

**ASSESSMENT OF POTENTIAL HEALTH RISK OF BANKNOTE DUST
(BND) IN SELECTED COMMERCIAL BANKS WITHIN BENIN
METROPOLIS IN EDO STATE, NIGERIA**

BY

OSAGIE FERDINAND AMAYO

PG/LSC2110439

**A THESIS SUBMITTED TO THE COLLEGE OF POSTGRADUATE
STUDIES IN PARTIAL FULFILMENT FOR THE AWARD OF MASTER OF
SCIENCE (CHEMISTRY TECHNIQUE), IN THE DEPARTMENT OF
SCIENCE LABORATORY TECHNOLOGY, FACULTY OF LIFE SCIENCES,
UNIVERSITY OF BENIN, BENIN CITY,
NIGERIA.**

FEBRUARY 2026

CERTIFICATION

This is to certify that this project work was carried out by Osagie Ferdinand Amayo with Matriculation number **PG/LSC2110439** in partial fulfilment of the requirements for the award of Master degree (M.Sc) in Chemistry Techniques in the Department of Science Laboratory Technology, Faculty of Life Sciences, University of Benin.

Osagie Ferdinand Amayo
(Student)

Date

Prof. Mrs. J. E. Ukpebor
(Project Supervisor)

Date

Prof. J.O. Osarumwense
(Head of Department)

Date

DEDICATION

This work is dedicated to the Almighty God: My source.

ACKNOWLEDGEMENT

I want to appreciate the Almighty God for the strength and wisdom given me to complete this study. My special thanks go to my project supervisor, Prof. (Mrs.) Justina E. Ukpebor for her guidance throughout the period of this study. Her selfless disposition stands her out among many. I would also like to appreciate the PG Coordinator, Prof. E. Oshomo for the time he took to encourage me during this study. Special thanks to the Dean of Science Laboratory Technology, Prof. J. Osarumwense for the fatherly role he played during this study. I also want to thank Dr. Collins Udinyiwe for taking time to look at part of this work. All members of staff of the Faculty of Science Laboratory Technology, I appreciate you for your cooperation.

To my very special wife, Mrs. Osagie-Amayo Osayi (ACA), my children, Umamwenosa, Uwamwenrobosa and Ufumwenosa, thank you so much for your understanding.

TABLE OF CONTENTS

Title page		i
Certification		iii
Dedication		iv
Acknowledgments		v
Table of Contents		vi
List of Figures		ix
List of Plates	x	
List of Tables	xi	
Abstract		x
CHAPTER ONE		
1.0	Introduction	1
1.1	Particulate Matter (PM)	1
1.2	Dust	2
1.3	Background of Study	6
1.4	Aim and Objectives	7
1.5	Scope of Study	8
1.6	Statement of Problem	8
1.7	Justification of Study	8
CHAPTER TWO		
2.0	Literature Review	10
2.1	Origin of Money	10
2.2	Pollution	11
2.3	Air Pollution	12
2.4	Sources of Polycyclic Aromatic Hydrocarbons (PAHs)	16
2.5	Environmental significance of PAHs.	18
2.6	Sources identified by PAHs diagnostic ratios	19

2.7	Heavy Metals	21
2.8	Health Effect of Heavy Metals	23
2.8	Bacteria Bound Dust and Its Effect on Human Health	27
CHAPTER THREE		
3.0	Materials and Methods	29
3.1	Materials	29
3.2	Methods	30
3.2.1	Sample Collection	30
3.3.0	Sample Analysis	31
3.3.1	Particle size analysis	31
3.3.2	Microbial analysis	31
3.3.3	Antibacterial Sensitivity Test	32
3.3.4	Determination of pH	33
3.3.5	Heavy Metal analysis	33
3.3.6	Analysis of Polycyclic Aromatic Hydrocarbon (PAHs)	34
3.3.7	Quality control measures taken	35
CHAPTER FOUR		
4.0	Results and Discussion	37
4.1	Results	37
4.2	Polydispersity index	52
CHAPTER FIVE		
5.0	Conclusion and Recommendation	56
5.1	Conclusion	56
5.2	Findings	58
5.3	Recommendation	59
5.4	Contribution to knowledge	60
REFERENCES		61

LIST OF FIGURES

Figure 1.1	Particle size distribution	1
Figure 2.1	Structure of sixteen PAHs	15
Figure 2.2	Natural and Anthropogenic sources of PAHs	17
Figure 2.3	Environmental fate of PAHs	18
Figure 4.1	Concentration of selected heavy metals from banknote dust (BND) for sample A and B	38
Figure 4.2	Concentration of the 16 priorities PAHs obtained from different sampling locations	44
Figure 4.3	PDI and Z-average of sample A	52
Figure 4.4	PDI and Z-average of sample B	53

LIST OF PLATES

Plate 1.1	Plate showing banknote dust deposited on counting machine	4
Plate 3.1	Plate showing fungi colony	32
Plate 3.2	Plate showing bacteria colony	32
Plate 3.3	Antibacterial sensitivity test	32

LIST OF TABLES

Table 2.1:	Diagnostic ratios listed with their typically reported values for a particular process	20	
Table 3.1:	Basic physiochemical constants of PAHs and abbreviations.	36	
Table 4.1:	Mean and standard deviation of heavy metals concentration	37	
Table 4.2:	Concentration of PAH in banknote dust.		41
Table 4.3:	Range of diagnostic ratios for PAHs sources in Banknote dust.	45	
Table 4.4:	Heterotrophic bacteria and fungi count of banknote dust (BND)	47	
Table 4.5:	Morphological, cultural, and biochemical characterization of bacteria and fungi isolates in banknote dust (BND)	47	
Table 4.6:	Antibiogram test of the bacteria isolates for banknote Dust.	51	

ABSTRACT

This study was designed to assess the presence and levels of selected heavy metals, polycyclic aromatic hydrocarbons (PAHs), and microbes in bank note dust as well as their potential health risks.

Two commercial banks (Location A, Ekehuan Road, located in Oredo Local Government Area, and Location B, Ugbowo, University of Benin Campus in Ovia North-East Local Government Area) were selected within Benin City metropolis and banknote dust from the counting rooms were collected. The samples were extracted using wet digestion for heavy metals concentrations and solvent (hexane) extraction for the PAHs. The extracted samples were cleaned up and the concentrations determined using an atomic absorption spectrophotometer, AAS (Buck Scientific, VGP210) and gas chromatograph fitted with flame ionization detector (GC-FID) were used to determine heavy metals and PAHs respectively. Particle size determination was carried out by using the dynamic light scattering (DLS) techniques based on Brownian movement principles.

Results obtained revealed that the sizes of the dust particles were in the range of 36.57 nm and 48.48 nm which the nano range (0-100 nm). The results of heavy metal analysis revealed that the concentration of iron was the highest value for both locations A ($2,055 \pm 70.06$ mg/kg) and B ($1,934.53 \pm 68.64$ mg/kg). This result is below standard (10,000 mg/kg) set by WHO/USEPA. While cadmium was the lowest concentration of 1.82 ± 0.30 mg/kg and 0.95 ± 0.15 mg/kg for locations A and B respectively, exceeding the permissible limit of 0.8 mg/kg for cadmium as set by WHO. Copper for locations A and B were found to be 56.06 ± 2.53 mg/kg and 50.56 ± 4.42 mg/kg respectively exceeding limit of 36.0 mg/kg standard set by WHO. The concentrations of the heavy metals were found to follow the order: Fe > Zn > Mn > Cr > Cu > Ni > Pb > Cd for location A and Fe > Zn > Mn > Cu > Cr > Ni > Pb > Cd for location B with location A having higher concentration of Cr than location B. PAHs results revealed that all 16 EPA priority PAHs as specified by WHO/USEPA were detected in the banknote dust samples from the two locations. Location A had the highest PAHs summation of $4.278 \mu\text{g/kg}$ with pyrene alone contributing $3.084 \mu\text{g/kg}$, while for location B, phenanthrene was the highest with a value of $1.167 \mu\text{g/kg}$. The diagnostic ratio suggests multi-sources ranging from petrogenic to pyrogenic, traffic to non-traffic emissions, coal and wood combustion. Microbial analysis revealed significant loads of bacteria with 1.2×10^4 cfu and 1.1×10^4 cfu obtained from locations A and B respectively while the fungi load was found to be

2.0 x 10⁴ cfu and 1.1 x 10⁴ cfu for locations A and B respectively. The bacteria identified was *streptococcus* spp while the fungi were *aspergillus* and *penicillium*. This study clearly indicated the potential health risk faced by bank staff especially those in the cash processing units due to long exposure to banknote dust and it is recommended that regulatory bodies monitor human exposure to these pollutants and adequate personal protective equipment (PPE) be made available to staff working in these sections of the banks.

CHAPTER ONE

1.0 Introduction

1.1 Particulate Matter (PM)

Particulate matter (PM) refers to the particles in air which can be a mixture of solid semi-solid and liquid. Examples of PM are dust, smoke, soot, dirt which may be large enough to be seen with the eye or so small that only an electron microscope can detect them. They vary both in particle size and composition with diameters less than $2.5 \mu\text{m}$ ($\text{PM}_{2.5}$ – fine particles) and between $2.5 - 10 \mu\text{m}$ (PM_{10} – coarse particles) (Lala *et al.*, 2023). These aerodynamic particle sizes include organic and elemental carbon, metals (nickel, zinc, lead, cadmium, copper, manganese etc.) nitrates, sulphates, sodium, potassium, ammonium, and calcium, and polycyclic aromatic hydrocarbons (PAHs) (Abrams *et al.*, 2017); Kim *et al.*, (2015).

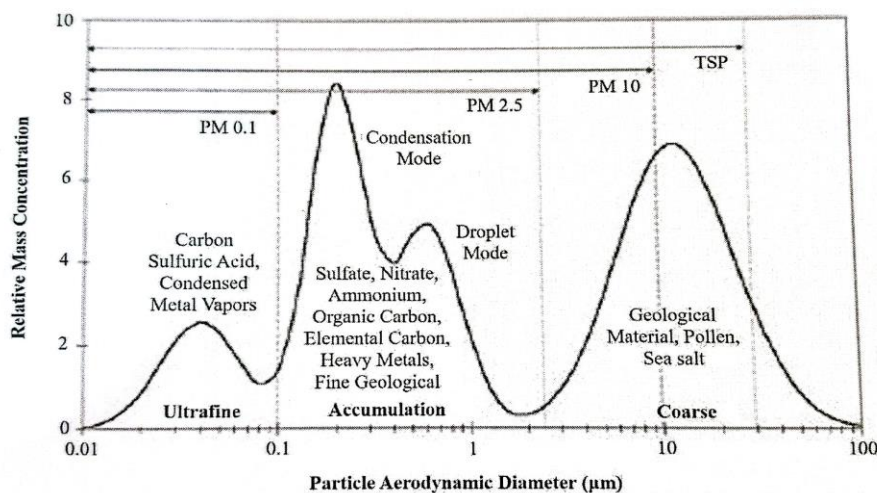


Figure 1.1. Particle size distribution model (source: Van Der Pol *et al.*, 2014)

Studies have shown that globally about 1.7 million estimated deaths related to lung cancer which results from the inhalation of particulate matter ($\text{PM}_{2.5}$) (Cohen *et al.*, 2017). $\text{PM}_{2.5}$ (fine particles) is more potent and dangerous in the human system when inhaled because of its

greater surface-area to volume ratio compared to PM₁₀ (coarse particles). PM results from various sources including natural occurrence like wildfire, industrial activities, agricultural activities etc. Particulate matter when inhaled by humans, can be harmful causing several respiratory health problems such as asthma, bronchitis, and other related diseases.

1.2 Dust

Dust is often dismissed as a mere nuisance, a sign that it is time to clean. Dust can be much more than just an irritant. It poses significant health risks that can affect both individuals and communities. Understanding these risks is crucial for both personal well-being and workplace safety, as well as for broader environmental health.

Dust could also be described as a complex mixture of tiny particles that can come from various sources, including soil, pollen, mold, human activities such as constructions activities e.g. roads and building constructions, vehicle movement along untarred roads, quarry, mining, various industrial activities, agricultural practices etc. The dust generated from these activities ranges in sizes and are generally referred to as particulate matter. When inhaled or ingested, these minuscule particles can lead to various health issues, particularly in sensitive populations such as children, the elderly, and individuals with pre-existing health conditions.

Dust may also be described as solid particulate matter made up of fine particles in the atmosphere. It is a mixture of dirt, dead skins cells and fibers from textiles and carpets, also regarded as solid aerosol. Dust mites, a common component of household dust, are a known allergen.

Dust particles can act as a medium of transportation for contaminants such as microbes and toxic compounds including heavy metals, which are harmful to human health in significant

ways, particularly the human respiratory system and even at times can result in death (Urrutia-Pereira *et al.*, 2021).

Long term exposure can lead to chronic obstructive pulmonary disease (COPD), silicosis, which is a type of lung disease caused by inhaling silica dust. Emerging research have indicated that dust exposure, particularly fine particulate matter can have adverse effects on the cardiovascular health conditions such as, increased risk of heart attacks, high blood pressure and eventually stroke. (Pope *et al.*, 2004).

Understanding the composition of dust is crucial in assessing its risks. Dust can be classified based on its origin and size:

Inorganic Dust: This includes materials like silica, asbestos, and metal particles. Inhalation can lead to serious respiratory diseases.

Organic Dust: Composed of biological materials such as mold spores, pollen, or animal dander. Organic dust can trigger allergic reactions and respiratory issues.

Respirable Dust: Particles that are small enough (typically less than 10 micrometers in diameter) which can be inhaled into the lungs, posing a greater risk to health, each type of dust poses unique risks. In many cases, symptoms may not appear immediately. For instance, a bulk teller who is exposed to dust from naira notes may not have noticed any issues for many years after prolonged exposure to dust. These delayed responses make it very challenging to link health problems to dust exposure, thus underlining the importance of preventive measures.

Dust particles are common in the environment and can carry a variety of pollutants, including heavy metals, microbes, and hydrocarbons. These can enter the body through ingestion, inhalation, and dermal contact (Al-Hemoud *et al.*, 2020). Persistent organic pollutants (POPs) have been detected in pristine environment far from where they were produced, applied or used

owing to their characteristics to undergo long- range transport (Wittayanan *et al.*, 2019; Chicas *et al.*, 2022). Banknotes can be a major carrier of pollutants because of frequent use and handling.

Heavy metals, including lead, mercury, cadmium, and chromium, nickel, zinc, arsenic manganese, copper, are naturally occurring elements with large atomic weights and hazardous effects. They are released into the environment because of a variety of human activities, such as industrial processes, vehicle emissions, agricultural practices, and waste management. Nweneewi and Nna, (2016) revealed that heavy metals are known to be toxic when they reach or exceed certain concentration in food, water, soil and air.



(a)

(b)

Plate 1.1: Banknote dust deposited on counting machine and table.

Heavy metals in dust particles represent major health and environmental concerns. When inhaled or swallowed, these poisonous compounds can build up in the body over time, causing respiratory issues, neurological disorders, organ damage, and even cancer.

Heavy metals have been detected in dust particles as they have the potential to adsorb to particulate matter and be transported to long distances. The outcomes of the studies carried out by Sezgin *et al.*, 2003, Tashakor *et al.*, 2022, Fumiyuki and Rupak, 2018, emphasizes the

significance of implementing preventive measures and raising awareness on the potential health dangers of heavy metals.

People can be exposed to heavy metal contaminated dust particles in a variety of ways, this includes the exchange of money from one person to another. This aspect has received little attention mainly due to ethical concerns expressed in the banking industries. Money, which is an indispensable aspect of our modern society, is crucial in facilitating financial transactions. Money serves as a medium of exchange. Central banks or monetary authorities issue banknotes as physical representations of currency. It provides convenience and facilitates economic activities across different industries. They are widely accepted and used in various commercial transactions.

The widespread use of money raises substantial concerns about contamination. Given how frequently banknotes change hands, they have the potential to get contaminated. As money is exchanged in numerous transactions, it encounters diverse places and people, increasing the likelihood of contaminants such as dust particles, bacteria, fungi, polycyclic aromatic hydrocarbons (PAHs), viruses, and even heavy metals. Although the level of contamination maybe typically lower than that of direct mining and industrial pollution, it nevertheless raises the background exposure level of heavy metals and other contaminants or disease-causing agents to humans.

Money is the most desired and widely used material in the world. It refers to notes of several and different denominations made of paper or polymer-based materials issued by the central bank or the government of a country. Globally, currency is widely used as a means of exchange for goods and services, to settle debts and remit payment. Since its introduction in China, circa 1000 AD, the use of paper currency has been adopted and it is the model of economic exchange of many nations (Alemu, 2014).

Scientists and researchers began to theorize the association and transmission of toxic materials and diseases involved with the circulation of money in the late 18th and early 19th centuries (Ofoedu *et al.*, 2021). Subsequently, the presence and isolations of toxicants and pathogenic organisms from the surface of money were confirmed by these postulations (Alemu, 2014; Ofoedu *et al.*, 2021). However, due to the large surface area of money, combined with its general use, constant and daily exchange by several individuals and diverse environment make currency a likely agent and carrier of heavy metals and other forms of pollutants.

Possible means of contamination includes coughing, sneezing, handling with unclean hands or other dirty means, placement on dirty surface, daily business activities have made the currency to banks to accumulate pollutants. Poor notes handling custom and indiscriminate use of money are common in many developing nations like Nigeria. Lack of orientation and improper awareness have made many to handle and keep cash in odd places such as burying underground, keeping beneath rugs and beds, placing money underwear, squeezing it in the hand, spraying in parties and so many other manhandling of the naira notes which can all leads to the introduction of numerous contaminants (Awe *et al.*, 2010; Anaam, 2019).

1.3 Background of Study

Dust from banknotes may contain heavy metals such as lead, arsenic and cadmium. Banknotes can also be contaminated with chemical residues from printing or handling process. The presence of microorganisms such bacteria (*E. coli*, *pseudomonas aeruginosa* or *Staphylococcus aureus*) cannot be ruled out. Other microorganisms like fungi (*aspergillus*, *penicillium* or *candida*) may also be found on banknotes dust. Viruses can survive on banknotes for a long period of time making the dust from it have potential health implications.

Studies have shown that frequent contact between different people and banknotes can lead to a high concentration of microorganisms. Paper money can act as an environmental vector that

facilitates the spread of potentially dangerous microorganisms (Brady and Kelly, 2000). Human occupational activities, especially those requiring the simultaneous handling of banknotes, may raise the risk of diseases in the absence of hygienic intervention. Contaminated banknotes have the potential to spread illnesses, which makes them a potential public health concern. The relationship between environmental contaminants and currency is a complex problem. Because of frequent handling and exposure to the environment, dust particles—which are made up of a wide variety of substances—can stick to their surfaces. This dirty currency can deposit dust particles on currency counting machines and the counting rooms' environment, thereby endangering both customers and bank staff alike.

1.4 Aim and Objectives

The aim of the study is to assess the levels of PAHs, heavy metals, and microbes in dust samples from selected commercial banks in Benin metropolis and the associated potential health risk.

To achieve the above aim, the following objectives were set.

1. Collection of banknote dust sample from selected commercial banks within Benin metropolis.
2. Determination of the particle size of the dust samples collected.
3. Extraction the heavy metals contents using wet acid digestion, determination of the concentration of heavy metals using Atomic Absorption Spectrophotometer.
4. Determination of the concentration of PAHs using Gas Chromatography- Flame ionization detector (GC-FID).
5. Determination of the sources of the PAHs using diagnostic ratio; and
6. analyze banknotes dust to determine the microbial loads (bacterial and fungi)

1.5 Scope of Study

The health risks posed by the poor handling of banknotes is of great concern. Dust generated from banknotes have received little or no attention from the authority and little information on the hazardous nature of banknote dust is available. This study is focused on the evaluation of the toxic nature of banknote dust and its potential risk to bank staff and customers alike. Heavy metals, PAHs, Nature of particulate matter (particle size) and biological analysis will be investigated to ascertain the potential health risk of banknotes dust. Banknote dusts were sampled and analyzed for the various contaminants as highlighted.

1.6 Statement of Problem

Dust particles could act as a medium of transportation for contaminants such as microbes and toxic compounds including heavy metals and polycyclic aromatic hydrocarbons (PAHs) which are harmful to the human health in significant ways, particularly the human respiratory system and even at times can result to death (Urrutia-Pereira *et al.*, 2021).

Emerging research have indicated that dust exposure, particularly fine particulate matter can have adverse effects on the cardiovascular health conditions such as, increased risk of heart attacks, high blood pressure and eventually stroke. Dust from banknotes may have the potential to accumulate various contaminants because of usage and handling procedure. Being the major means of exchange, banknote pick up a lot of contaminants that have the potential of causing various illnesses and diseases.

1.7 Justification of Study

Money is the major means of exchange. One of the forms of money or currency is the banknote which can either be made with polymer or paper. They come in different denominations and is usually issued by the central bank of a country which is the regulatory agency. In Nigeria,

people use the banknotes for various transactions including buying and selling. Others use it for different purpose such spraying in parties thereby making the notes to be dirty, some persons go as far as storing money under carpets or even digging it underground. New banknotes are usually crispy but due to manhandling and other forms of mismanagement, these notes get dirty and mutilated, they become dirty, dusty, and even torn. As these notes pass from one individual to another, there is the tendency for it to pick up various forms of contaminants such as heavy metals, microbes and PAHs which ultimately may pose health hazard to bank staff and customers. There is however little or no information on the hazards caused by banknotes dust. The concerns about the occupational safety of those who handle currency is paramount importance, there is need to raise public awareness of hygiene and health issues, the need to develop appropriate policies and regulations, and for scientific knowledge. An approach to human health risk assessment is therefore important, to estimate the possible hazard to health effects from exposure to metals and other potentially toxic elements in dust particles over a specific period of time (Envoh *et al.*, 2020, Envoh, C.E., 2020).

CHAPTER TWO

2.0 Literature Review

Money has been used in ancient times for the purchase of goods and services. Before the introduction of currency, man has had other means of transacting businesses, ranging from barter system to the use of a tangible means of exchange. The introduction of currency, saw the evolution of business, making it easier to carry out transaction. Banknote is the most desired and widely used material in the world. Currency (money) refers to notes of several and different denominations made of paper or polymer-based material, issued by the central bank or the government of a country. Globally, currency is widely used as a means of exchange for goods and services, to settle debts and remit payment. Since its introduction in China, circa 1000 AD, the use of paper currency has been adopted and it is the model of economic exchange of many nations (Alemu, 2014).

2.1 Origin of Money

The origin of money can be found in prehistoric societies where trade by barter system—the direct exchange of commodities and services—was the main form of commerce. But bartering had its limits. It was predicated on the coincidence of wants, which means that for a trade to occur, both parties have to want or desire what the other is giving. This made it harder to complete transactions effectively and slowed down economic expansion. Man started employing commodity money, or things having inherent worth as means of exchange, to get around these restrictions. Because of these goods' intrinsic worth and durability, such as gold, silver, and other precious metals, they were generally accepted, and because of their uncommon nature and appeal, they were perfect for promoting transactions.

Despite being widely utilized; commodity money had many drawbacks. Carrying significant amounts of precious metals for financial transactions was difficult and dangerous. In response to these issues, several representative money systems were developed, in which real commodities were replaced with tangible tokens or certificates representing a given value. This made transactions simpler and lessened the danger of transporting significant quantities of precious metals. Over time, paper money gained popularity.

The transfer of paper currency has been the model of economic exchange since its introduction in China circa 1000 AD (Bernholtz, 2003). The first paper money was created in the seventh century in Tang Dynasty China, known as "flying money" (Allen *et al.*, 2022). However, true paper money did not appear until the 11th century, during the Song Dynasty. Paper currency later spread throughout the Mongol Empire or Yuan Dynasty in China. (William *et al.*, 2005). However, Europe and other world regions waited longer to adopt paper money on a large scale. In the seventeenth century, Sweden issued the first banknotes, marking the beginning of paper money throughout Europe. Other nations, like England and France, followed suit. Nowadays, the majority of nations use paper currency as their main form of payment.

2.2 Pollution

Pollution is the introduction of contaminants into the environment that can causes detrimental effect. One of the major forms of air pollution is particulate matter. Particulate matters (PM) refer to the particles in the air which can be a mixture of solid or liquid. Examples of PM are dust, smoke, soot, dirt. Dust is a solid particulate matter made up of fine particles in the atmosphere. It is a mixture of dirt, dead skins cells, pollens and fibers and also regarded as solid aerosol which arise from various sources such as environmental activities involving natural soil, sand and rock erosions, constructions activities e.g. roads and building constructions, vehicle movement along untarred road quarry and mining industrial activities etc. Dust

particles could act as a medium of transportation for contaminants and toxic compounds including heavy metals, which are harmful to human health in significant ways, particularly the human respiratory system and even at times can result to death (Urrutia-Pereira *et al.*, 2021). The lungs and the respiratory system of humans are affected by the inhalation of dust particles. Dust particles of diameter lesser than 10µm in size can enter the respiratory system, and those smaller than 2.5µm can pass through the human lungs causing serious health problems such as asthma, pulmonary impairment, bronchitis, lung cancer etc. (Batsungneon and Kulworawanichpong, 2011). Asthma is an irritant respiratory disease that is persistent and characterized by cough, wheezing, reversible airway constriction, and airway hyper responsiveness (Higashi *et al.*, 2014). Handling of banknotes is one major means by which diseases can spread because of the way it is handled before it gets to the banking premises.

2.3 Air Pollution

Air pollution stands as a formidable threat to public health, exerting its deleterious effects through a myriad of pollutants present in the ambient air. Among these pollutants, Polycyclic Aromatic Hydrocarbons (PAHs), emerge as significant contributors, amplifying the health risks associated with air pollution (Wang *et al.*, 2017; affecting the respiratory system upon inhalation (El-Saeid *et al.*, 2023). Once within the lungs, PAHs can trigger inflammatory responses, exacerbate existing respiratory conditions such as asthma and chronic obstructive pulmonary disease (COPD), and impair lung function over time. Additionally, prolonged exposure to PAHs has been linked to an increased risk of developing lung cancer. particularly among individuals exposed to high levels of combustion-derived emissions (Letelier *et al.*, 2023; Bayat *et al.*, 2023). For example, the following studies provide a comprehensive review of the risks and epidemiological evidence supporting this assertion: The study of Armstrong and Gibbs (2009) focused on a cohort of aluminum smelter workers, assessing the exposure-response relationship between PAH exposure and lung cancer, while considering smoking

habits. The researchers found a clear trend of increasing lung cancer risk with cumulative PAH exposure, measured as benzo(a)pyrene (BaP). The study highlighted that both linear and non-linear models fit the data, with a significant risk increase even at moderate exposure levels. The results showed that workers exposed to 100 ug/m³ BaP/ year had a 2.68 times higher risk of developing lung cancer compared to those with no exposure. This finding underscores the significant increase in lung cancer risk due to the combined effects of occupational PAH exposure and smoking. Despite the large cohort and long follow-up, uncertainties remained regarding the exact shape of the exposure-response function and the combination of risks from PAH and smoking. Navaretnam *et al.*, 2023 posited that PAHs contribute to the persistence of toxicity and its associated health impact. Moorthy *et al.* (2015) provided a detailed review of the biochemical pathways through which PAHs contribute to lung cancer. They explained that upon entering the lungs, PAHs induce the activation of phase I and II metabolic enzymes via the aryl hydrocarbon receptor (AhR)-dependent pathways. These enzymes metabolize PAHs into reactive metabolites, such as diol-epoxides, radical cations, and o-quinones, which form DNA adducts leading to mutations and tumorigenesis. The review highlighted the role of genetic susceptibility, including polymorphisms in metabolic enzymes and tumor suppressor genes, in influencing lung cancer risk. This comprehensive overview underscored the complexity of PAH metabolism and its implications for lung cancer development.

Ravanbakhsh *et al.* (2022) conducted a meta-analysis of epidemiological studies on the health effects of PAHs, focusing on respiratory diseases and cancer. The review included 27 studies, concluding that PAH exposure significantly increases the risk of lung cancer, as well as other respiratory conditions like asthma and lung dysfunction. The study emphasized the importance of reducing PAH emissions from sources such as cooking, car exhaust, and industrial activities to mitigate these health risks. The findings reinforced the need for stringent control measures to limit PAH exposure and protect public health.

Holme *et al.* (2023) explored the link between air pollution, specifically fine particulate matter (PM_{2.5}), and lung cancer, with a focus on PAHs and the AhR pathway. The study noted that air pollution is a leading cause of lung cancer after tobacco smoking, accounting for 20% of lung cancer deaths. PAHs in PM_{2.5} activate the AhR, leading to increased metabolism, oxidative stress, DNA damage, and mutagenesis. The research suggested that while PAHs contribute to genotoxicity at high exposure levels, at lower levels typical of ambient air pollution, they primarily promote tumor growth in cells with pre-existing oncogenic mutations. This highlights a dose-response continuum where different mechanisms dominate at different exposure levels.

Moubarz *et al.*, (2023) focused on workers in secondary aluminum production plants, examining PAH concentrations in air and serum, and their potential role in lung cancer development. The researchers found significantly elevated levels of PAH biomarkers and tumor markers in exposed workers, even though PAH air concentrations were within permissible limits. The study also highlighted the role of genetic polymorphisms in susceptibility to PAH-induced lung cancer, emphasizing the need for periodic biological monitoring of workers to prevent cancer risk. This study underscored the significance of even low-level occupational PAH exposure in lung cancer risk among bank staff.

Najurudeen *et al.*, (2023) assessed PAH concentrations in PM₁₀ and PM_{2.5} in various urban and semi-urban areas, calculating health risks including lifetime lung cancer risk. The study found that PAH levels in particulate matter posed a low to moderate cancer risk, particularly for adults and adolescents in urban areas. This research emphasized the health risks associated with prolonged exposure to PAHs bound to banknote dust and the importance of monitoring and controlling banknote handling to protect public health.

Collectively, this study illustrates the significant health risks associated with prolonged exposure to PAHs, particularly in relation to lung cancer and related health complications. The evidence underscores the importance of reducing PAH emissions from various sources,

implementing stringent occupational safety measures, and conducting ongoing research to better understand the complex mechanisms through which PAHs induced carcinogenesis. Efforts to mitigate PAH exposure can significantly reduce the burden of lung cancer and other respiratory diseases, highlighting the critical need for public health interventions and policy regulations.

To understand the impact of PAHs on human health, it is important that we take a look at it's make up. PAHs constitute a broad class of chemical compounds characterized by two, three, or even seven fused aromatic rings which are produced as byproducts of incomplete combustion (Singh *et al.*, 2024).

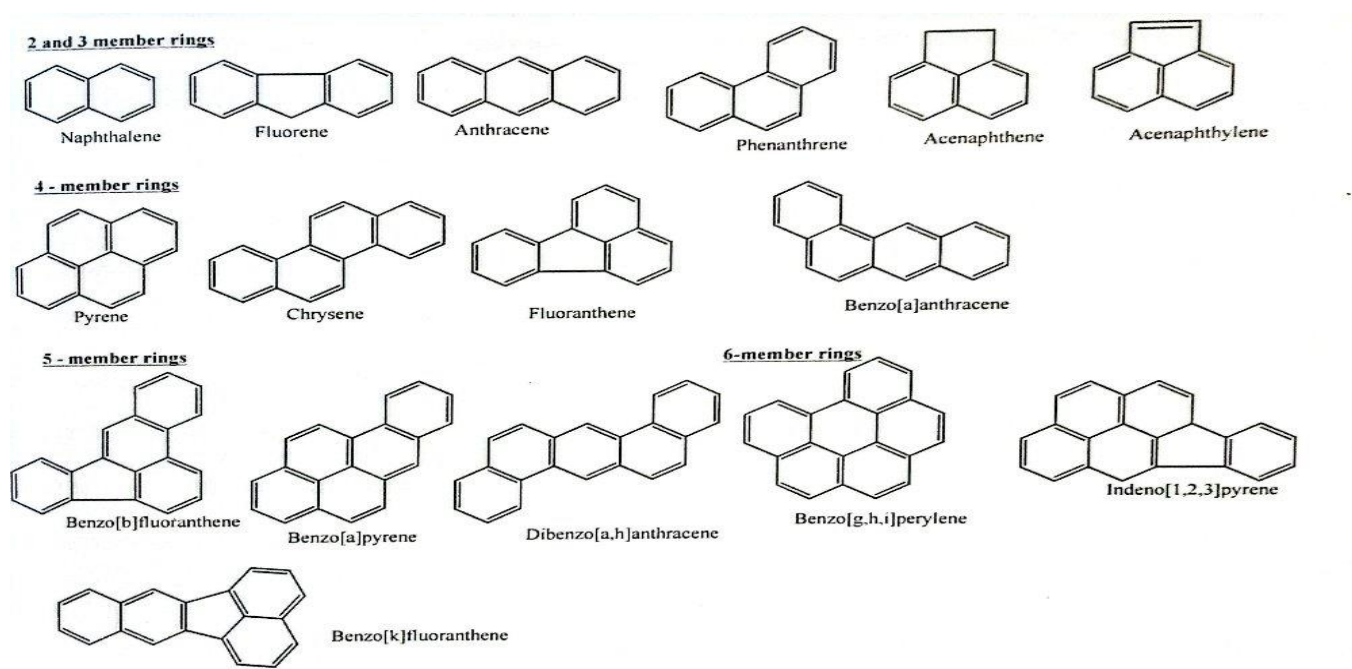


Figure 2.1: Structure of sixteen polycyclic aromatic hydrocarbon as US-Environmental Protection Agency and World Health Organization Priority Pollutants. Source: (Igwe and Ukaogo, 2015)

Alongside PAHs, various other heterocyclic aromatic compounds are co-generated during combustion including dioxins, furans, carbazole and acridine (Situma 2010). However,

substituted derivatives such as chloro-, nitro-, oxy-, hydroxyl-, and hydroxynitro- PAHs chemically interact with other pollutants in the environment.

PAHs are pervasive across various environmental compartment, comprising of air, water, soil, dust and sediments. They are also present in sources like cigarette smoke, vehicle emissions, industrial discharges, charred or grilled foods (IARC 2012), and banknote dust which has received little or no attention due to the nonavailability of data, which this study tends to address.

2.4 Sources of Polycyclic Aromatic Hydrocarbons (PAHs)

There are three main sources of PAHs in the environment, these includes: pyrogenic, petrogenic, and biological. In a process called pyrolysis, Pyrogenic PAHs are formed whenever organic substances are exposed to high temperatures under low oxygen or no oxygen conditions. The destructive distillation of coal into coke and coal tar, or the thermal cracking of petroleum residuals into lighter hydrocarbons are Pyrolytic processes that occur intentionally. Meanwhile, other unintended processes occur during the incomplete combustion of motor fuels in cars and trucks, the incomplete combustion of wood in forest fires and fireplaces, and the incomplete combustion of fuel oils in heating systems. The temperatures at which the pyrogenic processes are ranging from about (350°C to more than 1200°C). Pyrogenic PAHs are generally found in greater concentrations in urban areas and in locations close to major sources of PAHs. In addition, PAHs can also be formed at lower temperatures. It is worth mentioning that crude oils contain PAHs that formed over millions of years at temperatures as low as (100–150°C). In this respect, PAHs formed during crude oil maturation and similar processes are called petrogenic. PAHs such petrogenic PAHs are common due to the widespread transportation, storage, and use of crude oil and crude oil products. Some of the major sources of petrogenic PAHs include oceanic and freshwater oil spills, underground and

above ground storage tank leaks, and the accumulation of vast numbers of small releases of gasoline, motor oil, and related substances associated with transportation. It is well-known that PAHs can be formed during the incomplete combustion of organic substances. PAHs are also found in petroleum products. On the other hand, it is not well-known that PAHs can be produced biologically. For example, they can be synthesized by certain plants and bacteria or formed during the degradation of vegetative matter. The mode of PAHs formation can be either natural or anthropogenic. (Abdel-Shafy, *et al.* 2016)

This is illustrated in Figure 2.2 below.

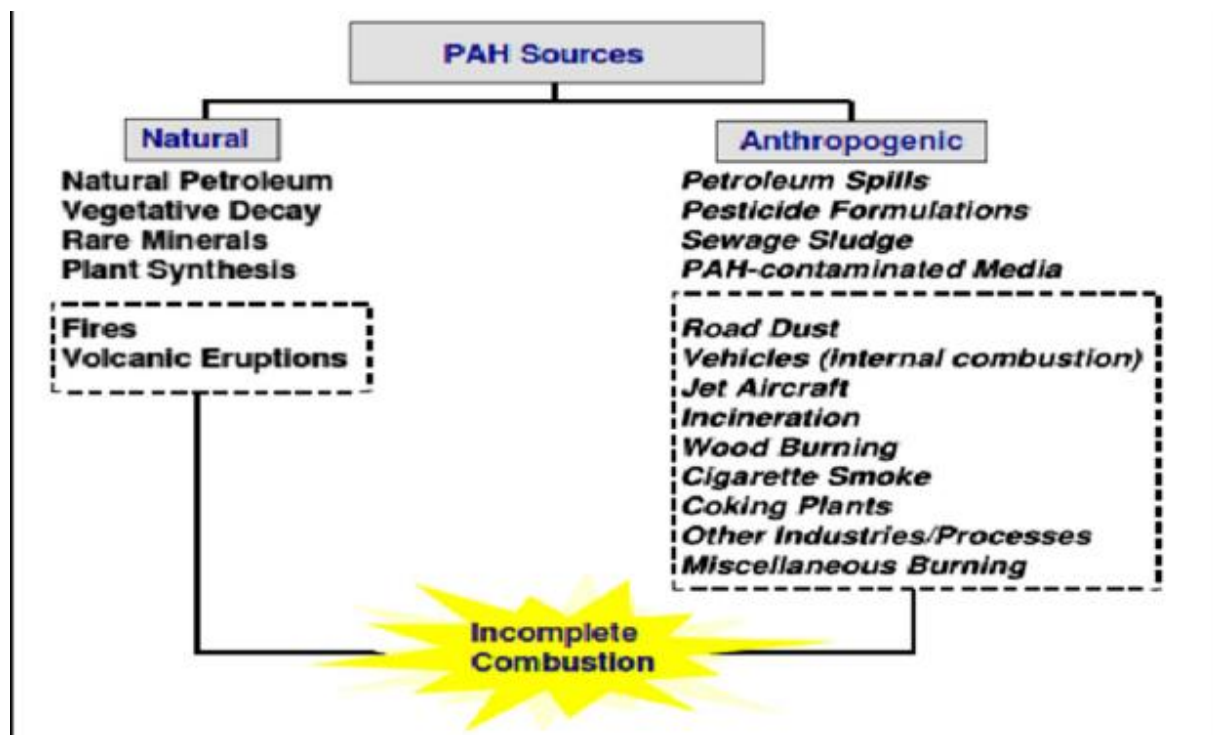


Figure 2.2: Natural and anthropogenic sources of polycyclic aromatic hydrocarbons (PAHs)

(Tolosa *et al.* 1996 and Seo, *et al.* 2007).

2.5 Environmental significance of PAHs.

The environmental significance of PAHs stems from their persistence, bio accumulative potential, and toxicity. The persistence of PAHs is due to the presence of the stable benzene ring structure. The higher the number of rings, the higher the persistency in the environment. They are over 200 chemicals and range from naphthalene $C_{10}H_{18}$ (2 rings) to coronene $C_{24}H_{12}$ (7 membered ring) (Amstrong *et al.*, 2004; Kim *et al.*, 2013; Abdel-Shafy and Mansour 2016; Zhang *et al.*, 2016). Certain PAHs are identified of suspected carcinogens and can induce respiratory and cardiovascular ailment (Mai *et al.*, 2024). They enter the human body via inhalation, ingestion, or skin tissues and organs, potentially instigating adverse health implications over time. PAHs often adsorb to dust particles in the atmosphere, where they can undergo long range atmospheric transport (LART) pristine areas (Ukpebor *et al.*, 2019). Initiatives aimed at curbing PAH emissions and exposure entail the adoption of cleaner technologies, reduction of fossil fuel combustion, regulation of industrial processes, and raising public awareness regarding potential exposure sources (Khan and Srivastava, 2024).

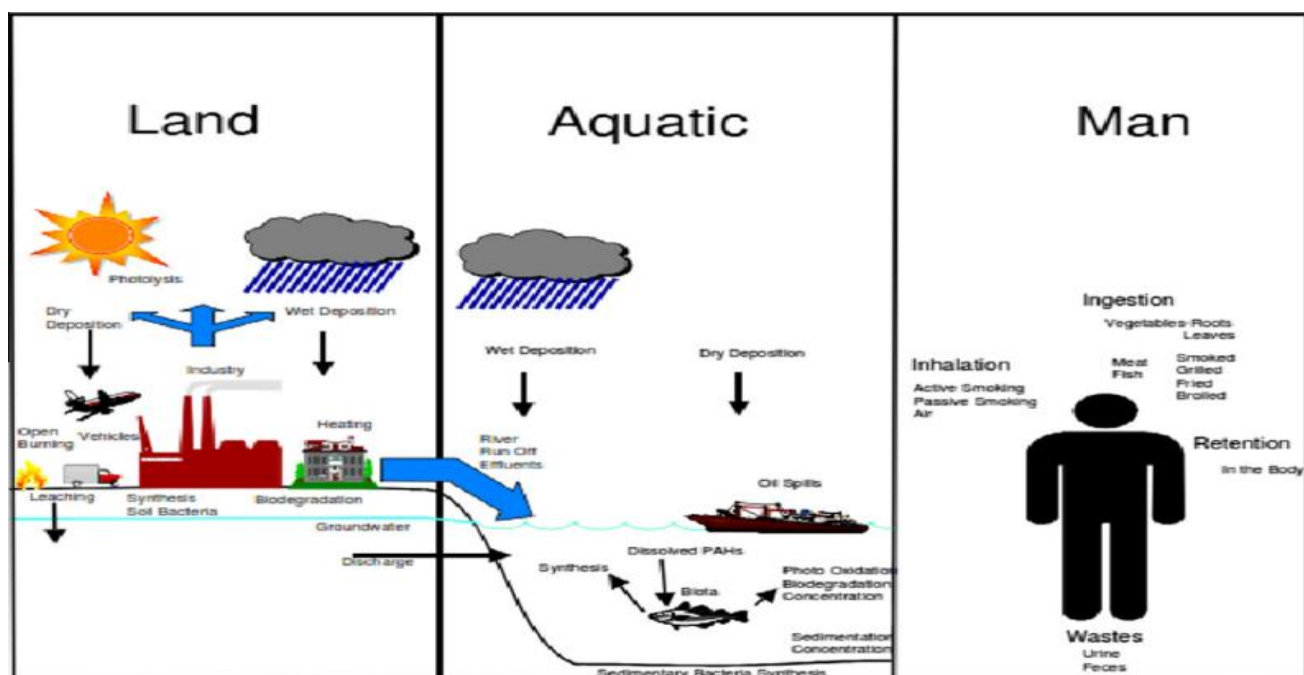


Figure 2.3: Environmental fate of PAHs. (Suess, 1976)

2.6 Sources identified by PAH diagnostic ratios.

The PAH emission profile for a given source depends on the processes producing the PAHs (Manoli *et al.*, 2004). During low temperature processes (e.g. wood burning), low molecular weight PAHs are usually formed, whereas high temperature processes, such as the combustion of fuels in engines, emit higher molecular weight PAH compounds (Mostert *et al.*, 2010). At high temperatures organic compounds are cracked to reactive radicals, which react to form stable PAHs during pyro synthesis. These PAHs are less alkylated, and their molecules contain more aromatic rings than petrogenic PAHs (Hwang *et al.*, 2003). PAH diagnostic ratios have been used to distinguish diesel and gasoline combustion emission (Ravindra *et al.*, 2008), different crude oil processing products and biomass burning processes, including bush, savanna, and grass fires (Yunker *et al.*, 2002).

PAH diagnostic ratios show intrasource variability but intersource similarity (Galarneau, 2008). The search for PAH emission sources using diagnostic ratios proceeds with the determination of the ratios for each emission source present in the area investigated. The PAH ratios calculated for each hypothetical source are not definitive: for instance, the diagnostic ratio reported by Manoli *et al.*,(2004) may show strong variations for a particular source (e.g. $BaA/(BaA + CHR) = 0.3 - 0.6$ for cement production) and be similar for many sources (e.g. $FLA/(FLA + PYR) = 0.4 - 0.5$ for cement production, metal manufacturing, fertilizer production, diesel combustion and road dusts). The application of diagnostic ratios requires an understanding of the relative thermodynamic stability of different PAHs, the characteristics of different PAH sources and the changes in the PAH composition between source and sediment, and the relative stability of different PAH isomers and PAHs from different sources. Combustion and/or anthropogenic sources are usually deduced from an increase in the proportion of the less stable (kinetic) PAH isomer compared to the more stable (thermo -

dynamic) isomer (Yunker *et al.*, 2002). Thus, PAH isomer ratios, when applied prudently, could be used to identify sources of PAHs. Some of the isomer ratios such as LMW/HMW, FLA/PYR, PHA/ANT, and ANT/ANT+PHA, could only be used to resolve petrogenic and pyrogenic sources. However, application of more specific isomer ratios can yield resolution of closely related sources such as petrol, diesel, and organic matter combustion (Stanley *et al.*, 2013), The table below lists typical diagnostic ratios taken from the literature.

Table 2.1: Diagnostic ratios used with their typically reported values for a particular process.

PAHs ratio	Value range	Source	References
Σ LMW/ Σ HMW	<0.1	Pyrogenic	Zhang <i>et al.</i> , 2008
	>0.1	Petrogenic	
FL/(FL+PYR)	<0.5	Petro emission	Ravinda <i>et al.</i> , 2008
	>0.5	Diesel emission	
ANT/(ANT+PHE)	<0.1	Petrogenic	Pies <i>et al.</i> , 2008
	>0.1	Pyrogenic	
FLA/(FLA+PRY)	<0.4	Petrogenic	De La Torres-Roche <i>et al.</i> , 2009
	0.4-0.5	Fossil fuel combustion	
	>0.5	Grass, wood, coal combustion	
BaA/(BaA+CHR)	0.2-0.35	Coal combustion	Akyuz and Cabuk 2010
	>0.35	Vehicular emission	
IcdP/(IcdP+BghiP)	<0.2	Petrogenic	Yunker <i>et al.</i> , 2002
	<0.5	Photolysis (ageing of particles)	
	<0.2	Petrogenic	
	0.2-0.5	Petroleum combustion	
BbF/BkF	2.5-2.9	Grass, wood and coal combustion	Yunker <i>et al.</i> , 2002
		Aluminium smelter emission	
BaP/BghiP	<0.6	Non traffic emission	Katsoyiannis <i>et al.</i> , 2007
	>0.6	Traffic emission	

Source: Marek *et al.*, 2012

Note: LMW (Low molecular weight), HMW (High molecular weight),

2.7 Heavy Metals

The organic and inorganic pollutants of dust can spread through two different pathways. These particles are composed of various elements. They are divided into two clusters: trace and major elements consisting of 16 elements (Chabukdhara and Nema, 2013). These elements are copper (Cu), manganese (Mn), mercury (Hg), zinc (Zn), chromium (Cr), vanadium (V), lead (Pb), arsenic (As), nickel (Ni), cadmium (Cd), and cobalt (Co) (Li *et al.*, 2018). These heavy metals are known to cause negative effects on the environment due to their unfriendly and noxious relation to the atmosphere (Klavinš *et al.*, 2000). They can also lead to various diseases, such as respiratory and cardiac issues. Due to their non-biodegradable properties, these heavy metals cannot be properly recognized by body tissues and skin cells and can lead to death and various contagious and infectious diseases (Zheng *et al.*, 2010; Wu *et al.*, 2010).

Recent studies have revealed that heavy metals bound dust and aerosols can have harmful effects on health, such as increased mortality rates and hospitalizations (Mohammadi *et al.* 2017). Heavy metals bound particulate matter is known to cause inflammation and respiratory disease, and it can also lead to pulmonary transformation. This is associated with respiratory mortality and morbidity by generating oxidative and inflammation stress (Hashizume *et al.*, 2020; Hasunuma *et al.*, 2021).

Heavy metals are generally referred to as those metals which possess a specific density of more than 5 g/cm³ and adversely affect the environment and living organisms (Järup, 2003). However, there's no general or unified definition of heavy metals, it is either a toxic or relatively dense (heavy) metal (Ali and Khan, 2018) such as lead and mercury which are both

dense and toxic. Generally, lead and mercury are agreed to be heavy metals since they are both dense and heavy whereas other heavy metals such as gold, are dense yet not particularly toxic. Some researchers classified these metals as "heavy metal" based on their density, while others exclude them from the list because they do not occur at a risk or pose a major health hazard (Helmenstine, 2021).

These metals are quintessential to maintaining various biochemical and physiological functions in living organisms when in very low concentrations, however they become noxious when they exceed certain threshold concentrations. Heavy metals are significant environmental pollutants, and their toxicity is a problem of increasing significance for ecological, evolutionary, nutritional, and environmental reasons (Jaishankar *et al.*, 2013; Nagajyoti *et al.*, 2010). Heavy metals occur naturally on Earth they have the capacity to penetrate the environment through natural processes such as volcanic eruptions, weathering of rocks, erosion of soil etc. (Hazrat *et al.*, 2018), as well as anthropogenic activities which includes pollutions, industrial operations, agricultural practices, technological applications, and mining (Khan, 2023). The high toxicity, contamination, concealment, persistence, and biological accumulation of heavy metals in the environment and in humans has drawn attention of many researchers and environmental bodies (Aguilera *et al.*, 2021). Many studies have been done in different parts of the world regarding the concentration of heavy metals in soil and dust fall particles. Gulson and Taylor in Australia, predicted the concentration of lead in the blood of children by measuring the concentration of lead in dust fall particles (Gulson, *et al.*, 2017). Based on statistical analysis, they found that there was a significant relationship with each other. Rahman *et al.*, (2019), assessed the risk to human health from heavy metal contamination through street dust in Bangladesh. This study shows that the concentrations of nickel, lead, cadmium, and arsenic are slightly higher than their concentrations in soil. They also found that lead, zinc, copper, cobalt, and chromium contamination were associated with industrial activities and

heavy traffic. In China, Leung *et al.*,(2008), collected dust fall particles on surface of school grounds and roadsides, and measured the concentration of heavy metals in the collected samples. The concentrations of metals in roadsides dust for lead and zinc were 22600 and 2370 mg/kg, respectively. In schools, the concentrations of lead, zinc, chromium, and cadmium were 5 to 10, 30 to 50, 700 to 800, 800 to 1000 mg/kg, respectively. The result from this study clearly shows that concentrations of heavy metals is consistent with that conducted for dust falls in Iran and other parts of the world (Goodarzi *et al.*, 2018 and Tang, *et al.*, 2017).

2.8 Health Effect of Heavy Metals

The accumulation of heavy metals in human can have adverse effects leading to health complications. Toxic heavy metals have a longer half- life in the atmosphere. Human exposure is increased by deep inhalation when pollutants are transported by wind after leaving the site of emission (Sovacool *et al.*, 20221; Urman *et al.*, 2016). Some of the metals of consideration in this study includes the following:

1. **Lead (Pb)** with a density of 11.34 g/cm^3 is the most important and prevalent toxic heavy metal that can be found in the environment. It is a metal of high toxicity which affects most organs of the body and majorly the nervous system (Wani *et al.*, 2015). Lead toxicity affects both adults and children, however, the threat to the health of children is greater than that of adults, due to children's internal and external soft tissues (Wani *et al.*, 2015). Some long-term side effects of lead poisoning include abdominal pain, constipation, kidney dysfunction, and damages of the reproductive system (Balali - Mood *et al.*, 2021).

Lead accumulation in the environment has detrimental effect on plant, animals, and humans. US-EPA, (2005), reported that automobile mechanic workshop contributes greatly to lead contaminated soil and environment. Ademoriti, (1997) stated that lead is known to inhibit the biosynthesis of heme B (the iron porphyrin component of hemoglobin) resulting in anemia.

2. **Cadmium (Cd)**: is a heavy metal of major concerns in the environment. Cd with a density of 8.6 g/cm^3 , is a heavy metal that is widely distributed and released into the environment from metallurgical industries, heating systems, trash incinerators, power plants, urban traffic, phosphate fertilizer products and cement work (WHO, 2019). This heavy metal is known to affect the kidneys. Cadmium is retained in the body for decades, it is persistent, bio-accumulative, and extremely toxic. The principal exposure pathway is through respiration and food. Adelekan and Alawode, (2011), reported that Cadmium poisoning is also responsible for hypertension, neurotoxin, carcinogenic, liver and kidney dysfunction.
3. **Zinc (Zn)** with a density of 7.13 g/cm^3 is to produce galvanized product for automobile and for structural components in the construction industry. Zinc is an essential plant micronutrient, however at high level, they may be toxic to plant. The important factors controlling the zinc solubility in the soil are clay mineral, hydroxide, and pH (Heidary and Monfared, 2011).
4. **Chromium (Cr)**: Chromium whose density is 7.19 g/cm^3 is considered a serious environmental pollutant due to industrial usage and expansion in particular chemical industries (Usman *et al.*, 2023). It exists in the form of hexavalent chromium or chromium (VI). Chromium exists naturally in the trivalent form chromium (III), other environmental sources of chromium are cement factories (cement contains chromium), wear and tear of asbestos coatings containing chromium, emissions from chromium-

based automotive catalytic converters, and cigarette smoke (ATSDR, 2008). It can damage DNA and has been linked to asthmatic bronchitis (Lenntech, 2009). Metals gets into the environment through land fill leachate or from fly ash generated when materials containing chromium (IV) are incinerated. This metal is used in protection against corrosion of untreated and galvanized steel plate. Chromium poisoning can cause bleeding, cancer of the respiratory tract, ulcer if the skin and mucus membrane (Adelekan and Alawode, 2011).

5. **Nickel (Ni):** Nickel has a density of 8.19 g/cm^3 and is a component in the manufacture of stainless steel, other corrosion resistant alloys, coins, armored plates etc. At high concentrations, the lung is damaged due to prolong exposure to nickel. Nickel can exist in the soil in several forms: inorganic crystalline minerals or precipitates, complexes or adsorbed on organic cation surface or on inorganic cation exchange surface, water soluble, free -ion or chelated metal complex in soil solution (Compel and Nikel,2006).
6. **Iron (Fe):** Iron with a density of 7.87 g/cm^3 is an essential micronutrient for plant growth and development, playing a critical role in various physiological processes, such as photosynthesis, respiration, and nitrogen metabolism. (Meherg, 2011). Plants need iron for growth just as iron in human blood is essential as it occurs in hemoglobin which is the carrier of oxygen in human. Hemoglobin is responsible for carrying oxygen from your lungs to all the tissues in your body. Iron is a part of hemoglobin and an essential mineral found in foods we eat. Iron helps the body make new red blood cells and can help to replace those lost through blood donations. However, excessive iron uptake can lead to iron toxicity, causing damage to the plant's cell membranes, reducing growth, yield, and affecting the overall health of the plant. Iron toxicity can occur in both soil-grown and hydroponic systems, and it is especially common in calcareous soils, which have high pH levels. (Meherg, 2011). High levels of iron in the soil can also lead to the

formation of toxic compounds, such as hydroxyl radicals, that can cause oxidative damage to plant cells.

7. **Copper (Cu):** Copper with a density of 8.96 g/cm^3 is an essential element for living organisms and soil is the primary natural Cu source for plants and other organisms; Cu concentrations depend primarily on soil parent material. Soil accumulation and consequent contamination by Cu from various sources have been reported from mining, dust fallout, former wood treatment sites, deposits of metal scraps. Cu contamination can present various ecological risks. Excessive Cu in topsoil from anthropogenic sources can affect plants, edaphic fauna and microorganisms, and compromise ecosystem functions.

Other heavy metals such as mercury (Hg) poisoning primarily causes neurotoxicity and renal toxicity, though it can also cause thyroid and kidneys problems (Mahurpawar, 2015). Moreso, the kidneys and central nervous system are affected by prolonged exposure to dust contaminated with mercury (Genchi *et al.*, 2020). Continuous cobalt (Co) exposure causes respiratory distress such as asthma, also its combines with several element but it's combination with tungsten carbide can leads to cancer (Leyssens *et al.*, 2017). Inhalation is the primary means of nickel (Ni) exposure, its carcinogenic effects extend beyond the development of lung and nasal cancers which also include multiple epigenetic effects (Genchi *et al.*, 2020). Whereas dermatitis, gastrointestinal symptoms, lung fibrosis, and cardiovascular disorders are non-carcinogenic side effects of nickel toxicity (Genchi *et al.*, 2020). Arsenic (As) on the other hand is a metalloid, however, respiratory cancer, nervous and cardiovascular disease are caused by the inhalation of arsenic (Isaifan, 2023) and numerous human health issues caused by arsenic be it of short, long-term exposure is termed "Arsenicosis" (Sadguru and Ashok, 2021).

Research has clearly indicated that the exposure to heavy metals, regardless of the organs they affect, eventually results in the generation of a reactive oxygen species, which causes oxidative

stress (Vyas *et al.*, 2017). This then result into various cancers, neurological conditions, damage to the kidneys, and other abnormalities related to the endocrine system. All the above listed heavy metals have become more intense and of great concern with an increase in population and activities occurring in the environment which poses risk to the human health. Most commercial banks are known to have their building sealed with no windows, there enhancing the circulation of dust generated during cash processing. Numerous studies have demonstrated that indoor dust serves as a repository for heavy metals, which can accumulate through natural or anthropogenic processes (Lin, *et al.*, 2015). Studies have also demonstrated the concentrations of metals in classroom dust and their associated health risks to children. (Alghamdi, *et al.*, 2019). Investigations have also focused on assessing exposure to indoor contaminants and examining indoor air quality (Sahu, *et al.*, 2018). Raising public awareness about the severity of indoor air pollution is crucial. There is a lack of data on the analysis of heavy metals in banknote dust within the study area, despite the importance of such information for assessing the hazard of banknote dust and environmental quality.

2.9. Bacteria Bound Dust and Its Effect on Human Health.

The relationship between ambient particulate matter exposure and health has been established. Ultrafine particles with particle size between 2.5 nm to 100 nm are known to increase pulmonary diseases risk. Epidemiological studies worldwide have consistently demonstrated links between ambient particulate matter exposure and adverse health outcomes, including increased rates of respiratory and cardiovascular illness, hospitalization, and premature death. (Thurston, 2017). Particles are usually defined based on size. Ultra fine particles (UFP) are those with diameter of 100nm or less, which are abundant in number but make only minor contribution to the total mass. (Warneck 1988). UFP do not readily sediment or flocculate and thus have a longer retention time in the atmosphere than fine particles, allowing them to be carried long distances by the wind. (Stone *et al.*, 2017). In terms of health hazards, fine particles

are only absorbed by alveolar macrophages when they enter lungs, whereas UFP are also absorbed by airway epithelial cells, which can trigger a potent airway inflammation response. Moreover, unlike fine particle, UFPs are absorbed into the body and increase the risk of cardiovascular and neuropsychiatric disease. Due to the ability to deeply infiltrate our normal lines of defense against foreign particulate matter, UFP are likely to be more harmful to health than fine particles. (Stone *et al.*, 2017). Indoor dust has significant effects on health, as it includes a wide variety of components, including PM₁₀, PM_{2.5}, nanoparticles, heavy metals, bacteria, fungi, and house dust mite-derived allergens. However, prominent organization such as WHO, EPA have not released specific regulations or guidelines in terms of the composition of pollutants or nanosized particles in the indoor environment. Rather, the existing regulations more broadly address the bacteria count and the acceptable levels of PM₁₀, PM_{2.5}, heavy metals, and other pollutants. Therefore, recent efforts have focused on exploring the specific causative factors and mechanisms involved in the effects of UFP as indoor air pollutants to understand the correlation between indoor air dust and disease.

Inhaled air pollutants such as dust are correlated with pulmonary disease and allergic diseases influenced by the environment, such as atopic dermatitis, asthma, and allergic rhinitis and chronic obstructive pulmonary disease (COPD). (Raaschou-Nielsen *et al.*, 2016). Biological factors such as allergens, viruses, and bacterial substances in dust can cause severe inflammatory reactions in certain cases. For example, bacterial factors might induce airway hypersensitivity due to exposure to protein antigens. Even when humans are exposed to very small amounts of bacterial factors, the body recognizes the antigens as harmful, and this can cause an inflammatory reaction. Biological factors in the indoor dust can induce immune dysfunction and chronic inflammation, leading to chronic inflammatory pulmonary diseases, including asthma and COPD, (Duan *et al.*, 2014).

CHAPTER THREE

3.0 Material and Methods

3.1 Materials

All materials and the reagents used were of analytical grades and sourced from reputable vendors within and outside Benin City.

The following are list of Reagents used for this research work:

Distill water (H_2O)

Perchloric acid ($HClO_4$) BDH

Nitric acid (HNO_3) BDH

n-Hexane (C_6H_{14}) BDH

Dichloromethane (CH_2Cl_2) BDH

Silica gel ($\gamma SiO_2 \cdot yH_2O$)

3.1.0 List of Equipment:

Atomic Absorption Spectrophotometer (AAS), Buck Scientific, Model VGP210, made in USA.

GC-FID (Hewlett Packard Model 5890 II Plus) made in Germany.

Sonic bath (Bandelin Sonorex, model RK 31)

Autoclave

Hot plate

Weigh balance (Mettler Toledo analytical balance model AB204-S). Made in China.

Refrigerator (Haier Thermocool)

Incubator

Forceps

Test tubes.

Sample bottles.

Sieve

Whatman filter paper No. 1

Funnel

3.2 Methods

3.2.1 Sample Collection

Dust particles from banknotes were collected from two commercial banks within the Benin Metropolis. The samples were collected twice over a period of two months. A composite sample was then made by mixing the samples together from which representative samples were taken for analysis. One bank located within the Ugbowo Campus of the University of Benin (Lat: 6.3908° N, Long: 5.61859° E) in Ovia North-East Local Government Area of Edo State and another from a commercial bank located along Ekewan road (Lat: 6.333776° N, Long: 5.6059781° E) in Oredo Local Government Area in Edo State, Benin City was sampled. The dust particles were obtained from the bulk counting room of each of the banks because that is where large volume of cash is being processed and under very poor ventilation.

The samples were stored in an airtight storage bag for onward transportation to the laboratory for analysis. Samples for microbial analysis were taken to the Department of Microbiology, University of Benin, Benin City immediately while the remaining samples were stored properly prior to other analysis.

3.3.0 Sample Analysis.

3.3.1 Particle size analysis:

The particle size analysis was done at a laboratory in Zaria, Kaduna State for the determination of the nature of particle size (polydispersity index).

3.3.2 Microbial analysis:

The microbial analysis was done at the Microbiology Department, University of Benin.

Media: Nutrient agar, mullein Hinton agar, Gram +ve Gram -ve disc.

Standard plate counts for the microbial analysis: Threefold dilution was prepared and sterilized using an autoclave for 15 mins at 121⁰C. 1ml of the aliquot (test samples) was transferred into sterile petri dish, mullein Hinton agar was added to isolate bacteria and molten potato dextrose agar added to the isolates. All the plates were incubated at temperature of 37⁰C for 24 hrs for bacteria colonies, while PDA plates were incubated at room temperature for 3-5 days. Upon incubation, emergent colonies were counted and the colony forming unit (cfu) per gramme calculated and recorded. The bacterial and fungi characterization was done based on their cultural morphological and biochemical test of the bacteria and fungi isolates. Identification was done using berge manual of bacterial identification.



Plate 3.1: Showing fungi colony.



Plate 3.2: Showing bacteria colony.

3.3.3 Antibacterial Sensitivity Test

Mullen Hinton agar was used for the antibacterial sensitivity test.

The agar was prepared, sterilized, and poured onto sterilized petri dishes and allowed to solidify. After solidification, the test bacteria isolates were stretched on the agar plates. A sterile forceps was used to pick up the antibiotics and place on the agar plates and all the plates were incubated at a temperature of 37⁰c for 24 hrs. After the incubation, the zone of inhibition of each antibiotic was measured using a graduated measuring rule.



Plate3.3: Showing antibacterial sensitivity test.

3.3.4 Determination of pH.

10 g of the dust sample were weighed using analytical balance, the weighed sample was quantitatively transferred into a 50 ml beaker and 10 ml of deionized water was added to it and left to stand for 2 hrs. pH meter (Jenway 3510 pH meter) was first calibrated using buffer 4, 7, and 10. The electrode was cleaned, rinsed properly and then inserted into the solution and the pH readings taken to the nearest units.

3.3.5 Heavy Metal analysis

The dust sample was digested prior to analysis for selected heavy metals (Fe, Cu, Zn, Pb, Cd, Ni, Mn, and Cr) by adopting the method as described by Paiko *et al.*, (2015) with modifications. 1 g of the dust sample was weighed into a 250 mL boiling tube which has been washed and rinsed with dilute acid, 10 mL concentrated nitric acid (HNO_3) was measured into the tube containing the sample and heated slowly over a hot plate for 1hr. The solid residue obtained was then digested with a 10 mL mixture of HNO_3 and HClO_4 in the ratio of 3:1. The mixture was left to stand for 10 mins at room temperature before heating on a hot plate for about 2 hrs at 150°C until a white dense fume is observed and a clear solution obtained. The mixture was left to cool at room temperature, about 20 mL of distilled water was added and

filtered through a Whatman No. 1 filter paper into a 100 mL standard volumetric flask. The solution was then made up to mark with distilled water. The filtrate was stored in pre-cleaned polyethylene sample bottles ready for analysis. Heavy metals concentration was determined using Atomic Absorption Spectrophotometer (AAS) in the Department of Chemistry, University of Benin. The settings and operational conditions of the instrument were in accordance with the manufacturer's specifications and standard method of analysis.

3.3.6 Analysis of Polycyclic Aromatic Hydrocarbon (PAHs)

Sample extraction and clean up:

Solvent extraction method was employed in the extraction of the PAHs. 10 g of the sample was weighed and transferred into a conical flask, 50 mL of dichloromethane and n-hexane (50:50) was added and placed in the sonic bath for 45 mins. The solvent was then transferred into a round bottom flask and the solvent reduced to about 1 mL.

Samples were cleaned up using silica gel column with a sodium sulphate layer to remove any moisture present. The samples were eluted using 15 mL n-hexane and collected in 20 mL amber vials. The eluent was then further reduced to about 1 mL using a blow down apparatus with compressed air for injection into the GC-FID for PAHs analysis.

Separation of the analytes was done on HP-5, 30 m x 0.25 m column and analyzed using a GC-FID (HP 5890 series plus II) in a splitless mode. Nitrogen gas (10.2 psi) was used as a carrier gas at 1.5 ml/min. The injector and detector temperature were 250⁰C and 320⁰C respectively. Separation was done using the following oven temperature program: start temperature with 80⁰C, held for 1 min, then ramped at the rate 20⁰C/min to 280⁰C, and further ramped at a rate of 2.5⁰C/min to 300⁰C and held for 10 mins. Peak detection and integration were carried out

using ChemStation software. Identification and quantification were carried out using external calibration standard. The amount of each PAHs in the analytes was calculated using the equation below:

$$\text{Concentration of analyte (ug/kg)} = A_x.V_t.D/W_d.CF$$

Where:

A_x = Area of the analyte in area count

V_t = Total volume of extract in μl

D = Dilution factor

W_d = dry weight of sample extracted in grams(g)

μCF = Average calibration factor for target PAH analyte

3.3.7 Quality control measures.

Blank samples were run intermittently during the analysis, the blanks were treated in the same way as the actual samples. They were run to investigate the possibility of contamination peaks. Any PAH detected in the blanks were subtracted from the sample extract. A ± 0.05 min window retention time was employed for peak detection in the calibration standard. The accuracy of the analytical method was assessed through matrix spike techniques using surrogate standards. The average recovery ranged from 88-115% for all recovery standards.

$$\% \text{ Recovery} = \frac{\text{concentration extracted}}{\text{concentration spike}} \times 100$$

Table 3.1: Basic Physiochemical Constants of PAHs and Abbreviations.

PAHs	Abbreviation	Water Solubility (mg/L) at 25 ⁰ C	Molar mass (g/mol)
Naphthalene	NP	31.000	128.170
Acenaphthylene	ACY	16.000	152.190
Acenaphthene	ACE	3.8.000	154.210
Fluorene	FL	1.9.000	166.220
Phenanthrene	PHE	1.100	178.230
Anthracene	ANT	0.040	178.230
Fluoranthene	FLA	0.200	202.250
Pyrene	PYR	0.130	202.250
Chrysene	CHR	0.011	228.290
Benzo(a)anthracene	BaA	0.0019	228.290
Benzo(b)fluoranthene	BbF	0.0015	252.310
Benzo(k)fluoranthene	B(k)F	0.0008	252.310
Benzo(a)pyrene	BaP	0.0015	252.310
Indenol(1,2,3,-cd)pyrene	IcdP	0.0002	276.330
Dibenzo(a,h)anthracene	DahA	0.0005	278.350
Benzo(g,h,i)perylene	BghiP	0.00014	276.330

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Results

Table 4.1: Mean and Standard Deviation of Heavy Metals Concentration

Sample	A _(mean)	SD	B _(mean)	SD	WHO Standard
Fe(mg/kg)	20.33333	±70.06	1934.53	±68.64	10,000.00
Cu(mg/kg)	56.06	±2.53	50.56	±4.42	36.00
Zn(mg/kg)	255.03	±5.05	205.28	±5.05	-
Pb(mg/kg)	13.79	±0.22	11.03	±1.12	100.00
Cd(mg/kg)	1.82	±0.03	0.95	±0.15	0.8.00
Ni(mg/kg)	43.93	±5.63	30.64	±0.63	-
Mn(mg/kg)	134.21	±22.82	141.65	±38.52	-
Cr(mg/kg)	63.32	±10.75	43.87	±5.43	-

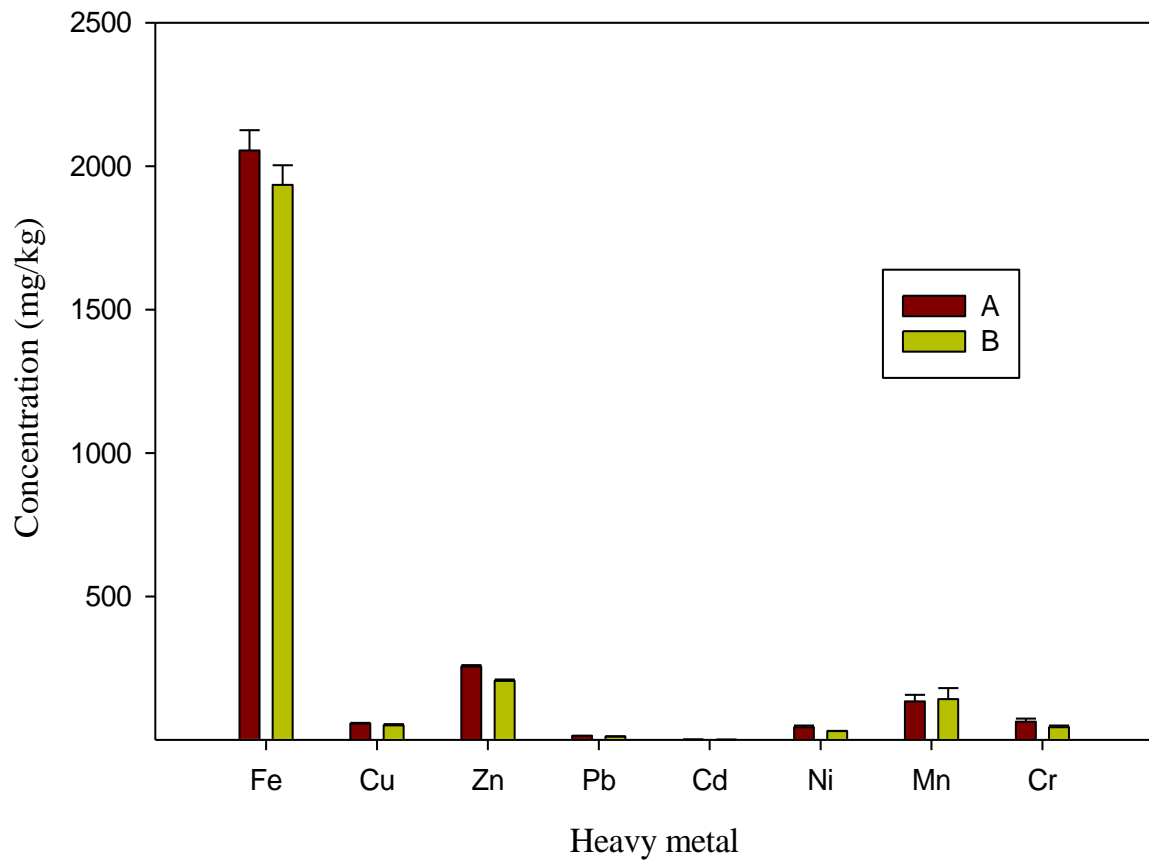


Figure 4.1: Concentration of Heavy Metals in Banknote dust

Results obtained indicate that iron (Fe) had the highest mean concentration with a range of 1934.53 ± 68.64 mg/kg to 2055.00 ± 70.06 mg/kg while cadmium (Cd) had the least mean concentration with a range of 0.95 ± 0.15 mg/kg to 1.82 ± 0.03 mg/kg. Lead (Pb) and nickel (Ni) revealed a concentration range of 11.03 ± 1.12 mg/kg to 13.79 ± 0.22 mg/kg and 30.64 ± 0.63 mg/kg to 43.93 ± 5.63 mg/kg respectively. Chromium (Cr) and copper (Cu) had mean concentration of 43.87 ± 5.43 mg/kg to 63.32 ± 10.75 mg/kg and 50.56 ± 4.42 mg/kg to 56.06 ± 2.53 mg/kg for both samples. The mean concentration for manganese (Mn) and zinc (Zn) were reported to be 134.21 ± 22.82 mg/kg to 141.65 ± 38.52 mg/kg. The concentration trend was observed to be in the order of Fe > Zn > Mn > Cr > Cu > Ni > Pb > Cd for sample A while the observed concentration trend for sample B is given as Fe > Zn > Mn > Cu > Cr > Ni > Pb > Cd. The concentration of Cr in sample A is higher than that of sample B.

Contrary to perceived notion that heavy metal may not be present in banknote dust, the result clearly shows otherwise, and the result offers an insight into the average concentration and variability of heavy metals present in banknote from two commercial banks in Benin.

Several studies have indicated that there are no fixed regulatory permissible limits for the concentration of heavy metals in dust samples. Several standards exist according to different countries and regulatory bodies such as USEPA, WHO, and EU.

Heavy metal such as iron (Fe) is part of the essential metals vital to humans and plants biochemical processes. Its toxicity arises due to increase in concentration level or combinations with some other compounds (Abdullahi *et al.*, 2022). Comparison of result with other studies conducted on different sources of dust sample indicated that the mean concentration of result obtained on respective heavy metals analyzed varies with sample source. For instance, in this study the mean concentration value of Fe in sample A is 2055.0 ± 70.06 mg/kg, while for sample B, the mean concentration of Fe is 1934.53 ± 68.64 mg/kg. This result shows that iron

is below acceptable limit of 10,000 mg/kg as set by WHO (WHO 2019). But according to the research conducted on classroom dust sample in Iran shows that the mean concentration value of Fe was 16,945.5 mg/kg (Moghtaderi *et al.*, 2020), which means that concentration of iron from banknote dust is lower than that of the classroom dust as reported above. The mean concentration of Ni on the other hand for sample A (43.93 ± 4.93) mg/kg was observed to be higher than that of sample B (30.64 ± 5.63) mg/kg, as compared to WHO standard of 25,000 mg/kg. Exposure to nickel has been linked to increase risk of kidney diseases, nasal cancer, pulmonary disorder as well as an increased incidence of death (Laden *et al.*, 2000).

Comparing the mean concentration result obtained with the standard regulatory permissible limits it can be observed that lead concentration value was significantly lower and found to be within the acceptable limits of $500 \mu\text{g}/\text{m}^3$. Lead toxicity affects both adult and children. However, children are mostly affected because of their soft tissues, (Wani *et al.*, 2015). Copper was also found to be within the standard acceptable limits. On the other hand, nickel was below the acceptable limits, but its value was close to the standard limit such that daily exposure could be a serious threat to human health due to its carcinogenic properties (Genchi *et al.*, 2020). The results for heavy metals for both samples clearly show that sample A has the highest concentrations of heavy metals as compared to sample B. This could be attributed to the location of the sampled site because location A is in a denser area than location B. Although some of the heavy metals are within the acceptable limit, bioaccumulation of these metals in human system poses a great danger to human health, therefore there is need to show great concern and take necessary action to safeguard workplace environment.

Table 4.2: Concentration of PAH in Banknote dust.

PAH	Concentration ($\mu\text{g}/\text{kg}$)	
	A	B
Naphthalene	<0.01	<0.01
Acenaphthylene	0.028	0.031
Acenaphthene	0.136	0.559
Fluorene	0.038	0.043
Phenanthrene	<0.01	1.167
Anthracene	0.068	0.060
Fluoranthene	0.271	0.237
Pyrene	3.084	0.056
Chrysene	0.166	0.033
Benzo(a)anthracene	0.148	0.110
Benzo(b)fluoranthene	0.072	0.040
Benzo(k)fluoranthene	0.136	0.078
Benzo(a)pyrene	0.025	0.132
Indeno(1,2,3-cd) pyrene	<0.01	<0.01
Dibenzo(a,h)anthracene	0.107	0.086
Benzo(g,h,i)perylene	<0.01	<0.01
Σ PAH	4.278	2.631

Results from PAHs analysis clearly shows that banknote dust contains the 16 priority PAHs. The table above presents the PAHs concentrations measured in the banknote dust from two two sampling locations. The sum total of the PAHs as measured showed that sample A has the highest value of approximately 4.278 $\mu\text{g}/\text{kg}$ while that of Ugbowo has a value of approximately 2.631 $\mu\text{g}/\text{kg}$. This may be because Ekehuan road axis is denser than the Ugbowo axis and more commercial activities are being experienced along that axis.

The concentration of naphthalene was observed to be lower than 0.01 $\mu\text{g}/\text{kg}$ for both locations. However, the concentration of acenaphthylene was observed to be higher in location B with a value of 0.013 $\mu\text{g}/\text{kg}$ as compared to that of Location A whose value was observed to be 0.028 $\mu\text{g}/\text{kg}$. The concentration of fluorene ranges between 0.038 $\mu\text{g}/\text{kg}$ 0.043 $\mu\text{g}/\text{kg}$ respectively while the concentration of phenanthrene was below 0.01 $\mu\text{g}/\text{kg}$ in sample A as compared to sample B with a concentration of 1.167 $\mu\text{g}/\text{kg}$.

The concentration of anthracene for both locations were observed to be within the same range of 0.068 $\mu\text{g}/\text{kg}$ and 0.060 $\mu\text{g}/\text{kg}$ respectively. Anthracene has been linked to respiratory diseases and potential carcinogenicity (ATSDR 2010). Fluoranthene concentrations for both locations were observed to be between 0.271 $\mu\text{g}/\text{kg}$ and 0.237 $\mu\text{g}/\text{kg}$ for both samples and A and B, with sample A having the highest value of concentration. The concentrations of pyrene from sample A were highest for all the PAHs measured, sample B has a value of 0.056 $\mu\text{g}/\text{kg}$, suggesting that location A is more polluted than Location B. Chrysene was observed to be 0.166 $\mu\text{g}/\text{kg}$ for Location A, while for B, it was to be 0.033 $\mu\text{g}/\text{kg}$. Benzo(a)anthracene was observed to be 0.148 $\mu\text{g}/\text{kg}$ for location A while that of B was given as 0.110 $\mu\text{g}/\text{kg}$ as compared to benzo(b)fluoranthene with values ranges between 0.04 $\mu\text{g}/\text{kg}$ and 0.072 $\mu\text{g}/\text{kg}$ respectively for Location B and A. The concentration of benzo(k)fluoranthene for Location A was 0.136 $\mu\text{g}/\text{kg}$ as compared to location B with a value of 0.078 $\mu\text{g}/\text{kg}$. These set of PAHs are implicated as carcinogens according to the Cal-EPA (California Environmental Protection

Agency). Consequently, it is feared that these set of PAHs can pose serious occupational health hazards to bank staff as they may be predisposed to high risk of cancer due to long-term exposure to banknote dust contaminated with PAHs. Benzo(a)pyrene concentration for location A was observed to be lower than that of Location B with each having a value of 0.025 $\mu\text{g}/\text{kg}$ and 0.132 $\mu\text{g}/\text{kg}$ respectively. Benzo(a)pyrene is considered to have high carcinogenic effects (Lee and Shim, 2007). The IARC (1987) listed Benzo(a)pyrene as highly carcinogenic and as Group 1 carcinogen. The health implication of PAHs has been extensively reviewed by Obini *et al.*, (2013).

Indo(1,2,3-cd) pyrene was below 0.01 $\mu\text{g}/\text{kg}$ for both locations, while the concentration of dibenzo(a,h)anthracene concentration for location A was 0.107 $\mu\text{g}/\text{kg}$ and B was 0.086 $\mu\text{g}/\text{kg}$ respectively. However, benzo(g,h,i)pyrene for both locations were below 0.01 $\mu\text{g}/\text{kg}$ respectively.

PAHs have demonstrated toxic, carcinogenic, genotoxic, mutagenic and teratogenic properties (Goldman *et al.*, 2001) and exhibit potent immunosuppressive effect (Burchiel 2001). Low molecular weight (LMW) PAHs (two or three rings) exhibit acute toxicity but lack carcinogenic potential. Although high molecular weight (HMW) PAHs (four to seven rings) have reduced toxicity, they do possess carcinogenic, mutagenic and teratogenic effects in various organisms, including fish, birds and human (Adami *et al.*, 2000).

This study revealed that LMW PAHs (NP, FL, ANT, ACE, PHE, ACY) has a total value of 0.269 $\mu\text{g}/\text{kg}$ and 1.860 $\mu\text{g}/\text{kg}$ for sample A and B respectively, while the total HMW PAHs (PY,CHR,FLA,BaA,BbF,DahA) for sample A is 4.01 $\mu\text{g}/\text{kg}$, and 0.694 $\mu\text{g}/\text{kg}$ for sample B. It therefore implies that BND has high toxicity and pose serious health challenges to bank staff, especially those that in the bulk counting room as there is little or no ventilation as observed in the commercial banks sampled. The pyrene concentrations of ~ 3.084 $\mu\text{g}/\text{kg}$ indicates that BND

has the potential of being carcinogenic because the Pyrene is among HMW PAHs which has carcinogenic, mutagenic, and teratogenic effect (Adami *et al.*, 2000). Serious attention and caution must be taken as concerning the health status of bank staff. The effect of PAHs depends mainly on the extent of exposure, dose, innate toxicity, and exposure routes. Other predisposing factors include preexisting health status and age. PAHs is ubiquitous, it is very common to detect even at a very low level and its toxicity is of utmost importance. Some studies have indicated that heavy PAHs can induce dioxin-like activity and weakened estrogenic responses. (Villeneuve *et al.*, 2002).

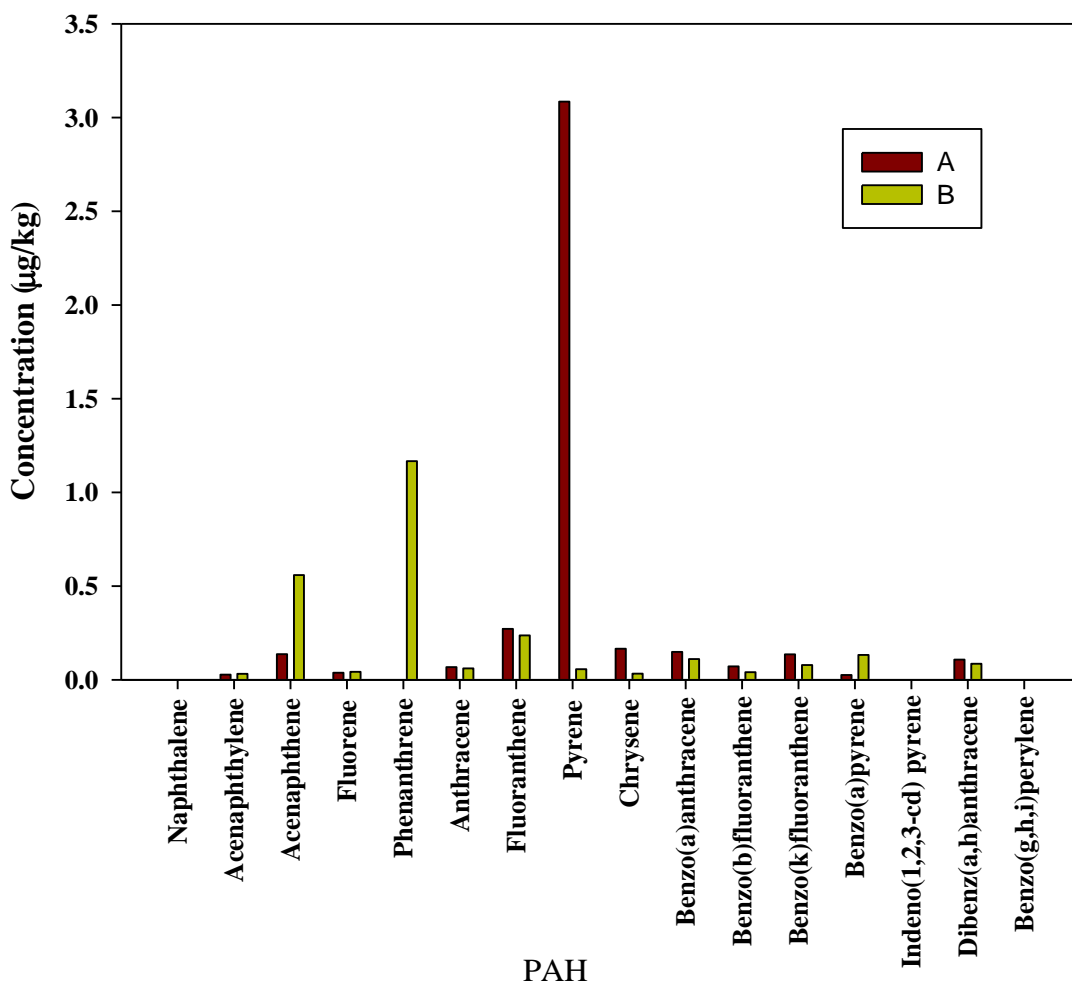


Figure 4.2: Concentration of the 16 priorities PAHs obtained in the different sampling locations.

Table 4.3: Range of diagnostic ratios for PAHs sources in Banknote Dust (BND)

PAHs diagnostic ratio	Sample A	Sample B	Sample A (Value ranges)	Sample B (value ranges)	Sample A possible sources	Sample B possible sources	Value ranges from Literature. Marek <i>et al.</i> , 2012
FL/FL+PYR	1.056	4.084	>0.5	>0.5	Diesel	Diesel	<0.5 petro emission >0.5 diesel emission
ANT/ANT+PHE	2.167	0.000	>0.1	<0.1	Pyrogenic	Petrogenic	<0.1 petrogenic >0.1 pyrogenic
FLA/FLA+PYR	4.084	1.056	>0.5	>0.5	Grass, wood, coal combustion	Grass, wood, coal combustion	<0.4 petrogenic 0.4 – 0.5 fossil fuel >0.5 grass, wood, Coal combustion
BaA/BaA+CHR	1.166	1.033	>0.35	>0.35	Vehicular emission	Vehicular emission	0.2 -0.35 coal combustion >0.35 vehicular emission <0.2 petrogenic
BbF/BkF	0.000	0.510	<0.5	>0.5	Grass, wood and coal		>0.5 grass, wood and coal combustion 2.5 – 2.9 (aluminum Smelter emission)
BaP/Bghi	0.000	0.000	<0.6	<0.6	Non traffic emission	Non traffic emission	>0.6 (non-traffic) >0.6 (traffic emission)
IcdP/IcdP+BghiP	0.000	0.000	<0.2	<0.2	Petrogenic	Petrogenic	0.5 (photolysis) 0.2 (petrogenic) 0.2 – 0.5 (grass)
Σ LMW/ Σ HMW	0.000	0.000	>0.1	>0.1	petrogenic	Petrogenic	>0.1 (pyrogenic) >0.1 (petrogenic)

Table 4.3 above on the diagnostic ratios of banknote dust clearly indicates multi-sources of PAHs as detected in the samples A and sample B. These sources includes both traffic and non-traffic emission to combustion from wood, coal, vehicular emission, and diesel engines. This can be explained from the fact that banknote (money currency) is collected from various sources arising from various business transactions and handling process before being taken to the bank for safe keeping. However, the diagnostic ratio of BaA/BaA+CHR with a value of >0.35 was found to be higher than the other diagnostic ratios as shown in the table above. This strongly suggested that the PAHs source is more of vehicular emission. However, some studies show that diagnostic ratios do not change with particle size. The studies of Wang et al. (2006) show that diagnostic ratios are virtually the same in samples of PM_{2.5}-PM₁₀ and PM_{2.5}. Diagnostic ratios applied to fine (2 nm) particulates collected in Beijing were similar with respect to ANT/ (ANT + PHE) and IcdP/(IcdP + BghiP). The values of FLA/(FLA + PYR) were 0.05-0.1 higher, those of BeP/(BeP + BaP) were also slightly higher, but those of BaA/(BaA CHR) were 0.1-0.15 lower for coarse particles. These diagnostic ratios confirmed that the dominant sources of PAHs were the combustion of coal/wood and diesel in the summer (Zhou *et al.*, 2005). These studies align with this present study on PAHs bound particulate matter of banknote dust reported as 36.57 - 48.4 nm respectively which were observed to fall within the nano range.

Table 4.4: Heterotrophic Bacteria and Fungi counts of banknote dust (BND)

Sample	Bacteria counts (cfu)	Fungi counts (cfu)
A	1.2 x 10 ⁴	2.0 x 10 ⁴
B	1.1 x 10 ⁴	1.1 x 10 ⁴

Table 4.5: Morphological, Cultural, and Biochemical Characterization of Bacteria and fungi Isolates in Banknote Dust (BN)

	Bacteria Isolate		Fungi Isolate	
	A	B	A	B
Size	1mm	1mm	2mm	1mm
Shape	Round	Round	Round	Round
Color	Green	Milky	Black	Light green
Elevation	Raised	Raised	ND	ND
Margin	Smooth	Rough	ND	ND
Wet/dry	Wet	Wet	ND	ND
Grm stain	+ve	-ve	ND	ND
Arrangement	Group	Singly	ND	ND
Catalase	-ve	-ve	ND	ND
Citrate	-ve	-ve	ND	ND
Oxidase	-ve	+ve	ND	ND
Heam	+ve	-ve	ND	ND
Coagulant	-ve	-ve	ND	ND
Suspected isolates	Streptococcus spp, pseudomonas spp	Streptococcus spp, pseudomonas spp	Aspergillus, penicillium notatun	Aspergillus, penicillium notatun
Hyphea type	ND	ND	Separated	Separated
Cell type	Cocci	Rod	ND	ND

Note: ND = Not determined

Table 4.6: Antibigram test of the bacteria isolates for Banknote Dust.

Antibiotics	Bacteria (streptococcus)	Bacteria (pseudomonas aeruginosa)
Rifamicin	Resistance	Not determined
Ceftazidime	Resistance	Resistance
Streptomycin	Susceptible	Susceptible
Azithromycin	Susceptible	Not determined
Ciprofloxacin	Susceptible	Resistance
Erythromycin	Resistance	Not determined
Levofloxacin	Susceptible	Not determined
Gentamycin	Susceptible	Susceptible
Cefuroxime	Resistance	Resistance
Amoxil	Susceptible	Not determined
Ofloxacin	Not determine	Susceptible
Augmentin	Not determined	Susceptible
Ceporex	Not determined	Resistance

The table above revealed in this study the microbial counts obtained from the banknotes dust ranging from 1.1×10^4 to 1.2×10^4 cfu/g for bacteria and 1.1×10^4 to 2.0×10^4 cfu/g for fungi. These high levels of microbial loads indicate poor hygiene associated with the handling of banknote leading to contamination. The findings corroborate previous reports by Adeyemi *et al.* (2020), who observed high microbial counts on frequently touched devices in open markets, shops, and other day to day activities. The high microbial load detected on the banknotes dust can serve as a reservoir for pathogens and facilitate their easy transmission among bank staff

also especially among immunocompromised individuals where poor hygiene practices is prominent.

The presence of pathogenic microbes in Table 4.8 in this study is evidence that bank notes can act as direct sources of infections. Microbes such *Streptococcus* spp., *Pseudomonas* spp. *Aspergillus niger*, *Penicillium notatum* which are often associated with human skin, respiratory secretion or environmental sources may cause opportunistic infection in immunocompromised individuals. This aligns with findings by Mbajiuka *et al.* (2015) who reported that contaminated devices in commercial areas contribute significantly to the spread of nosocomial and community acquired infection. The research of Mbajiuka *et al.* (2015) and Eze and Okoye (2021) reported that the level of contamination of public devices was strongly linked to the frequency of use rather than geographical differences. The movement of bank notes around the country where the hygiene status of users is not certain strongly support the report of this present study. The result from this study further emphasizes the public health risks posed by high-touch devices including currency /bank note in densely populated commercial centers.

The presence of the microbes isolated in this study from the bank note dust proves that bank notes serve as potential reservoir for microbial contamination, especially due to frequent handling by different individuals. This is consistent with the findings of Pal *et al* (2015) who reported that high touch surface such as mobile phones, keyboards and ATM machines harbor diverse microbial population due to frequent contact with human hands. The presence of *Streptococcus* spp. on bank notes is notable because several species are well-known human pathogens. For example, *Streptococcus pyogenes* causes pharyngitis, skin infections, and invasive diseases like rheumatic fever, while *Streptococcus pneumoniae* is a leading cause of pneumonia and meningitis (Cunningham, 2000). Their detection on banknote dust suggests contamination from respiratory droplets or skin fluids and indicates a potential risk of community transmission, especially in crowded commercial areas and workplace like the bank.

The isolation of *Pseudomonas* spp. in this study also raises concern, as it is an opportunistic pathogen associated with hospital-acquired infections and multidrug resistance. These findings align with studies by Akinyemi *et al.*, (2019) and Olowe *et al.*, (2020), who reported similar microorganisms from other high-touch surfaces such as ATMs and mobile phones in commercial environments. The predominance of *Pseudomonas* spp. in this study can be attributed to its well-documented capacity to thrive in diverse environmental conditions, including moist and frequently handled surfaces, as well as its intrinsic resistance to desiccation and many disinfectants (Pollack, 2000). These characteristics enhance its survival on fomites such as bank notes (Stephens *et al.*, 2007).

The result in table above revealed the antibiogram pattern of the bacterial isolates from the bank note dust. The antibiogram revealed resistance of the isolates to commonly used antibiotics such as erythromycin, ceftazidime, and cefuroxime while relative susceptibility was retained to streptomycin and gentamycin. The presence of resistant bacteria on banknotes dust suggests that beyond being reservoirs for pathogens, bank notes may also serve as vehicles for the spread of antimicrobial resistance among bank staff and customers alike. This is consistent with the World Health Organization (2023) warning that antimicrobial resistance is one of the greatest threats to global health. To reduce the risks associated with contaminated bank notes, it is crucial to implement interventions such as proper hygienic methods in handling of the bank notes, provision of personal protective equipment (PPE) such as nose mask, provision of alcohol-based sanitizers at transaction points, and health education campaigns on the proper handling of banknote to promote proper hygiene practices among both operators and users.

4.2 Polydispersity index Result

Dynamic light scattering results for sample A and B Respectively (Z-average = 36.57nm; PDI = 0.230 and Z-average = 48.43 nm; PDI = 0.245)

The dynamic light scattering (DLS) measurement of banknote dust (BDN) particles from two commercial banks in Benin City produced a Z-average hydrodynamic diameter of 36.57 and 48.43 nm, and a polydispersity index (PDI) of 0.230 and 0.245 respectively. The Z-average (also called the cumulants mean) is the primary, most stable DLS parameter and represents an intensity-weighted hydrodynamic diameter derived from the cumulant analysis of the intensity autocorrelation function.

The PDI is a unitless measure of the width (variance) of the size distribution derived from the second cumulant of the autocorrelation fit. By convention in DLS reporting, PDI values ≤ 0.10 indicate a highly monodisperse suspension, values around 0.10 – 0.20 indicate narrow (near monodisperse) distributions, while values above ~ 0.20 indicate increasing polydispersity; values above ~ 0.7 are considered very broad and unreliable for cumulant analysis. A PDI of 0.230 and 0.245 for sample A and B, therefore, indicates a moderately polydisperse sample, the distribution is not narrow and contains a measurable spread of particle sizes or minor populations/aggregates.

Results

	Size (d.n...	% Intensity:	St Dev (d.n...
Z-Average (d.nm): 36.57	Peak 1: 15.16	86.0	5.661
Pdl: 0.230	Peak 2: 363.5	9.1	306.1
Intercept: 0.760	Peak 3: 4145	3.1	1129

Result quality Good

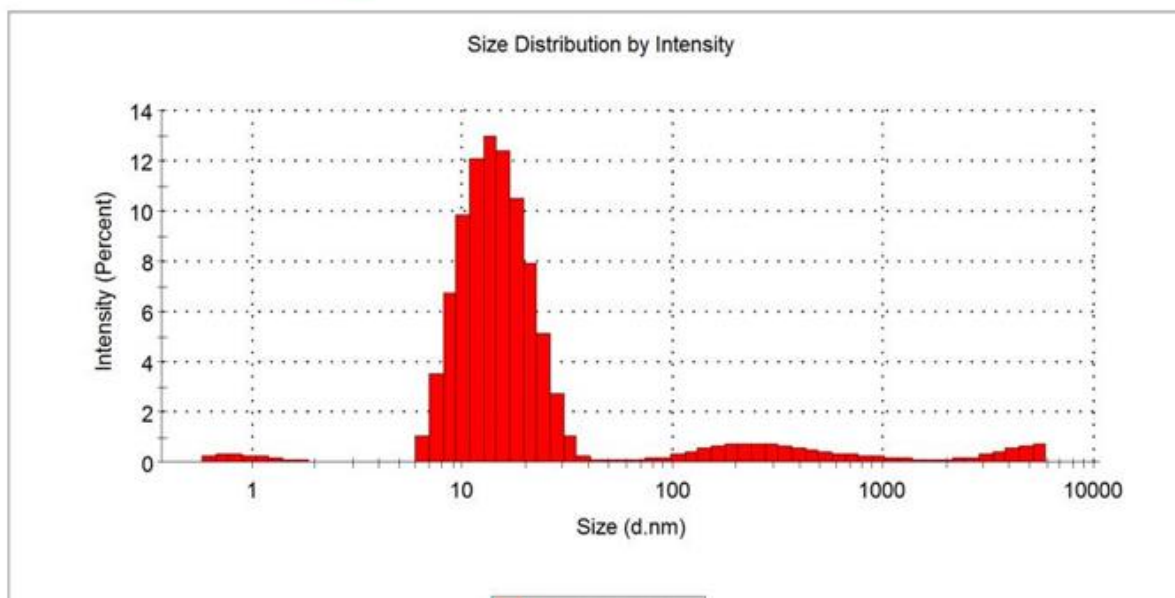


Figure 4.3 showing the PDI and Z-average of sample A

Results

	Size (d.n...	% Volume:	St Dev (d.n...
Z-Average (d.nm): 48.43	Peak 1: 11.41	87.2	5.227
Pdl: 0.245	Peak 2: 341.0	6.5	275.1
Intercept: 0.760	Peak 3: 4986	2.2	947.1
Result quality Good			

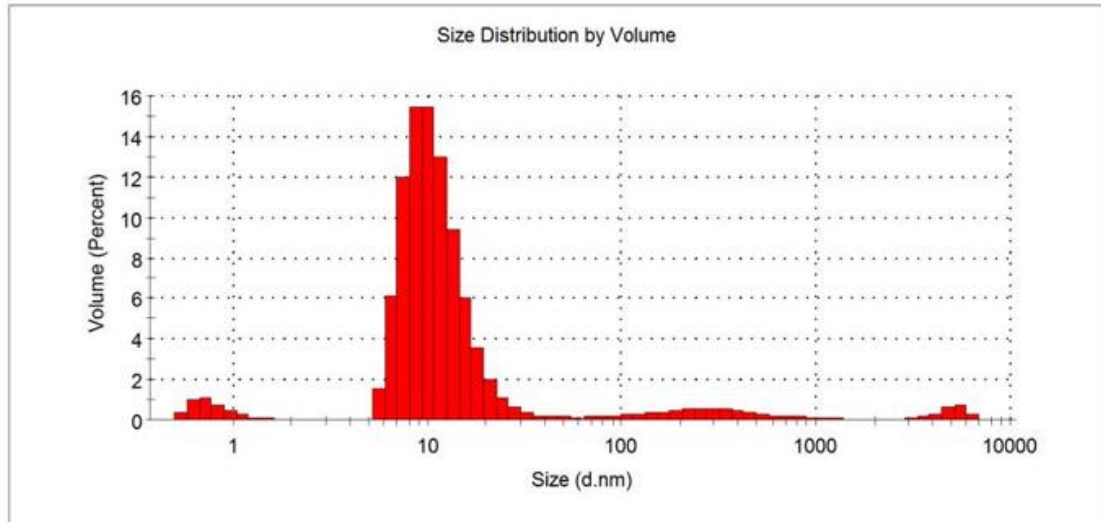


Figure 4.4 Showing the PDI and Z-average of sample B

Interpretation in the present context

1. **Size regime.** A Z-average of ~36 nm and ~48 nm for sample A and B places the measured dust fraction in the ultrafine/nanoparticle size range (<100 nm). Ambient urban aerosol studies show substantial number concentrations in the ultrafine mode (tens of nanometers). Thus, the measured Z-average is consistent with a substantial contribution from multiple-related ultrafine particles or fragments/resuspended fine particles in banknote.
2. **Polydispersity and sample complexity.** The PDI as observed in the samples, indicates that the dust particles are moderately polydisperse. For environmental dust, this is expected because atmospheric particulates are typically a mixture of primary particles (combustion-generated ultrafine), accumulation mode particles (coagulated or aged

particles), mineral dust fragments and occasional aggregates. The PDI thus reflects a real heterogeneity in the particle population or the presence of a small fraction of larger scatterers (aggregates) that broaden the distribution.

Comparison with other studies

Ukpebor et al. (2021) reported average PM_{2.5} and PM₁₀ concentrations in Benin City (31.48 µg/m³ and 21.4–57.8 µg/m³, respectively), both exceeding WHO limits, with motor vehicles identified as the dominant source (77.3% for PM_{2.5} and 70% for PM₁₀). Estimated respiratory deposition doses further indicated significant particle deposition in the head airway, tracheobronchial, and alveolar regions, underscoring serious health risks. These findings complement the DLS analysis of banknote dust, which revealed an ultrafine particle fraction (Z-average of 36.57 nm and 48.43 nm, PDI of 0.230 and 0.245). While the PM study quantified mass concentrations of fine and coarse particles, the DLS result demonstrates that banknote dust also contains nanoscale particles capable of deep lung penetration. This study highlights that particulate pollution problem extends beyond elevated PM mass to include ultrafine particles with enhanced toxicological significance.

High PM_{2.5} levels previously reported in Benin City by Onaiwu and Okuo (2023) align with the DLS result from this study (Z-average 36.57 nm and 48.43 nm, PDI 0.230 and 0.245), confirming the presence of both fine and ultrafine particles in the samples under investigation. While PM_{2.5} data emphasize mass concentrations, the DLS analysis reveals an ultrafine fraction that contributes little to mass concentration but poses greater health risks due to deep lung penetration and systemic effects.

The Z-average and PDI together suggest that the sample contains a dominant ultrafine population plus a distributional of fine particulate matter spread. The implication of this is that

banknote dust can easily enter the body system through inhalation and can pose serious health hazard.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

This study has revealed that the dust from banknote is within the nano range and therefore can be classified as particulate matter. The measured moderate polydispersity suggests mixed sources. This particulate matter can easily carry contaminants such as heavy metals which the study revealed to be evenly distributed in the banknote dust from the two commercial banks studied. Although, the level of heavy metals detected were within acceptable limits, potentially prolonged exposure can result in the bioaccumulation of these heavy metals with their attendant health risks.

The PAHs result revealed that the sixteen priority PAHs as specified by WHO/US-EPA were present and attributed to various sources as revealed from the source apportionment/diagnostic ratio analysis, suggestive of the likelihood of the BND to possess carcinogenic tendencies and other health threatening diseases. Furthermore, a study of the microbial contamination shows that banknote dust serves as a pathway for the transmission of pathogens and microbes which pose serious health challenge such as respiratory diseases because of long-term exposure. Biological factors such as allergens, viruses, and bacterial substances in dust can cause severe inflammatory reactions in certain cases. For example, bacterial factors might induce airway hypersensitivity due to exposure to protein antigens. Even when humans are exposed to very small amounts of bacterial factors, the body recognizes the antigens as harmful, and this can cause an inflammatory reaction. Biological factors in the indoor dust can induce immune dysfunction and chronic inflammation, leading to chronic inflammatory pulmonary diseases, including asthma and COPD, (Duan *et al.*, 2014). Inhaled air pollutants such as dust are correlated with pulmonary disease and allergic diseases influenced by the environment, such

as atopic dermatitis, asthma, and allergic rhinitis and chronic obstructive pulmonary disease (COPD). (Raaschou-Nielsen *et al.*, 2016).

5.2 FINDINGS

The findings from this study are as follows:

- 1 Particle size of the dust particles were in the nano range.
- 2 Presence of heavy metals in the banknote dust and the concentration of cadmium exceeded the world health organization (WHO) standard set limit for soil. WHO (2007).
- 3 All 16 EPA priority PAHs as specified by WHO/US-EPA were present in the samples, location A having the highest PAHs summation of 4.278 $\mu\text{g}/\text{kg}$ and location B having a summation of 2.632 $\mu\text{g}/\text{kg}$.
- 4 The diagnostic ratio suggested multi-sources.
- 5 The microbial results revealed significant loads of bacteria and bacteria isolate to be *Streptococcus* spp while the fungi isolates are *Aspergillus* and *Penicillium*.

5.3 RECOMMENDATIONS

To reduce the risks associated with contamination from banknote dust, it is crucial to implement interventions such as proper hygienic methods in handling of the bank notes, provision of personal protective equipment (PPE) such as nose mask for bank staff especially those in the bulk room, provision of alcohol-based sanitizers at transaction points, and health education campaigns on the proper handling of banknote to promote proper hygiene practices among both operators and users. Also, it is important that proper regulations be put in place to guide against the indiscriminate abuse of the banknote such as mutilation by way of improper handling such as spraying of the banknote. The cashless policy introduced by the government should be well encouraged and different payment option advocated to reduce the amount of banknote in circulation.

5.4 CONTRIBUTION TO KNOWLEDGE

This study has contributed to knowledge in the following ways:

1. Banknote dust from sampled sites is within the nano range (<100 nm)
2. It has provided data on the sixteen toxic PAHs as specified by WHO/USEPA for the sampled sites.
3. It has provided data on the selected heavy metals for the sampled sites.
4. It has shown that banknote dust contains microbes such as fungi and bacteria.
5. It has provided information on the potential health risk of banknote dust.

REFERENCES

- Abdel-Shaff, H.I.**, and Mansour, M.S.M., (2016). A Review on Polycyclic Aromatic Hydrocarbons; Sources, Environmental Impacts, Effects on Human Health and Remediation. *Egypt Journal of Petroleum*, **25**(2),107-123. <https://doi.org/10.1016/j.ejpe.2016.06.002>
- Abdullahi, M.**, Auwal, Y., and Usman, A.H. (2022). Determination of heavy metals (Co, Cu, Cd, Fe, Pb, Zn) in some edible insects and fingerlings in Dutsin-ma town, Fudma Journal of Sciences, **6**(04),6–11. <https://doi.org/10.33003/fjs-2022-0604-1035>
- Abrams, J.Y.**, Weber, R.J., Klien,M., Samat, S. E., Chang, H.H., Strickland, M.J., Verma. V., Fang, T., Bates, J.T., Mulholland, J.A., Russell, A.G., and Tolbert, P.E. (2017). Associations between Ambient Fine Particulate Oxidative Potential and Cardiorespiratory Emergency Department Visits. *Environmental Health Perspectives*, **125**:10, <https://doi.org/10.1289/ehp1545>.
- Adami, G.**, Barbieri, P., Piselli, S., Predonzani, S. and Reisenhofer, E., (2000). Detecting and characterizing source of persistent organic pollutants (PAHs and PCBs) in surface sediment of an industrialized area (Harbour of Trieste, Northan Ariatic sea). *Journal of environmental monitoring* **2**:261-265 <http://doi:101039/b0009950>.
- Adelekan, B. A.** and Alawode, A.O. (2011). Concentration of municipal refuse dumps to Heavy metals concentrations in soil profile and ground water in Ibadan, Nigeria. *Journal of Applied Biosciences*. **45**:4, 123-234.
- Ademoroti, C.M.A.**, (1996). Environmental Chemistry and Toxicology, Foludex Press, Ibadan.192-199.
- Adeyemi, T.**, Adebisi, O. and Eze, U., (2020). Microbial contamination of frequently handled devices in open markets. *African Journal of Public Health* **14**:3,221–229.
- Aguilera, A.**, Francisco, B., Avto, G. and Garcia-Oliva, F. (2021). Health risk of heavy metals in street dust. *Frontiers in Bioscience*, **26**(02): 327–345. <https://doi.org/10.2741/4896>
- Akinyemi, K.O.**, Atapu, A.D., Adetona, O.O. and Coker, A.O., (2019). The potential role of mobile phones in the spread of bacterial infections. *Journal of Infection and Public Health*, **12**(5),625–631.
- Akyüz, M.** and Çabuk, H., 2010. Gaseparticle partitioning and seasonal variation of polycyclic aromatic hydrocarbons in the atmosphere of Zonguldak, Turkey. *Science of the Total Environment*. **408**. 5550-5558.
- Alemu, A.** (2014). Microbial contamination of currency notes and coins in circulation: A potential public health hazard, *Biomedicine and Biotechnology*, vol. **2**(03): 46-53. <https://doi.org/10.12691/bb-2-3-2>.

- Alghamdi, M.A.** and Hassan, S.K., AlzahraniN.A., (2019). *International journal of environmental research of public health*. **16**(24), 5017.
- Al-Hemoud.** (2020). Sand and dust storm trajectories from Irag Mesopotamian flood plain to Kuwait.. *Science Total Environment*. 710. 13629
- Ali, H.,** and Khan, E. (2018). “What are heavy metals? Long-standing controversy over the scientific use of the term’ heavy metals’-proposal of a comprehensive definition,” *Toxicological and Environmental Chemistry*, vol. **100**(01): pp. 6–19.
- Allen, T.,** Grant, R. G., Parker, P., Celtel, K., Kramer, A., and Weeks, M. (2022). *Timelines of World History*. New York: DK, p. 82. ISBN 978-0-7440-5627-3
- Anaam, J.A.** (2019). A literature review on microbial contamination of paper currency, *International Journal of Environmental Chemistry*, **5**(01): 18–22p. <https://www.researchgate.net/publication/334120379>
- Armstrong, B.,** and Gibbs, G.W. (2004). Exposure-response relationship between lung cancer and polycyclic aromatic hydrocarbons (PAHs). *Occupational and Environmental Medicine*, **66**(11): 740-746. <https://doi.org/10.1136/oem.2008.043711>
- ATSDR,** (2008). Chromium Toxicity, Atlanta, Georgia. <https://www.atsdr.cdc.gov/csem/> (Accessed 13 August 2025).
- Awe, S.,** Eniola, K.I.T., Ojo, F. T., and Sani, A. (2010). Bacteriological quality of some Nigerian currencies in circulation. *African Journal of Microbiological Research* **4**(21):2231–2234
- Balali-Mood M.,** Kobra, N., Zoya, T., Mohammad, R.K., and Mahmood S. (2021). Toxic mechanisms of five heavy metals: mercury, lead, chromium, cadmium, and arsenic. *Frontiers in Pharmacology*, volume 12Ppp.
- Batsungneon, K.,** and Kulworawanichpong, T. (2011). Effect of dust particles in local rice mills on human respiratory system. *World Academy of Science, Engineering and Technology*, **80**, 421–426.
- Bayat, M.,** Asban, P., Nasab, F., Taherian, M., Sepahvad, A., Farhadi, A., Falahi, B., Mohammadi, M., and Farhadi, M. (2023). A review of the effect of outdoor polycyclic aromatic hydrocarbons on Bladder Cancer. *Health scope*. <https://doi.org/10581/healthscope-136234>.
- Bernholtz, P.** (2003). *Monetary Regimes and Inflation: History, Economic, and Political Relationships*. Basle, Switzerland: Edward Elgar Publishing.
- Brady, D. H.** and Kelly, M.O. (2000). *Pathogens associated with currencies; retrospective study of private diagnostic laboratories*. University press. 2000.
- Burchiel, S.W.** and Luster, M.L. (2001). Signaling by Environmental PAHs in Human Lymphocytes. *Journal of Clinical Immunology*, **98**:2 <http://doi101006/jclim2000>.

- California Environmental Protection Agency (Cal-EPA) (1994). Memorandum, to Cal/EPA Departments, Boards, and Offices from Standards and Criteria work Group, Office of Environmental Health Hazard Assessment. Subject: *California Cancer Potency Factors*. Pp 134
- Chabukdhara, M.,** and Nema, A.K. (2013). Heavy metals assessment in urban soil around industrial clusters in Ghaziabad, India: Probabilistic health risk approach. *Ecotoxicology and Environmental Safety*, 87, 57–64
- Chicas, S.D.,** Valladarez, J.G., Carrias, A.A., Oinine, K., Sirasankar, V. (2022). Management of POPs: A caribbean perspective. *Inorganic pollutants*. pp 91-155, Springer, Cham.
- Cohen, A.J.,** Brauer, M., Burnett, R., Anderson, H.R., Frostad, J., Estep, K., and Balakrishnan, K. (2017). Estimates and 25-year trends of the global burden of 627 disease attributable to ambient air pollution: *An analysis of data from the Global Burden of 628 Diseases Study 2015*. *The Lancet*, 389(10082), pp. 1907–1918
- De La Torre-Roche, R.J.,** Lee, W.-Y., Campos-Díaz, S.I. (2009). Soil-borne polycyclic aromatic hydrocarbons in El Paso, Texas: analysis of a potential problem in the United States/Mexico border region. *Journal of Hazardous Materials* 163, 946-958.
- Duan, M.C.** Zhong, X.N. and Liu, G.N. (2014) The Treg/ Th17 Paradigm. *Journal of immunology Research* 730380- Wiley online library.
- El-Saeid, M.,** Alghamdi, A., and Alzahrani, A. (2023). Impact of Atmospheric Polycyclic Aromatic Hydrocarbon (PAHs) of Falling Dust in Urban Area Settins: Status, Chemical Composition \, Sources and Potential Human Health Risks. *International Journal of Environmental Research and Public Health*, 20. <https://doi.org/10.3390/ijerph20021216>.
- Envoh, C.E.,** (2020). Bioavailability, average daily does and risk of heavy metals in soils from Children playground within Owerri, Imo State, Nigeria. *Chemistry Africa*, 3:427-438.
- Envoh, C.E.** and Isiuku, B.O. (2020). Determination and human health risk assessment of heavy metals in food basin soil in Owerri Southeastern Nigeria. *Chemistry Africa*, 3:1059, 1071 29. *Verla Environmental, AW*.
- Eze, E.** and Okoye, R. (2021). Multidrug resistance patterns of bacteria isolated from public devices in Enugu, Nigeria. *Nigerian Journal of Pharmaceutical Research*, 17(2): 133–140.
- Fabian, L.M.C.,** Daniela, B. Q., David, A., Jorge, E. P., Nestor, Y. R., Karen, B. (2025). Number Concentration, Size Distribution, and Lung deposited surface Area of Airborne Particles in Three Urban Areas of Colombia; Air quality in metropolitan areas and megacities. *Atmosphere*. 16(5), 558. <http://doi.org/10.3390/atmos/6050558>. Accessed 23 October 2025.
- Fumiyuki, N.** and Rupak, A. (2018). Heavy metals in urban dust. <http://dx.doi.org/10.5772/intechopen>. Accessed 10 November, 2025.
- Galarneau, E.** (2008). Source specificity and atmospheric processing of airborne PAHs: implications for source apportionment. *Atmospheric Environment* 42, 8139-8149.

- Genchi, G.,** Carocci, A., Lauria, G., Sinicropi, M. S., and Catalano, A. (2020). Nickel: Human Health and Environmental Toxicology. *International Journal of Environmental Research and Public Health*, **17**(3), 679.
- Goldman, R.,** Enewold, L., Pellizari, E., Beach, J.B., Bowman, E.D., Krishman, S.S., Shield, P. G. (2021). Smoking increases carcinogenic PAHs in Human Lung tissue. *Cancer research* **61**, 6367-6371
- Goodarzi, G.,** Asgharipour, D., Naimabadi, A., Ghorbanpoor, R., Hedari, M., Hashemzadeh, B. (2018). Analysis of chemical properties of precipitating particles in Ahvaz, Iran. *Journal of North Khorasan University of Medical Science*. **9**(4): 56-65. <http://doi:10.29252/nkjmd-09049>.
- Gulson, B.,** and Taylor, A.A. (2017). Simple lead dust fall method predicts children's blood level: A new evidence from Australia. *Environmental Resources*. **150**: 76-81. <http://doi:10.1016/j.envres.2017.07047>.
- Hashizume, M.,** Yoonhee, K., Fook, S., Yeonseung, C., Lina, M., Michelle, L., Yue, L. G., Haidong, K., Yasushi, H., Seung-Muk, Y., Ho, K., Yuji, N. (2020). Health effects of Asian dust: A systematic review and meta-analysis. *Environmental health perspectives*. **128**(6): 066001-1. <http://doi.org/10.1289/EHP5312>
- Hasunuma, H.,** Ayano, T., Rintaro, O. Yuko, A., Yoon, H., Itsushi, U., Atsushi, S., Yuji, N., Masahiro, H., David, J. A., Hiroshi, O. (2021). Effect of Asian dust on respiratory symptoms among children with and without asthma, and their sensitivity. *Science of total environment* **753**. <https://doi.org/10.1016/j.scitotenv.2020.141585>
- Haug, X.,** Sillanpaa, M., Gjeessing, E. T., Vogl, R. D. (2003). Water quality in the Tibetan plateau: Metal contents of four selected rivers. *Environmental pollution*. **156**(2).
- Hazrat, A.,** Ezzat, and K., Ikram, I. (2018). Environmental Chemistry and Ecotoxicology of hazardous heavy metals: Environmental persistence, Toxicity and Bioaccumulation. *Journal of chemistry*. 1-14.
- Heidary-Monfared, S.** (2011). Community garden. Heavy metal study. **8**(18).
- Helmenstine, A. M.** (2021). "Heavy Metal Definition and List." *ThoughtCo*. <https://www.thoughtco.com/definition-of-heavy-metal-605190> (Accessed 15 August 24, 2025).
- Higashi, T.,** Kambayashi, Y., Ohkura, N., Fujimura, M., Nakai, S., Honda, Y., and Nakamura, H. (2014). Effects of Asian dust on daily cough occurrence in patients with chronic cough: A panel study. *Atmospheric Environment*. **92**, 506–513.
- Holme, J. A.,** Vondracek, J., Machala, M., Lagadic-Gossmann, D., Vogel, C., Le Ferrec, E., Spafel, L., and Ovrevik, J. (2023). Lung Cancer associated with combustion particles and fine particulate matter (PM_{2.5}). The roles of polycyclic aromatic hydrocarbons (PAHs) and the aryl hydrocarbon receptor (AhR). *Biochemical Pharmacology*. **216**, 115801. <https://doi.org/10.1016/j.bcp.2023.115801>.
- Hu, X.,** Zhang, Y., Ding, Z., Wang, T., Lian, H., Sun, Y., and Wu, J. (2012). Bio accessibility and health risk of arsenic and heavy metals (Cd, Co, Cr, Cu, Ni, Pb, Zn and Mn) in TSP

- and PM_{2.5} in Nanjing, China, *Atmospheric Environment*, **57**, 146–152.
<https://doi.org/10.1016/j.atmosenv.2012.04.056>
- IARC** (2012) “International Agency for Research on Cancer: Chemical Agents and Related Occupations- A Review of Human Carcinogens.” *Monograph on the Evaluation of Carcinogenic Risks to Humans* **100**(5),233-240
- Igwe, J.C.** and Ukaogo, P.O. (2025). Environmental effects of Polycyclic aromatic hydrocarbons (PAHs). *Journal of Natural Sciences Research*. **5**(7).
- Igwe, J.C.,** Nnorom, I.C and Gbaruko, B.C. (2005). Kinetics of radionuclides and heavy metals behaviour in soils: Implications for plant growth. *African Journal of Biotechnology*, **4**(13),154-1547.
- Isaifan, R.J.** (2023). Air pollution burden of disease over highly populated states in the Middle East, *Frontiers in Public Health*, 10.
<https://doi.org/10.3389/fpubh.2022.1002707>.
- Jaishankar, M.,** Tseten, T., Anbalagan, N., Mathew, B. B., and Beeregowda, K. N. (2013). Toxicity, mechanism, and health effects of some heavy metals. *Interdisciplinary Toxicology*, **7**(2), 60–72.
- Jarup, Lar** (2003). Hazards of heavy metal contamination. **68**: 167-82. *Br Med Bull*.
<http://doi:10.1093/bmb/idg032>.
- Katsoyiannis, A.,** Terzi, E., Cai, Q.-Y., 2007. On the use of PAH molecular diagnostic ratios in sewage sludge for the understanding of the PAH sources. Is this use appropriate? *Chemosphere*. **69**, 1337-1339.
- Khan, A.,** Srivastava, R., Abdulla, A., Khan, S. (2024). Assessment of ambient air pollution levels: A five-year analysis of PM_{2.5}, NO, NO₂, NO_x, CO, and SO₂. *Rocznik ochrona srodowiska*. **26**: 366-373, 2720-7501. <http://doi.org/10.54740/ros.2024.035>
- Khan, M.** (2023). Trends of laboratory detected heavy metals in children: Solutions for heavy metal contamination in infant food products. *Food and Nutrition Sciences*. **14**, 791-811.
[doi:10.4236/fns.2023.149051](https://doi.org/10.4236/fns.2023.149051).
- Kim, K. H.,** Kabir, E. and Brown, R. J. (2013). A review of airborne polycyclic aromatic hydrocarbons (PAHs) and their human health effects. *Environmental International*. **60**(12):71-80.
- Kim, K.,** Kabir, E., Kabir, S. (2015). A review on the human health impact of airborne particulate matter. *Environmental International*, **74**, 136-143.
- Klavins, M.,** Briede, R.V., Kokorite, I., Parele, E., & Klavina, I. (2000). Heavy metals in rivers of Latvia. *Science of the Total Environment*, **262**(1–2), 175–183

- Laden, F.,** Joel, S., Frank, E., Douglas, W. (2000). Reduction in fine particulate pollution and mortality. *American journal of respiratory and critical care medicine*. 19; **173**(6):667-672.
- Lala, M.A.,** Onwunzoa, C.S., Adesina, O.A., and Sonibareb, J.A. (2023). Particulate matters pollution in selected areas of Nigeria: Spatial analysis and risk assessment, *Case Studies in Chemical and Environmental Engineering*, 7, p. 100288. <https://doi.org/10.1016/j.cscee.2022.100288>. Usman, M.M., Bala, S.S., and Hamza, K. (2023). *Environmental impact of heavy metals, in IntechOpen eBooks*. <https://doi.org/10.5772/intechopen.108973>.
- Lenntech** Water Treatment and Air Purification (2004). Water Treatment, published by Lenntech, Rotterdamseweg, Netherlands. Pp 54.
- Letelier, P.,** Saldias, R., Loren, P., Riquelme, I., and Guzman, N. (2023). MicroRNAs as Potential Biomarkers of Environmental Exposure to Polycyclic Aromatic Hydrocarbons and Their Link with Inflammation and Lung Cancer, *international Journal of Molecular Sciences*, 24. <https://doi.org/10.3390/ijms242316984>.
- Leung, A. O.,** Duzgoren-Aydin, N.S., Cheung, K.C., Wong, M.H. (2008). Heavy metals concentrations of surface dust from e-waste recycling and its human health implications in Southeast China. *Environmental science technology*. **42**(7): 2674-80. <http://doi:1021/es071873x>.
- Leyssens, L.,** Vinck, B., Van Der Straeten, C., Wuyts, F., and Maes, L. (2017). Cobalt toxicity in humans: A review of the potential sources and systemic health effects, *Toxicology*, 387, pp. 43–56. <https://doi.org/10.1016/j.tox.2017.05.015>.
- Lin, Y.,** Wang, F., Xu, M. (2015). Pollution distribution and health risk assessment of heavy metals in indoor dust in Anhui rural, China. *Environmental Monitoring Assessment*. 187,1-9. (springer)
- Mahurpawar, M.** (2015). Effects of heavy metals on human health. *International Journal of Research -Granthaalayah*, 3(9SE), 1–7. <https://doi.org/10.29121/granthaalayah.v3.i9SE.2015.3282>.
- Mai, Y.,** Wang, Y., Geng, T., Peng, S., Lai, Z., Wang, X., Li, H. (2024). A systematic toxicologic study of polycyclic aromatic hydrocarbons on aquatic organisms via food-web bioaccumulation. *Science of the total environment*, 172362. <http://doi.10.1016/j.scitoenv.2022.172362>.
- Manoli, E.,** Kouras, A., Samara, C. (2004). Profile analysis of ambient and source emitted particle-bound polycyclic aromatic hydrocarbons from three sites in northern Greece. *Chemosphere* 56, 867878
- Mbajiuka, C.** (2015). Isolation and identification of microorganisms associated with the use of automated teller machine (ATM) in Michael Okpara University of Agriculture, Umudike and its environs. *World Journal of Pharmaceutical Research* **4**(8): 85-99.
- Meherg A.A.** (2011) Trace element in soils and plants. 4: CRC. Press, Boca Raton, FL, USA.
- Mohammadi, M.J.,** Yari, A.R., Saghazadeh, M., Sobhanardakani, S., Geravandi, S., Afkar, A. (2017). A health risk assessment of heavy metals in people consuming sohan in Qom, Iran. *Toxin Reviews*, 37, 278-286. <http://doi.org/10.1080/15569543.2017.1362655>

- Moorthy, B.,** Chu, C., and Carlin, D.J. (2015): From metabolism to lung cancer. *Toxicological sciences*. **145**(1), 5-15. <https://doi.org/10.1093/toxsci/kfv040>.
- Moghtaderi, M.M.,** Ashraf, M.M., Moghtaderi, T.T., Teshnizi, S.H., and Nabavizadeh, S.H. (2020). Heavy metal concentration in classroom dust samples and its relationship with childhood asthma: a study from Islamic Republic of Iran, Eastern Mediterranean Health Journal/Eastern Mediterranean Health Journal, **26**(05),594–601. <https://doi.org/10.26719/emhj.19.072>.
- Moubarz, G.,** Saad-Husein, A., Shahy, E. M., Mahdy-Abdallah, H., Mohammed, A.M.F., Saleh, I.A., Abo-Zzeid, M.A.M and Abo-Elfadl, M.T. (2023). Lung cancer risk in workers occupationally exposed to polycyclic aromatic hydrocarbons with emphasis on the role of DNA repairs gene. *International Archives of Occupational and Environmental Health*. **96**(2). 313-329. <https://doi.org/10.1007/s00420-022-01926-9>.
- Nagajyoti, P.C.,** Lee, K.D., Sreekanth, T.V.M. (2010). Heavy metals, occurrence and toxicity for plants: a review. 8:199-216. *Environmental chemistry letters*.
- Najurudeen, B.N.N.,** Khan, F.M., Suradi, H., Mim, A.U., Raim, J.N.I., Rashid, B.S., Latif, M.T., and Huda, N.M. (2023). The presence of polycyclic aromatic hydrocarbons (PAHs) in air particle and estimation of the respiratory deposition flux. *Science of The Total Environment*, 878. 163129. <https://doi.org/10.1016/j.scitotenv.2023.163129>.
- Navaretnam, R.,** Jaafar, I., Shukor, M., and Yasid, N. (2023). Exposure and toxicity of polybrominated diphenyl ethers: A Mini Review. *Journal of environmental microbiology and toxicology*. <https://doi.org/10.54987/jemat.v11i2.846>.
- Nwineewi, J. D.** and Nna, P.J. (2016). Impact of Eleme Petrochemical Company (Indorama) on the levels of Some heavy Metals in penausmonoden (shrimp) from Eleme Creeks, Rivers State, Nigeria. *Acedemic Research international*, **7**(4):47-57
- Ofoedu, C.E.,** Jude, O.I., Ijeoma, M A., Perpetual, Z.O., Charles Odilichukwu, R.O., and Małgorzata, K. (2021). Bacterial contamination of Nigerian currency notes: A comparative analysis of different denominations recovered from local food vendors, *PeerJ*, 9, p. e10795. <https://doi.org/10.7717/peerj.10795>
- Oliveira, C.,** Martins, N., Tavares, J., Pio, C., Cerqueira, M., Matos, M., Silva, H., Oliveira, C., Camoes, F. (2011). Size distribution of polycyclic aromatic hydro-carbons in a roadway tunnel in Lisbon, Portugal. *Chemosphere*. doi:10.1016/ j. chemosphere.2011.01.011.
- Olowe, O.A.,** Adebayo, O. and Ogundipe, O. (2020). Assessment of microbial contamination of POS terminals in Lagos, Nigeria. *African Journal of Health, Safety and Environment*, **1**(2) :44–51.
- Onaiwu, G. E.,** and Okuo, J. M. (2023). Quantification of fine particulate matter (PM_{2.5}) and its correlation with meteorological parameters within the ambient air of automobile workshops in Benin City. *Aerosol Science and Engineering*, **7**(1), 59-68.

- Paiko, Y.B.,** Nkeruwem, O.N., Tsado, M.T., Dagaci., M.Z. (2015). Proximate, mineral and anti-nutritional composition of the outer peel and seed coat of *chrysophyllum albidum* (African star apple) obtained from Minna, Niger state, Nigeria. *Jewel Journal of scientific research.*3(1): 1-6
- Pal, S.,** Roy, S. and Goswami, S. (2021). Bacterial contamination of frequently touched objects in public transport and its implication for public health. *Journal of Environmental Health Science and Engineering* 19(3): 245–253.
- Pies, C.,** Hoffman, B., Petrowsky, J., Yang, Y., Ternes, T. A., Hoffman, T. (2008). Characterization and source identification of PAHs in riverbank soils. *Chemosphere* 72(10): 1594-1601
- Pollack, M.** (2000) *Pseudomonas aeruginosa*. In: Mandell, G.L., Bennett, J.E. and Dolin, R. (eds) *Principles and Practice of Infectious Diseases*. 5th ed. Philadelphia: Churchill Livingstone, pp. 2310–2335
- Pope, C.A.,** Burnett, R.T., Thurston, G.D., Thun, M.J., Calle, E.E., Krewski, D., Godleski, J.J. (2004). Cardiovascular Mortality and long-term exposure to particulate air pollution: Epidemiological evidence of general pathophysiological pathways of disease. *journal of Research Administration*, doi.org/10.1161/0.1
- Raaschou-Nielsen, O.,** Beelen, N., Wang, M., Hoek, G. (2016). Particulate matter air pollution components and risk for lung cancer. *Environment International Journal.* 87,66-73.
- Rahman, M.S.,** Khan, M., Jolly, Y., Kabir, J., Akter, S., Salam, A. (2019). Assessment risk to human health for heavy metal contamination through street dust in the Southeast Asian Megacity: Dhaka, Bangladesh. *Science Total Environment*; 660:1610-22. <http://doi:10.1016/j.scitotenv.2018.12.425>.
- Ravanbakhsh, M.,** Yousefi, H., Lak, H., Mohammad, J. A., Asban, P. (2022). Effect of polycyclic aromatic hydrocarbons (PAHs) on respiratory diseases and the risk factors related to cancer. 43(9): 1-7. <https://doi/10.1080/10406638.2022.2149569>
- Ravindra, K.,** Wauters, E., Van Grieken, R., (2008). Variation in particulate PAHs levels and their relationship with the transboundary movement of the air masses. *Science of the Total Environment* 396, 100-110.
- Rönkkö T,** Timonen H. Overview of Sources and Characteristics of Nanoparticles in Urban Traffic-Influenced Areas. *J Alzheimers Dis.* 2019;72(1):15-28. <https://doi/10.3233/JAD-190170>. PMID: 31561356; PMCID: PMC6839465
- Sahu, V.,** Elumalai, and S.P., Gautam, S. (2018). Characterization of indoor settled dust and investigation of indoor air quality in different micro-environments. *International journal of environmental health research.* 28(4), 419-431.
- Sardar, K.,** Ali, S., Hameed, S., Afzal, S., Fatima, S., Shakoor, M.B., and Tauqeer, H.M. (2013). Heavy metals contamination and what are the impacts on living organisms. *Greener Journal of Environmental Management and Public Safety*, 2(04), 172-179.
- Seo, J.S.,** Keum, Y.S., Harada, R.M., Li, Q.X. (2007). Isolation and Characterization of Bacteria Capable of Degrading Polycyclic Aromatic Hydrocarbons (PAHs) and

- Organophosphorus Pesticides from PAH-Contaminated Soil in Hilo, Hawaii. *Journal of Agricultural and Food Chemistry*. (55)14:5383-9. <http://doi:10.1021/jf0637630>.
- Sezgin, H.**, Kurtulus, O., Goksel, D., Semih, N., Cuma, B. (2003). Determination heavy metals concentrations in street dusts in Istanbul E-5 highway. *Environment International* 29. 979-985
- Singh, A.**, Dhau, J., Kummar, R., Badru, R., Singh, P., Mishra, Y.K., and Kaushik, A. (2024). Tailored carbon materials (TMC) for enhancing photocatalytic degradation of polyaromatic hydrocarbons. *Progress in Materials Science*. <http://doi:101016/j.pmatsci.2022.101289>.
- Sovacool, B.K.**, Griffiths, S., Kim, J., and Bazillian, M. (2021). Climate change and industrial F-gases: A critical and systematic review of developments, sociotechnical system and policy options for reducing synthetic greenhouse gas emissions. *Renewable Sustainable Energy Reviews*, 141,110759. <http://doi.org/10.1016/j.reser.2021.110759>
- Stanley, M.**, Rob, M., Ntebogeng, M., Jan, M., and Munyaradzi, M. (2013). Source apportionment of polycyclic aromatic hydrocarbons in sediments from polluted rivers. *Journal of pure and applied chemistry*. <http://dx.doi.org/10.1351>
- Stephens, A.** and Kwaku, T. (2007). Automatic teller machines (ATMs) as potential sources of food-borne pathogens: a case from Ghana. *Nature and Science* 9 (9): 63-67.
- Stone, V.**, Miller, M.R., Clift, M.J.D. (2017). Nanomaterials versus ambient ultrafine particles: an opportunity to exchange toxicology knowledge. *Environmental health perspective* 125, 106002.
- Tashakor, M.**, Reza, D.B., Seyed, R.A., Dimitris, G. k. (2022). Tracing of heavy metals embedded in indoor dust particles from the industrial city of Asaluyeh, South of iran. *International Journal of Environmental Resources and public health*. 19(13), 7902. <http://doi.org/10.3390/ijerph19137905>
- Thurston, G.D.** (2017). A joint ERS/ATS policy statement: What constitutes an adverse health effect of air pollution? An analytical framework. *European Respiratory journal*. 49, 1600419.
- Tolosa, I.**, Bayona, and J.M., Albaiges, J. (1996). Aliphatic and polycyclic aromatic hydrocarbons and sulfur/oxygen derivatives in Northwestern Mediterranean sediments: Spatial and temporal variability, fluxes, and budgets. *Environmental Science and Technology*. <http://doi:101012/es950647x>. 30(8)2495-2503.
- Ukpebor, J.**, Omagamre, W., Abayode, B., Unuigbe, C., Dibia, E., & Ukpebor, E. (2021). Baseline Concentrations of Fine and Coarse Particulate Matter in A Tropical City with Introduced Traffic Control Measures. *International Journal of Environmental Pollution and Environmental Modelling*, 4(1), 17-27.
- Ukpebor, J.E.**, Omagamre, W.E. and Olayinka, T.S. (2019). Human exposure to particulate matter (PM_{2.5}) and polycyclic aromatic hydrocarbons (PAHs) in diesel operated buses within Benin City, Nigeria. *Technical Transaction of Material Science and Technology* 2(1):29-38.

- Ukpebor, J.E.,** Omoruyi, C.I., Omonmhele, S.I., Imhotu, M., Ogboje, S.U., Isara, A.R., and Ukpebor, E.E. (2023). Concentration of PAHs from urban and rural areas in southern Nigeria using polyurethane foams (PUF): Health impact and cancer risk assessment. *Scientific African*. 22, e01976. <https://doi.org/10.1016/j.sciaf.2023.e1976>.
- Urman, R.,** Habre, R., Fruin, S., Gauderman, J., Lurmann, F., Gilliland, F., and McConnell, R. (2016). Health effects of indoor/outdoor pollution in Childhood: Exposure to transition metals in particulate matter air pollution and children's lung function in the southern California children's health study. *American Journal of Respiratory*.
- Urrutia-Pereira, M.,** Rizzo, L.V., Staffeld, P.L., Chong-Neto, H.J., Viegi, G., and Sole, D. (2021). Dust from the Sahara to the American Continent: Health impacts, *Allergol. Immunopath.*, 49, 187–194
- USEPA.** (2006). Inventory Update Rule. Office of Prevention, Pesticide and Toxic Substances. US Environmental Protection Agency. Washinton DC. Redrived from <http://www.epa.gov/optu/iuv/>.
- Van Der Pol, E.,** Coumans, F., Grootemaat, A., Gardiner, C., Sargent, I., Harrison, P., Sturk, A., Van Leeuwen, T., and Nieuwland, R. (2014). Particle size distribution of exosomes and microvesicles determined by transmission electron microscopy, flow cytometry, nanoparticles tracking analysis, and resistive pulse sensing. *Journal of thrombosis and haemostasis*, **12**(7), 1182-1192. <http://doi.org/10.1111/jth.12602>
- Vyas, M.,** Ruchika, P., Pawan, C., Narendra, K., Dr. Anil, V., and Dr. Suresh, K.S. (2017). A review of some heavy metals in plants and human health. *Journal of Emerging Technologies and Innovative Research (JETIR)* www.jetir.org, **4**(12). (Accessed 21, August 2025).
- Wang, G.,** Liu, H., Gong, Y., Wei, Y., Miso, A., Yang, L. and Zhang, H. (2017). Risk assessment of metals in Urban Soils from a typical Industrial City, Suzhou, Eastern China. *International Journal of Environmental Research and Public Health*. **14**(1025):1-7
- Wani, A. L.,** Anjum, A., and Usmani, J.A. (2015). Lead toxicity: A review, *Interdisciplinary Toxicology*, **8**(02), pp. 55–64. <https://doi.org/10.1515/intox-2015-0009>.
- Warneck, P.** (1988). Chemistry of the natural atmosphere, *Academic Press Inc., San Diego*. **41**(7).
- William N.G.** and Rouwenhorst, K.G. (2005). The Origins of Value: The Financial Innovations that Created Modern Capital Markets. Oxford University Press. p. 94. ISBN 978-0-19-517571-4.
- Wittayaman, W.,** Srikote, R. and Chaimongkol, T. (2019). Determination of organochlorine pesticides and polychlorinated biphenyl as POPs residues in freshwater animals in Thailand during 2017-2018. *science and Technology Asia*, 27-38.
- World Health Organization (**WHO**) (2019). Exposure to Cadmium: A major health concern. Chemical Safety and Health Unit (CHE), <https://www.who.int/publications/i/item/WHO-CED-PHE-EPE-19-4-3> (Accessed 24 July 2025).

- World Health Organization (**WHO**) (2023). Global Antimicrobial Resistance and Use Surveillance System (GLASS) Report 2023 Geneva: WHO Press.
- Yunker, M.B.**, Macdonald, R.W., Brewer, R., Sylvestre, S., Tuominen, T., Sekela, M., Mitchell, R.H., Paton, D.W., Fowler, B.R., Gray, C., Goyette, D., Sullivan, D. (2002). Assessment of Natural and Anthropogenic Inputs Using PAHs as Tracers. The Fraser River Basin and Strait of Georgia 1987–1997, *U.S. Environmental Protection Agency (Ed.)*. 36–47, EPA, Washington, DC.
- Zhang, M.**, Zhang, X., Shi, Y.E., Liu, Z. and Zhan, J. (2016). Surface enhanced Raman spectroscopy hyphenated with surface microextraction for in-situ detection of polycyclic aromatic hydrocarbons for food contact materials. *Talanta* 158(2):322-329.
- Zheng, N.**, Liu, J., Wang, Q., and Liang, Z. (2010). Health risk assessment of heavy metal exposure to street dust in the zinc smelting district, Northeast of China. *Science of the Total Environment*, **408**(4), 726–733
- Zhuo, S.**, Shen, G., Zhu, Y., Du, W., Pan, X., Li, T., Hau, Y., Lin, J., Cheng, H., Xing, B., Tao, S. (2017). Source-orientation risk assessment of inhalation exposure to ambient polycyclic aromatic hydrocarbons and contributions to non-priority isomers in urban Najig, a megacity located in Yangtze River, China. *Environmental pollution* **224**(10): 796-809

**ASSESSMENT OF POTENTIAL HEALTH RISK OF BANKNOTE DUST
(BND) IN SELECTED COMMERCIAL BANKS WITHIN BENIN
METROPOLIS IN EDO STATE, NIGERIA**

BY

Osagie Ferdinand AMAYO

PG/LSC2110439

**DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY,
FACULTY OF LIFE SCIENCES,
UNIVERSITY OF BENIN,
BENIN CITY.**

NOVEMBER 2025