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Addressing Heavy Metal Pollution in Nigeria: Evaluating Policies, Assessing Impacts, and Enhancing Remediation Strategies

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ABSTRACT: Heavy metal pollution is a significant environmental concern in Nigeria, posing risks to ecological integrity and public health. This study aims to evaluate the existing policies and regulations addressing heavy metal pollution, assess their effectiveness, and propose recommendations for improvement. The analysis reveals that while Nigeria has established a robust legislative framework, challenges in implementation, enforcement, and funding persist. The impact of reducing heavy metal pollution is influenced by resource constraints, limited capacity, and the need for stronger collaboration between regulatory bodies and industries. Community involvement and education play a crucial role in managing heavy metal pollution, emphasizing the importance of awareness, sustainable practices, and local engagement. Remediation strategies, such as bioremediation and phytoremediation, offer potential solutions. However, gaps in knowledge and research exist, calling for long-term monitoring, ecological impact assessments, and comprehensive health risk assessments. To enhance the effectiveness of current policies, periodic reviews, increased funding, and community-based monitoring programs are recommended. By addressing these gaps and implementing the proposed recommendations, Nigeria can make significant strides towards mitigating heavy metal pollution and achieving environmental sustainability.

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Heavy metals, a class of elements inherently dense and toxic, have become ubiquitous contaminants of grave concern within the global environmental landscape (Omonona *et al.*, 2020). These elements, despite being naturally occurring, are often mobilized and concentrated by human activities such as industrial manufacturing, mining operations, and agricultural practices (Yap and Al-Mutairi, 2021). Consequently, heavy metal pollution poses a significant threat to ecological integrity and public health, with metals such as arsenic, cadmium, chromium, lead, and mercury being particularly notorious for their toxicity and propensity for bioaccumulation (Javanshir, 2012; Sarah and Raj, 2023). The global burden of heavy metal contamination is a reflection of the complex interplay between economic development and environmental stewardship. As nations strive for industrial growth, the inadvertent release of heavy metals into the environment has escalated, affecting water bodies, soils, and air quality (Proshad *et al.*,

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2018; Hu *et al.*, 2019; Weissmannová *et al.*, 2019). This escalating pollution has been associated with severe health outcomes, including neurological damage, renal dysfunction, and various forms of cancer (Kurucz *et al.*, 2018; Ali *et al.*, 2022). The environmental repercussions are equally dire, with heavy metals causing disruptions in aquatic ecosystems, soil degradation, and loss of biodiversity (Hu *et al.*, 2019; Mantur *et al.*, 2022; Sarah and Raj, 2023). In this context, Nigeria, Africa's most populous nation and one of its largest economies, presents a poignant case study in the struggle against heavy metal pollution (Wogu and Okaka, 2011; Lala *et al.*, 2022; Obasi *et al.*, 2023; Ushie *et al.*, 2023; Usman, 2023). The country's substantial oil reserves and mineral wealth have fueled economic growth but have also led to significant environmental challenges (Anyanwu *et al.*, 2018). The oil industry, in particular, has been a source of environmental concern, with oil spills and gas flaring contributing to the heavy metal load in the Niger Delta region (Ordinioha and Brisibe, 2013; Idowu, 2022). Additionally, artisanal gold mining in the northern part of the country has resulted in devastating lead poisoning incidents, underscoring the urgent need for effective management and remediation strategies (Olujimi *et al.*, 2015; Johnbull *et al.*, 2018). Given the gravity of the situation, this review aims to dissect the multifaceted issue of heavy metal contamination in Nigeria, providing an in-depth analysis of its sources, distribution, and environmental and health impacts. The objectives of this review are to evaluate the existing legislative framework governing environmental protection in Nigeria, assess the effectiveness of current remediation efforts, and propose recommendations for enhancing Nigeria's capacity to manage heavy metal pollution. By situating Nigeria's experience within the global context, this manuscript seeks to contribute to a more profound understanding of the scope of the problem and the collaborative efforts required to combat it. In the subsequent sections, we will delve into the specifics of Nigeria's heavy metal contamination, examining the regional variations in sources and impacts, the current state of knowledge on the health implications for affected populations, and the effectiveness of national and local policies in mitigating this environmental challenge. The review will culminate in a set of recommendations aimed at safeguarding the health of Nigeria's citizens and the integrity of its environment for future generations.

MATERIALS AND METHODS

This study utilizes a comprehensive literature review approach to evaluate the existing policies and regulations addressing heavy metal pollution in Nigeria. Relevant academic articles, government reports, and policy documents are reviewed to gather information on the legislative framework, its implementation, enforcement, and effectiveness. The analysis focuses on identifying gaps, challenges, and areas for improvement. Additionally, case studies and research on remediation strategies, community involvement, and education are examined to provide insights and recommendations. The findings from the literature review are synthesized to develop a comprehensive understanding of the current state of heavy metal pollution in Nigeria and propose actionable recommendations for addressing the issue.

Sources of Heavy Metal Contamination

Overview of natural and anthropogenic sources: Naturally occurring heavy metals in the environment arise from a complex interplay of geological processes and parent rock weathering. Lithogenesis, the formation of sedimentary rocks from pre-existing materials, plays a key role in releasing these elements through weathering processes (Lyu *et al.*, 2019; Okonkwo and Okunlola, 2022; Zhou *et al.*, 2022). This contributes to the background concentration of heavy metals in groundwater and soil, with elements like radium, arsenic, and others originating directly from geological parent materials (Kouamé *et al.*, 2013; Prathima *et al.*, 2021; Saha *et al.*, 2022). Beyond lithogenesis, natural sources like volcanic eruptions, metal corrosion, atmospheric deposition, geochemical reactions, soil erosion, and sediment resuspension can further contribute to heavy metal distribution and abundance (Lu and Yuan, 2016; Guan *et al.*, 2018; Yao *et al.*, 2022). The presence of heavy metals in the environment is significantly influenced by anthropogenic activities, leading to contamination across various environmental components. Major sources of heavy metal contamination include industrial processes, mining, vehicle emissions, agricultural practices, wastewater discharge, and urban runoff (Stepanova *et al.*, 2021; Shimod *et al.*, 2022). These activities result in the release of heavy metals into the environment, leading to contamination of soil, sediments, water, and biota (Younis *et al.*, 2018; Imlani *et al.*, 2022). In addition, the deposition of metal mine tailings, improper disposal of high metal waste in landfills, use of leaded gasoline and lead-based paints, application of fertilizers, animal manure, and biosolids to land, the presence of coal combustion residues, petrochemicals, and atmospheric deposition contribute to the presence of heavy metals in contaminated soils (Sardar *et al.*, 2013; Younis *et al.*, 2018; Liu *et al.*, 2019; Chernykh *et al.*, 2021; Perumal *et al.*, 2021; Shaginimol *et al.*, 2022). Furthermore, industrial effluents, fuel production, mining and smelting operations, military activities, the use of agricultural chemicals, small-scale industries, brick kilns, and coal combustion are identified as sources of anthropogenic heavy metal contamination (Ameh *et al.*, 2020; Ameh and Ogbodo, 2020; Bryninger, 2020).

Industrial contributions: oil spills, gas flaring, and manufacturing: Industrial activities play a major role in heavy metal contamination in Nigeria, particularly through the oil and gas sector. Oil spills, a frequent occurrence, release metals like lead, mercury, and cadmium into the environment (Nagajyoti *et al.*, 2010; Egbon and Mgbame, 2020; Nuhu *et al.*, 2021). Gas flaring, a longstanding issue with economic and environmental consequences, adds further to the problem by polluting air and soil with heavy metals (Hassan, 2020; Nkemdilim *et al.*, 2021; Jonah and Francis, 2023). Beyond oil and gas, industrial processes like mining, smelting, and emissions contribute significantly to heavy metal pollution, as studies across various environmental matrices in Nigeria demonstrate (Ogundele *et al.*, 2017; Zo *et al.*, 2018; Nachana'a Timothy, 2019). Widespread contamination is evident in assessments of sediments, agricultural soils, and water bodies across the country. The presence of Cd, Cu, Pb, and Zn in heavily commuted areas points to combined automobile and industrial pollution (Akinnifesi *et al.*, 2021). This concern extends to the Niger Delta, where oil exploration activities have significantly polluted water bodies and wetlands (Sojinu *et al.*, 2010; Ebuete *et al.*, 2019). Sources of heavy metal pollution extend beyond industry and include pharmaceutical wastewater, traffic, agricultural chemicals, and automobile mechanic activities (Radaideh *et al.*, 2017; Ahmad *et al.*, 2021; Ajala *et al.*, 2022; Kaur *et al.*, 2023). These activities, along with oil spills, pose ecological risks and health threats, particularly impacting agricultural soil and food safety (Abuduwaili *et al.*, 2015; Wang *et al.*, 2016; Wu *et al.*, 2018). Bioaccumulation of heavy metals in aquatic organisms like catfish further underscores the widespread environmental impact. The extent of contamination necessitates remediation and monitoring efforts (Leung *et al.*, 2017; Vareda *et al.*, 2019). Assessments of sediments and soils in various regions highlight the urgency of this issue (Ratko *et al.*, 2011; Wuana and Okieimen, 2011; Liu *et al.*, 2013; Ololade, 2014; Ihedioha *et al.*, 2016; Proshad *et al.*, 2018; Bu *et al.*, 2020; Saha *et al.*, 2022; Olumayowa *et al.*, 2023). Implementing comprehensive solutions to address diverse sources of pollution remains crucial for safeguarding environmental health and human well-being in Nigeria.

Mining activities: artisanal gold mining and its associated risks: The allure of gold draws millions to artisanal mining, but its environmental and human health consequences are undeniable. Studies have highlighted the impact of illegal artisanal gold mining on heavy metal exposure to water bodies, leading to pollution and potential health risks (Olujimi *et al.*, 2015; Edogbo *et al.*, 2020; Yahaya *et al.*, 2023). River basins and mining landscapes bear the brunt of this contamination, with heavy metals leaching into waterways, disrupting ecosystems, and jeopardizing aquatic life (Ouma *et al.*, 2022; Orosun *et al.*, 2023). The pollution extends beyond water, with artisanal mining activities leaving behind a trail of contaminated soil and sediments, posing long-term environmental risks (Orisakwe *et al.*, 2017; Adedeji *et al.*, 2019; Fagbenro *et al.*, 2021). Moreover, the structural instability of mine shafts due to artisanal mining poses a threat to both the environment and local communities (Mhlongo *et al.*, 2019). Mine tailings, the waste products of artisanal mining, contribute significantly to greenhouse gas emissions and environmental degradation, further amplifying the industry's negative footprint (Wilson *et al.*, 2014; Munganyinka *et al.*, 2022). Research into heavy metal concentrations around artisanal mining sites sheds light on the anthropogenic sources of this contamination, highlighting the specific metals involved and their potential risks (Sofia *et al.*, 2017; Wireko-Gyebi *et al.*, 2020; Munganyinka *et al.*, 2022; Ouattara *et al.*, 2022; Cartolin and Felix, 2023). Assessments of surface water quality in artisanal gold mining areas reveal the alarming impact of intensive mining activities on water quality and the subsequent ecological threats (Rakotondrabe *et al.*, 2017; Sofia *et al.*, 2017; N'goran *et al.*, 2021; Timsina *et al.*, 2022)

Agricultural practices: use of pesticides and fertilizers: While macronutrient elements are required for plant development and performance, the importance of micronutrient elements such as cobalt, copper, iron, manganese, and zinc cannot be overstated (Hosamani *et al.*, 2020; N'goran *et al.*, 2021; Yao *et al.*, 2022). These nutrients are frequently deficient in various soils. As a result, such soils are supplemented with compounds containing these heavy metal nutrients (N'goran *et al.*, 2021; Isworo and Oetari, 2022; Soinne *et al.*, 2022). Heavy metals such as cadmium and lead are frequently employed in the manufacturing of macronutrient fertilizers to supply nutrients to the soil system (Chibueze *et al.*, 2012; Parameswari *et al.*, 2014). Heavy metals are present in many of the chemicals used in agriculture and associated activities. Examples include the Bordeaux Mixture for fungal management, lead arsenate for fruit parasite control, and copper, chromium, and arsenic compounds used in wood preservation (Maroulis *et al.*, 2007; Chopra *et al.*, 2009; Wuana and Okieimen, 2011). Modern agriculture, while boosting yields through pesticides and fertilizers, has emerged as a significant culprit in heavy metal contamination. Studies reveal these agrochemicals as key players, introducing heavy metals through impurities, spraying residues, and degradation products (Duke *et al.*, 2018; Witkowska *et al.*, 2021). Artificial fertilizers further exacerbate the issue through inherent impurities, processing contamination, and repeated application (Magyar *et al.*, 2019; Bassouny and Abbas, 2020; Mng'ong'o *et al.*, 2021). This accumulation unleashes a cascade of detrimental effects (Hubbs-Tait *et al.*, 2005; Jaishankar *et al.*, 2014; Yan *et al.*, 2020; Bawa-Allah, 2023). Recognizing the severity, researchers and policymakers are actively seeking solutions. Sustainable agricultural practices offer a promising path, while remediation strategies like phytoremediation and soil amendments are explored to address existing contamination (Igiri *et al.*, 2018; Ameh and Onuh, 2020; Yan *et al.*, 2020; Inobeme *et al.*, 2023). Stricter regulations on agrochemicals, coupled with effective monitoring programs, can further contribute to minimizing the problem at its source. By acknowledging this challenge and implementing comprehensive solutions, we can move towards a more sustainable and resilient agricultural system that safeguards both environmental health and crop quality.

Biosolids and manures: The use of biosolids and manures in agricultural activities is a significant source of heavy metal contamination in Nigeria. The application of biosolids and manures, such as sewage sludge, cattle manure, and compost, can introduce heavy metals, including cadmium, copper, lead, and zinc, into agricultural soils, posing potential risks to soil quality, crop productivity, and human health (Richards *et al.*, 2004; Baghaie *et al.*, 2011; Sharma *et al.*, 2017; Ali *et al.*, 2021). Studies have shown that the use of biosolids and manures in agricultural practices can lead to the contamination of food crops with heavy metals, contributing to adverse health effects, such as cancer, among the Nigerian population (Wei *et al.*, 2010; Wuana and Okieimen, 2011; Onakpa *et al.*, 2018). Additionally, the mobility and availability of heavy metals in contaminated wetland soil remediated with biochar-compost and the leaching of heavy metals in sandy soil after the application of composts produced from various organic materials have been investigated, highlighting the potential risks associated with heavy metal contamination from biosolids and manures in agricultural soils (Adesodun and Mbagwu, 2008; Odoemelam and Ajunwa, 2008; Christian *et al.*, 2021; Jacob *et al.*, 2022). Furthermore, the evaluation of pig manure for environmental or agricultural applications through gasification and soil leaching experiments has demonstrated the potential for reducing heavy metal concentrations in leachates, indicating the importance of proper manure management to mitigate heavy metal pollution in soils (Vamvuka and Raftogianni, 2021). Additionally, the residual effects of long-term biosolids application on concentrations of heavy metals in soils have been studied, emphasizing the need to consider biosolids source and soil properties to manage heavy metal accumulation in agricultural soils (Codling *et al.*, 2021). Moreover, the application of biosolids for sod production has been shown to impact the import/export of heavy metals and soil mineral matter, highlighting the potential environmental implications of biosolids use in agricultural activities (Griffith *et al.*, 2020).

Wastewater: Wastewater in Nigeria serves as a significant source of heavy metals and contaminants, posing environmental and public health risks (Khan *et al.*, 2008; Akpor *et al.*, 2014). Studies have highlighted the presence of heavy metals, antibiotic-resistant bacteria, and pharmaceutical effluents in wastewater, emphasizing the need for effective treatment and management strategies to mitigate the impact of wastewater pollution (Bonvin *et al.*, 2011; Nafarnda *et al.*, 2012; Obayiuwana *et al.*, 2018; Badejo *et al.*, 2021; Fork *et al.*, 2021; Okoduwa *et al.*, 2022; Masoner *et al.*, 2023). The discharge of untreated wastewater into the aquatic ecosystem in Nigeria has been identified as a serious risk to public health, contributing to the widespread practice of discharging hospital wastewater, industrial effluents, and agricultural runoff into the environment without adequate treatment (Olatunji *et al.*, 2014; Jenyo-Oni and Oladele, 2016; Ogbonna and Ajubo, 2017; Rabiu and Falodun, 2017; Osunmakinde *et al.*, 2021; Chinakwe *et al.*, 2022). This practice has led to the contamination of surface water and soil with heavy metals, pharmaceutical residues, and antibiotic-resistant bacteria, posing risks to human health and the environment (Afolabi *et al.*, 2023; Badamasi *et al.*, 2023; Okafor *et al.*, 2023). Furthermore, the presence of heavy metals in wastewater has been associated with the contamination of agricultural soils and the potential accumulation of heavy metals in commonly consumed vegetables, raising concerns about food safety and human exposure to heavy metal contaminants (Habu and Usman, 2021; Samuel *et al.*, 2022). Additionally, the impact of wastewater on fruit quality attributes and heavy metal contents of mango cultivars has been studied, highlighting the potential effects of irrigation water from different sources on agricultural produce (Anjum *et al.*, 2021). Moreover, the use of wastewater for irrigation and its impact on soil and water quality have been assessed, indicating the potential risks associated with the use of contaminated wastewater in agricultural practices (Aliyu *et al.*, 2017; Inyinbor *et al.*, 2019; Habu and Usman, 2021; Samuel *et al.*, 2022). The presence of heavy metals and contaminants in wastewater has also been linked to environmental pollution and the need for effective treatment strategies to remove heavy metals and contaminants from wastewater (Bonvin *et al.*, 2011; Akpor *et al.*, 2014; Igiri *et al.*, 2018; Ziarati *et al.*, 2020; Ahmad *et al.*, 2021).

Air borne sources: Air pollution in Nigeria stems from a wide range of sources, encompassing both natural and human-related factors (Marais *et al.*, 2014). These include inefficient vehicles, inadequate road infrastructure, substantial emissions of non-methane volatile organic compounds (NMVOCs), gas flaring in the Niger Delta area, illicit oil refining, gas leaks, pipeline explosions, diesel-powered backup generators and plants, and the burning of kerosene and fuelwood (Marais *et al.*, 2014; Marais and Wiedinmyer, 2016; Yakubu *et al.*, 2017; Fuwape *et al.*, 2020). Additionally, anthropogenic activities such as the application of fertilizer in agriculture, the use of pesticides and herbicides, and irrigation contribute to the release of harmful metals into the air (Onakpa *et al.*, 2018). Furthermore, the Niger Delta region of Nigeria is known for air pollution due to the release of unpleasant odours, particles, and harmful gases into the environment (Richard *et al.*, 2023). Additionally, the improper management of used lead-acid batteries and metallurgical activities contribute to the release of heavy metals into the air, impacting environmental quality (Ogundele *et al.*, 2017; Ugya and Imam, 2018). Moreover, the contamination of air with heavy metals in agrarian soil samples in Nigeria has been linked to pesticide use and poor waste disposal systems (Afonne *et al.*, 2022). The presence of trace metals in air-borne particulate matter in Nigerian megacities further underscores the diverse sources of air-borne metals in the country (Gc *et al.*, 2017). The impact of heavy metal air pollution from local metallurgical activities on living organisms, such as albino rats, highlights the potential health effects of air-borne metals in Nigeria (Ugya and Imam, 2018).

Environmental Impact of Heavy Metal Contamination

Soil contamination and its effect on agricultural productivity: The environmental impact of heavy metal contamination in Nigeria is a critical concern, particularly concerning soil contamination and its effect on agricultural productivity (Ogbaran and Uguru, 2021; Audu *et al.*, 2022; Obasi *et al.*, 2023; Umeoguaju *et al.*, 2023). The contamination of agricultural soils with heavy metals, often originating from anthropogenic activities, has been shown to have detrimental effects on soil quality (Wong *et al.*, 2002; Okunola *et al.*, 2007; Wuana and Okieimen, 2011; Wu *et al.*, 2018; Adedeji *et al.*, 2019; Yu *et al.*, 2021). This leads to reduced agricultural productivity and potential health risks associated with consuming crops grown in contaminated soils. Furthermore, the bioaccumulation of heavy metals in food crops grown in contaminated soils further exacerbates the environmental and health implications of soil contamination (Opaluwa *et al.*, 2012; Bassey *et al.*, 2014; Obiora *et al.*, 2016; Emurotu and Onianwa, 2017; Ogbaran and Uguru, 2021). This means that the heavy metals can accumulate in the crops, making them potentially harmful to human health when consumed. The impact of anthropogenic activities on soil contamination and associated environmental risks can be highlighted by assessing the pollution load indices of heavy metals in contaminated soil from small-scale cassava processing activities in rural communities (Izah *et al.*, 2017). This emphasizes the role of human activities in contributing to soil contamination and the need for effective remediation strategies and regulatory measures.

Water pollution and its consequences for aquatic life and ecosystems

The environmental impact of heavy metal contamination in Nigeria's water sources is a significant concern due to the potential health implications for the population (Onakpa *et al.*, 2018). Studies have shown that heavy metal accumulation in the environment and food crops are a prevalent issue, leading to environmental pollution and posing health risks to the people (Orisakwe *et al.*, 2012; Onakpa *et al.*, 2018; Hu *et al.*, 2019; Nkwunonwo *et al.*, 2020; Milam *et al.*, 2022; Obasi *et al.*, 2023). Furthermore, the consumption of beverages and fish from Nigeria's surface water has been associated with possible heavy metal-related diseases, highlighting the widespread nature of the issue (Izah and Angaye, 2016). This indicates that heavy metals present in surface water can enter the human body through food and beverages, potentially causing harm. The contamination of streams, rivers, and groundwater ecosystems with heavy metals remains a global environmental problem, with damaging effects on natural biological communities and wider ecosystem populations (Okolo *et al.*, 2018; Astatkie *et al.*, 2021; Bawa-Allah, 2023). This emphasizes the negative impact of heavy metal contamination on aquatic life and ecosystems. Moreover, the assessment of heavy metal concentrations in water sources around quarries and mine sites in Nigeria has revealed the degree of contamination due to mining and quarrying activities in the area, emphasizing the anthropogenic contribution to heavy metal pollution (Okolo *et al.*, 2018; Alabi *et al.*, 2019; Ochelebe *et al.*, 2020). This highlights the role of human activities, particularly mining and quarrying, in introducing heavy metals into water sources. Additionally, the evaluation of physicochemical parameters and heavy metal levels in surface water has been conducted to determine the potability and pollution status of water sources in Nigeria, indicating the extent of heavy metal pollution in these areas (Aliyu *et al.*, 2015; Ogbaran and Joseph-Akwara, 2021; Okafor *et al.*, 2023; Ubuoh *et al.*, 2023) This assessment provides insights into the pollution levels and potential risks associated with heavy metal contamination in Nigeria's water sources. The impact of heavy metals on water resources in Nigeria is exacerbated by anthropogenic activities, leading to geogenic heavy metal contamination and posing health risks to the population (Anyanwu *et al.*, 2018; Anyanwu and Nwachukwu, 2020). This highlights the need for effective measures to address heavy metal contamination and protect water resources and human health. Finally, the contamination of underground water sources in Nigeria has been assessed, revealing hazardous discharges of metals to other water sources in the area, further emphasizing the widespread nature of the issue (Nnabo, 2015). This indicates that heavy metal contamination can spread from underground water sources to other water sources, amplifying the environmental and health risks associated with it.

Furthermore, the assessment of ecological and human health exposure risks to heavy metals in Oji River sediments in Enugu State, Nigeria, has revealed the influence of abattoir and power station activities on heavy metal input into the sediments (Ugochukwu *et al.*, 2019). This highlights the specific sources of heavy metal contamination and their contribution to the overall environmental impact. These findings underscore the interconnectedness of heavy metal contamination across different environmental compartments.

Air quality degradation and atmospheric deposition

The environmental impact of heavy metal contamination in Nigeria extends beyond water sources to include air and soil. This is evident in the studies that have shown the serious public health problem of heavy metal contamination of environmental media around informal used lead-acid battery recycling centres in Nigeria (Oloruntoba *et al.*, 2022). Furthermore, the occurrence and impact of heavy metals on water, land, flora, and fauna resources across southwestern Nigeria have been documented, highlighting the significant contribution of rapid urbanization and industrialization to environmental pollution (Akinnifesi *et al.*, 2021). These findings emphasize the wide-ranging effects of heavy metal contamination on various environmental components. Moreover, the pollution status of Akata Lake sediments in Katsina-Ala, Benue State, Nigeria, has been studied to assess the extent of heavy metal pollution in the area (G.G *et al.*, 2021). This research underscores the environmental impact of heavy metal contamination, specifically in the sediments of Akata Lake.

Distribution of Heavy Metals in the Nigerian Environment

Heavy metals in groundwater: Several studies have investigated heavy metal contamination in groundwater in Nigeria. Oyeku and Eludoyin (2010) found elevated levels of Pd, Cu, Fe, and Co in groundwater samples from Ojota, Lagos state, posing risks to human and environmental health. Grema *et al.* (2022) and (Hamidu *et al.*, 2021) investigated heavy metal pollution in groundwater in the Kaffe community alongside its environs and within industrial areas in Sokoto River Basin and Kano City, North-Western Nigeria respectively. Both studies found detectable levels of metals above drinking water limits. Adebayo *et al.* (2021) conducted a comprehensive assessment of groundwater contamination and health risks in the Ikire community, Osun State, Nigeria, highlighting the spatial distribution of heavy metals and associated health risks. Balogun-Adeleye *et al.* (2022) evaluated heavy metal concentrations in groundwater near a metal recycling industry in Ogun State, Nigeria, shedding light on the impacts of metal recycling on groundwater quality. Ajiboye *et al.* (2018) focused on mapping radon distribution in groundwater in southwest Nigeria and assessing the associated health risks from heavy metals in drinking water. Oyeku and Eludoyin (2010) measured heavy metal levels in groundwater from 20 sampling stations in Ojota, Lagos state, finding elevated levels of Pd, Cu, Fe, and Co, posing risks to human and environmental health. Denkok *et al.* (2021) studied heavy metals in water samples from Jos, Plateau state, identifying concentrations of Cd, Pd, Cr, Cu, and Zn in drinking water above WHO limits. Abubakar and Sirajo (2023) assessed heavy metal concentrations in hand-dug well and borehole water samples from Mubi South L.G.A, Adamawa State, finding concentrations exceeding WHO and SON limits, posing potential health risks. Mshelia and Bulama (2023) conducted a study on the concentration and comparison of heavy metals in groundwater in Kano Metropolis, Nigeria. The study found that concentrations of heavy metals such as cadmium, chromium, mercury, arsenic, lead, iron, zinc, copper, and manganese exceeded WHO and NSDWQ limits. Oyebode *et al.* (2023) investigated the impact of the Olusosun landfill on groundwater quality in Lagos State, Nigeria, finding certain metals, such as iron, lead, manganese, and magnesium, present at concentrations higher than WHO, NESREA, and NSDWQ limits. Ahmed *et al.* (2023) assessed heavy metal contamination in groundwater sources in Hadejia Metropolis, Jigawa State, Nigeria, finding concentrations of chromium and iron exceeding the Nigerian Standard for Drinking Water Quality and WHO limits. Okafor *et al.* (2023) evaluated the levels of heavy metals in surface and groundwater in Ifite Ogwari, Southeastern Nigeria, finding some samples exceeding the maximum permitted levels for Ni, Cd, and Fe. Owamah *et al.* (2023) assessed the concentration and distribution of heavy metals in groundwater around automobile workshops in Ozoro, Nigeria, finding heavy metal levels higher than the reference point due to leachates from the workshops. Adejuwon and Odusote (2023) studied the physicochemical characteristics and heavy metals in groundwater at the Lafarge cement factory environment in Sagamu, Nigeria, finding elevated levels of phosphate, alkalinity, and salinity in some locations, exceeding standard limits. Akakuru *et al.* (2023) analyzed groundwater quality and contamination in Osisioma, Nigeria, finding low to moderate pollution levels of Cd, Fe, Pb, and As exceeding recommended standards which would negatively impact on groundwater quality.

Alao *et al.* (2023) evaluated groundwater vulnerability to open dumpsites and its potential environmental risk, finding high concentrations of heavy metals such as chromium, cadmium, lead, and iron in the groundwater near the dumpsite. Balogun *et al.* (2023) assessed the health risk associated with exposure to heavy metals in hand-dug wells in Gombe State, Nigeria, finding concentrations generally low and within regulatory standards, Ogwu *et al.* (2023); Ogwu *et al.* (2023). investigated heavy metal concentrations in the groundwater of Oshodi/Isolo/Ilasamaja industrial estate in Lagos Nigeria, finding elevated levels of heavy metals such as lead, chromium, cadmium, mercury, and arsenic concentrations exceeding WHO and USEPA limits. Sanga *et al.* (2023) investigated heavy metal pollution in leachates and its impact on groundwater quality around the Iringa municipal solid waste dumpsite, finding concentrations of heavy metals exceeding permissible limits. Ayejoto and Egbueri (2023) assessed the concentrations of heavy metals (Pb, Cd, Cu and Fe) in urban groundwater in Nnewi and Awka regions of Southeast Nigeria, finding levels exceeding permissible limits in all samples.

Heavy Metals in Water: The studies conducted by Wogu and Okaka (2011), Odebunmi *et al.* (2014), Abubakar (2015), and Sankhla *et al.* (2016) collectively highlight the presence of heavy metal contamination in surface water in Nigeria. Wogu and Okaka (2011) observed high concentrations of iron (Fe) and low concentrations of lead (Pb) in the Warri River, attributed to effluent discharge from the Aladja Iron and Steel Industry. Similarly, Odebunmi *et al.* (2014) found elevated levels of lead (Pb), mercury (Hg), arsenic (As), and cadmium (Cd) in drinking water sources in Osun State, exceeding WHO-permitted levels. In contrast, copper (Cu), iron (Fe), chromium (Cr), and zinc (Zn) were within the guidelines. Abubakar (2015). assessed heavy metal contamination in the Kakuri-Makera drainage and Long River Kaduna, where copper (Cu), zinc (Zn), and arsenic (As) were within WHO limits, while lead (Pb) exceeded tolerable levels. Moreover, Sankhla *et al.* (2016) emphasized the hazardous effects of heavy metals on human health, highlighting the presence of lead, cadmium, mercury, arsenic, selenium, iron, copper, manganese, and zinc in water sources. Adesiyan *et al.* (2018) examined the concentrations and human health risks of heavy metals in selected rivers in Southwest Nigeria. The analysis revealed the presence of manganese, arsenic, chromium, cadmium, and lead in the rivers, exceeding recommended limits and indicating potential risks to human health. Moreover, Anifowose and Oyebode (2019) focused on the heavy metal contents of the Osun River, highlighting the need for proper waste management systems to prevent the discharge of untreated industrial waste and protect the health of the local population. Similarly, Atama *et al.* (2020) analyzed the heavy metal content of urban rivers in Enugu, revealing the presence of zinc, arsenic, mercury, and other heavy metals, emphasizing potential environmental and health implications. Additionally, Taiwo *et al.* (2020) examined the concentration of heavy metals in water, sediments, and fishery organisms from Yewa Lagoon, underscoring the importance of monitoring heavy metal contamination to protect aquatic organisms and human populations. Furthermore, Ahiamadu *et al.* (2021) characterized heavy metals in crude oil spill sites, highlighting the need for effective measures to mitigate contamination and protect water resources. Hammani *et al.* (2020) evaluated heavy metal contamination in surface and groundwater in Maiganga, Gombe State, Nigeria, shedding light on the levels of heavy metal contamination in farmland water. Similarly, Oladunjoye *et al.* (2021)) examined the accumulations of heavy metals in water and crab species from Ojo River in Lagos State, providing insights into the distribution of heavy metals in the river and their potential impact on aquatic organisms. Additionally, Akinnifesi *et al.* (2021) highlighted the occurrence and impact of heavy metals in surface water samples across Southwestern states in Nigeria, emphasizing the need for comprehensive monitoring, assessment, and remediation strategies. Moreover, Ubuoh *et al.* (2023) assessed the effect of anthropogenic activities on water chemistry and potential ecological risk in Nworie Inland River, revealing heavy metal contamination and emphasizing the need for further research and measures to mitigate the contamination and protect water quality. Anya and Odo (2023) examined the concentrations of heavy metals in the surface water of Cross River in Akpo Catchment Area, Ebonyi State, Nigeria. The study found temporal patterns of variation in heavy metal levels, with iron (Fe) being the most abundant metal. Other metals present included arsenic (As), lead (Pb), zinc (Zn), manganese (Mn), copper (Cu), and chromium (Cr). Some metal concentrations exceeded permissible limits for potable water, indicating pollution. Similarly, Ogwu *et al.* (2023) investigated the concentration of heavy metals in the groundwater of the Oshodi/Isolo/Ilasamaja industrial estate in Lagos, Nigeria. The study found elevated levels of heavy metals, including lead (Pb), chromium (Cr), cadmium (Cd), mercury (Hg), and arsenic (As), exceeding maximum permissible limits set by WHO and USEPA. Furthermore, Nde *et al.* (2023) assessed the heavy metal characteristics of Muokolu River in Eleme, Rivers State, Nigeria, revealing that concentrations of all metals analyzed exceeded WHO limits for drinking water, posing a risk to human health. Additionally, Olalekan *et al.* (2023) evaluated seasonal variations in surface water quality in the gold mining areas of Osun State, Nigeria, identifying heavy metal contamination, including lead, cadmium, chromium, mercury, and arsenic. These findings emphasize the need for regular monitoring, proper waste management, and continuous assessment to mitigate the health hazards associated with heavy metal contamination. Okey-Wokeh *et al.* (2023) in their study, assessed the anthropogenic impacts on the physicochemical and heavy metal concentrations of Ogbor Hill River in southern Nigeria. Water samples were collected monthly for eight months and analyzed for physicochemical parameters and heavy metals. The results showed that the concentrations of heavy metals such as cadmium (Cd), copper (Cu), chromium (Cr), iron (Fe), manganese (Mn), nickel (Ni), lead (Pb), and zinc (Zn) were elevated in the river water, indicating the negative impacts of anthropogenic activities on water quality. The study highlighted the need for water management strategies and the reduction of anthropogenic activities to protect the surface water from contamination by heavy metals.

Adie *et al.* (2023) assessed the levels of heavy metals bioaccumulation in the surface water of Wasai Reservoir in Kano State, Nigeria. Significant differences in heavy metal concentrations were observed among different locations and months, with the highest concentrations of chromium, lead, and cadmium indicating contamination. This study emphasizes the need for effective measures to mitigate heavy metal contamination in surface water. Similarly, Agwu *et al.* (2023) evaluated heavy metal pollution in the catchment area of Ebonyi River in Nigeria. The concentrations of trace metals such as lead, cadmium, arsenic, copper, iron, nickel, mercury, and manganese exceeded acceptable limits for drinking water quality, highlighting the need for proper management practices to safeguard water bodies. Additionally, Nduka *et al.* (2023) assessed the contamination of surface water with heavy metals near a granite quarry site, revealing concentrations of lead, chromium, cadmium, and arsenic that exceeded WHO standards for potable water. This study emphasizes the potential health risks associated with consuming contaminated surface water. Furthermore, Smith (2009) emphasizes the importance of understanding metal levels and sources in surface water, highlighting the need for regular monitoring and assessment to ensure water quality and mitigate risks. Lastly, Chris *et al.* (2023) assessed heavy metal concentrations in surface water in the Opuroama creeks of the Niger Delta region, with lead exhibiting the highest concentration. The presence of heavy metals in surface water suggests potential ecological and human health risks associated with metal contamination. Aromolaran *et al.* (2023) investigated the environmental impacts of an unlined municipal solid waste landfill on groundwater and surface water quality, finding heavy metal contamination in surface water, including lead (Pb), cadmium (Cd), and copper (Cu). Ezekiel *et al.* (2023) assessed the pollution of surface water by agro-allied chemicals, identifying the presence of metals such as copper, calcium, zinc, chromium, and iron exceeding permissible limits, highlighting the need for measures to prevent and treat water pollution. Abulude *et al.* (2023) analyzed the physicochemical characteristics and contamination patterns of surface water samples, finding that the levels of heavy metals, including copper and iron, were below recommended limits. Adebanjo Jacob Anifowose *et al.* (2023) measured heavy metals in the Osun River, identifying high concentrations of metals such as iron, copper, and chromium, exceeding drinking water standards. The study also highlighted the carcinogenic risks posed by chromium, arsenic, and nickel. These studies collectively underscore the importance of monitoring, managing, and mitigating heavy metal contamination in surface water to protect human health and the environment.

Heavy Metals in Sediment in Nigeria: Several studies have been conducted on heavy metal contamination in

Nigerian water bodies and sediments, highlighting potential ecological risks and human health concerns. Enuneku *et al.* (2018) investigated heavy metal concentrations in the Benin River, Southern Nigeria, and found that most of these metals originated from anthropogenic sources. Adesiyan *et al.* (2018) focused on the distribution of heavy metals in surface sediments from streams and fishponds in Osun State, Nigeria, revealing elevated concentrations of heavy metals and potential ecological risks. Ekwuribe *et al.* (2016) examined heavy metal levels in sediments from Ahmadu Bello University Dam, observing concentrations below acceptable limits set by WHO. (Ibanga *et al.*, 2019)) analyzed heavy metal concentrations in sediment from Woji creek and Bonny estuary in the Niger Delta, emphasizing potential ecological risks associated with elevated concentrations of heavy metals. Also, Okorondu *et al.* (2021) investigated heavy metal contamination in sea bed sediments of the Bight of Bonny, Nigeria's southern Atlantic coast, and indicated a moderately to extremely contaminated environment, particularly with cadmium. Audu *et al.* (2022) collected sediment samples from different locations in Niger state, Nigeria, finding decreasing concentrations of heavy metals and concentrations below sediment quality requirements. Nwazue *et al.* (2022) studied heavy metal dispersion in stream sediments in River Iyiudene, Abakaliki, Southeastern Nigeria, highlighting elevated concentrations of heavy metals and potential ecological risks. Kolawole *et al.* (2023) assessed heavy metal contamination and ecological risks in soils and sediments of an industrial area in Southwestern Nigeria, revealing elevated concentrations of heavy metals and potential risks associated with anthropogenic activities.Akpomrere and Uguru (2020) conducted two studies on heavy metal contamination in swamp sediments in illegal refinery sites in Isoko South, Delta State, Nigeria, emphasizing the potential environmental and health risks associated with heavy metal contamination. Jolaosho *et al.* (2023) conducted a comprehensive geochemical assessment study, revealing elevated levels of heavy metals in sediment samples from dredged and non-dredged sites in Nigeria, highlighting potential ecological risks. Olagbemide and Owolabi (2023) investigated metal accumulation in the sediment of three major dams in Ekiti State, Nigeria, indicating a lower degree of pollution. Jafiya and Maina (2023) assessed heavy metal pollution in soils and sediments from farmlands in Askira Uba, Nigeria, revealing contamination with cadmium and potential environmental risks. Ighariemu *et al.* (2023) studied heavy metal concentrations in marine sediment impacted by oil spills in the Nembe area of the Niger Delta, Nigeria, highlighting potential environmental risks. Chris *et al.* (2023) evaluated heavy metal concentrations in water, sediment, and shellfish in the Opuroama creeks of the Niger Delta region, emphasizing potential risks to the ecosystem and public health. Bulus *et al.* (2023) analyzed the chemical composition of bauxite and rutile ores, as well as the contaminated vicinity soil, sediment, and plants in Plateau State, Nigeria, highlighting potential environmental contamination caused by unregulated mining activities. Popoola *et al.* (2023) assessed pollution indices and ecological risk associated with major elements and trace metals in the marine sediment of the western Nigeria continental shelf, Gulf of Guinea, suggesting minimal to moderate ecological risk. Ibekwe (2023) studied heavy metal assessment in water and sediments of the Obodo Oilfield, Delta State, Nigeria, suggesting considerable pollution and degradation. Edward and Adamu (2023) investigated seasonal variability of heavy metals in water, fish, and sediments in Kiri Reservoir, Nigeria, observing the presence of heavy metals in sediment samples during both the dry and wet seasons. Olutona (2023) assessed pollution levels of heavy metals in the bed sediment of Asunle stream, Nigeria, revealing contamination with various heavy metals. Chukwumati (2023) studied heavy metal accumulation in sediment from a crude oil-polluted mangrove ecosystem in Okrika, Nigeria, highlighting the potential environmental and health risks associated with heavy metal contamination. Bawa-Allah (2023) conducted a meta-analysis on heavy metal pollution in Nigerian surface freshwaters and sediment, emphasizing significant pollution and associated risks. Kolawole *et al.* (2023) assessed the levels, distribution, and ecological risks of heavy metals in sediment around a used-automobile spare part market in Nigeria, revealing elevated concentrations of heavy metals and potential ecological risks. Sule *et al*. (2023) assessed the ecological and human health risks of heavy metals in sediment and demersal fish species in Western Offshore Nigeria, Gulf of Guinea, highlighting potential risks to the ecosystem and human health

Heavy metals in Nigerian Soils: A comprehensive examination of heavy metal distribution in Nigerian soils has been conducted through various research studies, shedding light on the sources, concentrations, and potential ecological and human health risks associated with these contaminants. Okunola *et al.* (2007) conducted a comprehensive examination of soils along roads in Kaduna, Nigeria, determining mean concentrations of Zn, Mn, Pd, Cu, and Cd. They identified motor vehicles, petroleum waste, and industrial pollutants as likely sources. Ogunbanjo *et al*. (2016**)** contributed to the analysis of environmental and occupational hazards by conducting a study on the chemical speciation of some heavy metals and human health risk assessment in the soil around two municipal dumpsites in Sagamu, Ogun State, Nigeria. Armaya'u *et al*. (2020) expanded the scope by assessing heavy metals in soil samples from Lambun Sarki irrigation sites in Katsina Metropolis, revealing elevated concentrations of Cr, Cd, Pb, Zn, and Cu. Their study compared these concentrations to World Health Organization/Nigerian Federal Environmental Protection Agency limits, uncovering potential ecological and human health risks. Olatunde *et al.* (2020) investigated the distribution and degree of contamination of heavy metals in soils around a major cement factory in Ibese, Ogun State, Nigeria. Analyzing 20 soil samples for heavy metals such as lead (Pb), cadmium (Cd), chromium (Cr), zinc (Zn), and copper (Cu), they found high levels, with Pb being the most abundant. The study also assessed the ecological risk of heavy metals in the soil, concluding that the contamination poses a significant risk to the environment and human health. Ojo *et al.* (2018) contributed to the understanding of heavy metal pollution by assessing soils from farms in the vicinity of the Durumi Quarry Site in Mpape, Abuja, Nigeria. The study focused on the seasonal concentrations of total and bioavailable heavy metals, along with the physicochemical properties of the soil in vegetable farms around the rock quarry. Yahaya *et al.* (2023) conducted a study to assess the risk posed by heavy metals in the soil around a cement company in Sokoto, Nigeria. Soil samples were collected at different distances from the company, and the levels of lead (Pb), cadmium (Cd), copper (Cu), and zinc (Zn) were analyzed. The results showed that all the soil samples contained permissible levels of heavy metals according to WHO standards. However, the average daily inhalation (ADI), average daily dermal exposure (ADDE), hazard quotient (HQ), health risk index (HRI), and carcinogenic risk (CR) of the heavy metals were above the permissible limits, indicating potential health risks. Chokor (2023) conducted a study to assess the potential ecological and human health risks associated with toxic phenols and heavy metals in farmland soils of Obio-Akpor LGA, Rivers State, Nigeria. Soil samples were collected from five different communities and analyzed for phenols and heavy metals. The results showed wide variations in the concentrations of phenols and metals in the soils. Overall, the study suggests that the farmland soils in the communities are slightly polluted with heavy metals. Alagoa *et al.* (2023) conducted a study in Toru-Ebeni, Bayelsa State, Nigeria, to investigate the presence of heavy metals in soils with cassava processing activities. Soil samples were collected from three sites, two with cassava processing activities and one control site without such activities. The samples were analyzed for heavy metals, and the results showed significant differences in copper, lead, nickel, and chromium concentrations between the control site and the processing sites. Ogbuene *et al.* (2023) conducted a study to investigate the occurrence of heavy metals in soil and selected edible plants in the vicinity of major lead-zinc mining sites in Ebonyi State, Nigeria. The concentrations of heavy metals in the soil exceeded the limit values in most instances, indicating contamination. Omeka and Igwe (2023) conducted a study to assess the concentration of heavy metals in soils and crop plants within the vicinity of abandoned mine sites in Nigeria. The researchers used an integrated approach, combining indexical and chemometric methods, to evaluate the toxicological processes controlling heavy metal uptake in plants, the suitability of crops for consumption, and the possible sources of heavy metals. The results showed that the concentration of heavy metals in both soil and cassava plants exceeded the required standards, with cadmium (Cd) posing the highest contamination level. Olumayowa *et al.* (2023) conducted a study to assess the levels of heavy metals in soils around the Oke-Ere mining area in Kogi State, Nigeria, and evaluate the associated health risks. The study found that the soils were highly polluted by Sc, moderately polluted by Sn, and non-polluted to slightly polluted by other metals. Enrichment factor analysis showed significant enrichment by Sc, while Cr, Pb, Co, Mo, and Sn were moderately enriched. The contamination factor indicated low contamination for most metals except Cu and Co. The pollution load index indicated that mining activities had deteriorated soil quality. metals in the area. Okosa *et al.* (2023) conducted a study to assess the ecological and health risks of heavy metals from waste sites in residential areas in Umuahia, Nigeria. They analyzed soil samples from two residential estates and found that the concentrations of heavy metals were higher in rural soils than in urban soils. The contamination factor indices indicated a low contamination scenario for most heavy metals, except for cadmium which showed a very high contamination status. Cadmium was also found to be the highest contributor to ecological risk. Adewale *et al.* (2023), conducted a study to assess the level of heavy metal residues in the soil and leaves of commonly consumed vegetables in Lagos State, Nigeria. The study found that the concentrations of heavy metals, including Fe, Pb, Cd, and Cu, varied across the different study locations. While most heavy metal concentrations were within safe levels set by WHO/FAO, elevated levels of Pb and Cd were found in vegetables from urban farms. Nduka *et al.* (2023) assessed the spatial distribution and health risks associated with heavy metals in roadside soil in Enugu, Nigeria. Soil samples were collected from three economic zones, namely the industrial area, residential area, and commercial area. The results showed varying concentrations of heavy metals, including chromium, arsenic, nickel, copper, mercury, iron, lead, and manganese. The study identified traffic, industrial emissions, and natural sources as the main contributors to heavy metal contamination. In the study conducted by Orosun *et al.* (2023), the authors evaluated the causes, concentration, and associated health risks of heavy metals in soil samples collected from beryllium and gold mining fields in Nigeria. The samples were analyzed using Atomic Absorption Spectrophotometry, and the concentrations of various heavy metals including chromium, arsenic, iron, cadmium, nickel, manganese, magnesium, zinc, copper, and lead were determined. The study found that the mining activities contributed significantly to heavy metal pollution, posing potential risks to human health. In conclusion, these studies reveal a pressing need for proactive measures to address heavy metal contamination, safeguarding the environment, and mitigating potential health risks. The insights gleaned from these investigations underscore the importance of informed environmental management practices in the face of increasing industrialization and urban development in Nigeria.

Heavy Metals in Food in Nigeria: Heavy metals in food pose a significant concern in Nigeria due to their potential health risks. These toxic elements, such as lead, cadmium, mercury, and arsenic, can contaminate food through various sources, including agricultural practices, industrial activities, and environmental pollution. Edogbo *et al.* (2020) conducted a risk assessment in the Challawa district of Kano State, Nigeria, to evaluate heavy metal pollution in soil, vegetables, and fish. The study found that heavy metals (Cd, Cr, Pb, Zn) were present in water, fish, soil, and various edible crops grown in waste water irrigated fields. The levels of Cd and Cr exceeded the permissible limits set by regulatory authorities in the Challawa area. In a study by Jacob and Kakulu (2012)in Kaduna Metropolis, heavy metal contamination in food crops was examined. The identified heavy metals were Pb, Cd, Cr, and Ni. The concentrations of Pb, Cd, and Cr in vegetables exceeded the maximum acceptable limits set by WHO/FAO in all zones. However, there was no significant contamination of Ni in the analyzed food crops. The study highlighted that certain areas of the city were more contaminated by specific metals than others due to human activities, posing a risk of Pb, Cd, and Cr contamination in food crops throughout the city. In the same vain, Orisakwe *et al.* (2012) conducted a study in South Eastern Nigeria to measure lead, cadmium, and nickel levels in food crops, fruits, and soil samples collected from Ohaji, Umuagwo, and Owerri. The study found that the amounts of Pb, Cd, and Ni in Ohaji exceeded the maximum permitted values for agricultural soil set by the EU. The concentrations of lead, cadmium, and nickel in food crops varied, with the highest levels observed in *Oryza sativa*, *Glycine max*, and *Pentabacta microfila*, respectively. Additionally, Canarium schweinfurthii, *Citrus reticulata*, and *Ananas comosus* had the highest amounts of Pb, Cd, and Ni in their fruits, respectively. The study implicated agricultural operations, including the use of pesticides and fertilizers, as contributing factors to increased hazardous metal pollution. Similarly, Ewere (2016) examined heavy metals in the African giant snail *Archachatina marginata* and its parasites from three settlements in Edo State: Ubgogui, Okogbo, and Ugo. Iron was the most abundant in both the snail and parasite acquired from these ecosystems. The mean concentrations of Ni, Fe, and Mn were all within acceptable ranges. However, the mean concentrations of Cu, Pb, Cd, and Co (0.02mg/kg) were above the WHO's maximum allowed levels. Snails infected with parasites accumulated higher concentrations of heavy metals than uninfected snails. The ingestion of these contaminated snails may pose a health risk to consumers. Furthermore, Joseph *et al.* (2019) conducted an assessment of heavy metal concentrations in the surrounding soils and crops of the West African Ceramic Industry in Nigeria. The research focused on investigating heavy metal contamination in soil and food crops, including maize, sweet potato, and spinach, around the vicinity of the industry in Kogi State, Nigeria. This study contributes to the understanding of heavy metal contamination in food crops and its potential impact on food safety and human health in the region. In their review of heavy metal contamination in food crops, Onakpa *et al.* (2018) addressed the global concern of heavy metal contamination in food crops, highlighting the potential risks of toxicity and diseases in humans and animals through the consumption of contaminated soils and food crops. The review provided valuable insights into the agricultural and environmental aspects of heavy metal contamination in food crops, contributing to the understanding of this critical issue in Nigeria. The study by Felagha and Ogbolosingha (2018) provides an assessment of heavy metals concentration in selected foods sold in markets within Port-Harcourt city, Nigeria. This research contributes to the understanding of heavy metal contamination in food items available in local markets, addressing potential health risks associated with the consumption of contaminated foods. Ojezele *et al.* (2021) also reported heavy metal content in commonly consumed canned foods in South-west Nigeria. The research quantifies the levels of Ni, Cr, Cu, Pb, and Al in various canned food products, highlighting the potential risks of heavy metal exposure and toxicity associated with the consumption of these products. The study's findings, particularly the presence of lead (Pb) above the recommended limit, underscore the importance of caution during production and the need for awareness regarding the potential accumulation of heavy metals from canned food consumption, emphasizing the implications for public health and food safety in Nigeria. Similarly, Adowei *et al.* (2020) also conducted a study on the concentrations and human health risk assessment of Cd, Co, Cr, Ni, and Pb in white granulated garri, a widely consumed foodstuff in Nigeria. The study established the concentrations of heavy metals in commercial white granulated garri sold in major markets in Port Harcourt, Nigeria, using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) after microwave-assisted acid digestion. Also, Elemo *et al.* (2021) in their study on heavy metals in food crops, determined heavy metal leaching in foods cooked with stainless-steel pots and locally-made alloy pots, comparing the leached heavy metals in food samples cooked with the two commonly used pots in Nigeria. This research provides valuable insights into the potential bioaccumulation of heavy metals, particularly zinc and chromium, in foods cooked using different types of pots, addressing the safeness of these cooking utensils and their potential impact on food safety in Nigeria. The study by Onyedikachi *et al.* (2019) directly addresses the issue of heavy metal contamination in Ishiagu, Nigeria, by evaluating the human health risk associated with heavy metals in commonly consumed food crops grown in the area. The research sheds light on the bioaccumulation and hazard quotient of heavy metals in agricultural produce, emphasizing the potential threat to the food chain and the need for quality control measures to safeguard consumers from contamination. In their study, Bawa (2023) reported significant concentrations of heavy metals,), in pesticides, food crops, and soils in Paki, Nigeria. The study found that all tested food crops contained high levels of heavy metals, particularly cadmium and lead, exceeding acceptable limits. The soil in pesticide-fumigated crops also showed elevated levels of heavy metals. Children were found to be at potential non-cancer health risks from consuming certain The study by Obasi *et al.* (2023), assessed the health risks associated with consuming food crops grown in the Ishiagu mining area, where mining activities have increased the concentration of heavy metals in the soil. Samples of leaves and tubers from various crops were collected and analyzed for heavy metals. The results showed that Hg, Cd, and Pb were the most potent contaminants, with higher concentrations in tubers and higher frequencies in leaves. Children were found to be more vulnerable to the associated health risks. The study highlights the diverse degrees of health risks posed by consuming these crops due to the presence of Hg, Cd, and Pb.

Heavy metal in the Atmosphere: Ojiodu *et al* (2018) analyzed heavy metal levels in the atmosphere using moss plants at Yaba College of Technology in Lagos. Zn was the most abundant metal, while Ni was the least abundant. Cd was found near staff quarters and attributed to burning fossil fuels, metal smelting, and old paint chips. High levels of Zn, Pb, and Cu were attributed to vehicular operations, generator emissions, paint chipping, cosmetic usage, and metal disposal. Cr and Ni had low levels, possibly due to limited plant capacity for selective accumulation. Heavy metals have been detected in the atmosphere, according to studies. Ayua *et al.* (2020), measured the concentrations of eight heavy metals (Ni, Co, Cu, Pb, Cd, Cr, Mn, and Zn) in air samples taken from three industrial locations in Northern Nigeria: Kano, Kaduna, and Jos. The data was gathered between September 2018 and August 2019. Except for Ni, Pb, and Cd concentrations that exceeded the WHO/EU established limit with toxicity potential >1 in the Terytex industry, Kano, and Grand Cereals, Jos., the concentrations of the heavy metals investigated were determined to be within WHO/EU set guidelines. Similarly, Uzoekwe *et al.* (2021), in their study, assessed the environmental and human health hazards linked to heavy metals in atmospheric particulate matter (PM10) near a gas flaring facility in Bayelsa State, Nigeria. It was observed that the levels of heavy metals in the air were predominantly low, and the associated human health risk, including both carcinogenic and non-carcinogenic effects, fell within acceptable thresholds for various demographic groups.

The research carried out by Ogundele *et al.* (2017) in Ile-Ife, Nigeria, aimed to evaluate the occurrence of heavy metals in industrially emitted particulate matter and its potential implications for public health and the environment. The study area, known for its distinct dry and wet seasons, hosts an iron and steel scrap smelter. The study's findings demonstrated the presence of diverse heavy metals in the collected particulate matter, signifying potential environmental and health risks. This research underscored the importance of assessing heavy metal pollution in industrially emitted particulate matter, particularly in areas with industrial operations. The research conducted by Milam *et al.* (2022) in Barkin Ladi, Plateau State, Nigeria, identified elevated levels of heavy metals, such as arsenic, cadmium, chromium, copper, iron, manganese, nickel, lead, and zinc, in the edible parts of vegetables grown near abandoned mines. The risk assessment indicated that children face a heightened risk of developing cancer and non-carcinogenic health issues due to the consumption of contaminated vegetables. These findings underscore the critical necessity for implementing remediation and risk management measures to address the health hazards linked to heavy metal contamination in food crops. Uzoekwe *et al.* (2021) investigated heavy metals in particulate matter (PM10) suspended in the air around a gas flaring facility in Bayelsa state. Cobalt, arsenic, chromium, cadmium, copper, and iron were detected, with some concentrations exceeding safety limits. The study concluded that gas production and flaring did not significantly contribute to atmospheric metal loads. Anake *et al*. (2017): Determined PM2.5-bound trace metals in an industrial estate in Ogun state. The study reported inhalation exposure to cancer risks above acceptable levels, indicating a significant contribution of industrial activities to suspended metal levels in the air. Copper and chromium were found to be in an exchangeable form, posing risks if inhaled. Similarly, reports by Ogundele *et al.* (2017), investigated heavy metals (Pb, Mn, Cd, Zn, Cr, As, Ni, Cu, and Fe) in air particulate matter around iron and smelting companies in Ile-Ife, Osun state. Concentrations of cadmium, lead, manganese, and nickel exceeded safety limits, indicating pollution and potential health risks. In Port Harcourt, a city with oil refineries, Kalagbor *et al.* (2019) determined heavy metals in soot samples collected from residential areas. Concentrations of all metals exceeded limits set by the WHO, with high levels of cadmium and lead posing potential cancer risks, especially for children. Mafuyai *et al.* (2014) also Investigated heavy metals (Pb, Mn, Cd, Zn, Cr, Ni, Cu, and Fe) in respirable dust from seven locations in Jos metropolis, Plateau state. Concentrations of cadmium, nickel, and manganese greatly exceeded WHO-recommended limits, indicating vehicular traffic and waste incineration as sources. Further studies by Ayua *et al.* (2020) reported heavy metals in resp irable dust and particulate matter around industrial sites in Kano, Kaduna, and Jos. They reported concentrations of cadmium, nickel, and lead that exceeded WHO standards in some areas, implicating industrial activities as a significant contributor to air pollution. Richard *et al.* (2023) investigate air pollution in the Niger Delta region of Nigeria, focusing on sources, health effects, and mitigation strategies. The study identifies waste dumps, gas flaring, and food processing units as major sources of pollutants, including ammonia, hydrogen sulfide, carbon monoxide, sulfur dioxide, nitrogen dioxide, volatile organic compounds, and particulates. These pollutants often exceed recommended limits, leading to respiratory irritation, coughing, and organ dysfunctions. More studies by Okudo *et al.* (2023) focused on the concentrations of heavy metals in dry deposition samples collected from various locations in Enugu Urban, Nigeria. The findings revealed that the atmosphere in Enugu Urban is consistently being contaminated with toxic metals, posing a significant ecological risk. Among the metals analyzed, zinc, manganese, and copper exhibited the highest mean concentrations. The potential ecological risk indexes indicated elevated levels of contamination. Similarly, Aweda *et al.* (2023) conducted a study on the heavy metal concentration in Harmattan dust across selected stations in Nigeria. Using particle-induced x-ray emission (PIXE) technology, the researchers analyzed the elemental composition of the dust samples collected. The study revealed the presence of eighteen elements, including both heavy metals (Ti, Cr, Mn, Fe, Cu, Zn, and Zr) and non-heavy metals (Na, Mg, Al, Si, Cl, K, Ca, Rb, and Sr). The concentrations of these elements varied across the different locations, with Jos exhibiting the highest levels. The findings highlight the need for further research to address the environmental concerns associated with heavy metal contamination in Harmattan dust.

Abdulraheem *et al.* (2022) conducted a study to assess the contamination levels of heavy metals (HMs) in indoor dusts of different residential areas in Ilorin, Nigeria and evaluate the associated health risks. The study found that the mean concentrations of Fe, Pb, Zn, As, Co, Cr, Cu, Cd, Mn, and Ni in the indoor dust samples were within the range of 0.08-38.99 mg/kg. The positive Matrix Factorization (PMF) model identified six potential sources of HMs, with oil-based cooking and transportation contributing the highest percentage. The study also revealed that children are more susceptible to the health risks associated with HMs in indoor dust compared to adults. The contamination level of Cd was of particular concern, indicating a strong contribution from anthropogenic sources. Ushie *et al.* (2023), also assessed the levels of metals in ceiling fan dust in a tertiary institution in Calabar, Nigeria. Dust samples were collected from five lecture halls and analyzed for heavy metals. Results showed that most heavy metals were below contamination thresholds, indicating non-pollution. However, cadmium (Cd) exhibited high pollution levels. Regular cleaning of ceiling fans and awareness campaigns on the health risks associated with ceiling fan dust are recommended.

Public Health Implications

Exposure pathways for the Nigerian population: Elevated concentrations of heavy metals have been found in various environmental sources in Nigeria, including water, sediments, soil, vegetables, seafood, and others (Orisakwe *et al.*, 2012)). Understanding the exposure pathways is crucial to mitigate risks and ensure the safety of water sources, food, and the environment. Exposure to heavy metals in the Nigerian population occurs through various pathways, including ingestion, inhalation, and dermal contact (Anyanwu *et al.*, 2018; Ohiagu *et al.*, 2022). Water and sediments are major sources of heavy metal exposure. Laniyan and Adewumi (2023) assessed the ecological and human health risks associated with potentially toxic metals in water, identifying oral ingestion and dermal contact as the major exposure pathways. Similarly, Jolaosho *et al.* (2023) highlighted that heavy metals in water and sediments can be ingested, come into contact with the skin, or be inhaled. Hand-dug wells are another significant exposure pathway for heavy metals according to Balogun *et al.* (2023) who reported the exposure pathways and potential health risks associated with heavy metal contamination in hand-dug wells. Their findings emphasized that ingestion and dermal contact are significant pathways for heavy metal exposure from these wells. Chris *et al.* (2023) evaluated heavy metal contamination in water, sediment, and shellfish, highlighting ingestion and dermal contact as the main exposure pathways. Similar studies on groundwater are reported by Okafor *et al.* (2023) who evaluated heavy metal levels, emphasizing exposure pathways through ingestion and dermal contact for humans. Additionally, Ogarekpe *et al.* (2023) assessed the groundwater quality and potential health risks associated with heavy metal exposure, highlighting exposure pathways through ingestion and dermal contact. In the same vain, Ubong *et al.* (2023) reported the accumulation of heavy metals in seafood, particularly crabs, and emphasized the exposure pathway through the consumption of contaminated seafood. Felagha *et al.* (2020) also evaluated the health risk assessment of heavy metals in molluscs, indicating ingestion as the primary exposure route for individuals consuming products from polluted environments. Usman and Modibbo (2020) conducted a health risk assessment on edible crops and fish, highlighting ingestion as the main exposure route and indicating health risks above acceptable levels. The consumption of contaminated vegetables can contribute to heavy metal exposure. Yaradua *et al.* (2023) highlighted the exposure pathway through the consumption of contaminated vegetables. Soil contamination is an important exposure pathway for heavy metals. Olumayowa *et al.* (2023) assessed heavy metal levels in soils, emphasizing inhalation, ingestion, and dermal contact with contaminated soil. Similarly, Omang *et al.* (2023) identified dermal contact as a significant exposure pathway for local artisanal miners working with potentially toxic elements in soil. Indoor dust can contain heavy metals, leading to exposure through ingestion, dermal contact, and inhalation. Ajayi *et al*. (2023) investigated heavy metal presence in indoor dust samples, focusing on these exposure pathways. In summary, understanding the exposure pathways for heavy metal contamination in Nigeria is crucial for assessing the potential risks to the population. The pathways include ingestion, dermal contact, and inhalation through various sources such as water, sediments, hand dug wells, shellfish, soil, vegetables, indoor dust, and groundwater. Further research is needed to explore these exposure pathways in more detail and develop effective mitigation strategies to protect public health.

Toxicity of Heavy Metals: The toxicity of heavy metals refers to their ability to cause harmful effects on living organisms when they accumulate in the body beyond certain safe levels (Babula *et al.*, 2009; Ali *et al.*, 2019). Heavy metals such as lead, mercury, cadmium, arsenic, and chromium are known to be toxic to humans and can have detrimental effects on various organs and systems (Ungureanu and Mustățea, 2022). When heavy metals are not metabolized by the body and accumulate in soft tissues, they can become poisonous (Sobha *et al.*, 2007). The toxicity of heavy metals is a multifaceted issue influenced by various factors such as exposure routes, chemical species, bioavailability, the specific metal, the duration and level of exposure, and individual susceptibility (Ali *et al.*, 2019; Jibrin *et al.*, 2022). Athar *et al.* (2018) highlighted that the toxicity of heavy metals is dependent on factors such as exposure routes, age, gender, chemical species, nutritional status, and genetics of the affected individuals. Furthermore, Singh and Pant (2023) indicated that the toxicity of heavy metal ions is dose-dependent, and the bioavailability of heavy metals provides important evidence of metal toxicity. Symptoms of toxicity vary in different heavy metals, but there are general manifestations associated with certain metals. Once inside the body, heavy metals can interfere with essential biological processes. They can disrupt enzyme activity, damage DNA, generate reactive oxygen species (ROS), and cause oxidative stress (Sharma and Dietz, 2006; Athar *et al.*, 2018; Sudo *et al.*, 2019). These mechanisms can lead to a wide range of adverse health effects, including neurological disorders, kidney damage, respiratory issues, cardiovascular problems, reproductive and developmental abnormalities, and even cancer (Ouziad *et al.*, 2005; Orr *et al.*, 2018) . Certain heavy metals, such as lead and mercury, are particularly harmful to the developing brains of infants and young children, leading to cognitive and behavioral impairments (Athar *et al.*, 2018). Prolonged exposure to high levels of heavy metals can have chronic effects, while acute exposure to extremely high concentrations can cause severe poisoning and potentially be fatal. Due to their persistence in the environment and their ability to bioaccumulate in the food chain, heavy metals pose a significant risk to human health.

Although individual metals have different toxicity symptoms, the general symptoms of cadmium, lead, arsenic, mercury, zinc, copper, and aluminium poisoning include gastrointestinal disorders, diarrhoea, stomatitis, tremor, hemoglobinuria, ataxia, paralysis, and vomiting, as well as convulsion, depression, and pneumonia when vapours and fumes are inhaled (Jaishankar *et al.*, 2014). Lead ingestion or inhalation can harm children's brains, kidneys, bone marrow, and other systems. Blood lead levels as low as 5g/dL in babies and children have been linked to developmental difficulties such as decreased cognitive function, behavioural abnormalities, impaired hearing, and stunted growth (Ihedioha *et al.*, 2016), while levels exceeding 75g/dL cause unconsciousness, convulsions, and even death. Cadmium is a possible neurotoxicant, according to studies on pre- and postnatal cadmium exposure on cognitive quotient impairments (Davey, 2007). Developmental exposure in experimental animals suggests that operant performance and conditioned avoidance are also harmed. Hubbs-Tait and colleagues, 2005 Cadmium appear to pass the placental barrier and accumulate in the developing foetus, causing neurological diseases (CDC, 2008). Nickel is a trace element that is required in animals and is frequently linked to chronic bronchitis, emphysema, reduced pulmonary function, and fibrosis (Figueroa *et al.*, 2006). Copper and chromium are necessary metals, however excessive use is hazardous (Nkwunonwo *et al.*, 2020). While copper is a component of iron processing enzymes whose lack causes anaemia, chromium aids in blood glucose regulation and is commonly utilised in diabetic treatments (Onakpa *et al.*, 2018). Excessive copper and chromium toxicity occurs in both acute and chronic forms. Acute copper intoxication causes nausea, vomiting, jaundice, liver necrosis, renal proximal tubule destruction, and anaemia((Naz *et al.*, 2020). Wilson's illness is a kind of chronic copper poisoning in humans that manifests as mental changes, motor abnormalities, dysphagia, ataxia, hemolytic anaemia, renal dysfunction, kidney stones, and hepatic failure (Bradberry and Vale, 2014). Chromium poisoning is often caused by physical contact with contaminated dust or soil, which results in allergic dermatitis characterized by eczema (Teklay, 2016).

Health risks associated with specific heavy metals: Exposure to heavy metals poses significant health risks to individuals, with potential adverse effects on various organ systems and overall well-being (Rahman and Singh, 2019; Zulaikhah *et al.*, 2020). Heavy metals, such as lead, cadmium, mercury, arsenic, and chromium, are naturally occurring elements that can be found in the environment, but human activities have contributed to their widespread presence (Álvarez-Solorza *et al.*, 2022; Zahra *et al.*, 2022). These toxic substances can enter the body through various routes, including inhalation, ingestion, and dermal contact. Once absorbed, heavy metals can accumulate in tissues and organs, leading to chronic toxicity and a range of health issues, including neurological disorders, cardiovascular diseases, kidney damage, respiratory problems, and even cancer (Kannaujia and Singh, 2012). Several studies have assessed the levels of heavy metals in various environmental samples and evaluated the associated health risks through risk assessment methodologies. Olumayowa *et al.* (2023) conducted a risk assessment in the Oke-Ere mining area in Nigeria, revealing considerable contamination due to mining activities. Likewise, Chris *et al.* (2023) determined the risk of heavy metals in the Opuroama creeks, highlighting high mean carcinogenic and non-carcinogenic hazard index values in shellfish regularly consumed by humans residing in that area. In the same manner, Balogun *et al.* (2023) assessed the concentrations of heavy metals in hand-dug wells, finding that the concentrations were generally low and fell within regulatory standards, indicating a low non-carcinogenic health risk. Laniyan and Adewumi (2023) investigated the ecological and human health risks associated with potentially toxic metals in water from the Ijero mining area in Nigeria. The study revealed that the waters from this area were moderately to extremely polluted by heavy metals, posing significant health risks to the local population. In tandem, Jolaosho *et al.* (2023) aimed to assess the health risks associated with specific heavy metals in water and sediments. The study found a low non-carcinogenic risk but identified a carcinogenic risk associated with certain heavy metals, emphasizing the need for mitigating unsustainable mining activities. Bampoe *et al.* (2023) assessed the levels of heavy metals in dust from transport stations, indicating low potential for non-carcinogenic effects but a high cancer risk from cadmium exposure through ingestion. Gbadamosi *et al.* (2023) evaluated the health risks associated with specific heavy metals in waste dumpsites, finding that the mean concentrations of metals exceeded global average values in most samples, indicating potential health hazards. Ezenwa *et al.* (2022) assessed the health risks associated with heavy metals in spring water, revealing that the hazard quotient values for certain metals were below 1, indicating a low non-carcinogenic risk, but the hazard index values indicated a high chronic risk. Omokpariola and Omokpariola (2023) assessed the health and exposure risks associated with heavy metals in rainwater, identifying chromium-VI as the highest contributor to cancer risk. These studies collectively provide valuable insights into the contamination levels, potential exposure pathways, and the non-carcinogenic and carcinogenic health risks posed by specific heavy metals, emphasizing the need for effective preventive measures to safeguard human health.

Case studies of heavy metal poisoning incidents in Nigeria: The repercussions of heavy metal poisoning incidents in Nigeria are profound and have been extensively studied, shedding light on their severe health implications. Thurtle (2010) presents a heart-wrenching case study centred on the aftermath of a gold rush in northern Nigeria, which tragically resulted in a lead poisoning outbreak. Over 200 children lost their lives, and around 18,000 individuals were affected due to the inadvertent release of lead particles during manual ore grinding for gold. The ensuing health consequences were devastating, including death, deafness, blindness, brain damage, and muscular problems, marking an unprecedented scale of lead poisoning. Despite a mining ban, new cases continue to emerge, emphasizing the ongoing challenges in mitigating the aftermath (Mejia, 2015). Studies conducted in the Niger Delta region, a hotspot for heavy metal poisoning incidents, have also revealed negative health effects associated with heavy metal exposure, as detailed by Chinedu and Chukwuemeka (2018). Similarly, Ogamba *et al.* (2021) reported concentrations exceeding WHO limits in the surface water of Taylor creek, Bayelsa State, Nigeria, highlighting potential risks to local communities. Ubiogoro and Adeyemo (2017) identified elevated heavy metal levels in both water and fish samples, underscoring the need for comprehensive assessments and mitigation strategies. These studies collectively underscore the urgency of addressing heavy metal exposure in the Niger Delta and implementing effective mitigation measures. Adeyi and Babalola (2017) investigated the health implications of heavy metal poisoning, particularly lead and cadmium, in residential soils of Lagos and Ibadan. The study found higher concentrations of lead and cadmium around residential buildings than in control samples, posing significant health risks, especially for children. Lead exposure has been associated with adverse neurological, cardiovascular, and developmental effects, while chronic cadmium exposure is linked to increased mortality and higher risks of cancer and cardiovascular disease. These findings underscore the importance of addressing soil contamination and implementing measures to reduce heavy metal exposure for public health protection. Atikpo *et al.* (2021) conducted a study in the Agbabu community, revealing high levels of heavy metals, including cadmium, lead, zinc, and chromium, in both soils and vegetables. The health implications include hepatic and renal dysfunction from cadmium exposure, lead's harmful effects on cognitive abilities and reproductive systems, zinc-induced vomiting and weakened immune systems, and chromium-associated lung cancer and other disorders. Monitoring heavy metal contamination in food, particularly vegetables, is crucial to mitigate health risks. Nkwunonwo *et al.* (2020) discuss the health implications of heavy metals in Nigeria's food chain, emphasizing the abundance of metals like lead, cadmium, vanadium, cobalt, chromium, copper, iron, arsenic, nickel, manganese, tin, zinc, and mercury. These metals can contaminate aquatic foods, fruits, vegetables, and staple foods, posing a source of toxicity to humans. The health impacts include inhibited enzyme activity, developmental disorders, impaired cognitive function, behavioural changes, neurological disorders, and various adverse effects. The authors call for intensified monitoring and analysis of food components to ensure food safety and advocate for cautious food consumption by consumers. Orisakwe (2014) conducted a review on the effects of heavy metals on public health in Nigeria, highlighting increased incidences of metabolic disorders such as hypertension, diabetes, renal disease, cancer, and male infertility linked to heavy metal exposure. Lead and cadmium are particularly concerning, with high levels found in blood. The review stresses the need for heavy metal assays in diagnosing and managing these chronic diseases for early detection and intervention. It is evident that heavy metal exposure in Nigeria poses significant risks to public health and requires comprehensive preventive measures and awareness campaigns. Similar findings by Onakpa *et al.* (2018), Brown and Woolf (2022), and Biya *et al.* (2010) highlight the severe effects of heavy metal poisoning incidents on human health in Nigeria. The lead poisoning outbreak in Zamfara villages in 2010 resulted in the death of 163 people, including 111 children, due to the unauthorized and illegal mining of gold ores. Artisanal mining operations in Southwestern Nigeria also put around two million people at risk of lead and mercury poisoning (Adesipo *et al.*, 2020; Bartrem *et al.*, 2022). In another study by Eluke *et al.* (2021), heavy metal contamination in oil-producing communities in Nigeria's Niger Delta region is associated with significant health risks. Elevated concentrations of lead, iron, zinc, arsenic, nickel, and cadmium were found in both soil and water samples from affected areas. The study revealed an increased risk of cancer among the adult population, emphasizing the detrimental effects of heavy metal exposure on the health of local residents in Nigeria's oil-producing regions. The health effects include reproductive impairments, brain and kidney damage, gastrointestinal diseases, damage to the central nervous system, and disruption of vitamin D metabolism. These incidents underscore the urgent need for monitoring and addressing heavy metal contamination in Nigeria to protect public health.

Policy and Legislative Framework

The policy and legislative framework addressing heavy metal pollution in Nigeria are complex, with existing laws and regulations facing criticism for their inadequacy, as noted by Anya and Odo (2023). While the Nigerian Constitution recognizes the right to a healthy environment, statutory laws like the Federal Environmental Protection Agency (FEPA) Act of 1988 and the Environmental Impact Assessment (EIA) Act of 1992 provide a foundational framework. However, their implementation and enforcement have been ineffective, necessitating the need for stronger legislation to mitigate heavy metal pollution and fulfil the constitutional obligation. Various studies underscore the significance of policies and legislative frameworks in mitigating heavy metal pollution in different environmental contexts. Izah *et al.* (2016) discuss the impact of heavy metal contamination in potable water sources and the aquatic ecosystem in Nigeria, emphasizing the need for robust policies. Regulatory bodies like the National Agency for Food and Drug Administration and Control (NAFDAC) play crucial roles in setting standards and enforcing rules to ensure the quality of drinking water, protecting public health from the harmful effects of heavy metal contamination. Moreover, regulatory agencies like the Lagos State Environmental Protection Agency (LASEPA) and the National Environmental Standards and Regulation Enforcement Agency (NESREA) have been established to enforce safe limits for heavy metal discharge. Despite these efforts, the study highlights the need for stricter enforcement, especially for cadmium pollution, necessitating the revision and implementation of safe limits for heavy metal discharge in waste streams. Oloruntoba *et al.* (2021) emphasize the widespread environmental hazards caused by heavy metals in Nigeria, pointing to policies and legislative frameworks like the National Environmental Standards and Regulations Enforcement Agency (NESREA) Act of 2007. This legislation establishes standards for environmental protection, focusing on regulating industrial activities and setting safety limits for toxic pollutant discharge. The Federal Ministry of Environment also plays a pivotal role in enforcing environmental regulations and ensuring compliance with international standards. Furthermore, Izah *et al.* (2016) discuss the public health implications of heavy metal pollution in Sub-Saharan Africa (SSA), specifically in Nigeria. They highlight the prevalence of mineral resources leading to environmental safety threats and stress the urgent need for stricter regulations and enforcement. The authors underscore the importance of developing robust policies and legislation to address heavy metal pollution not only in Nigeria but the entire sub-Saharan African region. Anyanwu *et al.* (2018) conducted a study on the environmental metal load of Aba, Nigeria, revealing significant pollution. The study underscores the need for policies and legislative frameworks to address heavy metal pollution, with existing standards set by the Federal Environmental Protection Agency (FEPA) and the World Health Organization (WHO). However, the study reveals that mean concentrations in Aba exceed these standards, necessitating the implementation and enforcement of stricter laws to mitigate heavy metal pollution. In summary, while Nigeria has established several policies and legislations to combat heavy metal pollution, challenges persist in their implementation and enforcement. The need for stronger legislation, revision of safe limits, and enhanced monitoring are recurrent themes across these studies, highlighting the complex and evolving nature of addressing heavy metal pollution in the country.

Analysis of existing environmental policies and regulations in Nigeria: When we delve into the existing environmental policies and regulations in Nigeria, we uncover a complex web of approaches aimed at tackling heavy metal pollution. This analysis aims to dissect these frameworks, exploring their significance, and the hurdles they encounter, all while stressing the importance of ongoing enhancements.

To ensure the potency of our current policies and regulations, it's imperative to subject them to periodic scrutiny and refinement, aligning them with evolving scientific understandings and technological breakthroughs. This entails revisiting and recalibrating safe thresholds for heavy metal concentrations across various environmental domains, while also integrating cutting-edge strategies for pollution prevention and control.

Constitutional Recognition and FEPA Act: The Nigerian Constitution, specifically Section 20 of Chapter 2, recognizes the right to a healthy environment and mandates state protection (Ite *et al.*, 2016). Complementing this constitutional provision, the Federal Environmental Protection Agency (FEPA) Act of 1988 establishes a comprehensive framework for environmental protection and management, designating FEPA as the regulatory body (Ite *et al.*, 2016). The FEPA Act plays a crucial role in addressing metal pollution and its impact on the environment. FEPA is tasked with formulating policies, guidelines, and regulations to control and mitigate the release of pollutants, including heavy metals, into the environment. It sets standards for industries and conducts environmental impact assessments to ensure compliance with these regulations (Abubakar *et al.*, 2022; Umukoro and Omozue, 2022). FEPA also plays a vital role in monitoring and enforcing regulations related to the handling, storage, and disposal of hazardous substances, including metals, to prevent pollution and safeguard human health. The agency is instrumental in addressing heavy metal pollution, air quality, waste management, and environmental challenges associated with oil exploration in the Niger Delta region (Ite *et al.*, 2016; Awhefeada *et al.*, 2023). Through its initiatives, FEPA aims to reduce metal pollution and promote sustainable environmental practices in Nigeria. However, the challenges facing the effective implementation of the FEPA Act in Nigeria are multi-faceted, as highlighted by scholars in the field. Umukoro and Omozue (2022) point out that inadequate enforcement and implementation of environmental regulations pose a significant challenge to mitigating heavy metal pollution. Additionally, the limited resources and capacity within FEPA hinder its ability to conduct inspections, investigations, and enforcement actions (Abubakar *et al.*, 2022; Umukoro and Omozue, 2022). Furthermore, the lack of public awareness and participation results in limited engagement in environmental protection efforts and a lack of accountability (Nwaichi and Osuoha, 2021; Awhefeada *et al.*, 2023). Lastly, regulatory gaps or inconsistencies within the FEPA Act, as noted by Umukoro and Omozue (2022), can impede the effective regulation of emerging environmental issues and new industries. Addressing these challenges is essential to strengthen the regulatory framework and enhance the capacity of FEPA to address heavy metal pollution and other environmental concerns effectively.

National Environmental Standards and Regulations Enforcement Agency (NESREA) 2007: The National Environmental Standards and Regulations Enforcement Agency (NESREA) Act, 2007, assumes a pivotal role in mitigating heavy metal pollution (Ladan, 2012; Abubakar *et al.*, 2022). NESREA, empowered by the act, sets and enforces regulations related to heavy metals in various environmental compartments (Kafilat *et al.*, 2018; Bawa-Allah, 2023). It can develop specific regulations and standards to address heavy metal pollution, such as setting limits on heavy metal emissions from industries and establishing guidelines for the safe handling and disposal of heavy metal-containing waste (Abubakar *et al.*, 2022). NESREA's significance lies in its capacity to monitor, enforce regulations, and conduct risk assessments to protect public health and the environment from heavy metal effects (Akinnifesi *et al.*, 2021). Challenges, including enforcement limitations due to resource constraints, highlight areas for improvement (Ladan, 2012). The challenges associated with the implementation of the NESREA Act in Nigeria include limited resources, capacity-building needs, enforcement and compliance issues, stakeholder engagement, and monitoring and data management requirements (Umukoro and Omozue, 2022). These challenges, such as inadequate funding, staffing, and equipment, weak enforcement mechanisms, and limited awareness among industries, hinder NESREA's ability to effectively address environmental issues, including heavy metal pollution (Umukoro and Omozue, 2022).

National Policy on Environment, 1991: The National Policy on Environment, 1991, serves as a comprehensive framework for environmental protection and sustainable management in Nigeria (Abubakar *et al.*, 2022). The policy came into existence in 1991 and has been revised in 1999 and 2016 to address emerging environmental issues and concerns (Abubakar *et al.*, 2022). The policy was established to address the numerous environmental challenges in Nigeria, including air pollution, water pollution, lead poisoning, poor waste management, deforestation, desertification, wind erosion, and flooding (Awhefeada *et al.*, 2023). Addressing heavy metal pollution, the policy advocates strict regulations, environmentally friendly technologies, and regular monitoring (Umukoro and Omozue, 2022). However, challenges in implementation, corruption, agencies overlap lack of enforcement, and funding pose obstacles that need addressing for the policy's effectiveness. The implementation of the NPE and relevant guidelines faces challenges due to the non-justiciability constitutional clause, which limits the legal enforceability of policies and guidelines (Umukoro and Omozue, 2022). Additionally, the article identifies a lack of political will and the failure of administrative bodies and the government to involve the public in policy-making and implementation strategies as major challenges (Umukoro and Omozue, 2022). This lack of public participation hinders the effective implementation and enforcement of environmental protection measures.

The Environmental Impact Assessment (EIA) Decree of 1992: The Environmental Impact Assessment (EIA) Decree of 1992 is a crucial piece of legislation contributing to sustainable development and environmental protection in Nigeria. This act mandates developers to evaluate and mitigate the potential environmental impacts of their projects, including those associated with heavy metals (Umukoro and Omozue, 2022; Osuizugbo and Nnodu, 2023). Through the EIA process, projects posing risks of metal pollution can be identified, and necessary measures can be taken to prevent or minimize the release of heavy metals into the environment. In essence, the EIA involves conducting comprehensive studies to identify potential sources of metal pollution, assessing the risks and impacts on ecosystems and human health, and devising strategies to prevent or minimize pollution (Umukoro and Omozue, 2022). However, the implementation of the EIA Act in Nigeria faces specific challenges concerning heavy metals pollution. One significant challenge is the inadequate consideration of the specific risks and impacts associated with heavy metals within the EIA process (Osuizugbo and Nnodu, 2023). Often, the assessment may not thoroughly evaluate the potential sources of heavy metals pollution, the pathways through which they can enter the environment, and the potential risks they pose to ecosystems and human health. This can result in insufficient mitigation measures and inadequate protection against heavy metal pollution (Osuizugbo and Nnodu, 2023). Furthermore, the absence of robust monitoring and enforcement mechanisms can hinder the detection and control of heavy metal emissions, leading to ongoing pollution. Insufficient public participation and stakeholder engagement also limit the identification of concerns related to heavy metal pollution and the development of effective mitigation strategies (Osuizugbo and Nnodu, 2023). To address these challenges effectively, there's a need to enhance the technical expertise and capacity of regulatory agencies responsible for assessing heavy metals pollution. Additionally, efforts should focus on improving monitoring and enforcement measures while promoting meaningful engagement of stakeholders in the EIA process. This comprehensive approach is vital for ensuring effective management of heavy metals pollution in Nigeria (Umukoro and Omozue, 2022; Osuizugbo and Nnodu, 2023).

National Oil Spill Detection and Response Agency (NOSDRA) Act: The NOSDRA Act aims to protect human life and the environment from oil spills. While the primary focus is on oil spills, it can also be relevant to heavy metal pollution incidents resulting from oil exploration and production activities. The National Oil Spill Detection and Response Agency (NOSDRA) Act was established in 2006 in Nigeria, to address oil spillage and its environmental impact (Okere and Osemeke, 2020). However, the agency has acknowledged its limited capacity and technological resources to effectively carry out its role (Okere and Osemeke, 2020). This is significant as it indicates a potential gap in NOSDRA's ability to monitor and respond to incidents involving heavy metal contamination resulting from oil-related activities. Environmental rules and regulations have been implemented to prevent oil spills, but the risk of incidents persists (Jha *et al.*, 2008). Therefore, NOSDRA could play a crucial role in monitoring and responding to heavy metal pollution incidents caused by oil exploration and production activities, provided it receives the necessary support and resources to enhance its capacity and technological capabilities (Jha *et al.*, 2008; Okere and Osemeke, 2020).

National Water Policy Act and Heavy Metal Pollution: The National Water Policy in Nigeria stands as a cornerstone in promoting the sustainable management of water resources (Enyidi, 2017). This policy holds immense potential in combatting metal pollution in water bodies through its establishment of standards for acceptable levels of heavy metals in water sources, continual monitoring of water quality, and implementation of measures aimed at curtailing or mitigating metal contamination (Gbadegesin and Olorunfemi, 2009; Enyidi, 2017). By setting these standards and enforcing them through robust monitoring and preventive actions, the policy can significantly contribute to the preservation of water resources. Moreover, the policy's role in addressing heavy metal contamination aligns seamlessly with the broader objective of sustainable water resource management. The escalating industrialization and urban development in Nigeria have led to heightened levels of heavy metals in water sources. This reality underscores the urgency for effective policies and regulations, as highlighted by various studies (Adeniyi and Achukwu, 2018; Okere and Osemeke, 2020; Ahiamadu *et al.*, 2021; Osisanya *et al.*, 2022). Furthermore, the looming health risks associated with heavy metal contamination in food crops and aquatic ecosystems emphasize the critical need for stringent measures to safeguard water resources and ensure public health (Onakpa *et al.*, 2018). In essence, the National Water Policy in Nigeria plays an instrumental role in combating metal pollution in water bodies by not only establishing standards but also rigorously monitoring water quality and enforcing measures to prevent or reduce metal contamination. Its emphasis on sustainable water resource management perfectly aligns with the imperative to shield water sources from heavy metal pollution, thereby ensuring their safety for various uses and safeguarding public health and the environment.

International Standards and Their Application in Nigeria: International standards play a vital role in addressing heavy metal pollution in Nigeria (Adeyeye *et al.*, 2018; Afonne *et al.*, 2022; Essien *et al.*, 2022). International standards for heavy metal pollution and their application in Nigeria have been a topic of concern in several studies. The studies have focused on different aspects of heavy metal pollution, including its effects on water sources, staple food cultivars, drinking water, and soil (Nicholas *et al.*, 2022; Agbaje *et al.*, 2023). The results of these studies have shown that heavy metal concentrations in various environmental samples often exceed the recommended limits set by international standards such as those of the World Health Organization (WHO) and the Standard Organization of Nigeria. This indicates a potential health risk to human populations and ecosystems. Overall, research from Nigeria highlights the importance of adhering to international standards to protect human health and the environment from the adverse effects of heavy metal pollution (Adeyeye *et al.*, 2018; Afonne *et al.*, 2022; Essien *et al.*, 2022; Nicholas *et al.*, 2022; Agbaje *et al.*, 2023). International standards for heavy metal pollution also involve conventions, protocols, and agreements aimed at reducing and controlling the release of heavy metals into the environment. Notably, two key instruments address heavy metal pollution (UNECE, 1998; UNEP, 2015):

Convention on Long-Range Transboundary Air Pollution (CLRTAP) and its Protocol on Heavy Metals: This convention, established in 1979, addresses air pollution, including heavy metals, and promotes cooperation among parties to tackle transboundary air pollution issues. Its Protocol on Heavy Metals, signed in 1998, specifically targets mercury, lead, and cadmium, setting emission ceilings and encouraging the use of Best Available Techniques (BAT). It is worth noting that Nigeria is not a party to the LRTAP Convention (Kehinde, 2021). However, Nigeria has taken some steps to address air pollution at the national level.

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Minamata Convention on Mercury: The Minamata Convention on Mercury, adopted in 2013, has garnered global attention for its aim to minimize mercury releases into the environment (UNEP, 2015). This convention acts as a complement to the CLRTAP Protocol on Heavy Metals, specifically targeting mercury emissions with more stringent regulations. In the context of Nigeria, the convention holds particular significance due to the country's link between primary gold deposits and heavy metals like lead, arsenic, and copper (Odogwu, 2021). Nigeria's association with primary gold deposits underscores the importance of the Minamata Convention, as it places obligations on the country to develop and implement a National Action Plan (NAP) to reduce mercury use in artisanal and small-scale gold mining (ASGM). This is crucial in addressing the exposure of ASGM miners and their communities to mercury, given the environmental and health risks associated with such activities (UNEP, 2015; Brugger *et al.*, 2020). Having signed the convention in 2013 and ratified it in 2018, Nigeria has showcased its commitment to curbing mercury use and mitigating the impacts of ASGM on the environment and public health (Odogwu, 2021). The convention's emphasis on reducing mercury aligns well with Nigeria's ongoing efforts to tackle heavy metal pollution stemming from gold mining activities, safeguarding both the well-being of its population and the ecological balance (Brugger *et al*. 2020, Odogwu 2021. Moreover, Nigeria's substantial ASGM sector, a key source of anthropogenic mercury emissions, has underscored the urgency of implementing measures outlined in the Minamata Convention (Odogwu, 2021). Notably, incidents like the lead poisoning outbreak in northern Nigeria, attributed to ASGM practices, highlight the pressing need to address mercury use and its associated risks comprehensively. In essence, the Minamata Convention's targeted approach to reducing mercury aligns with Nigeria's objectives to combat heavy metal pollution linked to gold mining, underscoring the country's commitment to environmental sustainability and public health protection (Brugger *et al.*, 2020; Odogwu, 2021).

The Rotterdam Convention: The Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International Trade aims to promote shared responsibilities concerning the importation of hazardous chemicals and contribute to their safe use (UNEP, 2010; UNEP, 2015). The Convention, which entered into force on 24 February 2004, creates legally binding obligations for the implementation of the PIC procedure. It covers pesticides and industrial chemicals that have been banned or severely restricted for health or environmental reasons by Parties and which have been notified by Parties for inclusion in the PIC procedure. Nigeria is a Party to the Rotterdam Convention, having ratified it in 2001 (Babayemi *et al.*, 2022). As a Party, Nigeria has designated National Authorities (DNAs) responsible for implementing the Convention's obligations, including import decisions, notification of regulatory actions, and information exchange (Rotterdam Convention, n.d.). While Nigeria has made progress in implementing its obligations, challenges remain, such as the need for comprehensive legislation, role conflicts among ministries and agencies, and limited information exchange (FME, 2021). Efforts are underway to strengthen Nigeria's national chemicals management infrastructure and enhance inter-ministerial coordination to ensure full compliance with the Convention (FME, 2021). The Rotterdam Convention is an international treaty that aims to promote shared responsibilities and cooperative efforts among countries in the international trade of hazardous chemicals (FME, 2021; Babayemi *et al.*, 2022). It requires countries to obtain prior informed consent (PIC) from importing countries before exporting certain hazardous chemicals.

The Aarhus Protocol: The Aarhus Protocol on Heavy Metals, adopted in 1998, focuses on addressing emissions of cadmium, lead, and mercury by setting targets for parties to reduce emissions below 1990 levels and implement Best Available Techniques (BAT). This protocol was later updated in 2012 to include more stringent controls (UNECE, 1998). In 2012, the protocol underwent updates to introduce more stringent controls, reflecting the ongoing efforts to enhance environmental protection and reduce the impact of heavy metal pollution. The inclusion of additional measures in the updated protocol demonstrates a commitment to continuously improving regulations and practices to safeguard human health and the environment from the harmful effects of heavy metals (UNECE, 2023). These international standards help guide national policies and actions to manage heavy metal pollution, ensuring that nations cooperate to achieve sustainable development goals while protecting human health and the environment. However, challenges in monitoring, enforcement, weak governance, and the presence of informal sectors hinder their effective application (Agwu *et al.*, 2023; Bawa-Allah, 2023). Raising awareness among communities and international collaborations can address these challenges (Akinnifesi *et al.*, 2021); (Aremu and Inajoh, 2007). Strengthening these partnerships and addressing governance issues are essential for Nigeria to effectively mitigate heavy metal pollution and uphold public health (Emurotu and Onianwa, 2017; Ohiagu *et al.*, 2022). Identifying gaps in the legislative framework and areas for improvement is crucial for sustained progress.

Gaps in the Current Legislative Framework and Areas for Improvement: Despite the presence of comprehensive legislation, there are notable gaps and areas for enhancement that persist in Nigeria's current legislative framework regarding heavy metal (Anyanwu *et al.*, 2018). These gaps include:

a) Inadequate enforcement: Resource constraints and limited capacity hinder effective enforcement of existing regulations.

b) Lack of clear funding strategies: The absence of well-defined funding mechanisms poses challenges for the efficient implementation of policies aimed at addressing heavy metal pollution.

c) Weaknesses in periodic review mechanisms: The legislative frameworks lack robust mechanisms for regular reviews and updates to adapt to evolving environmental challenges.

d) Challenges in neglected regions: Certain regions, such as the Niger Delta, face neglect in terms of environmental protection measures, exacerbating pollution issues.

e) Limited monitoring and control capacity: Insufficient capacity for monitoring and controlling environmental activities undermines effective regulation of heavy metal pollution sources.

To bridge these gaps and drive improvements, a holistic approach is essential. This approach should involve:

a) Enhanced enforcement mechanisms: Strengthening enforcement capabilities through increased resources, training, and collaboration with enforcement agencies.

b) Sustainable funding strategies: Developing clear and sustainable funding mechanisms to support the implementation of policies and programs addressing heavy metal pollution.

c) Regular legislative reviews: Instituting periodic reviews of legislative frameworks to ensure alignment with current environmental challenges and best practices.

d) Increased community involvement: Engaging local communities and stakeholders in decision-making processes and pollution control efforts to enhance accountability and effectiveness.

By addressing these gaps and implementing the necessary improvements, Nigeria can bolster the long-term effectiveness of its legislative frameworks in combating heavy metal pollution, safeguarding the environment, and protecting public health.

Remediation and Management Strategies: Bioremediation of heavy metals in Nigeria has been explored through various studies. (Ekperusi and Aigbodion, 2015) investigated the use of the earthworm *Eudrilus eugeniae* for bioremediation of heavy metals and petroleum hydrocarbons. Nwagwu *et al.* (2017) isolated heavy metal-resistant bacteria from the Panteka stream in Nigeria, demonstrating their capacity for bioremediation. Ugboma *et al.* (2020) focused on the bioremediation of heavy metals from crude oil refinery-impacted soil using Bacillus flexus and Pseudomonas aeruginosa. Prakash (2023) critically reviewed the potential of nano-phytoremediation for heavy metal removal. Jethro *et al.* (2024) investigated the effect of particle sizes on the bioremediation of crude oil-polluted sandy soil. Nnaji *et al.* (2023) provided a comprehensive review on the bioremediation of heavy metals through bioaccumulation, highlighting various techniques such as phytoaccumulation, phytostimulation, and phytovolatilization. Ntesat *et al.* (2023) explored the bioremediation potential of *Jatropha tanjorensis* leaf extract in crude oil-contaminated soil, demonstrating its effectiveness in reducing heavy metal concentrations. Wani *et al.* (2023) investigated the potential of Brevibacillus parabrevis OZF5 for the bioremediation of hexavalent chromium and zinc through biosorption. (Olowomofe *et al.*, 2022) studied the bioremediation of metal-containing effluent using metal-tolerant bacteria isolated from fish-pond wastewater. Adebajo *et al.* (2023) examined the potential of bacterial strains isolated from industrial metal dumpsites and farmland soils for heavy metal bioremediation Anoliefo *et al.* (2023) focused on the ex-situ mycoremediation of petroleum-polluted soils, identifying the role of the mushroom *Pleurotus tuberregium* and observing a reduction in heavy metal concentrations. Adeyemo *et al.* (2023) investigated the use of indigenous hydrocarbon-utilizing bacteria in bioreactor-based bioremediation of hydrocarbon-polluted soil. (Olatomiwa and Ashaolu, 2023) compared the bioremediation potential of heavy metal-resistant fungi isolated from mechanic sites contaminated with zinc and copper. (Aransiola, 2023) explored the microbial and vermicompost-assisted phytoremediation of heavy metal-contaminated soil. Jaja, Olufunmilayo *et al.* (2023) investigated the potential of phytoremediation and bioaugmentation using Pseudomonas and Bacillus spp. for heavy metal removal in crude oil-contaminated soil.

Sustainable and Efficient Technologies for Heavy Metal Removal: Phytoremediation, a sustainable method for decontaminating heavy metals, involves plants and rhizospheric bacteria (Jayakumar *et al.*, 2021). Various techniques, such as phytovolatilization, phytoextraction, phytodegradation, phytostabilization, and phytofiltration, are commonly utilized (Grandlic *et al.*, 2008). Different plant species, particularly hyperaccumulator plants, exhibit varying abilities to absorb and detoxify heavy metals. The addition of plant growth-promoting rhizobacteria (PGPR) enhances phytoremediation capabilities by improving metal absorption from the root (Laniyan and Morakinyo, 2021). This emerging technology has gained attention for its non-invasiveness, cost-effectiveness, and aesthetic appeal in removing heavy metals from contaminated soil (Singh and Pant, 2023). In addition to biotechnological approaches and phytoremediation, sustainable recycling technologies play a crucial role in mitigating heavy metal effects. These technologies involve recovering and upcycling precious metals from e-waste, reducing the need for mining and associated environmental impacts (Laniyan and Morakinyo, 2021). Apart from environmental benefits, these recycling methods can create economic opportunities. The exploration of innovative and sustainable technologies for heavy metal removal is a vital research area, particularly concerning environmental sustainability and pollution prevention in Nigeria. Biosorption, bioremediation, electrocoagulation, nanomaterials, adsorption using natural adsorbents, ion exchange, electrokinetic remediation, chemical remediation, and hybrid zero-valent iron processes have been proposed as means to mitigate heavy metal impacts (Laniyan and Morakinyo, 2021). Biosorption, specifically the use of biomass to remove heavy metals from water, is identified as an efficient technique. Biochar development from floral waste for heavy metal removal from synthetic wastewater is also promising (Kucserka *et al.*, 2023). Furthermore, phytoremediation, an eco-friendly approach using plants to remove heavy metals, is recognized as a viable method for environmental remediation (Abidli *et al.*, 2022). Other innovative approaches, including electrocoagulation, nanomaterial-based remediation, and the use of natural adsorbents, show potential for removing and recovering toxic and valuable metals from wastewater (Akinnifesi *et al.*, 2021). However, to implement these technologies effectively, continuous scientific research, development, and integration into environmental policies and regulations are necessary. Capacitive deionization (CDI) and electrosorption emerge as methods for heavy metal removal, utilizing porous carbon materials as electrodes (Chen *et al.*, 2020; Kalfa *et al.*, 2020). CDI, a low-cost technique, involves adsorbing metal ions from water using an electric field and can enhance heavy metal removal efficiency when combined with other technologies (Chen *et al.*, 2020; Kalfa *et al.*, 2020) Activated carbon, due to its low cost and large specific surface area, is commonly used as the electrode material. However, further research is needed to develop materials capable of selectively removing specific ions. Biotechnological approaches and genetic engineering offer potential solutions to heavy metal pollution (Mosa *et al.*, 2016). These approaches use microorganisms and genetically modified plants to remove heavy metals through mechanisms like biosorption, biodegradation, and bioaccumulation (Abidli *et al.*, 2022; Saravanan *et al.*, 2022). In conclusion, the multifaceted issue of heavy metal removal in Nigeria requires a scientific, evidence-based, and policy-informed approach. By leveraging these technologies and addressing gaps in policy and regulation, Nigeria can make significant strides toward mitigating heavy metal pollution and achieving enhanced environmental sustainability.

Role of community involvement and education in managing heavy metal pollution: Community involvement and education are pivotal elements in managing pollution, particularly evident in various Nigerian studies. In the realm of waste management sustainability, research indicates the critical role of education and awareness in fostering sustainable practices (Marzo *et al.*, 2023). In the Nigerian context, community participation is acknowledged as a fundamental strategy in environmental adult education and management, engaging residents in resource management and heightening awareness about the perils of unsustainable environmental practices (Ebere, 2022). Moreover, environmental education is recognized as a vital tool, equipping the public with knowledge, values, and skills that bolster environmental protection, especially regarding water-related issues like pollution and scarcity (KolaOlusanya *et al.*, 2023). Specifically, in the Niger Delta, community involvement is indispensable for environmental decision-making and addressing the significant threats posed by pollution to biodiversity and human well-being (Adomokai and Sheate, 2004; Zabbey *et al.*, 2021). Engaging local communities in cleanup efforts and decision-making processes is crucial to address their needs, and concerns, and promote sustainable development in the face of environmental challenges. Transitioning to the specific issue of heavy metal pollution, Wang *et al.* (2023) stress the significance of community awareness regarding the risks associated with heavy metal contamination in meat products. Community engagement becomes a powerful tool to educate individuals about potential health effects and the importance of safe food consumption practices. Furthermore, community involvement can foster sustainable agricultural practices that minimize heavy metal pollution, emphasizing proper waste management and environmentally friendly farming techniques. This active participation also facilitates community monitoring, enabling early detection and response to instances of contamination. The significance of community engagement in managing heavy metal pollution is not confined to China alone. Studies in the lower stretch of the River Ganges in India (Sharma *et al.*, 2017) underscore the importance of government, NGOs, and local communities working collaboratively. The involvement of citizens in policy initiation, program design decisions, and active participation in river management is vital for the success of rehabilitation efforts. Community engagement also plays a crucial role in managing heavy metal pollution in various local contexts. In the battery technicians' workshops in the Ilorin metropolis, Nigeria, Sawyerr *et al.* (2019) stress the need for comprehensive monitoring and community involvement to address the level of heavy metals in the soil effectively. Additionally, Oloruntoba *et al.* (2022) emphasize community engagement in Badagry, Nigeria, to raise awareness about water pollution, implement wastewater management systems, and ensure safe drinking water in secondary schools. Traditional rulers in Nigeria are recognized as effective change agents in educating rural communities about environmental pollution, particularly heavy metal pollution (Ihemeje *et al.*, 2016). Their proximity to the community allows for better communication and understanding of local needs, enabling the implementation of environmental education programs and the promotion of sustainable practices. The crucial role of community engagement in managing heavy metal pollution extends to the food chain. Nkwunonwo *et al.* (2020) stress the importance of community involvement in monitoring and analyzing food components, ensuring the safety of the food consumed. Collaborative efforts between organizations like the Standard Organisation of Nigeria (SON) and local communities are essential to gather valuable information and mitigate the risks associated with heavy metal contamination. Lastly, a study conducted in the Lagos Lagoon, Nigeria, emphasizes the necessity of community engagement in monitoring and containing sources of pollution contributing to high concentrations of heavy metals in sediments (Bawa-Allah *et al.*, 2018). This underscores the critical role of local communities in maintaining the ecological balance and safeguarding human health.

Recommendations for Action

Proposals for enhancing remediation efforts: To enhance remediation efforts for heavy metal pollution in Nigeria, several proposals have been put forth. These proposals aim to address the complex issue of heavy metal contamination through a combination of diverse and integrated approaches. Various methods have been proposed to address the challenge of heavy metal pollution in Nigeria (Ugboma *et al.*, 2020). One approach is bioremediation, involving the use of microorganisms to degrade heavy metals and restore ecological balance (Singh and Prasad, 2015). This method shows promise in ecological restoration, as certain microorganisms effectively mitigate heavy metal contamination. Bioremediation Technologies, although requiring further research, have shown success in remediating heavy metal-contaminated soil

(Radočaj *et al.*, 2020). In addition to bioremediation, integrated remediation processes have been recommended, combining multiple methods to address heavy metal contamination comprehensively. Electrokinetic Remediation, involving low direct current or potential gradient applied to electrodes, can be integrated with various technologies (Reddy, 2013). Phytoremediation, microbial bioremediation, and biosurfactants are nature-based techniques that offer promising solutions for addressing heavy metal pollution with minimal secondary pollution (Ren *et al.*, 2018; Oyedeji *et al.*, 2022; Shi *et al.*, 2022). Subsurface bioremediation has been recognized as an effective method for remediating shallow aquifers and ensuring safe groundwater. This technique involves the use of natural processes such as phytoremediation and microbial bioremediation to mitigate heavy metal pollution in groundwater without causing secondary pollution (Rahman *et al.*, 2022).

Rhamnolipids, a type of biosurfactant, have demonstrated significant potential in soil remediation due to their ability to enhance the removal of heavy metals and organic contaminants from contaminated soils. Studies have shown that rhamnolipids can effectively stabilize and transport metal nanoparticles in porous media, indicating their potential for use in remediation strategies (Rahman *et al.*, 2022; Shi *et al.*, 2022; Lu *et al.*, 2023). Rhizoremediation, a plant-microbe symbiosis-based approach, has shown promise in the remediation of mixed-waste contaminated soil. Rhizoremediation leverages the synergistic interactions between plants and rhizospheric microorganisms to enhance the removal of various contaminants from soil, including heavy metals, (Grijalbo *et al.*, 2015; Adongbede and Olomu, 2022; Lee *et al.*, 2022). Biochar and modified biochar offer significant potential in physicochemical remediation. Biochar possesses unique physicochemical properties, such as abundant oxygen-containing functional groups, high porosity, and large specific surface areas, which make it an effective material for remediation processes (Zhang *et al.*, 2021; Liang *et al.*, 2023). Low-carbon remediation strategies aim to reduce greenhouse gas emissions while promoting sustainable development in the context of heavy metal pollution remediation ((O'Brien *et al.*, 2021). Prioritizing the development and implementation of these techniques offers an opportunity to reduce environmental impact and promote sustainable practices. Policy proposals also play a crucial role in enhancing remediation efforts (Tang *et al.*, 2021). Differentiated national pollution reduction policies should be implemented for cadmium, mercury, lead, and other heavy metals to improve water pollution control measures (Zlati *et al.*, 2022). Monitoring and assessment are essential for identifying the extent of heavy metal pollution and developing effective remediation strategies. The risks associated with soil and water contamination with heavy metals can be analyzed using sediment quality indices (Sodhi *et al.*, 2022). This information provides valuable insights for designing targeted and efficient remediation plans. Integrated treatment options have been proposed to remove and recover heavy metals from polluted soils, water, and sediments (Selvi *et al.*, 2019; Tang *et al.*, 2021). These methods include thermal treatment, adsorption, chlorination, chemical extraction, ion-exchange, membrane separation, electrokinetics, bioleaching, and others. By combining these techniques, a comprehensive and effective approach can be developed to remediate heavy metal pollution in Nigeria.

Recommendations for public health interventions and monitoring: To effectively address the challenge of heavy metal pollution in Nigeria and safeguard public health, a comprehensive set of recommendations for public health interventions and monitoring has been proposed. The initial focus lies in conducting Health Risk Assessments, a crucial step to estimate the health effects resulting from exposure to heavy metals. This assessment provides valuable insights into the potential impact on human health and serves as a foundation for developing targeted public health interventions (Ngwenya *et al.*, 2023). Additionally, it emphasizes the significance of monitoring air, water, and food for heavy metal contamination, allowing the identification of exposure pathways and enabling the implementation of precise interventions to reduce human exposure (Rajkumar *et al.*, 2023). Preventive frameworks and management strategies play a vital role in controlling and preventing heavy metal contamination. By developing frameworks that align with regulatory enforcement and environmental protection, these efforts aim to reduce the associated health risks linked with heavy metal exposure (Ngwenya *et al.*, 2023). Education and awareness programs constitute another crucial aspect of the proposed interventions. Raising awareness about the health risks associated with heavy metal pollution is essential, encompassing education for the public, industries, and healthcare professionals. This outreach emphasizes not only the potential health effects of heavy metal exposure but also underscores the importance of preventive measures (Rajkumar *et al.*, 2023). Integrated remediation strategies form a central recommendation, emphasizing the development and assessment of comprehensive approaches to mitigate heavy metal pollution across various environmental matrices. From soil to water and food, these strategies aim to reduce human exposure and the associated health risks linked with heavy metal contamination (Gaur *et al.*, 2021) Furthermore, recognizing the underrepresented toxicity of heavy metals in public health and medical education is crucial. Addressing this knowledge gap is vital for improving the identification and management of health effects associated with heavy metal exposure (Ngwenya *et al.*, 2023). Lastly, integrating environmental sustainability into public health interventions is emphasized, promoting practices and technologies that minimize the release of heavy metals into the environment (Laniyan and Morakinyo, 2021).

Suggestions for future research to address knowledge gaps: Suggestions for future research to address knowledge gaps in heavy metal pollution research can be made based on the provided references. These suggestions aim to advance the understanding and management of this environmental challenge. One important area for future research is long-term monitoring. Conducting long-term monitoring studies can provide insights into the temporal variations in heavy metal pollution levels in different environmental compartments such as soil, water, sediments, and air. This will help us understand the dynamics of heavy metal pollution and its impact over time (Zhou *et al.*, 2020). Another crucial area for research is investigating the ecological impact of heavy metal pollution on different ecosystems, including urban mangroves, agricultural lands, and natural scenic spots. Exploring and evaluating innovative remediation techniques for heavy metal-contaminated soils and aquatic environments is also important. This could involve assessing the effectiveness of bioremediation, phytoremediation, and chemical amendments in different environmental settings (Wang, 2015; Chen *et al.*, 2020; Wang *et al.*, 2022)). Comprehensive health risk assessments are needed to understand the potential human health implications of heavy metal pollution, especially in areas where heavy metal contamination is prevalent. This type of research can guide public health interventions and policies (Hu *et al.*, 2017; Su *et al.*, 2023).

Understanding the sources and pathways of heavy metal pollution in different environmental matrices, such as soil, sediments, and water, is crucial for effective pollution control and management (Pobi *et al.*, 2019; Chen *et al.*, 2020). Studying the underlying mechanisms of heavy metal remediation by natural and engineered systems, including the role of microorganisms, plants, and chemical amendments in immobilizing and detoxifying heavy metals in contaminated environments, is another important research area (Dixit *et al.*, 2015; Wang *et al.*, 2022; Su *et al.*, 2023). Developing and refining pollution indices for assessing heavy metal contamination in various environmental compartments, including soil, water, and sediments, can aid in standardizing pollution assessment methodologies and comparisons across different study areas (Albayati *et al.*, 2019; Soujanya Kamble *et al.*, 2020). Utilizing GIS-based approaches to spatially assess and map heavy metal pollution levels, especially in areas affected by industrial activities, mining, and urbanization, can provide valuable insights for targeted pollution control measures (Sekar *et al*., 2015; Chen *et al*., 2012). Investigating the impact of climate change on the mobility and bioavailability of heavy metals in different environmental compartments is important for understanding the climate-related factors influencing heavy metal pollution and predicting future pollution trends (Shi *et al*., 2022). Researching and developing innovative technologies for the remediation of heavy metal pollution, including the use of nanomaterials, advanced oxidation processes, and green remediation strategies, can contribute to the development of sustainable and efficient remediation techniques (Shi *et al*., 2021; Wang *et al*., 2022).

Conclusion: Heavy metal pollution poses a significant threat to ecological integrity and public health in Nigeria. The country's substantial oil reserves and mineral wealth have fueled economic growth but have also led to significant environmental challenges. Although Nigeria has established several policies and legislations to combat heavy metal pollution, challenges persist in their implementation and enforcement. There is a need for stronger legislation, revision of safe limits, and enhanced monitoring to effectively mitigate heavy metal pollution. Additionally, community involvement, education, and international collaborations play crucial roles in managing heavy metal pollution. By implementing comprehensive remediation strategies, conducting health risk assessments, and raising awareness, Nigeria can make significant strides toward mitigating heavy metal pollution and achieving enhanced environmental sustainability. It is crucial to address knowledge gaps through future research and continue improving legislative frameworks to protect public health and promote sustainable practices in the face of heavy metal pollution challenges.

REFERENCES

Abdulraheem MO, Adeniran JA, Ameen HA, Odediran ET, Yusuf M-NO, Abdulraheem KA (2022). Source identification and health risk assessments of heavy metals in indoor dust of Ilorin, North Central Nigeria. J Environ Health Sci Eng, 20(1): 315-330.

Abidli A, Huang Y, Ben Rejeb Z, Zaoui A, Park CB (2022). Sustainable and efficient technologies for removal and recovery of toxic and valuable metals from wastewater: Recent progress, challenges, and future perspectives. Chemosphere, 292: 133102. Available from https://www.sciencedirect.com/science/article/pii/S0045653521035748. DOI https://doi.org/10.1016/j.chemosphere.2021.133102.

Abubakar A, Ishak MY, Yaro KM, Zangina AS (2022). The role of government institutions in managing the environment in Nigeria: Policy and governance review. Borneo Sci, 43(1).

Abubakar H (2015). Assessment of physicochemical parameters along selected locations of River Kaduna, Kaduna State, Nigeria. ARC J Acad Res, 1(1): 11-16.

Abubakar M, Sirajo IT (2023). Assessment of some heavy metals and physicochemical parameters in hand-dug well and borehole water sample from Mubi South LGA Adamawa State. J Fundam Appl Sci, 15(2): 147-159.

Abuduwaili J, Zhang Zy, Jiang F (2015). Assessment of the distribution, sources and potential ecological risk of heavy metals in the dry surface sediment of Aibi Lake in northwest China. PLoS One. DOI 10.1371/journal.pone.0120001.

Abulude FO, Akinnusotu A, Adeoya EA, Mabayoje SO, Oluwagbayide SD, Arifalo KM, Adamu A (2023). Quality of surface and ground water in three states of Nigeria: Assessment of physicochemical characteristics and selected contamination patterns. Environ Sci Proc, 25(1): 48.

Adebajo SO, Bankole PO, Ojo AE, Ajibola AT, Ojesola CO, Akintokun AK (2023). Synthesis of biosurfactants by bacterial cells: Heavy-metals tolerance and siderophores. Sci African, 22: e01984. Available from https://www.sciencedirect.com/science/article/pii/S2468227623004386. DOI https://doi.org/10.1016/j.sciaf.2023.e01984.

Adebayo AS, Akinola BS, Adeyemi AF (2021). Groundwater contamination and human health risk assessment in Ikire community, Osun State, Nigeria. Sustainable Water Res Manag, 7: 1-10.

Adedeji OH, Olayinka OO, Tope-Ajayi OO (2019). Spatial distribution and health risk assessment of soil pollution by heavy metals in Ijebu-Ode, Nigeria. J Health Pollut, 9(22): 190601.

Adejuwon JO, Odusote AA (2023). Physicochemical characteristics and heavy metals of groundwater during the wet and dry seasons at the Lafarge Cement Factory environment, Sagamu, Ogun State, Nigeria. World Water Policy, 9(2): 178-203.

Adeniyi T, Achukwu PU (2018). Lead contamination induces neurodegeneration in prefrontal cortex of Wistar rats. Anat (Int J Exp Clin Anat). DOI 10.2399/ana.18.077.

Adesipo AA, Akinbiola S, Awotoye OO, Salami AT, Freese D (2020). Impact of mining on the floristic association of gold mined sites in Southwest Nigeria. BMC Ecol. DOI 10.1186/s12898-020-00276-9.

Adesiyan IM, Bisi-Johnson M, Aladesanmi OT, Okoh AI, Ogunfowokan AO (2018). Concentrations and human health risk of heavy metals in rivers in Southwest Nigeria. J Health Pollut, 8(19): 180907.

Adesodun JK, Mbagwu JSC (2008). Distribution of heavy metals and hydrocarbon contents in an Alfisol contaminated with waste-lubricating oil amended with organic wastes. Bioresour Technol, 99(8): 3195-3204.

Adewale P, Makinde SCO, Kusemiju VO (2023). Assessment of heavy metal residues in soil and vegetables along urban-peri-urban gradient of Lagos State Nigeria. J Environ Issues Clim Change, 2(1): 70-77.

Adeyemo IA, Akintimehin ES, Adeoye ET (2023). The use of indigenous hydrocarbon utilizing bacteria in bioreactor-based bioremediation of hydrocarbon-polluted soil of Awoye, Ondo State, Nigeria. Biol Environ Sci J Tropics, 20(01).

Adeyeye EI, Shittu O, Ayodele OJ, Ilori AA (2018). Heavy metal pollution potential in soil influenced by sawmill operations at Ado-Ekiti, Nigeria. Bangladesh J Sci Ind Res. DOI 10.3329/bjsir.v53i1.35907.

Adeyi AA, Babalola BA (2017). Lead and cadmium levels in residential soils of Lagos and Ibadan, Nigeria. J Health Pollut, 7(13): 42-55.

Adie DB, Bolorunduro PI, Shehu AH (2023). Heavy metals bioaccumulation in water and some organs of Oreochromis niloticus of Wasai Reservoir, Kano State Nigeria. Biol Environ Sci J Tropics, 20(1).

Adomokai R, Sheate WR (2004). Community participation and environmental decision-making in the Niger Delta. Environ Impact Assess Rev, 24(5): 495-518. Available from https://www.sciencedirect.com/science/article/pii/S0195925504000228. DOI https://doi.org/10.1016/j.eiar.2004.01.002.

Adongbede EM, Olomu AA (2022). Bioremediation potential of selected rhizosphere fungi of Tridax procumbens Linn. and Chromolaena odorata (L.) R.M. King & H. Rob. Niger J Biotechnol. DOI 10.4314/njb.v39i1.5.

Akakuru, OC, Njoku UB, Obinna-Akakuru AU, Akudinobi BEB, Obasi PN, Aigbadon GO, Onyeanwuna UB (2023). Non-carcinogenic health risk assessment and prediction of pollution indexing of groundwater around Osisioma, Nigeria, using artificial neural networks and multi-linear modeling principles. Stoch Environ Res Risk Assess: 1-31.

Akinnifesi O, Adesina F, Ogunwole G, Abiya S (2021). Occurrence and impact of heavy metals on some water, land, flora, and fauna resources across southwestern Nigeria. In: Heavy metals-their environmental impacts and mitigation. IntechOpen.

Akinnifesi OJ, Adesina F, Ogunwole GA, Abiya SE (2021). Occurrence and impact of heavy metals on some water, land, flora, and fauna resources across southwestern Nigeria. DOI 10.5772/intechopen.94982.

Akpomrere OR, Uguru H (2020). Potential ecological risk of swamps sediments in illegal refineries sites: A case study of Isoko South, Delta State, Nigeria. J Eng Res Rep, 16(2): 1-9.

Akpor OB, Ohiobor GO, Olaolu DT (2014). Heavy metal pollutants in wastewater effluents: Sources, effects, and remediation. Adv Biosci Bioeng, 2(4): 37-43.

Alabi OO, Sedara SO, Awowole SY (2019). Assessment of concentrations of heavy metals in soils around Espro asphalt production and quarry site, Wasinmi, Osun State, Southwest Nigeria. J Geogr Environ Earth Sci Int. DOI 10.9734/jgeesi/2019/v22i330148.

Alagoa KJ, Charles EE, Kariye E (2023). Cassava processing and heavy metal concentrations in soils of the riverine community Toru-Ebeni, Bayelsa State, Nigeria.

Alao JO, Abdo HG, Ayejoto DA, Mohammed MAA, Danladi E, Saqr AM, Almohamad H, Fahad A (2023). Evaluation of groundwater contamination and the health risk due to landfills using integrated geophysical methods and physiochemical water analysis. Case Stud Chem Environ Eng, 8: 100523.

Albayati TM, Sabri AA, Abed DB (2019). Adsorption of binary and multi-heavy metals ions from aqueous solution by amine functionalized SBA-15 mesoporous adsorbent in a batch system. Desalin Water Treat, 151: 315-321.

Ali H, Khan E, Ilahi I (2019). Environmental chemistry and ecotoxicology of hazardous heavy metals: Environmental persistence, toxicity, and bioaccumulation. J Chem. DOI 10.1155/2019/6730305.

Ali M, Ahmed T, Abu-Dieyeh MH, Al-Ghouti MA (2021). Investigating the quality and efficiency of biosolid produced in Qatar as a fertilizer in tomato production. Agronomy. DOI 10.3390/agronomy11122552.

Ali W, Ma Y, Zhu J, Zou H, Liu Z (2022). Mechanisms of cadmium-induced testicular injury: A risk to male fertility. Cells. DOI 10.3390/cells11223601.

Aliyu JA, Saleh Y, Kabiru S (2015). Heavy metals pollution on surface water sources in Kaduna metropolis, Nigeria. Sci World J, 10(2): 1-5.

Aliyu TH, Balogun OS, Namani CS, Olatinwo LK, Aliyu AS (2017). Assessment of the presence of metals and quality of water used for irrigation in Kwara State, Nigeria.

Álvarez-Solorza I, Upegui-Arango LD, Borja-Aburto VH, González-González N, Fischer F, Bustamante-Montes LP (2022). Perception and knowledge of mercury by occupationally exposed health care personnel. J Contin Educ Health Prof. DOI 10.1097/ceh.0000000000000399.

Ameh GI, Nwamba HO, Nwani CD, Ofordile EC (2020). Effects of heavy metals on agronomic attributes of some selected cereal crops (Zea mays and Sorghum bicolor). J Appl Life Sci Int. DOI 10.9734/jalsi/2020/v23i930184.

Ameh GI, Ogbodo LC (2020). Assessment of heavy metal concentration in fruit samples from three major markets during the wet season in Enugu State. J Adv Biol Biotechnol. DOI 10.9734/jabb/2020/v23i530158.

Ameh GI, Onuh EJ (2020). Phytoremediation of copper and nickel contaminated soil using Eleusine indica on soil properties. Int J Plant Soil Sci. DOI 10.9734/ijpss/2019/v31i530220.

Anifowose AJ, Oyebode AW (2019). Studies on heavy metals contents of Osun River at the pre-urban settlement and across Osogbo city, Nigeria. J Taibah Univ Sci. DOI 10.1080/16583655.2019.1567899.

Anifowose AJ, Salawudeen C, Osundiya FO, Adelele AE, Awojide SH, Kolawole TO (2023). Estimation of health risk to humans and source identification of heavy metals in a perennial river across the Osogbo metropolis, Nigeria. Environ Sustain, 6(1): 45-58.

Anjum F, Khan IM, Kim J, Aslam M, Blandin G, Heran M, Lesage G (2021). Trends and progress in anmbr for domestic wastewater treatment and their impacts on process efficiency and membrane fouling. Environ Technol Innov, 21: 101204.

Anoliefo GO, Nwaokolo M, Edegbai BO, Ikhajiagbe B (2023). Ex-situ mycoremediation of petroleum polluted soils in Ogoniland, Nigeria. bioRxiv: 2023-2001.

Anya CB, Odo GE (2023). Heavy metal concentration and pollution status of Cross River in Afikpo catchment area, Ebonyi State, Nigeria. Chem Africa: 1-11.

Anyanwu BO, Ezejiofor AN, Igweze ZN, Orisakwe OE (2018a). Heavy metal mixture exposure and effects in developing nations: An update. Toxics, 6(4): 65.

Anyanwu BO, Ezejiofor AN, Igweze ZN, Orisakwe OE (2018b). Heavy metal mixture exposure and effects in developing nations: An update. Toxics. DOI 10.3390/toxics6040065.

Anyanwu ED, Nwachukwu ED (2020). Heavy metal content and health risk assessment of a southeastern Nigeria river. Appl Water Sci, 10: 1-9.

Aransiola SA (2023). Microbial and vermicompost-assisted phytoremediation of heavy metal-contaminated soil in Shikira, Niger State, Nigeria.

Aremu MO, Inajoh A (2007). Assessment of elemental contaminants in water and selected seafood from River Benue, Nigeria. Curr World Environ. DOI 10.12944/cwe.2.2.17.

Aromolaran OK, Aromolaran O, Faleye ET, Faerber H (2023). Environmental impacts of an unlined municipal solid waste landfill on groundwater and surface water quality in Ibadan, Nigeria. Environ Geochem Health, 45(6): 3585-3616.

Astatkie H, Ambelu A, Mengistie E (2021). Contamination of stream sediment with heavy metals in the Awetu watershed of southwestern Ethiopia. Front Earth Sci. DOI 10.3389/feart.2021.658737.

Atama CI, Onovo CJ, Okeke CJ, Nelson O, Nwani CD (2020). Heavy metal analysis of three urban rivers in Enugu, Nigeria. Ann Res Rev Biol: 14-19.

Athar T, Waris AA, Nisar M (2018). A review on toxicity and environmental implications of heavy metals. Emergent Life Sci Res. DOI 10.31783/elsr.2018.423137.

Atikpo E, Okonofua ES, Uwadia NO, Michael A (2021). Health risks connected with ingestion of vegetables harvested from heavy metals contaminated farms in Western Nigeria. Heliyon, 7(8).

Audu Y, Aliyu AD, Dadi-Mamud NJ (2022). Evaluation of heavy metals contamination in the sediments of some selected waters of South Senatorial District of Niger State, Nigeria. Sci World J, 17(4): 487-494.

Aweda F, Falaiye O, Samson T (2023). Heavy metal concentration in harmattan dust across selected stations in Nigeria. Jordan J Phys, 16(4): 413-422.

Awhefeada UV, Aloamaka PC, Kore-Okiti ET (2023). A realistic approach towards attaining sustainable environment through improved public participation in Nigeria. Int J Prof Bus Rev, 8(4): e0844-e0844.

Ayejoto DA, Egbueri JC (2023). Human health risk assessment of nitrate and heavy metals in urban groundwater in Southeast Nigeria. Acta Ecol Sinica.

Ayua TJ, Tyovenda AA, Sombo T, Tikyaa EV, Igbawua T (2020). Fine particulate matter and heavy metals pollution status in ambient air of some selected industrial sites in Northern Nigeria. J Geosci Environ Prot, 8(08): 1.

Babayemi JO, Nnorom IC, Weber R (2022). Initial assessment of imports of chlorinated paraffins into Nigeria and the need for improvement of the Stockholm and Rotterdam Conventions. Emerg Contam, 8: 360-370. Available from https://www.sciencedirect.com/science/article/pii/S2405665022000269. DOI https://doi.org/10.1016/j.emcon.2022.07.004.

Babula P, Adam V, Opatrilova R, Zehnalek J, Havel L, Kizek R (2010). Uncommon heavy metals, metalloids and their plant toxicity: a review. Org Farm Pest Control Remediation Soil Pollut: Org Farm Pest Control Remediation Soil Pollut, pp.275-317.

Badamasi, H, Olusola JA, Durodola SS, Akeremale OK, Ore OT, Bayode AA (2023). Contamination levels, source apportionments, and health risks evaluation of heavy metals from the surface water of the Riruwai mining area, north-western Nigeria. Pollut, 9(3): 929-949.

Badejo, AA, Ndambuki JM, Kupolati WK, Adeyemo SA, Omole DO, Adekunle AA (2021). Evaluation of two-stage subsurface flow constructed wetlands for abattoir wastewater management. J Nat Sci Eng Technol. DOI 10.51406/jnset.v19i1.2106.

Baghaie, AH, Khoshgoftarmanesh AH, Afyuni M, Schulin R (2011). The role of organic and inorganic fractions of cow manure and biosolids on lead sorption. Soil Sci Plant Nutr. DOI 10.1080/00380768.2010.548309.

Balogun-Adeleye, RM, Adu JT, Adisa RO (2022). Assessment and impacts of metal recycling on groundwater quality in Ogijo, Ogun State, Nigeria. J Eng Technol, 7(2).

Balogun, LO, Sympa AH, Maigari MU, Mohammed AH, Abubakar D (2023). Carcinogenic and non-carcinogenic health risk assessment from exposure of heavy metals in hand dug wells in Gombe State. J Chem, 2(1): 1-13.

Bampoe, E, Cobbina SJ, Doke DA (2023). Assessment of heavy metal levels and associated human health risk in dust from high and low traffic transport stations in the Tamale metropolis, in the northern region of Ghana. Int J Environ Sci Technol, 20(8): 8497-8508.

Bartrem, C, Lindern Iv, Braun Mv, Tirima S (2022). Climate change, conflict, and resource extraction: Analyses of Nigerian artisanal mining communities and ominous global trends. Ann Glob Health. DOI 10.5334/aogh.3547.

Bassey, FI, Iwegbue CMA, Obi-Iyeke GE, Tesi GO, Rotu AR, Gobe OA, Tsafe AI (2014). Heavy metals in soils and tomatoes grown in urban fringe environment in Asaba, Delta State, Nigeria. Niger J Basic Appl Sci, 22(1-2): 27-31.

Bassouny, M, Abbas M (2020). Monitoring environmental pathways of trace elements in the northern east area of Egypt. Environ Biodivers Soil Secur. DOI 10.21608/jenvbs.2020.29403.1094.

Bawa-Allah, KA (2023). Assessment of heavy metal pollution in Nigerian surface freshwaters and sediment: A meta-analysis using ecological and human health risk indices. J Contam Hydrol, 256: 104199. Available from [URL]

Badamasi, H, Olusola JA, Durodola SS, Akeremale OK, Ore OT, Bayode AA (2023). Contamination levels, source apportionments, and health risks evaluation of heavy metals from the surface water of the Riruwai mining area, north-western Nigeria. Pollut, 9(3): 929-949.

Badejo, AA, Ndambuki JM, Kupolati WK, Adeyemo SA, Omole DO, Adekunle AA (2021). Evaluation of two-stage subsurface flow constructed wetlands for abattoir wastewater management. J Nat Sci Eng Technol. DOI 10.51406/jnset.v19i1.2106.

Baghaie, AH, Khoshgoftarmanesh AH, Afyuni M, Schulin R (2011). The role of organic and inorganic fractions of cow manure and biosolids on lead sorption. Soil Sci Plant Nutr. DOI 10.1080/00380768.2010.548309.

Balogun-Adeleye, RM, Adu JT, Adisa RO (2022). Assessment and impacts of metal recycling on groundwater quality in Ogijo, Ogun State, Nigeria. J Eng Technol, 7(2).

Balogun, LO, Sympa AH, Maigari MU, Mohammed AH, Abubakar D (2023). Carcinogenic and non-carcinogenic health risk assessment from exposure of heavy metals in hand dug wells in Gombe State. J Chem, 2(1): 1-13.

Bampoe, E, Cobbina SJ, Doke DA (2023). Assessment of heavy metal levels and associated human health risk in dust from high and low traffic transport stations in the Tamale metropolis, in the northern region of Ghana. Int J Environ Sci Technol, 20(8): 8497-8508.

Bartrem, C, Lindern Iv, Braun Mv, Tirima S (2022). Climate change, conflict, and resource extraction: Analyses of Nigerian artisanal mining communities and ominous global trends. Ann Glob Health. DOI 10.5334/aogh.3547.

Bassey, FI, Iwegbue CMA, Obi-Iyeke GE, Tesi GO, Rotu AR, Gobe OA, Tsafe AI (2014). Heavy metals in soils and tomatoes grown in urban fringe environment in Asaba, Delta State, Nigeria. Niger J Basic Appl Sci, 22(1-2): 27-31.

Bassouny, M, Abbas M (2020). Monitoring environmental pathways of trace elements in the northern east area of Egypt. Environ Biodivers Soil Secur. DOI 10.21608/jenvbs.2020.29403.1094.

Bawa-Allah, KA (2023). Assessment of heavy metal pollution in Nigerian surface freshwaters and sediment: A meta-analysis using ecological and human health risk indices. J Contam Hydrol, 256: 104199. Available from [URL]

Chris, DI, Onyena AP, Sam K (2023). Evaluation of human health and ecological risk of heavy metals in water, sediment and shellfishes in typical artisanal oil mining areas of Nigeria. Environ Sci Pollut Res: 1-15.

Christian, EE, Enenche ED, Chukwuemeka OC, Ifeyinwa OA, Ajiwe VIE, Okoye PAC (2021). Effect of poultry manure amendment on the distribution and mobility of heavy metals in naturally contaminated dump soil. Int J Environ Agric Biotechnol, 6(2).

Chukwumati, A (2023). Accumulation of hydrocarbons and some heavy metal contents on sediments and plants from crude oil polluted mangrove ecosystem in Okrika, Nigeria. World J Adv Res Rev, 17(3): 298-306.

Codling, EE, Jaja N, Adewunmi W, Evanylo GK (2021). Residual effects of long-term biosolids application on concentrations of carbon, cadmium, copper, lead and zinc in soils from two regions of the United States. Commun Soil Sci Plant Anal, 52(8): 896-904.

Davey, VJ (2007). Questions and answers on pandemic influenza. AJN The Am J Nurs, 107(7): 50-56.

Denkok, Y, Adesina O, Gurumtet I, Kopdora SW (2021). An evaluative study on metallic concentration in different ground and industrial water sources in Jos South Local Government Area of Plateau State, Nigeria. Asian J Biochem Genet Mol Biol, 7(1): 25-33.

Dixit, A, Dixit S, Goswami CS (2015). Eco-friendly alternatives for the removal of heavy metal using dry biomass of weeds and study the mechanism involved. J Bioremed Biodegrad, 6: 1-7.

Duke, SO, Stidham MA, Dayan FE (2018). A novel genomic approach to herbicide and herbicide mode of action discovery. Pest Manag Sci. DOI 10.1002/ps.5228.

Ebere, PU (2022). The role of environmental adult education in community development. J Multidisiplin Madani, 2(12): 4095-4106.

Ebuete, AW, Bisong AE, Chukuma O, Ndiwari LE, Ebuete IY (2019). Spatial variability of heavy metals in surface water and sediment in the Kolo Creek water body in the Niger Delta of Nigeria and geochemical factors that influence their interactions using geo-accumulation index. Curr J Appl Sci Technol. DOI 10.9734/cjast/2019/v37i330290.

Edogbo, B, Okolocha E, Maikai B, Aluwong T, Uchendu C (2020). Risk analysis of heavy metal contamination in soil, vegetables and fish around Challawa area in Kano State, Nigeria. Scientific African, 7: e00281.

Egbon, O, Mgbame CO (2020). Examining the accounts of oil spills crises in Nigeria through sensegiving and defensive behaviours. Account Audit Accountabil J. DOI 10.1108/aaaj-12-2018-3794.

Ekperusi, OA, Aigbodion IF (2015). Bioremediation of heavy metals and petroleum hydrocarbons in diesel contaminated soil with the earthworm: Eudrilus eugeniae. SpringerPlus, 4(1): 1-13.

Ekwuribe, SA, Uba S, Abdulkadir I (2016). Heavy metals pollution status of sediments of Ahmadu

Bello University Dam, Zaria-Nigeria. Niger J Basic Appl Sci, 24(1): 64-69.

Elemo, GN, Yusuf AS, Aderoju TA, Adebayo OK (2021). Heavy metal leaching in foods cooked with stainless-steel pots and locally made alloy pots. Eur J Adv Chem Res, 2(4): 6-9.

Eluke, UG, Ugbebor J, Membere E (2021). Carcinogenic risk from heavy metals exposure in oil-producing areas of Niger Delta, southern Nigeria. World J Innov Res, 10: 70-73.

Emurotu, JE, Onianwa PC (2017). Bioaccumulation of heavy metals in soil and selected food crops cultivated in Kogi State, North Central Nigeria. Environ Syst Res, 6(1): 1-9.

Enuneku, A, Omoruyi O, Tongo I, Ogbomida E, Ogbeide O, Ezemonye L (2018). Evaluating the potential health risks of heavy metal pollution in sediment and selected benthic fauna of Benin River, southern Nigeria. Appl Water Sci, 8: 1-13.

Essien, JP, Ikpe DI, Inam ED, Okon AO, Ebong GA, Benson NU (2022). Occurrence and spatial distribution of heavy metals in landfill leachates and impacted freshwater ecosystem: An environmental and human health threat. PLOS ONE. DOI 10.1371/journal.pone.0263279.

Ezekiel, BB, Adelalu TG, Christopher JN, Alhassan T (2023). Assessment of agro allied chemical pollution on surface water quality of River Lamurde and Mayo-Gwoi, Jalingo, Taraba State, Nigeria. Adv Environ Eng Res, 4(1): 1-21.

Ezenwa, IM, Obiesie AJ, Nnoli NG, Chidebem C, Orakwelu H, Omoigberale M (2022). Spring water contamination by heavy metal and human health risk assessment at Ezeani, Southeast Nigeria. Int J Curr Res Appl Stud (IJCRAS), 1 (1): 12-29.

Fagbenro, AA, Yinusa TS, Ajekiigbe KM, Oke AO, Obiajunwa EI (2021). Assessment of heavy metal pollution in soil samples from a gold mining area in Osun State, Nigeria using proton-induced x-ray emission. Sci Afr, 14: e01047.

Felagha, I, Monanu MO, Amadi BA (2020). Human health risk assessment of heavy metals in three species of mollusks (Egeria radiata, Limicolaria flammea, and Viviparus contectus) from Yenagoa, Bayelsa State, Nigeria. Asian J Adv Res Rep, 10(3): 21-26.

Felagha, I, Ogbolosingha AJ (2018). Assessment of heavy metals concentration in selected foods sold in markets within Port-Harcourt City, Nigeria. Open Access J Sci, 2(4): 233-236.

Figueroa, DA, Rodríguez-Sierra CJ, Jiménez-Vélez B (2006). Concentrations of Ni and V, other heavy metals, arsenic, elemental and organic carbon in atmospheric fine particles (PM2.5) from Puerto Rico. Toxicol Ind Health. DOI 10.1191/0748233706th247oa.

Federal Ministry of Environment (FME), Federal Ministry of Environment (FMoE) (2021). National action plan for the reduction and eventual elimination of mercury use in artisanal and small-scale gold mining in Nigeria.

Fork, ML, Fick J, Reisinger AJ, Rosi EJ (2021). Dosing the coast: Leaking sewage infrastructure delivers large annual doses and dynamic mixtures of pharmaceuticals to urban rivers. Environ Sci Technol. DOI 10.1021/acs.est.1c00379.

Fuwape, IA, Okpalaonwuka C, Ogunjo S (2020). Impact of COVID-19 pandemic lockdown on the distribution of inorganic pollutants in selected cities of Nigeria. Air Qual Atmos Health. DOI 10.1007/s11869-020-00921-8.

Gbadamosi, MR, Abayomi AA, Afolabi TA, Adegboye MA, Bakare HO, Banjoko OO, Ogunneye AL, Ugbomeh IL, Jegede DO, Ajetunmobi AE (2023). Pollution sources identification, health, and radiological risk assessment of naturally occurring radioisotopes and heavy metals in waste dumpsites in Ijebu-Ode, Ogun State, Southwest Nigeria. Environ Forensics, 24(5-6): 238-255.

Gbadegesin, AS, Olorunfemi FB (2009). Changing trends in water policy formulation in Nigeria: Implications for sustainable water supply provision and management. J Sustain Dev Afr, 11(4): 266-285.

Gc, E, Ib O, Asubiojo OI (2017). Trace metals and source identification of air-borne particulate matter pollution in a Nigerian megacity. J Environ Anal Toxicol. DOI 10.4172/2161-0525.1000463.

Grandlic, CJ, Mendez MO, Chorover J, Machado B, Maier RM (2008). Plant growth-promoting bacteria for phytostabilization of mine tailings. Environ Sci Technol. DOI 10.1021/es072013j.

Grema, HM, Hamidu H, Suleiman A, Kankara AI, Umaru AO, Abdulmalik NF (2022). Cadmium geochemistry and groundwater pollution status evaluation using indexing and spatial analysis for Keffe community and environs Sokoto Basin, northwestern Nigeria. Niger J Basic Appl Sci, 30(1): 05-23.

Griffith, S, Bero N, Stier J, Obear G, Ruis SJ, Soldat D (2020). Use of biosolids for sod production: Impact on the import/export of nutrients, heavy metals, and soil mineral matter. Agron J, 112(5): 3371-3382.

Grijalbo, L, Gutiérrez-Mañero FJ, Fernández-Pascual M, Lucas JA (2015). Photosynthetic and ultrastructure parameters of maize plants are affected during the phyto-rhizoremediation process of degraded metal working fluids. Int J Phytoremediation. DOI 10.1080/15226514.2015.1045132.

Guan, J, Wang J, He P, Yang C, Qu J, Lü N, Yuan X (2018). Heavy metals in Yinma River sediment in a major Phaeozems zone, Northeast China: Distribution, chemical fraction, contamination assessment and source apportionment. Sci Rep. DOI 10.1038/s41598-018-30197-z.

Habu, MA and Usman B (2021). Health risk assessment and heavy metal bioaccumulation in vegetables irrigated with wastewater in Kano State, Nigeria. Not Sci Biol, 13(1): 10890-10890.

Hamidu, H, Halilu FB, Yerima KM, Garba LM, Suleiman AA, Kankara AI, Abdullahi IM (2021). Heavy metals pollution indexing, geospatial and statistical approaches of groundwater within Challawa and Sharada industrial areas, Kano City, north-western Nigeria. SN Appl Sci, 3(7): 690.

Hammani, B, Osman MS, Mohammed KA (2020). Evaluation of heavy metal contamination in surface and groundwater in Maiganga, Gombe State, Nigeria. J Soil Water Sci, 5(2): 218-222.

Hassan, A (2020). Dealing with vulnerability to carbon emission from gas flaring: The roles of transparency and utilization policies in Nigeria. OPEC Energy Rev. DOI 10.1111/opec.12187.

Hosamani, V, Yalagi M, Sasvihalli P, Hosamani V, Nair KSS, Harlapur VK, Hegde CR, Mishra RL (2020). Importance of micronutrients (zinc) in crop production: A review. Int J Chem Stud. DOI 10.22271/chemi.2020.v8.i1n.8393.

Hu, B, Jia X, Hu J, Xu D, Xia F, Li Y (2017). Assessment of heavy metal pollution and health risks in the soil-plant-human system in the Yangtze River Delta, China. Int J Environ Res Public Health. DOI 10.3390/ijerph14091042.

Hu, Z, Li J, Wang H, Ye Z, Wang X, Li Y, Liú D, Song Z (2019). Soil contamination with heavy metals and its impact on food security in China. J Geosci Environ Prot. DOI 10.4236/gep.2019.75015.

Hubbs-Tait, L, Nation JR, Krebs NF, Bellinger DC (2005). Neurotoxicants, micronutrients, and social environments: Individual and combined effects on children's development. Psychol Sci Public Interest, 6(3): 57-121.

Ibanga, LB, Nkwoji JA, Usese AI, Onyema IC, Chukwu LO (2019). Hydrochemistry and heavy metal concentrations in sediment of Woji Creek and Bonny Estuary, Niger Delta, Nigeria. Reg Stud Mar Sci, 25: 100436.

Ibekwe, UM (2023). Physicochemical characteristics and heavy metals assessment in water and sediments of Obodo oilfield in Warri South Local Government Area of Delta State, Nigeria. J Appl Sci Environ Manage, 27(4): 709-715.

Idowu, GA (2022). Heavy metals research in Nigeria: A review of studies and prioritization of research needs. Environ Sci Pollut Res, 29(44): 65940-65961.

Ighariemu, I, Wegwu MO, Chuku LC, Olua V, Obadesagbo O (2023). Toxicological assessment of marine sediment in oil-spilled impacted areas of Nembe, Niger Delta, Nigeria. Int J Scholarly Res Rev, 2(01): 011-024.

Igiri, BE, Okoduwa SIR, Idoko GO, Akabuogu EP, Adeyi AO, Ejiogu IK (2018). Toxicity and bioremediation of heavy metals contaminated ecosystem from tannery wastewater: A review. J Toxicol, 2018.

Ihedioha, JN, Ujam OT, Nwuche CO, Ekere NR, Chime CC (2016). Assessment of heavy metal contamination of rice grains (Oryza sativa) and soil from Ada field, Enugu, Nigeria: Estimating the human health risk. Hum Ecol Risk Assess, 22(8): 1665-1677.

Ihemeje, G, Okorie N, Ikpe E (2016). Traditional ruler, environmental education, pollution and rural communities in Nigeria: Challenges and prospects. Eur J Sustainable Dev, 5(2): 75-75.

Imlani, A, TaŞTan Y, Tahiluddin A, Bilen S, Jumah YU, Sönmez AY (2022). Preliminary determination of heavy metals in sediment, water, and some macroinvertebrates in Tawi-Tawi Bay, Philippines. Mar Sci Technol Bull. DOI 10.33714/masteb.1070711.

Inobeme, A, Adetunji CO, Tsado MJ, Ajai AI, Inobeme J, Bamigboye MO, Onyeaku S, Maliki M, Eziukwu C, Tawa K (2023). Nanotechnology for bioremediation of heavy metals. In: Microbial technologies in industrial wastewater treatment. Springer: pp: 19-30.

Inyinbor, AA, Bello OS, Oluyori AP, Inyinbor HE, Fadiji AE (2019). Wastewater conservation and reuse in quality vegetable cultivation: Overview, challenges and future prospects. Food Control. DOI 10.1016/j.foodcont.2018.12.008.

Isworo, S and Oetari PS (2022). Flora and fauna in the areas around artisanal gold mining in Selogiri Sub-district, Wonogiri, Indonesia. Biodiversitas J Biol Divers. DOI 10.13057/biodiv/d231259.

Ite, AE, Ufot UF, Ite MU, Isaac IO, Ibok UJ (2016). Petroleum industry in Nigeria: Environmental issues, national environmental legislation and implementation of international environmental law. Am J Environ Prot, 4(1): 21-37.

Izah, SC and Angaye TCN (2016). Heavy metal concentration in fishes from surface water in Nigeria: Potential sources of pollutants and mitigation measures. Sky J Biochem Res, 5(4): 31-47.

Izah, SC, Bassey SE, Ohimain EI (2017). Assessment of pollution load indices of heavy metals in cassava mill effluents contaminated soil: A case study of small-scale processors in a rural community in the Niger Delta, Nigeria. Biosci Methods, 8.

Izah, SC, Chakrabarty N, Srivastav AL (2016). A review on heavy metal concentration in potable water sources in Nigeria: Human health effects and mitigating measures. Exposure Health, 8: 285-304.

Jacob, JN, Okuo JM, Archibong UD, Imafidon MI, Emeribe OF, Anegbe B (2022). Comparative studies on the effects of biochar and cow dung amendments on the mobility, bioavailability and toxicity of heavy metals in lead-acid contaminated soil. Dutse J Pure Appl Sci, 8: 171-186.

Jacob, JO and Kakulu SE (2012). Assessment of heavy metal bioaccumulation in spinach, jute mallow and tomato in farms within Kaduna metropolis, Nigeria. Am J Chem, 2(1): 13-16.

Jafiya, L and Maina HM (2023). A comparative study on the pollution status of heavy metals in soils and sediment from farmlands in Askira Uba, Nigeria. Int J Sci Res Archive, 10(2): 113-118.

Jaishankar, M, Tseten T, Anbalagan N, Mathew BB, Beeregowda KN (2014). Toxicity, mechanism and health effects of some heavy metals. Interdiscip Toxicol, 7(2): 60.

Javanshir, A (2012). Untitled. Turk J Fish Aquat Sci. DOI 10.4194/1303-2712-v12_3_07.

Jayakumar, M, Surendran U, Raja P, Kumar A, Senapathi V (2021). A review of heavy metals accumulation pathways, sources and management in soils. Arab J Geosci, 14: 1-19.

Jenyo-Oni, A and Oladele AH (2016). Heavy metals assessment in water, sediments and selected aquatic organisms in Lake Asejire, Nigeria. Eur Sci J, 12(24).

Jethro, N, Sule A, Akudo EO, Ebong ED (2024). Implication of particle sizes on bioremediation of crude oil polluted sandy soil in Okolomade part of Niger Delta Basin, Southern Nigeria. World News Nat Sci, 52: 34-57.

Jha, MN, Levy J, Gao Y (2008). Advances in remote sensing for oil spill disaster management: State-of-the-art sensors technology for oil spill surveillance. Sensors. DOI 10.3390/s8010236.

Jibrin, M, Abdulhameed A, Nayaya AJ, Ezra AG (2022). Health risk effect of heavy metals from pesticides in vegetables and soils: A review. Dutse J. Pure Appl. Sci. DOI 10.4314/dujopas.v7i3b.3.

Johnbull, O, Abbassi B, Zytner RG (2018). Risk assessment of heavy metals in soil based on the geographic information system-kriging technique in Anka, Nigeria. Environ. Eng. Res. DOI 10.4491/eer.2018.130.

Jolaosho, TL, Elegbede IO, Ndimele PE, Mekuleyi GO, Oladipupo IO, Mustapha AA (2023). Comprehensive geochemical assessment, probable ecological and human health risks of heavy metals in water and sediments from dredged and non-dredged rivers in Lagos, Nigeria. J. Hazard. Mater. Adv., 12: 100379.

Jonah, IB, Francis IO (2023). Geospatial analysis of oil spill in the selected parts of the Niger Delta. J. Environ. Geogr. Stud. DOI 10.58425/jegs.v2i1.121.

Joseph, PO, Ojomah FO, Idris OY (2019). Assessment of some heavy metals in the surrounding soils and crops of West African Ceramic Industry. Trop. Plant Res., 6(3): 467-471.

Kafilat, AB-A, Kayode J, Adebayo S, Akeem O (2018). Integrated assessment of the heavy metal pollution status and potential ecological risk in the Lagos Lagoon, Southwest, Nigeria. Hum. Ecol. Risk Assess., 24(2): 377-397.

Kalagbor, IA, Dibofori-Orji AN, Ekpete OA (2019). Exposure to heavy metals in soot samples and cancer risk assessment in Port Harcourt, Nigeria. J. Health Pollut., 9(24): 191211.

Kalfa, A, Shapira B, Shopin A, Cohen I, Avraham E, Aurbach D (2020). Capacitive deionization for wastewater treatment: Opportunities and challenges. Chemosphere, 241: 125003.

Kannaujia, RK, Singh S (2012). Levels, spatial distribution and possible sources of heavy metal contamination of suburban soil in Jhansi. Orient. J. Chem. DOI 10.13005/ojc/280453.

Kaur, H, Devi NSMPL, Siwal SS, Alsanie WF, Thakur MK, Thakur VK (2023). Metal–organic framework-based materials for wastewater treatment: Superior adsorbent materials for the removal of hazardous pollutants. Acs Omega. DOI 10.1021/acsomega.2c07719.

Khan, S, Cao Q, Zheng Y, Huang Y, Zhu Y (2008). Health risks of heavy metals in contaminated soils and food crops irrigated with wastewater in Beijing, China. Environ. Pollut. DOI 10.1016/j.envpol.2007.06.056.

KolaOlusanya, A, Oyeyemi E, Adewale PS, Omobuwa O (2023). Role of environmental education in water pollution prevention and conservation in Nigeria. Water Supply: ws2023337.

Kolawole, TO, Ajibade OM, Olajide-Kayode JO, Fomba KW (2023). Level, distribution, ecological, and human health risk assessment of heavy metals in soils and stream sediments around a used-automobile spare part market in Nigeria. Environ. Geochem. Health, 45(5): 1573-1598.

Kouamé, IK, Kouassi LK, Dibi B, Adou KM, Rascanu ID, Romanescu G, Savané I, Sandu I (2013). Potential groundwater pollution risks by heavy metals from agricultural soil in Songon area (Abidjan, Côte d'Ivoire). J. Environ. Prot. DOI 10.4236/jep.2013.412165.

Kucserka, T, Németh GI, Pálfi I, Kiss ZL, Tombácz E, Galambos I (2023). Adsorption-based pretreatment of irrigation water to prevent water quality issues. Separations, 10(9): 468.

Kurucz, V, Kiss B, Szigeti ZM, Nagy G, Orosz E, Hargitai Z, Harangi S, Wiebenga A, Vries RPd, Pócsi I, Emri T (2018). Physiological background of the remarkably high Cd2+ tolerance of the Aspergillus fumigatus af293 strain. J. Basic Microbiol. DOI 10.1002/jobm.201800200.

Ladan, MT (2012). Review of Natl. Environ. Stand. Regul. Enforcement Agency (NESREA) Act 2007 and regulations 2009-2011: A new dawn in environmental compliance and enforcement in Nigeria. Law, Environ. Dev. J., 8: 116.

Lala, MA, S Kawu, OA Adesina, & JA Sonibare (2022). Assessment of heavy metal pollution status in surface soil of a Nigerian university. J. Niger. Soc. Phys. Sci., 887-887.

Laniyan, TA, & AJ Adewumi (2023). Ecological and human health risk associated with potentially toxic metals in water from Ijero mining area, Southwest Nigeria. Int. J. Environ. Anal. Chem., 103(16): 4677-4701.

Laniyan, TA, & OM Morakinyo (2021). Environmental sustainability and prevention of heavy metal pollution of some geomaterials within a city in southwestern Nigeria. Heliyon, 7(4): e06796. Available from https://www.sciencedirect.com/science/article/pii/S2405844021008999. DOI https://doi.org/10.1016/j.heliyon.2021.e06796.

Lee, SY, Y-Y Lee, & K-S Cho (2022). Effect of Novosphingobium sp. Cut1 inoculation on the rhizoremediation of heavy metal- and diesel-contaminated soil planted with tall fescue. Environ.

Sci. Pollut. Res., DOI 10.1007/s11356-022-23339-4.

Leung, HM, NS Duzgoren-Aydin, CK Au, S Krupanidhi, KY Fung, KC Cheung, YK Wong, XL Peng, ZH Ye, & KKL Yung (2017). Monitoring and assessment of heavy metal contamination in a constructed wetland in Shaoguan (Guangdong province, China): Bioaccumulation of Pb, Zn, Cu and Cd in aquatic and terrestrial components. Environ. Sci. Pollut. Res., 24: 9079-9088.

Liang, Q, Y Pan, D Zhang, T Lü, H Zhao, & Y Zhang (2023). Preparation of bichar/layered double hydroxide@ alginate aerogel as a highly efficient adsorbent for Cu2+ and Cd2+. J. Appl. Polym. Sci., 140(4): e53361.

Liu, X, Z Bai, H Shi, W Zhou, & X Liu (2019). Heavy metal pollution of soils from coal mines in China. Nat. Hazards, DOI 10.1007/s11069-019-03771-5.

Liu, X, Q Song, Y Tang, W Li, J Xu, J Wu, F Wang, & PC Brookes (2013). Human health risk assessment of heavy metals in soil–vegetable system: A multi-medium analysis. Sci. Total Environ., 463: 530-540.

Lu, J, & F Yuan (2016). The assessment of heavy metal distribution in the sediment of eastern Chongming tidal flat, China. Environ. Impact Assess. Rev., DOI 10.2495/EID160091.

Lu, L, S Rughöft, D Straub, SB Joye, A Kappler, & S Kleindienst (2023). Rhamnolipid biosurfactants enhance microbial oil biodegradation in surface seawater from the North Sea. ACS ES&T Water, DOI 10.1021/acsestwater.3c00048.

Lyu, Q, S Luo, Y Guan, J Fu, X Niu, L Xu, S Feng, & S Li (2019). A new method of lithologic identification and distribution characteristics of fine-grained sediments: A case study in southwest of Ordos Basin, China. Open Geosci., DOI 10.1515/geo-2019-0002.

Mafuyai, GM, JJ Gongden, & NM Kamoh (2014). Monitoring and statistical evaluation of heavy metals in respirable dust in Jos metropolitan area, Nigeria.

Magyar, Z, P Pepó, & E Gyimes (2019). Effect of different levels of fertilizers and forecrops on rheological properties of winter wheat. Rev. Agric. Rural Dev., DOI 10.14232/rard.2019.1-2.47-52.

Mantur, VS, MS Somannavar, S Hegde, SS Vernekar, KK Das, & SS Goudar (2022). Nephroprotective effect of black tea extract on cadmium induced male Wistar rats. Biomedicine, DOI 10.51248/.v42i1.770.

Marais, EA, DJ Jacob, K Wecht, C Lerot, L Zhang, K Yu, TP Kurosu, K Chance, & B Sauvage (2014). Anthropogenic emissions in Nigeria and implications for atmospheric ozone pollution: A view from space. Atmos. Environ., 99: 32-40.

Marais, EA, & C Wiedinmyer (2016). Air quality impact of diffuse and inefficient combustion emissions in Africa (DICE-Africa). Environ. Sci. Technol., 50(19): 10739-10745.

Maroulis, M, A Economou, & A Voulgaropoulos (2007). Determination of Cd and Pb in phosphorites and phosphate fertilizers by means of a portable voltammetric analyzer based on "virtual instrumentation". Electroanalysis, DOI 10.1002/elan.200703906.

Marzo, DRR, HWJ Chen, H Anuar, MKB Abdul Wahab, MHNB Arifin, IAB Ariffin, AIB Ahmad, J Kawuki, & M Aljuaid (2023). Effect of community participation on sustainable development: An assessment of sustainability domains in Malaysia. Front. Environ. Sci., 11: 1268036.

Masoner, JR, DW Kolpin, IM Cozzarelli, PM Bradley, B Arnall, KJ Forshay, JL Gray, J Groves, ML Hladik, LE Hubbard, LR Iwanowicz, JB Jaeschke, RF Lane, RB McCleskey, BF Polite, DA Roth, MB Pettijohn, MC Wilson (2023). Contaminant exposure and transport from three potential reuse waters within a single watershed. Environ. Sci. Technol. DOI 10.1021/acs.est.2c07372.

Mejia, LT (2015). Lead contamination: Environmental geochemistry of gold mining villages in northwest Nigeria.

Mhlongo, SE, F Amponsah-Dacosta, C Muzerengi, WM Gitari, A Momoh (2019). The impact of artisanal mining on rehabilitation efforts of abandoned mine shafts in Sutherland goldfield, South Africa. J. Disaster Risk Stud. DOI 10.4102/jamba.v11i2.688.

Milam, C, D Jildawa, K Onanuga, V Daniel (2022). Potential risk assessment of heavy metals in agricultural crops cultivated around abandoned mine areas in Barkin Ladi, Plateau State, Nigeria.

J. Chem. Soc. Nigeria. DOI 10.46602/JCSN.V47I6.824.

Mng'ong'o, M, W Blake, S Comber, TH Hutchinson, PA Ndakidemi (2021). Soil fertility and land sustainability in Usangu Basin, Tanzania. Heliyon. DOI 10.1016/j.heliyon.2021.e07745.

Mosa, KA, I Saadoun, K Kumar, M Helmy, OP Dhankher (2016). Potential biotechnological strategies for the cleanup of heavy metals and metalloids. Front. Plant Sci., 7: 303.

Mshelia, SS, L Bulama (2023). Concentration and comparison of groundwater quality in Kano Metropolis, Nigeria. Br. J. Environ. Sci., 11(2): 23-35.

Munganyinka, JP, JB Habinshuti, JC Ndayishimiye, L Mweene, G Ofori-Sarpong, B Mishra, AR Adetunji, H Tanvar (2022). Potential uses of artisanal gold mine tailings, with an emphasis on the role of centrifugal separation technique. Sustainability. DOI 10.3390/su14138130.

N'goran, KPDA, D Diabaté, NgLB Kouassi, KM Yao, KC Kinimo, AA Ouattara, A Trokourey (2021). Speciation and spatial distribution of trace metals in sediments around gold mining areas in northern Côte d'Ivoire. DOI 10.21203/rs.3.rs-277930/v1.

Nachana'a Timothy, ETW (2019). Environmental pollution by heavy metal: An overview. Chem., 3(2): 72-82.

Nafarnda, WD, IE Ajayi, JC Shawulu, MS Kawe, GK Omeiza, NA Sani, OZ Tenuche, DD Dantong, SZ Tags (2012). Bacteriological quality of abattoir effluents discharged into water bodies in Abuja, Nigeria. ISRN Vet. Sci. DOI 10.5402/2012/515689.

Nagajyoti, PC, KD Lee, TVM Sreekanth (2010). Heavy metals, occurrence and toxicity for plants: A review. Environ. Chem. Lett. DOI 10.1007/s10311-010-0297-8.

Naz, A, A Chowdhury, R Chandra, BK Mishra (2020). Potential human health hazard due to bioavailable heavy metal exposure via consumption of plants with ethnobotanical usage at the largest chromite mine of India. Environ. Geochem. Health, 42: 4213-4231.

Nde, NB, GA Offong, SC Uchendu, SP Inyang (2023). Heavy metals characteristics of water samples from Muokolu River in Eleme Local Government Area of Rivers State, Nigeria.

Nduka, JK, HI Kelle, TC Umeh, PC Okafor, GC Iloka, E Okoyomon (2023). Ecological and health risk assessment of radionuclides and heavy metals of surface and groundwater of Ishiagu–Ezillo quarry sites of Ebonyi, southeast Nigeria. J. Hazard. Mater. Adv., 10: 100307.

Nduka, JK, TC Umeh, HI Kelle, MN Mgbemena, RA Nnamani, PC Okafor (2023). Ecological and health risk assessment of heavy metals in roadside soil, dust and water of three economic zones in Enugu, Nigeria. Urban Clim., 51: 101627.

Ngwenya, S, NS Mashau, ES Mhlongo, AN Traoré, AG Mudau (2023). Health risk management framework for heavy metals and cyanide in Kwekwe City of Zimbabwe: A mixed-method study protocol. J. Health, Popul. Nutr., 42(1): 26.

Nicholas, UT, AC Udebuani, UE Nwogu (2022). Heavy metal contamination index, metal index and polycyclic aromatic hydrocarbon content of Ochani River in Ogoni, Rivers State, Nigeria. Int. J. Biochem. Res. Rev.: 36-47.

Nkemdilim, I, A Akuirene, P Bwititi, JO Adjene, EU Nwose (2021). Impact of gas flaring on communities in Delta region of Nigeria, narrative review part 1: Environmental health perspective. Int. J. Scientific Reports. DOI 10.18203/issn.2454-2156.intjscirep20210548.

Nkwunonwo, UC, PO Odika, NI Onyia (2020). A review of the health implications of heavy metals in food chain in Nigeria. The Scientific World Journal, 2020.

Nnabo, PN (2015). Heavy metal distribution and contamination in soils around Enyigba Pb-Zn mines district, southeastern Nigeria. J. Environ. Earth Sci., 5(16): 38-53.

Nnaji, ND, H Onyeaka, T Miri, C Ugwa (2023). Bioaccumulation for heavy metal removal: A review. SN Appl. Sci., 5(5): 125.

Ntesat, UB, C Emeka, DQ Edward (2023). Bioremediation of heavy metals in crude oil-contaminated Ultisol, using nutrient formulate produced from Jatropha tanjorensis leaf extract. Res. J. Ecology Environ. Sci.: 37-46.

Nuhu, MM, ER Rene, AI Ishaq (2021). Remediation of crude oil spill sites in Nigeria: Problems, technologies, and future prospects. Environ. Qual. Manage. DOI 10.1002/tqem.21793.

Nwagwu, EC, VM Yilwa, NE Egbe, GB Onwumere (2017). Isolation and characterization of heavy metal tolerant bacteria from Panteka Stream, Kaduna, Nigeria and their potential for bioremediation. Afr. J. Biotechnol., 16(1): 32-40.

Nwaichi, EO, JO Osuoha (2021). Has the national policy on environmental pollution control in Nigeria been neglected in the Niger Delta region? An update. Environ. Dev. Sustainability. DOI 10.1007/s10668-021-01973-1.

Nwazue, EU, EJ Omietimi, E Mienye, OJ Imarhiagbe, OA Adeosun, PN Nnabo (2022). Heavy metal dispersion in stream sediments in River Iyiudene, Abakaliki southeastern Nigeria: Source, distribution pattern, and contamination assessment. J. Geosci. Environ. Prot. DOI 10.4236/gep.2022.107004.

O'Brien, RM, TJ Phelan, NM Smith, KM Smits (2021). Remediation in developing countries: A review of previously implemented projects and analysis of stakeholder participation efforts. Crit. Rev. Environ. Sci. Technol., 51(12): 1259-1280. Available from https://doi.org/10.1080/10643389.2020.1755203. DOI 10.1080/10643389.2020.1755203.

Obasi, P, A Chibuike, N Immaculate (2023). Contamination levels and health risk assessment of heavy metals in food crops in Ishiagu area, Lower Benue Trough southeastern Nigeria. Int. J. Environ. Sci. Technol. DOI 10.1007/S13762-022-04748-X.

Obayiuwana, A, AA Ogunjobi, M Yang, M Ibekwe (2018). Characterization of bacterial communities and their antibiotic resistance profiles in wastewaters obtained from pharmaceutical facilities in Lagos and Ogun States, Nigeria. Int. J. Environ. Res. Public Health. DOI 10.3390/ijerph15071365.

Obiora, SC, A Chukwu, TC Davies (2016). Heavy metals and health risk assessment of arable soils and food crops around Pb–Zn mining localities in Enyigba, southeastern Nigeria. J. African Earth Sci., 116: 182-189.

Ochelebe, I, GE Nkebem, EA Kudamnya (2020). Assessment of heavy metals concentration and enrichment levels in soils around quarries and barite mine sites in part of Akamkpa and Biase area, southeastern Nigeria. J. Geosci. Environ. Prot. DOI 10.4236/gep.2020.88009.

Odebunmi, EO, GO Olutona, EA Akintunde, EO Faboro, OS Balogun, OO Oluwaniyi (2014). Trace metal levels of drinking water sources in parts of Osun State, Nigeria. Ethiop. J. Environ. Stud. Manage., 7(6): 635-644.

Odoemelam, SA, O Ajunwa (2008). Heavy metal status and physicochemical properties of agricultural soil amended by short-term application of animal manure. Curr. World Environ., 3(1): 21-26.

Odogwu, G (2021). As Nigeria fulfils her obligation to Minamata Convention. In: Punch Newspaper, Nigeria Lagos, Nigeria.

Ogamba, EN, EE Charles, and SC Izah (2021). Distributions, pollution evaluation and health risk of selected heavy metal in surface water of Taylor Creek, Bayelsa State, Nigeria. Toxicol. Environ. Health Sci., 13: 109-121.

Ogarekpe, NM, CC Nnaji, OJ Oyebode, MG Ekpenyong, OI Ofem, IT Tenebe, and AD Asitok (2023). Groundwater quality index and potential human health risk assessment of heavy metals in water: A case study of Calabar metropolis, Nigeria. Environ. Nanotechnol. Monit. Manag., 19: 100780.

Ogbaran, AN, and IE Joseph-Akwara (2021). Evaluation of the impact of anthropogenic activities on wetland soil qualities: A case study of Isoko South area of Delta State, Southern Nigeria. Global J. Earth Environ. Sci. DOI 10.31248/gjees2021.099.

Ogbaran, AN, and H Uguru (2021). Evaluating the contamination degree and risk assessment of heavy metals around active dumpsite environment: A case study of Ozoro community, Delta State, Nigeria. Phys. Sci. Int. J. DOI 10.9734/psij/2021/v25i130236.

Ogbonna, DN, and TA Ajubo (2017). Assessment of the impact of municipal sewage disposal on the water quality in Obio/Akpor LGA, Rivers State. IIARD Int. J. Geogr. Environ. Manage., 3(1): 13-22.

Ogbuene, EB, OG Aloh, CT Eze, OO Eze, TE Ugochukwu, AM Oroke, CE Izueke-Okolo, AV

Ozorme, CJ Ibekwe, and CA Eze (2023). Occurrence of heavy metals in soil and selected edible plants in the vicinity of major lead-zinc mining sites in Ebonyi State, Nigeria. Nat. Environ. Pollut. Technol., 22(3).

Ogundele, LT, OK Owoade, PK Hopke, and FS Olise (2017). Heavy metals in industrially emitted particulate matter in Ile-Ife, Nigeria. Environ. Res., 156: 320-325.

Ogwu, C, F Obi-Okolie, and RE Abvbunudiogba (2023). Quantification of the heavy metals in the groundwater of Ikeja Industrial Estate, Ikeja Lagos. J. Res. Environ. Earth Sci., 9(3): 69- 73.

Ogwu, C, AC Ossai, DO Ejemeyovwi, and SE Unuafe (2023). Speciation of the heavy metals in the ground waters of Oshodi/Isolo/Ilasamaja Industrial Estate Lagos Nigeria. IOSR J. Environ. Sci. Toxicol. Food Technol., 17(3).

Ohiagu, FO, PC Chikezie, CC Ahaneku, and CM Chikezie (2022). Human exposure to heavy metals: Toxicity mechanisms and health implications. Mater. Sci. Eng. Int. J., 6(2): 78-87.

Ojezele, OJ, FJ Okparaocha, PO Oyeleke, and HI Agboola (2021). Quantification of some metals in commonly consumed canned foods in South-West Nigeria: Probable pointer to metal toxicity. J. Appl. Sci. Environ. Manage., 25(8): 1519-1525.

Ojiodu, CC, EG Olumayede, and JM Okuo (2018). The level of heavy metals in the atmosphere of a macroenvironment, Lagos State, Southwestern Nigeria using moss plant (Dicranium Scorparium) as bioindicator. Sci. World J., 13(4): 69-74.

Ojo, F. O., Wokhe, T. B., & Chima, M. P. (2018). Assessment of heavy metal pollution in soils from farms in the vicinity of Durumi quarry site in Mpape, Abuja Nigeria. *Curr World Environ*, *13*, 360-373.

Ojo, GJ, OS Onile, AO Momoh, BF Oyeyemi, V Omoboyede, AI Fadahunsi, and T Onile (2023). Physiochemical analyses and molecular characterization of heavy metal-resistant bacteria from Ilesha gold mining sites in Nigeria. J. Genet. Eng. Biotechnol., 21(1): 172.

Okafor, VN, DO Omokpariola, OF Obumselu, and CG Eze (2023). Exposure risk to heavy metals through surface and groundwater used for drinking and household activities in Ifite Ogwari, Southeastern Nigeria. Appl. Water Sci., 13(4): 105.

Okere, RO, and N Osemeke (2020). Public agencies in Nigeria's oil sector: Wealth distribution, economic development and poverty alleviation in the Niger Delta. J. Econ. Int. Finance. DOI 10.5897/jeif2020.1048b.

Okey-Wokeh, CG, OK Wokeh, E Orose, F Lananan, and MN Azra (2023). Anthropogenic impacts on physicochemical and heavy metal concentrations of Ogbor Hill River water, Southern Nigeria. Water, 15(7): 1359.

Okoduwa, IO, BJ Enagbonma, and EE Imade (2022). Effects of pharmaceutical effluents on soil microbiome and physicochemical parameters. J. Appl. Sci. Environ. Manage. DOI 10.4314/jasem.v26i8.7.

Okolo, CC, TDT Oyedotun, and FOR Akamigbo (2018). Open cast mining: Threat to water quality in rural community of Enyigba in south-eastern Nigeria. Appl. Water Sci. DOI 10.1007/s13201-018-0849-9.

Okonkwo, SI, and OA Okunlola (2022). Geochemical characterization of shale deposits around Afikpo area, southeastern Nigeria. DOI 10.21203/rs.3.rs-971508/v1.

Okorondu, JN, E Owhoeke, BE Diagi, JI Nwachukwu, and LC Izunobi (2021). Assessment of heavy metal contamination in sea bed sediment of the Bight of Bonny, southern Atlantic coast of Nigeria using index model analysis. J. Geosci. Environ. Prot., 9(12): 286-298.

Okosa, I, T Paul, CE Ikechukwu-Edeh, P Ehiomogue, CC Emeka-Chris, and AC Okereke (2023). Ecological and health risk assessment of heavy metals: A case study of residential waste sites in Umuahia, south-east Nigeria. Environ. Monit. Assess., 195(3): 360.

Okudo, CC, NR Ekere, and COB Okoye (2023). Heavy metals in dry depositions as indices of atmospheric pollution in Enugu urban, Enugu State, Nigeria. Water Environ. Sustain., 3(3): 30-41.

Okunola, OJ, A Uzairu, and G Ndukwe (2007). Levels of trace metals in soil and vegetation along major and minor roads in Metropolitan City of Kaduna, Nigeria. Afr. J. Biotechnol., 6(14).

Oladunjoye, RY, OO Fafioye, ST Bankole, AH Adedeji, and AS Edoh (2021). Heavy metals in shellfishes of Ojo River, Lagos State, Nigeria. Agro-Sci., 20(3): 99-103.

Olagbemide, PT, and OD Owolabi (2023). Metal accumulation in Ekiti State's three major dams' water and sediments, the ecological hazards assessment and consequences on human health. J. Exp. Biol. Agric. Sci., 11(1): 81-96.

Olalekan, AS, SO Adewoye, OH Sawyerr, and MO Raimi (2023). Comparative assessment of seasonal variations in the quality of surface water and its associated health hazards in gold mining areas of Osun State, South-West Nigeria. Adv. Environ. Eng. Res., 4(1): 011.

Olatomiwa, S-I, and JO Ashaolu (2023). Comparative study of bioremediation potential of heavy metal-resistant fungi isolated from mechanic sites. Int. J. Sci. Adv., 4(6).

Olatunde, KA, PA Sosanya, BS Bada, ZO Ojekunle, and SA Abdussalaam (2020). Distribution and ecological risk assessment of heavy metals in soils around a major cement factory, Ibese, Nigeria. Sci. Afr., 9: e00496. Available from https://www.sciencedirect.com/science/article/pii/S2468227620302349. DOI https://doi.org/10.1016/j.sciaf.2020.e00496.

Olatunji, OS, OS Fatoki, BO Opeolu, BJ Ximba, OO Zacheaus, and AN Kehinde (2014). Nutrient enrichment and hypoxia threat in urban surface water. Clean - Soil Air Water. DOI 10.1002/clen.201300292.

Ololade, IA (2014). An assessment of heavy-metal contamination in soils within auto-mechanic workshops using enrichment and contamination factors with geoaccumulation indexes. J. Environ. Prot. DOI 10.4236/jep.2014.511098.

Oloruntoba, E, O Gurusa, F Omokhodion, J Fobil, N Basu, J Arko-Mensah, and T Robin (2021). Spatial distribution of heavy metals and pollution of environmental media around a used lead-acid battery recycling center in Ibadan, Nigeria. J. Health Pollut., 11(29): 210304.

Oloruntoba, EO, OZ Wada, and M Adejumo (2022). Heavy metal analysis of drinking water supply, wastewater management, and human health risk assessment across secondary schools in Badagry coastal community, Lagos State, Nigeria. Int. J. Environ. Health Res., 32(9): 1897-1914.

Olowomofe, TO, OA Oluwole, and AO Adekanmbi (2022). Application of metal-tolerant bacteria isolated from aquaculture pond wastewater in the bioremediation of metal-containing effluent. Asia-Pac. J. Sci. Technol., 28(05).

Olufunmilayo, WJ, JS Emmanuel, and NR Renna (2023). Enhanced phytoremediation and physicochemical parameters of crude oil-polluted soil using Pseudomonas fluorescens and Bacillus substilis. South Asian J. Res. Microbiol., 17(3): 1-16.

Olujimi, OO, O Oputu, OS Fatoki, OE Opatoyinbo, OA Aroyewun, and J Baruani (2015). Heavy metals speciation and human health risk assessment at an illegal gold mining site in Igun, Osun State, Nigeria. J. Health Pollut. DOI 10.5696/i2156-9614-5-8.19.

Olumayowa, Oluwasola, O Oluoye, S Mohammad Bashir, OA Odewole, H Onyeka Abugu, KG Akpomie, M Kolade David, V Inumidun Fagorite, and M Aishatu Umar (2023). Geochemical and health risk assessment of heavy metals concentration in soils around Oke-Ere mining area in Kogi State, Nigeria. Int. J. Environ. Anal. Chem., 103(3): 685-700.

Olutona, GO (2023). Health risk assessment of heavy metals in sediment of tropical freshwater stream. J. Niger. Soc. Phys. Sci.: 983-983.

Omang, O, H Effiom, E Omeka, E Oko, A Asinya, T Ojikutu, and T Kave (2023). Trace element geochemical imprints and multi-path health risk assessment of potentially toxic elements in soils from the polymetallic area of Tashan-Jatau, Northwestern Nigeria. Global J. Geol. Sci., 21(1): 91-115.

Omeka, ME, and O Igwe (2023). Heavy metals concentration in soils and crop plants within the vicinity of abandoned mine sites in Nigeria: An integrated indexical and chemometric approach. Int. J. Environ. Anal. Chem., 103(16): 4111-4129.

Omokpariola, DO, and PL Omokpariola (2023). Health and exposure risk assessment of heavy metals in rainwater samples from selected locations in Rivers State, Nigeria. Phys. Sci. Rev., 8(8): 1305-1318.

Omonona, AO, TV Solotan, and AT Adetuga (2020). Heavy metals contamination in water, soil and plant samples of Okomu National Park, Edo State, Nigeria. Afr. J. Biomed. Res., 23(1): 29-34.

Onakpa, MM, AA Njan, and OC Kalu (2018). A review of heavy metal contamination of food crops in Nigeria. Ann. Glob. Health, 84(3): 488.

Onyedikachi, UB, CD Belonwu, and MO Wegwu (2019). Health risk assessment of chromium, manganese and arsenic through the consumption of food from industrial areas in South Eastern States of Nigeria. Ann. Res. Rev. Biol.: 1-20.

Opaluwa, OD, MO Aremu, LO Ogbo, KA Abiola, IE Odiba, MM Abubakar, and NO Nweze (2012). Heavy metal concentrations in soils, plant leaves and crops grown around dump sites in Lafia metropolis, Nasarawa State, Nigeria. Adv. Appl. Sci. Res., 3(2): 780-784.

Ordinioha, B, and S Brisibe (2013). The human health implications of crude oil spills in the Niger Delta, Nigeria: An interpretation of published studies. Niger. Med. J. DOI 10.4103/0300-1652.108887.

Orisakwe, OE (2014). Lead and cadmium in public health in Nigeria: Physicians' neglect and pitfall in patient management. N. Am. J. Med. Sci., 6(2): 61.

Orisakwe, OE, JK Nduka, CN Amadi, DO Dike, and O Bede (2012). Heavy metals health risk assessment for population via consumption of food crops and fruits in Owerri, South Eastern, Nigeria. Chem. Cent. J., 6(1): 1-7.

Orisakwe, OE, OO Oladipo, GC Ajaezi, and NA Udowelle (2017). Horizontal and vertical distribution of heavy metals in farm produce and livestock around lead-contaminated goldmine in Dareta and Abare, Zamfara State, Northern Nigeria. J. Environ. Public Health, 2017.

Orosun, MM, SO Inuyomi, MR Usikalu, HK Okoro, H Louis, M Omeje, EO Ehinlafa, and KJ Oyewumi (2023). Heavy metal contamination of selected mining fields in North-Central Nigeria. MethodsX, 10: 102201.

Orr, SE, MC Barnes, H George, L Joshee, B Jeon, A Scircle, O Black, JV Cizdziel, BA Smith, and CC Bridges (2018). Exposure to mixtures of mercury, cadmium, lead, and arsenic alters the disposition of single metals in tissues of Wistar rats. J. Toxicol. Environ. Health Part A. DOI 10.1080/15287394.2018.1551164.

Osisanya, OW, IF Agho, AS Saleh, and E Thompson (2022). Hydrogeochemical characterization and quality assessment of groundwater based on water quality index in Imo State, South Eastern Nigeria. J. Appl. Sci. Environ. Manage. DOI 10.4314/jasem.v26i12.13.

Osuizugbo, IC and CV Nnodu (2023). Barriers to environmental impact assessment implementation for construction projects in Nigeria. Built Environ. Proj. Asset Manage.

Osunmakinde, CO, R Selvarajan, BB Mamba, and TAM Msagati (2021). Viral communities distribution and diversity in wastewater treatment plants using high-throughput sequencing analysis. Polish J. Environ. Stud. DOI 10.15244/pjoes/127888.

Ouattara, G, GB Koffi, A Gnanzou, and KA Yao (2022). Analysis of the spatio-temporal evolution of artisanal and small-scale gold mining in Central Ivory Coast, West Africa. J. Geosci. Environ. Prot. DOI 10.4236/gep.2022.109009.

Ouma, KO, A Shane, and S Syampungani (2022). Aquatic ecological risk of heavy-metal pollution associated with degraded mining landscapes of the Southern Africa River Basins: A review. Minerals, 12(2): 225.

Ouziad, F, U Hildebrandt, E Schmelzer, and H Bothe (2005). Differential gene expressions in arbuscular mycorrhizal-colonized tomato grown under heavy metal stress. J. Plant Physiol. DOI 10.1016/j.jplph.2004.09.014.

Owamah, HI, TO Akpoedafe, SC Ikpeseni, E Atikpo, HO Orugba, and S Oyebisi (2023). Spatial distribution of heavy metals in groundwater around automobile workshops in a popular Niger-Delta university town, Nigeria. J. Eng. Appl. Sci., 70(1): 79.

Oyebode, OJ, FO Jimoh, S Ajibade, SA Afolalu, and FA Oyebode (2023). Strategic monitoring of groundwater quality around Olusosun landfill in Lagos State for pollution reduction and environmental sustainability. Nat. Environ. Pollut. Technol., 22(2).

Oyedeji, O, DI Onifade, and AA Onilude (2022). Production, characterization, and application of biosurfactant from *Lactobacillus plantarum* OG8 isolated from fermenting maize (*Zea mays*) slurry. Acta Univ. Cibiniensis Ser. E Food Technol. DOI 10.2478/aucft-2022-0022.

Oyeku, OT, and AO Eludoyin (2010). Heavy metal contamination of groundwater resources in a Nigerian urban settlement. Afr. J. Environ. Sci. Technol., 4(4).

Parameswari, E, V Davamani, S Arulmani, and A Rathinasami (2014). Soil degradation due to heavy metal accumulation under long-term fertilization of paddy (*Oryza sativa* L.). J. Appl. Nat. Sci. DOI 10.31018/jans.v6i1.397.

Perumal, K, JT Antony, and S Muthuramalingam (2021). Heavy metal pollutants and their spatial distribution in surface sediments from Thondi coast, Palk Bay, South India. Environ. Sci. Europe. DOI 10.1186/s12302-021-00501-2.

Pobi, KK, S Satpati, S Dutta, S Nayek, RN Saha, and S Gupta (2019). Sources evaluation and ecological risk assessment of heavy metals accumulated within a natural stream of Durgapur industrial zone, India, by using multivariate analysis and pollution indices. Appl. Water Sci., 9(3): 1-16.

Prakash, P (2023). Nano-phytoremediation of heavy metals from soil: A critical review. Pollutants, 3(3): 360-380.

Prathima, B, P Sughosh, and SBG L (2021). Study of heavy metals transport in the vadose zone of contaminated soil. Japanese Geotech. Soc. Spec. Publ. DOI 10.3208/jgssp.v09.cpeg129.

Proshad, R, T Kormoker, N Mursheed, MM Islam, MI Bhuyan, MS Islam, and TN Mithu (2018). Heavy metal toxicity in agricultural soil due to rapid industrialization in Bangladesh: A review. Int. J. Adv. Geosci. DOI 10.14419/ijag.v6i1.9174.

Rabiu, AG, and OI Falodun (2017). Multi-drug resistant *Pseudomonas* species isolated from the wastewater of an abattoir in Ibadan, Nigeria. J. Appl. Life Sci. Int. DOI 10.9734/jalsi/2017/34522.

Radaideh, JA, HA Abdulgader, and M Barjenbruch (2017). Evaluation of absorption process for heavy metals removal found in pharmaceutical wastewater. J. Med. Toxicol. Clin. Forensic Med. DOI 10.21767/2471-9641.100029.

Radočaj, D, N Velić, M Jurišić, and E Merdić (2020). The remediation of agricultural land contaminated by heavy metals. Poljorivreda, 26(2): 30-42.

Rahman, MM, MA Hasan, and KM Ahmed (2022). Arsenic and salinity affected groundwater in South-Western Bangladesh: An assessment of managed aquifer recharge and sub-surface arsenic removal as mitigation techniques. Environ. Earth Sci. Res. J. DOI 10.18280/eesrj.090207.

Rahman, Z, and VP Singh (2019). The relative impact of toxic heavy metals (THMs) (arsenic (As), cadmium (Cd), chromium (Cr)(VI), mercury (Hg), and lead (Pb)) on the total environment: An overview. Environ. Monit. Assess., 191: 1-21.

Rajkumar, H, PK Naik, G Singh, and M Rishi (2023). Hydrogeochemical characterization, multi-exposure deterministic and probabilistic health hazard evaluation in groundwater in parts of Northern India. Toxin Rev., 42(1): 204-227.

Rakotondrabe, F, JRN Ngoupayou, Z Mfonka, E Rasolomanana, AJN Abolo, BL Asone, AA Ako, and MH Rakotondrabe (2017). Assessment of surface water quality of Bétaféré-Oya gold mining area (East-Cameroon). J. Water Resour. Prot. DOI 10.4236/jwarp.2017.98064.

Ren, S, E Li, Q Deng, H He, and S Li (2018). Analysis of the impact of rural households' behaviors on heavy metal pollution of arable soil: Taking Lankao County as an example. Sustainability. DOI 10.3390/su10124368.

Richard, G, SC Izah, and M Ibrahim (2023). Air pollution in the Niger Delta region of Nigeria: Sources, health effects, and strategies for mitigation. J. Environ. Stud., 29(1): 1-15.

Richards, BK, BM Schulte, A Heilig, TS Steenhuis, MB McBride, EZ Harrison, and P Dickson (2004). Environmental impacts of applying manure, fertilizer, and sewage biosolids on a dairy farm. JAWRA J. Am. Water Resour. Assoc. DOI 10.1111/j.1752-1688.2004.tb01064.x.

Saha, A, BKS Gupta, S Patidar, and N Martínez-Villegas (2022). Estimating source apportionment of heavy metals contamination in surface soil based on a positive matrix factorization (PMF) model around Cerrito Blanco in San Luis Potosi, Mexico. DOI 10.3390/iecg2022-13746.

Samuel, O, MHD Othman, R Kamaludin, TA Kurniawan, T Li, H Dzinun, and A Imtiaz (2022). Treatment of oily wastewater using photocatalytic membrane reactors: A critical review. J. Environ. Chem. Eng., 108539.

Sanga, VF, C Fabian, and F Kimbokota (2023). Heavy metal pollution in leachates and its impacts on the quality of groundwater resources around Iringa Municipal Solid Waste Dumpsite. Environ. Sci. Pollut. Res., 30(3): 8110-8122.

Sankhla, MS, M Kumari, M Nandan, R Kumar, and P Agrawal (2016). Heavy metals contamination in water and their hazardous effect on human health-a review. Int. J. Curr. Microbiol. Appl. Sci., 5(10): 759-766.

Sarah, G, and SA Raj (2023). Heavy metal bioaccumulation in sediment and benthic biota. DOI 10.5772/intechopen.110015.

Saravanan, A, PS Kumar, B Ramesh, and S Srinivasan (2022). Removal of toxic heavy metals using genetically engineered microbes: Molecular tools, risk assessment, and management strategies. Chemosphere, 298: 134341.

Sardar, K, S Ali, H Samra, A Sana, S Fatima, BS Muhammad, AB Saima, and MT Hafiz (2013). Heavy metals contamination and what are the impacts on living organisms. Greener J. Environ. Manage. Public Safety. DOI 10.15580/gjemps.2013.4.060413652.

Sawyerr, HO, MO Raimi, AT Adeolu, and OE Odipe (2019). Measures of harm from heavy metal pollution in battery technicians within Ilorin metropolis, Kwara State, Nigeria. Communication, Society, and Media, ISSN: 2576-5388.

Selvi, A, A Rajasekar, J Theerthagiri, A Ananthaselvam, K Sathishkumar, J Madhavan, and PKSM Rahman (2019). Integrated remediation processes toward heavy metal removal/recovery from various environments-a review. Front. Environ. Sci., 7: 66.

Shaginimol, CN, B Manojkuma, and N S.Kaliraj (2022). Spatial distribution of heavy metals in surface water from coastal areas of Ernakulam district, Kerala, South West Coast of India. Ecol. Environ. Conserv. DOI 10.53550/eec.2022.v28i07s.026.

Sharma, B, A Sarkar, P Singh, and RP Singh (2017). Agricultural utilization of biosolids: A review on potential effects on soil and plant growth. Waste Manage., 64: 117-132.

Sharma, S and KJ Dietz (2006). The significance of amino acids and amino acid-derived molecules in plant responses and adaptation to heavy metal stress. J. Exp. Bot. DOI 10.1093/jxb/erj073.

Shi, J, Z Jin, Z Zhou, X Wang, X Yang, and W Qian (2022). Heavy metal pollution characteristics of soil around a copper-nickel mine tailings pond in the northwest arid area of China and evaluation of desert phytoremediation potential. DOI 10.1101/2022.10.24.513495.

Shimod, KP, V Vineethkumar, T Prasad, and G Jayapal (2022). Effect of urbanization on heavy metal contamination: A study on major townships of Kannur district in Kerala, India. Bull. Natl. Res. Centre. DOI 10.1186/s42269-021-00691-y.

Singh, A and SM Prasad (2015). Remediation of heavy metal-contaminated ecosystems: An overview of technology advancement. Int. J. Environ. Sci. Technol., 12: 353-366.

Singh, H and G Pant (2023). Phytoremediation: A low-input-based ecological approach for sustainable environment. Appl. Water Sci., 13(3): 85. Available from https://doi.org/10.1007/s13201-023-01898-2. DOI 10.1007/s13201-023-01898-2.

Smith, SR (2009). A critical review of the bioavailability and impacts of heavy metals in municipal solid waste composts compared to sewage sludge. Environ. Int., 35(1): 142-156.

Sobha, K, A Poornima, P Harini, and K Veeraiah (2007). A study on biochemical changes in the freshwater fish, *Catla catla* (Hamilton), exposed to the heavy metal toxicant cadmium chloride. Kathmandu Univ. J. Sci. Eng. Technol., 1(4): 1-11.

Sodhi, KK, LC Mishra, CK Singh, and M Kumar (2022). Perspective on heavy metal pollution and recent remediation strategies. Curr. Res. Microb. Sci., 3: 100166. Available from https://www.sciencedirect.com/science/article/pii/S2666517422000633. DOI https://doi.org/10.1016/j.crmicr.2022.100166.

Sofia, S, T Ibrahim, and M Risqa (2017). Neurological status disturbances caused by mercury exposures from artisanal gold mining area in West Aceh, Aceh Province. DOI 10.2991/phico-16.2017.53.

Soinne, H, M Kurkilahti, J Heikkinen, M Eurola, R Uusitalo, V Nuutinen, and R Keskinen (2022). Decadal trends in soil and grain microelement concentrations indicate mainly favorable development in Finland. J. Plant Nutr. Soil Sci. DOI 10.1002/jpln.202200141.

Sojinu, SO, J Wang, OO Sonibare, and EY Zeng (2010). Polycyclic aromatic hydrocarbons in sediments and soils from oil exploration areas of the Niger Delta, Nigeria. J. Hazard. Mater. DOI 10.1016/j.jhazmat.2009.09.099.

Soujanya Kamble, B, PR Saxena, RM Kurakalva, and K Shankar (2020). Evaluation of seasonal and temporal variations of groundwater quality around Jawaharnagar Municipal Solid Waste Dumpsite of Hyderabad city, India. SN Appl. Sci., 2: 1-22.

Stepanova, LP, AV Pisareva, and BA Раскатов (2021). Assessment of the state of soil's microbial community in the condition of intensive influence of pollutants. Ekológia (Bratislava). DOI 10.2478/eko-2021-0002.

Su, Q, X Zhang, Y Zhang, G Sun, Z Li, L Xiang, and J Cai (2023). Risk assessment of heavy metal pollution in agricultural soil surrounding a typical pharmaceutical manufacturing complex. Front. Environ. Sci. DOI 10.3389/fenvs.2022.1105910.

Sudo, K, CV Dao, A Miyamoto, and M Shiraishi (2019). Comparative analysis of in vitro neurotoxicity of methylmercury, mercury, cadmium, and hydrogen peroxide on SH-SY5Y cells. J. Vet. Med. Sci. DOI 10.1292/jvms.19-0059.

Tang, G, X Zhang, L Qi, C Wang, L Li, J Guo, X Dou, L Meng, and J Huang (2021). Nitrogen and phosphorus fertilization increases the uptake of soil heavy metal pollutants by plant community. DOI 10.21203/rs.3.rs-413625/v1.

Teklay, A (2016). Physiological effect of chromium exposure: A review. Int. J. Food Sci. Nutr. Diet. S, 7: 1-11.

Thurtle, NG, J Cooney, L Amitai, Y Ariti, C Brown, MJ Kosnett, D (2010). Lead poisoning disaster in Nigeria.

Timsina, S, NG Hardy, DJ Woodbury, MS Ashton, SC Cook- Patton, R Pasternack, and MP Martin (2022). Tropical surface gold mining: A review of ecological impacts and restoration strategies. Land Degrad. Dev. DOI 10.1002/ldr.4430.

Ubiogoro, OE and OK Adeyemo (2017). Heavy metal pollution of aquatic systems in oil-producing communities of Delta State, Nigeria. J. Appl. Biosci., 120: 11993-11998.

Ubong, UU, IO Ekwere, and CO Obadimu (2023). Human health risk assessment: A case study of heavy metals accumulations in tissues of Callinectus latimanus from Iko River, Eastern Obolo LGA, Akwa Ibom State. Res. J. Sci. Technol., 3(1): 29-41.

Ubuoh, EA, FU Nwogu, CC Ofoegbu, and PC Chikezie (2023). Environmental pollution loads on surface water chemistry and potentially ecological risks of inland aquatic ecosystems in southeastern Nigeria.

Ugboma, CJ, T Sampson, and NE Mbonu (2020). Bioremediation of heavy metals from artisanal crude oil refinery (Kpo-fire) impacted soil using Bacillus flexus and Pseudomonas aeruginosa in Ngie community, Degema Local Government Area, Rivers State, Nigeria. J. Appl. Sci. Environ. Manage., 24(12): 2049-2054.

Ugochukwu, UC, AL Onuorah, VU Okwu-Delunzu, UL Odinkonigbo, and OH Onuora (2019). Ecological and human health exposure risks to heavy metals in Oji River sediments: Effect of abattoir and power station. SN Appl. Sci. DOI 10.1007/s42452-019-0465-9.

Ugya, AY and TS Imam (2018). Assessment of ambient air quality resulting from anthropogenic emissions. Am. J. Prev. Med., 2: 1-7.

Umeoguaju, FU, JO Akaninwor, EB Essien, BA Amadi, CO Igboekwe, CJ Ononamadu, and CG Ikimi (2023). Heavy metals contamination of seafood from the crude oil-impacted Niger Delta region of Nigeria: A systematic review and meta-analysis. Toxicol. Rep.

Umukoro, BE and MO Omozue (2022). Environmental protection and the role of national policy and guidelines in Nigeria. Baltic J. Law Polit., 15(1): 2016-2029.

UNECE, UNECE (1998). Protocol on heavy metals: The 1998 Aarhus Protocol on Heavy Metals.

UNECE, UNECE (2023). Protocol on heavy metals: The 1998 Aarhus Protocol on Heavy Metals.

UNEP, UNEP (2010). The Rotterdam Convention: Overview. Secretariat of the Rotterdam Convention - UNEP, 11-13, Chemin des Anémones - 1219 Châtelaine, Switzerland.

UNEP, UNEP (2015). Heavy metals.

Ungureanu, E and G Mustățea (2022). Toxicity of heavy metals. DOI 10.5772/intechopen.102441.

Ushie, CA, AA Abong, and EO Obi (2023). Evaluation of pollution indices of heavy metals in ceiling fan dust in lecture halls of a tertiary institution, Calabar, Nigeria. J. Appl. Sci. Environ. Manage., 27(9): 1977-1984.

Usman, B (2023). Heavy metals concentration in food crops irrigated with pesticides and their associated human health risks in Paki, Kaduna State, Nigeria. DOI 10.1080/23311932.2023.2191889.

Usman, YM and UU Modibbo (2020). Health risk assessment on humans by contamination of heavy metals in some edible crops and fish at Galena mining area of Nahuta, Alkaleri Local Government Area, Bauchi State, Nigeria. Afr. J. Pure Appl. Chem., 14(3): 42-50.

Uzoekwe, SA, SC Izah, and AO Aigberua (2021). Environmental and human health risk of heavy metals in atmospheric particulate matter (PM10) around gas flaring vicinity in Bayelsa State, Nigeria. Toxicol. Environ. Health Sci., 1-13.

Vamvuka, D and A Raftogianni (2021). Evaluation of pig manure for environmental or agricultural applications through gasification and soil leaching experiments. Appl. Sci., 11(24): 12011.

Vareda, JP, AJM Valente, and L Durães (2019). Assessment of heavy metal pollution from anthropogenic activities and remediation strategies: A review. J. Environ. Manage., 246: 101-118.

Wang, JK (2015). An absorbent and method of application for the treatment of heavy metal wastewater. Chinese Patent: 201410072325.0.

Wang, L, Z Tian, H Li, C Jia, and W Shan-jun (2016). Spatial and temporal variations of heavy metal pollution in sediments of Daning River under the scheduling of Three Gorges Reservoir. DOI 10.2991/ifeesd-16.2016.186.

Wang, Z, Y Gao, X Xu, W Dong, and T Jiang (2023). Risk classification assessment and early warning of heavy metal contamination in meat products. Sustainability, 15(21): 15558.

Wang, Z, P Luo, X Zha, C Xu, S Kang, M Zhou, D Nover, and Y Wang (2022). Overview assessment of risk evaluation and treatment technologies for heavy metal pollution of water and soil. J. Clean. Prod., 134043.

Wani, PA, N Rafi, U Wani, H Bilikis A, and MSA Khan (2023). Simultaneous bioremediation of heavy metals and biodegradation of hydrocarbons by metal-resistant Brevibacillus parabrevis OZF5 improves plant growth promotion. Biorem. J., 27(1): 20-31.

Wei, J, Y Jin, T Sims, and KE Kniel (2010). Manure- and biosolids-resident murine norovirus 1 attachment to and internalization by romaine lettuce. Appl. Environ. Microbiol. DOI 10.1128/aem.02088-09.

Weissmannová, HD, S Mihočová, P Chovanec, and J Pavlovský (2019). Potential ecological risk and human health risk assessment of heavy metal pollution in industrially affected soils by coal mining and metallurgy in Ostrava, Czech Republic. Int. J. Environ. Res. Public Health. DOI 10.3390/ijerph16224495.

Wilson, SA, AL Harrison, GM Dipple, IM Power, SLL Barker, KU Mayer, S Fallon, M Raudsepp, and G Southam (2014). Offsetting of CO2 emissions by air capture in mine tailings at the Mount Keith nickel mine, Western Australia: Rates, controls, and prospects for carbon-neutral mining. Int. J. Greenh. Gas Control. DOI 10.1016/j.ijggc.2014.04.002.

Wireko-Gyebi, RS, MO Asibey, O Amponsah, RS King, I Braimah, G Darko, and AM Lykke (2020). Perception of small-scale miners on interventions to eradicate illegal small-scale mining in Ghana. Sage Open. DOI 10.1177/2158244020963668.

Witkowska, D, J Słowik, and K Chilicka (2021). Heavy metals and human health: Possible exposure pathways and the competition for protein-binding sites. Molecules. DOI 10.3390/molecules26196060.

Wogu, MD, and CE Okaka (2011). Pollution studies on Nigerian rivers: Heavy metals in surface water of Warri River, Delta State. J. Biodivers. Environ. Sci., 1(3): 7-12.

Wong, SC, X Li, G Zhang, S Qi, and Y Min (2002). Heavy metals in agricultural soils of the Pearl River Delta, South China. Environ. Pollut. DOI 10.1016/s0269-7491(01)00325-6.

Wu, J, J Lü, L Li, X Min, and Y Luo (2018). Pollution, ecological-health risks, and sources of heavy metals in the soil of the northeastern Qinghai-Tibet Plateau. Chemosphere. DOI 10.1016/j.chemosphere.2018.02.122.

Wuana, RA and FE Okieimen (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks, and best available strategies for remediation. ISRN Ecology. DOI 10.5402/2011/402647.

Wuana, RA and FE Okieimen (2011). Heavy metals in contaminated soils: A review of sources, chemistry, risks, and best available strategies for remediation. Int. Scholarly Res. Notices, 2011.

Yahaya, T, A Umar, M Abubakar, A Abdulazeez, B Musa, and Y Ibrahim (2023). Heavy metals in the soil around a cement company in Sokoto, northwestern Nigeria pose health risks. Ind. Domestic Waste Manage., 3(1): 17-26.

Yakubu, S, JO Folorunsho, and SA Adeniyi (2017). Assessment of irrigation water quality sourced from River Galma in Zaria, Nigeria. KIU J. Soc. Sci., 3(2): 193-199.

Yan, A, Y Wang, SN Tan, ML Mohd Yusof, S Ghosh, and Z Chen (2020). Phytoremediation: A promising approach for revegetation of heavy metal-polluted land. Front. Plant Sci., 11: 359.

Yao, Q, L Chen, L Mao, Y Ma, F Tian, R Wang, XZ Meng, and F Li (2022). Co-effects of hydrological conditions and industrial activities on the distribution of heavy metal pollution in Taipu River, China. Int. J. Environ. Res. Public Health. DOI 10.3390/ijerph191610116.

Yap, CK and KA Al-Mutairi (2021). Ecological-health risk assessments of heavy metals (Cu, Pb, and Zn) in aquatic sediments from the ASEAN-5 emerging developing countries: A review and synthesis. Biol., 11(1): 7.

Yaradua, AI, JI Bungudu, L Shuaibu, A Nasir, A Usman, IH Kankia, NU Matazu, ZA Suleiman, AA Sada, and FA Rumah (2023). Health risk assessment of heavy metals in vegetables: The contribution of illegal mining and armed banditry to heavy metal pollution in Katsina State, Nigeria. J. Sci. Res. Rep., 29(5): 19-27.

Younis, YM, IM Idris, and AA Elbashir (2018). Monitoring the anthropogenic and geochemical environment surrounding the Butana (Sudan) drinking water sources via the determination of heavy metals composition of the soil, stream sediments, and gold mining tailings in the wet season (III). Biomed. J. Sci. Tech. Res. DOI 10.26717/bjstr.2018.09.001821.

Yu, X, G Chen, X Zhang, J Zhang, L Jiang, H Zhu, Z Feng, Y Li, T Feng, and Z Xiang (2021). Migration and accumulation of heavy metals in a chicken manure-compost-soil-apple system. Pol. J. Environ. Stud. DOI 10.15244/pjoes/131254.

Zabbey, N, NC Kpaniku, K Sam, GN Nwipie, OE Okoro, FG Zabbey, and BB Babatunde (2021). Could community science drive environmental management in Nigeria's degrading coastal Niger Delta? Prospects and challenges. Environ. Dev., 37: 100571. Available from https://www.sciencedirect.com/science/article/pii/S2211464520300932. DOI https://doi.org/10.1016/j.envdev.2020.100571.

Zahra, FM, SS Rahardjo, and B Murti (2022). Indonesian J. Med. DOI 10.26911/theijmed.2022.07.01.07.

Zhang, H, Z Wang, C Du, W Liu, AR Gerson, and K Pi (2021). Properties and heavy metal leaching characteristics of leachate sludge-derived biochar. Water Environ. Res. DOI 10.1002/wer.1658.

Zhou, N, M Wang, S Lu, TJH Dodd, W Liu, and Y Guan (2022). Evolution of fractal pore structure in sedimentary rocks. Earth Space Sci. DOI 10.1029/2021ea00216.