, *Low Dose Ionizing Radiation Effects on the Immune System*, **Environment international**, *149*, 2021, 106212.

163. A., Al Shoyaib, S.R. Archie, & V.T., Karamyan, *Intraperitoneal Route of Drug Administration: Should it be used in Experimental Animal Studies?* **Pharmaceutical Research,** 37(1), 2019.

Chapter Three

Methodology

3.1 Research Design

This research was designed to assess the level of toxic environmental contaminants e.g. heavy metals, phthalates and polycyclic hydrocarbon (PAH) present in Aba-Eku municipal dumpsite located at Km 13, along Akaran Ijebu Igbo road in Ona-Ara Local Government Area of Oyo State and also determined the leachate pollution index of the municipal waste dumpsite. The site was inspected and samples were later collected. The analytical stage involves sample collection, sample preparation, laboratory bench work, instrumental analysis and data analysis.

3.2 Study Site

Ibadan was created in 1829 as a war camp for warriors coming from Oyo, Ife and Ijebu, and it is located between latitudes 3°35'N and 4°10'N and longitudes 7°2'E and 7°40'E. It is the capital city of Oyo state, one of the thirty-six states in Nigeria[1]. The Ibadan metropolis is made up of eleven Local Government Areas[2]. The city has had tremendous population and area growth from just 100 acres in 1830 to 12.5 km^2 in 1931, 30 km^2 in 1963, 112 km^2 in 1973, 136 km^2 in 1981, and 214 km^2 in 1988, more land was developed according to the National Population Commission. Some major dumpsites in the Ibadan metropolis include Awotan, Ajakanga, Lapite and Aba-Eku.

The study site, Aba Eku dumpsite is located at Km 13 along Akanran Road, Olunloyo, Ona Ara Local Government Area of Oyo State. It is about 600m away from the Aba-Eku community and is bordered by two other neighbouring residential areas: Aba-Epa and Amuloko. The dumpsite was since in the year 1994 and covered about 9.419 hectares of

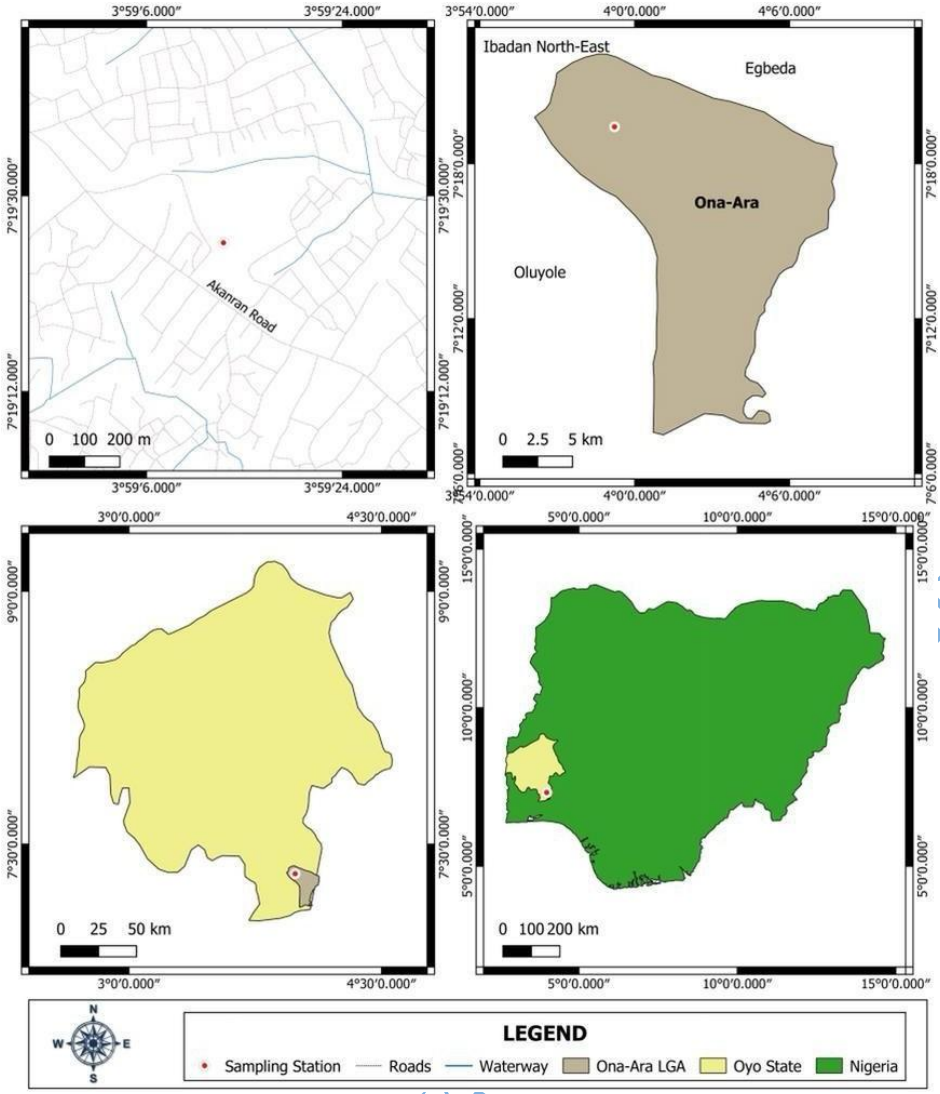


Fig 3.1: The map of Aba-Eku municipal dump site in Ibadan.Source: Author's Field Work, 2023

land. It has been used as an open dump since 1994. Reports of the death of some domestic animals attributed to the impacts of the dumpsite necessitated the upgrading to landfill, possibly in phases. It was thus upgraded and commissioned in 1998[1].The landfill site was sited in close proximity to residential areas. It covers around 10 hectares and has an elevation of 140-160m above sea level. It is characterized majorly by domestic wastes some of which include plastics, papers, nylons, kitchen waste, domestic wastes with very few electronic and poultry wastes, beverage cans among others[2].

3.3 Sample Collection

Impurities were removed from the glass bottles and beakers to be used for the collection by soaking it with little quantity of nitric acids, thoroughly shaken and rinsed with distilled water in order to prevent contamination and were put to use after the containers had dried off. Raw leachate was collected from 10 different leachate locations within the dumpsite and mixed together to form a composite sample in two 2.5L amber glass containers using a glass beaker. Before collection in the respective dumpsites, each of the glass beakers was rinsed with the leachates that were to be collected evenly before the collection was done and mixed then sealed.

The underground water sample was collected at lat.7.3256N/long 003.9891E, lat. 07.3244N/long 003.9879E etc., i.e., 300meters, 600meters and the river sample down gradient using a stainless bucket. The samples container when filled with underground water samples, was labeled and stored in an ice block cooler with ice to reduce vaporization and deficiency of dissolved gases from the water. The sample was then transferred to the laboratory in an ice chest for further analysis. Prior to the analysis of the water sample, it

Fig 3.2: A cross-section of Aba-Eku dumpsite

Source: Author's Field work, 2023

was filtered with 0.45um Whatman filter paper before the extraction for phthalate and polycyclic Aromatic hydrocarbon (PAH) analysis.

3.4 The Physicochemical Parameters Analysis

3.4.1 Determination of Chemical Oxygen Demand (COD)

This was done following the methods described by the USEPA (2006)[3]. Briefly, 2.5 mL ofthe test samples were put into glass vials after filtering with Whatman filter paper. A blankwas set with distilled water as well. To these vials was added 1.5 mL of potassium dichromate reagent (Digestion Reagent). Thereafter, 3.5 mL of sulfuric acid reagent (catalyst solution) was added. The vials were cocked and placed in the digester at 150°C for two hours. Upon cooling, the contents were titrated with 0.1N Ferrous Ammonium Sulfate Solution to a bluish-green end point using a ferroin indicator.

The amount of COD in the samples were expressed as:

COD (mg/L) = (A - B * N * 8 * 1000)/V

A= Volume of ferrous ammonium sulfate for blank

B= Volume of ferrous ammonium sulfate for sample

N= Normality of ferrous ammonium sulfate (0.1N)

V= Volume of sample used

Multiply the results obtained by 1000 to convert it to mg/L

Residual Chlorine mg/L = [(A-B) * 0.1 * 8 * 1000]/V

3.4.2 Estimation of Total Hardness

25.0 mL of the water sample was pipetted out into a clean conical flask. 5.0 mL ammoniabuffer and 2 drops of Eriochrome Black T indicator were added and titrated against 0.01M

EDTA solution from the burette. The end point was the change of colour from wine red to steel blue[2].

Calculation:

Total hardness (mg/L) = Volume of EDTA solution consumed × 1000 /Volume of Sample used.

3.4.3 Determination of Sulfate

Turbidity Method: Sulfate ion is precipitated in HCl medium with barium chloride in such a manner as to form barium sulfate crystals of uniform size. The absorbance of barium sulfate suspension is measured with a spectrophotometer and the sulfate ion concentration is determined by comparison of the reading with a standard curve.

Reagents

i. Conditioning Reagent

Mix 50mL glycerol with a solution containing 30mL Conc HCL, 300 ml distilled water, 100ml of 95% ethanol and 75g sodium chloride

ii. Stock Sulfate Solution

Dissolve 0.1479 g of anhydrous sodium sulfate in distilled water and dilute to 1L

iii. Standard Sulfate Solution

Prepare a series of standards by diluting stock solution of sulfate to cover the desired range in between 1 to 40mg/L.

iv. Hydrochloric Acid

Make 10% v/v of HCL solution

Procedure

The sample was filtered with appropriate Whatman filter paper and 2mL of the clear watersample was taken into test tube and 2mL of distilled water added to it. 1mL of 10% HCL

solution was added after which 1mL of conditioning reagent was added and mixed for 30 secs. The absorbance of the resulting mixture was taken after 10 at 420 nm[4].

For Standard

A series of standards were prepared by having different concentrations of the standard sulfate solution prepared in the range stated above. The standards were treated in a similar way with the samples and a calibration curve was plotted. The concentrations of sulfate in the samples were derived from the calibration curve plotted.

3.4.4 Determination of Nitrate

Reagents

2% CuSO4, 0.1% Sulfanilamide, 0.1% N-1-naphthylethylenediamine dichloride (NED)

Procedure

After filtering the sample appropriately, 250µL of 2% CuSO4 was added to 1ml of the sample and mixed. 1mL of sulfanilamide was added as well as 0.5mL of NED reagent. The mixture was allowed to stay for 10min after which the absorbance was taken at 540nm. The blank contained distilled water in place of the sample while the standard composed ofdifferent concentration of sodium nitrate (10-100µg/mL). The concentration of nitrates in the samples was derived from the standard curve plotted[2].

3.4.5 Determination of Biological Oxygen Demand (BOD), Dissolved Oxygen and Temperature

The Biological Oxygen Demand was done with the Extech Dissolved Oxygen Meter modelled 407510A according to the method outlined[4]. The probe of the dissolved oxygen meter was dipped into the test samples after calibration and allowed to stabilize. A stable reading was recorded. The samples were enclosed and kept in the dark at 20°C for five

days. After five days, the dissolved oxygen was recorded. The BOD of the test samples was expressed in mg/L as the difference between the DO of day one and day five. The values for temperature were equally recorded from the DO meter[2].

3.4.6 Determination of pH and TDS

The pH and Total Dissolve Solids of the water samples were determined using United States Environmental Protection Agency with Hanna pH multiple parameters meter modelled HI-1285-5. 50. 0 mL of the samples were poured into a beaker. After calibratingthe instrument, the pH and total dissolved solids were determined according to themanufacturer's instructions and recorded in appropriate units[5].

3.4.7 Determination of Heavy Metals

A total of seven (7) metals Copper, Chromium, Cobalt, Lead, Iron and Manganese heavy metals were analyzed. Elements were determined following the method contained in AOAC Manual (2019). Briefly, the water samples were filtered with Whatman filter paper. The filtrate was used to determine the respective heavy metals with the Atomic Absorption Spectrophotometer (AAS) modeled AA990 PG Instrument Ltd, England. The concentration of each element was read out in part per million (ppm). The calibration was done with standards prior to the determination of each element[2]

3.5 Determination of Phthalates Esters

Phthalates esters analysis was carried out using the standard method, USEPA 8061A, 3500, 3510 as described below; 500mL each of the leachate and underground water sample was spiked with 20m/L standard solution. The sample was extracted thrice with 30 mL dichloromethane. The extract was then transferred into hexane and concentrated to 0.25 mL prior to analysis. Using Agilent 6890 (GC-MS) gas chromatograph equipped with an on-

column automatic injector, flame ionization detector, HP 88 capillary column (100m x 0.25µm film thickness), CA, USA.

Table 3.1: AAS modeled AA990 PG Working Conditions

Element	Wavelength (nm)	Slit Width (nm)	Working Range (µg/mL)	Sensitivity (µg/mL)	Lamp Current	Flame Type
As	193.7	0.7	1-100	45	300	MHS
Cd	228.8	0.5	0.5-5	0.03	15	Air-C_2H_2
Cr	357.9	0.2	2.0-20	0.2	25	Air-C_2H_2
Pb	283.3	0.5	4.0-40	0.2	440	Air-C_2H_2
Zn	213.9	0.5	0.5-5	0.03	15	Air-C_2H_2

Source: Author's Field Work, 2023

Polycyclic aromatic hydrocarbons (PAH) analysis was carried out on Agilent LC-8518 (HPLC) with a low-pressure gradient and solvent delivery LC-8518 pump with high-pressure switching valves, a high-sensitivity LC-8518 Diode array (DA) detector.

- The column size is 150 x 4.6mm.
- Sample volume of 40 micro liter is injected.
- Detector system is DA detector.
- Mobile phase is Acetonitrile/Water/Formic acid 25:74:1.
- Lamda maximum (Wavelength) of 254nm.
- Column temperature of 40 degree centigrade.
- Run time of 25 minutes.

3.6 Quality Control and Quality Assurance Protocol

All quality control and quality assurance protocol was observed throughout the experiment.

To avoid cross contamination no plastic materials was used during sampling, transportation or analysis.

Glass jars with an aluminum foil under the cap and a stainless-steel bucket was used during the study.

All jars were rinsed with leachate and underground water before sample collection.All reagents are ensured to be analytical grade.

3.7 Extraction and Clean- up of Polycyclic Aromatic Hydrocarbons

Six (6) target PAHs were analyzed using Gas Chromatography-Mass Spectrometry (GS/MS) following modified USEPA methods (method 8270 C)[3].

3.7.1 Solvent Extraction

Approximately 5mL of each water sample and 5 g of anhydrous sodium sulphate were weighed and homogenized to a complete mixture. The mixtures were transferred to pre-cleaned extraction tubes, and 25 mL dichloromethane added. The tubes were tightly capped, allowed to stand for 30 minutes, and then shaken vigorously for 30 minutes. The mixture was allowed to settle and solvent layers were filtered using filter papers. The procedure was repeated twice with another 25 mL dichloromethane. The three extracts were combined, concentrated on a rotary evaporator (Büchi Rotavapor R-114), exchanged with 5 mL of n-hexane and re-concentrated to 1 mL for clean-up determined by calculating the amount of analyte[5].

2mL of the water samples were spiked with deuterate surrogate standards methylnaphthalene-d8, fluorine-d10, anthracene-d10, pyrene-d10, p-terphenyl-d14, benzo [a]pyrene-d12, and benzo (g.h.i) pyrene-d12), and then mixed with anhydrous magnesium sulphate for extraction. An appropriate amount of activated copper powder was also added to each extraction cell in order to remove sulphur during extraction. The PAHs were extracted from water samples through an accelerated solvent extraction system (ASE 200, Dionex, Sunny-vale, CA, USA) with a 1:1 (v/v) acetone/dichloromethane solvent mixture. Samples were extracted three times under the following conditions: Oven temperature 100°C, Pressure-1700 psi, Heat time- 5min, Statictime- 10min and a 60 % flash. The three extracts were pooled, concentrated with a rotatory evaporator and solvent exchange with 5mL of N-hexane.

3.7.2 Sample Clean-up Procedure

Sample clean-up was done on a silica gel-aluminum oxide glass column (10cm x 6 mm ID), and elution was conducted by successively loading 5ml n-hexane and 20ml n-hexane-dichloromethane (3:7, v/v) and the elution was collected for PAH determination. The elution was concentrated and solvent exchange to 1ml of hexane containing 200ug/L hexamethyl benzene and perylene-d12 as internal standards. The final extract was sealed and kept at -4°C until further analysis.

3.8 Leachate Pollution Index Calculation

$$LPI = \sum_{=1} wipi$$

LPI = leachate pollution index

Wi = weight for the *w i* is the weight for the *i*th pollutant variable;

Pi = the sub-index score of the *i*th leachate pollutant variable;

n = number of leachate pollutant variables used in calculating *LPI*;

Endnotes

1. O.O Aluko & M.K. Sridhar, *Application of Constructed Wetlands to the Treatment of Leachates from A Municipal Solid Waste Landfill,* **Journal of Environmental Health**, 67, 2005, 58-62

2. United States Environmental Protection Agency (USEPA) *Standard Methods for the Examination of Water and Wastewater,* (14th Edition), 2006, 427, Modified from Method 419D, Annual Book of ASTM Standards, Part 31, "Water", Standard D, 1976, 363.

3. APHA, *Standard Methods for the Examination of Water and Wastewater, American Public Health Association, American Water Works Association and Water Environmental Federation***,** Washington DC, (20th Edition), 1998.

4. Delzer G.C., & McKenzie S.W., *Five-Day Biochemical Oxygen Demand: U.S. Geological Survey Techniques of Water-Resources Investigations*, book 9, chap. A7 (3d ed.), 2003, section 7.0

5. Association of Official Analytical Chemists, *Mineral Determination in Soil/Water Matrixes. Official Method of Analysis*, AOAC International, Suite 300, 275 Research BLVD Rockville, Maryland, USA, (21st Edition) 1, 2019.

Chapter Four

Results and Discussion of Findings

4.1 Results of Physico - Chemical Analysis

The result of the Physico-chemical parameters e.g. Chemical oxygen demand (COD), Biochemical oxygen demand (BOD), Nitrates, pH, Total Solid, Dissolve Oxygen, Chloride, Total hardness, Sulphate, Phosphate, Ammonia, etc. are shown in Table 4.1.

4.2 Qualitative Analysis for Physicochemical Parameters of the Groundwater Samples

Qualitative analysis for physicochemical parameters of the groundwater samples are presented in Table 4.2, which explain the different ions with their units, minimum, maximum, average and standard deviation (SD) values. The values were also compared with the maximum allowed concentration of different ions in standards of the united state environmental protection agency (USEPA)

4.3. The Correlation Coefficients (R) and Significance Levels (P Values) for the Various Parameters Studied

Table 4.3 presents the correlation coefficients (r) and significance levels (p values) for the various parameters studied. The results revealed important relationships among the parameters. pH exhibited a strong negative correlation with both BOD ($r = -0.932$) and Dissolved oxygen ($r = -0.912$). These findings indicated that as pH decreases, both BODand Dissolved oxygen values tend to increase. Total Solids displayed significant positive associations with Chloride ($r = 0.977$, $p < 0.05$), Total Hardness ($r = 0.889$), Sulphate ($r = 0.955$, $p < 0.05$), and Phosphate ($r = 0.836$). This implies that higher concentrations of Total Solids corresponded to elevated levels of Chloride, Total Hardness, Sulphate, andPhosphate. Furthermore, pH positively correlated with COD ($r = 0.666$), Phosphate ($r = 0.282$), and Ammonia ($r = 0.438$).

Table 4.1: Concentration of Physico-Chemical Parameters in the Samples

Parameters (mg/L)	Leachate	300m	600m	River
pH	7.225	7.025	7.315	7.720
Total solids	0.696	0.012	0.014	0.160
COD	300.0	660.0	420.0	1060
BOD	0.600	0.750	0.700	0.300
Dissolved oxygen	6.450	6.850	6.700	6.050
Chloride	911.0	9.009	7.008	5.005
Total Hardness	778.0	358.0	134.0	158.0
NO^{-3}	0.026	0.035	0.031	0.027
Sulphate	4.665	0.570	0.945	0.435
Phosphate	3.918	3.640	3.792	3.780
Ammonia	0.389	0.468	0.345	0.524

COD = Chemical Oxygen Demand, BOD = Biochemical Oxygen Demand, NO^{-3} =Nitrates

Source: Author's Field Work, 2023

Table 4.2: Summary Statistics for Concentration of Physicochemical Parameters of Leachate and Aba – Eku Water with Comparison to National Standards

Parameters	Minimum	Maximum	Mean	Std. Deviation	USEPA
pH	7.025	7.720	7.321	0.292	6.5-8.5
Total solids	0.012	0.696	0.221	0.324	500.0
COD	300.0	1060	610.0	335.0	410.0
BOD	0.300	0.750	0.588	0.202	250.0
DO	6.050	6.850	6.513	0.350	-
Chloride	5.005	911.0	2277	4555	250.0
Total Hardness	134.0	778.0	357.0	298.1	0-75.0
NO-3	0.027	0.035	0.030	0.004	10.00
Sulphate	0.435	4.665	1.654	2.019	250.0

COD = Chemical Oxygen Demand, BOD = Biochemical Oxygen Demand, NO^{-3} =Nitrates, DO= Dissolved Oxygen.
USEPA= United State Environmental Protection Agency

Source: Author's Field Work, 2023

This suggests that as pH increases, the levels of COD, phosphate, and ammonia also tend to rise. On the other hand, COD exhibits a strong positive correlation with ammonia (r = 0.907), while it demonstrates a negative correlation with the remaining parameters, particularly BOD (r = -0.723). This implies that higher COD levels are associated with elevated ammonia concentrations, whereas they are inversely related to the levels of other parameters, especially BOD. BOD showed a strong positive correlation with dissolved oxygen (r = 0.984, $p < 0.05$) and NO^{-}_{3} (r = 0.742). This indicates that higher BOD levels corresponded to increased concentrations of dissolved oxygen and NO^{-}_{3}. However, BOD displayed a negative correlation with phosphate (r =

-0.286) and ammonia (r = 0.640). Consequently, higher BOD levels were associated with lower levels of phosphate, while they were linked to higher levels of ammonia. Chloridedemonstrates significant positive correlations with Total Hardness (r = 0.942), sulphate(r = 0.994, $p < 0.01$), and phosphate (r = 0.796). These results suggested that higher chloride concentrations corresponded to increased levels of Total Hardness, sulphate, andphosphate.

4.4 Two Way Analysis of Differences of Water Quality Parameters in Different Locations.

In Table 4.4 a significant difference was observed only in the chloride measurements among various locations at a 95% confidence interval. Specifically, significant differences were found between the Leachate and the 300m location, the Leachate and the 600m location, as well as the Leachate and the River location. However, no significant differences were detected among the other locations.

Table 4.3: **Pearson's Correlation Analysis of the Physicochemical Parameters and Heavy Metals among all Water Quality**.

Parameters	Correlation coefficient										
	pH	Total solids	COD	BOD	Dissolved oxygen	Chloride	Total Hardness	NO-3	Sulphate	Phosphate	Ammonia
pH	1										
Total solids	-0.024	1									
COD	0.666	-0.447	1								
BOD	-0.932	-0.172	-0.723	1							
Dissolved oxygen	-0.912	-0.326	-0.590	.984*	1						
Chloride	-0.220	.977*	-0.616	0.041	-0.119	1					
Total Hardness	-0.455	0.889	-0.593	0.208	0.078	0.942	1				
NO-3	-0.687	-0.699	-0.074	0.742	0.849	-0.555	-0.299	1			
Sulphate	-0.254	0.955*	-0.690	0.108	-0.058	0.994**	0.923	-0.528	1		
Phosphate	0.282	0.836	-0.455	-0.286	-0.450	0.796	0.545	-0.853	0.812	1	
Ammonia	0.438	-0.196	0.907	-0.640	-0.526	-0.350	-0.233	-0.060	-0.448	-0.437	1

* Correlation is significant at the 0.05 level (2-tailed),
** Correlation is significant at the 0.01 level (2-tailed).
COD = Chemical Oxygen Demand, BOD = Biochemical Oxygen Demand, NO^{-3} = NitratesSource:

Author's Field Work, 2023

Table 4.4: **Analysis of Differences of Water Quality Parameters in Different Locations Using Two Way ANOVA at a 95% Confidence**

Parameters	Leachate vs 300m		Leachate vs 600m		Leachate vs River		300m vs 600m		300m vs River		600m vs River	
	p-value	Sig.	p-value	Sig.	p-value	Sig.	p-value	Sig.	p-value	Sig.	p-value	Sig.
pH	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No
Total solids	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No
COD	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No
BOD	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No
Dissolved oxygen	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No
Chloride	P<0.001	Yes	P<0.001	Yes	P<0.001	Yes	P > 0.05	No	P > 0.05	No	P > 0.05	No
Total Hardness	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No
NO-3	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No
Sulphate	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No
Phosphate	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No	P > 0.05	No

Note: "Yes" denotes that the water quality parameters in different locations are significantly different, and "No" denotes that the water quality parameters in different locations are not significantly different.
Source: Author's Field Work, 2023

4.5 Results of Phthalate Analysis

Table 4.6 provides summary statistics on the concentration of Phthalate compounds found in the groundwater samples. The table includes information on various Phthalate compounds, along with their respective units, minimum and maximum values, as well as the average and standard deviation (SD). The results indicated that diethyl phthalateand benzyl butyl phthalate were present in high levels in the majority of the samples.

4.6 Results of PAH Analysis

Summary statistics for concentration of PAH compounds of the groundwater samples are presented in Table 4.7, which explain the different ions with their units, minimum, maximum, average and standard deviation (SD) values.

4.7 Results of LPI Analysis

The LPI (Leachate Pollution Index) of the water samples collected from Aba-Eku is presented in Table 4.8. The table indicated that the water samples obtained from three sources, namely leachate, 300m, and river contaminated by the accumulation of heavy metals. Among these sources, the river exhibited the highest LPI of 7.68, indicating significant contamination due to heavy metal accumulation. On the other hand, the water samples taken from 600m showed the lowest LPI of 5.56, indicating slight contamination from heavy metals. Overall, the mean LPI of the water samples from Aba-Eku was 7.0.

Table 4.5: Concentration of Phthalate Compounds in Water and Leachates of Aba- Eku

Phthalate compounds	Minimum	Maximum	Mean	Std. Deviation
Diethyl Phthalate	47.34	47.34	47.34	.
Dipropyl Phthalate	0.03	30.91	15.47	21.84
Diamyl Phthalate	6.09	8.80	7.45	1.92
Benzylbutyl Phthalate	36.14	36.14	36.14	.

Unit=µg/L

Source: Author's Field Work, 2023

Table 4.6: Concentration of PAH Compounds in Water and Leachates of Aba- Eku

PAH COMPOUNDS	Minimum	Maximum	Mean	Std. Deviation
Phenol	2.05	2.05	2.05	.
Biphenyl	34.38	34.38	34.38	.
Naphthalene	43.14	71.81	59.51	14.76
Pyrimidione	25.55	25.55	25.55	.
Quinolinee-6-Carbonitrile	2.64	7.01	4.83	3.09
Butylronitrile	3.36	3.36	3.36	.
Pyridine	2.71	2.71	2.71	.
5-Methyl Benzofuran	3.23	3.23	3.23	.
2-Methyl-4h3,1benzoxaazin-4-One	4.57	4.57	4.57	.
Tetrahydrofuran	86.18	86.18	86.18	.
Tetradecadiene	4.05	4.05	4.05	.
Methyl Stearate	45.80	45.80	45.80	.

Unit=µg/L

Source: Author's Field Work, 2023

Table 4.7: **The LPI of Aba-Eku Water Sample and Water Samples**

Samples	LPI	Mean	Standard Deviation
Leachate	7.595		
300m	7.151	6.997	0.987
600m	5.558		
River	7.683		

Source: Author's Field Work, 2023

Discussion of Findings

The concentrations of the PAHs of the leachates is shown in Table 4.7. The leachate samples contain Napthalene, Quinoline-6-carbonitrile, methyl stearate and tetradecadiene. The levels of the PAHs in the leachate samples were linked to the combustion of different waste materials in the dumpsite[1,2]. The levels of PAH found in the leachate were attributed to infiltration of pollutants from the dumpsite during rainfall which was in agreement with previous works[3],[4]. The range of distribution of PAHs concentration levels expunge from 7.009-43.141. The compound with the highest composition (%) in the leachate was methyl stearate, followed by naphthalene and quinolone-6-carbonitrile while the lowest were tetradecadiene. Pyromidione, butylronitrile,pyridine,5-methylbezofuran.

The PAHs concentrations for 300 meters location away from underground water sample contains butylronitrile, pyridine, 5-methylbenzofuran, tetrahydrofuran and 2-Methyl-4H-3,1-benzoxazin-4-one. The range of distribution of PAHs concentration levels ranged from 2.711-86.178. Naphthalene, a dominant constituent in the leachate.

The PAH concentration for 600 meters distance from dump-site and the river has the mean percentage concentration of 59.5077. However, naphthalene was reported as a minor constituent in its leachate sample[5]. This was followed by quinolone-6-carbonitrile found in leachate and in 600 meters sample. However, tetradecadiene was not found in the samples.

The results presented in Table 4.8 indicate that the river water samples obtained from Aba-Eku had highest LPI compared to other water sources, particularly leachate. This finding might seem counterintuitive, as one would expect leachate, which directly receives pollutants from waste materials, to have a higher LPI. However, several factors could explain why the river exhibited a higher LPI in this study. One possible explanation is that the river is a flowing water body, continuously moving

and transporting various contaminants along its course. As the river flows, it can pick up pollutants from different sources, such as industrial discharges, agricultural runoff, and urban waste, contributing to an accumulation of heavy metals[6]. The continuous influx of contaminants from upstream areas can lead to a higher overall LPI in the river compared to the stagnant leachate[7]. Additionally, the composition of contaminants in leachate and river water could differ. Leachate primarily originates from waste materials, such as landfill sites, where specific types of pollutants may dominate[8]. On the other hand, the river receives inputs from multiple sources, including industrial areas, agricultural lands, and urban centers, introducing a wider range of pollutants and potentially different heavy metal profiles[9]. These variations in contaminant composition could influence the LPI values observed in the different water sources.

Endnotes

1 Y. Kalmykova; K. Björklund; A. M., Strömvall & L. Blom, *Partitioning of Polycyclic Aromatic Hydrocarbons, Alkylphenols, Bisphenol A and Phthalates in Landfill Leachates and Stormwater*, **Water Research**, 47(3), 2013, 1317–1328.

2 C.C. Aralu; P.A.C. Okoye & K.G. Akpomie, *Toxicological Risk Evaluation of Polycyclic Aromatic Hydrocarbons in Boreholes Located within Unsanitary Dumpsite in Nnewi, Anambra State, Nigeria*, **International Journal of Environmental Analytical Chemistry,** 2021, 1–16,

3 A.A. Oketola & S.O. Akpotu, *Assessment of Solid Waste and Dumpsite Leachate and Topsoil*, **Chemistry and Ecology**, 31 (2), 2014, 134–46.

4 I. Tałałaj; P. Biedka; M. Walery & J. Leszczyński, *Monitoring of Leachate Quality at a Selected Municipal Landfill Site in Podlasie, Poland*, **Journal of Ecological Engineering**, 17(3), 2016, 175–184.

5 C.C. Aralu; P.A.C. Okoye; K.G. Akpomie & N.C. Eboagu, *Levels of Polycyclic Aromatic Hydrocarbons in Leachates from Unlined Dumpsite of Agu-Awka Anambra State*, **International Journal of Environmental Analytical Chemistry**, 2021.

6 D. Paul, *Research on Heavy Metal Pollution of River Ganga: A review*, **Annals of Agrarian Science**, 15(2), 2017, 278–286.

7.A. Wdowczyk & A. Szymańska-Pulikowska, *Comparison of Landfill Leachate Properties by LPI and Phytotoxicity-A Case Study,* **Frontiers in Environmental Science**, *9*, 2021.

8 M.S. Kabir; H. Wang; S. Luster-Teasley; L. Zhang & R. Zhao, *Microplastics In Landfill Leachate: Sources, Detection, Occurrence, and Removal*, **Environmental Science and Ecotechnology**, 16, 2023, 100256.

9 D.M. Mekuria; A.B. Kassegne & S.L. Asfaw, *Assessing Pollution Profiles along Little Akaki River Receiving Municipal and Industrial Wastewaters, Central Ethiopia: Implications for Environmental and Public Health Safety,* **Heliyon**, 7(7), 2021.

Chapter Five

Conclusion

5.1 Summary of Findings

The study revealed that the physicochemical parameters of the leachate and water around the sampling site met the acceptable standards set by international guidelines except the increase in the biological oxygen demand and the concentration of iron. The leachate pollution index indicated that the river sample had highest pollution level, followed by the leachate samples in the order of river > leachate > 300 meters > 600 meters. Among all the location examined, the pollution index of the river was higher than that of the dumpsites.

Furthermore, the study findings demonstrated contamination of the dumpsite and the surrounding water with Polycyclic Aromatic Hydrocarbons (PAHs). The PAH concentrations in descending order were Naphthalene - 59.508, Methyl Stearate - 45.805, Bi-Phenyl - 34.379, Pyrimidione - 25.545, Quiniline-Carbonitrile - 4.826, 2-Methyl-4h3,1benzoxaazin-4-One - 4.571, Tetradecadiene - 4.409, Butylronitrile - 3.364, 5-Methyl Benzofuran - 3.231, Pyridine - 2.711, Phenol - 2.05 (mean concentration). Notably, the dumpsite exhibited highest concentration of naphthalene among the PAHs. Additionally, the findings indicated that the dumpsite, as well as the underground water at 300 meters, 600 meters, and the river, were contaminated with Phthalates at varying concentrations. The Phthalate concentrations were as follows: Diethyl phthalate - 47.34%, Dipropyl phthalate - 30.91%, Diamyl phthalate - 8.8%, and Benzylbutyl phthalate - 36.14%.

5.2 Conclusion

Several findings have emerged from the observation and analysis of the dumpsite and its surrounding environment. Firstly, it was noted that both the dumpsite itself and the underground water in its vicinity are contaminated with leaching from the dumpsite. Furthermore, the dumpsite is also polluted with PAH and phthalate compounds. The pollution index of the dumpsite is moderately high, and this pollution has been spreading to the neighboring environment. In particular, the concentration of leachate pollution in the river near the dumpsite was found to be significantly higher. This can be attributed to the environmental interactions occurring within the community, likely influenced by anthropogenic activities.

In terms of the physico-chemical parameters, most values obtained from the study were found to be within the permissible limits set by local and international standards. However, the levels of COD and Fe exceeded the prescribed limits. Additionally, the concentration of metals in the leachate was higher compared to both the underground water and the river water.

Similarly, there was a notable increase in the concentration of PAHs and phthalate Esters in the leachate when compared to the underground water and the river water.

The calculated leachate pollution index (LPI) exceeded 7.0, indicating that the landfill site is a significant source of leachate pollution.

The results obtained from this study are consistent with previous studies conducted in 2015 and 2019.

These findings collectively suggest that the Aba-Eku landfill site is indeed polluted. Moreover, surface runoff from the landfill site poses a potential risk of polluting both the underground water and the river.

Considering the implications of these findings, there is a potential adverse impact on the public health of the general population in the Ona-Ara Local Government Area.

5.3 Recommendations

Based on the outcome of this study, it can be therefore recommended that:

1. The general public needs to be well sensitized and enlightened on heavy metals and PAHs, their source, health effects and how to check their discharge into the environment.
2. The dumpsite should be reconstructed or improve on the management.
3. The dumpsite should be well monitored by the environmental management and regulatory bodies and a robust Environmental Management System should put inplace.
4. Regular Environmental Audit should be carried out on the site
5. The use of environment friendly technologies that reduce the release of leachingcontaminants into the environment.

5.4 Contribution to Knowledge

- This study is the probably the first to examine spatial pollution status of the underground and river water of Aba-Eku landfill leachate.
- This study is probably the first to determine the leachate pollution index of Aba-Eku landfill site

- This study also assess the phthalate compound on the dump site.
- This study has generated a baseline for further studies on Aba-Eku land fill site.
- This study can be used for Ibadan land and Nigeria at large for literacy studies and policy formulations especially in the area of siting landfills away from residential areas

5.5 Suggested Areas for Further Research

There should be further research work on the underground water in the environment at seasonal variation to quantify the level of types of any organic contaminants present in the environment.

Bibliography

Chapters inBooks

Jezieerska .B, & Witeska M., *Uptake and Accumulation in Fish Living in Polluted Waters. In Soil and Water Pollution Monitoring, Protection and Remediation,* Springer: Berlin/Heidelberg, Germany, 69, 2006, 107–114.

Nyle C., & Ray R., *the Nature and Properties of Soils,* USA: Prentice Hall. Technology & Engineering (12th ed.)**,** 1999, 743–785.

United States Environmental Protection Agency (USEPA), *Standard Methods for the Examination of Water and Wastewater*, (14th Edition), 2006, 427, Modified from Method 419D, *Annual Book of ASTM Standards*, Part 31, "Water", Standard D, 1976, 363.

E-Books

APHA, *Standard Methods for the Examination of Water and Wastewater*, American Public Health Association, American Water Works Association and Water Environmental Federation**,** Washington DC, (20th Edition), 1998.

Association of Official Analytical Chemists, *Mineral Determination in Soil/Water Matrixes. Official Method of Analysis*, AOAC International, Suite 300, 275 Research BLVD Rockville, Maryland, USA, (21st Edition) 1, 2019.

Delzer G.C., & McKenzie S.W., *Five-Day Biochemical Oxygen Demand: U.S. Geological Survey Techniques of Water-Resources Investigations*, book 9, chap. A7 (3d ed.), 2003, section 7.0

Gray N.F. *Water Technology – An Introduction for Environmental Scientists and Engineers*, Butterworth-Heinemann, Oxford, United Kingdom, (Third edition), 2010.

Ludwig C., Hellweg S., & Stucki S., *Municipal Solid Waste Management: Strategies and Technologies for Sustainable Solutions*, Springer-Verlag, Berlin, 2003.

Tang, Jinfeng. "*Recovery of Copper and Zinc in Ashes from Municipal Solid Waste Combustion*." 2015.

Uchegbu S.N., *Environmental Management and Protection*, Spotlite Publishers, Nigeria, 1988

White P.R., Franke M. & Hindle P., *Integrated Solid Waste Management: A Lifecycle Inventory***.** Berlin: Springer, 1995.

Zielinska M., Wojnowska-Baryła I. & Cydzik-Kwiatkowska A., *Bisphenol A Removal from Water and Wastewater*, Springer, 2019.

Journals

Abdel-Shafy H.I., Ibrahim A.M., Al-Sulaiman A.M., &. Okasha R.A, *Landfill Leachate: Sources, Nature, Organic Composition, and Treatment: An Environmental Overview,* **Ain Shams Engineering Journal,** 2023, 102293.

Abiola, A.-H.O., Fakolade, F.C., Akodu, B.A., Adejimi, A.A., Oyeleye, O.A., Sodamade, G.A. & Abdulkareem, A.T., *Comparison of Respiratory and Skin Disorders between Residents Living Close to and Far from Solous Landfill Site in Lagos State, Nigeria,* **African Journal of Primary Health Care & Family Medicine,** 13(1), 2021, 7.

Abiriga D., Vestgarden L.S., & Klempe H., *Groundwater Contamination from A Municipal Landfill: Effect of Age, Landfill Closure, and Season on Groundwater Chemistry*, **Sci Total Environ**. 737, 2020, 140307.

Adesina O.A ., Adesina A .O. & .Adeniran, J.A *Level of Polycyclic Aromatic Hydrocarbon Emission in the Ambient Air and Residual Ash rom A Typical Munic-Ipal Solid Waste Open Burning Site in Nigeria,* **Waste Disposal Sustain. Energy**, 2 (2), 2020, 105–111 .

Adesina O.A ., Sonibare J.A . , Diagboya P.N. , Adeniran J.A. & *Yusuf R.O , Spatio-Temporal Distribution of Polycyclic Aromatic Hydrocarbons Close to a Typical Medical Waste Incinerator,* **Environ. Sci. Pollut. Res.** 25 (1), 2018, 274–282

Adesogan S. O. & Omonigho B. O. *Assessment of Leachate Contamination Potential of Landfills in Ibadan, Nigeria*, **African Journal of Environmental Science and Technology**, 15(5), 2021, 179-187.

Adeyemi-Ade O.A., Anifowoshe A.T. & Abdulkareem S.I., *Ecotoxicological Assessment of Leachate from Amilegbe Dumpsite, Ilorin, Nigeria Using Clarias Gariepinus* Burchell 1822

Agwu M.O., *Issues and Challenges of Solid Waste Management Practices in Port-Harcourt City, Nigeria-A Behavioural Perspective*, **Am. J. Soc. Manag. Sci.,** 3, 2012, 83–92

Akhtar, N., Syakir Ishak, M. I., Bhawani, S. A., & Umar, K., *Various Natural and Anthropogenic Factors Responsible for Water Quality Degradation: A Review,* **Water**, 13(19), 2021, 2660.

Al Shoyaib, A., Archie, S.R. & Karamyan, V.T., *Intraperitoneal Route of Drug Administration: Should it be used in Experimental Animal Studies?* **Pharmaceutical Research,** 37(1), 2019.

Alegbeleye, O., Odeyemi, O.A., Strateva, M. & Stratev, D., *Microbial Spoilage of Vegetables, Fruits and Cereals*, **Applied Food Research**, 2(1), 2022, 100122.

Alengebawy A., Abdelkhalek S.T., Qureshi S.R., & Wang M.Q. *Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications*, **Toxics,** 9(3), 2021, 42.

Alengebawy, A., Abdelkhalek, S.T., Qureshi, S.R. and Wang, M.-Q., *Heavy Metals and Pesticides Toxicity in Agricultural Soil and Plants: Ecological Risks and Human Health Implications,* **Toxics,** 9(3), 2021, 42.

Alessandra G., Dicma B. & Garfí M. *Waste Disposal in Developing Countries and Emergency Situations*. The Case of Saharawi Refugees Camps, 2016

Ali S.M, Pervaiz A., Afzal B., Hamid N., & Yasmin A., *Open Dumping of Municipal Solid Waste and Its Hazardous Impacts on Soil and Vegetation Diversity at Waste Dumping Sites of Islamabad City*, **J. King Saud Univ. Sci**., 26 (1), 2014, 59–65.

Alimba C.G., Adewumi O.O., Binuyo O.M. & Odeigah G.C., *Wild Black Rats (Rattus Rattus Linnaeus, 1758) as Zoomonitor of Genotoxicity and Systemic Toxicity Induced by Hazardous Emissions from Abule Egba Unsanitary Landfill, Lagos, Nigeria*, **Environ Sci Pollut Res** 28, 2021, 10603–10621.

Aluko .O & Sridhar M.K., *Application of Constructed Wetlands to the Treatment of Leachates from a Municipal Solid Waste Landfill,* **Journal of Environmental Health**, 67, 2005, 58-62

Amano K.O.A., Danso-Boateng E., Adom E., Kwame Nkansah D., Amoamah E.S., & Appiah-Danquah E. *Effect of Waste Landfill Site on Surface and Ground Water Drinking Quality*, **Water and Environment Journal,** 35(2), 2020, 715–729.

AmudA O.S., Adebisi S.A., Jimoda L.A. & Alade A.O., *Challenges and Possible Panacea to the Municipal Solid Wastes Management in Nigeria*, **J Sustain Dev Stud.,** 1, 2014, 64–70

Ankit, Saha, L., Kumar, V., Tiwarit, J., Sweta, Rawat, S., Singh, J. & Bauddh, K., *Electronic Waste and their Leachates Impact on Human Health and Environment: Global Ecological Threat and Management,* **Environmental Technology & Innovation,** 24, 2021, 102049.

Aralu C.C., Okoye P.A.C, Abugu H.O., &. Eze V.C. *Pollution and Water Quality Index of Boreholes within Unlined Waste Dumpsite in Nnewi, Nigeria*, **Discover Water**, 2(1), 2022.

Aralu C.C., Okoye P.A.C., Akpomie K.G. & Eboagu N.C., *Levels of Polycyclic Aromatic Hydrocarbons in Leachates from Unlined Dumpsite of Agu-Awka Anambra State*, **International Journal of Environmental Analytical Chemistry**, 2021, Available online: https://doi.org/10.1080/03067319.2021.1993842

Aralu C.C. & Okoye P.A.C., *Assessment of Heavy Metals Levels in Soil and Vegetables in the Vicinity of Unlined Waste Dumpsite in Nnewi, Anambra State Nigeria,* **Journal of Chemical Society of Nigeria**, 45(4), 2020, 687 (2020)

Aralu, C.C.,. Okoye, P.A.C & Akpomie, K.G. *Toxicological Risk Evaluation of Polycyclic Aromatic Hydrocarbons in Boreholes Located within Unsanitary Dumpsite in Nnewi, Anambra State, Nigeria*, **International Journal of Environmental Analytical Chemistry,** 2021, 1–16, Available online: **https://doi.org/10.1080/03067319.2021.1916485.**

Bala, S., Garg, D., Thirumalesh, B. V., Sharma, M., Sridhar, K., Inbaraj, B. S., & Tripathi, M., *Recent Strategies for Bioremediation of Emerging Pollutants: A Review for a Green and Sustainable Environment*, **Toxics,** 10(8), 2022

Balali-Mood, M., Naseri, K., Tahergorabi, Z., Khazdair, M.R. and Sadeghi, M., *Toxic Mechanisms of Five Heavy Metals: Mercury, Lead, Chromium, Cadmium, and Arsenic*, **Frontiers in Pharmacology,** 12, 2021, 643972.

Baloyi,N.D.,Tekere, M., Maphangwa K.W& Masindi, V. *Insights into the Prevalence and Impacts of Phthalate Esters in Aquatic Ecosystems*, **Front. Environ. Sci**. 9, 2021, 684190.

Barreca S., *Determination of Selected Polyaromatic Hydrocarbons by Gas Chromatography-Mass Spectrometryfor the Analysis of Wood to Establish the Cause of Sinking of an Old Vessel (Scauri Wreck) By Fire,* **Microchemical. J.** 117, 2014, 116–121 .

Basu R., *Solid Waste Management-A Model Study*, **Sies Journal of Management**, 6, 2009, 20- 24.

Beldean-Galea M.S. Vial J., Thiébaut D., &. Coman M.V, *Analysis of Multiclass Organic Pollutant in Municipal Landfill Leachate by Dispersive Liquid-Liquid Microextraction and Comprehensive Two-Dimensional Gas Chromatography Coupled with Mass Spectrometry,* **Environmental Science And Pollution Research**, 27(9), 2020, 9535–9546.

Burdon, J., Budnik, L.T., & Baur, X., *Health Consequences of Exposure to Aircraft Contaminated Air and Fume Events: A Narrative Review and Medical Protocol for the Investigation of Exposed Aircrew and Passengers*. ***Environ Health*** **22**, 2023, 43.

Can O.T., Tutun M.M. & Keyikoglu R., *Anodic Oxidation of Bisphenol A by Different Dimensionally Stable Electrodes*, **Water Sci. Technol.,** 83 (8), 2021, 1907–1919

Careghini A., Mastorgio A.F., Saponaro S. & Sezenna E. *Bisphenol A, Nonylphenols, Benzophenones, and Benzotriazoles in Soils, Groundwater, Surface Water, Sediments, and Food: A Review*, **Environ. Sci. Pollut. Res.** 22 (8), 2015, 5711–5741

Chai C., Cheng H., Ge W., Ma D. & Shi Y., *Phthalic Acid Esters in Soils from Vegetable Greenhouses in Shandong Peninsula, East China*, **PLoS ONE,** 9(4), 2014, e95701.

Chandrappa R., & Das D.B., *Solid Waste Management – Principles and Practice*, **Springer-Verlag**, Berlin, 2012.

Chaturvedi H., & Kaushal P., *Survey Findings to Study the Socio-Environmental and Economic Impact of Msw Leachate on Neighboring Residents*, **SSRN Electronic Journal**, 6(1), 2019

Chen G., Sun Y., Xu Z., Shan X. & Chen Z. *Assessment of Shallow Groundwater Contamination Resulting from a Municipal Solid Waste Landfill—A Case Study in Lianyungang,* **water** 11(12), 2019, 2496

Chen H., Dou J, &, Xu H, *Remediation Of Cr (VI)-Contaminated Soil With Co-Composting of Three Different Biomass Solid Wastes*, **J. Soils Sediments**, 18, 2018, 897–905.

Chiriac F.L., Paun I., Pirvu F, Iancu V. & Galaon T. *Fast and Sensitive LC-MS Detection of Bisphenol A and Butylhydroxyanisole in WWTP Sewage Sludge*. *70*(6), 2019, 2123–2127.

Daniel, A. Y., Ekeleme, I. K., Onuigbo, C. M., Ikpeazu, V. O. & Obiekezie, S. O., *Review on Effect of Dumpsite Leachate to the Environmental and Public Health Implication,* **GSC Advanced Research and Reviews**, 7(2), 2021, 051–060.

Daramola S.O. & Ilesanmi B.I., *Geotechnical Evaluation of Some Lateritic Soils from Ore, Southwestern Nigeria as Liners in Landfills*, **Current Journal of Applied Science and Technology,** 32(1), 2019, 1-7

Deng M., Han X., Ge J., Liang X., Du B., Li J. & Zeng L., *Prevalence of Phthalate Alternatives and Monoesters Alongside Traditional Phthalates in Indoor Dust from a Typical E-Waste Recycling Area: Source Elucidation and Co-Exposure Risk*, **J. Hazard. Mater**. 413, 2021, 125322.

Deng Q.X., Feng J.R. Gao P., & Ni H.G. *Combined Effects of Vehicles and Waste Incineration on Urban Air Halogenated and Parent Polycyclic Aromatic Hydrocarbons*, **Environment International,** 171, 2023, 107720–107720

Dong W., Xie WSu, X., C. Wen, X., Cao Z. & Y. Wan Z., *Micro-Organic Contaminants in Groundwater in China*, **Hydrogeol. J.** 26 (5), 2018, 1351–1369.

Dueñas-Moreno J., Mora A., Cervantes-Avilés P., & Mahlknecht J. *Groundwater Contamination Pathways of Phthalates and Bisphenol A: Origin, Characteristics, Transport, and Fate – A Review*, **Environment International**, 170, 2022, 107550.

Esfahani, H. K., Heggie, A., & Datta, B., *Integrated Sequential Groundwater Contaminant Source Characterization and Pareto-Optimal Monitoring Network Design Application for a Contaminated Aquifer Site*, **Journal of Water Resource and Protection,** *14*(07), 2022, 542–570.

Fadhullah W., Imran N.I.N., Ismail S.N.S., Jaafar M.H, & Abdullah H., *Household Solid Waste Management Practices and Perceptions among Residents in the East Coast of Malaysia*, **BMC Public Health,** 22(1), 2022.

Ferronato N., & Torretta V.W. *Waste Mismanagement in Developing Countries: A Review of Global Issues*, **Int. J. Environ. Res. Public Health** 16 (6), 2019, 1060

Fromme H., *Phthalates and Their Metabolites in Indoor Air and Dust*, **Environmental Science & Technology**, 41(18), 2007, 6341-6346.

Gao D.W. & Wen Z.D. *Phthalate Esters in the Environment: A Critical Review of Their Occurrence, Biodegradation, and Removal during Wastewater Treatment Processes*, **Science of the Total Environment,** 541, 2016, 986-1001.

Garcete, L.A.A., Martinez, J.E.R., Barrera, D.B.V., Bonugli-Santos, R.C. & Passarini, M.R.Z., *Biotechnological Potential of Microorganisms from Landfill Leachate: Isolation, Antibiotic Resistance and Leachate Discoloration*, **Anais da Academia Brasileira de Ciências**, 2022, 94(3).

Godswill A.C. & Godspel A.C. *Physiological Effects of Plastic Wastes on the Endocrine System (Bisphenol A, Phthalates, Bisphenol S, PBDEs, TBBPA),* **Int. J. Bioinform. Computational Biol.**4 (2), 2019, 11–29.

Gong, Z., Yang, S., Zhang, R., Wang, Y., Wu, X. and Song, L., *Physiochemical and Biological Characteristics of Fouling on Landfill Leachate Treatment Systems Surface,* **Journal of Environmental Sciences-china,** 135, 2022, 9–71.

Goutam Mukherjee, A., Ramesh Wanjari, U., Eladl, M.A., El-Sherbiny, M., Elsherbini, D.M.A., Sukumar, A., Kannampuzha, S., Ravichandran, M., Renu, K., Vellingiri, B., Kandasamy, S. and Valsala Gopalakrishnan, A., *Mixed Contaminants: Occurrence, Interactions, Toxicity, Detection, and Remediation*, **Molecules**, 27(8), 2022, 2577.

Haider, F.U., Liqun, C., Coulter, J.A., Cheema, S.A., Wu, J., Zhang, R., Wenjun, M. and Farooq, M., *Cadmium Toxicity in Plants: Impacts and RemediationStrategies*, **Ecotoxicology and Environmental Safety**, 211, 2021, 111887.

Hauser R., &. Calafat A.M, *Phthalates and Human Health*. **Occup. Environ. Med**., *62*, 2005, 806–818.

Heo H., Choi M.J, Park J., Nam T. & Cho J. *Anthropogenic Occurrence of Phthalate Esters in Beach Seawater in the Southeast Coast Region, South Korea*. **Water J.** 12 (122), 2020, 1–13.

Honda, M. and Suzuki, N., *Toxicities of Polycyclic Aromatic Hydrocarbons for Aquatic Animals*, **International Journal of Environmental Research and Public Health,** 17(4), 2020, 1363.

Hu, X., Wang, J., Lv, Y., Liu, X., Zhong, J., Cui, X., Zhang, M., Ma, D., Yan, X. and Zhu, X., *Effects of Heavy Metals/Metalloids and Soil Properties on Microbial Communities in Farmland in the Vicinity of a Metals Smelter,* **Frontiers in Microbiology**, 12, 2021.

Hussain K., Raza Rafiqul Hoque, Balachandran S., Subhash Medhi S.,, Idris, M., Rahman, M. & Farhaz Liaquat Hussain, *Monitoring and Risk Analysis of PAHs in the Environment,* **Springer eBooks,** 2019, 973–1007.

Hwang, J., Xu, C., Grunsted, P., Agnew, R.J., Malone, T.R., Clifton, S., Thompson, K. and Xu, X. *Urinary Metabolites of Polycyclic Aromatic Hydrocarbons in Firefighters: A Systematic Review and Meta-Analysis,* **International Journal of Environmental Research and Public Health,** 19(14), 2022, 8475.

Ibikunle R.A.,Titiladunayo I.F.,. Akinnuli B.O, Dahunsi S.O. & Olayanju, T.M.A. *Estimation of Power Generation from Municipal Solid Wastes: A Case Study of Ilorin Metropolis, Nigeri*a**, Energy Reports,** 5, 2019, 126–135.

Igboama, W.N., Hammed, O.S., Fatoba, J.O., *Review Article on Impact of Groundwater Contamination Due to Dumpsites using Geophysical and PhysiochemicalMethods,* **Appl Water Sci 12**, 2022, 130

Ige O.O., *Note on Liners for Containment of Leachate In Sanitary Landfills to Enhance Sustainable Environment,* **International Journal of Development and Sustainability**, 2(1), 2013, 380-389.

Iwegbue C.M.A., TesiG.O., ObiG. , Obi-Iyeke G.E,, Igbuku U.A., Bice S. & MartincighB.S., *Concentrations, Health Risks and Sources of Polycyclic Aromatic Hydrocarbons in Nigerian Honey,* **Toxicol. Environ. Health Sci.** 8 (1), 2016, 28–42 .

Johari A., Hashim H., Mat R., Alias H., Hasshim M.H. & Rozainee M. *Generalization, Formulation and Heat Contents of Simulate DMSW with Moisture Content,* **J. Eng. Sci. Technol**., 7 (6), 2012.

Jonsson S., Ejlertsson J., & Svensson B.H., *Transformation of Phthalates in Young Landfill Cells*, **Waste Manage**, 23, 2003, 641-651.

Murray K.E, Thomas S.M & Bodour A.A, *Prioritizing Research for Trace Pollutants and Emerging Contaminants in the Freshwater Environment.* **Environ Pollut.,** 158, 2010, 3462–71.

Kabir M.S., Wang H., Luster-Teasley S., Zhang L., & Zhao R., *Microplastics in Landfill Leachate: Sources, Detection, Occurrence, and Removal*, **Environmental Science And Ecotechnology**, 16, 2023, 100256, Available Online: Https://Doi.Org/10.1016/J.Ese.2023.100256

Kalmykova Y., Björklund K., Strömvall A. M., & Blom L., *Partitioning of Polycyclic Aromatic Hydrocarbons, Alkylphenols, Bisphenol A and Phthalates in Landfill Leachates and Stormwater*, **Water Research**, 47(3), 2013, 1317–1328. Available online: https://doi.org/10.1016/j.watres.2012.11.054.

Kannan K. & Choi J.W., *Phthalate Exposure and Associated Health Risks among School-Age Children Residing near Plastic Recycling Facilities,* **Environmental Health Perspectives**, 110(7), 2002, 737-739.

Karanth, S., Feng, S., Patra, D., & Pradhan, A. K., *Linking Microbial Contamination to Food Spoilage and Food Waste: The Role of Smart Packaging, Spoilage Risk Assessments, and Date Labelling,* **Frontiers in microbiology,** *14*, 2023, 1198124.

Kashyap D. & Agarwal T., *Concentration and Factors Affecting the Distribution of Phthalates in the Air and Dust: A Global Scenario*, **Sci Total Environ.** 635, 2018, 817-827.

Kayastha, V., Patel, J., Kathrani, N., Varjani, S., Bilal, M., Show, P. L., Kim, S. H., Bontempi, E., Bhatia, S. K., & Bui, X. T., *New Insights in Factors Affecting*

Groundwater Quality with Focus on Health Risk Assessment and Remediation Techniques, **Environmental Research**, 212, 2022, 113171.

Keyikoglu R., Karatas O., Rezania H., Kobya M. Cortina J. & Khataee A. *A Review On Treatment of Membrane Concentrates Generated from Landfill Leachate Treatment Processes,* **Separation and Purification Technology**, 259, 2021, 118182–118182.

Khalil C., Al Hageh C., Korfali S. & Khnayzer R.S., *Municipal Leachates Health Risks: Chemical and Cytotoxicity Assessment from Regulated and Unregulated Municipal Dumpsites in Lebanon*, **Chemosphere,** 208, 2018, 1–13

Kjelsen P., Barlaz M.A., Rooker A.P; Baun A., Ledin A. & Christensen T.H., *Present and Long-Term Composition of MSW Landfill Leachate: A Review*, **Crit Rev Environ Sci Technol.,** 2002; 32, 2002, 297–336.

Klimiuk E. & Kulikowska D., *The Influence of Hydraulic Retention Time and Sludge Age on the Kinetics of Nitrogen Removal from Leachate in SBR*, **Pol. J. Environ. Stud**., 13, 2004, 525.

KloÈ ting N., Hesselbarth N., Gericke M., Kunath A., Biemann R. & Chakaroun R., *Di-(2-Ethylhexyl)-Phthalate (DEHP) Causes Impaired Adipocyte Function and Alters Serum Metabolites*, **PLoS ONE,** 10(12) 2015, e0143190.

Kolekara K.A., Hazrab T. & Chakrabartyc S.N. *A Review on Prediction of Municipal Solid Waste Generation Models. Int. Conf. on Solid Waste Manage. 5IconSWM 2015*, **Procedia Environ. Sci.** 35, 2016, 238 – 244

Kotowska U., Kapelewska J., & Sawczuk R., *Occurrence, Removal, and Environmental Risk of Phthalates in Wastewaters, Landfill Leachates, and Groundwater in Poland*, **Environ. Pollut**. 267, 2020, 115643.

Kuddus M.A. Tynan E., &. McBryde E, *Urbanization: A Problem for the Rich and the Poor*? **Public Health Reviews**, 41(1), 2020.

Kwun Omang, D.I., Egbe John, G., Alain Inah, S. and Owan Bisong, J., *Public Health Implication of Solid Waste Generated by Households in Bekwarra Local Government Area,* **African Health Sciences**, 21(3), 2021, 1467–1473.

Laonamsai, J., Pawana, V., Chipthamlong, P., Chomcheawchan, P., Kamdee, K., Kimmany, B. & Julphunthon, P., *Groundwater Quality Variations in Multiple Aquifers: A Comprehensive Evaluation for Public Health and Agricultural Use, Geosciences*, 13(7), 2023, 195–195.

Lawal, A.T., Polycyclic Aromatic Hydrocarbons. A Review, **Cogent Environmental Science**, 3(1), 2017.

Lehr J.H. & Keeley J., *Landfill*, **Water Encyclopedia**, 1, 2005, 695-699.

Li A., Kang L., Li R., Wu S., Liu K., & Wang X. *Modeling di (2-ethylhexyl) Phthalate (DEHP) and Its Metabolism in a Body's Organs and Tissues through Different Intake Pathways into Human Body,* **International Journal of Environmental Research and Public Health,** 19(9), 2022, 5742.

Li Z., Feng Q, Dang J., Rong Y., Zhu X., Meng L. & Zhang X. *Types And Source Apportionment of Polycyclic Aromatic Hydrocarbons (Pahs) in Soil-Groundwater of a Closed Coking Plant in Shanxi Province,* China. 15(11), 2023, 2002–2002.

Lindamulla L., Nanayakkara N., Othman M., Jinadasa S., Herath G., & Jegatheesan V. *Municipal Solid Waste Landfill Leachate Characteristics and their Treatment Options in Tropical Countries***, Current Pollution Reports**, 8, 2022, 273–287

Liu H., Huang H., Xiao X., Zhao Z. & Liu, C. *Effects of Phthalate Esters (PAEs) on Cell Viability and Nrf2 of HepG2 and 3D-QSAR Studies*, **Toxics**, 9 (6), 2021, 134.

Liu H., Liang Y., Zhang D., Wang C., Liang H. & Cai H., *Impact of MSW Landfill on the Environmental Contamination of Phthalate Esters*, **Waste Management**, 30, 2010, 1569-1576.

Liu J., Li Q., Gu W. &Wang C. *The Impact of Consumption Patterns on the Generation of Municipal Solid Waste in China: Evidences from Provincial Data*, **Int. J. Environ. Res. Public Health,** 16, 2019, 1717.

Lora M.M, Vogler E., Gebhardt F.E., Graves D., & *Grabowski* J.F., *Enhanced Bioremediation of RDX and Co-Contaminants Perchlorate and Nitrate using an Anaerobic Dehalogenating Consortium in a Fractured Rock Aquifer,* **Chemosphere**, 2022, 133674.

Lu B L., Wang; Jiang J., Huang Q., Yu Z. & Li H. *Heavy Metal Contamination in Herbal Medicine: Determination Comprehensive Risk Assessment*, **Front. Pharmacol**. 11, 2020, 595335.

Lumniczky, K., Impens, N., Armengol, G., Candéias, S., Georgakilas, A. G., Hornhardt, S., Martin, O. A., Rödel, F., & Schaue, D., *Low Dose Ionizing Radiation Effects on the Immune System,* **Environment international**, *149*, 2021, 106212.

Ma S., Lin M., Tang J., Liu R., Yang Y., Yu Y., & Li G., *An, Occurrence and Fate of Polycyclic Aromatic Hydrocarbons from Electronic Waste Dismantling Activities: a Critical Review from Environmental Pollution to Human Health.*, **Journal of Hazardous Materials,** 424, 2022, 127683.

Machado R., Alves-Pereira I., Robalo M., & Ferreira R. *Effects Of Municipal Solid Waste Compost Supplemented with Inorganic Nitrogen on Physicochemical Soil Characteristics, Plant Growth, Nitrate Content, and Antioxidant Activity in Spinach*, **Horticulturae**, 7(3), 2021, 53.

Mahboob S., Kausar S., Jabeen F., Sultana S., Sultana T., Al-Ghanim K.A., Hussain B., Al-Misned F., & Ahmed Z. *Effect of Heavy Metals in Liver, Kidney, Gills and Muscles of Cyprinus Carpio and Wallago Attu Inhabited in the Indus*. **Braz. Arch. Biol. Technol.,** *59*, 2016, 1–10.

Manisalidis, I., Stavropoulou, E., Stavropoulos, A., & Bezirtzoglou, E., *Environmental and Health Impacts of Air Pollution: A Review*, **Frontiers in public health,** *8*, 2020, 14.

Mekuria D.M., Kassegne A.B. & Asfaw S.L., *Assessing Pollution Profiles along Little Akaki River Receiving Municipal and Industrial Wastewaters, Central Ethiopia: Implications for Environmental and Public Health Safety,* **Heliyon**, 7(7), 2021, Available Online: https://doi.org/10.1016/j.heliyon.2021.e07526

Mieiro C.L., Duarde A.C., Pereira M.E. & Pacheco M., *Mercury Accumulation Patterns and Biomedical Endpoints in Wild Fish (Liza Aurata): A Multiorgan Approach*, **Ecotox. Environ. Safety,** *74*, 2011, 2225–2232.

Mishra S., Tiwary D., Ohri A. & Agnihotri A.K. *Impact of Municipal Solid Waste Landfill Leachate on Groundwater Quality in Varanasi, India*, **Groundwater for Sustainable Development**, 9, 2019, 100230.

Mitra, S., Chakraborty, A.J., Tareq, A.M., Emran, T.B., Nainu, F., Khusro, A., Idris, A.M., Khandaker, M.U., Osman, H., Alhumaydhi, F.A.& Simal-Gandara, J., *Impact of Heavy Metals on the Environment and Human health: Novel Therapeutic Insights to Counter the Toxicity*, **Journal of King Saud University - Science,** 34(3), 2022, 101865.

Mohammad Reza Masjedi, Dobaradaran, S., Hossein Arfaeinia, Mohammad Reza Samaei, Novotny, T.E. and Rashidi, N. *Polycyclic Aromatic Hydrocarbon (PAH) Leachates from Post-Consumption Waterpipe Tobacco Waste (PWTW) into Aquatic Environment- A Primary Study,* **Environmental Pollution,** 327, 2023, 121500–121500.

Moorthy, B., Chu, C., & Carlin, D. J., *Polycyclic Aromatic Hydrocarbons: from Metabolism to Lung Cancer,* **Toxicological Sciences: an official journal of the Society of Toxicology,** *145*(1), 2015, 5–15.

Mor, S., Negi, P. and Khaiwal, R., *Assessment of Groundwater Pollution by Landfills in India using Leachate Pollution Index and Estimation of Error*, **Environmental Nanotechnology, Monitoring & Management,** 10, 2018, 467–476.

Mosotho G.J., *Determination and Quantification of Phthalic Acid Esters from the Soil Collected from the Municipal Solid-Waste Dumpsite in Maseru using a Simple Vortex-Assisted Low-Volume Organic Solvent Extraction*, **J Anal Pharm Res.**;7(5), 2018, 522–528.

MUDC, *Solid Waste Management Manual: With Respect to Urban Plans, Sanitary Landfill Sites and Solid Waste Management Planning; Urban Planning, Sanitation and Beautification Bureau*: Addis Ababa, Ethiopia, 2012.

Mukherjee, S., Mukhopadhyay, S., Hashim, M. A., & Sen Gupta, B., *Contemporary Environmental Issues of Landfill Leachate: Assessment and Remedies,* **Critical Reviews in Environmental Science and Technology**, *45*(5), 2014, 472–590.

Mukhopadhyay H. A, Sampath S., Munoz-Arnanz J. B. Jim´enez & Chakraborty P., *Plasticizers and Bisphenol A in Adyar and Cooum Riverine Sediments, India: Occurrences, Sources and Risk Assessment*, **Environ. Geochem. Health,** 42 (9), 2020, 2789–2802

Muzenda E., Belaid M., Mollagee M., Motampane N. &Ntuli F., *Reflecting on Waste Management Strategies for South Africa,* **World Congr Eng Comput Sci** 2, 2011, 19-21.

Baloyi,N.D.,Tekere, M., Maphangwa K.W& Masindi, V. *Insights into the Prevalence and Impacts of Phthalate Esters in Aquatic Ecosystems*, **Front. Environ. Sci**. 9, 2021, 684190.

Na G.S., Liu C.Y., Wang Z, Ge L.K., Ma X.D. & Yao Z.W., *Distribution and Characteristics of PAHs in Snow of Fildes Peninsula,* **J. Environ. Sci**., 23 (9), 2011, 1445–1451.

Nabegu A.B., *An Analysis of Municipal Solid Waste in Kano Metropolis, Nigeria*, **Journal of Human Ecology**, 31(2), 2010, 111–119.

Nawrot N., Wojciechowska E., Mohsin S M. Kuittinen, Pappinen A & Rezania S., *Trace Metal Contamination of Bottom Sediments: A Review of Assessment Measures and Geochemical Background Determination Methods*, **Minerals**, 11, 2021, 872.

Ndukwe, V.A., Uzoegbu, M.U., Ndukwe, O.S. & Agibe, A.N., *Environmental and Health Impact of Solid Waste Disposal in Umuahia and Environs, Southeast, Nigeria,* **Journal of Applied Sciences and Environmental Management,** 23(9), 2019, 1615.

Njoku, P.O., Edokpayi, J.N. & Odiyo, J.O., *Health and Environmental Risks of Residents Living Close to a Landfill: A Case Study of Thohoyandou Landfill, Limpopo Province, South Africa,* **International Journal of Environmental Research and Public Health**, 16(12), 2019, 2125.

Notardonato I., Russo M.V. & Avino P., *Phthalates and Bisphenol-A Residues in Water Samples: An Innovative Analytical Approach*, **Rendiconti Lincei. Scienze Fisichee Naturali,** 29 (4), 2018, 831–840

Nwosu, A. O. & Chukwueloka, H. E., *A Review of Solid Waste Management Strategies in Nigeria*, **Journal of Environment and Earth Science** 10(6), 2020, 2224-3216.

Nyiramigisha P., Komariah & Sajidan, *Harmful Impacts of Heavy Metal Contamination in the Soil and Crops Grown around Dumpsites,* **Reviews in Agricultural Science**, 9(0), 2021, 271–282.

Ogundele O.M., Rapheal O.M. & Abiodun A.M., *Effects of Municipal Waste Disposal Methods on Community Health in Ibadan- Nigeria,* **Polytechnica** 1, 2018, 61–72.

Ojekunle Z.O., Balogu M.A. Adeyemi A.A., Adegoke K.A., Anumah A.O. Taiwo A.M & Ganiyu, S.A. *Effect of Industrialization on Groundwater Quality in Shagamu and Ota Industrial Areas of Ogun State, Nigeria*. **Heliyon,** 6 (7), 2020, 1-13

Oketola A.A. & Akpotu S.O., *Assessment of Solid Waste and Dumpsite Leachate and Topsoil*, **Chemistry and Ecology**, 31 (2), 2014, 134–46. Available Online: https://doi.org/10.1080/02757540.2014.907280.

OlabanjiI.O. , AsubiojoO.I., AdedoyinK.M. , AkintomideA. & Adenijia.O. ,*Determination of Polycyclic Aromatic Hydrocarbons in Blood Plasma of Neurol-Ogy Patients,* **J. Toxicol. Environ. Health Sci.** 11 (1), 2019, 1–8

Olawoyin R., Grayson R.L. & Okareh O.T., *Eco-Toxicologicaland Epidemiological Assessment of Human Exposure to Polycyclic Aromatic Hydrocarbons in the Niger Delta, Nigeria,* **Toxicol. Environ. Health. Sci.** 4, 2012, 173–185

Ololade, O.O., Mavimbela, S., Oke, S.A. and Makhadi, R., *Impact of Leachate from Northern Landfill Site in Bloemfontein on Water and Soil Quality: Implications for Water and Food Security*, **Sustainability, 11**(15), 2019, 4238.

Olujimi O.O., Ajayi O.L. & Oputu, O.U. *Toxicity Assessment of Olusosun Andigando Leachates Using the African Catfish (Clariasgariepinus) As Bioindicator Species Part* I, **Ife Journal of Science,** 18(3), 2016, 693-701.

Ozbay, G., Jones, M., Gadde, M., Isah, S., & Attarwala, T., *Design and Operation of Effective Landfills with Minimal Effects on the Environment and Human Health*, **Journal of Environmental and Public Health**, 2021, 1–13.

Parvin F., & Tareq S.M., *Impact Of Landfill Leachate Contamination On Surface And Groundwater of Bangladesh: A Systematic Review and Possible Public Health Risks Assessment*, **Applied Water Science**, 11(6), 2021.

Patel A.B., Shaikh S., Jain K.R, Desai C., & Madamwar D., *Polycyclic Aromatic Hydrocarbons: Sources, Toxicity, and Remediation Approaches,* **Frontiers in Microbiology**, 11, 2020.

Paul D., *Research on Heavy Metal Pollution of River Ganga: A review*, **Annals of Agrarian Science**, 15(2), 2017, 278–286, Available Online: https://doi.org/10.1016/j.aasci.2017.04.001

Pivato A., & Gaspari L. *Acute Toxicity Test of Leachates from Traditional and Sustainable Landfills Using Luminescent Bacteria,* **Waste Manag,** 26, 2005, 1148–1155.

Prashanth L., Kattapagari K.K. Chitturi R.T, Baddam V.R. &. Prasad L.K, *A Review On Role of Essential Trace Elements in Health And Disease,* **JNTR Univ. Health Sci**., 4, 2015, 75–85.

Przybylińska P.A. & Wyszkowski M., *Environmental Contamination With Phthalates and its Impact in Living Organisms*, **Ecol Chem Eng S**., 23(2), 2016, 347-356.

Qian Y., Jia X., Ding T. Yang M., Yang B. & Li J. *Occurrence and Removal of Bisphenol Analogues in Wastewater Treatment Plants and Activated Sludge Bioreactor*, **Sci. Total Environ.** 758, 2021, 143606

Radjenović J. *Phthalate Esters in Wastewater Treatment Plants: Sources, Fate and Removal,* **Science of the Total Environment**, 621, 2018, 753-766.

Raffa, C.M., Chiampo, F. and Shanthakumar, S., *Remediation of Metal/Metalloid-Polluted Soils: A Short Review,* **Applied Sciences,** 11(9), 2021, 4134.

Rajoo, K.S., Karam, D.S., Ismail, A.& Abdu, A., *Evaluating the LeachateContamination Impact of Landfills and Open Dumpsites from Developing Countries using the Proposed Leachate Pollution Index for Developing Countries (LPIDC)*, **Environmental Nanotechnology, Monitoring & Management,** 2020, 100372.

Rashid A., Schutte B.J., Ulery A., Deyholos M.K., Sanogo S., Lehnhoff E.A., & Beck L., *Heavy Metal Contamination in Agricultural Soil: Environmental Pollutants Affecting Crop Health*, **Agronomy,** 13(6), 2023, 1521.

Rudel R.A., *Food Packaging and Bisphenol A and Bis(2-Ethylhexyl) Phthalate Exposure: Findings from a Dietary Intervention*, **Environmental Health Perspectives**, 119(7), 2011, 914-920.

Sada P.O., *Urbanization and Living Conditions in Nigerian Cities, Research Triangle Institute as Cited by Uwadiegwu and Chukwu, 2013, Strategies for Effective Urban Solid Waste Management*, **European Scientific Journal**, 9(8), 1984, 1857 – 7881 1

Saghir J. & Santo J., *Urbanization in Sub-Saharan Africa: Meeting Challenges by Bridging Stakeholders*, **Center for Strategic and International Studies (CSIS),** Washington, DC, 2018.

Sailas B., Selvanesan P., Moolakkariyil S.J., Sunil K. & Eiji M., *A Monograph on the Remediation of Hazardous Phthalates,* **Journal of Hazardous Materials**, 298, 2015, 58-72. 4

Salcedo Sánchez E.R., Martínez J.M.E., Morales M.M., Mendoza O.T. & Alberich M.V.E. *Ecological and Health Risk Assessment of Potential Toxic Elements from a Mining Area (Water and Sediments): The San Juan-Taxco River System, Guerrero, Mexico*, **Water**, 14, 2022, 518, 8

Sampaio G.R., Guizellini G.M., Da Silva S.A. De Almeida A.P, Pinaffi-Langley A.C.C., Rogero M.M, De Camargo A.C., & Torres E.A.F.S. *Polycyclic Aromatic Hydrocarbons in Foods: Biological Effects, Legislation, Occurrence, Analytical Methods, and Strategies to Reduce their Formation*, **International Journal of Molecular Sciences**, 22(11), 2021, 6010.

Sam-Uroupa E.R., &Ogbeibu A.E., *Effects of Solid Waste Disposal on the Receiving Soil Quality in Benin Metropolis, Nigeri*a, **Journal of Applied Sciences and Environmental Management,** 24(2), 2020, 393–401.

Savita, V.S. Chopra, & A. Sharma, *Environmental Contaminants: Sources and Effects, Evaluation of Environmental Contaminants and Natural Products: A Human Health Perspective*, **Bentham Science Publisher**, 23, 2019, 1-23.

Schwarzbauer I., Heim S., Brinker S. & Litke R., *Occurrence and Alteration of Organic Contaminants in Seepage and Leakage Water from a Waste Deposit Landfill*, **Water Resour.**, 36, 2002, 2275–2287.

Seyoum A. & Pradhan A., *Effect of Phthalates on Development, Reproduction, Fat Metabolism and Lifespan in Daphnia magna*, **Sci. Total Environ.** 654, 2019, 969–977.

Sheng Y., Yan C., Nie M., Jiang M., Ding M., Huang X. & Chen J. *The Partitioning Behavior of PAHs between Settled Dust and its Extracted Water Phase: Coefficients and Effects of the Fluorescent Organic Matter,* **Ecotoxicology and environmental safety**, 223, 2021, 112573–112573

Shershneva E.G. *Analysis of Correlation between Waste Accumulation and Countries Welfare Level,* **IOP Conference Series: Earth and Environmental Science**, 988(2), 2022, 022034.

Shin H.M., *Atmospheric Occurrence and Distribution of Phthalates in Urban and Suburban Residential Environments*, **Atmospheric Environment**, 45(18), 2011, 3132-3139.

Siddiqua, A., Hahladakis, J. N., & Al-Attiya, W. A. K. A., *An Overview of the Environmental Pollution and Health Effects Associated with Waste Landfilling and Open Dumping,* **Environmental Science and Pollution Research,** *29*, 2022, 58514–58536.

Simon-Oke, I.A., Oladele, O.O. and Dada, O.E., *Microorganisms in Soil and Groundwater of Epe and Laje Solid Waste Dumpsites in Ondo Town, Nigeria*, **Journal of Applied Sciences and Environmental Management,** 27(2), 2023, 217–322.

Smith CJ, Hopmans P, Cook FJ. *Accumulation of Cr, Pb, Cu, Ni, Zn and Cd in Soil following Irrigation with Untreated Effluents in Australia*, **Environ Poll**., 94(3), 1996, 317–323.

Sridhar C., Coker A.O, Shittu O.O., Laniyan T.A., & Achi C.G., *Phytotechnologies in Wastewater Treatment: A Low-Cost Option for Developing Countries*, **Sustainable Water Engineering**, 2020, Pages 137-164

Sun H., Li J., Zhao X., Zhu B. & Zhang G., *A Review on the Management of Municipal Solid Waste Fly Ash in American*, **Procedia Environmental Sciences**, 31, 206, 535–540.

Sun P., Liu X., Zhang M., Li Z., C. Cao C., Shi H. Yang Y., & Zhao Y., *Sorption and Leaching Behaviors between Aged Mps and BPA in Water: The Role of BPA Binding Modes within Plastic Matrix*, **Water Res**. 195, 2021, 116956.

Tadesse T, *Solid Waste Management. Produced in Collaboration with the Ethiopia Public Health Training Initiative*, **The Carter Center, the Ethiopia Ministry of Health, and the Ethiopia Ministry of Education**, Gondor University: Gondar, Ethiopia, 2004.

Tałałaj I., Biedka P., Walery M. & Leszczyński J., *Monitoring of Leachate Quality at a Selected Municipal Landfill Site in Podlasie, Poland*, **Journal of Ecological Engineering**, 17(3), 2016, 175–184. Available online: https://doi.org/10.12911/22998993/63477

Taylor, C.J., *Ground-Water-Level Monitoring and the Importance of Long-Term Water-Level Data* Circular 1217. Available online https://pubs.usgs.gov/circ/circ1217/pdf/circular1217.pdf

TrivedI J. & Chhaya U., *Bioremediation of Phenolic Pollutant Bisphenol A Using Optimized Reverse Micelles System of Trametes Versicolor Laccase in Non-Aqueous Environment,* **Biotech**, 11(6), 2021, 1–14.

Tytła M., Dmochowska A., Dmochowski D. & Jaworska K., *Ecological Risk Assessment of Trace Metals in the Bottom Sediments of the Young Water Reservoir - Bardowskiego Lagoon (Warsaw) Case Study*, **E3S Web Conf.**, 44, 2018, 00182.

Vaccari, M., Vinti, G., & Tudor, T., *An Analysis of the Risk Posed by Leachate from Dumpsites in Developing Countries*, **Environments,** *5*(9), 2018, 99.

Wang H., Liang H. & Gao D., *Occurrence and Distribution of Phthalate Esters (PAES) in Wetland Sediment*s, **J. For. Res**. 28 (6), 2017, 1241–1248.

Wang H., Tang S., Zhou X., Gao R., Liu Z., Song X. & Zeng F. *Urinary Concentrations of Bisphenol Analogues in the South of China Population and their Contribution to the Per Capital Mass Loads in Wastewater,* **Environ. Res**., 204, 2022, 112398

Wdowczyk A., & Szymańska-Pulikowska A. *Comparison of Landfill Leachate Properties by LPI And Phytotoxicity-A Case Study,* **Frontiers in Environmental Science**, *9*, 2021, Available Online: https://doi.org/10.3389/fenvs.2021.693112

Wijekoon, W.M.P.C., Koliyabandara, P.A., Cooray, A., Lam, S.S., Athapattu, B.C.L. and Vithanage, M., *Progress and Prospects in Mitigation of Landfill Leachate Pollution: Risk, Pollution Potential, Treatment and Challenges*, **Journal of Hazardous Materials,** 2021, 126627.

Willson C.J., *Phthalate Toxicity in Rats and Its Relation to Testicular Dysgenesis Syndrome in Humans,* **Toxicologic Pathology**, 49(8), 2021, 1416–1424.

Wirnkor V.A., V.E. Ngozi, C.M. Ajero, L.K. Charity, O.S.M. Ngozi; *Enyoh Christian; E.C. Ebere & A.C. Emeka,* Biomonitoring *of Concentrations of Polycyclic Aromatic Hydrocarbons in Blood and Urine of Children at Playgrounds Within Owerri, Imo State, Nigeria,* **Environ. Anal. Health Toxicol.** 34 (4), 2019, e2019011

Wuave, T., *Effect of Leachate on Soil in Jos Metropolis, Plateau State Nigeria*, IOP conference series**,** 1142(1), 2023, 012058–012058.

Xu D.D. & Liu D.S., *The Experiment Study of the Pollution of Phthalate Compounds and Heavy Metals to Rice in the Film,* **Trans Tech Publ**, 2014, 303–306

Xu, D.D., Liu, D.S., 2014. *The Experiment Study of the Pollution of Phthalate Compounds China,* **Water**, 11, 2019, 2496.

Yal G.P. & Akgun H., *Landfill Site Selection and Landfill Liner Design for Ankara, Turkey*, **Environmental Earth Sciences**, 70, 2013, 2729-2752.

Yan J. , Wang L., Fu P.P. & Yu H. , *Photomutagenicity of 16 Polycyclic Aromatic Hydrocarbons from the US EPA Priority Pollutant List,* **Mutat. Res.** 557 (1), 2004, 99–108

Yan, A., Wang, Y., Tan, S.N., Mohd Yusof, M.L., Ghosh, S. and Chen, Z., *Phytoremediation: A Promising Approach for Revegetation of Heavy Metal-Polluted Land,* **Frontiers in Plant Science,** 11(359), 2020.

Yeung L.W., Yamashita N., Taniyasu S., Lam P.K., Sinha R.K & Borole D.V., A *Survey of Perfluorinated Compounds in Surface Water and Biota Including Dolphins from the Ganges River and in Other Waterbodies in India*, Chemosphere**,** 76,(1), 2009, 55–62.

Zamri M. F., Kamaruddin M. A., Yusoff M. S, &. Aziz H. A, *Semi-Aerobic Stabilized Landfill Leachate Treatment by Ion Exchange Resin: Isotherm and Kinetic Study*, **Appl.Water Sci.**, 7, 2017, 581–590.

Thesis/Dissertation (Unpublished)

Adewoyin O.A., *Earthworm Diversity Abundance in Selected Dumpsites and Toxicity of Contaminated Water on Associated Fauna in Ibadan*, Ph.D. Thesis submitted to the Department of Zoology, University of Ibadan, Nigeria, 2016.

Alimba C. G., *DNA And Systemic Damage Induced by Landfill Leachates and Health Impacts of Human Exposure to Landfills in Lagos and Ibadan, Nigeria*, PhD thesis. Department of Zoology, University of Ibadan, Nigeria, 2013, 1-25.

Andersson M. &Säterskog H., *Removal of Organic Contaminants, Metals and Sludge Characterisation*, Master's Thesis in the Master's Programme Infrastructure and Environmental Engineering. Chalmers University of Technology Gothenburg, Sweden 2015.

Annepu R.K, *Sustainable Solid Waste Management in India*, MSc thesis. Department of Earth and Environmental Engineering, Fu Foundation School of Engineering and Applied Science, Columbia University in the City of New York, 2012, 1-189.

Websites

"Basel Convention." 1989. *"Basel Convention Home Page" (PDF). Archived (PDF) from the Original on 2017-05-16. Retrieved 2017-05-27.*

American Society of Mechanical Engineers (ASME), *Waste to Energy, Summary Repor*t,June 6, 2019 Available Online: http://www.asme.org

Jameson, C.W. Polycyclic aromatic hydrocarbons and associated occupational exposures. [online] PubMed. Available at: https://www.ncbi.nlm.nih.gov/books/NBK570325/.

Kaza, L. Yao, P. Bhada-Tata & F. VanWoerden, *What a waste 2.0: A Global Snapshot of Solid Waste Management to 2050.* Available Online: https://openknowledge.worldbank.org/handle/10986/30317

Olowe B. *Existing Situation of Solid Waste Management in Ibadan*. Available Online: http://www.google.com

Regulation (EC) *No 1272/2008 of the European Parliament and of the Council of 16 December 2008 on Classification, Labelling and Packaging of Substances and Mixtures, Amending and Repealing Directives 67/548/EEC and 1999/45/EC, and amending Regulation (EC) No 1907/2006*,: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32008R1272&from=en

S.L. Rothwell, *Antinuclear Movement*. **Encyclopedia Britannica**.2023 https://www.britannica.com/topic/anti-nuclear-movement

Rushbrook P., World Health Organization. Regional Office for Europe & European Centre for Environment and Health, *Guidance on Minimum Approaches for Improvements to Existing Municipal Waste Dumpsites*, **Copenhagen:** WHO Regional Office for Europe. Available Online: https://apps.who.int/iris/handle/10665/108432

United States for Environmental Protection Agency USEPA, *National Primary Drinking Water Regulations.* (NPDWRs). 2023. http://www.epa.gov/ogwdw/consumer/pdf/mcl.pdf.

United States Environmental Protection Agency (EPA), *National Overview: Facts and Figures about Materials, Waste and Recycling.* Available Online: https://www.epa.gov.

United States Environmental Protection Agency (USEPA), 2015, *Toxics Release Inventory Reporting Forms and Instructions.* Available Online: https://www.epa.gov/sites/production/files/201512/documents/ry_15_tri_chemical_list.pdf.

United States Environmental Protection Agency, *Office of Air and Radiation (US EPA, OAR) "Radioactive Waste*"2023. www.epa.org.

United States Environmental Protection Agency, *Office of Land and Emergency management (US EPA) OLEMS "Medical Waste*". 2023. www.epa.gov

US EPA, *Potential Well Water Contaminants and their Impacts,* 2023 https://www.epa.gov/privatewells/potential-well-water-contaminants-and-their-impacts

US EPA, OLEM, *Criteria for the Definition of Solid Waste and Solid and Hazardous Waste Exclusions* | US EPA. [online] US EPA. Available at: https://www.epa.gov/hw/criteria-definition-solid-waste-and-solid-and-hazardous-waste-exclusions.

USEPA, *Advancing Sustainable Materials Management: 2015 Fact Sheet. Assessing Trends in Material Generation, Recycling, Composting, Combustion with Energy Recovery and Landfilling in the United States*. Available Online: https://www.epa.gov/sites/production/files/201807/documents/2015_smm_msw_factsheet_07242018_fnl_508_002.pdf.

Wale B. *Energy. Energy Consult Powering Clean Energy Future, Solid Waste Management in Nigeria*. https://www.bioenergyconsult.com/solid-waste-nigeria.

Waste Atlas Report, *World's Fifty Biggest Dumpsites.* 2014. http://www.d-waste.com/Atlasreport2014/Waste-Atlas-report-2014-webEdition.pdf

Appendix I

Phthalate Compound and their Concentration in Leachate and Underground Water Samples

Sample ID	Phthalate compounds	Retention time	Concentration µg/10g
River Water	Diethyl Phthalate	0.715	36.1405
600m UW	Dipropyl Phthalate	1.307	6.0918
	Diamyl Phthalate	2.990	8.8009
300m UW	Diethyl Phthalate	0.740	0.0290
	Dipropyl Phthalate	1.365	30.9091
Leachates	Benzylbutyl Phthalate	1.523	47.34255

UW – Underground Water

Source: Author's Field Work, 2023

Appendix II

Characteristics of Aba-Eku River Water and its Leachate Pollution Index

Parameters	**Significance**	**Pollution Weight *(Wi)***	**Pollution Concentration**	**Sub-Index Value *(Pi)***	**Overall Rating *(Wipi)***
pH	3.509	0.055	7.72	5	0.275
BOD	3.902	0.061	0.3	0	0
COD	3.963	0.062	1060	36	2.232
TDS	3.196	0.05	0.16	5.2	0.26
Ammonia/Nitrogen	3.25	0.051	0.5238615	5	0.255
Chloride	3.078	0.048	5.005	5	0.24
Copper	3.17	0.05	0.01	5	0.25
Chromium	4.057	0.064	0	5	0.32
Lead	4.019	0.063	0	5	0.315
TKN	3.367	0.053	0.5507365	5	0.265
Iron	2.83	0.045	0.21	5	0.225
Total	38.341	0.602	1074.479598	81.2	4.637
LPI = 7.68272					

Source: Author's Field Work, 2023

Appendix III

Characteristics of Aba-Eku 600meters Underground Water and its Leachate Pollution Index

Parameters	Significance	Pollution Weight *(Wi)*	Pollution Concentration	Sub-Index Value *(Pi)*	Overall Rating *(Wipi)*
pH	3.509	0.055	7.315	5	0.275
BOD	3.902	0.061	0.7	0	0
COD	3.963	0.062	420	15.1	0.9362
TDS	3.196	0.05	0.014	4.9	0.245
Ammonia/Nitrogen	3.25	0.051	0.3445725	5	0.255
Chloride	3.078	0.048	7.0077	5	0.24
Copper	3.17	0.05	0.03	5.3	0.265
Chromium	4.057	0.064	0	5	0.32
Lead	4.019	0.063	0	5	0.315
TKN	3.367	0.053	0.3754475	5	0.265
Iron	2.83	0.045	0.1	5	0.225
Total	38.341	0.602	435.88672	60.3	3.3412
LPI = 5.5502					

Source: Author's Field Work, 2023

Appendix IV

Characteristics of Aba-Eku 300meters Underground Water and its Leachate Pollution Index

Parameters	Significance	Pollution Weight (*Wi*)	Pollution Concentration	Sub-Index Value (*Pi*)	Overall Rating (*Wipi*)
pH	3.509	0.055	7.025	5	0.275
BOD	3.902	0.061	0.75	0	0
COD	3.963	0.062	660	35	2.17
TDS	3.196	0.05	0.0119	5	0.25
Ammonia/Nitrogen	3.25	0.051	0.4678335	5	0.255
Chloride	3.078	0.048	9.0099	5	0.24
Copper	3.17	0.05	0	6	0.3
Chromium	4.057	0.064	0	5	0.32
Lead	4.019	0.063	0	5	0.315
TKN	3.367	0.053	0.50240855	5	0.265
Iron	2.83	0.045	0.1	5	0.225
Total	38.341	0.602	677.8670421	81	4.615
LPI = 7.151162					

Source: Author's Field Work, 2023

Appendix IV

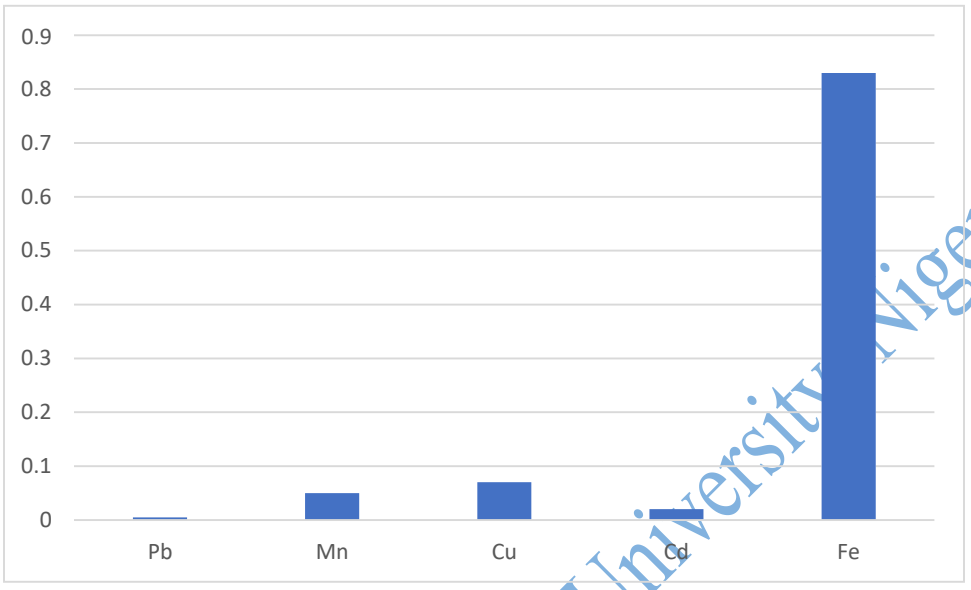
Characteristics of Aba-Eku Leachate and its Leachate Pollution Index

Parameters	Significance	Pollution Weight (*Wi*)	Pollution Concentration	Sub-Index Value (*Pi*)	Overall Rating (*Wipi*)
PH	3.509	0.055	7.225	5	0.275
BOD	3.902	0.061	0.6	0	0
COD	3.963	0.062	300	12.5	0.775
TDS	3.196	0.05	0.6963	15.2	0.76
Ammonia/Nitrogen	3.25	0.051	0.38933945	5	0.255
Chloride	3.078	0.048	911091.099	5	0.24
Copper	3.17	0.05	0.07	6	0.3
Chromium	4.057	0.064	0	5	0.32
Lead	4.019	0.063	0	5	0.315
TKN	3.367	0.053	0.415965	5	0.265
Iron	2.83	0.045	0.8	5	0.225
Total	38.341	0.602	911401.2956	68.7	3.73
LPI = 7.59468					

Source: Author's Field Work, 2023

Appendix VI

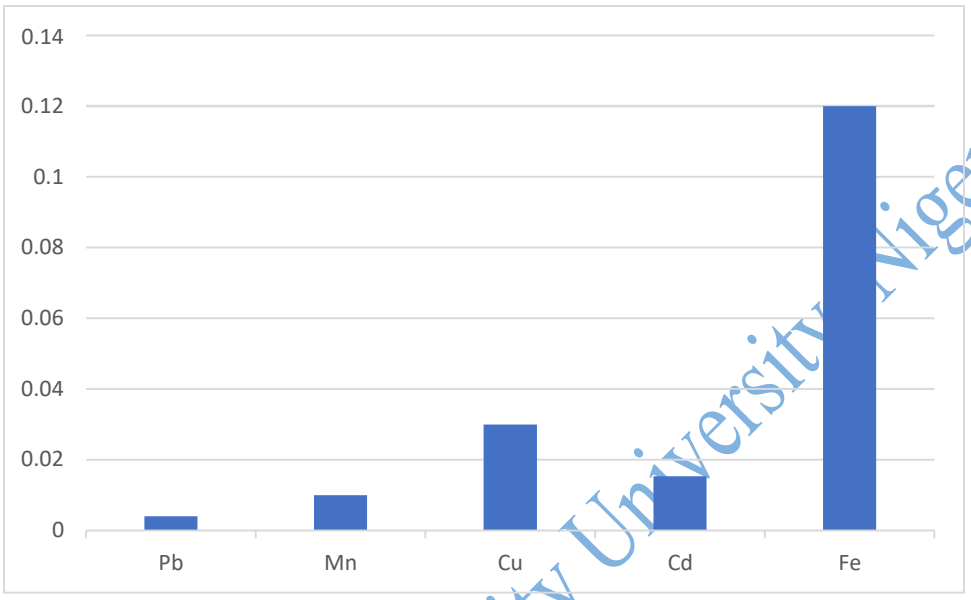
Concentration of Heavy Metal in Leachate Water Sample



Source: Author's Field Work, 2023

Appendix VII

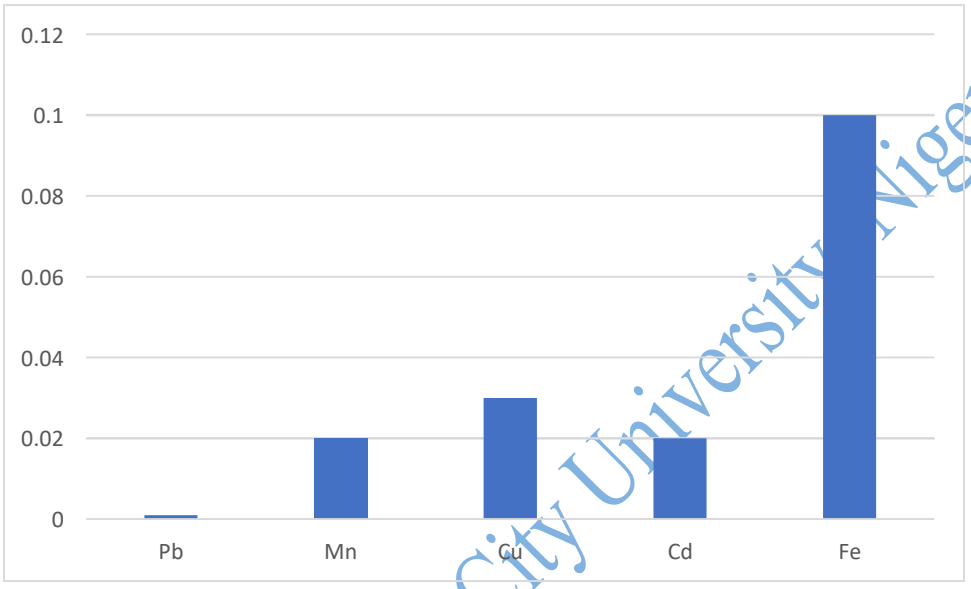
Concentration of Heavy Metal in 300meters Underground Water Sample



Source: Author's Field Work, 2023

Appendix VIII

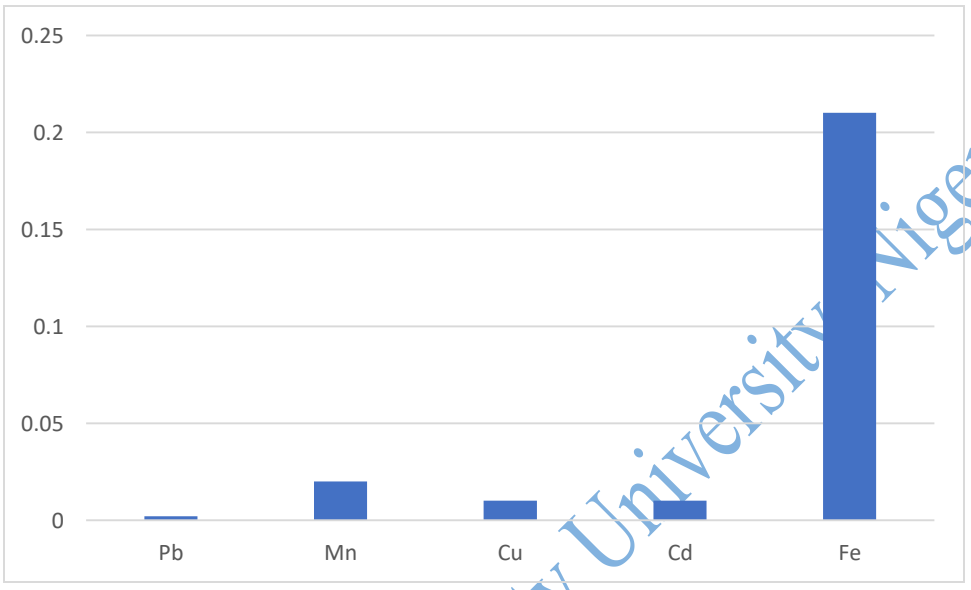
Concentration of Heavy Metal in 600meters Underground Water Sample



Source: Author's Field Work, 2023

Appendix IX

Concentration of Heavy Metal in the River Sample



Source: Author's Field Work, 2023

Appendix X

Entrance of Aba Eku Dumpsite

Source: Author's Field Work, 2023

Appendix XI

Leachate sampling

Source: Author's Field Work, 2023

Bio-data

A. Personal Data:

1.	**Full Name:**	Morolake Oluwatoyosi AFOLABI
		No. 5 Road G, Idowu Omojowolo Street, Alabede Junction Alakia Isebo, Iwo Road Ibadan.Oyo State.
		morolake3@gmail.com
		08135304644, 08039888733
2.	Date and Place of Birth:	15th October, 1977; Ibadan
3.	Nationality:	Nigerian
4.	State of Origin	Oyo State
5.	Name and Address of Next of Kin:	Mr Oluwatoyin Olakunle Afolabi
		No. 5 Road G, Idowu Omojowolo Street, Alabede Junction Alakia Isebo, Iwo Road Ibadan.Oyo State.

B. Educational Background:

Educational Institution Attended with Dates and Qualification:

School Attended	Dates	Qualifications
St. Patrick's Catholic Primary School, Abebi, Ibadan.	1983–1989	Pry Sch Leaving Cert.
Oba Akinbiyi High School I, Mokola Hill, Ibadan	1989–1995	WAEC Cert.
University of Ibadan, Ibadan	1996–2002	H.N.D. Sci Lab Tech)
Lead City University, Toll Gate Area, Ibadan Oyo state.	2017-2020	B.Sc.,Env. Mgt & Tox
Lead City University, Toll Gate Area, Ibadan Oyo State	2021 – till date	M.Sc. In View.

C. Working Experience with Date:

1. Laboratory Technologist, University of Ibadan	2012 – Till Date
2. Laboratory Technologist, Caleb University, Ikorodu Lagos	2010 - 2012
3. St. Whitefield Education Centre, Odo-Ona, Ibadan.	2002 - 2010

D. Award of Fellow

1. Fellow of the Nigeria Institute of Science Laboratory Technology

E Publication

- Sindiku O. & Afolabi M.O., *Assessment of Toxic Chemicals/Pollutants in Underground Water from Aba- Eku Municipal Solid Waste Dumpsite.* **FASCON International Conference**, 2022.

F. Professional Membership:

1. Institute of Public Analyst of Nigeria. P.E 1, 2012

2. Nigerian Institute of Science Laboratory Technology, 2006-till date,

(Associate Member)

G. Conferences attended:

FASCON International Conference**, 2022.**

H: Referees:

1. Mr. J. O. Ajayi Chief Technologist

Department of Chemistry,

University of Ibadan, Ibadan.

GSM: 08056357423

2. Professor J. A. Babalola

Vice-Chancellor,

Bowen University, Iwo, Osun State.

GSM: 08034540881

3. Mrs. O. A. Akinola

Department of Business Administration

The Polytechnic, Ibadan.

GSM: 08056164903.

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Signature **Date**

The University Compliance Certification

This is to certify that, this Thesis written by **Morolake Oluwatoyosi AFOLABI** with **Matric No. LCU/PG/002246** in the Department of Biological Science, Faculty of Natural and Applied Sciences, Lead City University, Ibadan is in full compliance with the approved University format and style.

Signature	**Date**