

Chapter one

Introduction

1.1 Background to the Study

Globally, the quantity of waste produced has increase significantly because of the accelerating rates of urbanization, industrialization and rise in population^{1,2}. Research indicate that unregulated practice, such as improper industrial waste disposal, fossil fuel combustion and gas flaring pose serious environment damage resulting in severe soil degradation, compromised water quality, and atmospheric pollution concerning aesthetic consideration^{3,4}. In Nigeria, a commitment to establish and implement a sustainable waste management policy based on public health principles, has resulted in numerous inadequate managed open dumpsites, where waste is incinerated openly, therefore releasing hazardous chemical pollution into the environmen^{5,6}. Poor waste dumpsite management endanger the groundwater supplies, as the intrusion of chemical leachates through aquifers and soil poses risk to human health and the environment^{7,8,9}.

A type of persistent organic pollutants known as polycyclic aromatic hydrocarbons (PAHs) are made up of two or more benzene rings, which include these uncharged compounds, which are made up of aromatic rings with carbon and hydrogen atoms, are one of the main environmental contaminants in the world. They are created when organic waste is not completely burned or when hydrocarbons undergo pyrolysis^{10,11}, planar, non-polar, and the majority are colorless, PAHs primarily posses high boiling and melting point, low solubility in water and low vapor pressures^{12,13}. There are different hundred of PAHs, that occur as

complex mixtures rather than single compounds. Various mixtures of PAHs are generated depending on the process involved. PAHs source could be natural or man-made (human practices) or industrial processes. Industrial waste, exhaust from automobile, and fume from burning wood, charcoal, and tobacco contain high levels of PAHs¹⁴.

PAHs are produced when organic materials are burned at low temperatures, like in cigarettes or wood fires. High-temperature chamber generate fewer PAHs. Fire smoke, such as smoke from wood tobacco, charcoal, nanoparticles contains PAHs and other chemicals¹⁵. Most PAHs are poorly soluble in water, instead, they tend to attach to sediment particles. These contaminated sediments can remain suspended in aquatic systems and be transported through water bodies. Improper disposal of PAH containing substances such as tar, creosote or ash in landfills can result in their leaching into the groundwater¹⁶.

PAHs originated from both anthropogenic sources, (vehicle emission and industrial activities) as well as natural processes like wildfires, volcanic eruptions and forest fire¹⁷.

PAHs are found in the air, water, soil, and food. They are often found in the environment as a gas or attached to small particles. More than 100 varieties of PAHs have been discovered and observed in nature, and 16 have been recognized as priority pollutants under control by EPA and the European^{18,19}.

As show in appendix 1, Among the 16 priority PAH, Benzo(a)Pyrene is carcinogenic but Indeno(1,2,3-cd)Pyrene, Benz(a)Anthracene, Naphthalene, Benzo(b)Fluoranthene, Chrysene, Benzo(k)Fluoranthene, Dibenz(ah)Anthracene, are possibly carcinogenic²⁰.

The presence of these chemical in different environmental media are prevalent in most

emerging countries dependent on natural resource exploitation²¹.

Soil SDGs 1, 2, 3, 14, 15, and 22 are supported by the United Nations Environment Programme global assessment. Base on UN study, soil that contributes approximately 95 % of pollution hinders the attainment of Sustainable Development Goals (SDGs), including the provision of human food, which is heavily impacted by human activity²². They will endanger human health in addition to harming the ecological environment. The accumulation of polycyclic aromatic hydrocarbons (PAHs) in soils and sediments is increased by their high hydrophobicity and low solubility in water, leading to strong adsorption onto soil particles. As a result, soils often act as a major reservoir or final sink for PAHs. This persistence in the soil environment has raised significant global environmental concerns. PAHs are widespread contaminants, occurring across terrestrial, aquatic, and atmospheric compartments. Soil contamination by PAHs is generally categorized into three levels, unpolluted $\Sigma\text{PAH} < 200 \text{ ng/g}$, moderately polluted $200\text{--}600 \text{ ng/g}$, and heavily polluted $>1,000 \text{ ng/g}$ ^{23,24,25,26}

1.2 Statement of the Problem

Polycyclic aromatic hydrocarbons (PAHs) are chemical molecule with numerous aromatic ring they are generated through the partial combustion of organic materials such as coal, oil, gas, wood, or waste. Dumpsites, especially those that involve the burning of waste or prolonged decomposition of organic materials, are significant sources of PAHs. These compounds can persist in the environment due to their chemical stability and hydrophobic nature, posing serious risks to human health and ecosystems.

1.3 Justification of the Study

- i. **Environmental Concern:** The Ajakanga waste dumpsite in Ibadan receives large volumes of mixed domestic, commercial, and industrial waste without proper management. Open burning and leachates formation release toxic compounds, including polycyclic aromatic hydrocarbons (PAHs), into the surrounding soil, air, and water.
- ii. **Persistence of Pollutants:** PAHs are persistent organic pollutants that are chemically stable, resist degradation, and tend to accumulate in soil and sediments. Their long-term presence increases the risk of contamination of nearby ecosystems and groundwater sources.
- iii. **Public Health Risk:** Continuous exposure to PAHs poses significant health hazards such as carcinogenicity, respiratory disorders, and genetic damage. Communities living around dumpsites are particularly vulnerable through inhalation, ingestion, and dermal contact.
- iv. **Data Gap:** Despite the environmental and health risks associated with dumpsites in Nigeria, limited scientific data exist on the levels, distribution, and sources of PAHs in Ibadan. This study fills this critical gap by providing baseline data on PAH contamination in Ajakanga dumpsite.
- v. **Policy and Management Relevance:** The results of this research will guide policymakers and environmental agencies in developing effective waste management regulations, monitoring programs, and remediation strategies to minimize exposure and protect public health.

- vi. Contribution to Knowledge: The findings strengthen the understanding of the environmental behavior of PAHs in tropical waste dumpsites and contribute to sustainable environmental management practices aligned with the United Nations Sustainable Development Goals (SDGs).

1.4 Sources of PAHs in Dumpsites

Dumpsites, especially open and poorly managed ones, serve as hot spots for PAH contamination. Key sources of PAHs in dumpsites include:

1.4.1 Burning of Waste

Open burning of municipal solid waste, such as garbage, coal coking, wood burning releases PAHs into the air, soil, and nearby water bodies.

1.4.2 Decomposition of Organic Waste

Organic components in waste such as plastics containing hydrocarbons, additive in plastics such as dyes or plasticized, rubber, food waste, textile waste, and organic chemical waste such as paint, solvent etc can generate PAHs during thermal or biochemical degradation.

1.4.3. Industrial Waste Dumpsites

PAH emissions in dumpsite can also come from partial combustion of industrial processes such waste incineration, the production of iron and steel, dye manufacturing, fungicides, refinery exhaust, and asphalt combustion of industrial activities such as waste incineration, iron and steel production, dye manufacturing, fungicide, exhaust from refineries and asphalt are also emission sources of PAH in dumpsite

1.5 Environmental Health Risks of PAHs

1.5.1 Carcinogenicity

Some PAHs, such as benzo(a)pyrene, have been grouped as carcinogenic by the International Agency for Research on Cancer (IARC). Chronic exposure to PAHs in dumpsites, through inhalation or dermal contact, increases the risk of lung, skin, and bladder cancers²⁷.

1.5.2 Respiratory Issues

Inhalation of PAHs from smoke generated by burning waste can cause a respiratory ailments such as asthma, chronic bronchitis, and reduced lung function²⁸.

1.5.3 Soil and Water Contamination

PAHs can leach into the soil and groundwater, contaminating these resources and creating long-term exposure risks for nearby populations. Contaminated water may lead to gastrointestinal issues and other chronic health conditions²⁹.

1.5.4 Bioaccumulation and Toxicity

PAHs are hydrophobic and bioaccumulate within living thing. These substances have the potential to cause toxicity when they get into food chain³⁰.

1.5.5 Genotoxic Effects

PAHs can cause DNA damage through the formation of reactive oxygen species (ROS) and PAH-DNA adducts. This Genotoxicity can lead to mutations and an increased risk of cancer³¹.

1.6 Impact on Vulnerable Populations

Communities living near dumpsites are particularly vulnerable to PAH exposure. Children and pregnant women are at greater risk due to their developing immune systems and higher susceptibility to toxic compounds.

1.7 Mitigation Strategies

To reduce the environmental health risks associated with PAHs in dumpsites, the following measures are recommended

1.7.1 Waste Management Improvements

Proper waste segregation, recycling, and disposal techniques can prevent the formation of PAHs. Alternatives to open burning, such as incineration in controlled environments, should be adopted.

1.7.2 Site Remediation

Contaminated dumpsites should undergo remediation techniques such as Bioremediation, soil washing, or thermal desorption to reduce PAH levels.

1.7.3 Regulation and Monitoring

Governments should enforce strict regulations to prevent illegal dumping and burning of hazardous waste. Regular monitoring of air, soil, and water quality around dumpsites is necessary.

1.7.4 Public Awareness

Educating communities about the dangers of dumpsite pollution and encouraging proper waste disposal practices can reduce exposure risks. Dumpsites are a significant source of PAHs, posing severe risks to human health and the environment. Long-term exposure to

PAHs can lead to cancer, respiratory issues, and other chronic health conditions. Addressing these risks requires a combination of improved waste management practices, remediation of contaminated sites, and public awareness. By reducing PAH emissions and exposure, it is possible to safeguard both environmental and public health.

In underdeveloped nations, the management of solid waste is exacerbated by unsustainable practices that enhance environmental pollution and the spread of diseases. In Nigeria, Ibadan south west Nigeria in particular, the major cause of concerns is the uncontrolled and unregulated disposal of waste at dumpsite, open burning of waste fractions and the mismanagement of the leachates produced in final disposal sites³². The situation deteriorates in slum location, that has higher human density, air, traffic, and water contamination. Uncontrolled disposal of waste in open spaces close to water bodies are normal issues in Ibadan, posing public health concerns³³.

1.8 Aim and Objectives of the Study

The aim of this study is to investigate the presence, distribution and risk of PAHs in Ajakanga waste dumpsite in Oluyole local Government, Ibadan.

The objectives are:

- To quantify the level of PAHs in Ajakanga waste dumpsite soil
- To identify the sources of PAHs in Ajakanga waste dumpsite soil
- Assess the potential health and ecological risk associated with PAHs contamination in Ajakanga waste dumpsite
- Evaluate the effectiveness of existing waste management practice in controlling PAHs in Oyo State

1.9 Research Questions

1. What are the levels of PAHS in dumpsite
2. What are the sources and dominant PAH compounds
3. To what extent do PAHs pose a risk to human health and environment

1.10 Significance of the Study

Understanding polycyclic aromatic hydrocarbons (PAHs) in dumpsites is crucial for several reasons related to environmental protection, policy making, and public health. PAHs are a group of organic chemical that are primarily generated from partial combustion of organic materials, including fossil fuels and waste. Their persistence in the environment and potential health risks make them a significant concern.

1.11 Environmental Protection

1.11.1 Persistence and Bioaccumulation

PAHs are known for their stability and resistance to degradation, this lead to their persistent in the environment for extended periods. They can accumulate in soil and sediments, leading to long-term contamination of ecosystems³⁴ Understanding their behavior in dumpsites helps in assessing the extent of environmental damage and the necessary remediation strategies.

1.11.2 Ecosystem Impact

PAHs can adversely affect soil and aquatic ecosystems. They are toxic to various organisms, including plants, fish, and microorganisms, disrupting ecological balance and food webs³⁴. Monitoring PAH levels in dumpsites is essential for protecting biodiversity and maintaining ecosystem health.

1.12 Policy making

1.12.1 Regulatory Framework

Knowledge of PAH contamination in dumpsites informs policymakers about the need for stricter regulations on waste management and industrial emissions. The U.S. Environmental Protection Agency (EPA) has classified certain PAHs as priority pollutants due to their toxicity and prevalence in hazardous waste sites^{35,36}. This classification aids in developing targeted policies for pollution control.

1.12.2 Risk Assessment and Management

Understanding the sources and concentrations of PAHs allows for better risk assessments related to waste disposal practices. Policymakers can implement more effective waste management strategies and remediation efforts based on scientific data regarding PAH toxicity and exposure pathways³⁷.

1.13 Public Health

1.13.1 Health Risks

PAHs are associated with several health difficulties, like respiratory issue, cancer, and developmental disorders. Exposure can occur through inhalation, ingestion, or dermal contact, particularly in communities near dumpsites^{35,36,37}. Understanding the health implications of PAH exposure is vital for public health initiatives aimed at reducing risks.

1.13.2 Community Awareness and Engagement

Educating communities about the dangers of PAHs and their sources can empower residents to advocate for cleaner environments and better waste management practices.

Community engagement in monitoring and remediation efforts can also enhance public

health outcomes³⁷.

1.13.3 Vulnerable Populations

Certain populations, such as children and those living in low-income areas, may be more susceptible to the harmful effects of PAHs. Understanding these dynamics can help tailor public health interventions and ensure that vulnerable groups receive adequate protection³⁷.

In summary, comprehending the implications of PAHs in dumpsites is essential for safeguarding the environment, informing effective policy making, and protecting public health. This understanding facilitates the development of strategies to mitigate contamination, regulate emissions, and educate communities about health risks.

1.14 Scope of the Study

The project site is AJAKANGA waste dumpsite, located in Oluyole local Government, Ibadan, Oyo State. Ibadan is located in southwestern Nigeria and serves as the capital city of Oyo State. Geographically, it is situated on the coordinates:

Latitude: 7.3775° N

Longitude: 3.9470° E

Oluyole Local Government Area (LGA) is located in the southwestern part of Oyo State, Nigeria, and is part of the Ibadan metropolitan area. It has its headquarters in Idi-Ayunre, which lies along the Ibadan-Ijebu Ode Road.

Geographical Coordinates:

Latitude: 7.2500° N

Longitude: 3.8500° E

Boundaries and Location:

Oluyole LGA is strategically positioned, sharing boundaries with several other LGAs and states

To the North: It shares a boundary with Ibadan South-West and Ibadan North LGAs.

To the South: It borders Ogun State.

To the East: It is bordered by Ona Ara Local Government Area.

To the West: It shares boundaries with Ido Local Government Area.

The Ajakanga waste dumpsite in Ibadan, Nigeria is located between the following coordinates

Latitude: 7°18.70'N to 7°18.90'N

Longitude: 3°50'E to 3°51'E

The Ajakanga dumpsite is in the Oluyole local government area of Ibadan, in the southwestern part of Nigeria. It is close to River Ona, separated only by Odo Ona Elewe Road.

The Ajakanga dumpsite is one of four dumpsites in Ibadan, along with Aba-Eku, Awotan, and Lapite. The Oyo State Waste Management Authority (OYWMA) manages all four dumpsites. The Ajakanga dumpsite is a forested area that opened in 1996 and is still in use today. It receives waste from a variety of sources, including commercial, hospital, electronic, household, and industrial^{38,39,40,41}.

Due to Rapid urbanization, the dumpsite is gradually being surrounded by built up areas.

It is approximately 128km northeast of Lagos And generates about 1,618,293 kg of solid wastes daily.

An overview and map of the dumpsite is Shown in appendix 2 and 3

1.15 Sample Size

18 samples will be analyse, 3 samples each at five different locations including control site and a triplicate sample for priority PAHs

PAHs Compound of Studied are the 16 priority PAHs identify by USAEPA which are list below

Benzo[ghi]perylene, Phenanthrene, Acenaphthene, Naphthalene, Indeno(1,2,3-cd)pyrene, Acenaphthylene, Benzo(a)anthracene, Anthracene, Benzo(b)fluoranthene, Benzo(k)fluoranthene, Chrysene, Dibenz(a,h)anthracene, Fluoranthene, Fluorene, Pyrene, Benzo(a)pyrene

End notes

1. C. C. Aralu, P. A. Okoye, V. C. Eze, H. O. Abugu, S. I. Abba, & J. C. Egbueri, . *Seasonality of Environmental Health Risks and Soil Pollution from an Unsanitary Landfill in Nigeria, Implications for Water Security, Agriculture, and Climate Adaptation*, **Journal of Hazardous Materials Advances**, 17, 2025, 100597.
2. Budi, H. S, Catalan Oplencia, M. J, Afra, A, Basseterre, W. K., Abdullaev, D, Majdi, A & Mohammadi, M. J. *Source, Toxicity and Carcinogenic Health Risk Assessment of Heavy metals*, **Reviews on Environmental Health**, 39(1), 2024, 77-90.
3. N. A. Althobaiti, *Heavy Metals Exposure and Alzheimer's Disease: Underlying Mechanisms and Advancing Therapeutic Approaches*, **Behavioural brain research**, 476, 2025, 115212.
4. J. O. Alao, *Impacts of Open Dumpsite Leachates on Soil and Groundwater Quality, Groundwater for Sustainable Development*, 20, 2023, 100877.
5. A. G. Khorram, N. Fallah, B. Nasernejad, N. Afsham, M. Esmaelzadeh, & V. Vatanpour, . *Electrochemical-Based Processes for Produced Water and Oily Wastewater Treatment, A Review*, **Chemosphere**, 338, 2023,139565.
- 6 D. A. Ayejoto, & J. C. Egbueri, *Human Health Risk Assessment of Nitrate and Heavy Metals in Urban Groundwater in Southeast Nigeria*, **Ecological Frontiers**, 44(1), 2024, 60-72.
7. V. K. Akinpelumi, K. G. Kumi, A. P. Onyena, K. Sam, A. N. Ezejiofor, C. Frazzoli, & O. E. Orisakwe, *A Comparative Study of The Impacts of Polycyclic Aromatic Hydrocarbons in Water and Soils in Nigeria and Ghana, Towards a Framework for Public Health Protection*, **Journal of Hazardous Materials Advances**, 11, 2023, 100336.
8. V. N. Okafor, D. O. Omokpariola, O. F. Obumsele, & C. G. Eze, *Exposure Risk to Heavy Metals Through Surface and Groundwater Used for Drinking and Household Activities in Ifite Ogwari, Southeastern Nigeria*, **Applied Water Science**, 13(4), 2023, 105.
9. Y. Guo, P. Li, X. He, & L. Wang, *Groundwater Quality in and Around a Landfill in Northwest China, Characteristic Pollutant Identification, Health Risk Assessment, and Controlling Factor Analysis*, **Exposure and Health**, 14(4), 2022, 885-901.
10. R. Tang, & C. Pfrang, *Indoor Particulate Matter (PM) from Cooking in UK Students' Studio Flats and Associated Intervention Strategies, Evaluation of Cooking Methods, PM Concentrations and Personal Exposures Using Low-Cost Sensors*, **Environmental**

Science, Atmospheres, 3(3), 2023, 537-551.

11. Y. Wang, H. Zhang, X. Zhang, P. Bai, A. Neroda, V. F. Mishukov, & N. Tang, *PM-Bound Polycyclic Aromatic Hydrocarbons and Nitro-Polycyclic Aromatic Hydrocarbons in the Ambient Air of Vladivostok, Seasonal Variation, Sources, Health Risk Assessment and Long-Term Variability*, **International Journal of Environmental Research and Public Health**, 19(5), 2022, 2878.

12. R. Tang, & C. Pfrang, *Indoor Particulate Matter (PM) from Cooking in UK Students' Studio Flats and Associated Intervention Strategies: Evaluation of Cooking Methods, PM Concentrations and Personal Exposures using Low-Cost Sensors*, **Environmental Science Atmospheres**, 3(3), 2023, 537-551.

13. S. Caumo, A. B. Yera, A. Vicente, C. Alves, D. A. Roubicek, & de Castro P. Vasconcellos, *Particulate Matter–Bound Organic Compounds, Levels, Mutagenicity, and Health Risks*, **Environmental Science and Pollution Research**, 29(21), 2022, 31293-31310.

14. A. Rezagholizade-Shirvan, M. Mohammadi, Y. Mazaheri, S. Fallahizadeh, H. Ghorbani, S. Shokri, & E. Shamloo, *Employing a magnetic chitosan/molybdenum disulfide nanocomposite for efficiently removing polycyclic aromatic hydrocarbons from milk samples*. **Scientific Reports**, 14(1), 2024, 15054.

15. A. Rezagholizade-Shirvan, M. Mohammadi, Y. Mazaheri, S. Fallahizadeh, H. Ghorbani, S. Shokri, & E. Shamloo, *Employing a Magnetic Chitosan/molybdenum Disulfide Nanocomposite for Efficiently Removing Polycyclic Aromatic Hydrocarbons from Milk Samples*, **Scientific Reports**, 14(1), 2024, 15054.

16. B. Ambade, A. Kumar, A. Kumar, & L. K. Sahu, *Temporal Variability of Atmospheric Particulate-Bound Polycyclic Aromatic Hydrocarbons (PAHs) over Central East India: Sources and Carcinogenic Risk Assessment, Air Quality*, **Atmosphere & Health**, 15(1), 2022, 115-130.

17. M. A. Mallah, L. Changxing, M. A. Mallah, S. Noreen, Y. Liu, M. Saeed, & Q. Zhang, *Polycyclic Aromatic Hydrocarbon and its Effects on Human health, An Overview*, **Chemosphere**, 296, 2022, 133948.

18. S. Caumo, A. B. Yera, A. Vicente, C. Alves, D. A. Roubicek, & de Castro P. Vasconcellos, *Particulate Matter–Bound Organic Compounds, Levels, Mutagenicity, and Health Risks*. **Environmental Science and Pollution Research**, 29(21), 2022, 31293-31310.

19 International Agency for Research on Cancer (IARC) IARC Monographs on the Identification of Carcinogenic Hazards to Humans, Accessed on April 19, 2022, <http://www.monographsiarcfr/ENG/Classification/index.php>.

20. EPA, U, *Toxic and Priority Pollutants Under the Clean Water Act*. US EPA available online: <https://www.epa.gov/eg/toxic-and-priority-pollutants-under-clean-water-act>, 2021, Accessed, 24.

21. S. Banerjee, N. Gupta, K. Pramanik, M. Gope, R. GhoshThakur, A. Karmakar, & S. Balachandran, *Microbes and Microbial Strategies in Carcinogenic Polycyclic Aromatic Hydrocarbons Remediation, A Systematic Review*, **Environmental Science and Pollution Research**, 31(2), 2024, 1811-1840.

22 K. Sam, A. P. Onyena, N. Zabbey, C. K. Odoh, G. N. Nwipie, D. K. Nkeeh, L .C. Osuji, D. I. Little, *Prospects of Emerging PAH Sources and Remediation Technologies, Insights from Africa*, **Environ. Sci. Pollut. Res. Int**, 2023, 1-23.

23. FAO and UNEP Global Assessment of Soil Pollution, *Summary for Policy Makers Rome*, **FAO** , 10, 2021, 4060.

24. S. Zhou, X. Wang, Y. Yang, R. Wang, J. Liao, P. Zhang, & Y. Deng, *Distribution and Source Identification of Polycyclic Aromatic Hydrocarbons (PAHs) with PCA-MLR and PMF Methods in the Topsoil of Chengdu at SW, China*, **Science of the Total Environment**, 908, 2024, 168263.

25. B. Ambade, S. S. Sethi, B. Giri, J. K. Biswas, & K. Bauddh, *Characterization, Behavior, and Risk Assessment of Polycyclic Aromatic Hydrocarbons (PAHs) in the Estuary Sediments*, **Bulletin of environmental Contamination and Toxicology**, 108(2), 2022, 243-252.

26. W. A. Wan Mahari, Y. F. Tsang, C. J. Hsu, H. Fazhan, Y. Wang, K. Tan, & S. S. Lam, *Protecting Mud Crabs from Pollution by Microplastics, Per-and Polyfluoroalkyl Substances, Polycyclic Aromatic Hydrocarbons, pesticides, and heavy metals in mangroves*, **Environmental Chemistry Letters**, 23(2), 2025, 677-706.

27. D. R. Middleton, R. Wedekind, A. L. Hall, E. Suonio, N. DeBono, R. Vermeulen, & M. K. Schubauer-Berigan, *Critical Reviews of Exposure Assessment in Carcinogenic Hazard Identification, the IARC Monographs Experience*, **Occupational and environmental medicine**, 81(7), 2024, 366-372.

28. B. Bukowska, K. Mokra, & J. Michałowicz, *Benzo [a] pyrene Environmental Occurrence, Human Exposure, and Mechanisms of Toxicity*, **International journal of molecular sciences**, 23(11), 2022, 6348.

29. O. I. Areguamen, N. N. Calvin, C. E. Gimba, O. J. Okunola, A. T. Abdulkadir, & A.

Elebo, *Assessment of Seasonal Variation in Distribution, Source Identification, and Risk of Polycyclic Aromatic Hydrocarbon (PAH)–Contaminated Sediment of Ikpoba River, South-South, Nigeria*, **Environmental Monitoring and Assessment**, 195(2), 2023, 302.

30. F. Barbosa Jr, B. A. Rocha, M. C. Souza, M. Z. Bocato, L. F. Azevedo, J. A. Adeyemi, & A. D. Campiglia, *Polycyclic Aromatic Hydrocarbons (PAHs): Updated Aspects of their Determination, Kinetics in the Human Body, and Toxicity*, **Journal of Toxicology and Environmental Health**, Part B, 26(1), 2023, 28-65.

31. T. F. Edigbonya, O. C. Oyinklusi, E. G. Okungbowa, & J. I. Uche, *Environmental and Human Health Risk Assessments of Polycyclic Aromatic Hydrocarbons in Particulate Matter in Nigeria*, **Environmental Monitoring and Assessment**, 194(8), 2022, 569.

32. M. Alhawamdeh, J. A. Ferriz-Papi, & A. Lee, *Examining the Drivers to Support Improved Construction and Demolition Waste Management for a Circular Economy, A Comprehensive Review using a Systematic Approach*, **Sustainability**, 16(14), 2024, 6014.

33. J. K. Ooi, K. S. Woon, & H. Hashim, *A Multi-Objective Model to Optimize Country-Scale Municipal Solid Waste Management with Economic and Environmental Objectives, A Case Study in Malaysia*, **Journal of Cleaner Production**, 316, 2021, 128366.

34. 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, 562813.

35. Q. Meng, S. Mitra, L. Del Rosario, M. Jerrett, C. Janzen, S. U. Devaskar, & B. Ritz, *Urinary Polycyclic Aromatic Hydrocarbon Metabolites and their Association with Oxidative Stress Among Pregnant Women in Los Angeles*, **Environmental Health**, 23(1), 2024, 68.

36. H. Indresand, & I. T. Kero. *Polycyclic Aromatic Hydrocarbons (PAH) in Industrial Emissions Challenges and Strategies to Measure, Monitor, Control and Reduce PAH Emissions*, 2022.

37. T. M. Florencia, T. B. Iván, & C. H. Alejandra, *Health Risk Assessment of Exposure to Polycyclic Aromatic Hydrocarbons in Household Indoor Environments*, **Environmental Advances**, 7, 2022, 39.

38. B. Barnabas, M. Bavorova, M. Y. Madaki, & H. Kächele, *Food safety knowledge, attitudes, and practices of food vendors participating in Nigeria's school feeding program*, **Journal of Consumer Protection and Food Safety**, 19(2), 2024, 199-212.

39. E. D. Ossai, *Gender-Responsive Education in Emergency in Nigeria, Safeguarding*

Girls' Presents and Futures, Echidna Global Scholars Program. Policy Brief, Center for Universal Education at The Brookings Institution, 2021.

40. D. H. Locke, A. Ossola, J. P. Schmit, & J. M. Grove, *Sub-Parcel Scale Analysis is needed to Capture Socially-Driven Canopy Cover Change in Baltimore, MD. Landscape and Urban Planning*, 253, 2025, 105187.

41. M. O. Lasisi, F. F. Akinola, & B. S. Awe, *Application of Geographic Information System and Remote Sensing in the Development of Drainage Pattern of Oluyole Local Government Area, Nigeria*, 2022.

Lead City University Ibadan DO NOT COPY

Chapter Two

Literature Review

2.1 Polycyclic Aromatic Hydrocarbons (PAHs)

Polycyclic aromatic hydrocarbons (PAHs) are organic molecules composed of aromatic rings, containing hydrogen and carbon atoms, they are classified as organic persistent pollutant compounds, that contain multiple benzene rings, and are hydrophobic in nature, partially soluble in water and high octanol-water partition coefficient, they are produced by partial combustion of organic matter or pyrolysis of hydrocarbon^{1,2}. Soil pollution has become a major environmental concern globally, because their sources of contamination are due to natural and anthropogenic activity. PAHs are resistant to chemical and biological degradation because they adsorb securely to organic matter in soil^{2,3,4}.

PAHs are highly mobile and ubiquitous chemical, that are by-products of many chemical reactions, which has potential environmental threat^{5,6,7,8,9}.

Anthropogenic sources are the major sources of PAHs in human environment while natural sources PAHs are referred to as background PAHs. Anthropogenic source PAHs has more aromatic rings than naturally synthesized PAHs. Higher concentrations of PAHs in soils are often linked to nearby pollution sources. These compounds are distributed across all parts of the environment, including air, water, and soil. PAHs formed through natural processes generally contain fewer aromatic rings compared to those produced by human activities. Extensive research has highlighted their widespread occurrence in various environmental compartments and identify soil as main exposure source of PAHs because

89.9 % of these pollutants are accumulated in the soil environment. PAHs are transferred to food chain as a result of PAHs present in soil contaminate crops and vegetables^{10,11,12,13,14,15,16}.

Industries play a vital role in driving national economic development. However, it is widely recognized that industrial zones tend to exhibit higher levels of environmental contamination compared to urban settings. This is primarily due to inadequate waste disposal practices, inefficient emission control technologies, and outdated process systems. Although advancements such as recycling initiatives and resource recovery methods have improved the sustainability of industrial operations, significant challenges remain. Persistent organic pollutants (POPs), including polycyclic aromatic hydrocarbons (PAHs), are of particular concern due to their carcinogenic and mutagenic potential, attributed to their fused aromatic ring structures. PAHs exhibit strong hydrophobicity and chemical stability, leading to their accumulation in soils. These soil-bound PAHs can enter the human body through both direct and indirect exposure pathways. Key contributors to PAH contamination include vehicular emissions, the burning of fossil fuels, the use of synthetic fertilizers in agriculture, and industrial activities such as pyrolysis^{17,18,19,20,21,22,23,24,25,26}.

Long-term exposure to PAHs can cause cancerous tumors in human organs. Exposure calculations use randomly selected parameter values from distributions²⁷. Monte Carlo simulations, which assess probabilistic uncertainty, can be used to determine the impact of these parameters on overall health risk using probability density functions for each input parameters^{28,29, 30}. Exposure through ingestion, inhalation, and dermal absorption are

the three routes by which PAHs in the soil enter the human body. Deposition of soil-bound PAHs in food, and soil particles erosion from the earth surface and absorption of PAHs carrying particles on open surfaces of human skin, bio-accumulation in soil, specific risk assessment parameters such as body weight (BW), exposure sensitivity analysis. Globally, Monte Carlo probabilistic approaches with sensitivity inhalation are the common ways of human exposures. Apart from the PAHs levels, the most important factors for the risk value^{31,32,33,34} are exposure duration (ED), exposure frequency (EF), skin surface area (SA), and inhalation rate.

The role of these parameters in the total health risk levels can be determined through analysis, they are common practice to estimate the human health risk levels.³⁵

2.2 Characteristics, Chemical Structure and Classification PAH

Polycyclic aromatic hydrocarbons (PAHs) are a class of organic compounds known for their characteristic structural composition of multiple fused aromatic rings. These compounds generally exist in solid form at ambient conditions due to their relatively high melting and boiling points. They also exhibit low volatility and extremely poor solubility in water, properties that become even more pronounced with an increase in molecular size and the number of aromatic rings. Conversely, PAHs display strong solubility in non-polar organic solvents, which is attributed to their hydrophobic and lipophilic nature.

One of the most distinctive analytical features of PAHs is their ultraviolet (UV) absorbance behavior. Each PAH molecule has a specific UV absorption profile, allowing for the differentiation and identification of individual isomers based on their unique spectral characteristics. Moreover, many PAHs exhibit fluorescence and are capable of

emitting light at characteristic wavelengths when excited, making them useful in spectroscopic detection methods. As the molecular complexity of PAHs increases, they tend to show greater resistance to oxidative and reductive reactions. In addition to these physicochemical properties, PAHs also possess several functional characteristics, such as thermal stability, sensitivity to light, electrical conductivity, and resistance to corrosion. These attributes, combined with their biological interactions, underscore the relevance of PAHs in both environmental and industrial contexts^{36,37}. PAHs are hydrophobic and do not easily dissolve in water or volatilize into the atmosphere, except for naphthalene, which was formerly used in moth balls, PAHs are chemical stable, has low water solubility, and high sorption capacity which contribute to their long term persistence in the environment^{38,39}.

2.3 Chemical Structure and Classification

Polycyclic aromatic hydrocarbons (PAHs) are a type of chemical compounds consisting parent structure with six aromatic rings that can be recognized by contemporary analytical of two or more fused aromatic rings, Naphthalene ($C_{10}H_8$) forms the tiny parent PAH ring structure with two aromatic rings, while coronene ($C_{24}H_{12}$) crate the largest parent composition with six aromatic rings that can be detected by modern analytical techniques. The classification of PAHs can be done based on various criteria, including their structural features, molecular size, origin, and functional groups^{40a}

2.3.1 Classification of PAH Based on their Aromatic Rings

Polycyclic aromatic hydrocarbons (PAHs) are commonly classified based on the number of fused aromatic rings within their molecular structure. PAHs containing two to three rings are typically referred to as low molecular weight (LMW) PAHs, whereas those composed of four to six rings fall under the category of high molecular weight (HMW) PAHs^{40b}. This classification is not only indicative of molecular size but also strongly correlates with the physicochemical properties and environmental behavior of the compounds.

LMW PAHs are generally more volatile, more water-soluble, and less lipophilic compared to their HMW counterparts. These properties influence their environmental mobility and biological availability. In contrast, HMW PAHs exhibit lower solubility in water, reduced volatility, and greater persistence

2.3.2 Classification Based on Molecular Structure

PAHs can be categorized based on the arrangement and number of their aromatic rings:

a. Linear PAHs

In linear PAHs, the aromatic rings are arranged in a straight line.

Examples Anthracene (C₁₄H₁₀) A three-ring linear PAH where the rings are fused in a straight sequence.

Tetracene (C₁₈H₁₂) A four-ring linear PAH.

b. Angular PAHs

Angular PAHs have rings fused in a non-linear, angular fashion.

Examples; Phenanthrene (C₁₄H₁₀): A three-ring PAH with an angular arrangement.

Chrysene (C₁₈H₁₂): A four-ring angular PAH.

c. Clustered or Pericondensed PAHs

These PAHs have more complex, compact arrangements where rings share more than one carbon atom.

Examples: Pyrene (C₁₆H₁₀): A four-ring clustered PAH.

Coronene (C₂₄H₁₂): A six-ring PAH arranged in a circular pattern.

d. Alternant and Non-Alternant PAHs

Alternant PAHs: These are PAHs where the π -electrons are distributed alternately over the structure. Example: Benzo[a]pyrene.

Non-Alternant PAHs: These are PAHs with structural features that disrupt alternating patterns of π -electrons (e.g., rings containing five or seven members). Example: Fluorene (a three-ring PAH with a five-member central ring).

2.3.3 Classification Based on Molecular Size

PAHs are often classified by the number of fused aromatic rings in their structure:

a. Low Molecular Weight

Low Molecular Weight (LMW) PAHs composed of 2–3 aromatic rings. Generally less toxic and more volatile than larger PAHs.

Examples: Naphthalene (C₁₀H₈): A two-ring PAH. Anthracene (C₁₄H₁₀): A three-ring PAH.

b. Medium Molecular Weight

Medium Molecular Weight (MMW) PAHs composed of 4–5 aromatic rings. Examples:

Fluoranthene (C₁₆H₁₀): A four-ring PAH Benzo[a]pyrene (C₂₀H₁₂): A five-ring PAH.

c. High Molecular Weight

High Molecular Weight (HMW) PAHs composed of six or more aromatic rings. These

PAHs are usually less volatile but more toxic and carcinogenic. Examples: Coronene

(C₂₄H₁₂): A six-ring PAH.

Ovalene (C₃₂H₁₄): A ten-ring PAH.

2.3.4 Classification Based on Origin

PAHs can also be classified based on their source or mode of formation

● Pyrogenic PAHs

They are formed by the incomplete combustion of organic matter (e.g., fossil fuels, wood, or biomass). Typically higher molecular weight PAHs. Examples: Benzo[a]pyrene, Indeno[1,2,3-cd]pyrene.

● Petrogenic PAHs

They are derived from unburned fossil fuels such as crude oil, coal, and petroleum products. Typically lower molecular weight PAHs. Examples: Naphthalene, Phenanthrene.

● Biogenic PAHs

They are Produced by biological processes in plants, fungi, and microorganisms. These PAHs are often precursors for more complex PAHs in the environment. Examples: Retene

(a PAH derived from plant resins).

- **Anthropogenic PAHs**

They are result from human activity, including industrial processes, vehicle emissions, and waste incineration.

Examples: Fluoranthene, Chrysene,

- **Natural PAHs**

PAHs formed through natural processes such as volcanic eruptions, forest fires, and diagenesis of organic matter in sediments.

2.3.5 Classification Based on Functional Groups

While most PAHs are purely hydrocarbons, some may contain functional groups that modify their chemical and physical properties. Based on this, PAHs can be classified as:

- **Parent (Unsubstituted) PAHs**

Contain only carbon and hydrogen atoms, with no functional groups. Examples: Benz[a]anthracene, Pyrene.

- **Contain Alkyl Groups**

Attached to the aromatic rings, (methyl, ethyl, etc.)

Examples: Methyl phenanthrene, Dimethyl naphthalene

- **Oxygenated PAHs (Oxy-PAHs)**

Contain oxygen-containing functional groups such as carbonyl (C=O) or hydroxyl (-OH).

These often form as degradation products of PAHs. Examples: 9,10-Anthraquinone
1-Hydroxyphenanthrene.

- **Nitrogen-Containing PAHs (N-PAHs)**

Contain nitrogen atoms in the aromatic ring system or as substituent. They formed during combustion processes or as environmental degradation products. Examples: Carbazole, Acridine

- **Sulfur-Containing PAHs (S-PAHs)**

Contain sulfur atoms in the aromatic ring system or as substituent. Examples: Dibenzothiophene

2.3.6 Classification Based on Toxicity and Environmental Impact

PAHs can also be grouped based on their toxicity, persistence, and bio-accumulation potential:

- **Priority Pollutant PAHs**

The U.S. Environmental Protection Agency (EPA) has identified 16 PAHs as priority pollutants due to their carcinogenicity and environmental persistence:

Benzo[ghi]perylene, Phenanthrene, Acenaphthene, Naphthalene, Indeno(1,2,3-cd)pyrene
Acenaphthylene, Benzo(a)anthracene, Anthracene, Benzo(b)fluoranthene,
Benzo(k)fluoranthene, Chrysene, Dibenzo(a,h)anthracene, Fluoranthene, Fluorene, Pyrene,
Benzo(a)pyrene

- **Carcinogenic PAHs**

Some PAHs are known carcinogens and pose significant health risks. Examples:

Benzo[a]pyrene, Dibenzo[a,h]anthracene

- **Non-Carcinogenic PAHs**

PAHs with lower toxicity or carcinogenic potential. Examples: Fluorene, Anthracene.

2.4 Environmental Persistence and Bioaccumulation

Polycyclic aromatic hydrocarbons (PAHs) are persistent organic pollutants that pose significant environmental and health risks due to their bio accumulation and limited degradability⁴⁰. These compounds are lipophilic, allowing them to accumulate in fatty tissues, as evidenced by higher concentrations found in human adipose tissue compared to other biological samples⁴¹. Their persistence in the environment is attributed to their resistance to bio-degradation, with many heterocyclic PAHs showing limited biodegradability even after microbial adaptation⁴². Furthermore, PAHs are prevalent in aquatic ecosystems, where they accumulate in sediments and biota, leading to potential bio-magnification in food webs⁴³.

2.4.1 Environmental Persistence

PAHs exhibit low degradability, allowing them to persist in various environmental matrices.

Studies indicate that many heterocyclic PAHs are non-readily biodegradable, complicating remediation efforts⁴²,

Their mobility in the environment leads to widespread contamination, affecting both terrestrial and aquatic ecosystems⁴³.

2.4.2 Bioaccumulation

PAHs accumulate in fatty tissues, with significant concentrations found in human adipose tissue, indicating a direct link to human health risks⁴⁰.

Aquatic organisms, such as fish, also show high levels of PAH accumulation, raising concerns about food safety and ecosystem health⁴².

While the persistence and bio-accumulation of PAHs are well-documented, some studies suggest that bio-remediation techniques using adapted microbial communities may offer potential solutions for mitigating their environmental impact⁴⁴. However, the effectiveness of these methods remains variable and requires further investigation.

2.5 General Sources of PAHs

Polycyclic aromatic hydrocarbons (PAHs) originate from two primary source categories: natural and anthropogenic emissions. Natural sources include phenomena such as volcanic activity, wildfires, and lightning-induced peat-land fires, though their contribution is relatively minor compared to human activities⁴⁵. PAHs are generated through the incomplete combustion of organic material and can enter the environment via both natural and synthetic pathways. In the general population, dietary intake is the principal exposure route, with tobacco smoke being the primary contributor among smokers³⁸.

Anthropogenic sources, which represent the dominant cause of PAH pollution, are typically classified into four major groups: industrial, mobile, domestic, and agricultural emissions⁴⁶. Industrial emissions arise mainly from incomplete combustion in activities such as waste incineration, metallurgical processes (e.g., steel and aluminum production), cement and coal-tar pitch manufacturing, chemical production, refinery operations, and energy generation⁴⁷. Additional industrial contributors include coal gasification, electric arc and oxygen furnaces, and combustion engines used in heavy equipment⁴⁸.

Mobile sources of PAHs encompass emissions from aircraft, ships, trains, and both on-road and off-road vehicles⁴⁹. Domestic contributions involve everyday household practices like burning solid fuels, cooking on gas/oil stoves, and using wood or kerosene for heating⁵⁰. Agricultural emissions are often linked to open burning of biomass and agricultural waste, especially under sub-optimal combustion conditions⁵¹.

In rural settings, PAH contamination is largely attributed to domestic and agricultural practices, whereas urban areas face greater contributions from industrial, mobile, and domestic activities. Seasonal variations also influence PAH concentrations, with the highest levels observed in winter, followed by spring, autumn, and summer. The elevated winter and spring levels are associated with increased fossil fuel use, intensive residential heating, limited photodegradation, and restricted atmospheric dispersion due to low temperatures and calm air conditions⁵².

PAHs can further be categorized based on their origin of formation into three main types: pyrogenic, petrogenic, and biogenic⁵³. Pyrogenic PAHs are produced during the incomplete combustion of organic matter at high temperatures (350–1,200°C) under low oxygen conditions⁵⁴. They are also formed during processes like coal carbonization and thermal cracking of petroleum, and are more prevalent in urban environments⁵⁵. In contrast, petrogenic PAHs are associated with petroleum and its derivatives, which are dispersed into the environment through leaks, spills, storage, and transportation⁵⁶. Typically, pyrogenic sources are dominated by high molecular weight (HMW) PAHs, whereas petrogenic sources contain mostly low molecular weight (LMW) PAHs⁵⁷.

Biogenic PAHs are naturally synthesized by microorganisms, algae, phytoplankton, and

plants, often as a result of the slow biological transformation of organic substances⁵⁸.

Once released into the atmosphere, PAHs exist either as gases or attached to particles, and are deposited onto soil, water bodies, and vegetation through wet and dry deposition processes. Due to their low vapor pressure and high hydrophobicity, PAHs with three or more rings tend to strongly adhere to soil particles⁵⁹. The persistence of PAHs in soil or sediments may lead to their secondary migration into groundwater, plants, and food chains. For instance, plant roots may absorb PAHs from contaminated soils and transport them to edible parts. Currently, complete avoidance of PAH exposure is unrealistic, as it can occur through inhalation, ingestion, and dermal absorption⁶⁰. Often, multiple exposure routes may act simultaneously, such as skin contact and inhalation from polluted soils⁶¹.

Occupational settings pose a significant risk, particularly for workers in coke production, food processing industries, and traffic management, where inhalation of PAH-laden air and dust is a concern⁶². However, non-occupational exposures are also prevalent through contaminated food, drinking water, and smoking⁶³. For instance, a single cigarette can deliver 20–40 nanograms of benzo(a)pyrene, a potent PAH, while dietary intake accounts for up to 70 % of exposure in non-smokers⁶⁴.

In drinking water, PAH concentrations typically range between 1 ng/L and 11 ng/L, with the World Health Organization (WHO) setting a maximum acceptable limit of 0.7 µg/L for benzo(a)pyrene⁶⁵. Domestic and industrial cooking methods, including grilling, roasting, frying, barbecuing, and drying, can also lead to PAH formation⁶⁶. Additionally, fruits and vegetables grown in contaminated soils or exposed to atmospheric PAHs may

also serve as significant sources of dietary intake⁶⁷

2.5.1 Sources of PAH in Waste Dumpsite

Mechanisms of PAHs formation in waste dumpsite

2.5.1.1 Burning of Waste

Open burning of waste materials, such as plastics, wood, and rubber, is a major source of PAHs in dumpsites. Combustion processes release PAHs into the air, soil, and surrounding environment.

2.5.1.2 Leachates Formation

As waste decomposes, leachates (a liquid that drains from waste) can transport PAHs into the soil and groundwater.

2.5.1.3 Industrial and Urban Waste

Industrial waste, such as petroleum products, tar, asphalt, and chemical residues, often contains PAHs. Improper disposal of urban waste contributes to PAH contamination.

2.5.1.4 Petroleum-Derived Products

Spilled or improperly disposed motor oil, lubricants, and fuels in dumpsites can be a source of PAHs.

2.5.1.5 Natural Sources

Anthropogenic activities are the primary sources, natural processes such as wildfires or natural organic material degradation can also contribute to PAH levels in waste dumpsites.

2.6 Analytical Techniques for PAH Detection

2.6.1 Sampling Techniques

Sampling techniques for polycyclic aromatic hydrocarbons (PAHs) in soil, water, and leachates are crucial for accurate analysis and assessment of contamination.

2.6.2 Soil Sampling

Random Sampling: Select random locations within the study area to obtain a representative sample.

Systematic Sampling: Establish a grid and collect samples at regular intervals to ensure area coverage.

Composite Sampling: Combine multiple sub-samples from the same location to reduce variability.

2.6.3 Grab Sampling

Collect a single sample from a specific location at a specific time. This is useful for detecting peak concentrations.

Composite Sampling: Combine samples taken at different times or locations to obtain an average concentration.

2.6.4 Depth-Integrated Sampling

For lake or river sampling, collect water from different depths to account for stratification.

2.7 Leachates Sampling

Direct Collection: Collect leachates directly from collection wells or pipes.

Pumping: Use a pump to extract leachates, ensuring minimal exposure to air to avoid

volatilization of PAHs.

Grab Sampling: Similar to water sampling; obtain samples during specific time intervals to capture variations.

These sampling techniques help ensure that the data collected accurately reflect the presence and concentration of PAHs in the environment.

2.8 Extractions Method

Polycyclic aromatic hydrocarbons (PAHs) are composed of fused aromatic (benzene) rings and exhibit hydrophobic characteristics, which result in their low solubility in water and high affinity for organic matter in soil. This strong adsorption to soil organic components reduces their availability for microbial or chemical breakdown. Over extended periods, PAHs become increasingly embedded within soil micropores, further enhancing their resistance to degradation⁶⁸. Their high octanol-water partition coefficient (K_{ow}) also contributes to their persistence in the environment. These physicochemical properties complicate the extraction and analysis of PAHs from contaminated soils, necessitating the use of advanced and varied analytical extraction techniques. such as sonication, accelerated solvent extraction, mechanical agitation and Soxhlet extraction but are not limited to this only

2.9 Analytical Methods for PAHs

Polycyclic aromatic hydrocarbons (PAHs), along with their distinct coefficients, are typically quantified globally after extraction from environmental, biological, or industrial samples using standardized analytical protocols. These procedures are recognized and endorsed by regulatory bodies such as the United States Environmental Protection

Agency (USEPA), the International Organization for Standardization (ISO), and the National Institute for Occupational Safety and Health (NIOSH). These analytical methods generally fall into three major categories: immunoassays, spectrometric techniques, and chromatographic approaches^{69,70}.

Immunoassay-based techniques (e.g., EPA 4030 and 4035, Update III), which are predominantly commercially available in kit form, are less commonly used due to their tendency to yield biased results. Their lower sensitivity, specificity, and accuracy especially in detecting a wide range of aromatic compounds limit their application primarily to preliminary field screening for soil and water analysis^{70,71}. Within the realm of spectrometry, ultraviolet (UV) and infrared (IR) methods are commonly employed. UV-based techniques (both absorption and fluorescence) demonstrate good selectivity and sensitivity toward PAHs but are prone to interference from matrix components such as lipids. Similarly, although IR spectrometry is cost-effective and rapid, it necessitates an essential post-extraction cleanup due to its poor selectivity⁶⁹.

Chromatographic techniques, particularly gas chromatography (GC) and liquid chromatography (LC), are more widely adopted for PAH determination despite their relatively high cost and extended processing time^{72,73,74}. High-performance liquid chromatography (HPLC), one of the primary LC techniques, employs detectors such as UV, fluorescence (FL), mass spectrometers, photo-diode array (PDA), or a combination of PDA and FL (EPA 550, 610, 8310; NIOSH 5506, 5800; ISO 17993)^{75,76,77,78,79,80}. GC-based methods often follow EPA-approved organic extraction procedures and utilize

detectors like flame ionization (EPA 610, 8100; NIOSH 5515), Fourier transform-infrared (EPA 8410), and mass spectrometers (EPA 525, 625, 8270; ISO 18287, DTS 28581, FDIS 28540, EN 15527), including thermal extraction configurations (EPA 8275)^{75,80,81}.

HPLC is generally favored for analyzing thermally unstable, semi-volatile, or non-volatile compounds. EPA methods 550, 610, and 8310 require aqueous samples to undergo pre-treatment via liquid-liquid extraction (LLE) or solid-phase extraction (SPE) before instrument analysis. Solid matrices are typically extracted with solvents using Soxhlet or ultrasonic devices^{82,83,84}. Extracts must then be re-dissolved in a solvent compatible with the initial extraction for proper injection⁷⁰. However, NIOSH 5506 is limited to acetonitrile-extracted samples and exhibits reduced performance when high concentrations of particulates such as fly ash or diesel soot are present. Nonetheless, the method is sensitive enough to detect PAHs in mixtures of aliphatic compounds even at trace levels. NIOSH 5800 differs by utilizing a flow-injection setup with dual-wavelength fluorescence detection for quantifying total PAHs⁸⁵.

The combination of UV and fluorescence detectors in HPLC methods (e.g., EPA 550, 610, 8310; NIOSH 5506) enhances the detection range for various PAHs. Less fluorescent compounds like naphthalene and fluorene are typically analyzed with UV detectors, while more fluorescent compounds are better detected using FL detectors⁶⁹. EPA 8310 is particularly suitable for detecting PAHs in water samples at parts-per-billion levels and is also effective for effluent analysis⁷⁰. While UV/Vis detectors can detect most PAHs within the 190–360 nm range, fluorescence detectors offer higher selectivity and

sensitivity, especially when optimal excitation/emission wavelengths are applied^{77,78,86,87}.

PDA detectors are more sensitive than standard UV/V types, and are occasionally used either alone^{72,78,87} or in combination with FL^{79,88}. Despite these options, fluorescence detection remains the most sensitive and is preferred for trace-level PAH determination⁸⁹.

Mass spectrometry (MS) is another significant LC detector, providing precise identification and quantification of trace polar organic compounds, particularly when multiple analytes are involved^{90,91}. Comprehensive LC/MS approaches employ complex interfaces (e.g., thermospray, electrospray, moving belt, particle beam) to transfer separated compounds from the chromatography stage into the mass spectrometer for detailed characterization^{90,92}. However, no universal interface exists that is effective for all PAHs⁷⁷.

Gas chromatography (GC) is best suited for separating volatile, thermally stable, non-polar organic substances, including certain semi-volatile PAHs^{90,91}. Detectors used in GC for PAH analysis include PID, FID, FT-IR, and MS^{70,93,94,95}. The technique excels in resolution, particularly with capillary columns. However, PAHs with molecular weights above 300 amu are often problematic due to low volatility and potential decomposition under high temperatures⁷⁷.

EPA 8021B, a GC/PID method, is commonly applied to measure BTEX compounds, oxygenates, and other volatile organics in various samples including groundwater, sludge, and soils. Despite its selectivity and sensitivity, the method is prone to contamination from high molecular weight substances^{70,96}. EPA 610 allows PAH detection in wastewater

via LLE using methylene chloride, applicable to both LC (with UV/FL detection) and GC (with packed or capillary columns and FID)^{77,82}. EPA 8100, a packed-column GC/FID method, accommodates both aqueous and solid samples, though it struggles to resolve specific PAH isomer pairs unless capillary columns or silica gel cleanup are employed^{77,81}. NIOSH 5515, another GC/FID method, targets airborne PAHs after sample filtration, though it requires careful cleanup due to FID's sensitivity to background interferences^{76,93,97}.

GC/MS methods like EPA 525, 625, and 8270 are widely utilized for quantifying PAHs across water, soil, and air media^{77,98}. EPA 525 targets semi-volatiles in drinking water following pH adjustment and SPE^{99,100}. EPA 625 is designed for wastewater, employing dual pH LLE followed by GC/MS, with its updated version allowing SPE as an alternative¹⁰¹. EPA 8270 covers a wide range of organic pollutants including PAHs, with extraction protocols tailored to the matrix type LLE for liquids and Soxhlet or solvent extraction for solids. It also permits TCLP leachates extraction via SPE and extends to compounds such as pesticides, nitrosamines, phenols, and ethers¹⁰².

EPA 8272 focuses on ten parent PAHs and two alkylated derivatives in water and sediment pore water, utilizing flocculation and SPME followed by SIM-mode GC/MS^{103,104,105}.

GC/MS is particularly advantageous for its dual function of retention-time and spectral identification, offering high sensitivity in SIM mode^{72,106}. While more costly than GC/FID or PID, GC/MS enables accurate quantification of volatile and semi-volatile petroleum

constituents. Nevertheless, unknown compound identification remains challenging with electron ionization; chemical ionization or high-resolution MS can provide supplementary structural data^{69,70,91}.

EPA 8410 and 8275 are GC-based techniques for PAHs. EPA 8410 employs FTIR detection and complements EPA 8270 by helping differentiate PAH isomers that are difficult to distinguish via MS alone. The method mandates extract cleanup prior to injection and is applicable to wastewater, soils, and solid wastes¹⁰⁷. EPA 8275, a capillary GC/MS method with thermal extraction, quantifies PCBs and EPA priority PAHs in solid matrices. Samples are thermally extracted at 340°C and injected into the GC, followed by separation and MS detection^{77,108}.

2.10 Environmental and Health Impacts of PAHs

Polycyclic Aromatic Hydrocarbons (PAHs) are a group of organic chemicals made up of several interconnected aromatic rings. They are mainly produced during the incomplete burning of organic substances such as fossil fuels, wood, and tobacco. PAHs are commonly found in the environment and are a major concern because they persist for long periods, can accumulate in living organisms, and pose serious health risks^{109,110}.

2.10.1 Environmental Impacts of PAHs

2.10.1.1 Persistence in the Environment

PAHs are highly stable and resistant to degradation, allowing them to persist in soil, water, and sediments for long periods¹¹¹. They can be transported over long distances through atmospheric deposition and water systems.

2.10.1.2 Soil and Sediment Contamination

PAHs accumulate in soils and sediments, particularly in industrial and urban areas. These contaminated sites may act as reservoirs, leading to prolonged release into the environment^{112,113}. Contaminated sediments can harm benthic organisms (bottom-dwelling species), disrupting aquatic ecosystems¹¹⁴.

2.10.1.3 Bioaccumulation

PAHs can bioaccumulate in aquatic species, leading to toxic effects on fish and other organisms in the food chain. They may biomagnify through the food web, affecting predators and eventually humans¹¹⁵.

2.10.1.4 Toxicity to Aquatic Life

PAHs are notable toxicant to aquatic organisms, causing developmental, reproductive, and immunological effects^{116,117}. For instance, fish exposed to PAHs may exhibit deformities, reduced growth, and lower survival rates^{118,119}.

2.10.1.5 Air Pollution:

PAHs are a significant component of particulate matter (PM), especially in urban and industrial regions. They contribute to smog formation and impact air quality.

2.10.2 Health Impacts of PAHs

PAHs are dangerous to human health because of their teratogenic, carcinogenic, and mutagenic properties. Routes of exposure include inhalation, ingestion, and dermal contact.

2.10.2.1. Carcinogenicity:

Many PAHs are identified as carcinogens by the International Agency for Research on Cancer (IARC). For example, Benzo(a)pyrene (BaP) is a well-known carcinogen linked to lung, skin, and bladder cancers. Long-term exposure, especially by breathing in of polluted air or consumption of contaminated food with PAH increases cancer risk^{120,121,122}

2.10.2.2 Respiratory Effects:

Inhalation of PAHs (e.g., from vehicle emissions, industrial processes, or tobacco smoke) can cause respiratory irritation, asthma, and chronic bronchitis^{123,124}. Long-term exposure to PAHs in particulate matter contributes to reduced lung function and pulmonary diseases.

2.10.2.3 Reproductive and Developmental Toxicity

PAHs can interfere with reproductive systems, leading to reduced fertility and developmental delays in offspring^{125,126}.

antenatal exposure to PAHs has been linked to lower birth weight and impaired psychological feature development in children^{127,128}.

2.10.2.4 Genotoxicity

PAHs can form DNA adducts (binding to DNA), leading to mutations and genetic damage¹²⁹. This genotoxic potential underpins their carcinogenic and mutagenic effects.

2.10.2.5 Dermal Toxicity

Skin exposure to PAHs, especially in occupational settings, can cause irritation, rashes, and even skin cancer with prolonged contact¹³⁰.

2.10.2.6 Immune System Effects

PAHs may suppress immune responses, making individuals more susceptible to infections and diseases^{131,132,133,134,135,136,137}.

2.11 Regulatory Standards for PAH

Regulatory standards for polycyclic aromatic hydrocarbons (PAHs) in water, soil, and sediment are established by various organizations, including the World Health Organization (WHO) and the European Union (EU) Environmental Protection Agency (EPA). Here's an overview of the relevant standards and guidelines.

2.11.1 WHO Guidelines

The WHO has not established specific numerical guidelines for PAHs in water, soil, or sediment. However, it emphasizes the importance of monitoring PAHs due to their potential health risks, particularly their carcinogenic properties. The WHO often relies on assessments from other organizations, such as the International Agency for Research on Cancer (IARC), which classifies certain PAHs as carcinogenic to humans^{138,139,140,141}.

2.11.2 EU Standards

The EU has developed several regulatory frameworks concerning PAHs, particularly in food and environmental media^{142,143,144,145,146}.

2.11.2.1 Water Quality Standards

The EU Water Framework Directive 2000/60/EC includes PAHs in its list of priority substances. Specific limits for PAHs in water bodies are set to protect aquatic life and human health. The EU has established Environmental Quality Standards (EQS) for certain PAHs, such as benzo[a]pyrene, which is often used as a marker for the presence of

other carcinogenic PAHs¹⁴⁷.

2.11.2.2 Soil and Sediment Quality Guidelines

The EU has guidelines for the assessment of contaminated sites, which include PAHs. The European Commission has recommended monitoring specific PAHs in soil and sediments, particularly in areas affected by industrial activities. The guidelines suggest using a combination of empirical and mechanistic approaches to derive sediment quality guidelines (SQGs) that protect benthic organisms from adverse effects

2.11.2.3. Food Safety Regulations

The European Food Safety Authority (EFSA) has assessed the risks associated with PAHs in food. The SCF (Scientific Committee on Food) recommended monitoring 15 PAHs in food products, highlighting their carcinogenic potential. The EU has set maximum levels for certain PAHs in foodstuffs, particularly those that are known to be carcinogenic.

2.12 Key PAHs Monitored

The following PAHs are commonly monitored due to their toxicity and prevalence in environmental samples

Benzo[a]pyrene

Benz[a]anthracene

Chrysene

Fluoranthene

Pyrene

These compounds are often included in regulatory assessments and monitoring programs due to their significant health risks

While WHO does not provide specific numerical standards for PAHs, it recognizes their health risks. The EU has established comprehensive guidelines for monitoring PAHs in water, soil, sediment, and food, focusing on protecting human health and the environment.

2.13 Regulation of PAHs in Nigeria

In Nigeria, the regulation of polycyclic aromatic hydrocarbons (PAHs) is primarily the responsibility of the Federal Ministry of Environment and the National Environmental Standards and Regulations Enforcement Agency (NESREA). The Nigerian government has established laws and regulations to control the release of PAHs into the environment.

The Environmental Guidelines and Standards for Industrial Processes (EGSIP) is a set of regulations that outline the acceptable levels of PAHs in various industrial processes and emissions. The guidelines specify the maximum allowable concentrations of PAHs in air, water, and soil.

The Nigerian government has also established the National Environmental Policy (NEP) which aims to protect the environment and ensure sustainable development. The NEP sets out policies and guidelines for the management of PAHs and other hazardous substances.

In terms of specific regulations, the Nigerian government has established the following standards and guidelines for PAHs

1. The National Environmental Standard and Regulations Enforcement Agency (NESREA) has set a standard for the maximum allowable concentration of PAHs in industrial effluent of 0.1 mg/L.

2. The Nigerian Oil and Gas Industry Content Development Act (NOGICD Act) requires

oil and gas companies to implement measures to prevent the release of PAHs and other pollutants into the environment.

3. The Nigerian National Petroleum Corporation (NNPC) has established guidelines for the management of PAHs in the petroleum industry, including the use of best available technology to minimize emissions.

It's worth noting that while these regulations and guidelines are in place, enforcement and monitoring are often challenging due to limited resources and capacity^{148,149,150,151,152,153}.

In Oyo State, Nigeria, the regulation of polycyclic aromatic hydrocarbons (PAHs) is primarily the responsibility of the Oyo State Ministry of Environment and Natural Resources. And their sole responsible is enforcing environmental laws and regulations in the state, including those related to PAHs.

The Oyo State Environmental Policy outlines the state's commitment to protecting the environment and promoting sustainable development. The policy sets out principles and guidelines for the management of PAHs and other hazardous substances.

The Oyo State Environmental Management and Protection Law provides the legal framework for the regulation of environmental activities in the state, including the control of PAHs. The law requires all industries and individuals to obtain permits and comply with environmental standards and regulations.

In terms of specific regulations, the Oyo State Government has established the following standards and guidelines for PAHs

The Oyo State Environmental Protection Agency (OySEPA) has set a standard for the maximum allowable concentration of PAHs in industrial effluent of 0.1 mg/L¹⁵⁴.

* The Oyo State Environmental Guidelines and Standards for Industrial Processes outline the acceptable levels of PAHs in various industrial processes and emissions¹⁵⁴.

* The Oyo State Ministry of Environment and Natural Resources has established guidelines for the management of PAHs in the agricultural sector, including the use of best agricultural practices to minimize PAHs in soil and water¹⁵⁵. It's worth noting that while these regulations and guidelines are in place, enforcement and monitoring are often challenging due to limited resources and capacity.

Lead City University Ibadan DO NOT COPY

End notes

1. D. Wu, L. Chen, Z. Ma, D. Zhou, L. Fu, M. Liu, & Q. Zhen, *Source Analysis and Health Risk Assessment of Polycyclic Aromatic Hydrocarbon (PAHs) in Total Suspended Particulate Matter (TSP) from Bengbu, China*, **Scientific reports**, 14(1), 2024, 5080.
2. M. Matei, R. Zaharia, S. I. Petrescu, C. G. Radu-Rusu, D. Simeanu, D. Mierliță, & I. M. Pop, *Persistent Organic Pollutants (POPs): A Review Focused on Occurrence and Incidence in Animal Feed and Cow Milk*, **Agriculture**, 13(4), 2023, 873.
3. E. Nizio, K. Czwartkowski, & G. Niedbała, *Impact of Smoking Technology on the Quality of Food Products: Absorption of Polycyclic Aromatic Hydrocarbons (PAHs) by Food Products During Smoking*, **Sustainability**, 15(24), 2023, 16890.
4. M. Honda, K. Hayakawa, L. Zhang, N. Tang, & H. Nakamura, *Seasonal Variability and Risk Assessment of Atmospheric Polycyclic Aromatic Hydrocarbons and Hydroxylated Polycyclic Aromatic Hydrocarbons in Kanazawa, Japan*, **Applied Sciences**, 12(19), 2022, 9469.
5. T. Seko, K. Ishihara, T. Suzuki, S. Takagi, K. Taga, Y. Iida, & Y. Yamashita, *Effects of Moisture Content of Firewood Used in the Manufacture of Japanese Traditional Smoked-Dried Bonito, Katsuobushi, on Polycyclic Aromatic Hydrocarbon (PAH) Generation*, **Journal of Food Composition and Analysis**, 111, 2022, 104630.
6. M. M. Uddin, & F. Xu, *Sources, Occurrences, and Risks of Polycyclic Aromatic Hydrocarbons (PAHs) in Bangladesh, A Review of Current Status*, **Atmosphere**, 15(2), 2024, 233.
7. Y. Cai, Z. Wang, L. Cui, J. Wang, X. Zuo, Y. Lei, & W. Li, *Distribution, Source Diagnostics, and Factors Influencing Polycyclic Aromatic Hydrocarbons in the Yellow River Delta Wetland*, **Regional Studies in Marine Science**, 67, 2023, 103181.
8. M. Vijayanand, A. Ramakrishnan, R. Subramanian, P. K. Issac, M. Nasr, K. S. Khoo, & B. Ravindran, *Polyaromatic Hydrocarbons (PAHs) in the Water Environment, A Review on Toxicity, Microbial Biodegradation, Systematic Biological Advancements, and Environmental Fate*, **Environmental Research**, 227, 2023, 115716.
9. K. Hayakawa, P. Kim-Oanh, A. Takami, H. Odajima, E. G. Nagato, A. Hara, & H. Nakamura, *Contributions of Long-Range Transport from the Asian Continent and Local Emissions on Atmospheric, PM_{2.5}, Polycyclic Aromatic Hydrocarbons, and their Nitro-Derivatives in Kanazawa and Noto Peninsula, Japan*, **Heliyon**, 10(5), 2024.
10. K. Lin, R. Wang, L. Tan, S. Jiang, H. Xu, Y. Cao, & J. Wang, *Assessing the Potential Risks, Sources and the Relationship Between the Dissolved and Particulate Polycyclic Aromatic Hydrocarbons (PAHs) in the Typical Semi-Enclosed Bay, Bohai Bay of China*,

11. Y. M. Lee, K. M. Choi, S. H. Mun, J. W. Yoo, & J. H. Jung, *Gut Microbiota Composition of the Isopod Ligia in South Korea Exposed to Expanded Polystyrene Pollution*, **Plos One**, 19(8), 2024 ,e0308246.
12. D. Bănăduc, A. Curtean-Bănăduc, S. Barinova, V. L. Lozano, S. Afanasyev, T. Leite, & K. Cianfrangione, *Multi-Interacting Natural and Anthropogenic Stressors on Freshwater Ecosystems, Their Current Status and Future Prospects for 21st Century*, **Water**, 16(11), 2024, 1483.
13. M. Arienzo, M. Toscanesi, M. Esposito, D. Iaccarino, F. Di Nocera, S. Canzanella, & M. Trifuoggi, *Comparative Study of Polycyclic Aromatic Hydrocarbons (PAHs) in Salt Gland and Liver of Loggerhead Turtle Caretta Caretta (Linnaeus, Cheloniidae) Stranded Along the Mediterranean Coast, Southern Italy*, **Ecotoxicology and Environmental Safety**, 263, 2023, 115355.
14. A. Wnorowski, D. Harnish, Y. Jiang, V. Celo, E. Dabek-Zlotorzynska, & J. P. Charland, *Assessment and Characterization of Alkylated PAHs in Selected Sites Across Canada*, **Atmosphere**, 13(8), 2022, 1320.
15. D. Chung, J. H. Lee, S. Y. Lee, Y. S. Oh, & H. S. Shin, *Quantitative Analysis and Contamination Profiles of PCBs, OCPs, and PAHs in Black-Tailed Gull Eggs in the Republic of Korea*, **Environmental Monitoring and Assessment**, 194(4), 2022, 268.
16. S. Barathi, J. Gitanjali, G. Rathinasamy, N. Sabapathi, K. N. Aruljothi, J. Lee, & S. Kandasamy, *Recent Trends in Polycyclic Aromatic Hydrocarbons Pollution Distribution and Counteracting Bio-Remediation Strategies*, **Chemosphere**, 337, 2023, 139396.
17. V. Valskys, H. R. Hassan, S. Wołkiewicz, J. Satkūnas, G. Kibirkštis, & G. Ignatavičius, *A Review on Detection Techniques, Health Hazards and Human Health Risk Assessment of Arsenic Pollution in Soil and Groundwater*, **Minerals**, 12(10), 2022, 1326.
18. A. Mallah, L. Changxing, M. A. Mallah, S. Noreen, Y. Liu, M. Saeed, & Q. Zhang, *Polycyclic Aromatic Hydrocarbon and its Effects on Human Health, An Overview*, **Chemosphere**, 296, 2022, 133948.
19. B. Marmett, R. B. Carvalho, A. L. Muccillo-Baisch, P. R. M. Baisch, M. Dos Santos, E. M. Garcia, & F. M. R. Da Silva Júnior, *Emissions Monitoring and Carcinogenic Risk Assessment of PM 10-Bounded PAHs in the Air from Candiota's Coal Activity Area, Brazil*, **Environmental Geochemistry and Health**, 45(3), 2023, 899-911.
20. D. Armada, M. Llompart, M. Celeiro, P. Garcia-Castro, N. Ratola, T. Dagnac, & J. de Boer, *Global Evaluation of the Chemical Hazard of Recycled Tire Crumb Rubber*

Employed on Worldwide Synthetic Turf Football Pitches, **Science of The Total Environment**, 812, 2022, 152542.

21. M. Ravanbakhsh, H. Yousefi, E. Lak, M. J. Ansari, W. Suksatan, Q. A. Qasim, & M. J. Mohammadi, *Effect of Polycyclic Aromatic Hydrocarbons (PAHs) on Respiratory Diseases and the Risk Factors Related to Cancer*, **Polycyclic Aromatic Compounds**, 43(9), 2023, 8371-8387.
22. R. A. Grmasha, M. H. Abdulameer, C. Stenger-Kovács, O. J. Al-Sareji, Z. Al-Gazali, R. A. Al-Juboori, & K. S. Hashim, *Polycyclic Aromatic Hydrocarbons in the Surface Water and Sediment Along Euphrates River System, Occurrence, Sources, Ecological and Health Risk Assessment*, **Marine Pollution Bulletin**, 187, 2023, 114568.
23. Y. Yang, Q. Zhu, X. Peng, J. Sun, C. Li, X. Zhang, & Y. Zhang, *Hydrogels for the Removal of the Methylene Blue Dye from Wastewater, A Review*, **Environmental Chemistry Letters**, 20(4), 2022, 2665-2685.
24. B. Ambade, A. Kumar, A. Kumar, & L. K. Sahu, *Temporal Variability of Atmospheric Particulate-Bound Polycyclic Aromatic Hydrocarbons (PAHs) Over Central East India, Sources and Carcinogenic Risk Assessment*, *Air Quality*, **Atmosphere & Health**, 15(1), 2022, 115-130
25. T. K. Sankar, A. Kumar, D. K. Mahto, K. C. Das, P. Narayan, M. Fukate, & B. Ambade, *The Health Risk and Source Assessment of Polycyclic Aromatic Hydrocarbons (PAHs) in the Soil of Industrial Cities in India*, **Toxics**, 11(6), 2023, 515.
26. K. Isinkaralar, O. Isinkaralar, & E. P. Bayraktar, *Ecological and Health Risk Assessment in Road Dust Samples from Various Land Use of Düzce City Center, Towards The Sustainable Urban Development*, **Water, Air, & Soil Pollution**, 235(1), 2024, 84.
27. G. Venkatraman, N. Giribabu, P. S. Mohan, B. Muttiah, V. K. Govindarajan, M. Alagiri, & S. A. Karsani, *Environmental Impact and Human Health Effects of Polycyclic Aromatic Hydrocarbons and Remedial Strategies, A Detailed Review*, **Chemosphere**, 351, 2024, 141227.
28. L. C. Honscha, F. O. Reis, P. Aikawa, M. V. Coronas, A. L. Muccillo-Baisch, P. R. M. Baisch, & F. M. R. Da Silva Júnior, *Human Health Risk Assessment of Air Pollutants in the Largest Coal Mining Area in Brazil*, **Environmental Science and Pollution Research**, 30(21), 2023, 59499-59509.
29. S. Li, X. Yan, M. Zhang, Q. Sun, & X. Zhu, *Microbial Remediation Technology for Heavy Metal Contamination of Mine Soil*, **Chemoecology**, 34(2), 2024, 47-59.
30. S. Wang, T. Qin, R. Tu, T. Li, G. I. Chen, D. C. Green, & Q. Fu, *Indoor Air Quality in Subway Microenvironments, Pollutant Characteristics, Adverse Health*

Impacts, and Population Inequity, **Environment International**, 190, 2024, 108873.

31. H. A. Arregocés, G. J. Bonivento, L. A. Ladino, E. Beristain-Montiel, G. Restrepo, J. Miranda, & R. Rojano, *Human Health Risk Assessment of PM10-Bound Heavy Metals and PAHs Around the Latin America's Largest Opencast Coal Mine*, **Environmental Science and Pollution Research**, 30(60), 2023, 125915-125930.

32. I. Jakovljević, I. Smoljo, Z. Sever Štrukil, & G. Pehnek, *Carcinogenic Activity and Risk Assessment of PAHs in Ambient Air, PM10 particle fraction and bulk deposition*, **Toxics**, 11(3), 2023, 228.

33. J. N. Rao, & T. Parsai, *Pollution and Toxicity of Heavy Metals in Wildfires-Affected Soil and Surface Water; A Review and Meta-Analysis*, **Environmental Pollution**, 2025,125845.

34. D. Roy, J. Kim, M. Lee, S. Kim, & J. Park, *PM10-Bound Microplastics and Trace Metals, A Public Health Insight from the Korean Subway and Indoor Environments*, **Journal of Hazardous Materials**, 477, 2024, 135156.

35. S. Su, S. Li, Y. Ding, P. Mao, & D. Chong, *Health Damage Assessment of Commuters and Staff in the Metro System Based on Field Monitoring, A Case Study of Nanjing*, **Frontiers in Public Health**, 11, 2024, 1305829.

36. Miller, Plant, and Ash Pond, *Annual Groundwater Monitoring and Corrective Action Report*, 2024.

37. K. Sam, A. P. Onyena, N. Zabbey, C. K. Odoh, G. N. Nwipie, D. K. Nkeeh, & D. I. Little, . *Prospects of Emerging PAH Sources and Remediation Technologies, Insights from Africa*, **Environmental Science and Pollution Research**, 30(14), 2023, 39451-39473.

38. S. Kumari, & S. Das, *Bacterial Enzymatic Degradation of Recalcitrant Organic Pollutants, Catabolic Pathways and Genetic Regulations*, **Environmental Science and Pollution Research**, 30(33), 2023, 79676-79705.

39. Z. Zhou, C. J. Zhang, P. F. Liu, L. Fu, R. Laso-Pérez, L. Yang, & L. Cheng, *Non-Syntrophic Methanogenic Hydrocarbon Degradation by an Archaeal Species*, **Nature**, 601(7892), 2022, 257-262

40^a. G. Venkatraman, N. Giribabu, P. S. Mohan, B. Muttiah, V. K. Govindarajan, M. Alagiri, & S. A. Karsani, *Environmental Impact and Human Health Effects of Polycyclic Aromatic Hydrocarbons and Remedial Strategies, A Detailed Review*, **Chemosphere**, 351, 2024, 141227.

40. M. A. Mallah, L. Changxing, M. A. Mallah, S. Noreen, Y. Liu, M. Saeed, & Q.

Zhang, *Polycyclic Aromatic Hydrocarbon and its Effects on Human Health, An Overview*, **Chemosphere**, 296, 2022, 133948.

41. S. Sousa, M. L. Maia, C. Delerue-Matos, C. Calhau, & V. F. Domingues, *The Role of Adipose Tissue Analysis on Environmental Pollutants Biomonitoring in Women, The European Scenario*, **Science of The Total Environment**, 806, 2022, 150922.

42. G. Stolte, S. Müller, S. Schattenberg, F. & M. Markiewicz, *Environmental Persistence Assessment of Heterocyclic Polyaromatic Hydrocarbons, Ultimate and Primary Biodegradability using Adapted and Non-adapted Microbial Communities*, **Journal of Hazardous Materials**, 460, 2023, 132370.

43. A. Suresh, V. Soman, A. A. R. KR, & K. H. Rahman, *Sources, Toxicity, Fate and Transport of Polyaromatic Hydrocarbons (PAHs) in The Aquatic Environment, A Review*, **Environmental Forensics**, 26(1), 2025. 35-57.

44. S. Tarigholizadeh, S. Sushkova, V. D. Rajput, A. Ranjan, J. Arora, T. Dudnikova, & M. H. Wong, *Transfer and Degradation of PAHs in the Soil-Plant System, A Review*, **Journal of Agricultural and Food Chemistry**, 72(1), 2023, 46-64.

45. G. J. Udom, C. Frazzoli, O. C. Ekhaton, A. P. Onyena, B. Bocca, & O. E. Orisakwe, . *Pervasiveness, Bioaccumulation and Subduing Environmental Health Challenges Posed by Polycyclic Aromatic Hydrocarbons (PAHs), A Systematic Review to Settle a One Health Strategy in Niger Delta, Nigeria*, **Environmental Research**, 226, 2023, 115620.

46. A. Sarker, M. A. Al Masud, D. M. Deepo, K. Das, R. Nandi, M. W. R. Ansary, & T. Islam, *Biological and Green Remediation of Heavy Metal Contaminated Water and Soils, A State-of-the-Art Review*. **Chemosphere**, 332, 2023, 138861.

47. M. Vijayanand, A. Ramakrishnan, R. Subramanian, P. K. Issac, M. Nasr, K. S. Khoo, & B. Ravindran, *Polyaromatic Hydrocarbons (PAHs) in the Water Environment, A Review on Toxicity, Microbial Biodegradation, Systematic Biological Advancements, and Environmental Fate*, **Environmental research**, 227, 2023, 115716.

48. L. T. González, I. M. Hernández-Romero, A. Mendoza, A. I. Ramirez, Y. Mancilla, B. Kharissov, & F. E. Longoria, *Source Attribution, Health Risk Analysis, and Policy Implications of PAHs and NPAHs in PM in Northern Mexico*, **Scientific Reports**, 14(1), 2024, 31823.

49. P. R. Yaashikaa, J. Palanivelu, & R. V. Hemavathy, *Sustainable Approaches for Removing Toxic Heavy Metal from Contaminated Water, A comprehensive Review of Bioremediation and Biosorption Techniques*, **Chemosphere**, 357, 2024, 141933.

50. M. Ali, X. Song, D. Ding, Q. Wang, Z. Zhang, & Z. Tang, *Bioremediation of PAHs and Heavy Metals Co-Contaminated Soils: Challenges and Enhancement Strategies*.

Environmental Pollution, 295, 2022, 118686.

51. M. Mali, R. Ragone, M. M. Dell'Anna, G. Romanazzi, L. Damiani, & P. Mastorilli, *Improved Identification of Pollution Source Attribution by using PAH Ratios Combined with Multivariate Statistics*, **Scientific Reports**, 12(1), 2022, 19298.

52. J. Ye, M. Liu, L. Chen, L. Jing, H. Qi, B. Wu, & M. Cai, *Air-Sea Exchange of PAHs in The Taiwan Strait, Seasonal Dynamics and Regulation Mechanisms Revealed by Machine Learning Approach*, **Journal of Hazardous Materials**, 474, 2024, 134792.

53. F. Jackulin, P. S. Kumar, B. Chitra, S. Karthick, & G. Rangasamy, *A Review on Recent Advancements in the Treatment of Polyaromatic Hydrocarbons (PAHs) using Sulfate Radicals Based Advanced Oxidation Process*, **Environmental Research**, 253, 2024, 119124.

54. O. Samuel, M. H. D. Othman, R. Kamaludin, H. Dzinun, A. Imtiaz, T. Li, & T. A. Kurniawan, *Photocatalytic Degradation of Recalcitrant Aromatic Hydrocarbon Compounds in Oilfield-Produced Water, A Critical Review*, **Journal of Cleaner Production**, 415, 2023, 137567.

55. N. Gunjyal, S. Rani, B. Asgari Lajayer, V. Senapathi & T. Astatkie, *A Review of the Effects of Environmental Hazards on Humans, their Remediation for Sustainable Development, and Risk Assessment*, **Environmental Monitoring and Assessment**, 195(6), 2023, 795.

56. S. Sher, M. Waseem, M. K. Leta. *Review of Techniques for the Removal of Polycyclic Aromatic Hydrocarbons from Produced Water*, **Environments**, 10(3), 2023 ,40.

57. S. Sivasamy, S. Rajangam, T. Kanagasabai, D. Bisht, R. Prabhakaran, S. Dhandayuthapani, *Biocatalytic potential of pseudomonas species in the degradation of polycyclic aromatic hydrocarbons*, **Journal of Basic Microbiology**, 65(2), 2025, e2400448.

58. M. Vijayanand, A. Ramakrishnan, R. Subramanian, P. K. Issac, M. Nasr, K. S. Khoo, & B. Ravindran, *Polyaromatic Hydrocarbons (PAHs) in the Water Environment, A Review on Toxicity, Microbial Biodegradation, Systematic Biological Advancements, and Environmental Fate*, **Environmental research**, 227, 2023, 115716.

59. N. Zeydalinejad, A. A. Javadi, & J. L. Webber, *Global Perspectives on Groundwater Infiltration to Sewer Networks, A Threat to Urban Sustainability*, **Water research**, 262, 2024, 122098.

60. G. J. Udom, C. Frazzoli, O. C. Ekhtor, A. P. Onyena, B. Bocca, & O. E. Orisakwe, *Pervasiveness, Bioaccumulation and Subduing Environmental Health Challenges Posed by Polycyclic Aromatic Hydrocarbons (PAHs), A Systematic Review to Settle A One*

Health Strategy in Niger Delta, Nigeria, **Environmental Research**, 226, 2023, 115620.

61. P. J. Landrigan, H. Raps, M. Cropper, C. Bald, M. Brunner, E. M. Canonizado, & S. Dunlop, *The Minderoo-Monaco Commission on Plastics and Human Health*, **Annals of Global Health**, 89(1), 2023, 23.

62. M. Ravanbakhsh, H. Yousefi, E. Lak, M. J. Ansari, W. Suksatan, Q. A Qasim, & M. J. Mohammadi, *Effect of Polycyclic Aromatic Hydrocarbons (PAHs) on Respiratory Diseases and the Risk Factors Related to Cancer*, **Polycyclic Aromatic Compounds**, 43(9), 2023, 8371-8387.

63. B. P Singh, T. A. Zughaibi, S. A. Alharthy, A. I. Al-Asmari, & S. Rahman, *Statistical Analysis, Source Apportionment, and Toxicity of Particulate-and Gaseous-Phase PAHs in the Urban Atmosphere*, **Frontiers in public health**, 10, 2023, 1070663.

64. S. J. Akinsete, & A. D. Olatimehin, *Priority Polycyclic Aromatic Hydrocarbons and Heavy Metals in Urban Roadside Soils of Heavy-Traffic Density Areas in Ibadan, Nigeria, Levels, Sources and Health Risk Assessment*, **Environmental Forensics**, 25(4), 2024, 239-253.

65. S. Dey, T. Mondal, & P. Samanta, *Polyaromatic Hydrocarbons (PAHs), Sources, Distribution, and Health Impacts in Aquatic Vertebrates*, **In Xenobiotics in Urban Ecosystems: Sources, Distribution and Health Impacts**, 185-208, 2023.

66. S. A. O. Adeyeye, & T. J. Ashaolu, *Polycyclic Aromatic Hydrocarbons Formation and Mitigation in Meat and Meat Products*, **Polycyclic Aromatic Compounds**, 42(6), 2022, 3401-3411.

67. I. M. Odika, G. C. Nwanisobi, N. V. Nwankwo, E. C. Mmaduakor, & O. A. Ikeh, *Polycyclic Aromatic Hydrocarbons, PAHs Contamination Levels and Health Risks in Foods Consumed in Nigeria*, **A Review**, 2023.

68. A. M. Aresta, & C. Zambonin, *Determination of Polycyclic Aromatic Hydrocarbons (PAHs) in Coffee Samples by DI-SPME-GC/MS*, **Food Analytical Methods**, 16(6), 2023, 1009-1016.

69. M. Khan, S. W. Ali, M. Shahadat, & S. Sagadevan, *Applications of Polyaniline-Impregnated Silica Gel-Based Nanocomposites in Wastewater Treatment as an Efficient Adsorbent of some Important Organic Dyes*, **Green Processing and Synthesis**, 11(1), 2022, 617-630.

70. R. Pozzan, A. de Almeida Roque, H. Iwamoto, F. de Campos Guerreiro, A. P. da Silva, D. A. Rubio-Vargas, & C. A. de Oliveira Ribeiro, *Polycyclic Aromatic Hydrocarbons in Marine Environments Affect Fish Reproduction, A Critical Review*, **Toxics**, 13(9), 2025, 747.

71. A. K. Sahoo, S. R. Madgaonkar, N. Chivukula, P. Karthikeyan, K. Ramesh, S. R. Marigoudar, & A. Samal, *Network Based Investigation of Petroleum Hydrocarbons-Induced Ecotoxicological Effects and their Risk Assessment*, **Environment International**, 194, 2024, 109163.
72. B. K. Majeed, D. M. Shwan, & K. A. Rashid, *A Review on Environmental Contamination of Petroleum Hydrocarbons, Its Effects and Remediation Approaches*, **Environmental Science, Processes & Impacts**, 27 (3), 2025, 526-548.
73. H. Vistnes, N. A. Sossalla, A. Røsvik, S. V. Gonzalez, J. Zhang, T. Meyn, & A. G. Asimakopoulos, *The Determination of Polycyclic Aromatic Hydrocarbons (PAHs) with HPLC-DAD-FLD and GC-MS Techniques in the Dissolved and Particulate Phase of Road-Tunnel Wash Water; A Case Study for Cross-Array Comparisons and Applications*, **toxics**, 10(7), 2022, 399.
74. A. C. Richer-de-Forges, Q. Chen, N. Baghdadi, S. Chen, C. Gomez, S. Jacquemoud, & D. Arrouays, *Remote Sensing Data for Digital Soil Mapping in French Research, A Review*, **Remote Sensing**, 15(12), 2023, 3070.
75. D. Saunders, J. C. Carrillo, E. R. Gundlach, O. Iroakasi, K. Visigah, N. Zabbey, & M. Bonte, *Analysis of Polycyclic Aromatic Hydrocarbons (PAHs) in Surface Sediments and Edible Aquatic Species in an Oil-Contaminated Mangrove Ecosystem in Bodo, Niger Delta, Nigeria, Bioaccumulation and Human Health Risk Assessment*, **Science of the Total Environment**, 832, 2022, 154802.
76. T. M. Mogashane, L. Mokoena, & J. Tshilongo, *A Review on Recent Developments in the Extraction and Identification of Polycyclic Aromatic Hydrocarbons from Environmental Samples*, **Water**, 16(17), 2024, 2520.
77. M. C. Kander, A. F. Wilkinson, I. C. Chen, S. Bertke, R. M. Kesler, D. L. Smith, & K. W. Fent, *Evaluating the Ingress of Total Polycyclic Aromatic Hydrocarbons (PAHs) Specifically Naphthalene through Firefighter Hoods and Base Layers*, **Journal of Occupational and Environmental Hygiene**, 22(3), 2025, 169-177.
78. J. Jeong, G. Kim, & J. G. Lee, *A Review of Food Contamination with Nitrated and Oxygenated Polycyclic Aromatic Hydrocarbons: Toxicity, Analysis, Occurrence, and Risk Assessment*, **Food Science and Biotechnology**, 33(10), 2024, 2261-2274.
79. H. Hua, S. Wu, & X. Ma, *Determination of Trans-4-Hydroxy-2-Alkenals in Thermally Treated Soybean Oil by SPE-HPLC*, **Grain & Oil Science and Technology**, 5(3), 2022, 107-113.
80. H. Vistnes, N. A. Sossalla, A. Røsvik, S. V. Gonzalez, J. Zhang, T. Meyn, and A. G. Asimakopoulos, *The Determination of Polycyclic Aromatic Hydrocarbons (PAHs) with HPLC-DAD-FLD and GC-MS Techniques in the Dissolved and Particulate Phase of*

Road-Tunnel Wash Water; A Case Study for Cross-Array Comparisons and Applications. **toxics**, 10(7), 2022, 399.

81. A. Comas, *Analysis of Polycyclic Aromatic Hydrocarbons in Tobacco Related Samples via High Performance Liquid Chromatography and Laser Excited Time Resolved Shpol'Skii Spectroscopy*, 2023.

82. X. Geng, & L. Bai, *Characteristics of Particulate Matter and Polycyclic Aromatic Hydrocarbon Pollution Generated during Kitchen Cooking and Health Risk Assessment*, **Indoor and Built Environment**, 33(4), 2024, 722-740.

83. R. Paradelo, M. Celeiro, C. Herbón, M. T. Barral, & C. García-Jares, *Polycyclic Aromatic Hydrocarbons Concentration and Spatial Distribution in the Soils of Santiago de Compostela (Northwestern Spain)*. **Geoderma Regional**, 34, 2023, e00703.

84. I. O. Ololade, A. O. Apata, N. A. Oladoja, B. A. Alabi, & O. O. Ololade, *Polycyclic Aromatic Hydrocarbons in Rivers and Health Risk Consequences of Human Exposure, A Nigerian Case Study*, **International Journal of Energy and Water Resources**, 9(2), 2025, 341-358.

85. R. N. Queiroz, P. Prediger, & M. G. A. Vieira, *Adsorption of Polycyclic Aromatic Hydrocarbons from Wastewater using Graphene-Based Nanomaterials Synthesized by Conventional Chemistry and Green Synthesis, A Critical Review*, **Journal of Hazardous Materials**, 422, 2022, 126904.

86. C. C. Aralu, P. A. C. Okoye, H. O. Abugu, N. C. Eboagu, & V. C. Eze, . *Characterization, Sources, and Risk Assessment of PAHs in Borehole Water from the Vicinity of an Unlined Dumpsite in Awka, Nigeria*, **Scientific reports**, 13(1), 2023, 9688.

87. B. M. da Costa Filho, A. C. Duarte, & T. A. Rocha-Santos, *Environmental Monitoring Approaches for the Detection of Organic Contaminants in Marine Environments, A Critical Review*, **Trends in Environmental Analytical Chemistry**, 33, 2022, 00154.

88. T. A. Akinnifesi, F. B. Borokini, A. O. Adegun, E. Mafinuyomi, A. Olonisakin, N. B. Omodara, & N. A. Oladoja, *Polycyclic Aromatic Hydrocarbon in Sediment, Ground and Surface Water Resources in Coastal Areas of Ondo State, Nigeria*, **Journal of Chemical Society of Nigeria**, 49(2), 2024.

89. H. Vistnes, N. A. Sossalla, A. Røsvik, S. V. Gonzalez, J. Zhang, T. Meyn, & A. G. Asimakopoulos, *The Determination of Polycyclic Aromatic Hydrocarbons (PAHs) with HPLC-DAD-FLD and GC-MS Techniques in the Dissolved and Particulate Phase of Road-Tunnel Wash Water; A Case Study for Cross-Array Comparisons and Application*,

Toxics, 10(7), 2022, 399.

90. A. Onjia, *Concentration Unit Mistakes in Health Risk Assessment of Polycyclic Aromatic Hydrocarbons in Soil, Sediment, and Indoor/Road Dust*, **Frontiers in Environmental Science**, 12, 2024, 1370397.

91. G. Yan, Y. Xu, B. Liu, Y. Liu, M. Zhong, K. Ma, & S. Li, *Molecular Characterization of Polar Compounds in Crude Oil Affecting Sandstone Wettability Revealed by Fourier Transform-Ion Cyclotron Resonance-Mass Spectrometry*, **SPE Journal**, 27(03), 2022, 1782-1795.

92. P. Mishra, N. S. Kiran, L. F. R. Ferreira, K. K. Yadav, & S. I. Mulla, *New Insights into The Bioremediation of Petroleum Contaminants, A Systematic Review*, **Chemosphere**, 326, 2023, 138391.

93. H. Yang, Q. Feng, J. Zhu, G. Liu, Y. Dai, Q. Zhou, & Y. Zhang, *Towards Sustainable Futures, A Review of Sediment Remediation and Resource Valorization Techniques*, **Journal of Cleaner Production**, 435, 2024, 140529.

94. H. Qiu, B. Zhu, J. Zhu, S. Chen, C. Ma, H. Xiang, & S. Tong, *Recent Advances in Application of Cyclodextrin-Based Chiral materials for Enantioseparation*, **TrAC Trends in Analytical Chemistry**, 175, 2024, 117708.

95. F. Barbosa Jr, B. A. Rocha, M. C. Souza, M. Z. Bocato, L. F. Azevedo, J. A. Adeyemi, & A. D. Campiglia, *Polycyclic Aromatic Hydrocarbons (PAHs): Updated Aspects of their Determination, Kinetics in the Human Body, and Toxicity*, **Journal of Toxicology and Environmental Health, Part B**, 26(1), 2023, 28-65

96. T. Zhang, Q. Li, X. Yang, D. Zheng, H. Deng, Z. Zeng, & A. R. Gerson, *Pb Contaminated Soil From A Lead-Acid Battery Plant Immobilized by Municipal Sludge and Raw Clay*, **Environmental Technology**, 45(14), 2024, 2796-2808.

97. NIOSH (National Institute for Occupational Safety and Health). Method 5515: *Polynuclear Aromatic Hydrocarbons by GC*. Fourth Edition, Issue 2 [Internet]. 1994. Available from: <https://www.cdc.gov/niosh/docs/2003-154/pdfs/5515.pdf>.

98. R. N. Queiroz, P. Prediger, & M. G. A. Vieira, *Adsorption of Polycyclic Aromatic Hydrocarbons from Wastewater using Graphene-Based Nanomaterials Synthesized by Conventional Chemistry and Green Synthesis, A Critical Review*, **Journal of Hazardous Materials**, 422, 2022, 126904.

99. A. S. Kazemi, M. J. Arshia, & A. Khabazian, *Sea Water Desalination Sludge Perspectives for Circular Economy, from Membranes to Energy Storage Devices*, **Desalination**, 2025, 119109.

100. EPA (Environmental Protection Agency). Method 525.2, *Determination of Organic Compounds in Drinking Water by Liquid-Solid Extraction and Capillary Column Gas Chromatography/Mass Spectrometry* [Internet]. 1995. Available from: https://www.ssi.shimadzu.com/industry/methods/m_525_2
101. EPA (Environmental Protection Agency), Method 625, *Base/Neutrals and Acids (Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater)* [Internet], 1984, Available from: [https://www.epa.gov/sites/production/files/2015-10/documents/method 625, 1984.](https://www.epa.gov/sites/production/files/2015-10/documents/method_625_1984.pdf)
102. EPA (Environmental Protection Agency). Method 8270D: *Semi-volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS), Revision 5*, [Internet], 2014, Available from: [https://www.epa.gov/sites/production/files/2015-12/documents/ 8270d.](https://www.epa.gov/sites/production/files/2015-12/documents/8270d.pdf)
103. P. V. B. Bahia, M. M. Nascimento, V. Hatje, J. B. de Andrade, & M. E. Machado, *Microscale Extraction Combined with Gas Chromatography/Mass Spectrometry for the Simultaneous Determination of Polycyclic Aromatic Hydrocarbons and Polycyclic Aromatic Sulfur Heterocycles in Marine Sediments*, **Journal of Chromatography A**, 1653, 2021,462414.
104. H. Liu, X. Hu, J. Zhang, H. Ning, & Z. Huang, *Hollow Fiber-Solid Phase Microextraction of Polycyclic Aromatic Hydrocarbons from Environment Water followed by Flash Evaporation GC/MS*, **Chromatographia**, 85(5), 2022, 387-394.
105. EPA (Environmental Protection Agency), Method 8272, *Parent and Alkyl Polycyclic Aromatics in Sediment Pore Water by Solid-Phase Micro-extraction and Gas Chromatography/Mass Spectrometry in Selected Ion Monitoring Mode*, Revision 0, 2007, Available from: [https://www.epa.gov/sites/production/files/2015-12/documents/8272.](https://www.epa.gov/sites/production/files/2015-12/documents/8272.pdf)
106. Q. Zhou, Y. Yuan, Y. Sun, X. Sheng, & Y. Tong, *Magnetic Solid Phase Extraction of Heterocyclic Aromatic Hydrocarbons from Environmental Water Samples with Multiwalled Carbon Nanotube Modified Magnetic Polyamido-Amine Dendrimers Prior to Gas Chromatography-Triple Quadrupole Mass Spectrometer*, **Journal of Chromatography A**, 1639, 2021, 461921.
107. EPA (Environmental Protection Agency). Method 8410: *Gas Chromatography/Fourier Transform Infrared Spectrometry for Semi-volatile Organics, Capillary Column*. Revision 1, Update V. 2014, Available from: <http://www.epadatadump.com/pdf-files/8410>, Analytical Methods for Polycyclic Aromatic Hydrocarbons and their Global Trend of Distribution... [http://dx.doi.org/10.5772/intechopen,71163](http://dx.doi.org/10.5772/intechopen.71163), 423
108. EPA (Environmental Protection Agency). Method 8275A: *Semivolatile Organic Compounds (PAHs and PCBs) in Soils/Sludges and Solid Wastes Using Thermal*

Extraction/ Gas Chromatography/Mass Spectrometry (TE/GC/MS), Revision 1 [Internet], 1996. Available from, <https://www.epa.gov/sites/production/files/2015-12/documents/8275a>.

109. J. N. Anyahara, *Effects of Polycyclic Aromatic Hydrocarbons (PAHs) on the Environment: A Systematic Review*. **International Journal of Advanced Academic Research**, 7(3), (2021)

110. M. U. Ali, L. Siyi, B. Yousaf, Q. Abbas, R. Hameed, C. Zheng, & M. H. Wong, . *Emission Sources and Full Spectrum of Health Impacts of Black Carbon Associated Polycyclic Aromatic Hydrocarbons (PAHs) in Urban Environment: A Review*. Critical Reviews in **Environmental Science and Technology**, 51(9), 2021,857-896.

111. M. Kumar, N. S. Bolan, S. A. Hoang, A. D. Sawarkar, T. Jasemizad, B. Gao, & J. Rinklebe, *Remediation of Soils and Sediments Polluted with Polycyclic Aromatic Hydrocarbons: to Immobilize, Mobilize, or Degrade*, **Journal of Hazardous Materials**, 420,2021, 126534.

112. C. Dai, Y. Han, Y. Duan, X. Lai, R. Fu, S. Liu, & L. Zhou, Review on the Contamination and Remediation of Polycyclic Aromatic Hydrocarbons (PAHs) in Coastal Soil and Sediments, **Environmental research**, 205,2022, 112423.

113. M. Kumar, N. S. Bolan, S. A. Hoang, A. D. Sawarkar, T. Jasemizad, B. Gao, & J. Rinklebe,. *Remediation of Soils and Sediments Polluted with Polycyclic Aromatic Hydrocarbons: to Immobilize, Mobilize, or Degrade*, **Journal of Hazardous Materials**, 420,2021, 126534.

114. D. S. Malik, A. K Sharma, A. K. Sharma, R. Thakur, & M. Sharma, *A Review on Impact of Water Pollution on Freshwater Fish Species and their Aquatic Environment*. **Advances in environmental pollution management**, Wastewater Impacts and Treatment Technologies, 2021.

115. M. Han, H. Li, Y. Kang H. Liu, X. Huang, R. Zhang, R., & K. Yu, *Bioaccumulation and Trophic Transfer of PAHs in Tropical Marine Food Webs from Coral Reef Ecosystems, the South China Sea: Compositional Pattern, Driving Factors, Ecological Aspects, and Risk Assessment*, **Chemosphere**, 308, 2022, 136295.

116 P. M. Mayer, K. D. Moran, E. L. Miller, S. M. Brander, S. Harper, M. Garcia-Jaramillo, & M. Mendez, *Where the Rubber Meets the Road: Emerging Environmental Impacts of Tire Wear Particles and their Chemical Cocktails*, **Science of The Total Environment**, 927,2024, 171153.

117. K. Sun, Y. Song, F. He, M. Jing, J. Tang, & R. Liu, . *A Review of Human and Animals Exposure to Polycyclic Aromatic Hydrocarbons: Health Risk and Adverse Effects, Photo-Induced Toxicity and Regulating Effect of Microplastics*, **Science of The Total Environment**, 773, 2021, 145403.
119. S. Karki, G. Hazarika, D. Yadav, & P. G. Ingole, *Polymeric Membranes for Industrial Applications: Recent Progress, Challenges and Perspectives*, **Desalination**, 573, 2024, 117200.
120. M. Ravanbakhsh, H. Yousefi, E. Lak, M. J. Ansari, W. Suksatan, Q. A. Qasim, & M. J. Mohammadi, *Effect of Polycyclic Aromatic Hydrocarbons (PAHs) on Respiratory Diseases and the Risk Factors Related to Cancer*, **Polycyclic Aromatic Compounds**, 43(9), 2023, 8371-8387.
121. Malla, Manthar Ali, Li Changxing, Mukhtiar Ali Mallah, Sobia Noreen, Yang Liu, Muhammad Saeed, He Xi et al, *Polycyclic Aromatic Hydrocarbon and its Effects on Human Health, An Overview*, **Chemosphere** 296, 2022, 133948.
122. A. J. Badyda, W. Rogula-Kozłowska, G. Majewski, K. Bralewska, K. Widziewicz-Rzońca, B. Piekarska, & J. S. Białowicz, *Inhalation Risk to PAHs and BTEX During Barbecuing: The Role of Fuel/Food Type and Route of Exposure*, **Journal of Hazardous Materials**, 440, 2022, 129635.
123. M. F. Ahmad, F. A. Ahmad, A. A. Alsayegh, M. Zeyauallah, A. M. AlShahrani, K. Muzammil, & S. Hussain, *Pesticides Impacts on Human Health and the Environment with their Mechanisms of Action and Possible Countermeasures*, **Heliyon**, 10(7), 2024.
124. G. Venkatraman, N. Giribabu, P. S. Mohan, B. Muttiah, V. Govindarajan, M. Alagiri, & S. A. Karsani, *Environmental Impact and Human Health Effects of Polycyclic Aromatic Hydrocarbons and Remedial Strategies, A Detailed Review*, **Chemosphere** 141227, 2024.
125. A. Ramesh, K. J. Harris, & A. E. Archibong, *Reproductive Toxicity of Polycyclic Aromatic Hydrocarbons. In Reproductive and Developmental Toxicology*, **Academic press**, 2022, 759-778.
126. P. Xu, B. Liu, H. Chen, H. Wang, X. Guo, & J. Yuan, *PAHs as Environmental Pollutants and their Neurotoxic Effects. Comparative Biochemistry and Physiology Part C, Toxicology & Pharmacology*, .2024,109975.
127. A. M. Tartaglione, A. Racca, & L. Ricceri, *Developmental Exposure to Polycyclic Aromatic Hydrocarbons (PAHs): Focus on Benzo [a] Pyrene Neurotoxicity*, **Reproductive Toxicology**, 119,2023, 108394.

128. C. Torres-Moreno, L. Puente-DelaCruz, G. Codling, A. L. Villa, M. Cobo, J. Klanova, & B. Johnson-Restrepo, *Polycyclic Aromatic Hydrocarbons (PAHs) in Human Breast Milk from Colombia: Spatial Occurrence, Sources and Probabilistic Risk Assessment*, **Environmental Research**, 204, 2022, 111981.
129. A. Singh, J. Dhau, R. Kumar, R. Badru, P. Singh, Y. K. Mishra, & A. Kaushik, *Tailored Carbon materials (TCM) for Enhancing Photocatalytic Degradation of Polyaromatic Hydrocarbons*, **Progress in Materials Science**, 144, 2024, 101289.
130. E. Y. Lim, & G. D. Kim, *Particulate Matter-Induced Emerging Health Effects Associated with Oxidative Stress and Inflammation*, **Antioxidants**, 13(10), 2024, 1256.
131. Y. Y. Yu, H. Jin, & Q. Lu, *Effect of Polycyclic Aromatic Hydrocarbons on Immunity*, **Journal of Translational Autoimmunity**, 5, 2022, 100177.
132. M. A. Mallah, L. Changxing, M. A. Mallah, S. Noreen, Y. Liu, M. Saeed, & Q. Zhang, *Polycyclic Aromatic Hydrocarbon and its Effects on Human Health: An Overview*, **Chemosphere**, 296, 2022, 133948.
133. C. R. Ohoro, A. O. Adeniji, A. I. Okoh, & O. O. Okoh, *Polybrominated Biphenyl Ethers in the Environmental Systems, A Review*, **Journal of Environmental Health Science and Engineering**, 19(1), 2021, 1229-1247.
134. D. R. Middleton, R. Wedekind, A. L. Hall, E. Suonio, N. DeBono, R. Vermeulen, & M. K. Schubauer-Berigan, *Critical Reviews of Exposure Assessment in Carcinogenic Hazard Identification: The IARC Monographs Experience*, **Occupational and environmental medicine**, 81(7), 2024, 366-372.
135. S. L. Bharati, *4 Heavy Metal Pollutants, Heavy Metal Contamination in the Environment*, **Health Impacts and Potential Remediation Approaches**, 46, 2024.
136. C. Ogwu, V. Ideh, J. Ogana, & O. M. Adinkwu, *Quantification of Polycyclic Aromatic Hydrocarbons in Wetlands in Aja-Pessu and Environs (Oil Bearing Communities) Warri South Delta, Nigeria*, **Journal of Applied Sciences and Environmental Management**, 28(12B Supplementary), 2024, 4293-4297.
137. L. Lu, & R. Ni, *Bibliometric Analysis of Global Research on Polycyclic Aromatic Hydrocarbons and Health Risk Between 2002 and 2021*, **Environmental Science and Pollution Research**, 29(56), 2022, 84034-84048.
138. R. Singh, S. Dutt, P. Sharma, A. K. Sundramoorthy, A. Dubey, A. Singh, & S. Arya, *Future of Nanotechnology in Food Industry, Challenges in Processing, Packaging, and*

Food Safety, Global Challenges, 7(4), 2023, 2200209.

139. R. Singh, S. Dutt, P. Sharma, A. K. Sundramoorthy, A. Dubey, A. Singh, & S. Arya, *Future of Nanotechnology in Food Industry: Challenges in Processing, Packaging, and Food Safety*, **Global Challenges**, 7(4), 2023, 2200209.

139. S. Radoor, J. Karayil, A. Jayakumar, D. R. Kandel, J. T. Kim, S. Siengchin, & J. Lee, *Recent Advances in Cellulose-and Alginate-Based Hydrogels for Water and Wastewater Treatment, A Review*, **Carbohydrate Polymers**, 323, 2024, 121339.

140. S. Meharda, *In Utero Exposure to Benzo [a] pyrene Results in Ovarian Follicular Depletion in F1 MutaTM mouse*, **University of California**, Irvine, 2016.

142. European Union. *Council Directive 98/83/EC*, **Official Journal of European Union**, L330/32 98/83/EC, 1998.

143. D. Pisanello, & D. Pisanello, *EU regulations on chemicals in foods. Chemistry of foods, EU legal and regulatory approaches*, 15-77, 2014.

144. I. Stumpe-Vīksna, V. Bartkevičs, A. Kukāre, & A. Morozovs, *Polycyclic aromatic hydrocarbons in meat smoked with different types of wood*, **Food Chemistry**, 110(3), 2008, 794-797.

145. European Commission, E. C.. *Commission Regulation (EU) No 835/2011 of 19 August 2011 amending Regulation (EC) No 1881/2006 as regards maximum levels for polycyclic aromatic hydrocarbons in foodstuffs*, **Official Journal of the European Union**, 215(4), 2011, 1-5.

146. EU Commission. *Regulation (EU) No 835/2011 amending Regulation (EC) No 1881/2006 as regards maximum levels for polycyclic aromatic hydrocarbons in foodstuffs*. **Official Journal of the European Union**, L, 215(4), 2011.

147. European Union *Commission Regulation (EC) No 1881/2006*, **Official Journal of European Union**, L364 1881, 2006.

148, Federal Republic of Nigeria, *National Environmental Policy*, **Federal Republic of Nigeria**, 1999.

149, Federal Republic of Nigeria . *Nigerian Oil and Gas Industry Content Development Act*, **Federal Republic of Nigeria**, 2010.

150, NESREA, *Environmental Guidelines and Standards for Industrial Processes*, **National Environmental Standards and Regulations Enforcement Agency**, 2012.

- 151, NNPC, *Guidelines for the Management of Polycyclic Aromatic Hydrocarbons (PAHs) in the Petroleum Industry*, **Nigerian National Petroleum Corporation**, 2017.
152. T. O. Ogunwale, P. B. Oladeji, A. B. Oyedare, S. O. Oyetola, A. I. Oluwalana, T. A. Basiru, & O. F. Ogunrinola, *Household Solid Waste Management and Environmental Impacts in the Ibadan Metropolis, Nigeria*, **Industrial and Domestic Waste Management**, 4(2), 2024, 84-105.
153. A. Amin, A. B. D. U. L. R. A. U. F. Ambali, & T. M. Isiaq, *Strategies for the Implementation of Environmental Protection Regulations Towards Sustainable Waste Management in Oyo State*, **Global International Journal of Management and Social Science**, 7(2), 2024, 1-10.
- 154, A. L. Adeyemi, A. A. Luqman, & A. Akande, *Environmental and Social Impact Assessment (ESIA) of Ijaiye Agribusiness Industrial Hub (IAIH) project*, 2022.
- 155, Oyo State Ministry of Environment and Natural Resources). *Guidelines for the Management of Polycyclic Aromatic Hydrocarbons (PAHs) in the Agricultural Sector*, **Oyo State Ministry of Environment and Natural Resources**, 2020.

Chapter Three

Methodology

3.1 Research Design

This investigation into polycyclic Aromatic Hydrocarbon (PAHs) contamination associated with the Ajakanga Waste dumpsite adopts an environmental sampling and analytical study that employs a comparative approach with control sites and incorporates human health risk assessment, this is deliberately selected for its methodological strength and suitability to the study's objectives. This design provides a structured and immediate evaluation of the environmental conditions and potential public health risk within the specific environmentalism context of Oluyole Local Government Area, Oyo State, Nigeria. This method strength lies in its ability to yield precise, reproducible, and reliable value of high-quality standard data essential for understanding contamination dynamics at an environmentally sensitive yet under explored site. The section hypothesis allows for a comprehensive assessment at a particular point in time, making it highly effective for preliminary environmental studies that seek to establish baseline contamination levels

The environmental sampling and analytical study of this research focuses on assessing the extent of contamination, identifying the sources of PAHs, evaluating the potential risks to human health and the ecosystem, and providing data to inform remediation strategies and regulation.

The principal objective of environmental sampling protocols within dumpsite surroundings is the acquisition of representative samples. Such samples must accurately delineate the concentration levels and spatial distribution of Polycyclic Aromatic

Hydrocarbons (PAHs).

3.1.1 Quantification of Contamination

Ascertaining the total concentration of PAHs, with specific emphasis on the 16 priority PAHs designated by the United States Environmental Protection Agency (US EPA). This quantification, applied to soil and proximate media is fundamental to determining the extent of pollution.

3.1.2 Spatial Distribution Mapping

Elucidating the spatial (horizontal) and vertical (depth) variability of PAH concentrations. This is critical, as PAHs exhibit strong sorption to soil organic matter but retain the potential for leachate-mediated migration into groundwater, a risk exacerbated in unlined disposal sites.

3.1.3 Establishment of Baseline Data

Collecting comparative samples from both the contaminated locus and a pristine control area, situated remotely from industrial activities. This provides a crucial benchmark for quantifying the environmental impact attributable to the dumpsite.

3.1.4 Assessment of Migration Pathways

Sampling diverse environmental compartments to elucidate the fate, transport mechanisms, and potential bioaccumulation of PAHs within the local environment and associated food webs.

The analytical study component involves the rigorous laboratory analysis of collected samples to derive detailed chemical information regarding the PAH congeners present.

3.1.5 Identification and Quantification

Employing advanced analytical instrumentation, predominantly Gas Chromatography - Flame Ionization Detector (GC-FID), to precisely identify and quantify individual PAH compounds within the environmental matrices.

3.1.6 Source Apportionment

Utilizing molecular diagnostic ratios as chemical-fingerprinting tools and ratio of the low molecular weight to high molecular weight PAHs. This allows for the differentiation between pyrolytic (pyrogenic) sources, such as the incomplete combustion of organic materials (e.g, open burning), and petrogenic sources, originating from petroleum products¹ (e.g, crude oil or diesel spills).

3.1.7 Physicochemical Correlation Analysis

Investigating statistical relationships between measured PAH concentrations and key soil physicochemical parameters. This examination seeks to understand the factors governing PAH behavior, persistence, and bio availability within the soil matrix.

3.1.8 Toxicological Risk Assessment

Calculating Toxicity Equivalent Quantities (TEQs) for identified carcinogenic PAHs. This facilitates the assessment of potential carcinogenic and non-carcinogenic health risks to human receptors (via ingestion, dermal contact, and inhalation exposure pathways) and the broader ecosystem.

3.1.9 Informing Remediation and Policy

Generating the empirical data necessary for policymakers, public health experts, and regulatory agencies. This data serves as the foundation for designing effective pollution

abatement measures, selecting and implementing appropriate remediation strategies such as bioremediation, thermal desorption, and enforcing pertinent environmental legislation.

3.2 Study Area

The project site is AJAKANGA waste dumpsite, located in Oluyole local Government, Ibadan, Oyo State. Ibadan is located in southwestern Nigeria and serves as the capital city of Oyo State. Geographically, it is situated on the coordinates:

Latitude: 7.3775° N

Longitude: 3.9470° E¹

Oluyole Local Government Area (LGA) is located in the southwestern part of Oyo State, Nigeria, and is part of the Ibadan metropolitan area. It has its headquarters in Idi-Ayunre, which lies along the Ibadan-Ijebu Ode Road.

Geographical Coordinates:

Latitude: 7.2500° N

Longitude: 3.8500° E

Boundaries and Location:

Oluyole LGA is strategically positioned, sharing boundaries with several other LGAs and States

To the North: It shares a boundary with Ibadan South-West and Ibadan North LGAs.

To the South: It borders Ogun State.

To the East: It is bordered by Ona Ara Local Government Area.

To the West: It shares boundaries with Ido Local Government Area.

The Ajakanga waste dumpsite in Ibadan, Nigeria is located between the following

coordinates:

Latitude: 7°18.70'N to 7°18.90'N

Longitude: 3°50'E to 3°51'E

The Ajakanga dumpsite is in Oluyole local government area of Ibadan, in the southwestern part of Nigeria.

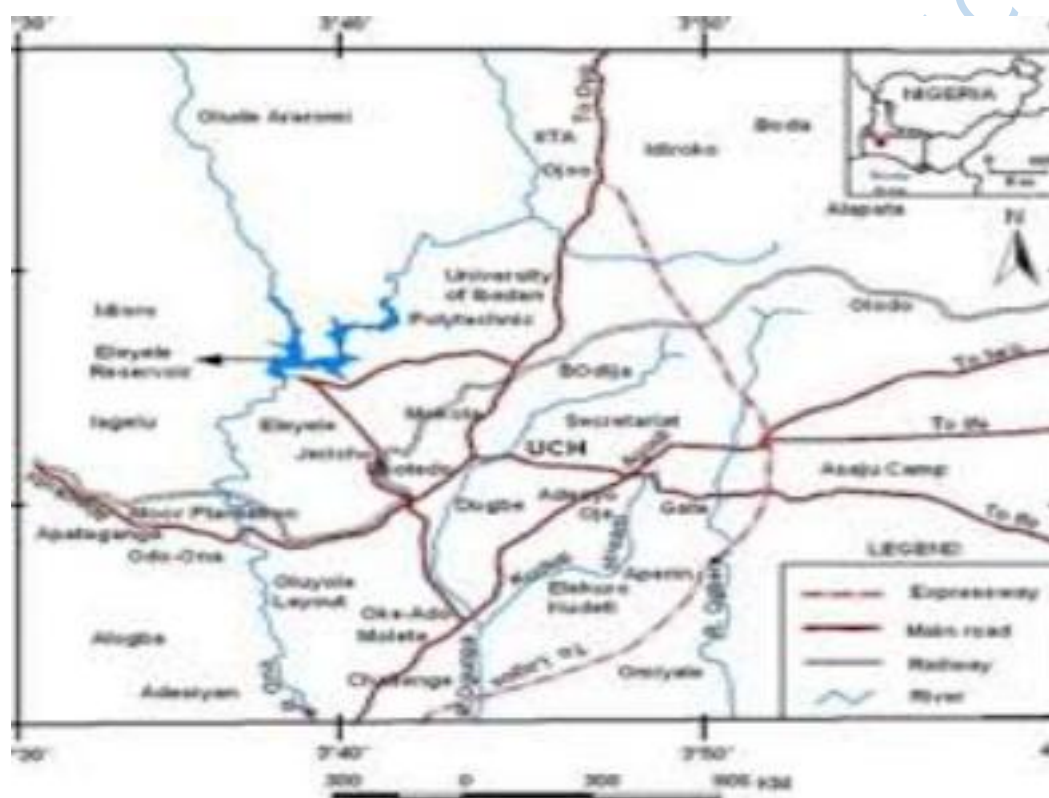


Figure 3.1: Map Of Ajakanga Waste Dumpsite, Oluyole Local Government, Ibadan, Oyo State

Source: Oyo State Waste Management Authority (OYOWMA), Agodi-Gate

Figure 3.1 show the location map and the pictorial view of the location site, It is close to River Ona, separated only by Odo Ona Elewe Road^{2,3}. The site is surrounded majorly with low-income residents, artisans, waste pickers, farmers, and traders, who rely on the area for both livelihood and habitation. The estimated population density of the

Ajakanga–Ayegun–Oluyole axis is about 1,200 – 1,500 persons per square kilometer, with most households lacking adequate waste management infrastructure or access to piped water.

The Ajakanga dumpsite is one out of four dumpsites in Ibadan managed by Oyo State Waste Management Authority (OYWMA). The Ajakanga landfill is an active unlined used since 1996, and is still in use today. It receives waste from a variety of sources, including commercial, hospital, electronic, household, and industrial^{2,3,4,5}

3.3 Population of Study

The population of this study encompasses the environmental and human systems associated with the Ajakanga Municipal Solid Waste (MSW) Dumpsite, located in Oluyole Local Government Area, Ibadan, Oyo State, Nigeria. The dumpsite is situated between latitude 7°18'N and longitude 3°50'E, occupying an extensive area that has served as a major waste disposal point for the Ibadan metropolis for over two decades. The site receives large volumes of mixed municipal waste daily, including household refuse, plastics, electronic waste, agricultural residues, and small-scale industrial wastes. The primary study population comprises soil samples collected from various zones within and around the Ajakanga dumpsite. These soils represent the principal environmental medium for the accumulation and persistence of Polycyclic Aromatic Hydrocarbons (PAHs) and other hazardous organic pollutants resulting from waste degradation, leachate percolation, and open burning practices. Sampling within different zones (upwind, downwind, and control locations) ensures that the data reflect the spatial variation and potential dispersion of contaminants.

The secondary population includes the human settlements and socio-economic activities surrounding the dumpsite, extending approximately 500m – 800m radius from the center of the dumpsite. This population consists predominantly of low-income residents, artisans, waste pickers, farmers, and traders, who rely on the area for both livelihood and habitation. The estimated population density of the Ajakanga–Ayegun–Oluyole axis is about 1,200 – 1,500 persons per square kilometer, with most households lacking adequate waste management infrastructure or access to piped water. The inhabitants are therefore potentially exposed to environmental contaminants through inhalation of contaminated dust, ingestion of crops cultivated on nearby soils, and dermal contact during daily activities.

soil sample and surrounding human communities provides a comprehensive framework for understanding the extent of PAH contamination and the associated ecological and health risks. This approach aligns with the study's objectives to evaluate the environmental and public health implications of PAH pollution arising from continuous waste dumping and open burning at the Ajakanga site.

These research ensures that findings are representative of both ecological and anthropogenic dimensions of contamination. Which also supports evidence-based recommendations for environmental monitoring, policy formulation, and community health protection in waste-impacted environments.

3.4 Sampling Technique and Sample Size

The sampling frame for this study comprised defined zones within and around the Ajakanga Municipal Solid Waste (MSW) Dumpsite, Oluyole Local Government Area,

Ibadan, Oyo State, Nigeria. The selection of sampling points was guided by the need to capture spatial variations in Polycyclic Aromatic Hydrocarbon (PAH) contamination resulting from waste disposal, leachate migration, and atmospheric deposition from open burning of refuse.

To ensure representative samples, the study area was systematically divided into five zones (A–E) based on proximity to the dumpsite center, topography, and observed waste disposal intensity. Zones A, B, C, D, and E were located within the active waste disposal area and immediate surroundings 0–200 m, and control zones respectively. Each zone was further subdivided into sampling points spaced approximately 50 meters apart to ensure adequate spatial coverage and to minimize sampling bias.

A total of eighteen (18) composite soil samples were collected three samples from each zone using a systematic random sampling technique. At each sampling point, sub-samples were collected at depths of 0–15 cm, representing the topsoil layer most susceptible to contamination by PAHs due to atmospheric deposition and leachate infiltration. The sub-samples were homogenized to form a composite sample for each point, properly labeled, and stored in pre-cleaned aluminum foil and glass containers to prevent photodegradation or contamination prior to analysis.

The sample size determination was based on both spatial representation and analytical feasibility, following methodological recommendations for soil pollution studies^{7,8}. The chosen number of samples provided sufficient replication for statistical analysis while maintaining cost-effectiveness and analytical accuracy. The inclusion of a control zone (Zone F), located approximately 500 m from the dumpsite in a relatively unaffected area,

enabled comparison with background PAH concentrations and assessment of contamination gradients.

This structured sampling frame ensured that the data generated were representative of the different contamination zones, enabling a comprehensive evaluation of PAH distribution patterns, potential sources, and environmental risks associated with waste dumping and open burning at the Ajakanga site.

3.5 Sample Collection and Preparation

The collection and preparation of soil samples were carried out following standard environmental sampling protocols to ensure the accuracy, reliability, and representativeness of the results. The procedures adhered to the guidelines recommended by the United States Environmental Protection Agency⁶.

3.5.1 Sample Collection

Soil samples were collected from five delineated zones (A–E) within and around the Ajakanga Municipal Solid Waste (MSW) Dumpsite, as described in Section 3.4. Within each zone, three (3) sampling points were selected using a systematic random sampling technique to ensure spatial coverage and minimize sampling bias.

At each sampling point, surface soil samples 0 – 15 cm depth were obtained using a stainless steel hand auger and placed into solvent-rinsed, airtight glass jars. This depth range was selected because it represents the most active layer for pollutant accumulation and microbial degradation, and is most directly affected by waste deposition and atmospheric fallout.

Approximately 500 g of soil was collected per point. For each zone, sub-samples from the

three points were thoroughly mixed to obtain a composite sample representative of that zone. Each composite sample was properly labeled with sample code, date, and location coordinates (obtained via GPS), and transported in an ice-packed cooler at 4°C to the laboratory to minimize photodegradation and volatilization of organic compounds.

3.5.2 Sample Preparation and Pretreatment

In the laboratory, the samples were air-dried at room temperature 25 – 28 °C for 48 – 72 hours to remove residual moisture while preventing the loss of volatile organic compounds. After drying, the samples were gently crushed using a mortar and pestle made of porcelain and then sieved through a 2 mm stainless-steel mesh to remove stones, roots, and debris, ensuring uniform particle size for extraction.

Prepared samples were stored in clean, amber glass bottles with Teflon-lined caps and kept in a refrigerator at 4 °C until further extraction and analysis. This storage condition prevented microbial activity and chemical degradation prior to instrumental analysis.

3.6 Sample Extraction and Analytical Procedure

The extraction and analysis of Polycyclic Aromatic Hydrocarbons (PAHs) from soil samples were carried out using Soxhlet extraction followed by Gas Chromatography coupled with Flame Ionization Detection (GC–FID), in accordance with the USEPA Method 354⁰C and Method 8100. These methods were selected due to their accuracy, reproducibility, and suitability for quantifying PAHs in complex environmental matrices such as soil.

3.6.1 Soxhlet Extraction Procedure

For each composite soil sample, 5 g of homogenized, air-dried soil was accurately weighed into a extraction thimble. The extraction was performed using a Soxhlet apparatus with a 250ml round-bottom flask containing 50 ml of a solvent mixture of hexane and acetone (1:1 v/v). The solvent combination was chosen because of its complementary polarity, which enhances the efficient dissolution and recovery of both low molecular weight (LMW) and high molecular weight (HMW) PAHs⁸.

The extraction process was carried out for 6 hours, maintaining a constant reflux rate of 4 – 6 cycles per hour to ensure thorough extraction of PAHs from the soil matrix. After extraction, the solvent extract was allowed to cool and subsequently concentrated using a rotary evaporator at 40 °C. The extract was then transferred into a pre-cleaned vial for cleanup.

3.6.2 Cleanup and Concentration

To remove co-extracted impurities such as lipids, waxes, and pigments that may interfere with chromatographic analysis, the crude extracts were purified using a silica gel/alumina column cleanup procedure. The column was prepared with activated silica gel 5 g layered over 2 g of anhydrous sodium sulfate to eliminate moisture. The column was preconditioned with 5 ml of hexane before sample introduction.

The concentrated extract was loaded onto the column and eluted successively with 20 ml of hexane and 20 ml of acetone. The eluate containing the target PAH compounds was collected and further concentrated to 1 ml under a gentle stream of high-purity nitrogen gas (N₂) before GC–FID analysis.

3.6.3 Instrumental Analysis GC - FID (USEPA Method 610, 8100)

3.6.3.1 GC–FID Analysis

Quantitative determination of PAHs was carried out using a Gas Chromatography (GC) equipped with a Flame Ionization Detector (FID) and a capillary column (DB-5, 30 m × 0.25 mm i.d., 0.25 µm film thickness). The analytical conditions were optimized for resolution and sensitivity as follows

Carrier gas: Nitrogen at 1.5 ml/min (constant flow)

Injector temperature: 250 °C

Detector temperature: 300 °C

Injection mode: Splitless, with 1 µL sample volume

Oven temperature program

Initial temperature 60 °C held for 2 min

Ramp at 10 °C/min to 180 °C held for 2 min

Then 5 °C/min to 280 °C held for 10 min

3.6.3.2 Principle of Gas Chromatography for PAH Analysis

Gas Chromatography (GC) is a fundamental analytical technique extensively employed in the separation, identification, and quantification of Polycyclic Aromatic Hydrocarbons (PAHs) in environmental matrices such as soil, water, and air. The principle of GC analysis for PAHs is based on the differential partitioning of analyte molecules between a mobile gaseous phase (carrier gas) and a stationary phase coated inside a chromatographic column⁹.

PAHs are hydrophobic, semi-volatile organic compounds composed of fused aromatic

rings. Their volatility and thermal stability make them well-suited for gas chromatographic separation¹⁰. The extracted and concentrated PAH sample is introduced into the injection port, where it is instantly vaporized at a controlled high temperature. The carrier gas usually helium, hydrogen, or nitrogen serves as the mobile phase that transports the vaporized molecules through the column. The stationary phase, typically a non-polar or slightly polar liquid film bonded to the inner wall of a fused silica capillary column, interacts with the analytes based on van der Waals forces and dispersion interactions¹¹.

Separation of individual PAHs is achieved due to differences in their boiling points and interaction strengths with the stationary phase. Low molecular weight (LMW) PAHs elute earlier due to their lower boiling points, while high molecular weight (HMW) with higher boiling points and stronger affinity for the stationary phase, elute later¹².

To improve resolution, temperature programming is employed, whereby the oven temperature is gradually increased during the analysis. This allows compounds with a wide range of volatilities to be efficiently separated within a single run.

Detection of PAHs Flame Ionization Detector (FID) was used for the detection of PAHs. The FID is particularly suitable for PAHs due to its high sensitivity to hydrocarbons, wide linear dynamic range, and minimal susceptibility to most inorganic impurities¹³.

In FID, the effluent from the GC column is burned in a hydrogen–air flame, producing ions and electrons from organic carbon compounds. The resulting ion current, measured between a collector electrode and the flame tip, is proportional to the number of carbon atoms entering the detector per unit time, allowing quantitative determination of PAH

concentrations¹².

The efficiency of GC separation for PAHs depends on the distribution coefficient of each compound between the stationary and mobile phases. The retention time (t_R) of each analyte serves as a characteristic parameter for qualitative identification, while the peak area or height provides quantitative information. Calibration using PAH standards of known concentration ensures accurate quantification¹¹.

In environmental investigations such as soil contamination in Ajakanga waste dumpsite studies, GC coupled with FID provides high sensitivity, reproducibility, and selectivity for the detection of trace levels of PAHs. This makes GC an indispensable tool for evaluating the extent of hydrocarbon pollution, source identification (pyrogenic or petrogenic origin), and environmental risk assessment¹⁴.

3.6.3.3 Working Principle of GC–FID for PAH Determination

The Gas Chromatography–Flame Ionization Detector (GC–FID) system operates on the principle of separation followed by ionization-based detection of organic compounds, particularly hydrocarbons such as Polycyclic Aromatic Hydrocarbons (PAHs). This technique is widely adopted in environmental monitoring due to its high selectivity, sensitivity, and stability in quantifying organic pollutants in complex matrices like soil¹¹. After separation in the chromatographic column, the effluent containing individual PAHs is directed into the Flame Ionization Detector, the eluate is introduced into a hydrogen air flame where thermal energy causes combustion of the organic molecules. During this combustion process, carbon atoms in the PAH molecules are converted into ions and electrons. The ions produced, primarily CHO^+ species, are collected by a polarized

electrode positioned above the flame. The resulting ion current is directly proportional to the number of carbon atoms entering the detector per unit time¹².

The FID generates an electrical signal that is measured in picoamperes (pA), and this signal is recorded as a chromatographic peak. The area under each peak corresponds to the relative quantity of the PAH compound, while the retention time serves as an identifying characteristic. Quantitative analysis is achieved through comparison with calibration curves obtained from standard PAH mixtures of known concentrations¹¹.

FID detection is particularly advantageous for PAHs because these compounds are hydrocarbon rich and exhibit strong ionization responses, yielding high signal intensities with minimal interference from water, oxygen, or inorganic species. The detector exhibits a nearly universal carbon response, meaning that all carbon-containing compounds produce proportional signals regardless of molecular structure¹¹.

This characteristic enhances the reliability and accuracy of quantitative determination in PAH analysis.

For effective operation, GC–FID parameters such as hydrogen flow rate, air flow rate, and detector temperature must be optimized to ensure complete combustion and maximum ion production. Typically, detector temperatures are maintained between 250°C and 300°C to prevent condensation of heavier PAHs before detection¹¹.

The quantitative determination of PAHs using GC–FID is often expressed using the calibration equation:

$$C_X = A_X / A_s * C_s / R_f$$

where:

* (C_x) = concentration of the PAH in the sample (mg/kg),

* (A_x) = peak area of the analyte,

* (A_s) = peak area of the standard,

* (C_s) = concentration of the standard (mg/L), and

* (R_f) = response factor obtained from calibration.

This approach provides both qualitative and quantitative information essential for environmental contamination assessment and source identification of PAHs in soil samples.

3.6.4 Preparation of Working Standard

A working calibration standard was prepared from a commercially obtained Certified Reference Standard for stock solution with a concentration of 1000 ppm using dilution formula

$C_1V_1 = C_2V_2$, which based on principle of conservation of mass

where C_1 initial concentration of the stock solution

V_1 initial volume of the stock solution used for dilution

C_2 final concentration of the new diluted solution

V_2 final Volume new diluted solution

3.6.5 Standard Check Solution

In Gas Chromatography – Flame Ionization Detection (GC–FID) analysis of Polycyclic Aromatic Hydrocarbons (PAHs) in soil samples such as those collected from a dumpsite, the standard check solution plays a vital role in ensuring analytical accuracy, reliability, and consistency.

➤ **Instrument Calibration Verification**

The standard check solution is used to confirm that the GC–FID system remains properly calibrated during the analytical sequence. It contains known concentrations of target PAHs, which are injected periodically to verify that the instrument's response (peak area or height) corresponds to the expected values within the acceptable range. This ensures that the calibration curve remains valid throughout the analysis.

➤ **Quality Control and Assurance**

The solution serves as a quality control (QC) sample, confirming the precision and accuracy of the analytical run. Deviations in retention time or detector response from the standard check indicate possible instrument drift, column degradation, or contamination. This helps in maintaining data integrity and complying with QA/QC protocols.

➤ **Detection of Instrumental Drift or Malfunction**

During extended analytical runs common in environmental monitoring of multiple soil samples the instrument's sensitivity can change. Regular injection of the standard check solution allows the analyst to detect signal drift or baseline instability early, enabling timely corrective action (e.g., recalibration, column maintenance, or detector cleaning).

➤ **Verification of Analytical Precision and Reproducibility**

Repeated analysis of the standard check solution allows the calculation of relative standard deviation (RSD) of detector response. A low RSD usually $\leq 15\%$ demonstrates method precision and the reliability of the GC–FID system under consistent analytical conditions.

➤ **Retention Time Confirmation**

The standard check solution helps to confirm the retention times of specific PAH compounds. This is especially important when analyzing complex matrices such as dumpsite soils, where co-eluting compounds might interfere with peak identification.

➤ **Data Validation and Traceability**

The use of standard check solutions provides documented evidence that the analytical system performed correctly at the time of analysis. This traceability is critical for regulatory compliance, publication credibility, and inter laboratory comparability of results.

The standard check solution is indispensable in GC-FID analysis of PAHs in soil because it

- * Confirms calibration validity,
- * Ensures instrument stability,
- * Detects analytical drift,
- * Verifies method precision, and
- * Provides a basis for data quality assurance.

3.7 Quality Control Measures

To maintain data integrity, all sampling and preparation equipment were pre-cleaned with hexane and acetone (1:1 v/v) before and after each use to avoid cross-contamination. Field blanks and triplicate samples were included to assess potential contamination during sampling and handling. All procedures were conducted under minimal light exposure to prevent PAH photodegradation.

These careful collection and preparation procedures ensured that the soil samples accurately represented the contamination profile of the Ajakanga dumpsite environment and provided a reliable basis for subsequent Soxhlet extraction and Gas Chromatography with Flame Ionization Detection (GC–FID) analysis.

3.8 Quality Assurance and Quality Control (QA/QC)

To ensure data accuracy and reliability, strict QA/QC measures were implemented throughout the analytical process. These included the use of method blanks, duplicate samples, and spiked recoveries for performance validation. The limit of detection (LOD) and limit of quantification (LOQ) were determined for each PAH compound based on signal to noise ratios of 3:1 and 10:1, respectively. Recoveries for the spiked samples ranged between 82–105%, which is within the acceptable limits for PAH determination in environmental samples (USEPA, 2007).

All glassware and sampling containers were pre-cleaned with acetone and hexane and baked at 120 °C to eliminate residual organic contaminants. Analytical results were expressed in milligrams per kilogram (mg/kg) of dry weight soil.

3.9 Data Analysis and Interpretation

The data obtained from the laboratory analysis were subjected to systematic statistical and interpretative evaluation to determine the concentration, distribution, sources, and potential environmental risk of Polycyclic Aromatic Hydrocarbons (PAHs) in the soil samples collected from the Ajakanga Municipal Solid Waste (MSW) Dumpsite. The analytical results were processed using standard statistical tools and diagnostic indices to provide a comprehensive understanding of contamination patterns.

3.9.1 Data Processing and Statistical Analysis

The concentrations of individual PAHs in the soil samples were recorded in milligrams per kilogram (mg/kg) of dry weight and summarized using descriptive statistical methods (mean, range, standard deviation), and coefficient of variation. These statistical parameters provided insights into the variability and distribution of PAHs across the different zones of the dumpsite.

Data were tabulated and graphically presented using Microsoft Excel 2021 and SPSS version 26.0. Graphical representations such as bar charts, pie charts, and spatial distribution maps were used to illustrate the concentration trends and variations among zones (A–E).

3.9.2 Diagnostic Ratio Analysis for Source Identification

To identify possible sources of PAHs, molecular diagnostic ratios were applied, comparing specific PAH isomers with similar physicochemical properties. Ratios such as $\text{Ant}/(\text{Ant} + \text{Phe})$, $\text{Flu}/(\text{Flu} + \text{Pyr})$, $\text{BaA}/(\text{BaA} + \text{Chr})$, and LMW/HMW were calculated and interpreted following established literature criteria¹⁵.

Ratios of $\text{Ant}/(\text{Ant} + \text{Phe}) > 0.1$ and $\text{Flu}/(\text{Flu} + \text{Pyr}) > 0.5$ were interpreted as indicative of pyrogenic sources (combustion of biomass, coal, or waste),

While ratios below these thresholds were associated with petrogenic origins (oil spills, lubricants, or crude residues).

Similarly, $\text{LMW}/\text{HMW} < 1$ indicated dominance of high-molecular-weight PAHs (pyrogenic input), whereas $\text{LMW}/\text{HMW} > 1$ suggested low-molecular-weight dominance typical of petrogenic sources.

These ratios, in combination with field observations (such as evidence of open burning and leachate flow), were used to infer the dominant emission sources influencing the PAH profile at the dumpsite.

3.9.3 Comparison with Regulatory Standards

The mean concentrations of total PAHs ($\Sigma 16\text{PAHs}$) and individual compounds were compared with National and International soil quality guidelines, including those established by the World Health Organization (WHO, 2010), the Canadian Council of Ministers of the Environment (CCME, 2008), and the Dutch Target and Intervention Values (RIVM, 2010).

This comparative assessment enabled evaluation of whether PAH concentrations in these study area exceeded permissible limits and thus posed potential ecological or health risks. Emphasis was placed on key carcinogenic compounds such as benzo[a]pyrene, benzo[b]fluoranthene, and indeno[1,2,3-cd]pyrene, due to their toxicological significance.

3.9.4 Ecological and Health Risk Interpretation

To evaluate the potential ecological and human health implications, the Toxic Equivalency Factor (TEF) approach was applied to estimate BaP-equivalent concentrations (BaP_{eq}) for each sampling zone, using the weighting factors proposed by Nisbet and LaGoy¹⁶. This provided an estimate of the overall carcinogenic potency of the PAH mixture relative to benzo[a]pyrene.

Furthermore, contamination indices such as the Contamination Factor (CF), Degree of Contamination (Cd), and Pollution Load Index (PLI) were computed to quantify the extent of soil contamination relative to reference values from uncontaminated sites.

These indices aided in classifying the contamination levels (low, moderate, or high) and provided a scientific basis for risk prioritization and management decisions.

3.9.5 Risk Assessment Model

Risk assessment for polycyclic aromatic hydrocarbons (PAHs) involves evaluating their potential to cause adverse health effects, including carcinogenic and non-carcinogenic risks, to humans. The assessment typically follows a structured approach based on standardized frameworks, such as those recommended by World Health Organization (WHO), U.S. Environmental Protection Agency (EPA) and other regulatory agencies.

Risk assessment for PAHs generally includes the following steps

3.9.6 Hazard Identification

Identifies the specific PAHs of concern and their toxicological properties (e.g., carcinogenicity, mutagenicity, and developmental toxicity).

Example: The EPA has classified benzo[a]pyrene (BaP) as a Group 1 carcinogen (carcinogenic to humans).

3.9.7 Dose-Response Assessment

Establishes the relationship between exposure levels and the likelihood of adverse effects.

Carcinogenic PAHs often follow a low-dose linear model, while non-carcinogenic effects are assessed using threshold models.

3.9.8 Exposure Assessment

Quantifies the levels of PAH exposure through various pathways such as ingestion, inhalation, or dermal contact.

3.9.9 Risk Characterization

Integrates dose-response and exposure data to estimate risks, distinguishing between carcinogenic and non-carcinogenic risks

3.9.10 Carcinogenic Risk Assessment

For PAHs, carcinogenic risk is assessed using lifetime cancer risk models based on Benzo[a]pyrene Toxic Equivalents (BaP-TEQs).

3.9.11 Toxic Equivalency Factor (TEF)

PAHs are assigned a Toxic Equivalency Factor (TEF) relative to benzo[a]pyrene (BaP), regarded as the reference compound with a TEF of 1.

The BaP-TEQ is calculated as:

$$\text{BaP-TEQ} = \sum (\text{Concentration of individual PAH} \times \text{TEF for that PAH})$$

3.9.12 Carcinogenic Risk (CR)

The LCR is calculated as $\text{CR} = \text{CDI} \times \text{SF}$ equ 1

CDI = Chronic Daily Intake (mg/kg/day)

CDI is determined based on exposure frequency, duration, and body weight:

$$\text{CDI} = (\text{C} \times \text{IR} \times \text{EF} \times \text{ED}) / (\text{BW} \times \text{AT})$$

C = PAH concentration (mg/kg or mg/m³)

IR = Intake rate (e.g., ingestion/inhalation rate)

EF = Exposure frequency (days/year)

ED = Exposure duration (years)

BW = Body weight (kg) Children 15kg and adult 70kg

AT = Averaging time (days)

SF = Slope Factor (risk per unit dose, mg/kg/day). For BaP, the EPA provides a slope factor of $7.3 \text{ (mg/kg/day)}^{-1}$. Acceptable Risk Levels:- Regulatory threshold: Carcinogenic risks are typically considered acceptable if $\text{LCR} < 1 \times 10^{-6}$ (1 in 1,000,000 risk) ^{7,8,9,10,11}.

3.9.13 Non-Carcinogenic Risk Assessment

For non-carcinogenic effects, PAHs are assessed using the Hazard Quotient (HQ) and Hazard Index (HI).

3.9.14 Hazard Quotient (HQ)

$$\text{HQ} = \text{CDI} / \text{RfD}, \dots \dots \dots \text{equ 2}$$

CDI = Chronic Daily Intake (mg/kg/day) (same calculation as above).

RfD = Reference Dose (mg/kg/day), provided by regulatory agencies such as the EPA.

3.9.15 Hazard Index (HI)

If multiple PAHs are present, the HI is the sum of individual HQs : $\text{HI} = \Sigma \text{HQ}$

Interpretation:

$\text{HI} < 1$: No significant non-carcinogenic risk.

$\text{HI} > 1$: Potential for adverse non-carcinogenic effects.

3.9.16 Key Reference Values

RfD for BaP (oral): 0.0003 mg/kg/day (EPA).

3.9.17 Combined Risk Assessment Approaches

Monte Carlo Simulation

Used to account for variability and uncertainty in exposure parameters (e.g., body weight, intake rates).

Generates probabilistic estimates of both carcinogenic and non-carcinogenic risks.

3.9.18 Cumulative Risk Assessment

Focuses on the combined effects of multiple PAHs and other co-contaminants.

Uses both TEFs for carcinogenicity and HI for non-carcinogenicity to assess cumulative impacts.

3.10 Interpretation and Integration

Interpretation of results integrated statistical outcomes, diagnostic ratios, and contamination indices to provide a coherent picture of PAH behavior in the Ajakanga dumpsite environment. Spatial patterns were evaluated in relation to proximity to waste burning zones, leachate flow paths, and human activity intensity.

The findings were discussed in comparison with similar studies within Nigeria international research reports^{17,18}, providing contextual relevance and strengthening the interpretation of contamination sources, environmental risks, and management implications.

This analytical framework ensured that the data generated were not only statistically sound but also scientifically interpretable in terms of pollution sources, ecological significance, and potential human health impacts associated with PAHs in soils around the Ajakanga MSW dumpsite.

3.11 Summary of Methodology

This chapter presented the detailed methodological framework adopted for the investigation of Polycyclic Aromatic Hydrocarbons (PAHs) contamination in soils associated with the Ajakanga Municipal Solid Waste (MSW) Dumpsite, located in

Oluyole Local Government Area, Ibadan, Oyo State, Nigeria. The study employed a descriptive analytical research design, which enabled systematic evaluation of contamination levels and spatial distribution of PAHs within the dumpsite environment.

The population of study comprised the soil environment and surrounding human settlements within a 500m – 700m radius of the dumpsite. The area was stratified into five zones (A–E) based on distance from the dumpsite and intensity of waste disposal activities. A total of eighteen (18) composite soil samples were collected using a systematic random sampling technique to ensure spatial representativeness. Each sample was air-dried, homogenized, sieved, and properly preserved for laboratory analysis.

Extraction of PAHs from the soil samples was carried out using Soxhlet extraction with a hexane and acetone solvent mixture (1:1 v/v), followed by silica gel/alumina column cleanup to eliminate impurities. Quantitative determination of PAHs was achieved using Gas Chromatography coupled with Flame Ionization Detection (GC–FID), operated under optimized instrumental conditions. Quality assurance measures such as method blanks, spiked recoveries, and replicate analyses were implemented to ensure precision, accuracy, and reliability of results.

The data obtained were statistically analyzed using descriptive and inferential techniques to evaluate concentration trends, variability, and spatial distribution. Diagnostic ratios were employed to infer potential PAH sources (pyrogenic or petrogenic), while comparisons with national and international soil quality standards provided an assessment of contamination severity. Additionally, contamination indices and toxic equivalency factors were used to interpret the health risk implications.

Overall, the methodology provided a scientifically sound and replicable framework for assessing the extent, distribution, sources, and environmental risks of PAHs at the Ajakanga dumpsite. This approach laid a solid foundation for the presentation and discussion of results .

Lead City University Ibadan DO NOT COPY

End notes

1. Kong, J., Yan, S., Cao, X., Zhang, Y., Ran, C., Chen, X., & He, H. *Quantitative Source Apportionment and Health Risk Assessment for Polycyclic Aromatic Hydrocarbon and their Derivatives in Indoor Dust from Housing and Public Buildings of a Mega-City in China*. **Journal of Hazardous Materials**, 486,2025, 137057.
- 2 B. Tiamiyu, *An Investigation of the Use and Sustainability of GRID3 Infrastructure for Social and Sustainable Development in Nigeria*, 2024.
- 3 L. Abubakar, S. L. Dalglish, B. Angell, O. Sanuade, S. Abimbola, A. L. Adamu, & F. H Zanna, *The Lancet Nigeria Commission, Investing in Health and The Future of The Nation*, **The Lancet**, 399(10330), 2022, 1155-1200.
- 4 M. Oweibia, G. C. Timighe, E. B. Agbedi, T. Egberipou, & E. F. Tamaradielaye, *Birth Registration in Nigeria's Delta Region, Analyzing LGA-Level Compliance Disparities and Systemic Barriers*, **medRxiv**, 2025-07
5. M. O. Lasisi, F. F. Akinola, & B. S. Awe, *Application of Geographic Information System and Remote Sensing in the Development of Drainage Pattern of Oluyole Local Government Area, Nigeria*, 2022.
6. A. I. López-Lorente, F. Pena-Pereira, S. Pedersen-Bjergaard, V. G. Zuin, S. A. Ozkan, & E. Psillakis, *The Ten Principles of Green Sample Preparation*, **TrAC Trends in Analytical Chemistry**, 148, 2022, 116530.
7. T. M. Mogashane, O. Mapazi, M. A. Motlatle, L. Mokoena, & J. Tshilongo, *A Review of Recent Developments in Analytical Methods for Determination of Phosphorus from Environmental Samples*, **Molecules**, 30(5), 2025, 1001.
- 8 Y. Zhang, Z. Guo, C. Peng, & Y. He, *Introducing a Land-Use-Based Weight Factor in Regional Health Risk Assessment of PAHs in Soils of an Urban Agglomeration*, **Science of the Total Environment**, 887, 2023, 163833.
- 9 Y. M. Lim, V. Swamy, N. Ramakrishnan, E. S. Chan, & H. P. Kesuma, *Volatile Organic Compounds (VOCs) in Wastewater; Recent Advances in Detection and Quantification*, **Microchemical Journal**, 195, 2023, 109537.
- 10 R. Ghamarpoor, A. Fallah, & M. Jamshidi, *A Review of Synthesis Methods, Modifications, and Mechanisms of ZnO/TiO₂-Based Photocatalysts for Photodegradation of Contaminants*, **ACS Omega**, 9(24), 2024, 25457-25492.

11. T. K. Chakraborty, M. S. Islam, G. C. Ghosh, P. Ghosh, S. Zaman, A. Habib, & M. S. K. Josy, *Human Health Risk and Hydro-Geochemical Appraisal of Groundwater in the Southwest Part of Bangladesh Using GIS, Water Quality Indices, and Multivariate Statistical Approaches*, **Toxin Reviews**, 42(1), 2023, 285-299.
12. J. C. Egbueri, J. C. Agbasi, A. L. Ezugwu, M. E. Omeka, I. A. Ucheana, C. C. Aralu, & H. O. Abugu, *Metal (loid)s, Nitrate, Polycyclic Aromatic Hydrocarbons, and Radioactive Contaminants in Nigerian Water Resources, State-of-The-Art of their Ecological and Health Risk Assessments*, **Environment, Development and Sustainability**, 2024, 1-50.
13. H. Liu, X. Hu, J. Zhang, H. Ning, & Z. Huang, *Hollow Fiber-Solid Phase Microextraction of Polycyclic Aromatic Hydrocarbons from Environment Water followed by Flash Evaporation GC/MS*, **Chromatographia**, 85(5), 2022, 387-394.
14. Y. Zhang, Z. Guo, C. Peng, & Y. He, *Introducing a Land-Use-Based Weight Factor in Regional Health Risk Assessment of PAHs in Soils of an Urban Agglomeration*, **Science of the Total Environment**, 887, 2023, 163833.
15. A. Rabieimesbah, S. Sobhanardakani, M. Cheraghi, & B. Lorestani, *Concentrations, Source Identification and Potential Ecological and Human Health Risks Assessment of Polycyclic Aromatic Hydrocarbons (PAHs) in Agricultural Soils of Hamedan County, West of Iran, Soil and Sediment Contamination*, **An International Journal**, 33(4), 2024, 482-506.
16. M. M. Donets, A. D. Borovkova, M. A. Belanov, T. V. Boychenko, & V. Y. Tsygankov, *Polycyclic Aromatic Hydrocarbons in Bivalves from the Black Sea*, **Environmental Chemistry Letters**, 2025, 1-24.
17. J. J. M. Abayi, C. T. Gore, C. Nagawa, B. A. M. Bandowe, H. Matovu, E. Mubiru, & P. Ssebugere, *Polycyclic Aromatic Hydrocarbons in Sediments and Fish Species from the White Nile, East Africa, Bioaccumulation Potential, Source Apportionment, Ecological and Health Risk Assessment*, **Environmental Pollution**, 278, 2021, 116855.
18. S. J. Akinsete, & A. D. Olatimehin, *Priority Polycyclic Aromatic Hydrocarbons and Heavy Metals in Urban Roadside Soils of Heavy-Traffic Density Areas in Ibadan, Nigeria: Levels, Sources and Health Risk Assessment*, **Environmental Forensics**, 25(4), 2024, 239-253.

Chapter Four

4.1 Results And Discussion of Findings

This chapter presents and discusses the findings of the investigation into Polycyclic Aromatic Hydrocarbon (PAH) contamination in soil samples collected from the Ajakanga Municipal Solid Waste (MSW) Dumpsite, located in Oluyole Local Government Area, Ibadan, Oyo State, Nigeria. The results are organized and interpreted in relation to the study objectives, which focus on determining the concentration, spatial distribution, and probable sources of PAHs, as well as evaluating their potential ecological and health risks.

The data obtained from the Gas Chromatography Flame Ionization Detection (GC–FID) analysis are presented as concentrations of individual and total PAHs ($\Sigma_{16}\text{PAHs}$) in milligrams per kilogram (mg/kg) of dry soil. The results are further categorized according to the five delineated sampling zones (A–E) within and around the dumpsite, representing variations in contamination intensity and proximity to waste deposition activities.

Descriptive statistical tools, graphical illustrations, and inferential analyses were employed to interpret the results. The discussion integrates the findings with published studies from similar environmental settings within Nigeria and globally, to highlight comparative trends and implications. The key aspects covered in this chapter include:

- Concentration and Distribution of PAHs in Soil Samples
- Composition Pattern of Low and High Molecular Weight PAHs
- Source Identification Using Molecular Diagnostic Ratios
- Comparison with National and International Standards

- Human Health Risk Assessment
- Comparative Evaluation with Previous Studies

Lead City University Ibadan DO NOT COPY

Table 4.1 Mean Concentration of 16 Priority US EPA in Soil samples of Ajakanga Waste Dumpsite

PAHs	Samples																			
	R2 V	ST D	Nor th 1	Nor th 2	Nor th 3	We st 1	We st 2	We st 3	Ea st 1	Ea st 2	Eas t 3	Sou th 1	Sou th 2	Sou th 3	Cent er 1	Cent er 2	Cent er 3	Cont rol 1	Cont rol 2	Cont rol 3
Ace	1.0	4.0	ND	ND	ND	ND	ND	ND	N D	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Acy	1.0	4.0	3.28	4.08	2.53	4.84	6.16	8.58	2.25	1.83	6.30	5.71	5.41	2.30	8.43	7.25	4.34	1.69	4.59	4.95
Ant	1.0	4.0	ND	ND	ND	ND	ND	ND	N D	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BaA	1.0	4.0	ND	ND	ND	ND	ND	ND	N D	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
BaP	1.0	4.0	0.12	0.21	0.15	0.41	0.23	0.21	0.38	0.17	0.11	0.11	0.42	0.5	0.16	0.53	0.15	0.17	0.11	0.16
BbF	1.0	4.0	3.85	2.50	1.55	2.97	3.77	5.26	1.38	1.12	3.86	3.5	3.31	1.41	5.16	4.44	2.66	1.04	2.81	3.03
BkF	1.0	4.0	ND	ND	ND	ND	ND	ND	N D	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Chr	1.0	4.0	ND	ND	ND	ND	ND	ND	N D	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
DbA	1.0	4.0	ND	ND	ND	ND	ND	ND	N D	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND

Fla	1.0	4.0	1.29	0.84	0.52	0.9 9	1.2 6	1.7 6	0.4 6	0.3 8	1.2 9	1.17	1.11	0.47	1.73	1.49	0.89	0.35	0.94	1.02
Flu	1.0	4.0	0.47	0.30	0.19	0.3 6	0.4 6	0.6 4	0.1 7	0.1 4	0.4 7	0.43	0.4	0.17	0.63	0.54	0.32	0.13	0.34	0.37
IcdP	1.0	4.0	0.51	0.33	0.21	0.4 0	0.5 0	0.7 0	0.1 8	0.1 5	0.5 1	0.47	0.44	0.19	0.69	0.59	0.35	0.14	0.37	0.40
Nap	1.0	4.0	ND	ND	ND	ND	ND	ND	N D	N D	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Phe	1.0	4.0	3.42	2.23	1.38	2.6 4	3.3 6	4.6 8	1.2 3	1.0 0	3.4 4	3.12	2.95	1.25	4.60	3.95	2.37	0.92	2.50	2.70
Pyr	1.0	4.0	2.88	1.87	1.16	2.2 2	2.8 2	3.9 3	1.0 3	0.8 4	2.8 9	2.62	2.48	1.05	3.86	3.32	1.99	0.78	2.1	2.27
BghiP	1.0	4.0	3.64	2.37	1.47	2.8 1	3.5 7	4.9 8	1.3 1	1.0 6	3.6 6	3.32	3.14	1.33	4.89	4.21	2.52	0.98	2.66	2.87
Σ16P AHs 1			19.4 6	14.7 4	9.16	17. 65	22. 14	30. 74	8.4 1	6.6 8	22. 52	20.4 5	19.6 6	8.68	30.1 5	26.3 3	15.5 9	6.19	16.43	17.76
mean			2.16	1.64	1.02	1.9 6	2.4 6	3.4 2	0.9 3	0.7 4	2.5	2.27	2.18	0.96	3.35	2.93	1.73	0.69	1.83	1.97
SD			1.54	1.31	0.81	1.5 4	1.9 9	2.7 9	0.6 9	0.5 8	2.0 6	1.86	1.72	0.7	2.75	2.31	1.41	0.53	1.49	1.61

Below detection limit (<0.00015) Zone A NORTH, Zone B WEST, Zone C EAST, Zone D SOUTH, Zone E centre of the dumpsite and Zone F 500m away from dumpsite ground, Naphthalene(Nap), Acenaphthalene (Ace),

Acenaphthylene (Acy), Phenanthrene (Phe), Anthracene (Ant), Fluorene (Flu), Fluoranthene (Fla), pyrene (Pyr), Benzo(a)anthracene (BaA), Chrysene (Chr), Benzo(b)fluoranthene (BbF), Benzo(k)fluoranthene (BkF),

Benzo(a)pyrene(BaP), Indeno(1,2,3-cd)pyrene (IcdP), Dibenzo(a,h)anthracene (DbA) and Benzo(ghi)perylene (BghiP)]. Σ 16 PAHs summation of 16 US EPA priority PAHs

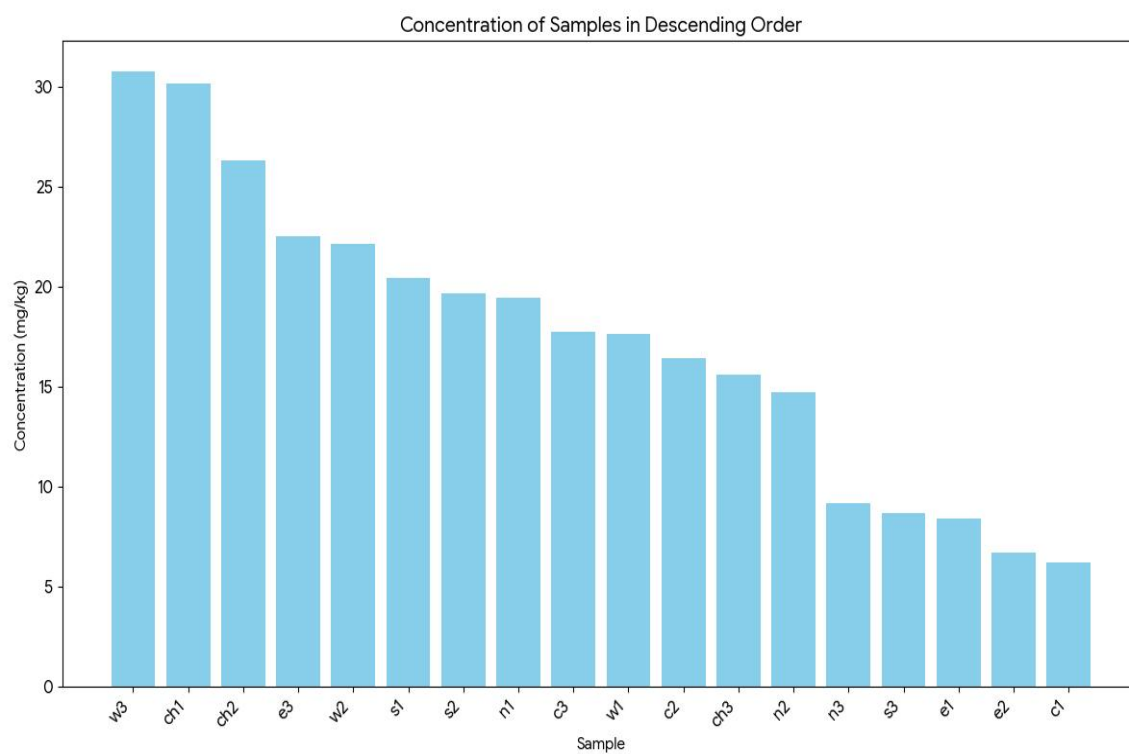


Figure 4.1 : Concentration of PAHs in Soil Samples in Descending Order in each Sampling Location

Source : Research Fieldwork, 2025

Table 4.2 Concentration of PAHs for Different Zone in Ajakanga Waste Dumpsite mg/kg

PAHs	Samples					
PAHs	Zone A	Zone B	Zone C	Zone D	Zone E	Zone F
Acenaphthene	ND	ND	ND	ND	ND	ND
Acenaphthylene	3.30±0.78	6.53±1.90	3.46±2.74	4.47±1.89	6.67±2.10	3.74±1.78
Anthracene	ND	ND	ND	ND	ND	ND
Benzo(a)anthracene	ND	ND	ND	ND	ND	ND
Benzo_a_pyrene	0.16±0.04	0.28±0.11	0.22±0.14	0.34±0.21	0.28±0.21	0.15±0.04
Benzo_b_fluoranthene	2.63±1.15	4.00±1.16	2.12±1.15	2.74±1.16	4.09±1.29	2.29±1.09
Benzo_k_fluoranthene	ND	ND	ND	ND	ND	ND
Chrysene	ND	ND	ND	ND	ND	ND
Dibenzo[ah]anthracene	ND	ND	ND	ND	ND	ND
Fluoranthene	0.88±0.39	1.34±0.39	0.71±0.51	0.92±0.39	1.37±0.43	0.77±0.31
Fluorene	0.32±0.14	0.49±0.14	0.26±0.18	0.33±0.14	0.50±0.16	0.28±0.13
Indeno[123cd]Pyrene	0.35±0.15	0.53±0.15	0.28±0.20	0.37±0.15	0.54±0.17	0.31±0.15
Naphthalene	ND	ND	ND	ND	ND	ND
Phenanthrene	2.34±1.03	3.56±1.03	1.89±1.35	2.44±1.03	3.64±1.15	2.04±0.97
pyrene	1.97±0.86	2.99±0.87	1.59±1.13	2.05±0.87	3.06±0.97	1.72±0.82
Benzo(ghi)perylene	2.49±1.09	3.79±1.10	2.01±1.43	2.60±1.10	3.87±1.22	2.17±1.04
Σ16PAHsZ	14.46	23.51	12.54	16.26	24.02	13.46
mean	1.61	2.61	1.39	1.81	2.67	1.50
SD	1.18	2.11	1.11	1.42	2.16	1.21

Below detection limit (<0.00015) Zone A NORTH, Zone B WEST, Zone C EAST, Zone D SOUTH, Zone E centre of the dumpsite and Zone F

500m away from dumpsite ground, Naphthalene(Nap), Acenaphthalene (Ace), Acenaphthylene (Acy), Phenanthrene (Phe), Anthracene (Ant),

Fluorene (Flu), Fluoranthene (Fla), pyrene (Pyr), Benzo(a)anthracene (BaA), Chrysene (Chr), Benzo(b)fluoranthene (BbF),

Benzo(k)fluoranthene (BkF), Benzo(a)pyrene(BaP), Indeno(1,2,3-cd)pyrene (IcdP), Dibenzo(a,h)anthracene (DbA) and Benzo(ghi)perylene

(BghiP)]. Σ 16 PAHs summation of 16 US EPA priority PAHs

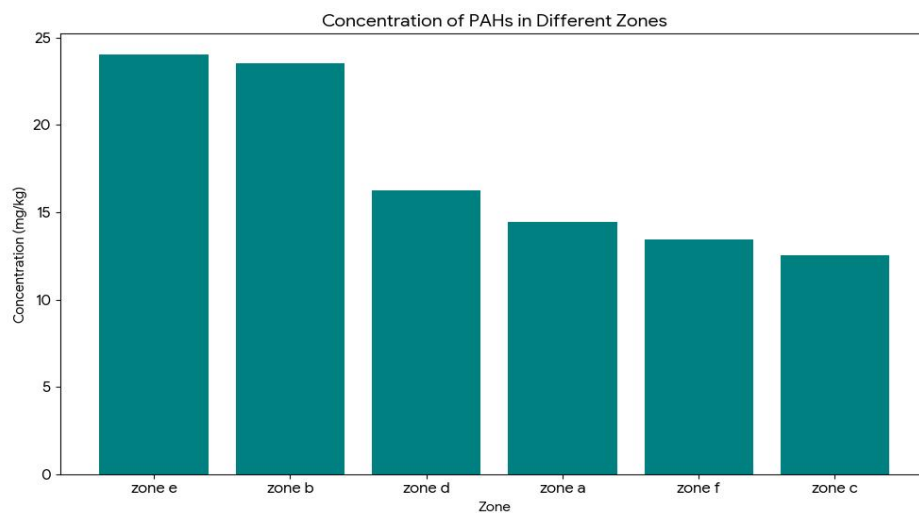


Figure 4.2 : Concentration of PAHs in Different Zones

Source : Research Fieldwork 2025

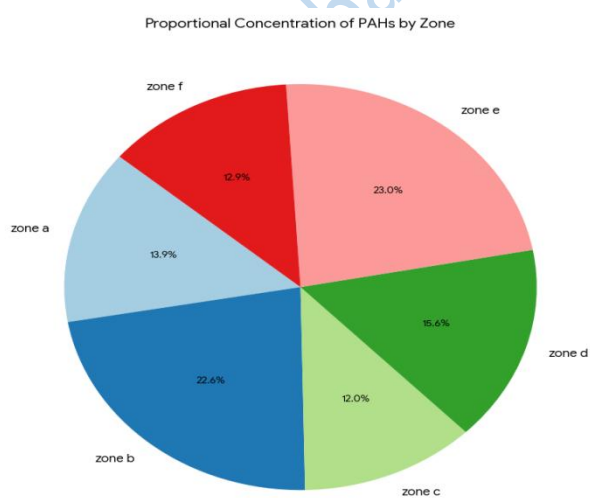


Figure 4.3 : Percentage Concentration of PAHs in Different Zones

Source : Research Field Work,2025

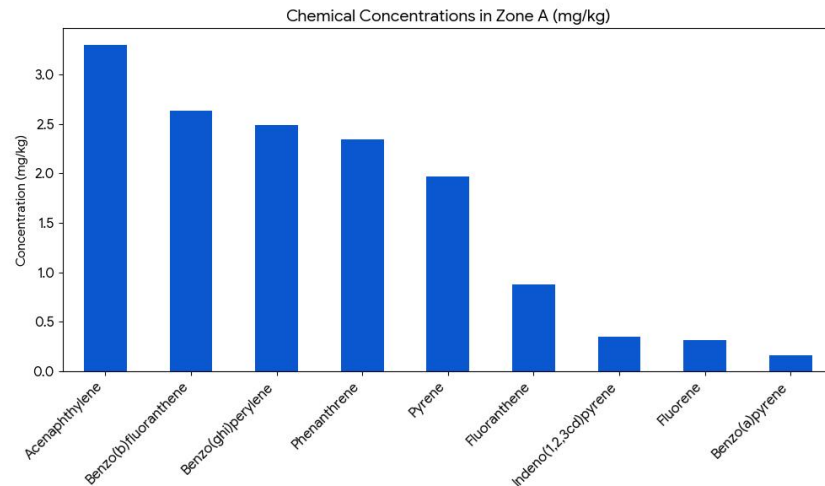


Figure 4.4: Concentration of Individual PAHs in Zone A

Source : Research Field Work 2025

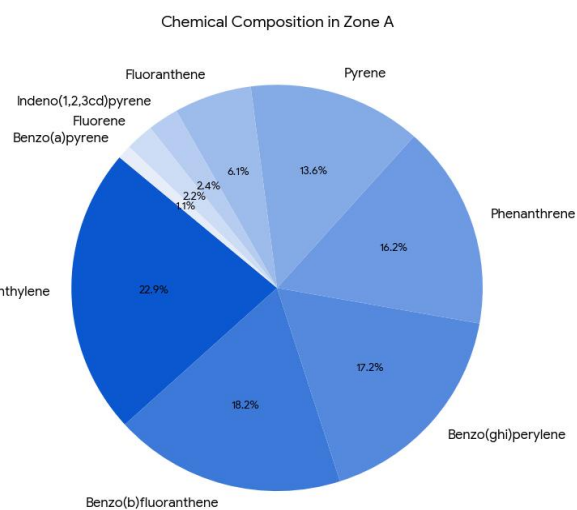


Figure 4.5 : Percentage Concentration of Individual PAHs in Zone A

Source : Research Field Work, 2025

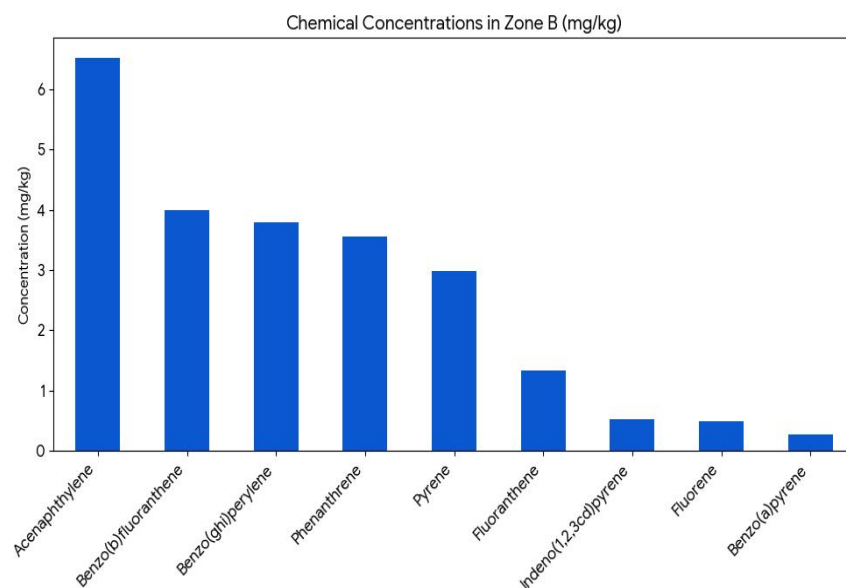


Figure 4.6 : Concentration of Individual PAHs in Zone B

Source : Research Field Work 2025

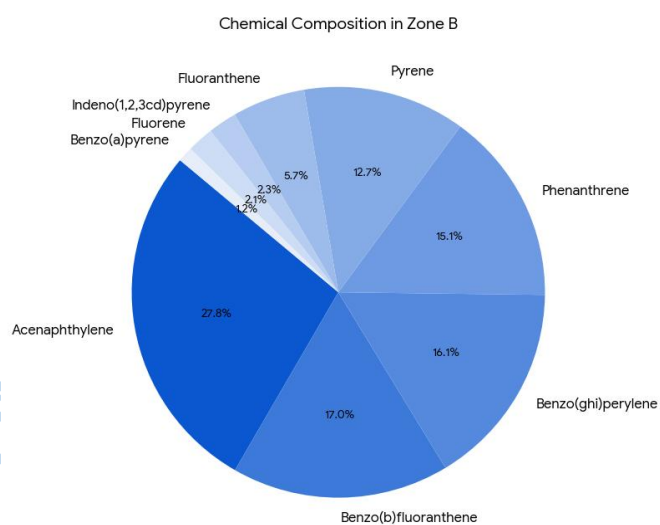


Figure 4.7 : Percentage Concentration of Individual PAHs in Zone B

Source : Research Field Work 2025

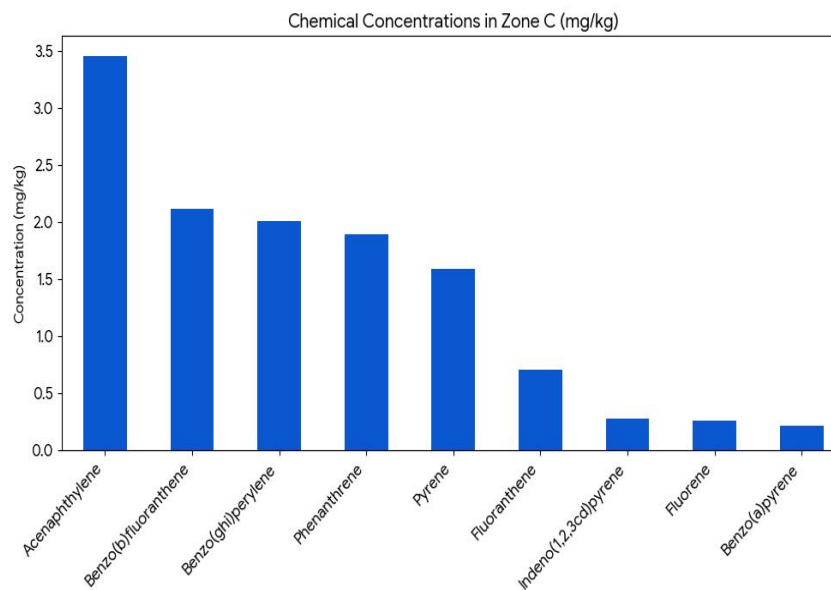


Figure 4.8 : Concentration of Individual PAHs in Zone C

Source : Research Field Work, 2025

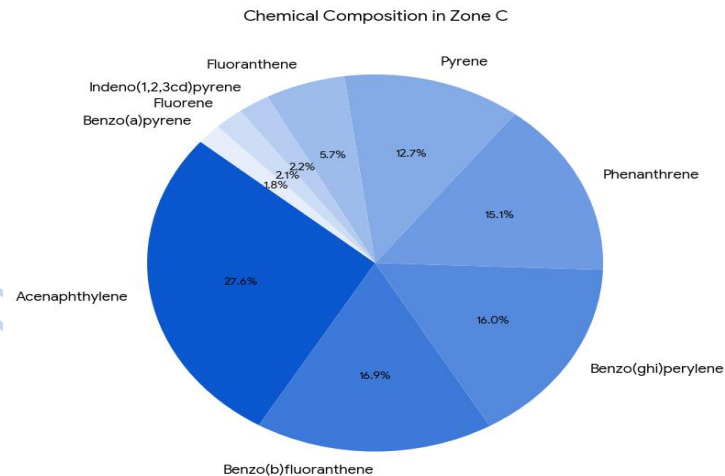


Figure 4.9 : Percentage Concentration of Individual PAHs in Zone C

Source : Research Field Work, 2025

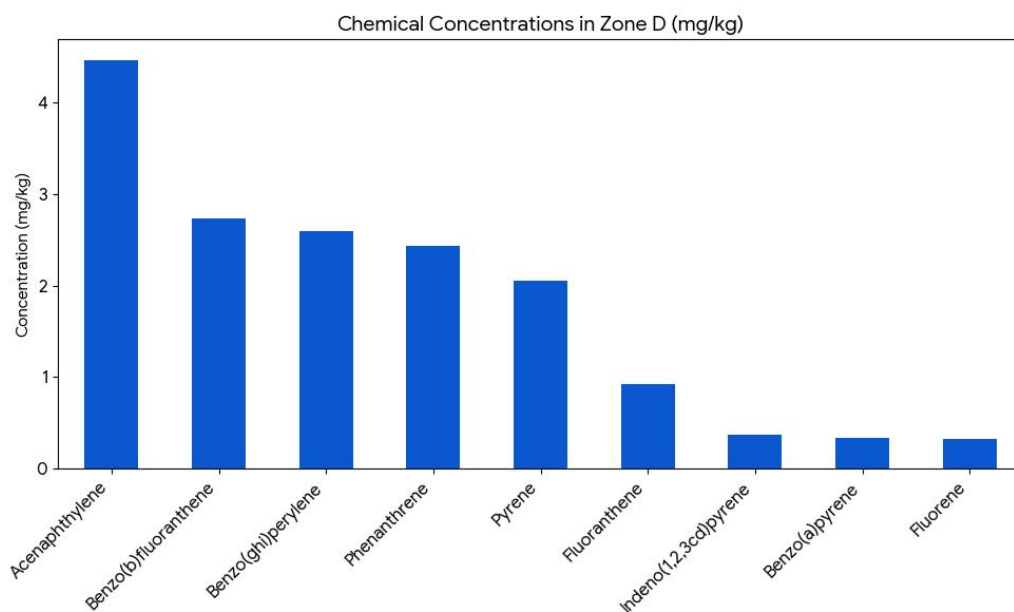


Figure 4.10 : Concentration of Individual PAHs in Zone D

Source : Research Field Work, 2025

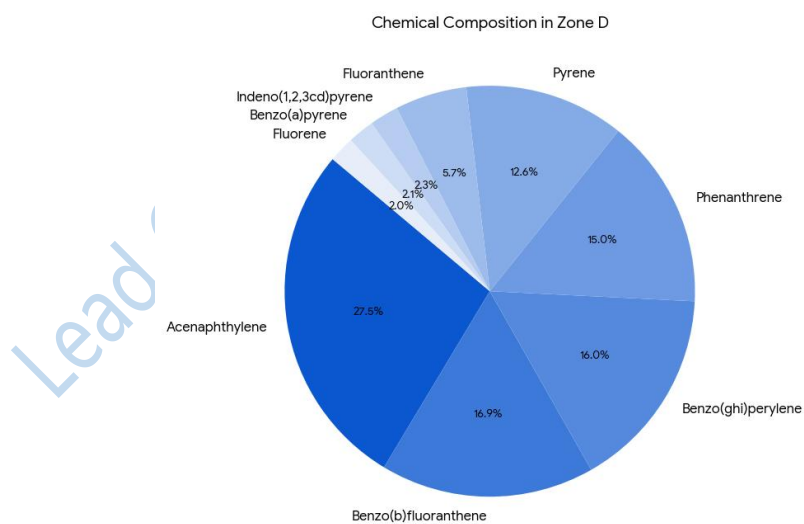


Figure 4.11 : Percentage Concentration of Individual PAHs in Zone D

Source : Research Field Work, 2025

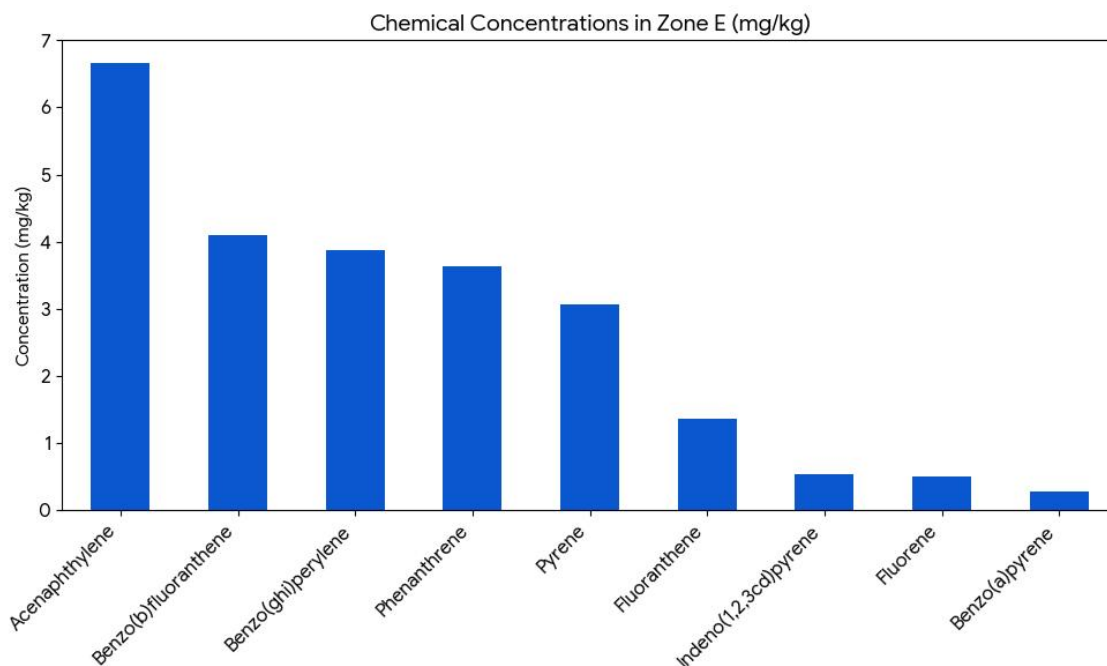


Figure 4.12 : Concentration of Individual PAHs in Zone E

Source : Research Field Work 2025

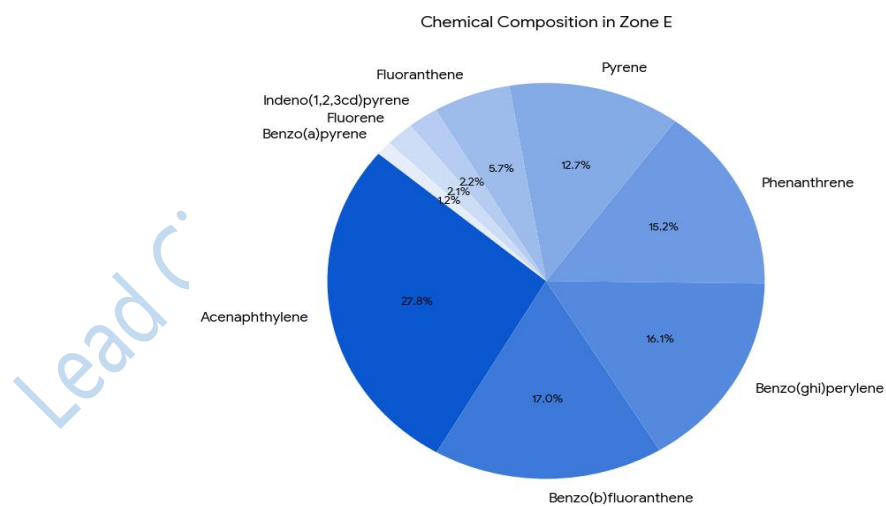


Figure 4.13 : Percentage Concentration of Individual PAHs in Zone E

Source : Research Field Work 2025

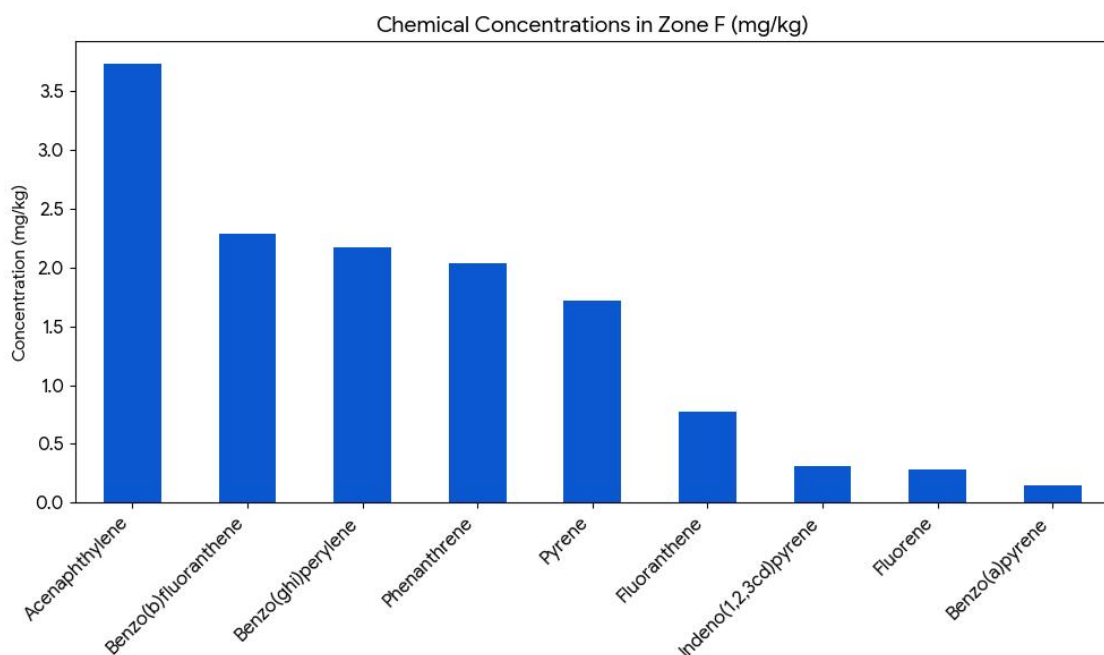


Figure 4.14 : Concentration of Individual PAHs in Zone F

Source : Research Field Work 2025

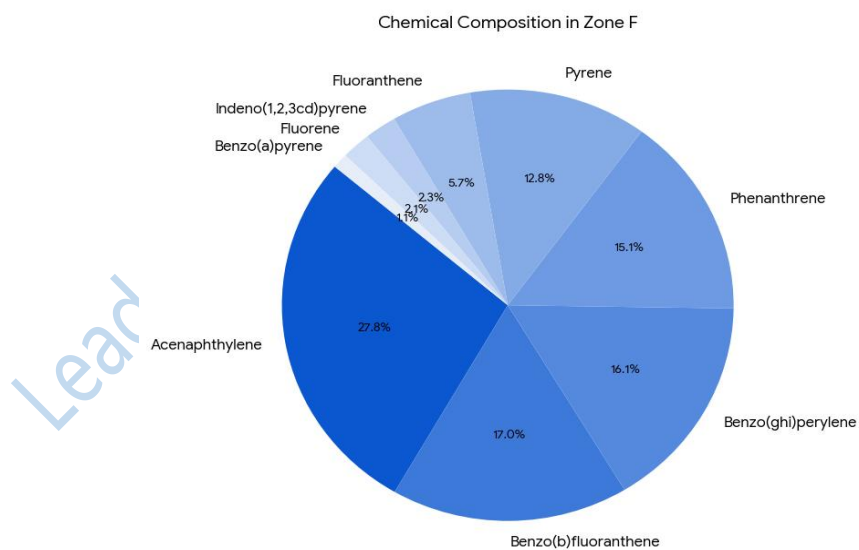


Figure 4.15 : Percentage Concentration of Individual PAHs in Zone F

Source : Research Field Work 2025

Table 4.3 PAHs Concentration by Number of Ring

PAHs	HMW	mn/sdHMW	LMW	mn/sdLMW	LMW / HMW	Σ16PAHs	ΣPAHcar	ring_2	ring_3	ring_4	ring_5	ring_6
Zone_A	8.4944	2.83±0.03	5.9606	1.99±1.52	.7017	14.4550	5.6420	-	5.9606	2.8524	2.7966	2.8454
Zone_B	12.9390	4.31±0.03	10.5741	3.52±3.02	.8172	23.5131	8.6058	-	10.5741	4.3332	4.2833	4.3225
Zone_C	6.9305	2.31±0.03	5.6052	1.87±1.60	.8088	12.5357	4.6335	-	5.6052	2.2970	2.3422	2.2913
Zone_D	9.0175	3.01±0.07	7.2463	2.42±2.07	.8036	16.2638	6.0481	-	7.2463	2.9695	3.0859	2.9622
Zone E	13.2160	4.41±0.03	10.8085	3.60±3.09	.8178	24.0245	8.7868	-	10.8085	4.4292	4.3684	4.4183
Zone F	7.4012	2.46±0.02	6.0613	2.02±1.73	.8190	13.4625	4.9173	-	6.0613	2.4839	2.4395	2.4778

Zone A NORTH, Zone B WEST, Zone C EAST, Zone D SOUTH, Zone E centre of the dumpsite and Zone F 500m away from dump site, HMW

(high molecular weight PAHs), LMW (low molecular weight PAHs), ΣPAHcar (total carcinogenic PAHs) 2-ring (PAHs with two aromatic ring)

3-ring (PAHs with three aromatic ring) 4-ring (PAHs with four aromatic ring) 5-ring (PAHs with five aromatic ring) 6-ring (PAHs with six

aromatic ring), LM/HM (ration of low molecular weight PAHs to high molecular weight PAHs).

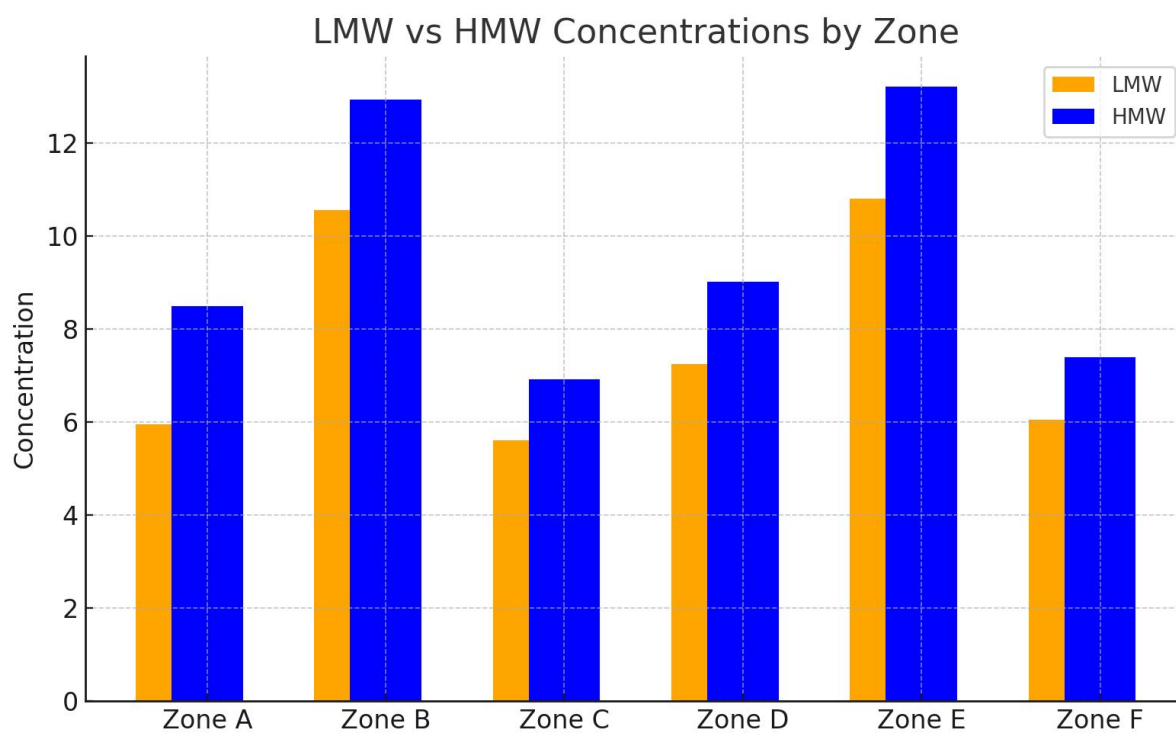


Figure 4.16 : Low Molecular Weight and High Molecular Weight PAHs Concentration for each Zones

Source : Research Field Work, 2025

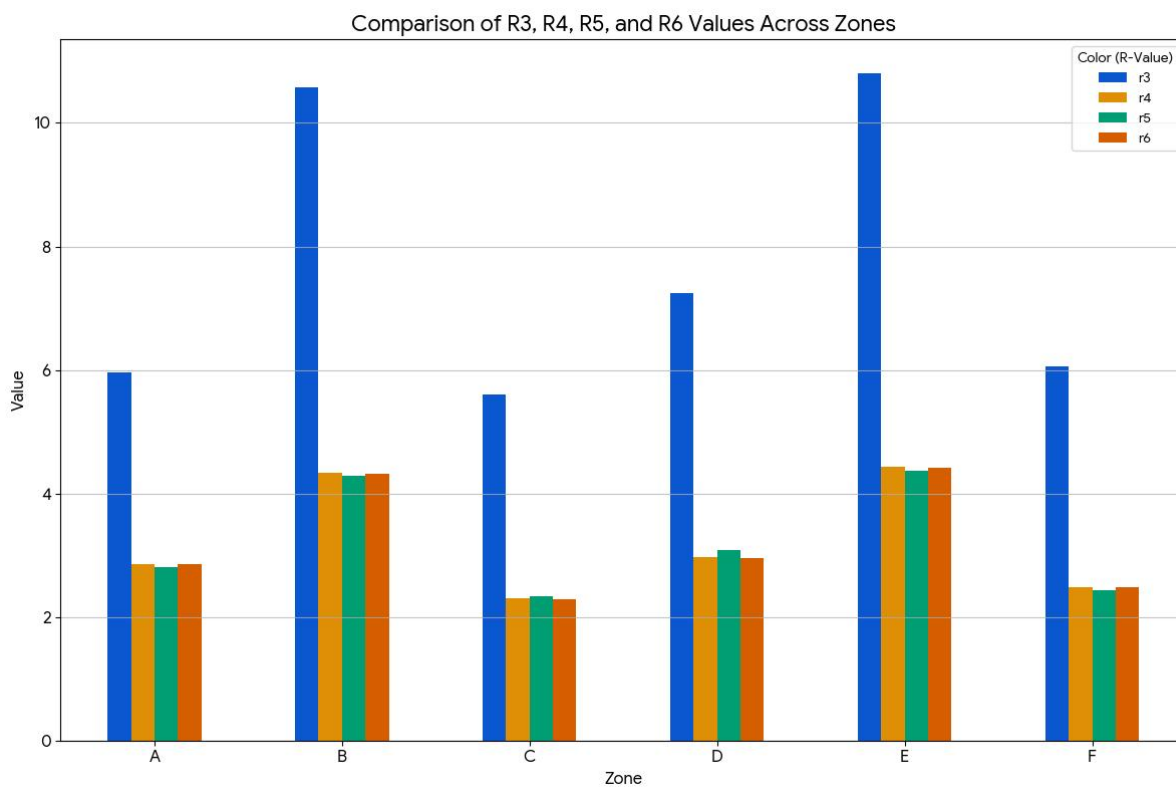


Figure 4.17 : PAHs Concentration by Number of Rings in each Zones

Source : Research Field Work, 2025

Table 4.4 PAHs Diagnostic Ratios

	Fla/(fla+pyr)	Icdp/(Icdp+Bghip)	Fla/Pyr
Zone A	0.3093	0.1232	0.4478
Zone B	0.3093	0.1232	0.4478
Zone C	0.3093	0.1232	0.4478
Zone D	0.3093	0.1232	0.4478
Zone E	0.3093	0.1232	0.4478
Zone F	0.3093	0.1232	0.4478
Petrogenic	< 0.4	< 0.5	< 1
Pyrogenic	> 0.5	> 0.5	> 1

Table 4.5 Total Equivalent Factor_{TEF} Individual PAHs

PAHs	TEF	Rfd-value(mg/kg/day)
Banzo(a)pyrene	1	-
Pyrene	0.001	0.03
Indeno(1,2,3,cd)pyrene	0.1	0.0003
Chrysene	0.01	0.001
Benz(a)anthracene	0.1	0.0003
Acenaphthylene	0.001	0.04
Fluorene	0.001	0.04
Anthracene	0.01	0.03
Dibenz(a,h)anthracene	1	
Benzo(k)fluoranhene	0.1	0.0003
Naphthalene	0.01	0.02

Table 4.6 Carcinogenic Potency of PAHs in Ajakanga Waste Dumpsite

Carcinogenic PAHs	TEF	BaPeq					
		<u>Zone A</u>	Zone B	Zone C	Zone D	Zone E	Zone F
Benzo(b)Fluoranthene	0.1	0.2633	0.4	0.212	0.2741	0.4089	0.2293
Benzo(a)Pyrene	1	0.1634	0.2832	0.2218	0.3447	0.2797	0.1465
Indeno(123-cd)Pyrene	0.1	0.0351	0.0533	0.0282	0.0365	0.0545	0.0305
Benzo(ghi)Perylene	0.01	0.0249	0.0379	0.0201	0.026	0.0387	0.0217
Acenaphthylene	0.001	0.0033	0.0065	0.0035	0.0045	0.0067	0.0037
Fluoranthene	0.001	0.0009	0.0013	0.0007	0.0009	0.0014	0.0008
Fluorene	0.001	0.0003	0.0005	0.0003	0.0003	0.0005	0.0003

Phenanthrene	0.001	0.0023	0.0036	0.0019	0.0024	0.0036	0.002
Pyrene	0.001	0.002	0.003	0.0016	0.0021	0.0031	0.0017
Total		0.4955	0.7893	0.4901	0.6915	0.797	0.4366

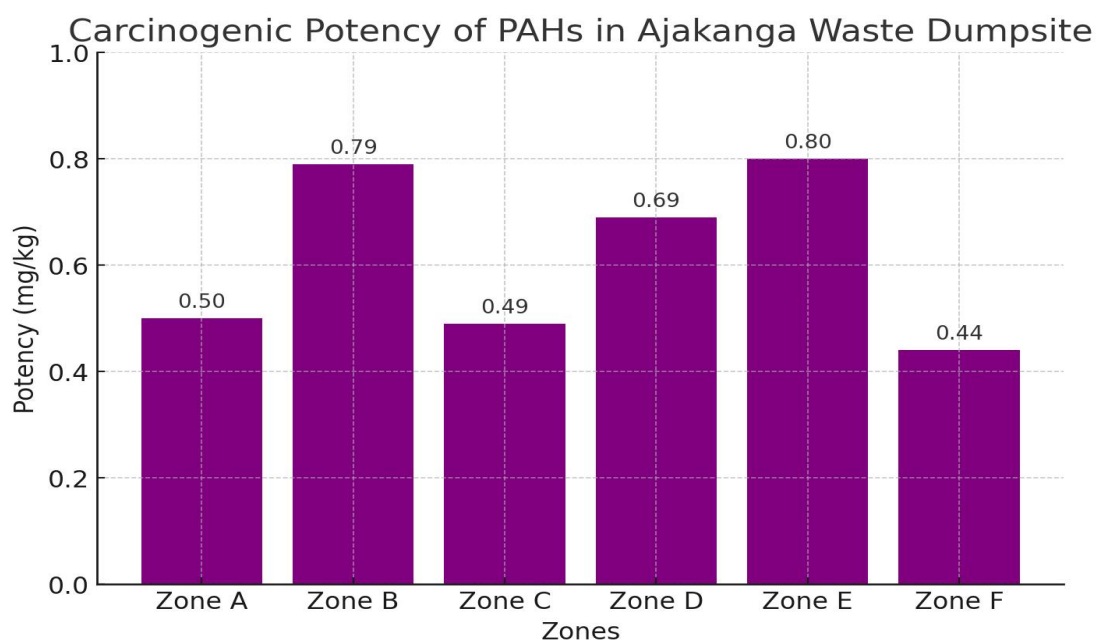


Figure 4.18 : Carcinogenic Potency of PAHs In Ajakanga Waste Dumpsite

Source : Research Field Work, 2025

Table 4.7 Parameters Used in Calculating the Lifetime Carcinogenic Risk Assessment

Variable Definition	Symbol	Unit	Children	Adult
Body weight	BW	KG	15	60
Exposure Frequency	ED	year	3	10
Air inhalation rate soil	IRsoil	Mg/d	400	200
Average lifespan	AT	day	70×365	70×365
Exposure duration	ED	year	250	250
Skin exposure area	SA	cm ² /d	1600	4350
Soil particle emission factor	PEF	m ³ /kg	1.36×10 ⁹	1.36×10 ⁹
Skin adhesion factor	AF	mg/cm ²	0.2	0.13
Skin adsorption parameter	ABS	-	0.13	0.13

**Table 4.8 Lifetime Cancer Risk Calculation for Children and Adult
(ingestion, inhalation and dermal)**

PAH	ZONE A		ZONE B		ZONE C		ZONE D		ZONE E		ZONE F	
	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad	Ch	Ad
Ace	1.52E-8	1.25E-8	3.03E-8	2.48E-8	1.60E-8	1.31E-8	2.07E-8	1.70E-8	3.09E-8	2.53E-8	1.74E-8	1.42E-8
Bap	7.60E-7	6.20E-7	1.30E-6	1.10E-6	1.00E-6	8.40E-7	1.60E-6	1.30E-6	1.30E-6	1.10E-6	6.80E-7	5.60E-7
BbF	1.20E-6	9.99E-7	1.90E-6	1.50E-6	9.80E-7	8.05E-7	1.27E-6	1.04E-6	1.90E-6	1.56E-6	1.06E-6	8.70E-7
Flu	4.1E-9	3.3E-9	6.2E-9	5.1E-9	3.3E-9	2.7E-9	4.3E-9	3.5E-9	6.4E-9	5.2E-9	3.6E-9	2.9E-9
IcdP	1.62E-7	1.3E-7	2.47E-7	2.02E-7	1.31E-7	1.07E-7	1.69E-7	1.39E-7	2.53E-7	2.07E-7	1.42E-7	1.16E-7
Flu	1.5E-9	1.2E-9	2.3E-9	1.8E-9	1.2E-9	1.0E-9	1.5E-9	1.3E-9	2.3E-9	1.9E-9	1.3E-9	1.1E-9
Phena	1.08E-8	8.9E-9	1.65E-8	1.35E-8	8.8E-9	7.2E-9	1.13E-8	9.3E-9	1.69E-8	1.38E-8	9.5E-9	7.7E-9
pyr	9.1E-9	7.5E-9	1.39E-8	1.14E-8	7.4E-9	6.0E-9	9.5E-9	7.8E-9	1.42E-8	1.16E-8	8.0E-9	6.5E-9
Bpy	1.15E-7	9.47E-8	1.76E-7	1.438E-7	9.32E-8	7.63E-8	1.21E-7	9.86E-8	1.80E-7	1.47E-7	1.00E-7	8.25E-8
Sum	2.29E-6	1.88E-6	3.66E-6	3.00E-6	2.27E-6	1.86E-6	3.21E-6	2.62E-6	3.70E-6	3.03E-6	2.03E-6	1.66E-6

Table 4.9 Hazard Quotient in Ajakanga Waste Dumpsite

	Children				Adult			
	Ingestion	Dermal	Inhalation	Total	Ingestion	Dermal	Inhalation	Total
Zone A	2.87×10^{-4}	3.00×10^{-5}	NG	3.17×10^{-4}	1.20×10^{-4}	2.37×10^{-5}	NG	1.43×10^{-4}
Zone B	4.76×10^{-4}	4.95×10^{-5}	NG	5.25×10^{-4}	1.98×10^{-4}	3.92×10^{-5}	NG	2.38×10^{-4}
Zone C	2.25×10^{-4}	2.62×10^{-5}	NG	2.79×10^{-4}	1.05×10^{-4}	2.08×10^{-5}	NG	1.26×10^{-4}
Zone D	3.26×10^{-4}	3.39×10^{-5}	NG	3.60×10^{-4}	4.89×10^{-4}	2.69×10^{-5}	NG	4.89×10^{-4}
Zone E	4.86×10^{-4}	5.06×10^{-5}	NG	5.37×10^{-4}	2.03×10^{-4}	4.01×10^{-5}	NG	2.43×10^{-4}
Zone F	2.73×10^{-4}	2.84×10^{-5}	NG	3.01×10^{-4}	1.36×10^{-4}	2.25×10^{-5}	NG	1.59×10^{-4}

Table 4.10 ILCR and Hazard Index in Ajakanga Waste Dumpsite

	Children	Adult
ILCR _{ingestion}	2.11×10^{-6}	1.40×10^{-6}
ILCR _{dermal}	7.49×10^{-7}	9.45×10^{-7}
ILCR _{inhalation}	8.00×10^{-10}	5.33×10^{-10}
ILCR _{total}	2.96×10^{-6}	2.34×10^{-6}
HQ	4.04×10^{-4}	2.48×10^{-4}

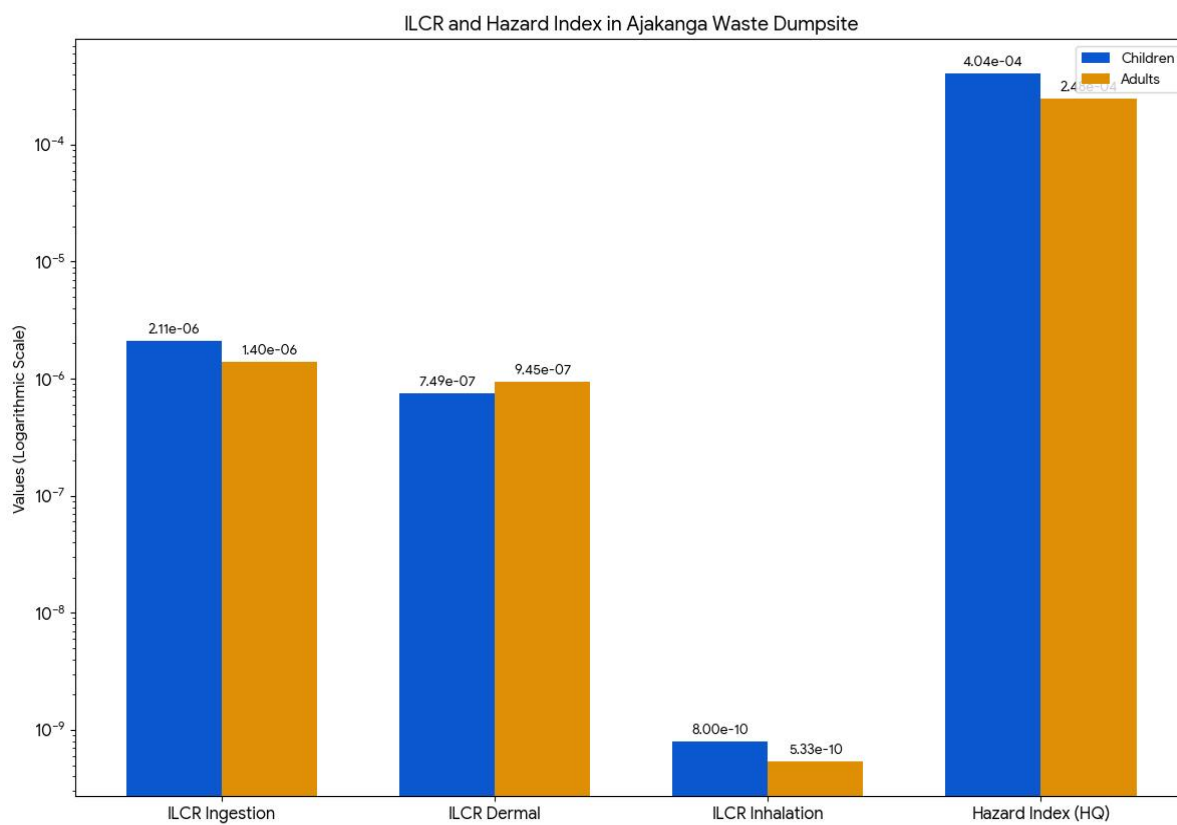


Figure 4.19 : Carcinogenic Potency of PAHs in Ajakanga Waste Dumpsite

Source : Research Field Work, 2025

4.2 Discussion of Findings

The concentrations of the sixteen priority PAHs identified by the United States Environmental Protection Agency (USEPA) were determined for each composite soil sample. Table 4.1 presents the concentrations of individual and total PAHs ($\Sigma_{16}\text{PAHs}$) across the five sampling zones and control site. The results reveal noticeable spatial variation in PAH levels, reflecting the influence of waste burning, leachate migration, and distance from the active disposal area.

The concentration of the 16 priority PAHs were determined in the soil samples from Ajakanga waste dumpsite between 1cm to 15 cm dept at six different point from the site represented as North 1, 2, & 3, West 1, 2, & 3, East 1, 2, & 3, South 1, 2, & 3, centre CH 1, 2, & 3, and control C 1, 2, & 3.

The result of the analysis for the 16 US EPA priority is presented in table 4.1 and figure 4.1 The minimum detection limit for GC-FID used for the analysis is 0.00015 mg/kg.

The highest concentration of total PAHs was recorded in West 1 (30.74 mg/kg), followed closely by Centre (30.15 mg/kg), while the lowest was found in Centre 1 (6.19 mg/kg)

This variation indicates a heterogeneous distribution of PAHs, strongly influenced by the intensity of waste combustion, waste composition, and micro-topographical differences that control pollutant dispersion¹, similar to other literature publication².

as show in figure 4.1. Acenaphthylene has the high value ranging from (1.69 - 8.58 mg/kg), Benzo(b)fluoranthene (1.12 - 5.26 mg/kg), Benzo(ghi)Perylene (0.98 - 4.98 mg/kg), Phenanthrene (0.92 - 4.68 mg/kg), Pyrene (0.78 - 3.93 mg/kg) Fluoranthene (0.35 - 1.76 mg/kg) respectively.

The highest concentration of total PAHs was recorded in Zone E (24.02 mg/kg), followed closely by Zone B (23.51 mg/kg), while the lowest was found in Zone C (12.54 mg/kg). This variation indicates a heterogeneous distribution of PAHs, strongly influenced by the intensity of waste combustion, waste composition, and micro-topographical differences that control pollutant dispersion as show in table 4.2 there are similar report for MSW dumpsites in Lagos $\Sigma_{16}\text{PAHs} = 18.2\text{--}25.7 \text{ mg/kg}$ ³ and Osun State $\Sigma_{16}\text{PAHs} = 10.4\text{--}22.6 \text{ mg/kg}$, ⁴ but exceed the background concentrations (<5 mg/kg) reported for uncontaminated soils by CCME⁵ These findings suggest that open burning and leachate infiltration are the principal contributors to PAH accumulation in the Ajakanga dumpsite soils

4.3 PAHs Concentrate

PAHs typically do not occur as individual compounds in the environment, but rather as part of a mixture. Their presence is usually assessed based on the total concentration of the combined PAHs.

9 out of the 16 priority PAHs were identified at five different point as show in Table 4.2 , the concentration of PAHs in Zone A, Zone B, Zone C, Zone D, Zone E and Zone F varies between below detection limit (BDL,<0.00015ppb) to 3.30 mg/kg, <0.00015 to 6.53 mg/kg, <0.00015 to 3.46 mg/kg, <0.00015 to 4.47 mg/kg, <0.00015 to 6.67 mg/kg, <0.00015 to 3.74 mg/kg respectively.

Zone E (centre) (24.02 mg/kg) with 23.0 % has the highest total PAHs level (Σ_{16} EPA PAHs)

Zone B (west) (23.51 mg/kg) with 22.6 %, has the second highest total of (Σ_{16} EPA PAHs) follow by Zone D (South) with (Σ_{16} EPA PAHs) (16.26 mg/kg) with 15.6 %, Zone A

(North) total PAHs ($\Sigma 16$ EPA PAHs) (14.46 mg/kg) with 13.9 %. Zone F (500m away from the dumpsite) total PAHs ($\Sigma 16$ EPA PAHs) (13.46 mg/kg) with 12.9 % and Zone C recorded the lowest total PAHs ($\Sigma 16$ EPA PAHs) 12.54 mg/kg with 12.0 % as show in figure 2 and 3.

Figure 4 and 5 reveal that, Acenaphthylene has the highest PAHs concentration of 3.30 mg/kg with 22.9 %, Benzo(b)fluoranthene 2.63 mg/kg with 18.2 %, Benzo(ghi)perylene 2.49 mg/kg with 17.2 %, Phenanthrene 2.34 mg/kg with 16.2%, Pyrene 1.97 mg/kg with 13.6%, Fluoranthene 0.88 mg/kg with 6.1%, Indeno(1,2,3cd) 0.35 mg/kg with 2.4 %, Fluorene 0.32 mg/kg with 2.2 % and Benzo(a)pyrene 0.16 mg/kg with 1.1 %

In zone B, as show in figure 6 and 7, Acenaphthylene has the highest PAHs concentration of 6.53 mg/kg with 27.8 %, Benzo(b)fluoranthene 4.00 mg/kg with 17.0 %, Benzo(ghi)perylene 3.79 mg/kg with 16.1 %, Phenanthrene 3.56 mg/kg with 15.1 %, Pyrene 2.99 mg/kg with 12.7 %, Fluoranthene 1.34 mg/kg with 5.7 %, Indeno(1,2,3cd)pyrene 0.53 mg/kg with 2.3 %, Fluorene 0.49 mg/kg with 2.1 % and Benzo(a)pyrene 0.28 mg/kg with 1.2 %.

In zone C, as show in figure 8 and 9, Acenaphthylene has the highest PAHs concentration of 3.46 mg/kg with 27.6 %, Benzo(b)fluoranthene 2.12 mg/kg with 16.9 %, Benzo(ghi)perylene 2.01 mg/kg with 16.0 %, Phenanthrene 1.89 mg/kg with 15.1 %, Pyrene 1.59 mg/kg with 12.7 %, Fluoranthene 0.71 mg/kg with 5.7 %, Indeno(1,2,3cd)pyrene 0.28 mg/kg with 2.2 %, Fluorene 0.26 mg/kg with 2.1 % and Benzo(a)pyrene 0.22 mg/kg with 1.8 %.

In zone D, as show in figure 10 and 11, Acenaphthylene has the highest PAHs

concentration of 4.47 mg/kg with 27.5 %, Benzo(b)fluoranthene 2.74 mg/kg with 16.9 %, Benzo(ghi)perylene 2.60 mg/kg with 16.0 %, Phenanthrene 2.44 mg/kg with 15.0 %, Pyrene 2.05 mg/kg with 12.6 %, Fluoranthene 0.92 mg/kg with 5.7 %, Indeno(1,2,3cd)pyrene 0.37 mg/kg with 2.3 %, Benzo(a)pyrene 0.34 mg/kg with 2.1 % and Fluorene 0.33 mg/kg with 2.0 % respectively.

In zone E, as show in figure 12 and 13, Acenaphthylene has the highest PAHs concentration of 6.67 mg/kg with 27.8 %, Benzo(b)fluoranthene 4.09 mg/kg with 17.0 %, Benzo(ghi)perylene 3.87 mg/kg with 16.1 %, Phenanthrene 3.64 mg/kg with 15.2 %, Pyrene 3.06 mg/kg with 12.7 %, Fluoranthene 1.37 mg/kg with 5.7 %, Indeno(1,2,3cd)pyrene 0.54 mg/kg with 2.2 %, Fluorene 0.50 mg/kg with 2.1 % and Benzo(a)pyrene 0.23 mg/kg with 1.2 % respectively.

In zone F as show in figure 14 and 15, Acenaphthylene has the highest PAHs concentration of 3.74 mg/kg with 27.8 %, Benzo(b)fluoranthene 2.29 mg/kg with 17.0 %, Benzo(ghi)perylene 2.17 mg/kg with 16.1 %, Phenanthrene 2.04 mg/kg with 15.1 %, Pyrene 1.72 mg/kg with 12.8 %, Fluoranthene 0.77 mg/kg with 5.7 %, Indeno(1,2,3cd)pyrene 0.31 mg/kg with 2.3 %, Fluorene 0.28 mg/kg with 2.1 % and Benzo(a)pyrene 0.15 mg/kg with 1.1 % respectively.

In all the zone, the PAHs concentration follow this order, Acenaphthylene>Benzo(b)fluoranthene>Benzo(ghi)perylene>Phenanthrene>Pyrene>Fluoranthene>Indeno(1,2,3cd)pyrene>Fluorene>Benzo(a)pyrene except in zone D where the concentration of Benzo(a)pyrene is higher than the concentration fluorene.this result is also similar to other publication².

PAHs with low molecular weight (LMW PAHs) were present in all the samples at high concentration, this also correlate with other research publish^{6,7,8}.

Zone E has the highest value of 10.8085mg/kg and Zone C has the lowest value of 5.6052 mg/kg and are well distributed in all the samples as show in figure 16 and table 4.3.

Naphthalene, Acenaphthene, and Anthracene were not detected in all the samples, while Acenaphthylene, Fluorene and Phenanthrene were all detected in all the samples with Acenaphthylene been the dominant follow by Phenanthrene and Fluorene has the lowest concentration among the low molecular weight PAHs detected.

The low molecular weight PAHs consist of 2-ring and 3-ring PAHs, but the 2-ring PAHs (Naphthalene) was not detected in all the samples.

The high molecular weight PAHs (HMW PAHs) consist of 4-ring, 5-ring and 6-ring, they were well distributed in all the sample analyzed. Zone E has the highest concentration value of 13.2160mg/kg and Zone C has the lowest concentration of 6.9305mg/kg, Benzo(b)Fluoranthene has the highest total concentration of 17.87mg/kg, Benzo(ghi)Perylene 16.93mg/kg, Pyrene 13.38mg/kg, Fluoranthene 5.99mg/kg, Indeno(1,2,3-cd)Pyrene 2.38mg/kg and Benzo(a)Pyrene 1.43mg/kg. Chrysene, Benz(a)anthracene, Benzo(k)Fluoranthene and Dibenzo(a,h) anthracene was not detected in all the samples.

High molecular weight PAHs is dominant in all the zones which implied sources such as incomplete combustion of organic matter, vehicle exhaust or industrial discharge this also similar to research value of sources of PAHs^{9,10}.

4.4 PAHs Distribution Pattern in Ajakanga Waste Dumpsite

Polycyclic Aromatic Hydrocarbons (PAHs) are often classified according to the number of fused aromatic rings into Low Molecular Weight (LMW) PAHs (2–3 rings) and High Molecular Weight (HMW) PAHs (4–6 rings). This classification provides valuable information on the origin, environmental behavior, and potential toxicity of the detected compounds. The relative abundance of these two groups in the analyzed soil samples from the Ajakanga Municipal Solid Waste (MSW) Dumpsite is presented in Table 4.3.

The composing structure of PAHs detected in the samples by the number of rings are shown in fig 17 and table 4.3, 2 ring PAHs were not detected in all the samples analysed, 3 ring has the highest concentration of 46.256 mg/kg, 4 ring has 19.3652 mg/kg, 6 ring has 19.3175 mg/kg and 5 ring has the lowest 19.3159 mg/kg.

As shown in Table 4.3, HMW PAHs were dominant in all the five zones (A, B, C, D, and E), The LMW/HMW ratios ranged from 0.70 to 0.82, with an average value below unity (0.79), indicating a predominantly pyrogenic origin of PAHs in the Ajakanga dumpsite soils.

Zones B and E, which exhibited the highest total PAH concentrations 23.51 mg/kg and 24.02 mg/kg, respectively, also showed strong dominance of HMW PAHs such as benzo[a]pyrene, benzo[b]fluoranthene, and indeno[1,2,3-cd]pyrene. These compounds are typically formed during high-temperature combustion processes, including the open burning of municipal waste, biomass, and plastic materials all common activities at the dumpsite.

The predominance of HMW PAH in all zones is consistent with observations from other

studies on municipal waste sites in Nigeria and elsewhere. For instance, there is a reported HMW dominance in soils around the Solous dumpsite in Lagos³, and another similar pattern was found in urban waste burning areas, attributing them to incomplete combustion of organic matter¹¹.

Furthermore, HMW PAHs are known for their higher carcinogenic potential, stronger adsorption to soil organic matter, and lower volatility, making them more persistent and environmentally hazardous compared to LMW congeners. This persistence poses long-term risks of bioaccumulation and ecological toxicity, particularly in areas used for farming or inhabited by local communities.

Overall, the compositional analysis indicates that the PAH contamination at the Ajakanga dumpsite is largely driven by pyrogenic processes, primarily open burning of solid waste and biomass, with localized petrogenic contributions from oil-based residues and leachate migration^{6,7}.

4.5 Source Identification Using Molecular Diagnostic Ratios

Identifying the potential sources and origins of polycyclic aromatic hydrocarbons (PAHs) in the environment is essential for evaluating associated environmental risks. PAHs derived from petrogenic origins are typically dominated by low molecular weight (LMW) compounds, consisting of two- to three-ring structures. In contrast, PAHs from pyrogenic sources generally exhibit a higher proportion of high molecular weight (HMW) PAHs, comprising four to six aromatic rings⁸. This distribution reflects the formation conditions. LMW PAHs are typically produced under low to moderate temperatures, such as during biomass burning, whereas HMW PAHs are formed through high-temperature processes.

like those occurring in vehicle exhaust emissions.

To further distinguish between PAHs sources, diagnostic ratios are employed. These ratios take advantage of the chemical and physical stability of specific PAH compounds, offering a useful tool for source identification^{9,10}.

To complement the compositional pattern analysis, the molecular diagnostic ratio (MDR) approach was employed to distinguish between the possible origins of PAHs detected in the Ajakanga dumpsite soils. Diagnostic ratios are widely used as reliable indicators to infer whether PAHs originate from petrogenic sources (derived from petroleum and oil residues) or pyrogenic sources formed by incomplete combustion of organic materials such as wood, coal, or refuse¹².

Diagnostic ratio of the PAHs obtained in Ajakanga waste dumpsite are show in table 4.3

The ration of fluoranthene/(fluoranthene +pyrene) in all the zones were less than 0.4, this implied that the source of PAHs was from Petrogenic sources¹³, furthermore the use of [Indeno(1,2,3-cd)Pyrene/Indeno(1,2,3-cd)Pyrene + Benzo(ghi)Perylene] ratio give a value that is less than 0.5 for all the zones which also implied that the sources of PAHs is petrogenic¹¹, more also the use of Fluoranthene/Pyrene ratio give a value less than 1 which also implied a petrogenic source of PAHs¹². The ratio of (LMW PAHs/HMW PAHs) is less than 1 in all the zone, and varies from (0.7017 mg/kg to 0.8190 mg/kg) which indicate that the sources of pollution is pyrogenic which originated from combustion process of organic matter ¹³ this was also related to research work ¹⁰ the LMW PAHs has 44.37% while the HMW PAHs has 55.63%

4.6 Comparison of PAHs Concentrations with National and International Standards

Assessing the concentration of Polycyclic Aromatic Hydrocarbons (PAHs) relative to established environmental guidelines is essential for determining the degree of contamination and potential ecological and health risks associated with soil exposure at the Ajakanga dumpsite. The measured total PAH concentrations in the five sampling zones (ranging from 12.54 to 24.02 mg/kg) were compared against national and international regulatory standards and value.

When compared with these benchmarks, the total PAH concentrations in all zones (12.54–24.02 mg/kg) at the Ajakanga dumpsite exceed both the DPR intervention value (10 mg/kg) and the EU and WHO soil quality guidelines (1 mg/kg), indicating that the site is heavily polluted. The contamination levels are high enough to pose potential ecological and health hazards, particularly due to the dominance of high molecular weight (HMW) PAHs, many of which are carcinogenic, mutagenic, and teratogenic (e.g., benzo[a]pyrene, indeno[1,2,3-cd]pyrene, and benzo[k]fluoranthene).

Comparatively, the PAH levels recorded in this study are consistent with findings from other Nigerian dumpsites. For instance, there was a reported total PAH concentrations of 18.25 mg/kg in soils around the Solous dumpsite³, Lagos, while another recorded 21.7 mg/kg in Bodija dumpsite soils⁵, Ibadan. Similarly, there was an observed concentrations ranging from 11.2 to 28.6 mg/kg in urban waste-impacted soils¹⁴. These values align closely with those obtained at Ajakanga, confirming that uncontrolled waste burning and leachate infiltration are significant contributors to PAH accumulation in Nigerian

municipal dumpsites.

On a global scale, the concentration levels at Ajakanga are higher than those reported in controlled landfills of developed countries. There was a reported mean total PAHs of 2.1–6.4 mg/kg in European urban soils³, and a recorded 4.8–9.2 mg/kg in Chinese managed waste sites¹⁵. The disparity underscores the influence of poor waste management practices, open dumping, and burning prevalent in developing nations, leading to greater PAH emissions.

The exceedance of regulatory limits in this study suggests potential long-term environmental and human health implications. Prolonged exposure to PAH-contaminated soils through inhalation of dust particles, dermal contact, or ingestion of crops grown on contaminated land could increase the risk of respiratory illnesses, skin disorders, and cancer among residents and waste workers. Moreover, PAHs adsorbed to soil particles may undergo leaching into groundwater or bioaccumulation in food chains, posing secondary risks to ecosystems.

In summary, the PAH concentrations in soils from the Ajakanga dumpsite exceed safe limits prescribed by national (DPR) and international (EU, WHO, CCME) standards, indicating significant contamination and potential health risks. The findings emphasize the urgent need for environmental monitoring, remediation, and strict regulation of open waste burning to mitigate PAH exposure within the study area

4.7 Estimation of Carcinogenic Potency

Polycyclic Aromatic Hydrocarbons (PAHs) are a major class of environmental pollutants with well documented carcinogenic, mutagenic, and teratogenic effects¹⁶.

Assessing the health and ecological implications of their presence in the Ajakanga dumpsite soil is therefore essential to evaluate potential exposure risks to both humans and the surrounding ecosystem.

This is commonly estimated by expressing the concentrations of individual carcinogenic PAH compounds in terms of their benzo(a)pyrene equivalents (BaPeq).

$$\text{Total BaPeq} = \sum (C_i * \text{TEF}_i) \text{ equ (1)}$$

C_i represents the concentration of each individual PAH, while TEF_i denotes its corresponding toxic equivalency factor. For benzo(a)pyrene, the TEF is assigned a reference value of one. The toxic equivalent (TEQ) for each PAH was determined using the TEF values proposed by Nisbet and LaGoy, which allow for the estimation of cumulative carcinogenic potential PAH mixtures based on their relative toxicities¹⁴, table 4.5 show the TEF and RFD value for each PAHs.

The carcinogenic potency of polycyclic aromatic hydrocarbons (PAHs) in soils from the Ajakanga waste dumpsite was evaluated using the toxic equivalency factor (TEF) approach, expressing each compound in terms of its benzo(a)pyrene equivalent (BaPeq).

The total BaPeq values across the sampling zones ranged from 0.4366 mg/kg Zone F to 0.7970 mg/kg Zone E, with a mean value of 0.6167 mg/kg, indicating a moderate carcinogenic potential in the study area. The highest carcinogenic potency observed in Zone E the central portion of the dumpsite may be attributed to higher accumulation of

combustion residues, petroleum wastes, and organic matter degradation, which are known contributors to elevated PAH concentrations in dumpsite soils.

Among the detected carcinogenic PAHs, benzo(a)pyrene (BaP), benzo(b)fluoranthene (BbF), indeno(1,2,3-cd)pyrene (IcdP), and benzo(ghi)perylene (BghiP) exhibited the highest toxicity contributions. BaP, a Group 1 carcinogen classified by the International Agency for Research on Cancer (IARC), contributed substantially to total BaPeq, with concentrations ranging from 0.1465 mg/kg Zone F to 0.3447 mg/kg Zone D. This dominance of BaP aligns with findings from other journal, who reported that BaP contributed over 40% of total carcinogenic PAH burden in soils of Hamedan County²⁰, Iran. The predominance of high molecular weight (HMW) PAHs such as BbF, BaP, and IcdP in the Ajakanga soils further supports a pyrogenic origin, consistent with the diagnostic ratio analysis presented earlier in this study. Pyrogenic PAHs typically arise from incomplete combustion of organic waste, plastics, and fossil fuels¹⁸. The elevated BaPeq values in Zones B, D, and E suggest active waste burning and vehicular emissions within and around the dumpsite, corroborating findings linked higher carcinogenic PAH loads in urban landscapes to anthropogenic combustion activities¹².

Comparatively, the mean BaPeq of 0.6167 mg/kg obtained in this study is lower than the 1 mg/kg threshold recommended by the World Health Organization (WHO) for soils with high carcinogenic concern, implying that while Ajakanga soil shows a moderate carcinogenic burden, the immediate risk level remains within tolerable limits. Similar moderate values 0.43–0.92 mg/kg were reported in coastal sediments of Morocco²¹. However, the dominance of carcinogenic PAHs approximately 98 % of total BaPeq

suggests a concerning long term exposure risk, especially for local populations engaged in waste picking and open burning activities. This pattern is consistent with studies who reported that chronic exposure to similar PAH concentrations in indoor dust and soil could increase lifetime cancer risks through ingestion and dermal contact²⁴.

Overall, the carcinogenic potency data from Ajakanga dumpsite imply that the carcinogenic risk from PAHs is moderate but significant, and sustained exposure could elevate potential health hazards. Continuous environmental monitoring and remediation strategies such as bioremediation, phytoremediation, or soil washing are therefore recommended to mitigate further accumulation and associated risks²⁰.

4.8 Incremental Lifetime Carcinogenic Risks (ILCRs).

ILCR is a quantitative estimate used to assess the potential cancer risk associated with long term exposure to carcinogenic substances. In this study, the ILCR for PAHs in soil was evaluated in accordance with guidelines provided by the United States Environmental Protection Agency (USEPA) standards^{13,14,17,18}.

In this study, ILCR values for PAHs in the Ajakanga waste dumpsite soils were computed for children and adults through three primary exposure pathways ingestion, dermal contact, and inhalation using standard U.S. EPA models and site-specific parameters.

The ILCR equation for soil is as follows:

$$\begin{aligned}
ILCR_{Ingestion} &= \frac{CS \times \left(CSF_{Ingestion} \times \sqrt[3]{\frac{BW}{70}} \right) \times IR_{soil} \times EF \times ED}{BW \times AT \times 10^6} \\
ILCR_{Dermal} &= \frac{CS \times \left(CSF_{Dermal} \times \sqrt[3]{\frac{BW}{70}} \right) \times SA \times AF \times ABS \times EF \times ED}{BW \times AT \times 10^6} \\
ILCR_{Inhalation} &= \frac{CS \times \left(CSF_{Inhalation} \times \sqrt[3]{\frac{BW}{70}} \right) \times IR_{air} \times EF \times ED}{BW \times AT \times PEF} \\
ILCR &= ILCR_{Ingestion} + ILCR_{Dermal} + ILCR_{Inhalation}
\end{aligned}$$

In the ILCR calculation, CS represents the toxic equivalent concentration of monomeric PAHs in the soil sample, expressed in milligrams per kilogram (mg/kg). The value 10^{-6} serves as a unit conversion factor to adjust PAH concentrations appropriately for risk assessment calculations. The cancer slope factor (CSF), measured in $\text{mg}^{-1} \cdot \text{kg} \cdot \text{day}^{-1}$, quantifies the carcinogenic potential of individual PAHs and is based on the potency of benzo(a)pyrene (BaP), which serves as the reference compound¹⁶.

The parameter values applied in this assessment, including exposure duration, frequency, and body weight, were sourced from the Guidelines for Site Environmental Assessment (DB11/T 656-2009).

The lifetime carcinogenic risk (ILCRs) less than or equal to 10^{-6} are regarded basically as negligible lifetime cancer risk, ILCRs between 10^{-6} and 10^{-4} are regarded as low risk while ILCRs greater than 10^{-4} are regarded as high potential health risk¹⁶.

4.8.1 Interpretation of Incremental Lifetime Carcinogenic Risk (ILCR)

The estimated total ILCR values ranged from 2.34×10^{-6} for adults to 2.96×10^{-6} for children, indicating that both groups fall within the acceptable risk range $10^{-6} - 10^{-4}$ recommended by the U.S. EPA 2023 and the World Health Organization (WHO). These

results imply that, although there is measurable carcinogenic risk, it remains relatively low under current exposure conditions. Nonetheless, continued accumulation of PAHs in surface soils could elevate long-term risk, particularly for children, who are more vulnerable because of higher soil-ingestion rates and lower body weight¹⁷

Among the three exposure routes, dermal contact contributed the largest fraction 70 % of total ILCR for both adults and children, followed by ingestion 25 % and inhalation 5 %. This dominance of the dermal pathway is consistent with the hydrophobic nature of high-molecular-weight PAHs, which adhere strongly to soil particles and are efficiently transferred through skin contact¹⁸. Comparable exposure patterns were reported in sediments from Ikpoba River, South-South Nigeria, where dermal absorption accounted for over two-thirds of total cancer risk¹⁹.

Spatially, Zones B, D, and E recorded slightly higher ILCR values than the peripheral zones A, C, and F. This spatial pattern aligns with the higher BaP_{eq} concentrations and combustion related PAH loads discussed previously, confirming that localized waste burning and hydrocarbon residues are principal contributors to incremental cancer risk at the site. The moderate ILCR range obtained at Ajakanga $10^{-6} - 10^{-5}$ is comparable to findings by²⁰ for PAH-contaminated soils in southeastern Nigeria and by²¹ for coastal sediments in Morocco. However, it is lower than the elevated ILCR $> 10^{-4}$ reported by²² in agricultural soils of Hamedan County, Iran, and by²³ in heavily industrialized Chinese soils.

Although the current ILCR values fall within the low-risk category, prolonged exposure, bioaccumulation, and potential dietary transfer through crops cultivated near the dumpsite

may gradually raise human health risks. low-level chronic exposure to PAHs in soil and dust can have cumulative carcinogenic effects, especially among children and occupationally exposed adults²⁴.

Consequently, while immediate cancer risk from PAHs at Ajakanga dumpsite is not alarming, the findings underscore the necessity for continuous monitoring, public-health awareness, and remediation interventions such as bioremediation, soil washing, and controlled waste-management practices. These measures would minimize further PAH buildup and safeguard residents and waste-site workers against long-term carcinogenic impacts.

4.9 Interpretation of Hazard Quotient (HQ) and Hazard Index (HI)

The Hazard Quotient (HQ) represents the ratio of the estimated daily intake (EDI) of a contaminant to its reference dose (RfD), while the Hazard Index (HI) is the cumulative sum of HQs from multiple exposure pathways or compounds. An HQ or HI value below 1.0 indicates that non-carcinogenic effects are unlikely, whereas values greater than 1.0 signify potential adverse health impacts²⁵.

The HQ values for individual exposure pathways ingestion, dermal contact, and inhalation in soils from Ajakanga waste dumpsite ranged from 1.05×10^{-4} to 4.89×10^{-4} for adults and 2.25×10^{-4} to 5.06×10^{-5} for children. The corresponding Hazard Index (HI) values were below 1.0 for both adults and children across all sampling zones, signifying that non-carcinogenic health effects due to PAH exposure are negligible under present environmental conditions. However, children recorded slightly higher HQ and HI values than adults, reflecting their higher vulnerability owing to soil ingestion tendencies,

lower body weight, and longer potential exposure duration¹⁷.

Among the exposure routes, dermal contact contributed the largest share to the overall HI followed by ingestion while inhalation contribution was negligible. This exposure trend aligns with the hydrophobic and lipophilic nature of PAHs, which favors adsorption onto soil particles and facilitates dermal absorption upon direct contact¹⁸.

A similar dominance of the dermal route was observed in sediments from the Ikpoba River in southern Nigeria¹⁹ and also in Moroccan coastal sediments²¹.

Spatially, Zones B and E recorded the highest HQ and HI values, consistent with their elevated PAH concentrations and carcinogenic potencies previously discussed. This spatial pattern suggests that areas closer to the central portion of the dumpsite experience more intense contamination due to waste combustion, vehicular emissions, and organic degradation processes.

When compared with other studies, the mean HI values at Ajakanga as shown in 4.9 are notably lower than those reported in highly industrialized regions²².

Similarly, HI values between 0.35 and 1.84 in industrial soils of Northwest China were observed²³, where continuous PAH accumulation from coal combustion posed considerable health threats. The lower HI values in the Ajakanga dumpsite indicate that while PAHs are present, the overall non-carcinogenic risk remains within the safe threshold.

Nevertheless, the potential for cumulative exposure through food-chain transfer, groundwater percolation, and particulate resuspension warrants continuous monitoring. It has been emphasized that even sub-threshold HQ levels can contribute to long-term

ecological and human health stress when combined with other environmental contaminants such as heavy metals and nitrated PAH derivatives^{20,24}.

In summary, the HQ and HI values obtained for Ajakanga waste dumpsite soils confirm that non-carcinogenic risks are currently insignificant for both children and adults. However, sustained waste burning, informal recycling, and prolonged exposure could elevate the risk over time. It is therefore essential to strengthen waste management practices, enforce open-burning restrictions, and promote remediation technologies such as bioremediation and phytoremediation to minimize future health implications.

4.10 Comparison of results of finding with previous studies

Ajakanga dumpsite, has an average mean range 12.54 – 24.02 mg/kg, and individual PAHs max 30.74 mg/kg, these show the dumpsite is highly contaminated compare to other studies^{4,5}. Other research also show the concentration of $\Sigma 16$ PAHs higher than the value obtained in these research or even similar¹.

Figure 4.22 show that, The Benzo[a]pyrene equivalent (BaPeq) concentrations and Incremental Lifetime Cancer Risk (ILCR) values for children and adults obtained in this study compare with those reported by other researchers. The BaPeq values for Ajakanga 0.44–0.80 mg/kg, mean 0.62 mg/kg fall below the 1 mg/kg safety guideline established by the World Health Organization (WHO), indicating that although the dumpsite is moderately contaminated, its carcinogenic potency remains within acceptable limits. The ILCR values for children (2.86×10^{-6}) and adults (2.34×10^{-6}) are within the low-risk range (10^{-6} – 10^{-4}), similar to or lower than those reported^{7,13} and below those from more industrially impacted areas²².

This suggests limited but potential long term carcinogenic risk, especially for children who are more vulnerable to soil ingestion and dermal exposure pathways.

The combined BaPeq and ILCR comparison demonstrates that although the total Σ_{16} PAHs concentration at Ajakanga is higher than most municipal dumpsites in Nigeria, the weighted toxicity and risk indices are comparatively moderate. This reflects a pollution profile dominated by low- and medium-molecular-weight PAHs, which are less carcinogenic than high-molecular-weight congeners such as Benzo[a]pyrene and Dibenzo[a,h]anthracene. Nevertheless, the consistent ILCR values above 10^{-6} indicate a potential cumulative risk from chronic exposure, aligning with other research publication^{4,5}, that uncontrolled waste burning significantly elevates PAH-related health risks in Nigerian dumpsites. Continuous monitoring and phased remediation are therefore recommended to prevent future escalation of contamination and exposure risks.

4.11 Summary of Findings on PAHs Risk Assessment

This study assessed the carcinogenic and non-carcinogenic risks associated with polycyclic aromatic hydrocarbons (PAHs) in soils from the Ajakanga waste dumpsite using standard U.S. EPA models. The findings reveal that although PAHs are present in measurable concentrations, their overall risk levels fall within the moderate to acceptable range.

The carcinogenic potency, expressed as benzo(a)pyrene equivalents (BaPeq), ranged from 0.4366 to 0.7970 mg/kg, with a mean of 0.6167 mg/kg, indicating moderate contamination and a predominant contribution from high molecular weight (HMW) PAHs of pyrogenic origin.

The Incremental Lifetime Carcinogenic Risk (ILCR) values, ranging from 2.34×10^{-6} (adults) to 2.86×10^{-6} (children), fall within the acceptable risk range 10^{-6} – 10^{-4} prescribed by the U.S. EPA and WHO, signifying low but non-negligible cancer risk. The dermal contact pathway contributed most significantly to total ILCR, consistent with the strong soil-binding characteristics of PAHs. Spatial variations indicate that Zones B, D, and E exhibited higher cancer risk potentials due to more intensive waste-burning activities.

For non-carcinogenic risks, the Hazard Quotient (HQ) and Hazard Index (HI) values were below unity ($HI < 1$) for both adults and children, implying that adverse health effects are unlikely under present conditions. However, children showed slightly higher risk values, reflecting their greater vulnerability to environmental contaminants.

Overall, the results demonstrate that while the current PAH concentrations in the Ajakanga dumpsite soils do not pose immediate severe health hazards, the persistent dominance of carcinogenic PAHs, pyrogenic source signatures, and elevated dermal exposure risks indicate potential long term implications if site conditions remain unmanaged. Therefore, sustained environmental monitoring, public health sensitization, and remediation interventions such as bioremediation, soil washing, and phytoremediation are recommended to mitigate the gradual buildup of toxic PAHs and protect nearby communities.

End notes

1. A. K. Kieta et al. *Polycyclic Aromatic Hydrocarbons in Terrestrial and Aquatic Ecosystems, Occurrence, Sources and Key Influencing Factors*, **Environmental Reviews**, 30, 2022, 195–220.
- 2 A. Rabieimesbah, S. Sobhanardakani, M. Cheraghi, & B. Lorestani, *Concentrations, Source Identification and Potential Ecological and Human Health Risks Assessment of Polycyclic Aromatic Hydrocarbons (PAHs) in Agricultural Soils of Hamedan County, West of Iran*. Soil and Sediment Contamination, **An International Journal**, 33(4), 2024, 482-506.
- 3 T. O. Ale, T. H. Ogunribido, O. Ademila, & A. S. Akingboye, *Soil Pollution Status Due to Potentially Toxic Elements in Active Open Dumpsites, Insights from Different Nigerian Geological Environments*, **Environmental Earth Sciences**, 83(18), 2024, 535.
- 4 G. Yang, M. Liu, Y. Gao, S. Han, F. Meng, T. Ju, & J. Jiang, *A Review on the Evaluation Models and Impact Factors of Greenhouse Gas Emissions from Municipal Solid Waste Management Processes*, **Environmental Science and Pollution Research**, 31(19), 2024, 27531-27553.
- 5 F. Ding, W. Zhang, S. Cao, S. Hao, L. Chen, X. Xie, & M. Jiang, *Optimization of Water Quality Index Models Using Machine Learning Approaches*. **Water Research**, 243, 2023, 120337.
- 6 S. O. Mulikat, *Assessment of Heavy Metals, Persistent Organic Pollutants and Polycyclic Aromatic Hydrocarbons Contamination of Soil and Underground Water of Selected Abattoir Markets in North Central Nigeria, Master's thesis, Kwara State University Nigeria*, 2022.
- 7 V. K. Akinpelumi, K. G. Kumi, A. P. Onyena, K. Sam, A. N. Ezejiofor, C. Frazzoli, & O. E. Orisakwe, *A Comparative Study of The Impacts of Polycyclic Aromatic Hydrocarbons in Water and Soils in Nigeria and Ghana, Towards a Framework for Public Health Protection*, **Journal of Hazardous Materials Advances**, 11, 2023, 100336.
- 8 S. S. V. Vuppaladadiyam, B. S. Thomas, C. Kundu, A. K. Vuppaladadiyam, H. Duan, & S. Bhattacharya, *Can E-Waste Recycling Provide a Solution to The Scarcity of Rare Earth Metals, An Overview of E-Waste Recycling Methods*, **Science of The Total Environment**, 924, 2024, 171453.
- 9 T. M. Mogashane, L. Mokoena, & J. Tshilongo, J. *A review on recent developments in the extraction and identification of polycyclic aromatic hydrocarbons from environmental samples*, **Water**, 16(17), 2024, 2520.
- 10 M. Liu, P. Qiao, Y. Shan, Z. Zhang, P. Pan, & Y. Li, *Migration and Accumulation*

Simulation Prediction of PPCPs in Urban Green Space Soil Irrigated with Recycled Water; A Review, **Journal of Hazardous Materials**, 476, 2024,135037.

11 B. S. Fakinle, E. L. Odekanle, C. Ike-Ojukwu, O. O. Sonibare, O. A. Falowo, F. W. Olubiyo, & C. O. Aremu, *Quantification and Health Impact Assessment of Polycyclic Aromatic Hydrocarbons (PAHs) Emissions from Crop Residue Combustion*, **Heliyon**, 8(3).2022.

12 C. Choochuay, W. Deelaman, & S. Pongpiachan, *Polycyclic Aromatic Hydrocarbons in Thai and Myanmar Rice: Concentrations, Distribution and Health Concerns*, **Nature Environment & Pollution Technology**, 22(3), 2023.

13 T. Dudnikova, S. Minkina, A. Sushkova, E. Barbashev, E. Antonenko, M. Konstantinova, & M. Gorbunova, *Background Content of Polycyclic Aromatic Hydrocarbons during Monitoring of Natural and Anthropogenically Transformed Landscapes in the Coastal Area Soils*, **Water**, 15(13), 2023, 2424.

14 E. A. Okoye, A. N. Ezejiofor, I. L. Nwaogazie, C. Frazzoli, & O. E. Orisakwe, *Polycyclic Aromatic Hydrocarbons in Soil and Vegetation of Niger Delta, Nigeria, Ecological risk assessment*, **Journal of Toxicology**, (1), 2023, 8036893.

15 R. Chang, L. Zhao, R. Xing, J. Li, & X. Yan, *Functional Chromopeptide Nanoarchitectonics, Molecular Design, Self-Assembly and Biological Applications*, **Chemical Society Reviews**, 52(8), 2023, 2688-2712.

16 T. F. Ediabonyia, T. E. Omotade, & O. S. Ihuoma, *Health Risk Associated with Polycyclic Aromatic Hydrocarbons (PAHs) in Dumpsites in Southwestern Nigeria*, **Environmental Nanotechnology, Monitoring & Management**, 23, 2025,101028.

17 B. Ambade, A. Kumar, A. Kumar, & L. K. Sahu, *Temporal Variability of Atmospheric Particulate-Bound Polycyclic Aromatic Hydrocarbons (PAHs) over Central East India, Sources and Carcinogenic Risk Assessment, Air Quality*, **Atmosphere & Health**, 15(1), 2022, 115–130.

18 Y. Zhang, Z. Guo, C. Peng, & Y. He, *Introducing a Land-Use-Based Weight Factor in Regional Health Risk Assessment of PAHs in Soils of an Urban Agglomeration*, **Science of the Total Environment**, 887, 2023, 163833.

19 O. I. Areguamen, N. N. Calvin, C. E. Gimba, O. J. Okunola, A. T. Abdulkadir, & A. Elebo, *Assessment of Seasonal Variation in Distribution, Source Identification, and Risk of Polycyclic Aromatic Hydrocarbon (PAH)–Contaminated Sediment of Ikpoba River, South-South Nigeria*, **Environmental Monitoring and Assessment**, 195(2), 2023, 302.

20 J. C. Egbueri, J. C. Agbasi, & M. E. Omeka, *Metal(loids), Nitrate, Polycyclic*

Aromatic Hydrocarbons, and Radioactive Contaminants in Nigerian Water Resources, State-of-the-Art of Their Ecological and Health Risk Assessments, **Environment, Development and Sustainability**, 1–50, 2024.

21 A. Bouzekry, B. Mghili, T. Bottari, M. Benomar, & M. Aksissou, *Polycyclic Aromatic Hydrocarbons in Sediments and Bivalves along the Moroccan Mediterranean Coast, Spatial Distribution, Sources, and Risk Assessment*, **Environmental Pollution**, 363, 2024, 125073.

22 A. Rabieimesbah, S. Sobhanardakani, M. Cheraghi, & B. Lorestani, *Concentrations, Source Identification, and Potential Ecological and Human Health Risks of PAHs in Agricultural Soils of Hamedan County, Iran*, **Soil and Sediment Contamination**, 33(4), 2024, 482–506.

23 L. Wang, Y. Guo, P. Li, & X. He, *Comprehensive Health Risk Assessment of Polycyclic Aromatic Hydrocarbons in Soils from Industrial Regions of Northwest China*, **Environmental Geochemistry and Health**, 45(7), 2023, 3205–3222.

24 J. Kong, S. Yan, X. Cao et al, *Quantitative Source Apportionment and Health Risk Assessment for Polycyclic Aromatic Hydrocarbons and Their Derivatives in Indoor Dust from a Mega-City in China*, **Journal of Hazardous Materials**, 486, 2025, 137057.

25 U.S. EPA. *Regional Screening Levels (RSLs) , Generic Tables May 2023*, **United States Environmental Protection Agency**, 2023.

Chapter Five

Conclusion

5.1 Summary of finding

In this study, The PAHs profile in Ajakanga waste dump site indicate a low to moderate contamination with PAHs. The sum of 16 EPA PAHs detected in the soil samples ranged from 12.54 to 24.02 mg/kg which is above the ATSDR levels of 1.0 mg/kg for significant contaminated site, European commission classification, also confirm that the site is heavily contaminated, but the Dutch guideline for soil contamination of PAHs in dumpsite based on the target values and their intervention value for the sum of ten PAHs is 40mg/kg, meaning soil contamination exceeding this value required remediation while concentration below it are considered less concern for the ecosystems and human health.

The total value of BaP_{eq} range from 0.4901 to 0.7893 mg/kg, this implied a moderate carcinogenic burden, which could not pose a severe health risk to human.

The diagnostic ratio and LMW/HMW indicate that the PAH in this study were from petrogenic and pyrogenic sources. The lifetime carcinogenic risk on Ajakanga dumpsite soil for children and adult are 2.858×10^{-6} and 2.340×10^{-6} respectively, this implied that within 2.858×10^{-6} (2.858 million) children expose to Ajakanga dumpsite there is possibility of 3 child having cancer and within 2.340×10^{-6} (2.430 million) adult expose to Ajakanga dumpsite there is possibility of 2 adult having cancer.

The value obtained in these analysis is within the low cancer risk or probable cancer effect of PAHs to humans, and the hazard index for non carcinogenic health risk for children and adult are 4.04×10^{-4} and 2.48×10^{-4} respectively.

5.2 Conclusion

The study established that the Ajakanga waste dumpsite soil is significantly contaminated with polycyclic aromatic hydrocarbons (PAHs). The total concentration of the sixteen U.S. EPA priority PAHs ranged from 12.54 to 24.02 mg/kg, far exceeding the Agency for Toxic Substances and Disease Registry (ATSDR) contamination threshold of 1.0 mg/kg and the European Commission's classification of heavily polluted soil >1 mg/kg.

The calculated Benzo[a]pyrene equivalent (BaPeq) concentrations (0.4901–0.7893 mg/kg) indicate a moderate carcinogenic burden, which, though below the World Health Organization (WHO) guideline of 1 mg/kg for high concern, still warrants serious attention due to long-term exposure potential.

Diagnostic ratio analysis showed that both pyrogenic and petrogenic sources contribute to the contamination, consistent with emissions from open burning and petroleum residues.

When compared with international standards, the observed PAH levels surpass the European Union (EU) and U.S. Environmental Protection Agency (USEPA) soil quality limits, which classify concentrations below 0.2 mg/kg as uncontaminated. In Nigeria, NESREA and Environmental Guidelines and Standards for Industrial Processes (EGSIP) similarly recommend remediation when PAH levels exceed 1 mg/kg. Thus, the Ajakanga dumpsite represents a clear environmental pollution hotspot.

The Incremental Lifetime Carcinogenic Risk (ILCR) values for children and adults were 2.96×10^{-6} and 2.34×10^{-6} , respectively within the USEPA acceptable range of 10^{-6} – 10^{-4} , indicating a low but notable cancer risk. The Hazard Quotient (HQ) and Hazard Index (HI) values (4.04×10^{-4} for children and 2.48×10^{-4} for adults) were below 1, signifying

minimal non-carcinogenic health effects . However, children exhibited higher exposure potential due to their greater soil ingestion rates, highlighting the importance of continuous environmental surveillance.

When compared with related studies, these findings align closely with earlier research conducted in Nigeria and abroad. These parallels confirm that the contamination pattern at Ajakanga mirrors conditions in other urbanized and industrial environments of developing nations.

Although the ILCR and HI values suggest a current low health risk, the persistently elevated concentrations of carcinogenic PAHs—particularly benzo[a]pyrene, indeno[1,2,3-cd]pyrene, and benzo[b]fluoranthene pose a potential long-term environmental and public health threat. Accumulation of these compounds in the soil ecosystem may lead to gradual ecological degradation and increased carcinogenic exposure over time.

5.3 Recommendation

Continuous monitoring and regulatory control to mitigate long-term exposure risks.

- i. **Waste Management Improvements:** Proper waste segregation, recycling, and disposal techniques can prevent the formation of PAHs. The adoption of alternatives to open burning, such as controlled incineration, is also recommended.
- ii. **Site Remediation:** Contaminated dumpsites should undergo remediation techniques like bioremediation, soil washing, or thermal desorption to reduce PAH levels.
- iii. **Regulation and Monitoring:** Governments should enforce strict regulations to prevent illegal dumping and burning of hazardous waste. Regular monitoring of air, soil, and water quality around dumpsites is also necessary.
- iv. **Public Awareness:** Educating communities about the dangers of dumpsite pollution and encouraging proper waste disposal practices can reduce exposure risks.

5.4 Contribution to Knowledge

The contribution to knowledge is the assessment of polycyclic aromatic hydrocarbons (PAHs) at the Ajakanga waste dumpsite in Ibadan, Nigeria. The study found the following:

PAH Levels: The soil samples had PAH concentrations ranging from 12.54 to 30.74 mg/kg, which is significantly higher than the contamination threshold of 1.0 mg/kg.

PAH Sources: Diagnostic ratio analysis indicated that the PAHs originated from both pyrogenic (combustion) and petrogenic (petroleum) sources.

Cancer Risk: The estimated lifetime cancer risk for children and adults fell into the low-risk category, with values of 2.96×10^{-6} and 2.34×10^{-6} respectively.

Non-Carcinogenic Risk: The non-carcinogenic hazard indices were below 1, suggesting no immediate health risks.

5.5 Suggestion for Further Research

Investigating the long-term health impacts of low-risk PAH exposure in the communities surrounding the dumpsite, especially for vulnerable populations like children and pregnant women.

Assessing the effectiveness of the current waste management practices in Oyo State in controlling PAH levels.

A deeper analysis of the specific sources of the pyrogenic and petrogenic PAHs found in the dumpsite to better target mitigation strategies.

Expanding the study to include the analysis of PAHs in the groundwater and surface water surrounding the dumpsite, as the document mentions this is a potential risk.

Evaluating the viability and effectiveness of different remediation techniques (e.g., bioremediation) for the specific type of PAH contamination found at the Ajakanga dumpsite. The findings highlight the need for continuous monitoring and regulatory control to reduce the long-term exposure risks.

Bibliography

Journal

- Abayi, J. J. M. Gore, C. T. Nagawa, C. Bandowe, B. A. M. Matovu, H. Mubiru, E. & Ssebugere, P. *Polycyclic aromatic hydrocarbons in sediments and fish species from the White Nile, East Africa, Bioaccumulation potential, source apportionment, ecological and health risk assessment*, **Environmental Pollution**, 278, 2021, 116855.
- Abdel-Shafy, H. I. and Mansour, M. S. M. *A Review on Polycyclic Aromatic Hydrocarbons, Source, Environmental Impact, Effect on Human Health and Remediation*, **Egypt. J. Pet**, 25, 2016, 107–123.
- Acer, O. Johnston, G. P. Lineman, D. & Johnston, C. G. *Evaluating degradation of polycyclic aromatic hydrocarbon (PAH) potential by indigenous bacteria isolated from highly contaminated riverbank sediments*, **Environmental Earth Sciences**, 80, 1-15, 2021.
- Adeniji, A. Okoh, O. and Okoh, A. *Levels of polycyclic aromatic hydrocarbons in the water and sediment of Buffalo River Estuary, South Africa and their health risk assessment*. **Arch. Environ. Con.** 2019. **Tox.** 76, 657–669.
- Adeyeye, S. A. O. & Ashaolu, T. J. *Polycyclic aromatic hydrocarbons formation and mitigation in meat and meat products*. **Polycyclic Aromatic Compounds**, 42(6), 2022, 3401-3411.
- Akinnifesi, T. A. Borokini, F. B. Adegun, A. O. Mafinuyomi, E. Olonisakin, A. Omodara, N. B. & Oladoja, N. A. *Polycyclic Aromatic Hydrocarbon in Sediment, Ground and Surface Water Resources in Coastal Areas of Ondo State, Nigeria*. **Journal of Chemical Society of Nigeria**, 49(2), 2024.
- Akinsete, S. J. & Olatimehin, A. D. *Priority polycyclic aromatic hydrocarbons and heavy metals in urban roadside soils of heavy-traffic density areas in Ibadan, Nigeria: Levels, sources and health risk assessment*, **Environmental Forensic** 25(4), 2024, 239-253.
- Alao, J. O. *Impacts of open dumpsite leachates on soil and groundwater quality*, **Groundwater for Sustainable Development**, 20, 2023, 100877.
- Ali, M. U.; Siyi, L.; Yousaf, B.; Abbas, Q.; Hameed, R.; Zheng, C.; Wong, M. H. *Emission sources and full spectrum of health impacts of black carbon associated polycyclic aromatic hydrocarbons (PAHs) in urban environment, A review*, **Critical Reviews in Environmental Science and Technology**, 51(9), 2021, 857–896.

- Ali, M. Song, X. Ding, D. Wang, Q. Zhang, Z. & Tang, Z. Bioremediation of PAHs and heavy metals co-contaminated soils: challenges and enhancement strategies, *Environmental Pollution*, 295, 2022, 118686.
- Ambade, B. Kumar, A. Kumar, A. and Sahu, L. K. *Temporal Variability of Atmospheric Particulate-Bound Polycyclic Aromatic Hydrocarbons (PAHs) over central East India: Sources and Carcinogenic Risk Assessment*, **Air Qual. Atmos. Health** 14, 2021a, 1–16.
- Ambade, B. Kurwadkar, S. Sankar, T. K. and Kumar, A. *Emission Reduction of Black Carbon and Polycyclic Aromatic Hydrocarbons during COVID-19 Pandemic Lockdown*. **Air Qual. Atmos. Health**, 14, 2021, 1081–1095.
- Ambade, B. Sethi, S. S. Kurwadkar, S. Kumar, A. and Sankar, T. K. *Toxicity and Health Risk Assessment of Polycyclic Aromatic Hydrocarbons in Surface Water, Sediments and Groundwater Vulnerability in Damodar River Basin*, **Groundwater Sustain. Develop.**, 13, 2021d, 100553.
- Amirdivani, S. Khorshidian, N. Ghobadi Dana, M. Mohammadi, R. Mortazavian, A. M. Quiterio de Souza, S. L. Barbosa Rocha, H. Raices. R. *Polycyclic aromatic hydrocarbons in milk and dairy products*. **Int. J. Dairy Technol.**, 2019, 72
- Anyahara, J. N. *Effects of Polycyclic Aromatic Hydrocarbons (PAHs) on the environment: A systematic review*, **International Journal of Advanced Academic Research**, 7(3) 2021.
- Aralu, C. C. Okoye, P. A. C. Abugu, H. O. N. C. Eboagu, N. C. & Eze, V. C. . *Characterization, sources, and risk assessment of PAHs in borehole water from the vicinity of an unlined dumpsite in Awka, Nigeria*, **Scientific reports**, 13(1), 2023, 9688.
- Areguamen, O. I. Calvin, N. N. Gimba, C. E. Okunola O. J., Abdulkadir, A. T. & Elebo, A. *Assessment of seasonal variation in distribution, source identification, and risk of polycyclic aromatic hydrocarbon (PAH)–contaminated sediment of Ikpoba River, South-South, Nigeria*, **Environmental Monitoring and Assessment**, 195(2), 2023, 302.
- Aresta, A. M. & Zambonin, C. *Determination of polycyclic aromatic hydrocarbons (PAHs) in coffee samples by DI-SPME-GC/MS*. **Food Analytical Methods**, 16(6),(2023) 1009-1016.
- Arienzo, M. Toscanesi, M. Esposito, M. Iaccarino, D. Di Nocera, F. Canzanella, S. & Trifuoggi, M. *Comparative study of polycyclic aromatic hydrocarbons (PAHs) in salt gland and liver of loggerhead turtle *Caretta caretta* (Linnaeus, Cheloniidae) stranded along the Mediterranean coast, Southern Italy*.

- Arregocés, H. A. Bonivento, G. J. Ladino, L. A. Beristain-Montiel, E. Restrepo, G. Miranda, J. & Rojano, R. *Human health risk assessment of PM10-bound heavy metals and PAHs around the Latin America's Largest opencast coal mine. Environmental Science and Pollution Research*, 30(60), 125915-125930.(2023).
- Badyda, A. J.; Rogula-Kozłowska, W.; Majewski, G.; Bralewska, K.; Widziewicz-Rzońca, K.; Piekarska, B.; Bihałowicz, J. S. *Inhalation risk to PAHs and BTEX during barbecuing: The role of fuel/food type and route of exposure. Journal of Hazardous Materials*, 440, 129635 (2022)
- Bahia, P. V. B.; Nascimento, M. M.; Hatje, V.; de Andrade, J. B.; Machado, M. E. *Microscale extraction combined with gas chromatography/mass spectrometry for the simultaneous determination of polycyclic aromatic hydrocarbons and polycyclic aromatic sulfur heterocycles in marine sediments. Journal of Chromatography A*, 1653 (2021) 462414
- Barbosa Jr, F. Rocha, B.A Souza, M. C. Bocato, M. C. Azevedo, L. F. Adeyemi, J. A. & Campiglia, A. D. *Polycyclic aromatic hydrocarbons (PAHs): updated aspects of their determination, kinetics in the human body, and toxicity. Journal of Toxicology and Environmental Health, Part B*, 26(1), 28-65.(2023)
- Bouzekry, A. Mghili, B. Bottari, T. Bouadil, O. Mancuso, M. Benomar, M. & Aksissou, M. . *Polycyclic aromatic hydrocarbons in sediments and bivalves along the Moroccan Mediterranean coast: Spatial distribution, sources, and risk assessment. Environmental Pollution*, 363,(2024) 125073.
- Buell, M. C.; Johannessen, C.; Drouillard, K.; Metcalfe, C. *Concentrations and source identification of PAHs, alkyl-PAHs and other organic contaminants in sediments from a contaminated harbor in the Laurentian Great Lakes. Environmental Pollution*, 270, 116058 (2021)
- Bukowska, B. Mokra, K. & Michałowicz, J. *Benzo [a] pyrene—Environmental occurrence, human exposure, and mechanisms of toxicity. International journal of molecular sciences*, 23(11), 6348.(2022)
- Cai, Y. Wang, Z. Cui, L. Wang, J. Zuo, X. Lei, Y. & Li, W. *Distribution, source diagnostics, and factors influencing polycyclic aromatic hydrocarbons in the Yellow River Delta wetland. Regional Studies in Marine Science*, 67, 103181.(2023)
- Chakraborty, B. Bera, B. Roy, S. Adhikary, P. P. Sengupta, D. & Shit, P. K. . *Assessment of non-carcinogenic health risk of heavy metal pollution: Evidences from coal mining region of eastern India. Environmental Science and Pollution*

Research, 28(34), 47275-47293.(2021)

- Chung, D. Lee, J. H. Lee, S. Y. Oh, Y. S. & Shin, H. S. *Quantitative analysis and contamination profiles of PCBs, OCPs, and PAHs in black-tailed gull eggs in the Republic of Korea. Environmental Monitoring and Assessment*, 194(4), 268.(2022)
- Cong, Y. Wang, Y. Zhang, M. Jin, F. Mu, J. Li, Z. & Wang, J. *Lethal, behavioral, growth and developmental toxicities of alkyl-PAHs and non-alkyl PAHs to early-life stage of brine shrimp, Artemia parthenogenetica. Ecotoxicology and Environmental Safety*, 220, 112302. (2021)
- Costa Filho, B. M. da. Duarte, A. C. & Rocha-Santos, T. A. *Environmental monitoring approaches for the detection of organic contaminants in marine environments: A critical review. Trends in Environmental Analytical Chemistry*, 33,(2022). e00154.
- Dai, C.; Han, Y.; Duan, Y.; Lai, X.; Fu, R.; Liu, S.; Zhou, L. *Review on the contamination and remediation of polycyclic aromatic hydrocarbons (PAHs) in coastal soil and sediments. Environmental Research*, 205, 112423 (2022)
- Ediagbonya, T. F. Oyinlusi, O. C. Okungbowa, E. G. & Uche, J. I. *Environmental and human health risk assessments of polycyclic aromatic hydrocarbons in particulate matter in Nigeria. Environmental Monitoring and Assessment*, 194(8), 569 (2022).
- Egbueri, J. C. *Heavy metals pollution source identification and probabilistic health risk assessment of shallow groundwater in Onitsha, Nigeria. Analytical letters*, 53(10), 1620-1638.(2020)
- Ephraim-Emmanuel, B. C. & Ordinioha, B. *Exposure and public health effects of polycyclic aromatic hydrocarbon compounds in sub-saharan africa: a systematic review. International Journal of Toxicology*, 40(3), 250-269.(2021).
- EU Commission. (2011). Regulation (EU) No 835/2011 amending Regulation (EC) No 1881/2006 as regards maximum levels for polycyclic aromatic hydrocarbons in foodstuffs. **Official Journal of the European Union**, L, 215(4).
- Florencia, T. M. Iván, T. B. & C. H. Alejandra, C. H. *Health risk assessment of exposure to polycyclic aromatic hydrocarbons in household indoor environments. Environmental Advances*, 7, 100159.(2022)
- Genkinger, J. M., Stigter, L., Jedrychowski, W., Huang, T. J., Wang, S., Roen, E. L., & Perera, F. P. . *Prenatal polycyclic aromatic hydrocarbon (PAH) exposure, antioxidant levels and behavioral development of children ages 6–9. Environmental research*,(2015) 140, 136-144.

- González, L. T. Hernández-Romero, I. M. Mendoza, A. Ramirez, A. I. Mancilla, Y. Kharissov, B. & Longoria, F. E. *Source attribution, health risk analysis, and policy implications of PAHs and NPAHs in PM in Northern Mexico. Scientific Reports*, 14(1), 31823.(2024)
- Gunjyal, N. Rani, S. Asgari Lajayer, B. Senapathi, V. & T. Astatkie, T. A review of the effects of environmental hazards on humans, their remediation for sustainable development, and risk assessment. **Environmental Monitoring and Assessment**, 195(6), 795.(2023).
- Gorleku, M. A.; Carboo, D.; Palm, L. M. N.; Quasie, W. J.; Armah, A. K. *Polycyclic aromatic hydrocarbons (PAHs) pollution in marine waters and sediments at the Tema Harbour, Ghana. Academia Journal of Environmental Sciences*, 2(7), 108–115 (2014). DOI: 10.15413/ajes.2014.0112
- Guo, Y. Li, P. He, X. & Wang, L. *Groundwater quality in and around a landfill in northwest China: characteristic pollutant identification, health risk assessment, and controlling factor analysis. Exposure and Health*, 14(4), 885-901.(2022).
- Cai, Z. Wang, L. Cui, J. Wang, X. Zuo, Y. Lei, & W. Li, *Distribution, source diagnostics, and factors influencing polycyclic aromatic hydrocarbons in the Yellow River Delta wetland. Regional Studies in Marine Science*, 67, 103181.(2023)
- Han, M.; Li, H.; Kang, Y.; Liu, H.; Huang, X.; Zhang, R.; Yu, K. *Bioaccumulation and trophic transfer of PAHs in tropical marine food webs from coral reef ecosystems, the South China Sea: Compositional pattern, driving factors, ecological aspects, and risk assessment. Chemosphere*, 308, 136295 (2022)
- Hayakawa, K. Kim-Oanh, P. Takami, A. Odajima, H. Nagato, E. G. Hara, A. & Nakamura, H. *Contributions of long-range transport from the Asian continent and local emissions on atmospheric PM_{2.5}, polycyclic aromatic hydrocarbons, and their nitro-derivatives in Kanazawa and Noto Peninsula, Japan. Heliyon*, 10(5).(2024)
- Honda, M. Mukai, K. Nagato, E. Uno, S. & Oshima, Y. *Correlation between polycyclic aromatic hydrocarbons in wharf roach (Ligia spp.) and environmental components of the intertidal and supralittoral zone along the Japanese Coast. International journal of environmental research and public health*, 18(2), 630.(2021)
- Honda, M.; Suzuki, N. *Toxicities of polycyclic aromatic hydrocarbons for aquatic animals. International Journal of Environmental Research and Public Health*, 17(4), 1363 (2020)
- Honda, M. Qiu, X. Koyama, J. Uno, S. Undap, S. L. Shimasaki, Y. Oshima, Y.

The wharf roach, Ligia sp., A novel indicator of polycyclic aromatic hydrocarbon contamination in coastal areas. Int. J. Environ. Res. 2018, 12, 1–11.

- Honscha, L. C. Reis, F. O. Aikawa, Coronas, P. M. V. Muccillo-Baisch, A. L. Baisch, P. R. M. & Da Silva Júnior, F. M. R. *Human health risk assessment of air pollutants in the largest coal mining area in Brazil. Environmental Science and Pollution Research*, 30(21), 59499-59509.(2023).
- Hua, H. Wu, S. & Ma, X. *Determination of trans-4-hydroxy-2-alkenals in Thermally Treated Soybean Oil by SPE-HPLC. Grain & Oil Science and Technology*, 5(3),(2022) 107-113.
- Incardona, J. P.; Collier, T. K.; Scholz, N. L. *Defects in cardiac function precede morphological abnormalities in fish embryos exposed to polycyclic aromatic hydrocarbons. Toxicology and Applied Pharmacology*, 196(2), 191–205 (2004)
- Jackulin, F. Kumar, P. S. Chitra, B. Karthick, S. & Rangasamy, G. *A review on recent advancements in the treatment of polyaromatic hydrocarbons (PAHs) using sulfate radicals based advanced oxidation process. Environmental Research*, 253, 119124(2024)
- Jeong, J. Kim, G. & Lee, J. G. *A review of food contamination with nitrated and oxygenated polycyclic aromatic hydrocarbons: toxicity, analysis, occurrence, and risk assessment. Food Science and Biotechnology*, 33(10), 2261-2274.(2024)
- Jin, H., Lin, Z., Pang, T., Wu, J., Zhao, C., Zhang, Y., & Lu, Q. (2017). *Effects and mechanisms of polycyclic aromatic hydrocarbons in inflammatory skin diseases. Science of The Total Environment*, 171492.
- Kabyl, A. Yang, M. Abbassi, R. Li. S. *A risk-based approach to producing water management in offshore oil and gas operations. Proc Saf Environ Prot* 2020;139:341361.<https://doi.org/10.1016/j.psep.2020.04.021>
- Kander, M. C. Wilkinson, A. F. Chen, I. C. Bertke, S. Kesler, R. M. Smith, D. L. & Fent, K. W. *Evaluating the ingress of total polycyclic aromatic hydrocarbons (PAHs) specifically naphthalene through firefighter hoods and base layers. Journal of Occupational and Environmental Hygiene*, 22(3),(2025). 169-177.
- Khan, M. Ali, S. W. Shahadat, M. & S. Sagadevan, S. *Applications of polyaniline-impregnated silica gel-based nanocomposites in wastewater treatment as an efficient adsorbent of some important organic dyes. Green Processing and Synthesis*, 11(1),(2022) 617-630.
- Kim, H. S. Kim, J. Choi, J. Paik, Y. Moon, B. Joo, Y. S. & Lee, K. W. *Polycyclic aromatic hydrocarbons in beverage and dairy products in South Korea: a risk characterization using the total diet study. Food Science and Biotechnology*, 30, 989-1002(2021)

- Kong, S. Yan, X. Cao, Y. Zhang, C. Ran, X. Chen, & H. He, . *Quantitative source apportionment and health risk assessment for polycyclic aromatic hydrocarbon and their derivatives in indoor dust from housing and public buildings of a mega-city in China*. **Journal of Hazardous Materials**, 486,(2025) 137057.
- Kumar, M.; Bolan, N. S.; Hoang, S. A.; Sawarkar, A. D.; Jasemizad, T.; Gao, B.; Rinklebe, J. *Remediation of soils and sediments polluted with polycyclic aromatic hydrocarbons: to immobilize, mobilize, or degrade?* **Journal of Hazardous Materials**, 420, 126534 (2021)
- Kumar, A. Sankar, T. K. Sethi, S. S. and B. Ambade, B. *Characteristics, Toxicity, Source Identification and Seasonal Variation of Atmospheric Polycyclic Aromatic Hydrocarbons over East India*. **Environ. Sci. Pollut. Res.** 27 (1),(2020) 678–690. doi:10.1007/s11356-019-06882-5
- Låg, M.; Øvrevik, J.; Refsnes, M.; Holme, J. A. *Potential role of polycyclic aromatic hydrocarbons in air pollution-induced non-malignant respiratory diseases*. **Respiratory Research**, 21, 1–22 (2020)
- Lin, K. Wang, R. Tan, L. Jiang, S. Xu, H. Cao, Y. & Wang, J. *Assessing the potential risks, sources and the relationship between the dissolved and particulate polycyclic aromatic hydrocarbons (PAHs) in the typical semi-enclosed bay, Bohai Bay of China*. **Marine Environmental Research**, 192, 106192.(2023)
- Liu, H.; Hu, X.; Zhang, J.; Ning, H.; Huang, Z. *Hollow fiber-solid phase microextraction of polycyclic aromatic hydrocarbons from environment water followed by flash evaporation GC/MS*. **Chromatographia**, 85(5), 387–394 (2022)
- Mali, M. Ragone, R. Dell’Anna, M. M. Romanazzi, G. Damiani, L. & Mastrorilli, P. *Improved identification of pollution source attribution by using PAH ratios combined with multivariate statistics*. **Scientific Reports**, 12(1), 19298(2022)
- Malik, D. S.; Sharma, A. K.; Sharma, A. K.; Thakur, R.; Sharma, M. *A review on impact of water pollution on freshwater fish species and their aquatic environment*. **Advances in Environmental Pollution Management: Wastewater Impacts and Treatment Technologies** (2021)
- Mallah, M. A. Changxing, L. Mallah, M. A. Noreen, S. Liu, Y. Saeed, M & Zhang, Q *Polycyclic aromatic hydrocarbon and its effects on human health: An overview*. **Chemosphere**, 296, 133948.(2022).
- Marmett, B. Carvalho, R. B. Muccillo-Baisch, A. L. Baisch, P. R. M. Dos Santos, M. Garcia, E. M. & Da Silva Júnior, F. M. R. *Emissions monitoring and carcinogenic risk assessment of PM 10-bounded PAHs in the air from Candiota’s coal activity area, Brazil*. **Environmental Geochemistry and Health**, 45(3), 899-911.(2023)

- Marris, C. Kompella, S. N. Miller, M. Incardona J. P. Brette, F. Hancox et al, J. C. *Polyaromatic hydrocarbons in pollution: a heart-breaking matter. J. Physiol.* 598, 227–247.(2020). doi: 10.1113/jp278885
- Mendoza, M. J. A. Corona, R. L. Iturbe, A. R. & Castro, R. A. A. *Distribution and Behaviour of Four Polyaromatic Compounds in Oil Facilities in Mexico. Arch Earth Environ Sci*, 1, 1-14.(2021).
- Milimo, M. Graham, H. & Michael, P. *The environmental impact of landfill fires and their contaminant plumes at the Chunga landfill site, Lusaka, Zambia. African Journal of Environmental Science and Technology*, 15(12), 569-579(2021).
- Mohammed, R. Zhang, Z. F. Kan, Z. Jiang, C. Liu, L. Y. Ma, W. L. & Li, Y. F. *Determination of polycyclic aromatic hydrocarbons and their methylated derivatives in sewage sludge from northeastern China: occurrence, profiles and toxicity evaluation. Molecules*, 26(9),(2021). 2739.
- Mojiri, A. Zhou, J. L. Ohashi, A. Ozaki, N. and Kindaichi, T. *Comprehensive review of polycyclic aromatic hydrocarbons in water sources, their effects and treatments. Sci. Total Environ.* 2019:133971. doi: 10.1016/j.scitotenv.2019.133971
- Ojaniyi, O. F. Okoye, P. A. C. Omokpariola. D. O. *Heavy Metals Analysis and Health Risk Assessment of Three Fish Species, Surface Water and Sediment Samples in Ogbaru Axis of River Niger, Anambra State, Nigeria. Asian J Appl Chem Res* 2021; 9(1): 64-81. <https://doi.org/10.9734/AJACR/2021/v9i130205>
- Omokpariola, D. O. Omokpariola. O. L. *Health and exposure risk assessment of heavy metals in rainwater samples from selected locations in Rivers State, Nigeria. Phy Sci Rev.* 2021. <https://doi.org/10.1515/psr-2020-0090>
- Omokpariola, D. O. Nduka, J. K. Omokpariola, P. L. Omokpariola, E. C. O. *Ionic composition of rainwater from different sampling surfaces across selected locations in Rivers State, Nigeria. World Sci News* 2020;150:132-147.
- Onwukeme, V. I. Okechukwu. V. U. *Leaching matrix of selected heavy metals from soil to ground water sources in active dumpsites: A case study of Southern Nigeria. IOSR J Environ Sci, Toxicol Food Technol* 2021;15(4): 118
- Ooi, J. K. Woon, K. S. & Hashim, H. *A multi-objective model to optimize country-scale municipal solid waste management with economic and environmental objectives: A case study in Malaysia. Journal of Cleaner Production*, 316, 128366.(2021).

- Pande, P. Kapley, A. & Brar, S. K. *Biodegradation of high molecular weight polyaromatic hydrocarbons in different environments*. **Frontiers in Microbiology**, 12, 704897.(2021)
- Patel, A. B. Shaikh, A. B. S. Jain, K. R. Desai, C. D. *Madamwar Polycyclic aromatic hydrocarbons: sources, toxicity, and remediation approaches* **Front. Microbiol.**, 11 (2020), Article 562813
- Peng, et al. C. *Polycyclic aromatic hydrocarbons in urban soils of Beijing: Status, sources, distribution and potential risk*. **Environ. Pollut.** 159, 802808 (2011)..)
- Pisanello, D., & Pisanello, D. (2014). *EU regulations on chemicals in foods*. **Chemistry of foods: EU legal and regulatory approaches**, 15-77
- Pluta-Kubica, A. Filipczak-Fiutak, M. Domagała, J. Duda, I. Migdał, W. *Contamination of traditionally smoked cheeses with polycyclic aromatic hydrocarbons and biogenic amines*. **Food Control**. 2020;112:107115. doi: 10.1016/j.foodcont.2020.107115
- Rabieimesbah, A. Sobhanardakani S., Cheraghi, M. & B. Lorestani, B. L. *Concentrations, source identification and potential ecological and human health risks assessment of polycyclic aromatic hydrocarbons (PAHs) in agricultural soils of hamedan county, west of Iran*. *Soil and Sediment Contamination: An International Journal*, 33(4),2024 482-506.
- Ravanbakhsh, M.; Yousefi, H.; Lak, E.; Ansari, M. J.; Suksatan, W.; Qasim, Q. A.; Mohammadi, M. J. *Effect of polycyclic aromatic hydrocarbons (PAHs) on respiratory diseases and the risk factors related to cancer*. **Polycyclic Aromatic Compounds**, 43(9), 8371–8387 (2023)
- Ravindran, A. Sajayan, A. Priyadharshini, G. B. Selvin, J. and Kiran, G. S. *Revealing the efficacy of thermostable biosurfactant in heavy metal bioremediation and surface treatment in vegetables*. **Front. Microbiol.** 11:222.(2020). doi: 10.3389/fmicb.2020.0022
- Ribeiro, C.; Gonçalves, R.; Tiritan, M. E. *Separation of enantiomers using gas chromatography: Application in forensic toxicology, food and environmental analysis*. **Critical Reviews in Analytical Chemistry**, 51(8), 787–811 (2021)
- Roy, D. Ahn, S. H. Lee, T. K. Seo, Y. C. and Park, J. *Cancer and Non-cancer Risk Associated with PM10-Bound Metals in Subways*. *Transport. Res. D: Transport Environ.* 89, 102618.(2020). doi:10.1016/j.trd.2020.102618
- Roy, D. Singh, G. and Seo, Y. C. *Coal Mine Fire Effects on Carcinogenicity and Non-carcinogenicity Human Health Risks*. **Environ. Pollut.** 254, 113091.

(2019c)doi:10.1016/j.envpol.2019.113091

- Roy, D. Singh, G. and Seo, Y. C. *Cancer and Non-cancer Risks from PM10-And PM2.5-bound Metal in a Critically Polluted Coal Mining Complex. Atmos. Pollut. Res.* 10, 1964–1975. doi:10.1016/j.apr.2019.09.002
- Sahoo, B. M. Ravi Kumar, B. V. Banik, B. K. & Borah, P. *Polyaromatic hydrocarbons (PAHs): structures, synthesis and their biological profile. Current Organic Synthesis*, 17(8), 625-640.(2020).
- Sam, K. Onyena, A. P. Zabbey, N. Odoh, C. K. Nwipie, G. N. Nkeeh, D. K. Osuji, L. C. Little, D. I. *Prospects of emerging PAH sources and remediation technologies: insights from Africa Environ. Sci. Pollut. Res. Int.* (2023), pp. 1-23
- Sánchez-Piñero, J. Moreda-Piñero, J. Turnes-Carou I., M. Fernández-Amado, M. Muniategui-Lorenzo, S. & López-Mahía, P. *Polycyclic aromatic hydrocarbons in atmospheric particulate matter (PM 10) at a Southwestern Europe coastal city: status, sources and health risk assessment. Air Quality, Atmosphere & Health*, 14, 1325-1339.(2021)
- Saunders, D. Carrillo, J. C, Gundlach, E, R. Iroakasi, O. Visigah, K. Zabbey, N. & Bonte, M. *Analysis of polycyclic aromatic hydrocarbons (PAHs) in surface sediments and edible aquatic species in an oil-contaminated mangrove ecosystem in Bodo, Niger Delta, Nigeria: Bioaccumulation and human health risk assessment. Science of the Total Environment*, 832,(2022) 154802
- Sekar, M. & Praveenkumar, T. R. *Critical review on the formations and exposure of polycyclic aromatic hydrocarbons (PAHs) in the conventional hydrocarbon-based fuels: Prevention and control strategies. Chemosphere*, 350,(2024) 141005.
- Seko, T. Ishihara, K. Suzuki, T. Takagi, S. Taga, K. Iida, Y. & Yamashita, Y. *Effects of moisture content of firewood used in the manufacture of Japanese traditional smoked-dried bonito, katsuobushi, on polycyclic aromatic hydrocarbon (PAH) generation. Journal of Food Composition and Analysis*, 111, 104630.(2022).
- Shariatifar, N. Dadgar, M. Fakhri, Y. Shahsavari, S. Moazzen, M. Ahmadloo, M. Kiani, A. Aenehvand, S. Nazmara, S. Mousavi Khanegah, A. *Levels of polycyclic aromatic hydrocarbons in milk and milk powder samples and their likely risk assessment in Iranian population. J. Food Compos. Anal.* 2020;85:103331. doi: 10.1016/j.jfca.2019.103331.
- Sher, S. Waseem, M. Leta, M. K. *Review of techniques for the removal of polycyclic aromatic hydrocarbons from produced water. Environments*. 2023 Feb 26;10(3):40
- Singh, B. P. Zughaibi, T. A. Alharthy, S. A. Al-Asmari, A. I. & Rahman, S.

- Statistical analysis, source apportionment, and toxicity of particulate-and gaseous-phase PAHs in the urban atmosphere. Frontiers in public health*, 10,2023 1070663
- Sivasamy, S. Rajangam, S. Kanagasabai, T. Bisht, D. Prabhakaran, R. Dhandayuthapani, S. *Biocatalytic potential of pseudomonas species in the degradation of polycyclic aromatic hydrocarbons. Journal of Basic Microbiology*. 2025 Feb;65(2):e2400448.
- Sousa, S. Maia, M. L. Delerue-Matos, C. Calhau, C. & Domingues, V. F. (2022). *The role of adipose tissue analysis on Environmental Pollutants Biomonitoring in women: The European scenario. Science of The Total Environment*, (2022).806, 150922.).
- Stolte, G. Müller, S. Schattenberg, S. & Markiewicz, M. *Environmental persistence assessment of heterocyclic polyaromatic hydrocarbons—Ultimate and primary biodegradability using adapted and non-adapted microbial communities. Journal of Hazardous Materials*,(2023) 460, 132370.)
- Stumpe-Vīksna, I., Bartkevičs, V., Kukāre, A., & Morozovs, A. (2008). *Polycyclic aromatic hydrocarbons in meat smoked with different types of wood. Food Chemistry*, 110(3), 794-797
- Suman, S., Sinha, A. & Tarafdar, A. *Polycyclic aromatic hydrocarbons (PAHs) concentration levels, pattern, source identification and soil toxicity assessment in urban traffic soil of Dhanbad India. Sci. Total Environ.*545, 353–360 (2016).
- Sun, K.; Song, Y.; He, F.; Jing, M.; Tang, J.; Liu, R. *A review of human and animals exposure to polycyclic aromatic hydrocarbons: Health risk and adverse effects, photo-induced toxicity and regulating effect of microplastics. Science of The Total Environment*, 773, 145403 (2021)
- Sun, Y. Yan, K. Wu, S. Gong, G. *Occurrence, spatial distribution and impact factors of 16 polycyclic aromatic hydrocarbons in milks from nine countries. Food Control*. 2020;113:107197. doi: 10.1016/j.foodcont.2020.107197
- Tang, R. & Pfrang, C. *Indoor particulate matter (PM) from cooking in UK students' studio flats and associated intervention strategies: evaluation of cooking methods, PM concentrations and personal exposures using low-cost sensors. Environmental Science: Atmospheres*, 3(3), 537-551(2023)
- Tarafdar, A. Oh, M. J. Nguyen-Phuong, Q. and Kwon, J. H. *Profiling and Potential Cancer Risk Assessment on Children Exposed to PAHs in Playground Dust/soil: a Comparative Study on Poured Rubber Surfaced and Classical Soil Playgrounds in Seoul. Environ. Geochem. Health* 42, 1691–1704.(2020) doi:10.1007/s10653-019-00334-2

- Tarigholizadeh, S. Sushkova, S. Rajput, V. D. Ranjan, A. Arora, J. Dudnikova, T. & Wong, M. H. *Transfer and degradation of PAHs in the soil–plant system: a review. Journal of Agricultural and Food Chemistry*, 72(1),(2023). 46-64.)
- Tartaglione, A. M., Racca, A., & Ricceri, L. (2023). *Developmental exposure to polycyclic aromatic hydrocarbons (PAHs): focus on benzo [a] pyrene neurotoxicity. Reproductive Toxicology*, 119, 108394
- Udom, G. J. Frazzoli, C. Ekhaton, O. C. Onyena, A. P. Bocca, B. & Orisakwe, O. E. *Pervasiveness, bioaccumulation and subduing environmental health challenges posed by polycyclic aromatic hydrocarbons (PAHs): A systematic review to settle a one health strategy in Niger Delta, Nigeria. Environmental Research*, 226, 115620. (2023)
- Ugrina, M & Jurić, A. *Current trends and future perspectives in the remediation of polluted water, soil and air—A review. Processes*, 11(12), 3270.132302(2023)
- Uzochukwu, C. Weems, M. Pavuk, M. Bove, F. Reh, C. & Breyse, P. DIRECT FROM ATSDR. *Journal of Environmental Health*, 84(3),(2021). 34-37.
- Van Hamme, J. V, Singh, A. Ward, O. P. *Recent advances in petroleum microbiology. Microbiology and Molecular Biology Reviews*, 67(4), 503-549. doi: 10.1128/MMBR.67.4.503-549.2003
- Venkatraman, G.; Giribabu, N.; Mohan, P. S.; Muttiah, B.; Govindarajan, V.; Alagiri, M.; Karsani, S. A. *Environmental impact and human health effects of polycyclic aromatic hydrocarbons and remedial strategies: a detailed review. Chemosphere*, 141227 (2024)
- Vijayanand, M. Ramakrishnan, A. Subramanian, R. Issac, P. K. Nasr, M. Khoo, K. S. & Ravindran, B. *Polyaromatic hydrocarbons (PAHs) in the water environment: A review on toxicity, microbial biodegradation, systematic biological advancements, and environmental fate. Environmental research*, 227, 115716.(2023)
- Wang, R. Huang, Q. Cai, J. & Wang, J. *Seasonal variations of atmospheric polycyclic aromatic hydrocarbons (PAHs) surrounding Chaohu Lake, China: Source, partitioning behavior, and lung cancer risk. Atmospheric Pollution Research*, 12(5), 101056.(2021).
- Xu, P., Liu, B., Chen, H., Wang, H., Guo, X., & Yuan, J. (2024). *PAHs as environmental pollutants and their neurotoxic effects. Comparative Biochemistry and Physiology Part C: Toxicology & Pharmacology*, 109975.
- Wang, Y. S. Wu, F. X. Gu, Y. G. Huang, H. H. Gong, X. Y. & Liao, X. Y. *Polycyclic Aromatic Hydrocarbons (PAHs) in the intertidal sediments of Pearl River Estuary: Characterization, source diagnostics, and ecological risk*

- assessment. **Marine Pollution Bulletin**, 173,(2021) 113140.
- Wang, Y. Zhang, H. Zhang, X. Bai, P. Neroda, A. Mishuko, V. F. & Tang, N. . *PM-bound polycyclic aromatic hydrocarbons and nitro-polycyclic aromatic hydrocarbons in the ambient air of Vladivostok: Seasonal variation, sources, health risk assessment and long-term variability. International Journal of Environmental Research and Public Health*, 19(5), 2878.(2022)
- Wnorowski, A. Harnish, D. Jiang, Y. Celo, V. Dabek-Zlotorzynska, E. & Charland, J. P. *Assessment and characterization of alkylated PAHs in selected sites across Canada. Atmosphere*, 13(8), 1320.(2022)
- Yan, G. Xu, Y. Liu, B. Liu, Y. Zhong, M. Ma, K. & Li, S. *Molecular Characterization of Polar Compounds in Crude Oil Affecting Sandstone Wettability Revealed by Fourier Transform-Ion Cyclotron Resonance-Mass Spectrometry. SPE Journal*, 27(03),(2022) 1782-1795.
- Yang, L. Zhang, H. Zhang, X. Xing, W. L. Wang, Y. Bai, P. C. Zhang, L. L. Hayakawa, K. Toriba, A. Tang, N. *Exposure to atmospheric particulate matter-bound polycyclic aromatic hydrocarbons and their health effects: A review. Int. J. Environ. Res. Public Health*. 2021;18:2177. doi: 10.3390/ijerph18042177
- Yang, L. Zhang, X. Xing, W. Zhou, Q. Zhang, L. Wu, Q. & Tang, N. *Yearly variation in characteristics and health risk of polycyclic aromatic hydrocarbons and nitro-PAHs in urban shanghai from 2010–2018. Journal of Environmental Sciences*, 99, 72-79 (2021)
- Zhang, Y. Guo, Z. Peng, C. & He, Y. *Introducing a land use-based weight factor in regional health risk assessment of PAHs in soils of an urban agglomeration. Science of The Total Environment*, 887,(2023). 163833."
- Zhang, H. Yang, L. Zhang, X. Xing, W. L. Wang, Y. Bai, P. C. Zhang, L. L. Li, Y. Hayakawa, K. Toriba, A. *Characteristics and health risks of polycyclic aromatic hydrocarbons and nitro-PAHs in Xinxiang, China in 2015 and 2017. Int. J. Environ. Res. Public Health*. 2021;18:3017. doi: 10.3390/ijerph18063017.
- Zhao, C. Xu, J. Shang, D. Zhang, Y. Zhang, J. Xie, H. & Wang, Q. *Application of constructed wetlands in the PAH remediation of surface water: A review. Science of The Total Environment*, 780, 146605.(2021)
- Zhou, Q.; Yuan, Y.; Sun, Y.; Sheng, X.; Tong, Y. *Magnetic solid phase extraction of heterocyclic aromatic hydrocarbons from environmental water samples with multiwalled carbon nanotube modified magnetic polyamido-amine dendrimers prior to gas chromatography-triple quadrupole mass spectrometer. Journal of Chromatography A*, 1639, 461921 (2021)
- Zhu, Z. Li, L. Yu, Y. Tan, L. Wang, Z. Suo, S. & Liang, W. *Distribution, source,*

risk and phytoremediation of polycyclic aromatic hydrocarbons (PAHs) in typical urban landscape waters recharged by reclaimed water. **Journal of Environmental Management**, 330,(2023) 117214

INTERNET

Agency for Toxic Substances and Disease Registry (ATSDR): *ATSDR Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs)*.
<https://www.atsdr.cdc.gov/>

Dionex Corporation. Application Note 95: Polycyclic Aromatic Hydrocarbon Determination by Reversed-phase High-performance Liquid Chromatography [Internet]. 1994. Available from: <http://tools.thermofisher.com/content/sfs/brochures/AN-95-Polycyclic%20Aromatic%20Hydrocarbon-Determination-LPN0570.pdf> [Accessed: 2017-08-12]

European Commission, E. C. (2011). Commission Regulation (EU) No 835/2011 of 19 August 2011 amending Regulation (EC) No 1881/2006 as regards maximum levels for polycyclic aromatic hydrocarbons in foodstuffs. Official Journal of the European Union, 215(4), 1-5.

EPA (Environmental Protection Agency). Method 525.2: Determination of Organic Compounds in Drinking Water by Liquid-Solid Extraction and Capillary Column Gas Chromatography/Mass Spectrometry [Internet]. 1995. Available from: https://www.ssi.shimadzu.com/industry/methods/m_525_2.pdf [Accessed: 2017-06-08]

EPA (Environmental Protection Agency). Method 625: Base/Neutrals and Acids (Methods for Organic Chemical Analysis of Municipal and Industrial Wastewater) [Internet]. 1984. Available from: https://www.epa.gov/sites/production/files/2015-10/documents/method_625_1984.pdf [Accessed: 2017-07-17]

EPA (Environmental Protection Agency). Method 8021B: Aromatic and Halogenated Volatiles by Gas Chromatography Using Photoionization and/or Electrolytic Conductivity Detectors [Internet]. 2014. Available from: <http://www.epadatadump.com/pdf-files/8021b.pdf> [Accessed: 2017-08-12]

EPA (Environmental Protection Agency). Method 8270D: Semi-volatile Organic Compounds by Gas Chromatography/Mass Spectrometry (GC/MS), Revision 5 [Internet]. 2014. Available from: <https://www.epa.gov/sites/production/files/2015-12/documents/8270d.pdf> [Accessed: 2017-08-09]

EPA (Environmental Protection Agency). Method 8272: Parent and Alkyl Polycyclic Aromatics in Sediment Pore Water by Solid-Phase Micro-extraction and Gas

- Chromatography/Mass Spectrometry in Selected Ion Monitoring Mode, Revision 0. 2007. Available from: <https://www.epa.gov/sites/production/files/2015-12/documents/8272.pdf> [Accessed: 2017-08-08]
- EPA (Environmental Protection Agency). Method 8275A: Semivolatile Organic Compounds (PAHs and PCBs) in Soils/Sludges and Solid Wastes Using Thermal Extraction/Gas Chromatography/Mass Spectrometry (TE/GC/MS); Revision 1 [Internet]. 1996. Available from: <https://www.epa.gov/sites/production/files/2015-12/documents/8275a.pdf> [Accessed: 2017-06-08]
- EPA (Environmental Protection Agency). Method 8410: Gas Chromatography/Fourier Transform Infrared Spectrometry for Semi-volatile Organics: Capillary Column. Revision 1, Update V. 2014. Available from: <http://www.epadatadump.com/pdf-files/8410.pdf> [Accessed: 2017-08-12]
- EPA, U. *Toxic and priority pollutants under the clean water act*. US EPA available online: [https://www.epa.gov/eg/toxic-and-priority-pollutants-under-clean-water-act.\(2021\).](https://www.epa.gov/eg/toxic-and-priority-pollutants-under-clean-water-act.(2021).) Accessed, 24
- European Commission, E. C. (2011). Commission Regulation (EU) No 835/2011 of 19 August 2011 amending Regulation (EC) No 1881/2006 as regards *maximum levels for polycyclic aromatic hydrocarbons in foodstuffs*. **Official Journal of the European Union**, 215(4), 1-5.
- Federal Republic of Nigeria (1999). National Environmental Policy. Federal Republic of Nigeria.
- Federal Republic of Nigeria (2010). Nigerian Oil and Gas Industry Content Development Act. Federal Republic of Nigeria.
- International Agency for Research on Cancer (IARC): Monographs on the Identification of Carcinogenic Hazards to Humans. <https://monographs.iarc.who.int/>
- National Center for Biotechnology Information (NCBI): Studies on Health and Environmental Effects of PAHs. <https://www.ncbi.nlm.nih.gov/>
- NESREA (2012). Environmental Guidelines and Standards for Industrial Processes. National Environmental Standards and Regulations Enforcement Agency.
- NNPC (2017). Guidelines for the Management of Polycyclic Aromatic Hydrocarbons (PAHs) in the Petroleum Industry. Nigerian National Petroleum Corporation.
- U.S. EPA (2004). *Risk Assessment Guidance for Superfund (RAGS), Vol. I: Human Health Evaluation Manual* (Part E, Supplemental Guidance for Dermal Risk Assessment). Washington, DC: USEPA.

USEPA. 2017d. “*Regional Screening Levels (RSLs) – Users Guide* “. U. S. **Environmental Protection Agency**.
<https://www.epa.gov/risk/regional-screening-levels-rsls-users-guide->

FAO and UNEP Global Assessment of Soil Pollution - *Summary for Policy Makers Rome*,
FAO (2021), 10.4060/cb4827

Google Earth & Geographic Tools: Used to verify the coordinates and topographical details of Oluyole LGA.

International Agency for Research on Cancer (IARC) IARC Monographs on the identification of carcinogenic hazards to humans., Accessed on April 19, 2022, <http://www.monographsiarcfr/ENG/Classification/index.php>.

Fu, R. Zou, Y. *Analysis of Polynuclear Aromatic Hydrocarbons (PAHs) in Water with ZORBAX Eclipse PAH Column [Internet]*. 2008. Available from:
<https://www.agilent.com/cs/library/applications/5989-7953EN.pdf> [Accessed: 2016-06-04]

NIOSH (National Institute for Occupational Safety and Health). Method 5506: *Polynuclear Aromatic Hydrocarbons by HPLC. Fourth Edition, Issue 3 [Internet]*. 1998. Available from:
<https://www.cdc.gov/niosh/docs/2003-154/pdfs/5506.pdf> [Accessed: 2017-08-04]

International Solid Waste Association. *Global waste management outlook beyond an age of waste*, turning rubbish into a resource. 2024:

National Population Commission (NPC), Nigeria: Provides population and geographical data on local government areas in Nigeria.

Oyo State Government Official Website:
[\[https://oyostate.gov.ng\]](https://oyostate.gov.ng) (<https://oyostate.gov.ng>) Contains detailed information on the LGAs within Oyo State, including Oluyole.

Toxicological review of benzo[a]pyrene [Internet]. Washington, D.C.: United States Environmental Protection Agency; 2017 Jan [cited 2018 Oct 22]. 234 p. Report No: EPA/635/R-17/003Fa. Available from: <https://cfpub.epa.gov/ncea/iris/irisdocuments/documents/toxreviews/0136tr.pdf>

UNDP Nigeria Reports: Offers insights into the socio-economic and geographical aspects of LGAs in Nigeria.

United States Environmental Protection Agency (EPA): Technical Fact Sheet on PAHs. <https://www.epa.gov/>

World Health Organization (WHO): Air Quality Guidelines: Polycyclic Aromatic Hydrocarbons. <https://www.who.int/>

MAGAZINE ARTICLES

Buddhadasa, S. Methodologies for the Analysis of Petroleum Hydrocarbons Extracted from Contaminated Soils. Australia: Victoria University of Technology; 2002

Burchiel, S. W. and Luster, M. L. *Signaling by environmental polycyclic aromatic hydrocarbons in human lymphocytes*. Clin. Immunol. 98, 2–10.(2001). doi: 10.1006/clim.2000.4934

Middleton, D. R. Wedekind, R. Hall, A. L. Suonio, E. DeBono, N. Vermeulen, R. & Schubauer-Berigan, M. K. *Critical reviews of exposure assessment in carcinogenic hazard identification: the IARC Monographs experience. Occupational and environmental medicine*, 81(7), 366-372. (2024).

IARC (2010). *Some Non-heterocyclic Polycyclic Aromatic Hydrocarbons and Some Related Exposures*. **IARC Monogr. Eval. Carcinog Risks Hum.** 92, 1–8531.

Jakovljević, I. Smoljo, I. Sever Štrukil, Z. & Pehnec, G. *Carcinogenic activity and risk assessment of PAHs in ambient air: PM10 particle fraction and bulk deposition*. Toxics, 11(3), 228.(2023).

Polycyclic aromatic hydrocarbons: chemistry and carcinogenicity. **Cambridge**

University Press: Cambridge, 396 pgs. ISBN 978-0521292047

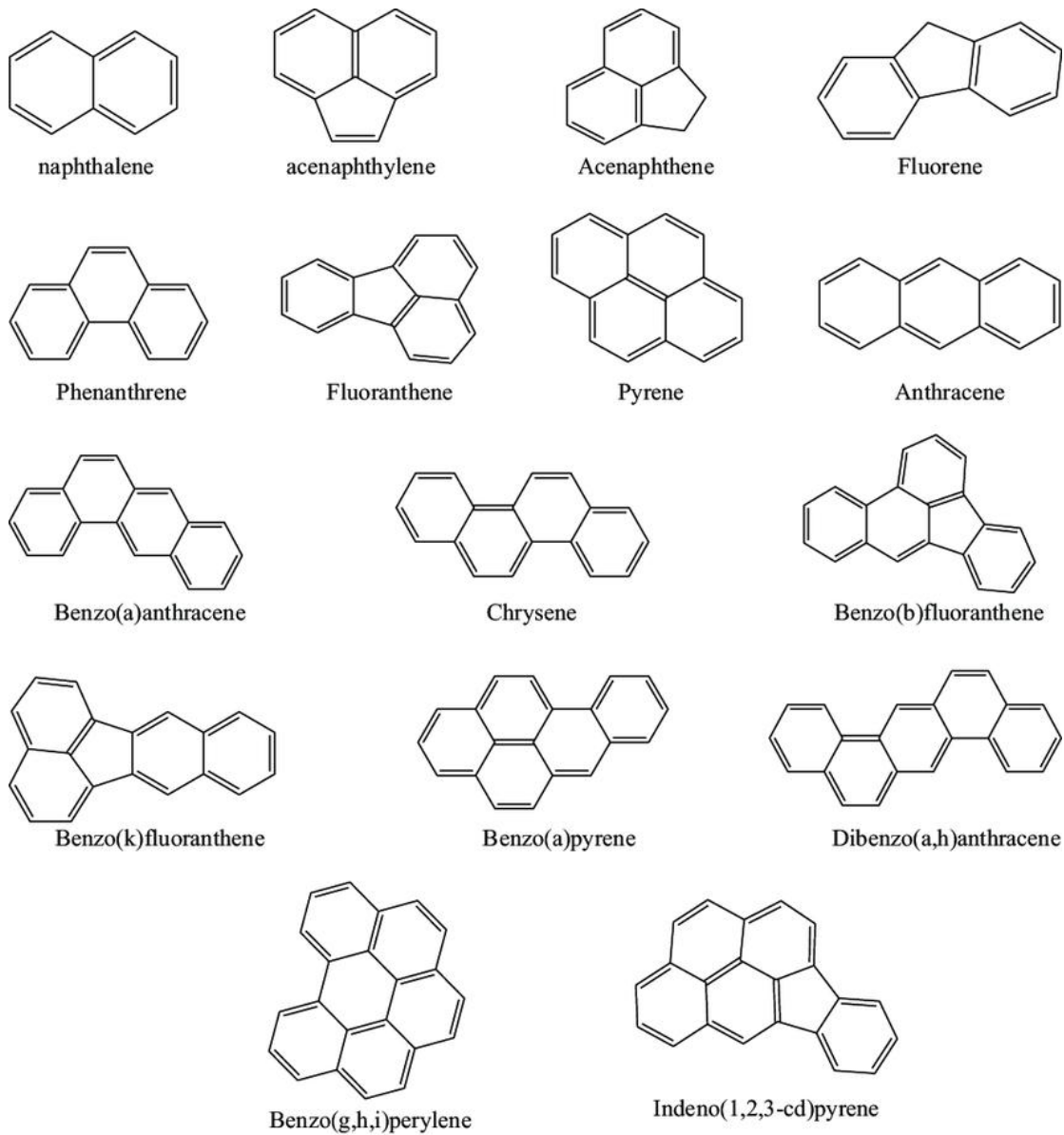
W. Weisman editor. *Analysis of Petroleum Hydrocarbons in Environmental Media, Total Petroleum hydrocarbon Criteria Working Group Series [internet]*. **Vol. 1. Amherst Scientific Publishers**; 1998. Available from: <http://www.hawaiiidoh.org/references/TPHCWG%201998>.

Yue, Z. Shi, Q. Ai, J. Peng, S. Miao, X. & Wang, Z. *A review on analytical methods of petroleum hydrocarbons in water and sediment of aquatic systems*. In IOP Conference Series: **Earth and Environmental Science** (Vol. 621, No. 1, p. 012011).(2021) IOP Publishing

Meharda, S. (2016). In Utero Exposure to Benzo [a] pyrene Results in Ovarian Follicular Depletion in F1 MutaTM mouse. University of California, Irvine.

Nisbet, I. C. & Lagoy, P. K. *Toxic equivalency factors (TEFs) for polycyclic aromatic hydrocarbons (PAHs)*. **Regulatory toxicology and pharmacology**, 16(3),(1992). 290-300.

Appendix



Appendix 1 *Structure of the 16 priority polycyclic aromatic hydrocarbons*

Source (https://www.researchgate.net/figure/Molecular-Structures-of-PAHs_fig1_323700398)

s Analysis	LAB NO/21	SAMPLE	ppb Aacer	ppb Acridit	ppb Anthic	ppb Anthic	ppb 10H-A	ppb Antho
1	2025 FEBRUARY SAMPLE NO N1	SAMPLE NO N1	3.2760	0.3985	0.1909	0.3082	10.7588	2.9138
2	2025 FEBRUARY SAMPLE NO N2	SAMPLE NO N2	4.0820	0.2592	0.1242	0.2005	6.9978	1.8952
3	2025 FEBRUARY SAMPLE NO N3	SAMPLE NO N3	2.5296	0.1606	0.0770	0.1242	4.3364	1.1745
4	2025 FEBRUARY SAMPLE NO W1	SAMPLE NO W1	4.8429	0.3075	0.1473	0.2378	8.3022	2.2485
5	2025 FEBRUARY SAMPLE NO W2	SAMPLE NO W2	6.1559	0.3908	0.1873	0.3023	10.5529	2.8581
6	2025 FEBRUARY SAMPLE NO W3	SAMPLE NO W3	8.5791	0.5447	0.2610	0.4213	14.7070	3.9831
7	2025 FEBRUARY SAMPLE NO E1	SAMPLE NO E1	2.2532	0.1431	0.0685	0.1106	3.8626	1.0461
8	2025 FEBRUARY SAMPLE NO E2	SAMPLE NO E2	1.8284	0.1161	0.0556	0.0898	3.1344	0.8489
9	2025 FEBRUARY SAMPLE NO E3	SAMPLE NO E3	6.2965	0.3998	0.1916	0.3092	10.7940	2.9234
10	2025 FEBRUARY SAMPLE NO CH1	SAMPLE NO CH1	8.4255	0.5350	0.2563	0.4138	14.4438	3.9118
11	2025 FEBRUARY SAMPLE NO CH2	SAMPLE NO CH2	7.2484	0.4602	0.2205	0.3559	12.4258	3.3653
12	2025 FEBRUARY SAMPLE NO CH3	SAMPLE NO CH3	4.3379	0.2754	0.1320	0.2130	7.4365	2.0140
13	2025 FEBRUARY SAMPLE NO C1	SAMPLE NO C1	1.6902	0.1073	0.0514	0.0830	2.8975	0.7847
14	2025 FEBRUARY SAMPLE NO C2	SAMPLE NO C2	4.5870	0.2912	0.1396	0.2253	7.8635	2.1297
15	2025 FEBRUARY SAMPLE NO C3	SAMPLE NO C3	4.9453	0.3140	0.1505	0.2428	8.4777	2.2960
16	2025 FEBRUARY SAMPLE NO SI	SAMPLE NO S1	5.7130	0.3627	0.1738	0.2805	9.7937	2.6525
17	2025 FEBRUARY SAMPLE NO S2	SAMPLE NO S2	5.4059	0.3432	0.1645	0.2655	9.2673	2.5099
18	2025 FEBRUARY SAMPLE NO S3	SAMPLE NO S3	2.2976	0.1459	0.0699	0.1128	3.9387	1.0667
19	Standard as QC Solution Conc. 4.0 ppm	Standard as QC Solution Conc. 4.0 ppm	3.9998	4.0035	3.9897	3.9995	3.9998	3.9857
20	R2 Values	R2 Values	0.9995	0.9866	0.9998	0.9988	0.9970	0.9998

ppb Coronene	ppb Fluoranthene	ppb 9H-Fluorene	ppb 9H-Fluorene -9-one	ppb Indeno-1,2,3-cd Pyrene	ppb 1H-Indole	ppb Isoquinoline	ppb Naphthalene	ppb Naphtho-1,2,3,4-def-Chryser	ppb Pentaphene	ppb Perylene	ppb Naphtho-2,3-f quinoline	ppb Phenanthraquinone	ppb 1H-Phenylene	ppb Phenanthrene
0.3682	1.2888	0.4687	2.4656	0.5123	1.7931	0.2455	0.7285	0.1287	2.1069	16.0946	2.3707	6.3208	20.5463	3.4244
0.2395	0.8383	0.3048	1.6037	0.3332	1.1663	0.1597	0.4738	0.0837	1.3704	10.4683	1.5420	4.1112	13.3638	2.2273
0.1484	0.5195	0.1889	0.9938	0.2065	0.7227	0.0989	0.2936	0.0519	0.8492	6.4871	0.9555	2.5477	8.2814	1.3802
0.2842	0.9945	0.3616	1.9026	0.3953	1.3837	0.1894	0.5621	0.0993	1.6258	12.4196	1.8294	4.8775	15.8548	2.6425
0.3612	1.2642	0.4597	2.4184	0.5025	1.7588	0.2408	0.7145	0.1262	2.0666	15.7866	2.3254	6.1998	20.1531	3.3589
0.5034	1.7618	0.6406	3.3703	0.7003	2.4512	0.3356	0.9958	0.1759	2.8801	22.0008	3.2407	8.6403	28.0861	4.6810
0.1322	0.4627	0.1683	0.8852	0.1839	0.6438	0.0881	0.2615	0.0462	0.7564	5.7782	0.8511	2.2693	7.3764	1.2294
0.1073	0.3755	0.1365	0.7183	0.1493	0.5224	0.0715	0.2122	0.0375	0.6138	4.6889	0.6907	1.8415	5.9858	0.9976
0.3694	1.2930	0.4702	2.4736	0.5140	1.7990	0.2463	0.7308	0.1291	2.1138	16.1472	2.3785	6.3415	20.6135	3.4356
0.4944	1.7302	0.6292	3.3100	0.6878	2.4073	0.3296	0.9780	0.1727	2.8286	21.6071	3.1827	8.4857	27.5835	4.5972
0.4253	1.4885	0.5413	2.8476	0.5917	2.0710	0.2835	0.8413	0.1486	2.4334	18.5883	2.7381	7.3002	23.7298	3.9550
0.2545	0.8908	0.3239	1.7042	0.3541	1.2394	0.1697	0.5035	0.0889	1.4563	11.1246	1.6386	4.3689	14.2016	2.3669
0.0992	0.3471	0.1262	0.6640	0.1380	0.4829	0.0661	0.1962	0.0347	0.5674	4.3345	0.6385	1.7023	5.5334	0.9222
0.2691	0.9420	0.3425	1.8021	0.3745	1.3106	0.1794	0.5324	0.0940	1.5399	11.7634	1.7327	4.6198	15.0171	2.5028
0.2902	1.0156	0.3693	1.9428	0.4037	1.4129	0.1934	0.5740	0.1014	1.6602	12.6821	1.8681	4.9806	16.1899	2.6983
0.3352	1.1732	0.4266	2.2444	0.4664	1.6323	0.2235	0.6631	0.1171	1.9179	14.6509	2.1581	5.7538	18.7032	3.1172
0.3172	1.1101	0.4037	2.1238	0.4413	1.5445	0.2115	0.6275	0.1108	1.8148	13.8634	2.0421	5.4445	17.6979	2.9497
0.1348	0.4718	0.1716	0.9026	0.1876	0.6564	0.0899	0.2667	0.0471	0.7713	5.8920	0.8679	2.3140	7.5217	1.2536
3.9992	4.0013	3.9789	4.0126	4.0037	3.9689	3.9998	4.0146	3.9877	4.0366	3.9994	3.9900	4.0354	3.9700	4.0020
0.9890	1.0000	0.9999	0.9988	0.9900	0.9998	0.9970	0.9998	0.9970	0.9996	0.9900	0.9999	0.9980	0.9989	0.9999

ppb 9,10-Phenanthrenedione	ppb Phenanthridine	ppb 1,10-Phenanthroline	ppb Phenanthro-4,5-bcd-thiophene	ppb Phenazine	ppb Phenazone	ppb Picene	ppb Quinoline	ppb Triphenylene	ppb 9H-Xanthene	ppb Dibenzo-b,h-phenanthrene	ppb Dibenzo-a,e-pyrene	ppb Dibenzo-thiophene	ppb Dibenzo-a,h-pyrene	ppb Dibenzo-a,h-pyrene
1.2642	1.3698	5.1746	0.2779	14.8770	7.2673	0.1263	21.8019	4.6800	0.1103	8.9561	3.7848	2.5272	6.7391	16.4008
0.8222	0.8909	3.3657	0.1808	9.6764	4.7268	0.0822	14.1805	3.0440	0.0717	5.8252	2.4617	1.6437	4.3833	10.6675
0.5095	0.5521	2.0857	0.1120	5.9963	2.9292	0.0509	8.7875	1.8863	0.0445	3.6098	1.5255	1.0186	2.7163	6.6105
0.9755	1.0570	3.9931	0.2145	11.4801	5.6079	0.0975	16.8237	3.6114	0.0851	6.9111	2.9206	1.9501	5.2003	12.6559
1.2400	1.3435	5.0756	0.2726	14.5923	7.1282	0.1239	21.3847	4.5904	0.1082	8.7847	3.7124	2.4788	6.6101	16.0870
1.7281	1.8724	7.0735	0.3799	20.3364	9.9342	0.1727	29.8025	6.3974	0.1508	12.2427	5.1737	3.4545	9.2121	22.4194
0.4539	0.4918	1.8578	0.0998	5.3411	2.6091	0.0454	7.8272	1.6802	0.0396	3.2154	1.3588	0.9073	2.4194	5.8882
0.3683	0.3991	1.5075	0.0810	4.3342	2.1172	0.0368	6.3516	1.3634	0.0321	2.6092	1.1026	0.7362	1.9633	4.7781
1.2683	1.3742	5.1915	0.2788	14.9257	7.2911	0.1267	21.8732	4.6953	0.1107	8.9854	3.7972	2.5354	6.7611	16.4544
1.6971	1.8389	6.9470	0.3731	19.9725	9.7564	0.1696	29.2691	6.2829	0.1481	12.0236	5.0811	3.3927	9.0472	22.0182
1.4600	1.5820	5.9764	0.3210	17.1821	8.3933	0.1459	25.1799	5.4051	0.1274	10.3438	4.3712	2.9187	7.7833	18.9420
0.8738	0.9468	3.5767	0.1921	10.2830	5.0231	0.0873	15.0694	3.2348	0.0762	6.1904	2.6161	1.7468	4.6580	11.3362
0.3405	0.3689	1.3936	0.0749	4.0066	1.9572	0.0340	5.8715	1.2604	0.0297	2.4120	1.0193	0.6806	1.8149	4.4169
0.9240	1.0011	3.7821	0.2031	10.8735	5.3116	0.0923	15.9348	3.4206	0.0806	6.5459	2.7663	1.8471	4.9255	11.9872
0.9961	1.0793	4.0775	0.2190	11.7227	5.7264	0.0995	17.1793	3.6877	0.0869	7.0572	2.9823	1.9913	5.3102	12.9234
1.1508	1.2469	4.7104	0.2530	13.5425	6.6154	0.1150	19.8462	4.2602	0.1004	8.1527	3.4453	2.3005	6.1346	14.9296
1.0889	1.1799	4.4573	0.2394	12.8146	6.2598	0.1088	18.7794	4.0312	0.0950	7.7145	3.2601	2.1768	5.8048	14.1271
0.4628	0.5014	1.8944	0.1017	5.4463	2.6605	0.0462	7.9814	1.7133	0.0404	3.2787	1.3856	0.9252	2.4671	6.0041
3.9979	3.9985	3.9988	3.9875	4.0037	4.0027	3.9980	4.0014	4.0036	3.9890	4.0033	4.0016	4.0042	3.9800	4.0000
0.9990	1.0000	0.9999	0.9987	0.9985	0.9988	1.0032	1.0015	0.9987	0.9983	1.0000	0.9987	1.0000	0.9987	0.9986

ppb Dibenzo-def,p-chrysene												
ppb a,i-pyrene												
ppb 7H-Benzo-c-fluorene												
ppb Benzo-b-fluoranthene												
ppb Benzo-ghi-fluoranthene												
ppb 1H-Benzo-b-fluorene												
ppb Benzo-H-naphtho-1,2-fluorene												
ppb Benzo-b-naphtho-2,1-d-thiophene												
ppb Benzo-ghi-perylene												
ppb Benzo-c-phenanthrene												
ppb Benzo-a-pyrene												
ppb Benzo-e-pyrene												
ppb Benzo-f-quinoline												
7.6756	2.8784	3.0124	3.8468	1.9040	9.2107	0.3719	2.2313	3.6446	1.9687	0.1250	0.0599	0.0967
4.9924	1.8722	1.9593	2.5021	1.2384	5.9909	0.2419	1.4513	2.3706	3.3371	0.2119	0.1015	0.1639
3.0937	1.1601	1.2142	1.5505	0.7674	3.7125	0.1499	0.8994	1.4690	2.4150	0.1533	0.0735	0.1186
5.9230	2.2211	2.3246	2.9685	1.4692	7.1076	0.2870	1.7218	2.8124	6.4766	0.4112	0.1970	0.3180
7.5287	2.8233	2.9547	3.7732	1.8676	9.0345	0.3648	2.1886	3.5749	3.6483	0.2316	0.1110	0.1792
10.4923	3.9346	4.1179	5.2585	2.6027	12.5908	0.5084	3.0502	4.9821	3.2570	0.2068	0.0991	0.1599
2.7557	1.0334	1.0815	1.3811	0.6836	3.3068	0.1335	0.8011	1.3085	6.0601	0.3848	0.1844	0.2976
2.2362	0.8386	0.8776	1.1207	0.5547	2.6834	0.1083	0.6501	1.0618	2.6686	0.1694	0.0812	0.1310
7.7007	2.8878	3.0222	3.8594	1.9102	9.2409	0.3731	2.2386	3.6565	1.7513	0.1112	0.0533	0.0860
10.3045	3.8642	4.0442	5.1644	2.5561	12.3655	0.4993	2.9956	4.8929	2.5087	0.1593	0.0763	0.1232
8.8649	3.3243	3.4791	4.4429	2.1990	10.6379	0.4295	2.5771	4.2093	8.3129	0.5278	0.2529	0.4082
5.3054	1.9895	2.0822	2.6589	1.3160	6.3665	0.2570	1.5423	2.5192	2.3943	0.1520	0.0728	0.1176
2.0671	0.7752	0.8113	1.0360	0.5128	2.4806	0.1002	0.6009	0.9815	2.7284	0.1732	0.0830	0.1340
5.6100	2.1038	2.2017	2.8116	1.3916	6.7320	0.2718	1.6309	2.6638	1.6815	0.1068	0.0512	0.0826
6.0482	2.2681	2.3737	3.0312	1.5003	7.2578	0.2930	1.7582	2.8719	2.5145	0.1596	0.0765	0.1235
6.9871	2.6202	2.7422	3.5018	1.7332	8.3845	0.3385	2.0312	3.3177	1.7708	0.1124	0.0539	0.0870
6.6115	2.4793	2.5948	3.3136	1.6400	7.9338	0.3203	1.9220	3.1394	6.5670	0.4170	0.1998	0.3225
2.8099	1.0537	1.1028	1.4083	0.6970	3.3719	0.1361	0.8169	1.3343	7.9479	0.5046	0.2418	0.3903
4.0022	4.0042	3.9995	4.0016	3.9969	4.0000	4.0036	4.0042	3.9800	4.0000	4.0022	4.0042	3.9995
1.0002	0.9997	0.9987	1.0000	1.0001	0.9998	0.9983	1.0000	0.9987	0.9986	1.0002	0.9997	0.9987

ppb Benzo-h-quinoline	ppb Benzo-b-triphenylene	ppb Benzo-Biphenylene	ppb 9H-Carbazole	ppb Dibenz-a,h-acridine	ppb Dibenz-a,j-acridine	ppb Dibenz-a,c-anthracene	ppb Dibenz-a,j-anthracene	ppb 7H-Dibenz-a,g-carbazole	ppb Benzo-c-acridine	ppb Benzo-e-acephenanthrylene	ppb Benzanthrone	ppb Benzo-c-chrysene
3.3750	0.9141	6.4452	1.0742	0.3966	0.4297	1.6232	0.0872	4.6668	2.2797	0.0396	6.8391	1.4681
5.7208	1.5494	10.9251	1.8209	0.6722	0.7283	2.7515	0.1478	7.9106	3.8643	0.0672	11.5928	2.4885
4.1399	1.1212	7.9061	1.3177	0.4864	0.5271	1.9912	0.1069	5.7246	2.7964	0.0486	8.3892	1.8008
11.1027	3.0070	21.2031	3.5339	1.3046	1.4135	5.3400	0.2868	15.3526	7.4996	0.1304	22.4989	4.8296
6.2543	1.6939	11.9439	1.9907	0.7349	0.7963	3.0081	0.1616	8.6483	4.2246	0.0734	12.6738	2.7206
5.5834	1.5122	10.6627	1.7771	0.6560	0.7108	2.6854	0.1442	7.7206	3.7714	0.0656	11.3143	2.4287
10.3888	2.8136	19.8397	3.3066	1.2207	1.3226	4.9967	0.2684	14.3654	7.0174	0.1220	21.0521	4.5190
4.5747	1.2390	8.7363	1.4561	0.5375	0.5824	2.2003	0.1182	6.3258	3.0901	0.0537	9.2702	1.9899
3.0023	0.8131	5.7335	0.9556	0.3528	0.3822	1.4440	0.0776	4.1515	2.0280	0.0353	6.0839	1.3060
4.3007	1.1648	8.2131	1.3689	0.5053	0.5475	2.0685	0.1111	5.9469	2.9050	0.0505	8.7150	1.8708
14.2507	3.8596	27.2148	4.5358	1.6745	1.8143	6.8541	0.3681	19.7055	9.6260	0.1673	28.8779	6.1989
4.1045	1.1116	7.8384	1.3064	0.4823	0.5226	1.9741	0.1060	5.6756	2.7725	0.0482	8.3174	1.7854
4.6773	1.2668	8.9323	1.4887	0.5496	0.5955	2.2496	0.1208	6.4676	3.1594	0.0549	9.4782	2.0346
2.8826	0.7807	5.5050	0.9175	0.3387	0.3670	1.3864	0.0745	3.9860	1.9471	0.0338	5.8414	1.2539
4.3105	1.1674	8.2318	1.3720	0.5065	0.5488	2.0732	0.1114	5.9605	2.9116	0.0506	8.7349	1.8750
3.0356	0.8221	5.7971	0.9662	0.3567	0.3865	1.4600	0.0784	4.1975	2.0505	0.0356	6.1514	1.3205
11.2578	3.0490	21.4992	3.5832	1.3228	1.4333	5.4146	0.2908	15.5670	7.6043	0.1322	22.8130	4.8970
13.6250	3.6901	26.0200	4.3367	1.6009	1.7347	6.5532	0.3520	18.8404	9.2034	0.1600	27.6101	5.9268
4.002	4.004	3.999	4.002	3.997	4.000	4.004	3.999	4.001	4.033	4.013	3.999	3.987
1.000	1.000	0.999	1.000	1.000	1.000	0.998	0.999	1.000	0.999	1.004	1.000	0.999

ppb Benzo-g-chrysene	ppb Benzo-c-cinnoline	ppb Benzo-a-dibenzothiophene	ppb TPAHs
0.0346	2.8095	1.1873	242.7626
0.0586	4.7622	2.0125	197.3738
0.0424	3.4462	1.4564	128.6406
0.1138	9.2424	3.9058	280.0955
0.0641	5.2063	2.2002	272.3918
0.0572	4.6478	1.9642	346.2725
0.1065	8.6481	3.6546	185.9057
0.0469	3.8081	1.6093	109.8230
0.0308	2.4992	1.0562	242.4819
0.0441	3.5801	1.5129	327.4869
0.1461	11.8629	5.0132	394.0274
0.0421	3.4167	1.4439	188.7272
0.0479	3.8936	1.6454	106.2940
0.0296	2.3996	1.0141	184.0515
0.0442	3.5882	1.5164	211.2274
0.0311	2.5270	1.0679	223.3269
0.1154	9.3714	3.9603	300.5690
0.1397	11.3420	4.7931	221.8334
4.004	4.003	3.998	
0.998	0.999	1.003	



Lead City University (LCU), Ibadan

Motto: Knowledge for Self Reliance

Oba Otudeko Avenue, Toll gate Area, P.O. Box 30678, Secretariat, Ibadan, Oyo State, Nigeria
www.lcu.edu.ng

Department of Chemical Sciences

The Managing Director

Mottainai Recycling

Shoun Ajagungbade, Bodija

Ibadan

24 July 2024

Dear Sur/Madam,

Request for Access to the Waste Dump Sites

The bearer, Mr. Fowosere Olatilewa David is a registered MSc Student of Lead City University, Ibadan in the Department of Chemical Sciences. He is presently working on a research project titled "Polycyclic Aromatic Hydrocarbons in Waste Dump Sites in Ibadan" and I am his research supervisor for the project. He needs to collect soil samples from the waste dump sites for analysis to assess the levels of polycyclic aromatic hydrocarbons (PAHs) in them. The results of the project is purely for academic purpose but the result will add value by providing data on the levels of PAHs in the waste dump sites which could be one of the sources of these compounds in the sites. The results of the study will also contribute to local, national and international data on the levels of PAHs in the environment. PAHs are toxic compounds in the environment and the need for effective waste management to reduce their levels in the environment is essential. This results of this study may assist in developing such strategies. I shall be grateful if you will grant him access.

Thank you for your cooperation.

Yours Sincerely,

Prof Olatokun Siyanbola Fatoki



Lead City University (LCU), Ibadan

Motto: Knowledge for Self Reliance

Ora Oluoko Avenue, Toll gate Area, P.O. Box 30678, Secretariat, Ibadan, Oyo State, Nigeria

www.lcu.edu.ng

Department of Chemical Sciences

The Commissioner
Ministry of Environment & Natural Resources
Secretariat, Ibadan,
Oyo State

18 September 2024

Dear Sir,

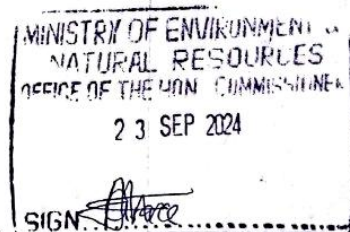
Request for Access to the Waste Dump Sites

The bearer, Mr. Fowosere Olatilewa David is a registered MSc Student of Lead City University, Ibadan in the Department of Chemical Sciences. He is presently working on a research project titled "Polycyclic Aromatic Hydrocarbons in Waste Dump Sites in Ibadan" and I am his research supervisor for the project. He needs to collect soil samples from the waste dump sites for analysis to assess the levels of polycyclic aromatic hydrocarbons (PAHs) in them. The results of the project is purely for academic purpose but the result will add value by providing data on the levels of PAHs in the waste dump sites which could be one of the sources of these compounds in the sites. The results of the study will also contribute to local, national and international data on the levels of PAHs in the environment. PAHs are toxic compounds in the environment and the need for effective waste management to reduce their levels in the environment is essential. This results of this study may assist in developing such strategies. I shall be grateful if you will grant him access.

Thank you for your cooperation.

Yours Sincerely,

Prof Olalekan Siyanbola Fatoki





**MINISTRY OF ENVIRONMENT AND NATURAL RESOURCES
SECRETARIAT, IBADAN,
OYO STATE OF NIGERIA.**

E-mail: oyoenvironment17@gmail.com

DEPARTMENT OF ADMIN AND SUPPLIES

Your Ref. No.....

Our Ref. No. AD.1317/115

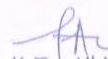
14th October, 2024.
Date.....20.....

The Dump Manager
Ajakanga Dump Site,
Oluyole Local Government,
Ibadan.

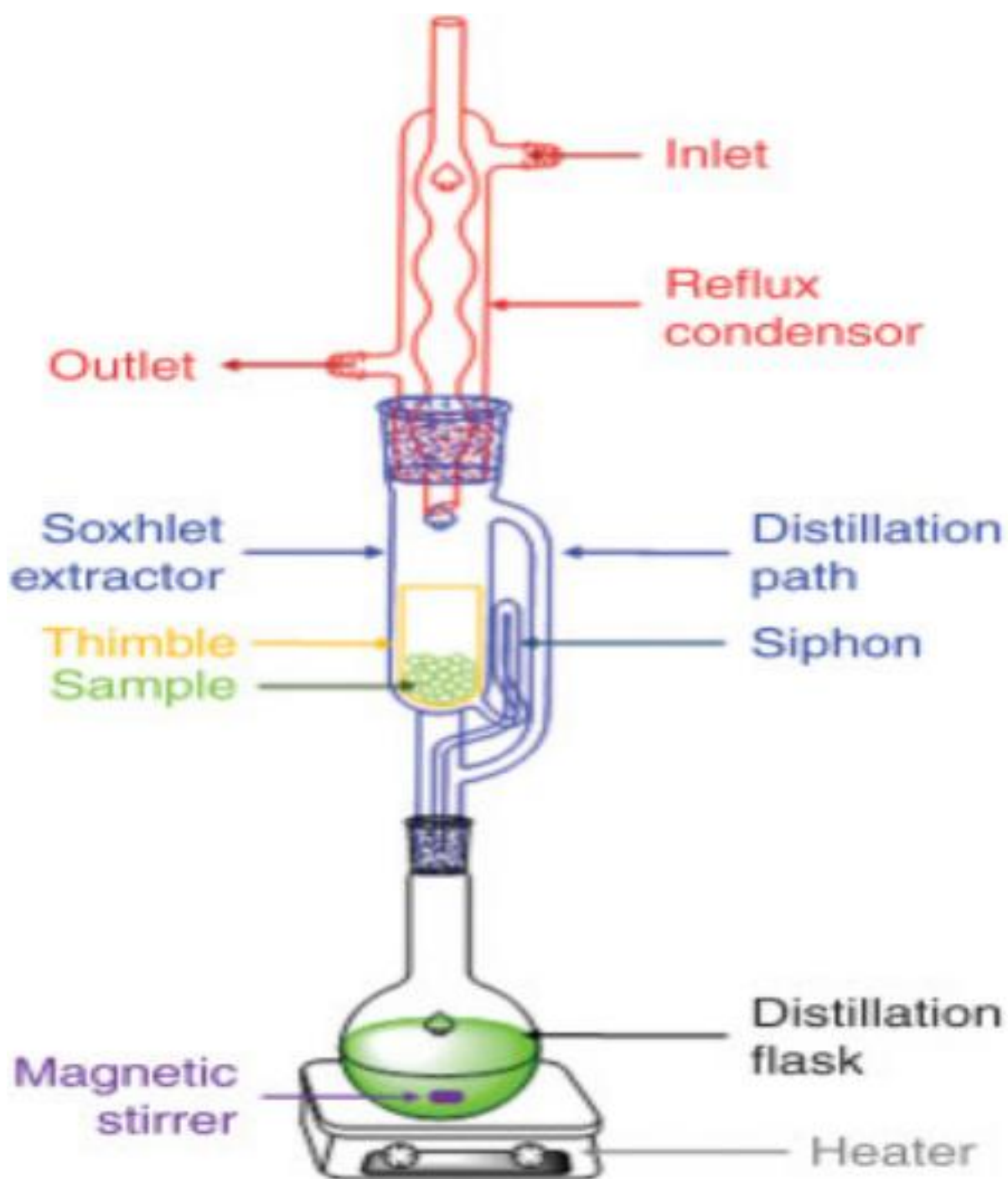
RE: REQUEST FOR ACCESS TO THE WASTE DUMP SITE

I am directed to inform you that, Mr. Fowosere Oiatilewa David, a Post Graduate student of Lead City University, Ibadan, Department of Chemical Sciences, is carrying out a research work on " Polycyclic Aromatic Hydrocarbons in Waste Dump Site in Ibadan " and that you should to allow him to collect soil sample at your dump site.

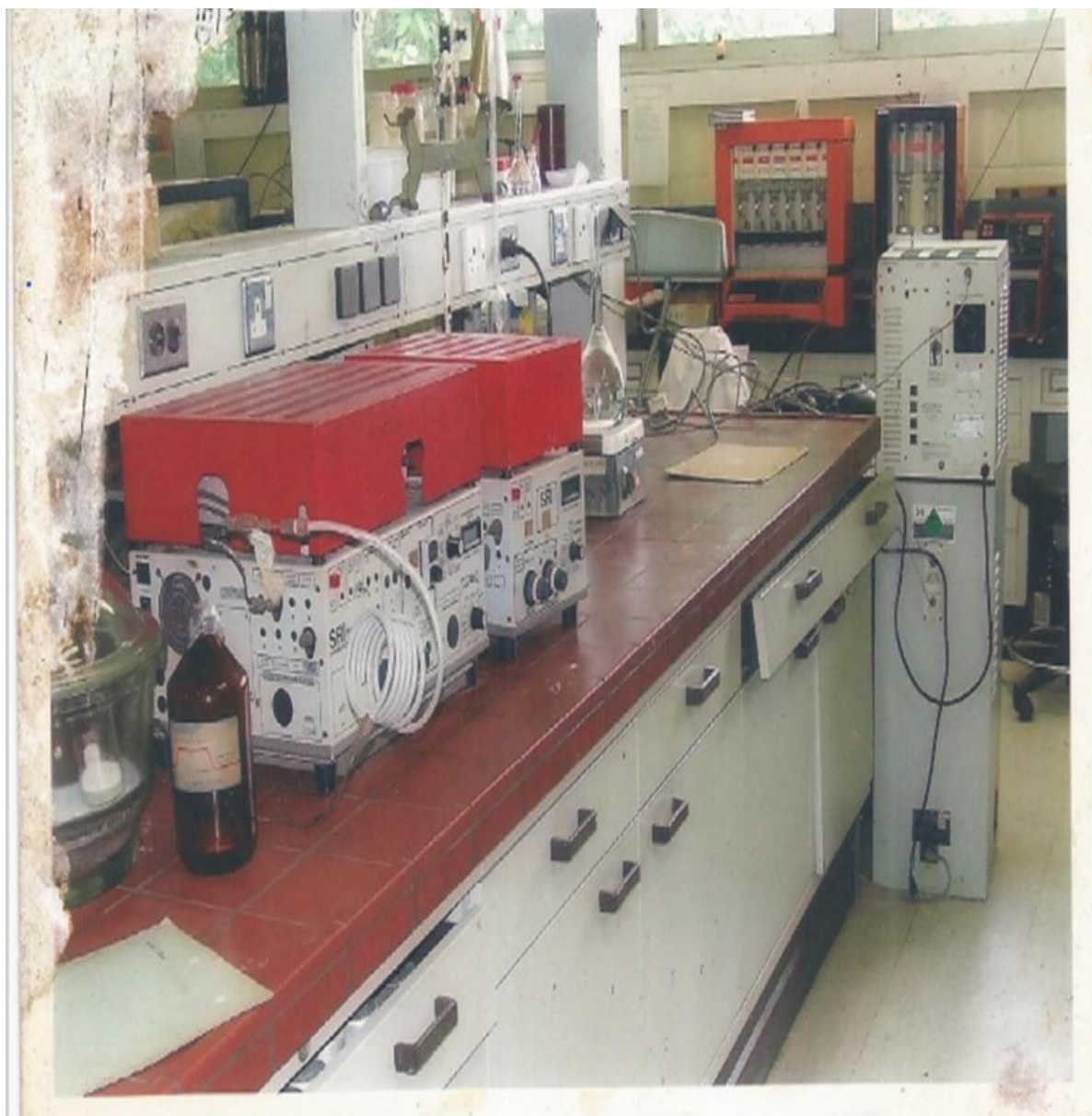
2. The research work is for academic purpose.
3. Thanks for your cooperation in this regards.


K.T. Aiki

for: Honourable Commissioner



Soxhlet Extraction Apparatus



GC-FID Instrument



Lead C
Picture Of a Burning Dumpsite

Bio data

Personal Data

Name	Olatilewa David Fowosere
Address	Sw9/Abdullahi Stress Odo Ona, Apata, Ibadan.
Email Address	fowosereola@gmail.com
Telephone	08059135128,08133090713
Date and place of birth	21 st August,1981, Kano State
Nationality	Nigeria
Marital Status	Married
Number of children	2: 9years and 5years
Name and address of spouse	Mrs. Damilola Olabisi Fowosere, Same as above
Name and address of next of kin	Mrs. Damilola Olabisi Fowosere Same as above

Educational Institution Attended with Date and Qualification

Mapatachi Primary school,Kano. First school leaving certificate	1987-1991
St.Joseph Catholic primary school, Ijebu Igbo	1991-1992
Abusi Odumare Academy, Ijebu-Igbo Secondary School	
Certificate	1992-1998
Olabisi Onabanjo University, Ago-Iwoye, Ogun State (B.Sc)	2004-2010

Work Experience

Branch Manager / Sales Rep Plastic Furniture Company 2000-2001

Ojodu Road, beside Omole Estate, Lagos

Field Man (Estate Management) Focent & Co. 2001-2002

Sumal Road, Opposite Oluyole Police state , Ibadan.

Production supervisor Alcanah Limited 2010-2024

Plot5,Block, Oluyole Industrial Estate, Ibadan.

Project

Aflatoxin in Infant Food B.Sc project 2009

Referees

Dr.Akeem Odusote

General Hospital,

Ijebu Ode, Ogun State

08055902836

Mr.Anthony Olayinka Adekoya

Industrial Maintenance Department

Yaba College of Technology Lagos

08062498485

The University Compliance Certification

This is to certify that this thesis written by Olatilewa David, FOWOSERE with matriculation number LCU/PG/005475 in the department of Chemical Sciences, Faculty of Natural and Applied Sciences, Lead City University, Ibadan, Oyo State is in full compliance with the approved University format and style.

Signature

Date