ECOLOGICAL RISK ASSESSMENT OF HEAVY METAL IN AROUND OLUKU DUMPSITES, BENIN CITY, EDO STATE

BY

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BENIN CITY.

NOVEMBER, 2025

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PROJECT SUBMITTED TO THE DEPARTMENT OF SCIENCE LABORATORY TECHNOLOGY, FACULTY OF LIFE SCIENCES, UNIVERSITY OF BENIN, IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF BACHELOR OF SCIENCE (BSc.) DEGREE IN SCIENCE LABORATORY TECHNOLOGY (GEOLOGY AND MINING TECHNIQUES).

NOVEMBER, 2025

CERTIFICATION

This is to certify that this thesis "**ECOLOGICAL RISK ASSESSMENT OF HEAVY METAL IN AROUND OLUKU DUMPSITES, BENIN CITY, EDO STATE"** was carried out by **Odosa OTUBU** with Matriculation Number LSC2009826 of the Department of Science Laboratory Technology (Geology and Mining Techniques), Faculty of Life Sciences, University of Benin, Benin-City, under the supervision of Dr. K. Ojeaga.

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DEDICATION

This Project work is dedicated to GOD Almighty for giving me the Strength, Finances and Guidance.

ACKNOWLEDGEMENTS

First and foremost, I want to Acknowledge God my creator for keeping me alive all through my years in school. I want to acknowledge my late mum, Mrs. Dolly Izoduwa Otubu, you were my role model and you ensured I had everything I needed to have a formal Education. It was your dream to see me graduate and I achieved it. Also, my Dad, Benjamin Osamamwande Otubu for always being there for me and ensuring I concluded my academic journey. My siblings, Harry Osamamwande, Osamede Otubu and Faith Otubu, thank you for always playing an important role in my life and thank you for your love and support through my academic journey. Special thanks to my project supervisor Dr. K. Ojeaga, thank you for standing as a guide through my academic days in school sir, I appreciate your efforts and I say thank you for everything you've done for me, Also a special appreciation to my Girlfriend, Samantha Oghogho Eucharia, thank you for your constant encouragement, care and support. Not to forget, my friends and coursemates through my academic sessions, Valentina, Sammy, Gloryan, Victor, Glory and others. You guys are the real MVPs, thank you for always being there and thank you for making this journey fun for me. Of course, my Aunties and Uncles who supported me throughout this journey. Last but not the least, I want to acknowledge myself for not giving up, through my tough moments and bright moments, I say thank you.

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ABSTRACT

The indiscriminate disposal of solid waste and the proliferation of open dumpsites pose serious threats to soil quality, groundwater integrity and plant health. This study evaluated the ecological risk associated with heavy metals in soils collected around open dumpsites in Oluku, Benin City, Edo State, Nigeria. Ten soil samples were randomly collected using an auger and analyzed for heavy metal concentrations using Atomic Absorption Spectrophotometry (AAS). The mean concentrations of the analyzed metals ranged from 1.22 mg/kg for Cu to 3.05 mg/kg for Mn, following the decreasing order: Mn > Cd > Pb > Cr > Ni > Co > Zn > Fe > Cu. The contamination factor (CF) values for Fe, Zn, Cu, Pb, Cd, Mn, Ni, Cr and Co were 1.23, 1.26, 1.22, 1.95, 2.48, 3.05, 1.36, 1.42 and 1.29, respectively, indicating moderate contamination by Cd and considerable contamination by Mn. The ecological risk factor (Eir) of individual metals revealed that Cd (mean = 74.4) contributed the highest ecological risk, followed by Mn (30.58) and Pb (9.77). The overall potential ecological risk index (RI) was 133.92, suggesting a moderate level of ecological risk in the study area. The findings imply that uncontrolled dumping and anthropogenic activities contribute significantly to the accumulation of toxic metals in the soil, which may pose long-term environmental and health risks. Proper waste management strategies and periodic monitoring of soil quality are therefore recommended to mitigate further contamination and safeguard environmental health.

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF STUDY

Developing countries face a daunting challenge of managing rapidly increasing waste generation, which is exacerbated by inadequate facilities and resources (Samadder *et al.,* 2017). The inability of waste management authorities to cope with the volume of waste generated has led to indiscriminate disposal, transforming many Nigerian cities into sprawling ghettos. This has resulted in severe pollution of land, air and water, exposing the population to numerous health hazards. A healthy environment is intricately linked with human health and pollution from various sources, including industrial emissions, agricultural runoff and sewage disposal, can have devastating consequences. The disposal of waste on land poses significant risks, including surface and groundwater contamination by leachate and bioaccumulation of toxic heavy metals in soil (Ghrefat *et al*., 2012). Heavy metals, such as mercury, arsenic and lead, can accumulate in soil and be taken up by plants, leading to biomagnification up the food chain (Qu *et al*., 2012). Moreover, heavy metal contamination can hamper soil productivity by disrupting soil fauna and flora. Municipal solid waste open dumps are a significant source of groundwater, surface water and soil contamination, posing a major threat to environmental and human health (Samadder *et al*., 2017). Landfill leachate often contains high levels of heavy metals, which can persist in the environment and pose long-term health risks (Moody *et al*., 2017). Exposure to heavy metal-contaminated soils can occur through ingestion, dermal contact, or inhalation and can have adverse health effects, particularly in children (Saeedi *et al*., 2012). The issue of groundwater contamination by landfill waste has been a concern since the 1970s, particularly in developing countries where waste management practices are often inadequate (Oyelami *et al*., 2013). Uncontrolled dumping and unscientific disposal of municipal solid waste can lead to severe environmental and health consequences, emphasizing the need for effective waste management strategies.

In 2018, Thailand generated approximately 27.8 million tons of waste, representing a 1.64 % increase from 2017. Despite recycling efforts, which accounted for 9.58 million tons (34 %) of the waste, the country still faces significant waste management challenges. Hazardous waste content totaled 638,000 tons, a 3.2 % increase from 2017, largely due to urbanization, population growth and tourism (Pollution Control Department, 2018).

Thailand has numerous community waste disposal sites, with 3,205 sites across the country, of which 2,785 are open and 419 are closed. Unfortunately, many of these open dumpsites lack proper design and management, posing environmental and health risks. Groundwater, often used for agriculture and livestock purposes without testing or treatment, is particularly vulnerable to contamination.

Heavy metals, naturally occurring in the earth's crust, have been increasingly released into the environment through human activities. Anthropogenic sources of heavy metals include vehicle emissions, industrial processes, waste disposal and consumer products such as batteries, paints and pesticides. These metals can accumulate in the environment and pose significant health risks.

Research has shown elevated levels of heavy metals in various environments, including street dusts (Mnolawa *et al*., 2011), agricultural soils (Dinev *et al.*, 2008), cemeteries (Amuno, 2013), solid waste dumps (Adelekan and Alawode, 2001), oil and gas facilities (Iwegbue *et al.*, 2006) and lake sediments (Li *et al.,* 2013). Exposure to high levels of heavy metals can cause a range of health problems, from mild illnesses like gastrointestinal disorders and respiratory issues to life-threatening diseases such as cancer, cardiovascular disease and kidney damage (Mahmood *et al.,* 2014).

Health and ecological risk assessment is an appropriate tool for assessing and quantifying the probable adverse effects of different pollutants on human health and environment (Krcmar, *et al*., 2018). Calculating the risk value can help policymakers perform strategies to mitigate adverse health effects through removing the source of pollution, Therefore, to run an effective program for a further control of human health risk, a comprehensive health and ecological risk assessment is needed.

1.2 AIM AND OBJECTIVES

This research work is aimed at investigating the environmental risk posed by heavy metals in around open dumpsite.

The Specific objectives include to:

i. determine the heavy metal concentration, such as Zn, Pb, Ni, Cd, Mn, Fe, Cr, Al and Cu in soil around open dump site..
ii. assess the contamination factor and potential ecological risks of heavy metal contaminants in the soil.

1.3 STATEMENT OF PROBLEM

The indiscriminate disposal of solid waste in open dumpsites is a common practice in many developing regions, often due to inadequate waste management infrastructure. These dumpsites frequently contain a variety of hazardous substances, including heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), mercury (Hg) and chromium (Cr), which pose significant environmental and public health risks. When waste is exposed directly to the ground, heavy metals can leach into the surrounding soil and groundwater, potentially contaminating local water supplies, affecting vegetation and disrupting soil microbial communities.

Despite increasing awareness of the dangers posed by heavy metals in the environment, many open dumpsites remain unmonitored, with limited data on the concentrations and mobility of these contaminants. Moreover, there is often a lack of systematic ecological risk assessment to determine the extent of environmental degradation and the potential threat to nearby ecosystems and human populations. This situation is particularly alarming as heavy metals are non-biodegradable, tend to accumulate in the food chain and can have long-term toxic effects on plants, animals and humans. In the absence of comprehensive ecological assessments, policymakers and stakeholders lack the necessary information to design effective mitigation strategies or enforce environmental regulations. Therefore, there is a critical need to assess the ecological risks associated with heavy metals in open dumpsites, particularly those located near residential areas, agricultural lands, or water bodies. Such assessments will provide a scientific basis for risk management and help guide remediation efforts to protect environmental and public health.

1.4 JUSTIFICATION OF STUDY

The increasing use of open ground dumpsites for waste disposal presents significant environmental and public health concerns, particularly in areas lacking effective waste management systems. This study is necessary to assess the ecological and human health risks associated with heavy metal contamination resulting from such practices. Heavy metals like lead, cadmium, mercury, arsenic and chromium, often present in domestic, industrial and electronic waste, are non-biodegradable and tend to persist in the environment. When these metals leach into the soil, they can alter its structure, reduce fertility, interfere with microbial activity and inhibit plant growth, ultimately disrupting the balance of local ecosystems. In addition to environmental degradation, the presence of heavy metals in soil and water sources poses serious health risks to nearby human populations. These toxic elements can enter the food chain through crops grown on contaminated soil or through drinking water sourced from polluted groundwater. Long-term exposure to heavy metals has been linked to a range of severe health problems, including neurological disorders, kidney and liver damage, weakened immune function, reproductive issues and various cancers. Vulnerable groups such as children and pregnant women are especially at risk. Despite these dangers, many open dumpsites remain unassessed and there is often limited data available on the levels of heavy metals and the associated risks in specific locations. This study seeks to fill that gap by generating site-specific data and conducting a thorough ecological risk assessment. The findings will provide valuable insights for policymakers, environmental regulators and health authorities, enabling them to make informed decisions about waste management, land use and public health protection. Moreover, the research will contribute to the broader goal of promoting environmental sustainability and safeguarding human well-being in affected communities.

CHAPTER TWO

LITERATURE REVIEW

2.1 OVERVIEW

The rapid industrialization and population growth in many countries have led to a significant increase in waste generation, with thousands of tonnes of waste produced daily (Sharma and Shah, 2005; CPCB, 2004; Shekdar *et al*., 1992). Solid waste, comprising organic and inorganic materials, is a major cause of pollution and is generated by human and animal activities in urban societies (Berkun, 1991; Mee and Topping, 1998). The composition of solid waste varies widely depending on socio-economic conditions, location and waste management practices (El-Fadel *et al*., 1997).

The increasing amounts of municipal solid waste generated annually have raised concerns about the economic and environmental sustainability of current waste disposal methods (Daskalopoulos *et al*., 1998). While developed countries have established regulatory frameworks for waste disposal, developing countries often rely on unsophisticated methods such as open dumps (Kocasoy, 2002). Open dumps pose significant environmental and health risks, including the generation of leachates and obnoxious odors and can act as breeding sites for disease-causing vectors (Everett, 1992; Knoll, 1983; Adhikari *et al*., 2006). The lack of proper waste management infrastructure in developing countries exacerbates the problem, with open dumps often unfenced and lacking leachate and gas control systems (Krajewski *et al*., 2001). This can lead to the spread of diseases such as cholera, diarrhea and typhoid fever (Fobil *et al., 2008*; Everett, 1992; Knoll, 1983; Afrane *et al.,* 2004). Effective waste management strategies are essential to mitigate these risks and promote a healthier environment.

The rapid urbanization, changing lifestyles and population growth in developing countries have led to a significant increase in the quantity and complexity of solid waste generated (Alam and Ahmade, 2013). Unfortunately, the current municipal solid waste management practices in these countries are inadequate, leading to environmental and health problems (Srivastava *et al.*, 2015). The absence of effective waste management systems has resulted in communities resorting to indiscriminate dumping and open burning, posing significant threats to public health and the environment (Ejaz *et al*., 2010). Open dumps are a common feature in many developing countries, including Ethiopia and can lead to air and water pollution (Ejaz *et al.,* 2010).

The illegal disposal of waste can lead to the generation of greenhouse gases, leachate and other pollutants that can contaminate soil, water and air (Bobeck, 2010). In urban areas, municipal solid waste can clog drains, creating breeding grounds for insects and leading to flooding during rainy seasons (Ejaz *et al.,* 2010).The improper disposal of municipal solid waste has been linked to various health problems, including malaria, diarrhea and respiratory infections (Kafando *et al*., 2013). Exposure to pollutants from waste can also cause a range of health issues, including respiratory problems, skin irritation and gastrointestinal disorders (De and Debnath, 2016). Vulnerable populations, such as children, the elderly and those with pre-existing medical conditions, are disproportionately affected by the health impacts of poor waste management (Zanobetti *et al.,* 2000). Long-term exposure to pollutants from waste can lead to chronic health effects, including respiratory problems and lung cancer (WHO, 2000). Maternal exposure to air pollution from waste can also have adverse birth outcomes, including low birth weight and preterm birth (Rushton, 2003). Effective waste management practices are essential to mitigate these health and environmental impacts.

Waste disposal methods, including open dumps, landfills, sanitary landfills and incinerators, are notable sources of metal emissions into the environment (Yarlagadda *et al.*, 1995; Waheed *et al.*, 2010; Iwegbue *et al.,* 2010; Rizo *et al*., 2012). Leachate generation is primarily linked to precipitation infiltration through waste, resulting in leachate migration into groundwater and subsequent pollution (Samuding, 2009). Leachate migration has led to soil contamination with heavy metals like lead, copper, zinc, iron, manganese, chromium and cadmium, which pose serious problems due to their non-biodegradable nature (Hong *et al*., 2002). The primary sources of heavy metals in landfills are industrial waste, incinerator ash, mine waste and household hazardous materials like batteries, paints and dyes (Erses and Onay, 2003). Heavy metal contamination of soil from waste disposal sites is a significant issue in industrial and urban areas (Mandal and Sengupta, 2006). Soils act as a sink for heavy metals released into the environment, as many heavy metals bind to soil particles (Obiajunwa *et al*., 2002). When assessing pollutant levels in soil and leachate at contaminated sites, direct results are often necessary for soil classification and determining remediation strategies (Banar *et al.,* 2007).

2.2 IMPACTS OF HEAVY METALS POLLUTION

Heavy metals have played a significant role in human development since ancient times. Early humans used metals like gold, silver and copper for various purposes and the advent of mining and metallurgy established the connection between heavy metals, pollution and human history (Sharma *et al.,* 2016). Industrial activities like mining and metal recovery drove economic growth and technological advancement. However, large-scale smelting of heavy metals in ancient times, such as during the Roman Empire, resulted in environmental pollution and adverse health effects.

Heavy metals like copper, gold and mercury were also used in ancient medicines, art and agriculture. However, their toxic effects were not well understood until recent times. The Minamata disease outbreak in Japan in the 1950s and the Iraq grain poisoning incident in the 1970s highlighted the dangers of methylmercury. The US Environmental Protection Agency (EPA) first listed 24 hazardous substances, including heavy metals like lead, mercury and cadmium, in 1978. The Agency for Toxic Substances and Disease Registry (ATSDR) has also classified heavy metals as priority pollutants due to their potential harm to humans (Dokmeci, 2020).

Under normal conditions, heavy metal levels in nature are minimal and non-threatening. However, human activities have led to a significant increase in heavy metal levels in the environment, posing a threat to living organisms due to their bioaccumulation, persistence and toxicity (Sharma *et al*., 2016; Ali *et al*., 2021). The introduction of heavy metals into marine systems can result in various chemical, biological and physical processes, affecting the environment and the metals themselves (Guo *et al.,* 2018). Heavy metals can impact plants and animals in aquatic areas, causing changes in population density, diversity and community structure. However, natural factors like temperature and light can influence these responses, making it challenging to assess the impacts of heavy metal pollution (Martinez *et al*., 2018). Heavy metals can also affect cellular components, leading to DNA damage, apoptosis and carcinogenesis (Tchounwou *et al.,* 2012). The effects of heavy metals on human health, plants and animals have been extensively discussed in the literature (Ayangbero *et al*., 2017).

2.3 SOURCES OF HEAVY METALS AROUND OPEN DUMPSITES.

Open dumpsites are significant environmental hazards due to their potential to release various heavy metals into surrounding soil, water and air systems. These heavy metals originate from multiple anthropogenic sources and can persist in the environment, posing long-term risks to ecosystems and human health.

1. **Leachate from Mixed Municipal Waste**

Open dumpsites are a significant source of heavy metal pollution, primarily due to the leachate generated from decomposing municipal waste. As rainwater seeps through the waste, it dissolves and transports heavy metals like lead (Pb), cadmium (Cd), chromium (Cr), nickel (Ni) and zinc (Zn) into the soil and groundwater (Saheed *et al*., 2020). In Ibadan, Nigeria, the leachate from dumpsites has been found to contain high concentrations of heavy metals, exceeding the limits set by the World Health Organization (WHO) and Nigerian Standards for Drinking Water Quality (NSDWQ) (Saheed *et al.,* 2020). This highlights the need for proper waste management practices to mitigate the environmental and health risks associated with heavy metal pollution.

2. **Electronic Waste (E-Waste) and Batteries**

E-waste dumpsites, which receive discarded electronic devices such as mobile phones, computers, televisions and batteries, are significant sources of heavy metal pollution. These wastes contain toxic elements like mercury (Hg), arsenic (As), lead (Pb) and cadmium (Cd). A study at the Onitsha e-waste dumpsite in Nigeria found high levels of aluminum (Al), copper (Cu) and nickel (Ni) in the soil due to unregulated dismantling and open burning of electronic components (Odoh *et al*., 2022).

3. **Automobile Parts and Used Lubricants**

Abandoned car parts and used engine oils at open dumpsites are significant sources of heavy metals, including chromium (Cr), lead (Pb), copper (Cu) and nickel (Ni). These pollutants can enter the environment through leaching or direct spillage and corrosion of vehicle components (Nduka *et al*., 2008). A study at the Ugwuaji dumpsite in Enugu found heavy metals like manganese (Mn), iron (Fe) and arsenic (As) in the environment, which were linked to waste from automobiles (Okori*e et al.,* 2022).

4. **Open Burning of Waste**

Open burning, a common practice in unmanaged dumpsites to reduce waste volume, results in the release of heavy metals into the environment. When plastics, e-waste and rubber materials are burned, toxic metals like lead (Pb), cadmium (Cd) and chromium (Cr) are released into the air and eventually settle in nearby soils and water bodies (Ideriah *et al*., 2006). A study in Port Harcourt found higher concentrations of metals during the dry season, when open burning is more frequent, highlighting the seasonal variability of heavy metal pollution in the area (Ideriah *et al*., 2006).

5. **Industrial and Construction Debris**

Heavy metals like arsenic, lead and zinc can also contaminate the environment through the disposal of industrial waste, such as paint cans, metal scraps and building materials. This is particularly common in urban and peri-urban dumpsites where waste is not properly sorted (Awoyemi *et al.*, 2023). The lack of effective waste management practices in these areas contributes to the presence of these toxic metals.

2.4. EFFECTS OF HEAVY METAL CONTAMINATION ON PLANT PHYSIOLOGY AND NUTRIENT DYNAMICS

Fruits and vegetables are crucial for daily nutrition due to their high content of proteins, carbohydrates, vitamins, minerals and fibers (Baghaie and Fereydoni, 2019). A diet rich in fruits and vegetables offers numerous health benefits, including lower blood pressure, reduced risk of heart disease and stroke, prevention of certain cancers and protection against eye and digestive problems. Given these benefits, the World Health Organization (WHO) recommends consuming at least 400 grams of fruits and vegetables daily, excluding starchy tubers like potatoes (WHO, 2004). Despite their nutritional value, vegetables can absorb significant amounts of toxic metals from the environment (Xiong, 1998; Cobb *et al.,* 2000). These metals accumulate in various plant parts, including roots, stems, fruits, grains and leaves. Heavy metals pose a significant environmental threat due to their toxicity, persistence and non-degradability, particularly in urban areas (Zwolak *et al*., 2019). Elevated metal levels in agricultural soils and plants primarily result from human activities like mining, smelting, waste disposal, vehicle emissions, sewage and the use of agrochemicals. The application of agrochemicals and wastewater for irrigation is a primary source of metal contamination in vegetables (Mahmood and Malik, 2014; Chauhan and Chauhan, 2014). In addition to soil-to-plant transfer, metals can accumulate through aerial deposition on leaf surfaces. Heavy metal accumulation in edible plants poses severe health risks, including cellular damage and carcinogenic effects (Jomova *et al.*, 2011). The presence of toxic metals in food can also reduce essential nutrients, leading to weakened immune function and malnutrition-related disabilities (Liu *et al*., 2005).

2.5. HEALTH IMPACTS OF HEAVY METALS

Heavy metals can enter the human body through ingestion, skin absorption, or inhalation. These toxic metals are a significant concern for human health due to their capacity to damage cellular membranes, alter DNA structure and interfere with protein functions and enzymatic activities. Heavy metals can infiltrate the food chain through plant uptake, contamination during food processing, or trophic transfer (Witkowska *et al.,* 2021). Although these metals occur naturally in trace amounts, they become hazardous to humans and other organisms when present in high concentrations (Shakya and Agarwal, 2020). Unlike energy, which diminishes as it progresses through trophic levels, heavy metals persist and accumulate in ecosystems, emphasizing the need for rigorous monitoring of metal concentrations in soil, particularly around quarry sites, to ensure food safety and minimize health risks, including carcinogenic effects. These metals are present in trace amounts in natural water bodies, yet many are toxic even at low concentrations. At elevated levels, both essential and non-essential heavy metals can disrupt cellular functions, compromise enzyme activity and damage DNA integrity (Wu *et al.,* 2016).

Lead poisoning generally occurs after extended exposure over a long period, typically months or years (ATSDR, 2020). Young children, especially those under six, are the most at risk, as even minimal lead exposure can result in lasting health problems during crucial developmental phases.

In adults, significant exposure can be deadly. The symptoms of lead poisoning vary widely and may include weight loss, high blood pressure, headaches, stomach pain and various cognitive and neurological disorders. Other consequences include kidney damage, fertility problems, gastrointestinal issues, heart disease and gradual failure of multiple organ systems. Accumulation of chromium in the body can cause several adverse health effects, commonly manifesting as allergic responses, digestive problems, reduced male fertility and damage to the nervous, cardiovascular, liver and kidney systems. The presence and extent of chromium poisoning are usually determined through blood and urine tests (Franchini and Mutti, 1988).

Hexavalent chromium [Cr(VI)] compounds—like chromium trioxide (CrO_3), sodium chromate (Na_2CrO_4), potassium chromate (K_2CrO_4) and potassium dichromate ($K_2Cr_2O_7$)—are especially toxic to the skin and are known to cause serious burns. These skin injuries can act as a pathway for chromium to enter the body and cause systemic toxicity (Jumina and Harizal, 2019). Following contact with potassium chromate, skin fibroblasts may undergo mitochondria-driven cell death (apoptosis) (Lee and Goh, 1988). In healthy human fibroblast cultures, Cr(VI) exposure triggers activation of ATM kinase, a protein crucial for managing cellular responses to DNA damage (Ha *et al*., 2004), which leads to DNA breaks during the S phase of the cell cycle.

Animal studies have shown that exposure to chromate compounds can result in skin inflammation, swelling, tissue death and in extreme cases, deep skin damage and scarring (ATSDR, 2012). Ingesting Cr (VI) can rapidly cause digestive issues such as abdominal pain, gastritis, duodenal ulcers and liver conditions like cirrhosis (Katsas *et al.,* 2024). Symptoms from oral exposure typically include nausea, vomiting, diarrhea, stomach pain and fever shortly after ingestion.

Chronic exposure to nickel and its compounds can result in serious health consequences, such as lung fibrosis, kidney and cardiovascular diseases and cancers of the respiratory tract (Zambelli *et al.,* 2016). Another crucial aspect of chronic exposure to heavy metals is their carcinogenic potential. Although the precise mechanisms are not fully understood, it is believed that disruptions in genomic integrity and gene expression play a role. Carcinogenic metals like arsenic, cadmium and chromium can interfere with DNA synthesis and repair processes, contributing to their toxic and carcinogenic effects (Koedrith *et al.*, 2013). The toxicity and potential for carcinogenicity of heavy metals depend on the dosage. Increased levels of arsenic in limestone negatively affect both plants and humans. Exposure to arsenic can lead to damage to vital organs, including the brain, liver and kidneys and is also associated with an increased risk of cancer (Srinivasa *et al.,* 2007; Anake *et al.,* 2018). . Elemental mercury, a widely distributed environmental toxicant, can cause numerous changes in body tissues, leading to adverse health outcomes (Sarlak, 2015). When absorbed through environmental exposure, mercury accumulates in the kidneys, neurological tissues and liver, resulting in effects such as neurotoxicity, nephrotoxicity and gastrointestinal issues (De Miguel *et al.,* 2007)

CHAPTER THREE

MATERIALS AND METHODS

3.1 THE STUDY AREA

The study area Oluku and environs is located in Ovia North East local government area in Edo State. The area lies between Latitude $N06^0$ and Longitude $E005^0$. The area is accessible from Uselu axis of the Benin-Lagos Road. The study area is known for hosting an active compressed natural gas station; active sand mining sites. Many of these sand mines have been turned into open dumpsites by residents due to non-adherence to international best practices by mine developers. These activities are potential sources of heavy metal enrichment in the environment.

3.2 THE GEOLOGY OF THE STUDY AREA

The study area Oluku and environs (latitude 6°25′59″N and longitude 5°35′59″E), lies within the Benin Formation, a major stratigraphic unit of the Southern Sedimentary Basin. The Benin Formation is composed predominantly of reddish to reddish-brown lateritic sands, sandy clays, silts, gravels and ferruginized sandstones (Short and Stauble, 1967; Akujieze and Irabor, 2014).

The surface layer is typically lateritized, underlain by loose sands and sandy clays, often with reticulate mud cracks. Parkinson (1907) first described this lithologic unit as “Benin Sand,” representing deposits of a paleo-coastal environment dating from the Paleocene to Pleistocene. Subsequent studies (Tattam, 1943) referred to the sequence as “Coastal Plain Sands,” extending across parts of Benin, Calabar, Owerri and Onitsha. These sediments constitute the upper continental facies of the Niger Delta, reflecting ancient fluvial and coastal plain depositional systems.

3.3 SOIL SAMPLING

10 soil samples were randomly obtained from ten (10) different locations within Oluku environs of including control samples obtained Iyowa, a community with no record of any active dumpsites. The soil samples were collected as topsoil (0-15cm) using the hand auger. After being carefully labeled and kept in a clean plastic container, the soil samples were transported to the University of Benin, Ecotoxicological Laboratory for additional processing.

3.4 SAMPLE PREPARATION

After being allowed to air dry in the lab, the soil samples were sieved using 2mm screen and placed in clear polyethylene bags with a well line until further analysis.

3.4.1 Digestion

1g of soil samples was broken down by hydrofluoric acid, nitric acid, perchloric acid and sulfuric acid (HF-HNO_3-$HCLO_4$-H_2SO_4) in aqua regia. Next, 50 ml of distilled water was added to the clear digest.

3.4.2 Chemical Analysis

Using an Atomic absorption spectrophotometer AAS the concentration of heavy metals in soil samples were measured.

3.4.3 Contamination factor (CF)

It is the proportion of each metal to the background values of that metal in the current sample.

$$CF_i = \left(\frac{C_{metalof\ sample}}{C_{metal\ of\ background}}\right) \quad (3)$$

Where, $C_{metal\ of\ sample}$ is the observed value of individual metal and $C_{metal\ of\ background}$ is the background value (Sadhu *et al.*, 2012; Likuku *et al.*, 2013)

low ≤1,

moderately 1≤ CF <3,

considerably = 3 ≤CF <6

very high ≥6.

3.4.4 Ecological Risk Factor (ERF) and Potential Ecological Risk Index (PERI)

The first method to quantify different degrees of ecological risk in sediments was put out by Hakanson (1980).

$$ER_i = T_r \times CF_i \quad (7)$$

Where, ER =ecological risk of each metal, T_r, = toxic response factor for each heavy metal.

$$\text{PERI} = \sum_{i=1}^{n=9} ER_i \quad (8)$$

Slightly < 40

mediumly 40-80

strongly 80-160,

very strongly = 160-320

extremely strong≥ 320,

Table 3.1: Grade standards for potential ecological risks

Risk level	Low risk	Moderate risk	High risk	Very high risk	Disastrous risk
Grade	I	II	III	IV	V
E_i^r	<40	40≤ E_i^r 80	80≤ E_i^r 160	160≤ E_i^r 320	E_i^r ≥320
PERI	<95	95≤ RI<190	95≤ RI<380	RI>380	

CHAPTER FOUR

PRESENTATION OF RESULTS

The results of contamination factor (CF), Ecological risk and potential ecological risks (PERI) of heavy metals in soil obtained from the study area is presented in Table2 and Table 3 respectively. The CF values of Fe ranged from 1.11-1.42 with averaged value of 1.23. The value of Zn ranged from 1.01-1.60 with and averaged value of 1.26. CF values of Cu ranged from 0.91-1.47 with an averaged value of 1.22. Pb (1.56-2.28), Cd (1.8-3.66), Mn (2.9-3.41), Ni (1.28-1.51), Cr (1.31-1.56) and Co (1.15-1.35). The results of ecological risk index (E_i^r) of individual metals and the potential ecological risk factor (overall risk index RI) in the soils are presented in Table 6. It was observed that the ecological risk index of each metal decrease in order of Cd>Mn>Pb>Ni>Cu>Cr>Co>Zn>Fe. The E_i^r of Cd varies from (38-110) with mean value of 74.4. Mn varies from (28.04-34.19) mean value of 30.58, Pb, (7.82-11.43) with mean of 9.77, Ni ranged from (6.42-7.59) with mean values of 6.81, Cu (4.55-7.35) with mean of 5.68. Cr (2.62-3.12) mean of 2.85, Co (1.15-1.365) with mean of 1.29, Zn (1.02-1.60) with mean of 1.26 and Fe (1.18-1.42) with a mean of 1.23.

Table 4.1: Results of contamination factor of heavy metals in soil samples analyzed in the area of study.

Heavymetals	L1	L2	L3	L4	L5	L6	L7	L8	L9	L10	Mean
Fe	1.338645	1.180923	1.179517	1.118819	1.401453	1.429107	1.121865	1.180455	1.173424	1.269745	1.239395
Zn	1.282663	1.017884	1.600596	1.387978	1.425733	1.098857	1.147541	1.322901	1.132638	1.206657	1.262345
Cu	5.292135	4.55618	6.264045	5.485955	6.539326	7.353933	6.233146	6.033708	6.511236	7.132022	1.228034
Pb	11.31783	10.50388	7.829457	8.75969	9.186047	10.5814	11.43411	10.03876	8.837209	9.302326	1.955814
Cd	109	83	64	65	75	53	38	54	110	93	2.48
Mn	30.71429	33.66667	31.57143	31.57143	31.04762	27.80952	29	34.19048	28.2381	28.04762	3.058571
Ni	7.198068	7.592593	7.093398	6.89211	6.650564	6.425121	6.457327	6.795491	6.449275	6.626409	1.363607
Cr	2.773684	3.036842	2.626316	2.910526	2.652632	2.847368	2.668421	2.821053	3.115789	3.121053	1.428684
Co	1.150538	1.311828	1.215054	1.295699	1.365591	1.365591	1.317204	1.33871	1.27957	1.333333	1.297312

Table 4.2: Ecological risk index and potential ecological risk index of heavy metals in soils.

Heavy metals	**L1**	**L2**	**L3**	**L4**	**L5**	**L6**	**L7**	**L8**	**L9**	**L10**	**Mean** (E_i^r)
Fe	1.338645	1.180923	1.179517	1.118819	1.401453	1.429107	1.121865	1.180455	1.173424	1.269745	1.239395
Zn	1.282663	1.017884	1.600596	1.387978	1.425733	1.098857	1.147541	1.322901	1.132638	1.206657	1.262345
Cu	5.292135	4.55618	6.264045	5.485955	6.539326	7.353933	6.233146	6.033708	6.511236	7.132022	5.684551
Pb	11.31783	10.50388	7.829457	8.75969	9.186047	10.5814	11.43411	10.03876	8.837209	9.302326	9.77907
Cd	109	83	64	65	75	53	38	54	110	93	74.4
Mn	30.71429	33.66667	31.57143	31.57143	31.04762	27.80952	29	34.19048	28.2381	28.04762	30.58571
Ni	7.198068	7.592593	7.093398	6.89211	6.650564	6.425121	6.457327	6.795491	6.449275	6.626409	6.818035
Cr	2.773684	3.036842	2.626316	2.910526	2.652632	2.847368	2.668421	2.821053	3.115789	3.121053	2.857368
Co	1.150538	1.311828	1.215054	1.295699	1.365591	1.365591	1.317204	1.33871	1.27957	1.333333	1.297312
										Risk Index (RI)	**133.9238**

CHAPTER FIVE

DISCUSSION OF RESULTS

5.1 CONTAMINATION FACTOR (CF)

The result of contamination factor of the metals analyzed across sampling sites is shown in Table …..The contamination factor of heavy metals revealed that Fe ranged from 1.11-1.42, Zn (1.01-1.60), Cu (0.91-1.47), Pb (1.56-2.28), Cd (1.8-3.66), Mn (2.9-3.41), Ni (1.28-1.51), Cr (1.31-1.56) and Co (1.15-1.35). The contamination factor was used to determine the extent of contamination of heavy metals in soils using the control values. The mean CF values of heavy metals in the soils within the study area with the exception of Mn (CF > 3.05) pose moderate contamination. While Mn indicates considerable contamination. This suggests that industrial activities and indiscriminate dumping of refuse are contributing to the presence of these metals especially Cd and Mn to the soils which is a major sink of contaminants. This findings is consistent with (Smart *et al.,* 2023) who reported moderate and considerable contamination in their research shows that cadmium (Cd) recorded the highest CF values in Locations 1(3.63) and 9(3.66) with an overall mean value of 2.48. Mn recorded its highest value in Location 4 (3.41) and has an overall average value of (3.05). The mean CF values of other aforementioned metals were below 2.This implies that all soil bound Cd and Mn in the sampling locations show considerable contamination soils in the area of research ($1 \leq CF < 3$)

5.2 ECOLOGICAL RISKS

The results of ecological risk index (E_i^r) of individual metals and the potential ecological risk factor (overall risk index RI) in the soils are presented in Table 6. It was observed that the ecological risk index of each metal decrease in order of Cd>Mn>Pb>Ni>Cu>Cr>Co>Zn>Fe. The E_i^r of Cd varies from (38-110) with mean value of 74.4. Mn varies from (28.04-34.19) mean value of 30.58, Pb, (7.82-11.43) with mean of 9.77, Ni ranged from (6.42-7.59) with mean values of 6.81, Cu (4.55-7.35) with mean of 5.68. Cr (2.62-3.12) mean of 2.85, Co (1.15-1.365) with mean of 1.29, Zn (1.02-1.60) with mean of 1.26 and Fe (1.18-1.42) with a mean of 1.23. Among the metals analyzed Cadmium (Cd) recorded the highest ecological risk index with mean value of 74.4 ($40 \leq E_i^r$ 80) posing moderate risk to the environment, this was succeeded by Manganese (Mn) with mean value of 30.58 (E_i^r <40) posing low ecological risk to the environment. The (E_i^r) values of Lead (Pb), Nickel (Ni), Copper (Cu), Chromium (Cr), Cobalt (Co), zinc (Zn) and iron (Fe) indicates that they possess low ecological risk to the environment. This aligns with the findings of (Smart *et al.,* 2023; Tesleem *et al.,* 2023; Soltani-Gerdefaramarzi *et al.,* 2021) who reported similar higher (E_i^r) values for Cd. The International Agency for Research on Cancer (IARC) classified Cd as carcinogenic among other health risk associated with its dietary intake that are related to neurons, skeleton and kidneys including cardiovascular disorders (Renleri *et al.,* 2022). Sources of cadmium includes industrial wastes, vehicular emissions, burning of coal, incineration of wastes and disposal of Ni-Cd batteries have very great influence in the ecological assessment of study. The overall or cumulative risk index (RI) was 133.92, this implies that the soils around the sampling area and the environment are at moderate risk of pollution of toxic metals which might increase the vulnerability of humans to diseases.

CONCLUSION

The present study investigated the concentration and the level of contamination within an open dumpsite in Oluku. A preliminary assessment of the ecological risk posed to the environment was carried out. The results of contamination factor indicates that Mn had the highest value posing considerable contamination. The sampling locations showed that Cd and Mn demonstrated considerable and moderate ecological risk. It is suggested that municipal wastes sites should be sited far away from residential areas and should be located in geologic settings with non-permeable materials to prevent leaching of effluents into groundwater sources.

REFERENCES

Aboyeji, O. S. and Eigbokhan, S. F. (2016). Evaluations of groundwater contamination by leachates around olusosun open dumpsite in Lagos metropolis, southwest Nigeria. *Journal of Environmental Management* **183**: 333–341.

Adelekan, B. A. and Alawode, A. O. (2001). Contribution of municipal refuse dumps to heavy metal concentration in soil profile and groundwater in Ibadan, Nigeria. *Journal of Applied Biosciences* **40**: 2727–2737.

Adhikari, B. K., Barrington, S. and Martinez, J. (2006). Predicted growth of world urban food waste and methane production. *Waste Management Research* **24**(5): 21–33.

Afrane, Y. A., Klinkenberg, E., Drechsel, P., Owusu-Daaku, K., Garms, R. and Kruppa, T. (2004). Does irrigated urban agriculture influence the transmission of malaria in the city of Kumasi Ghana? *Acta Tropica* **89**(2): 125–134.

Alam, P. and Ahmade, K. (2013). Impact of solid waste on health and the environment. *International Journal of Sustainable Development and Green Economics* **2**(1): 1.

Ali, M. M., Hossain, D., Al-Imran, Khan, M. S., Begum, M. and Osman, M. H. (2021). Environmental pollution with heavy metals: A public health concern. In *Heavy metals: Their environmental impacts and mitigation*.

Amoah, P., Drechsel, P., Henseler, M. and Abaidoo, R. C. (2007). Irrigated urban vegetable production in Ghana: Microbiological contamination in farms and markets and associated consumer risk groups. *Journal of Water and Health* **5**(3): 455–466.

Amuno, S. A. (2013). Potential ecological risk of heavy metal distribution in cemetary soils. *Water, Air and Soil Pollution* **224**(2): 1–12.

Anake, W. U., Oyeyemi, K. D. and Ana, G. R. E. E. (2018). Fine particulate matter–based air quality index: A case study. *International Journal of Mechanical Engineering and Technology* **9**(8): 1321–1328.

Anand, P. B. (1999). Waste management in Madras revisited. *Environment and Urbanization*, **11**(2): 161–176.

APHA. (1998). Standard methods for the examination of water and wastewater (17^{th} ed.). American Public Health Association.

ASTM D3987. (2006). Standard test method for shake extraction of solid waste with water. Annual Book of American Society for Testing and Materials Standards.

ATSDR. (2012). Toxicological profile for cadmium. Agency for Toxic Substances and Disease Registry.

ATSDR. (2020). Toxicological profile for lead. Agency for Toxic Substances and Disease Registry.

Awoyemi, O. M., Olofintoye, L. K. and Akintunde, I. M. (2023). Assessment of heavy metal concentrations in groundwater around selected dumpsites in Ado-Ekiti, Nigeria. *Dujopas*, **9**(2): 151–162.

Ayangbenro, A. S. and Babalola, O. O. (2017). A new strategy for heavy metal polluted environments: A review of microbial biosorbents. *International Journal of Environmental Research and Public Health* **14**(1): 94.

Baghaie, A. H. and Fereydoni, M. (2019). The potential risk of heavy metals on human health due to the daily consumption of vegetables. *Environmental Health Engineering and Management Journal* **6**(1): 11–16.

Banar, M., Ozkan, A. and Altan, M. (2009). Modelling of heavy metal pollution in an unregulated solid waste dumping site with GIS research. *Journal of Environmental and Earth Sciences* **1**(2): 99–110.

Banar, M., Ozkan, A. and Vardar, C. I. (2007). Characterization of an urban landfill soil by using physicochemical analysis and solid phase microextraction (SPME)—GC/MS. *Environmental Monitoring and Assessment* **127**: 337–351.

Berkun, M. (1991). Solid waste characteristic and removal planning in the Eastern Black Sea Region research projects no. 91112001. Karadeniz Technical University.

Bobeck, M. (2010). Organic household waste in developing countries. Mid Sweden University.

Central Pollution Control Board (CPCB). (2004). Management of municipal solid waste. Ministry of Environment and Forests.

Chauhan, G. and Chauhan, U.K. (2014). Human health risk assessment of heavy metals via dietary intake of vegetables grown in wastewater-irrigated areas of Rewa, India. *International Journal of Scientific and Research Publications* **4**(9): 1-9.

Cobb, G. P., Sands, K., Waters, M., Wixson, B. G. and Dorward-King, E. (2000). Accumulation of heavy metals by vegetables grown in mine wastes. *Environmental Toxicology and Chemistry* **19**(3): 600-607.

Daskalopoulos, E., Badr, O. and Probert, S. D. (1998). Municipal solid waste: A prediction methodology for the generation rate and composition in the European Union countries and the United States of America. Resources, *Conservation and Recycling* **24**: 155–166.

De Miguel, E., Iribarren, I., Chacon, E., Ordonez, A. and Charlesworth, S. (2007). Risk-based evaluation of the exposure of children to trace elements in playgrounds in Madrid (Spain). *Chemosphere* **66**: 505–513.

De, S. and Debnath, B. (2016). Prevalence of health hazards associated with solid waste disposal- A case study of Kolkata, India. *Procedia Environmental Sciences* **35**: 201–208.

Dean, J. R., Elom, N. I. and Entwistle, J. A. (2017). Use of simulated epithelial lung fluid in assessing the human health risk of Pb in urban street dust. *Science of the Total Environment* **579**: 387–395.

Dinev, N., Banov, M. and Nikova, I. (2008). Monitoring and risk assessment of contaminated soils. *General and Applied Plant Physiology* **34**(3–4): 389–396.

Dökmeci, A. H. (2020). Environmental impacts of heavy metals and their bioremediation. In *Heavy metals-Their environmental impacts and mitigation*.

Ejaz, N., Akhtar, N., Nisar, H. and Naeem, U. (2010). Environmental and health impact of solid waste disposal in developing cities: A case study of Rawalpindi City. *WIT Transactions on Ecology and the Environment* **142**: 379–387.

El-Fadel, M., Findikakis, A. N. and Leckie, J. O. (1997). Environmental impacts of solid waste land filling. *Journal of Environmental Management* **50**: 1–25.

Erses, A. S. and Onay, T. T. (2003). In situ heavy metal attenuation in landfills under methanogenic conditions. *Journal of Hazardous Materials* **99**: 159–175.

Everett, M. (1992). The sacred and the profane. *Earthwatch* **3**: 11–13.

Fanchini, I. and Mutti, A. (1988). Selected toxicological aspects of chromium (VI) compounds. *Science of the Total Environment* **71**(3): 379–387.

Fobil, J. N., Armah, N. A. and Hogarh, J. N. (2008). The influence of institutions and organizations on urban waste collection systems: An analysis of waste collection system in Accra Ghana (1985–2000). *Journal of Environmental Management* **86**(1): 262–271.

Ghasemidehkordi, B., Malekirad, A. A., Nazem, H., Fazilati, M., Salavati, H., Shariatifar, N., Rezaei, M., Fakhri, Y. and Mousavi Khaneghah, A. (2018). Concentration of lead and mercury in collected vegetables and herbs from Markazi province, Iran: A non-carcinogenic risk assessment. *Food and Chemical Toxicology* **113**: 204–210.

Ghrefat, H. A., Yusuf, N., Jamarh, A. and Nazzal, J. (2012). Fractionation and risk assessment of heavy metals in soil samples collected along Zerqa river, Jordan. *Environmental Earth Sciences* **66**(1): 199–208.

Guo, Q., Li, N., Bing, Y., Chen, S., Zhang, Z., Chang, S. and Chen, Y. (2018). Denitrifier communities impacted by heavy metal contamination in freshwater sediment. *Environmental Pollution* **242**: 426–432.

Ha, L., Ceryak, S. and Patierno, S. R. (2004). Generation of S phase-dependent DNA double-strand breaks by Cr (VI) exposure: Involvement of ATM in Cr (VI) induction of gamma-H2AX. *Carcinogenesis* **25**(11): 2265–2274.

Hong, K. J., Tokunaga, S. and Kajiuchi, T. (2002). Evaluation of remediation process with plant-derived biosurfactant for recovery of heavy metals from contaminated soils. *Chemosphere* **49**: 379–387.

Huang, J., Yuan, F., Zeng, G., Li, X., Gu, Y., Shi, L. and Liu, W. (2017). Influence of pH on heavy metal speciation and removal from wastewater using micellar-enhanced ultrafiltration. *Chemosphere* **173**: 199–206.

IARC. (2012). IARC monographs on the identification of carcinogenic hazards to humans: Volumes 1–125.

Ideriah, T. J. K., Briggs, A. O. and Stanley, H. O. (2006). Seasonal variation of heavy metals in soils around the municipal dumpsite in Port Harcourt, Nigeria. *Global Journal of Environmental Sciences* **5**(2): 97–100.

Iwegbue, C. M. A., Egbozue, F. E. and Opuene, K. (2006). Preliminary assessment of heavy metal levels of soils of an oilfield in the Niger Delta, Nigeria. *International Journal of Environmental Science and Technology* **3**(2): 167–172.

Iwegbue, C. M. A., Nwajei, G. E., Ogala, J. E. and Overah, C. L. (2010). Determination of trace metal concentrations in soil profiles of municipal waste dumps in Nigeria. *Environmental Geochemistry and Health* **32**: 415–430.

Jomova, K., Jenisova, Z., Feszterova, M., Baros, S., Liska, J. and Valko, M. (2011). Arsenic: Toxicity, oxidative stress and human disease. *Journal of Applied Toxicology* **31**: 95-107.

Jomova, K., Raptova, R., Alomar, S. Y., Alwasel, S. H., Nepovimova, E., Kuca, K. and Valko, M. (2023). Reactive oxygen species, toxicity, oxidative stress and antioxidants: Chronic diseases and aging. *Archives of Toxicology* **97**: 2499–2574.

Jumina, I. and Harizal, H. (2019). Dermatologic toxicities and biological activities of chromium, chromium toxicity. In Murillo-Tovar, M. A. (Ed.), *Trace metals in the environment: New approaches and recent advances.* IntechOpen. Pp. 90-94.

Kabata-Pendias, A. and Pendias, H. (2000). Trace elements in soils and plants. CRC Press. Pp. 67-70.

Kafando, P., Segda, B., Nzihou, J. and Koulidiati, J. (2013). Environmental impacts of waste management deficiencies and health issues: A case study in the city of Kaya, Burkina Faso. *Journal of Environmental Protection* **4**: 1080–1087.

Katsas, K., Diamantis, D. V., Linos, A. and Psaltopoulou, T. (2024). The impact of exposure to hexavalent chromium on the incidence and mortality of oral and gastrointestinal cancers and benign diseases: A systematic review of observational studies. *Reviews on Environmental Health* **11**(1): 21-24

Knoll, K. H. (1983). Hygienic problems in dumping composting and incineration of urban refuse. *Zentralblatt für Bakteriologie, Mikrobiologie und Hygiene* **178**(1–2): 166–173.

Kocasoy, G. (2002). Solid waste management in Turkey. *Waste Management* **21**:12-14.

Koedrith, P., Kim, H., Weon, J. I. and Seo, Y. R. (2013). Toxicogenomic approaches for understanding molecular mechanisms of heavy metal mutagenicity and carcinogenicity. *International Journal of Hygiene and Environmental Health* **216**(5): 587-598.

Krajewski, J. A., Szarapińska-Kwaszewska, J., Dudkiewicz, B., Cyprowski, M., Tarkowski, S., Kończalik, J. and Stroszejn-Mrowca, G. (2001). Assessment of exposure to bioaerosols in workplace ambient air during municipal waste collection and disposal. *Medycyna Pracy* **52**(6): 417–422.

Krčmar, D., Tenodi, S., Grba, N., Kerkez, D., Watson, M., Rončević, S. and Dalmacija, B. (2018). *Science and Total Environment* **615**: 1341–1354.

Lee, H. S. and Goh, C. L. (1988). Occupational dermatosis among chrome platers. *Contact Dermatitis* **18**(2): 89–93.

Li, F., Huang, J., Zeng, G., Yuan, X., Li, X., Liang, J. and Wang, X. (2013). Spatial risk assessment and sources identification of heavy metals in surface sediments from Dongting Lake, Middle China. *Journal of Geochemical Exploration* **132**: 75–83.

Likuku, A.S., Khumoetsile, B., Mmolawa, B. and Gilbert, K.G. (2013). Assessment of heavy metal enrichment and degree of contamination around the copper-nickel mine in the selebi phikwe region, Eastern Botswana, *Environmental ecological Research* **1**(2): 32-40

Liu, H., Probst, A. and Liao, B. (2005). Metal contamination of soils and crops affected by the Chenzhou lead/zinc mine spill (Hunan, China). *Science of the Total Environment* **339**: 153–166.

Mahmood, A. and Malik, R.N. (2014). Human health risk assessment of heavy metals via consumption of contaminated vegetables collected from different irrigation sources in Lahore, Pakistan. *Arabian Journal of Chemistry* **7**: 91–99.

Mandal, A. and Sengupta, D. (2006). An assessment of soil contamination due to heavy metals around a coal-fired thermal power plant in India. *Environmental Geology* **51**: 409–420.

Martínez-Cortijo, J. and Ruiz-Canales, A. (2018). Effect of heavy metals on rice irrigated fields with waste water in high pH Mediterranean soils: The particular case of the Valencia area in Spain. *Agricultural Water Management* **210**: 108–123.

Mee, D. L. and Topping, G. (1998). Black Sea pollution assessment. In GEF Black Sea environmental programme. *Black Sea Environmental Series* **10**: 12-21.

Miri, M., Akbari, E., Amrane, A., Jafari, S. J., Eslami, H., Hoseinzadeh, E. and Zarrabi, M. (2017). Health risk assessment of heavy metal intake due to fish consumption in the Sistan region, Iran. *Environmental Monitoring and Assessment* **189**(11): 43-45.

Mnolawa, K. B., Likuku, A. S. and Gaboutloeloe, G. K. (2011). Assessment of heavy metals pollution in soils along major roadside areas of Botswana. *African Journal of Environmental Science and Technology* **5**(3): 186–196.

Moody, C. M. and Townsend, T. G. (2017). A comparison of landfill leachates based on waste composition. *Waste Management* **63**: 267–274.

Musmeci, L. and Gucci, P. M. (1997). Health and hygiene aspects of the production of high-quality compost. *Annali dell'Istituto Superiore di Sanità* **33**(4): 595–603.

Nduka, J. K., Orisakwe, O. E. and Ezenweke, L. O. (2008). Heavy metal contamination of soils and crops at municipal waste dumpsites in Nigeria. Bulletin of Environmental *Contamination and Toxicology* **81**(1): 70–74

Obiajunwa, E. I., Pelemo, D. A., Owalabi, S. A., Fasai, M. K. and Johnson-Fatokun, F. O. (2002). Characterisation of heavy metal pollutants of soils and sediments around a crude oil production terminal using EDXRF. Nuclear Instruments and Methods in Physics Research Section B: *Beam Interactions with Materials and Atoms* **194**: 61–64.

Odoh, R., Nnaji, A. O. and Okonkwo, I. C. (2022). Heavy metal concentrations around an e-waste dumpsite in Onitsha, southeastern Nigeria. *Environmental Research Journal* **16**(4): 45–57.

Okorie, I. A., Nnaji, C. C. and Ezeh, H. N. (2022). Risk assessment of heavy metal contamination in groundwater around Ugwuaji open dumpsite, Enugu, Nigeria. *Applied Water Science* **12**(3): 1–12.

Onakpa, M.M., Njan, A.A. and Kalu, O.C. (2018). A review of heavy metal contamination of food crops in Nigeria. *Annals of Global Health* **84**(3): 488–494.

Oyelami, A. C., Aladejana, J. A. and Agbede, O. O. (2013). Assessment of the impact of open waste dumpsites on groundwater quality: A case study of the Onibu-Eja dumpsite, southwestern Nigeria. *Procedia Earth and Planetary Science* **7**: 648–651.

Qu, C., Sun, K., Wang, S., Huang, L. and Bi, J. (2012). Monte Carlo simulation-based health risk assessment of heavy metal soil pollution: A case study in the Qixia mining area, China. Human and Ecological Risk Assessment: *An International Journal* **18**(4): 733–750.

Rizo, O. D., Merlo, M. H., Castillo, F. E. and Lopez, J. A. O. (2012). Assessment of metal pollution in soils from a former Havana (Cuba) solid waste open dump. *Bulletin of Environmental Contamination and Toxicology* **88**: 182–186.

Rushton, L. (2003). Health hazards and waste management. *British Medical Bulletin* **68**: 183–197.

Saeedi, M., Li, L. Y. and Salmanzadeh, M. (2012). Heavy metals and polycyclic aromatic hydrocarbons: Pollution and ecological risk assessment in street dust of Tehran. *Journal of Hazardous Materials* **227**(228): 9–17.

Saheed, A. M., Olaniyan, A. M. and Ogunbanjo, O. I. (2020). Assessment of heavy metals in soil and groundwater near municipal dumpsites in Ibadan, Nigeria. *Nigerian Journal of Technology* **39**(1): 101–110.

Samadder, S. R., Prabhakar, R., Khan, D., Kishan, D. and Chauhan, M. S. (2017). Analysis of the contaminants released from municipal solid waste landfill site: A case study. *Science of the Total Environment* **580**: 593–601.

Samuding, K. (2009). Distribution of heavy metals profile in groundwater system at solid waste disposal site. *European Journal of Scientific Research* **37**: 58–66.

Sankoh, F., Yan, X. and Tran, Q. (2013). Environmental and health impact of solid waste disposal in developing cities: A case study of Granville Brook dumpsite, Freetown, Sierra Leone. *Journal of Environmental Protection* **4**: 665–670.

Sarlak, M. R. (2015). Characterization of the particle size fraction associated heavy metals in arable soils from Ahwaz size, Iran. *International Journal of Current Microbiology and Applied Science* **4**(7): 65–75.

Shakya, A. and Agarwal, T. (2020). Potential of biochar for the remediation of heavy metal contaminated soil. *Biochar applications in agriculture and environment management*, pp.77-98.

Sharma, A., Kaur, M., Katnoria, J. K. and Nagpal, A. K. (2016). Heavy metal pollution: A global pollutant of rising concern. In: *Toxicity and Waste Management Using Bioremediation*. IGI Global. pp. 1–26.

Sharma, S. and Shah, K. W. (2005). Generation and disposal of solid waste in Hoshangabad. In *Book of Proceedings of the 2nd International Congress of Chemistry and Environment* pp. 749–751.

Shekdar, A. V., Krishnawamy, K. N., Tikekar, V. G. and Bhide, A. D. (1992). Indian urban solid waste management systems—jaded systems in need of resource augmentation. *Journal of Waste Management* **12**(4): 379–387.

Smart, M. O., Asabia, L. O., Roberts, A. E., Okumodi, B. O. and Ibironke, O. H. (2023). Heavy metal contamination and associated ecological risk on farms around Oluyole Industrial Area, Ibadan. *Journal of Research in Forestry, Wildlife and Environment* **15**(2): 121-128

Soltani-Gerdefaramarzi, S., Ghasemi, M. and Ghanbarian, B. (2021). Geogenic and anthropogenic sources identification and ecological risk assessment of heavy metals in the urban soil of Yazd, Central Iran. *Plos One* **16**(11): 1-14.

Srinivasa, S., Gowd and Govil, P.K. (2007). Distribution of heavy metals in surface water of Ranipet industrial area in Tamil Nadu, India. *Environmental Monitoring and Assessment* **136**: 197-207.

Srivastava, V., Ismail, S., Singh, P. and Singh, R. (2015). Urban solid waste management in the developing world with emphasis on India: Challenges and opportunities. *Reviews in Environmental Science and Bio/Technology* **14**(2): 317–337.

Tchounwou, P. B., Yedjou, C. G., Patlolla, A. K. and Sutton, D. J. (2012). Heavy metal toxicity and the environment. *Molecular, Clinical and Environmental Toxicology:* **3**: 133-164.

USEPA. (2004). Risk assessment guidance for superfund, Volume I: Human Health Evaluation Manual (Part A).

USEPA. (2009). National Primary/Secondary and Drinking Water Regulations.

Vardhan, K. H., Kumar, P. S. and Panda, R. C. (2019). A review on heavy metal pollution, toxicity and remedial measures: Current trends and future perspectives. *Journal of Molecular Liquids* **290**: 111197.

Waheed, S., Siddique, N., Hamid, Q. and Chaudhry, M. M. (2010). Assessing soil pollution from a municipal waste dump in Islamabad, Pakistan: A study by INAA and AAS. *Journal of Radioanalytical and Nuclear Chemistry* **285**: 723–732.

WHO. (2000). Air Quality Guidelines for Europe (European Series No 91). World Health Organization Regional Office for Europe.

Witkowska, D., Slowik, J. and Chilicka, K. (2021). Heavy metals and human health: Possible exposure pathways and the competition for protein binding sites. *Molecules* **26**(19): 6060.

World Health Organization (WHO). (2004). *Fruit and Vegetables for Health*- Report of a Joint FAO/WHO Workshop, 1–3 September 2004.

Wu, X., Cobbina, S. J., Mao, G., Xu, H., Zhang, Z. and Yang, L. (2016). A review of toxicity and mechanisms of individual and mixtures of heavy metals in the environment. *Environmental Science and Pollution Research* **23**: 8244-8259.

Xiong, Z. T. (1998). Lead uptake and effects on seed germination and plant growth in a Pb hyperaccumulator Brassica pekinensis Rupr. *Bulletin of Environmental Contamination and Toxicology* **60**: 285-291.

Yarlagadda, P. S., Matsumoto, M. R., VanBenschoten, J. E. and Kathuria, A. (1995). Characteristics of heavy metals in contaminated soils. *Journal of Environmental Engineering* **121**(4): 276–286.

Zambelli, B., Uversky, V.N. and Ciurli, S. (2016). Nickel impact on human health: An intrinsic disorder perspective. *Biochimica et Biophysica Acta (BBA)-Proteins and Proteomics* **1864**(12): 1714-1731.

Zanobetti, A., Schwartz, J. and Gold, D. (2000). Are there sensitive subgroups for the effects of airborne particles? *Environmental Health Perspectives* **108**: 841–845.

Zhao, Z., Shi, H., Liu, C., Kang, X., Chen, L., Liang, X. and Jin, L. (2018). Duckweed diversity decreases heavy metal toxicity by altering the metabolic function of associated microbial communities. *Chemosphere* **203**: 76–82.

Zwolak, A., Sarzyńska, M., Szpyrka, E. and Stawarczyk, K. (2019). Sources of soil pollution by heavy metals and their accumulation in vegetables: A review. *Water Air Soil Pollution* **230**: 164.