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Heavy Metal Contamination of Soils in Aladja and Its Environs: Assessing the Impact of Steel Industry Activities on Soil Quality and Environmental Health

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Abstract

This study investigates the extent of heavy metal contamination in soils surrounding the Delta Steel Company (DSC) in Aladja, Ovwian, and Warri, Southern Nigeria. The steel industry, while essential for economic development, has been implicated in significant environmental degradation, particularly through the release of heavy metals such as copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), lead (Pb), cadmium (Cd), and chromium (Cr). Soil samples were collected from 29 locations at varying distances from the steel plant, and their concentrations of heavy metals were analyzed using Atomic Absorption Spectrophotometry (AAS). The physiochemical properties of the soils, including pH, total organic carbon (TOC), and total organic matter (TOM), were also assessed to understand their influence on metal mobility and bioavailability. Results indicate elevated concentrations of heavy metals near the steel plant, with iron (Fe) exhibiting the highest concentration (3249 mg/kg), followed by lead (Pb) at 705 mg/kg. Other metals such as Cu, Mn, and Zn also showed elevated levels, with mean concentrations of 52.5 mg/kg, 358 mg/kg, and 46 mg/kg, respectively. These metals pose a serious risk to environmental health, particularly by decreasing soil fertility and contaminating water sources. This study underscores the urgent need for stricter environmental regulations, soil remediation efforts, and public health interventions to mitigate the impact of industrial pollution in the Niger Delta region. Future research should focus on deeper soil layers and additional heavy metals to provide a more comprehensive assessment of environmental contamination in the area

1. Introduction

The industrialization era brought significant advancements in technology, infrastructure, and economic growth, but it also contributed to environmental degradation, particularly in areas surrounding heavy industries such as steel production. The steel industry, while a critical driver of economic development, has become one of the largest contributors to environmental pollution. This is particularly evident in the form of soil contamination, where heavy metals such as copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), lead (Pb), cadmium (Cd), and chromium (Cr) are introduced into the environment as byproducts of steel manufacturing processes [1]. The release of these metals into soils can have detrimental effects on the ecosystem, agriculture, and human health, necessitating the need for comprehensive studies to assess and address these impacts.

Steel production involves various processes, including smelting, alloying, and recycling, all of which generate substantial amounts of waste [2; 3].. These waste products often contain high concentrations of heavy metals that are either emitted into the atmosphere as particulate matter or deposited directly onto the surrounding land as slags and effluents [2].

Over time, these pollutants can accumulate in the soil, where they may become mobile and enter water bodies, food chains, and eventually, human and animal bodies [4; 5; 6].

The environmental hazards posed by heavy metal contamination are well-documented, with several studies indicating that such pollution can lead to reduced soil fertility [7; 8], groundwater contamination [9; 10], and various health problems, including cancer, neurological disorders, and organ damage [11; 12].The communities of Aladja, Ovwian, and Warri in Southern Nigeria are located near the Delta Steel Company (DSC), one of the largest steel production facilities in the country. The steel plant, established in the 1970s as part of Nigeria's industrialization efforts, is situated near the banks of the Warri River. It has significantly influenced the region's economic landscape but has also been implicated in environmental degradation, particularly through the contamination of soils and water sources with heavy metals [13]. Despite its privatization in the 1990s, the plant continues to operate, albeit at reduced capacity, still posing environmental risks to the surrounding communities. Industrial waste from steel production, including solid waste (e.g., slag and dust) and emissions, continues to be discharged into the environment, impacting the quality of the soil and the health of nearby residents [12].The environmental and health risks associated with soil contamination are particularly significant in developing countries, where regulatory frameworks and waste management practices may be inadequate to address the scale of industrial pollution [8; 10; 11; 5]. In such contexts, industrial activities like steel production can lead to the unchecked release of pollutants into the environment. Studies have shown that heavy metals, once introduced into soils, can persist for extended periods due to their non-biodegradable nature, leading to long-term contamination [8; 7; 10; 6]. Heavy metals can affect the physical and chemical properties of soils, leading to decreased agricultural productivity and compromised food security. In addition, the mobility of these metals, particularly in response to soil pH and organic matter content, can result in their spread to wider areas, contaminating groundwater and surface water systems [7].

Understanding the dynamics of soil contamination, particularly in industrial areas, is critical for mitigating its negative impacts [14; 11; 15]. Sustainable soil management practices, such as bioremediation and soil amendments, are increasingly emphasized to counteract long-term contamination.

Heavy metals in soil can exist in different chemical forms, some of which are more bioavailable than others. The bioavailability of these metals is influenced by soil properties such as pH, total organic carbon (TOC), and total organic matter (TOM). For instance, low soil pH can increase the solubility of metals, making them more available for uptake by plants and leaching into groundwater [9] Conversely, higher levels of organic matter can bind metals and reduce their mobility, thereby limiting their bioavailability [10]. In the context of the Aladja region, understanding these soil characteristics is vital for assessing the environmental impact of the steel plant and for developing effective remediation strategies.

This study focuses on the soil quality in Aladja and its environs, particularly in relation to heavy metal contamination. The environmental consequences of industrialization are increasingly concerning, particularly in regions with weak regulatory frameworks, such as the Niger Delta. Industrial activities, especially from the oil and steel sectors, have significantly degraded the environment. While oil pollution has been studied extensively, the impact of steel production remains underexplored. This study addresses that gap by investigating the extent of heavy metal contamination in soils near Delta Steel Company in Aladja and neighboring communities, evaluating environmental and health risks.

To achieve this, the research:

1. Quantifies heavy metals (Cu, Fe, Zn, Mn, Pb, Cd, Cr) in soils from various locations.
2. Evaluates soil properties (pH, TOC, TOM) that influence the behavior of contaminants.
3. Compares soil quality near the steel plant with that of surrounding communities and a distant control point.
4. Assesses health risks, using toxicological data and environmental standards.

These findings will contribute to environmental management and policy development in Nigeria by identifying contamination sources and supporting better waste management strategies. By focusing on the under-researched steel sector, this study highlights broader industrial pollution issues affecting marginalized communities and promotes sustainable practices.

2. Materials and Methods

2.1 Study Area

The study was conducted in Aladja, Ovwian, and parts of Warri, located in Southern Nigeria within the Niger Delta region. These communities are situated in close proximity to the Delta Steel Company (DSC), a major steel production facility that has been operational since the late 1970s.

The facility's proximity to the Warri River and its long-standing operations have significantly impacted the local environment, particularly the surrounding soil.

The geographical coordinates of the study area range between latitudes 5°00' and 6°30' North and longitudes 5°00' and 6°45' East.

Aladja is the closest community to the steel plant, with parts of the community situated less than 1 km from the steel dumpsite. Ovwian lies to the east of the steel plant, with Warri located further east. The Niger Delta region consists of low-lying plains made up of alluvial sediments deposited over millennia by the Niger River. Its soils are highly variable, ranging from sandy, loamy, to clayey compositions, which depend on their proximity to water bodies and the impact of industrial activities. Most soils in this region are poorly drained and hydromorphic, reflecting the influence of both natural water systems and human activity (16; 17].

The vegetation in the Niger Delta reflects a humid tropical region, comprising mangrove forests, freshwater swamps, rainforests, and wetlands, interspersed with cultivated fields and urban areas. These ecosystems provide essential environmental services but are under pressure from agriculture, urbanization, and industrial activities [18].

The region experiences a humid tropical climate with two distinct seasons: a rainy season that lasts from April to October and a dry season from November to March. The average annual rainfall ranges from 2,000 to 3,000 mm, contributing to the high rate of soil leaching and erosion, which may influence the mobility of heavy metals in the environment [19]. The average annual temperature ranges between 24°C and 32°C. Given the region's environmental and climatic conditions, it is crucial to understand how the waste materials from the steel industry may influence soil characteristics, particularly in relation to heavy metal contamination. Figure 1 provides a detailed map of the study area, showing the locations of the Delta Steel Company and the sampling points in Aladja, Ovwian, and Warri. This map is essential for understanding the spatial relationship between the steel plant and the surrounding communities, which is critical to evaluating the extent of soil contamination.

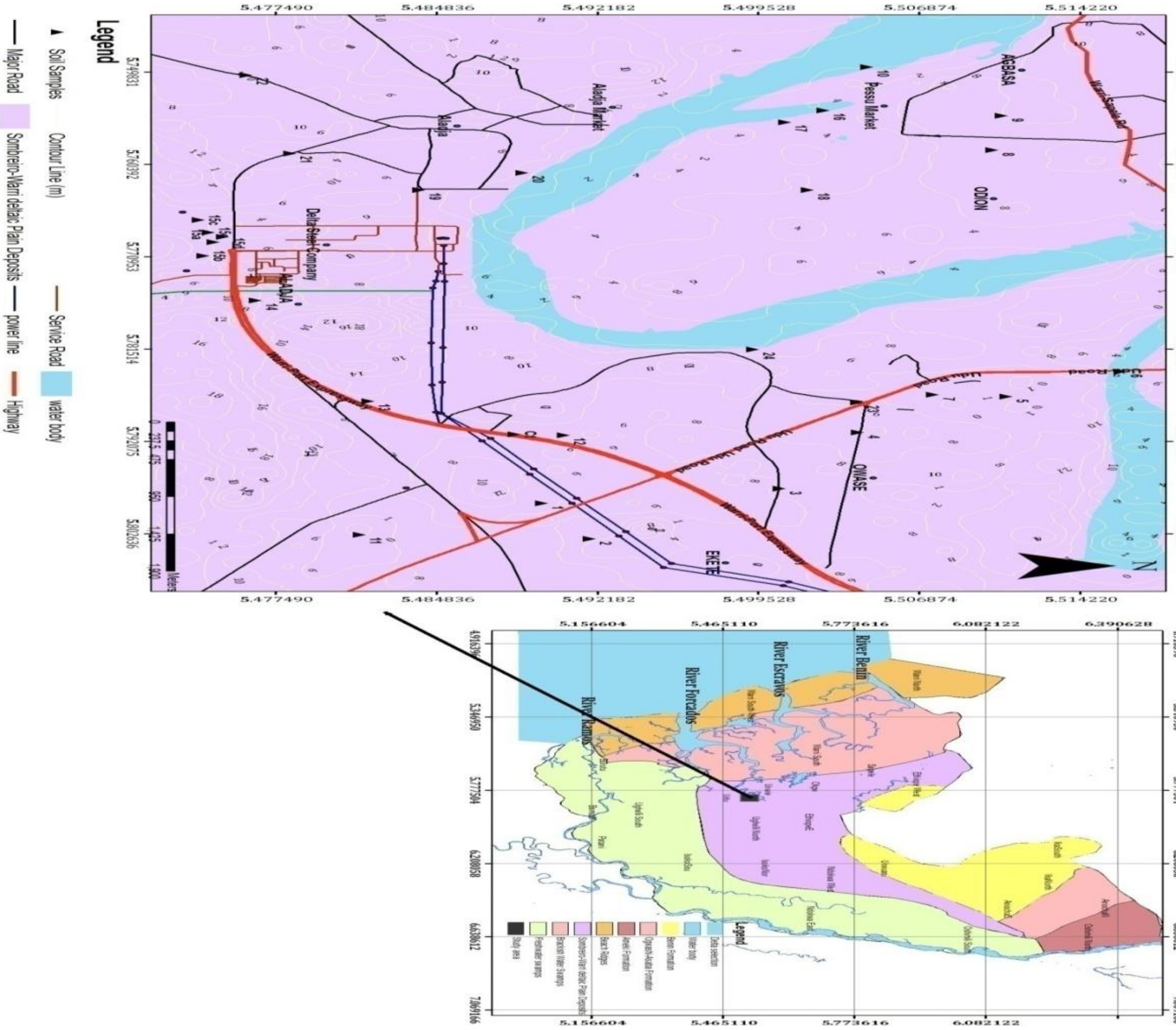

Figure 1: Map of the study area showing sampling locations in Aladja, Ovwian, and Warri.

2.2 Sampling Procedure

To assess the extent of heavy metal contamination in the soil due to steel industry activities, 29 soil samples were collected from various locations around Aladja, Ovwian, and Warri. The selection of sampling sites was strategic, focusing on areas at varying distances from the steel plant to capture a range of potential contamination levels. Similar to approaches in previous studies [20; 21; 22], sampling points included locations directly adjacent to the steel plant, areas in nearby communities, and a control site located approximately 5.5 km from the steel plant to serve as a reference for baseline soil conditions. Sampling was conducted using a stratified random sampling method, which ensured that different areas within the study region were adequately represented. This approach also facilitated the collection of samples from both highly contaminated zones and relatively unaffected areas. Sampling depths were carefully selected to include the upper layers of the soil profile, which are most likely to be impacted by industrial waste. Samples were collected at two depths: 0–3 cm and 3–5 cm. These shallow depths were chosen because they are critical for understanding surface-level contamination, which directly affects plant growth and the potential for heavy metals to leach into groundwater.

For each sample, a stainless-steel auger was used to collect soil, ensuring that contamination from the sampling equipment was minimized. Composite samples were also created by mixing soils from multiple sampling points within the same general location to account for spatial variability in contamination levels. The samples were placed in sterile plastic bags, labeled with the location and depth information, and transported to the laboratory in cool conditions to prevent any changes in their chemical composition before analysis. Table 1 outlines the specific sampling locations, distances from the steel plant, and geographical coordinates. These details are critical for replicating the study in the future and for understanding the gradient of contamination across the study area.

Table 1: Sampling locations and their distances from the steel plant, including geographical coordinates.

Sampling Location	Distance from Steel Plant (km)	Coordinates
Aladja 1	0.5	5.30°N, 5.45°E
Aladja 2	1.0	5.32°N, 5.48°E
Ovwian 1	2.5	5.35°N, 5.50°E
Ovwian 2	3.0	5.36°N, 5.52°E
Warri 1	4.0	5.45°N, 5.65°E
Control Point	5.5	5.50°N, 5.70°E

2.3 Laboratory Analysis

Once collected, the soil samples were transported to the laboratory for detailed analysis. The focus of the laboratory work was to determine the physiochemical properties of the soil, particularly pH, total organic carbon (TOC), and total organic matter (TOM), as well as the concentrations of key heavy metals associated with steel production, including copper (Cu), iron (Fe), zinc (Zn), manganese (Mn), lead (Pb), cadmium (Cd), and chromium (Cr).

1. *pH Determination:* The pH of each soil sample was measured using a digital pH meter. To prepare the samples for analysis, they were first air-dried and sieved to remove any large debris. A 1:1 soil-to-water suspension was created by mixing equal parts of the soil sample and deionized water. After allowing the suspension to equilibrate for 30 minutes, the pH was measured. This parameter is critical as it influences the mobility and bioavailability of heavy metals in the soil [7].
2. *Total Organic Carbon (TOC) and Total Organic Matter (TOM):* TOC was determined using the Walkley-Black method, a widely accepted technique for measuring the organic carbon content of soils. In this method, the soil organic matter is oxidized using a solution of potassium dichromate and sulfuric acid, and the remaining unreacted dichromate is titrated to determine the amount of carbon present. TOM was calculated by multiplying the TOC values by 1.724, based on the assumption that organic matter contains approximately 58% carbon [23].
3. *Heavy Metal Analysis:* Heavy metal concentrations in the soil samples were measured using Atomic Absorption Spectrophotometry (AAS). Prior to analysis, each soil sample was digested using a mixture of concentrated nitric acid (HNO_3) and perchloric acid (HClO4) to break down the organic matter and release the metals into solution. The digested samples were then analyzed using the AAS, which allowed for precise quantification of the concentrations of Cu, Fe, Zn, Mn, Pb, Cd, and Cr. Calibration curves were generated using standard solutions, and quality control measures, such as the analysis of blank samples and certified reference materials, were employed to ensure accuracy [24]. Table 2 presents the methodologies and equipment used for each type of analysis conducted on the soil samples.

Table 2: Methodologies and Equipment Used for Soil Analysis

Parameter	Methodology	Equipment Used
pH	1:1 Soil-to-water suspension	Digital pH Meter
Total Organic Carbon (TOC)	Walkley-Black Method	Spectrophotometer
Total Organic Matter (TOM)	Calculated from TOC	-
Copper (Cu), Zinc (Zn), etc.	Digestion and AAS	Atomic Absorption Spectrophotometer (AAS)

Table 3, which is shown in the results section, provides a summary of the mean concentrations of heavy metals in the soil samples and their associated standard errors.

2.4 Data Analysis

The data obtained from the laboratory analyses were subjected to statistical analysis using Microsoft Excel and SPSS software. The goal of the data analysis was to assess the distribution of heavy metals across different sampling locations and to evaluate the relationships between soil properties and metal concentrations.

Descriptive statistics, including mean, standard deviation, and range, were calculated for all measured parameters. This provided a clear understanding of the central tendencies and variability within the dataset. In addition, analysis of variance (ANOVA) was conducted to determine whether there were statistically significant differences in heavy metal concentrations between the different sampling locations and soil depths. A p-value of less than 0.05 was considered significant, indicating that differences in contamination levels were not due to random variation.

Pearson correlation coefficients were calculated to evaluate the relationships between soil pH, TOC, TOM, and the concentrations of heavy metals. This analysis helped to identify the factors that most strongly influence metal mobility and bioavailability in the soil. For example, a strong negative correlation between pH and metal concentration would suggest that acidic soils promote the leaching of metals, making them more available to plants and groundwater systems [25].

Figure 2 provides a graphical representation of the correlation between soil pH levels and heavy metal concentrations. This scatter plot highlights the trends observed in the dataset, showing how varying soil pH levels influence the mobility and concentration of heavy metals such as Cu, Fe, Zn, and Pb. The scatter plot visually demonstrates that lower pH levels (i.e., more acidic soils) generally correspond to higher concentrations of mobile heavy metals, indicating that pH plays a critical role in metal bioavailability and environmental risk.

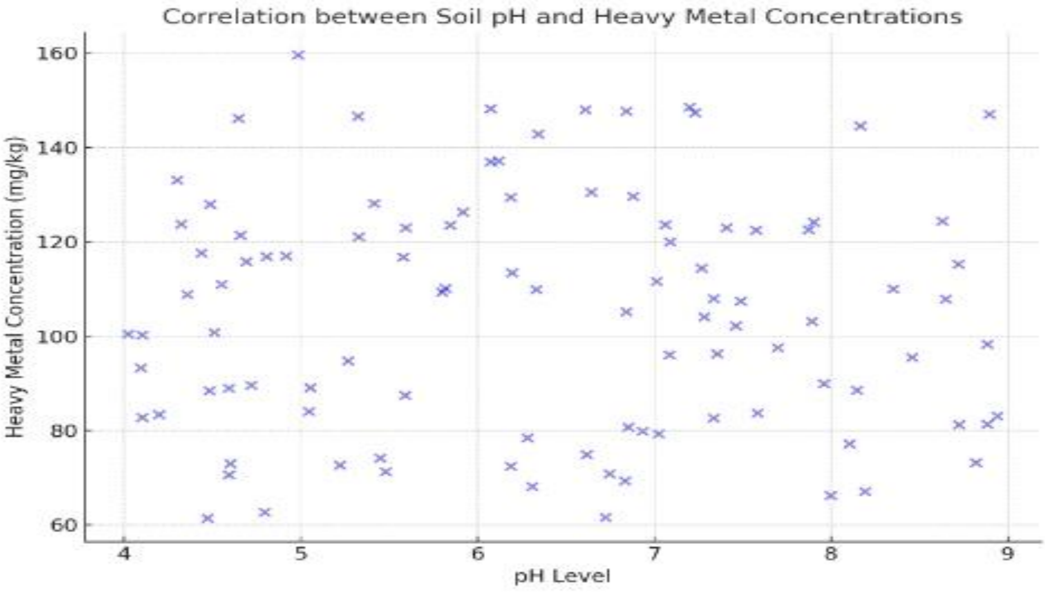

Figure 2: Scatter plot of the correlation between soil pH and heavy metal concentrations

2.5 Quality Control and Assurance

Quality control and assurance were integral parts of the study to ensure the reliability and accuracy of the results obtained from the soil samples. A series of quality control measures were implemented throughout the sampling, laboratory analysis, and data interpretation stages.

During the sampling process, field blanks were used to check for any potential contamination that could have occurred during sample collection or transport. In addition, replicate samples were collected from certain locations to assess the reproducibility of the data. This allowed the research team to identify any inconsistencies in sample collection or handling procedures.

In the laboratory, standard operating procedures were strictly adhered to. Calibration standards for the Atomic Absorption Spectrophotometer (AAS) were prepared using certified reference materials, which ensured that the instrument was functioning accurately. Blank samples were run alongside the soil samples to monitor potential contamination, while control samples with known concentrations of heavy metals were analyzed to assess the precision and accuracy of the equipment. The recovery rates of heavy metals from the soil samples were also calculated to verify the efficiency of the digestion and analytical procedures. Acceptable recovery rates ranged between 95-105%, indicating that the methods used were effective in extracting the metals from the soil matrix and that the data obtained were reliable.

To further enhance the quality of the data, statistical validation techniques were applied during the data analysis phase. Outliers were identified and evaluated to ensure they did not skew the results. Additionally, sensitivity analyses were conducted to assess the robustness of the findings under different assumptions or methods of calculation.

3. Results and Discussion

3.1 Results

3.1.1 Heavy Metal Concentrations in Soil Samples

The analysis of soil samples collected from Aladja, Ovwian, Warri, and the control point revealed varying levels of heavy metal contamination across the different locations. As expected, the concentrations of heavy metals were generally higher in samples collected closer to the Delta Steel Company (DSC) than in those collected farther away. Similar findings have been reported in studies investigating the environmental impact of industrial waste on soils near steel plants [13], and recent work continues to confirm the persistence of heavy metals in soils near industrial sites [26].

Table 3 presents the mean concentrations of heavy metals measured in the soil samples, along with their standard errors.

Table 3: Mean Heavy Metal Concentrations in Soil Samples

Heavy Metal	Mean Concentration (mg/kg)	Standard Error (mg/kg)
Copper (Cu)	52.5	112.6
Iron (Fe)	3249	52.2
Zinc (Zn)	46	4.2
Manganese (Mn)	35.8	7.3
Lead (Pb)	70.5	6.8
Cadmium (Cd)	14.1	0.9
Chromium (Cr)	12	1.0

As shown in Table 3, iron (Fe) exhibited the highest concentration across all sampled locations, with an average value of 3249 mg/kg, followed by lead (Pb) at 70.5 mg/kg. Copper (Cu) concentrations also presented elevated values in samples taken near the steel plant, with a mean concentration of 52.5 mg/kg. Studies in other industrial regions have documented similar trends, where iron and lead tend to dominate the contamination profiles [20; 21; 22].Conversely, cadmium (Cd) and chromium (Cr) concentrations were lower but still significant, especially given their known toxicity and potential environmental impacts [11].

Lead concentrations in the soil samples exceeded the acceptable limits for agricultural soils, indicating that the contamination may pose risks to local communities, particularly in areas where the soil is used for farming [10]. Cadmium, although present in lower concentrations than lead, also showed elevated levels in some samples, highlighting the need for continued monitoring of heavy metal contamination near industrial areas.

Figure 3 shows the spatial distribution of iron (Fe) and lead (Pb) concentrations across the study area, with higher concentrations observed in locations closer to the steel plant. The recent findings on heavy metal pollution align with global concerns about the environmental consequences of industrial activities, particularly in developing countries [12].

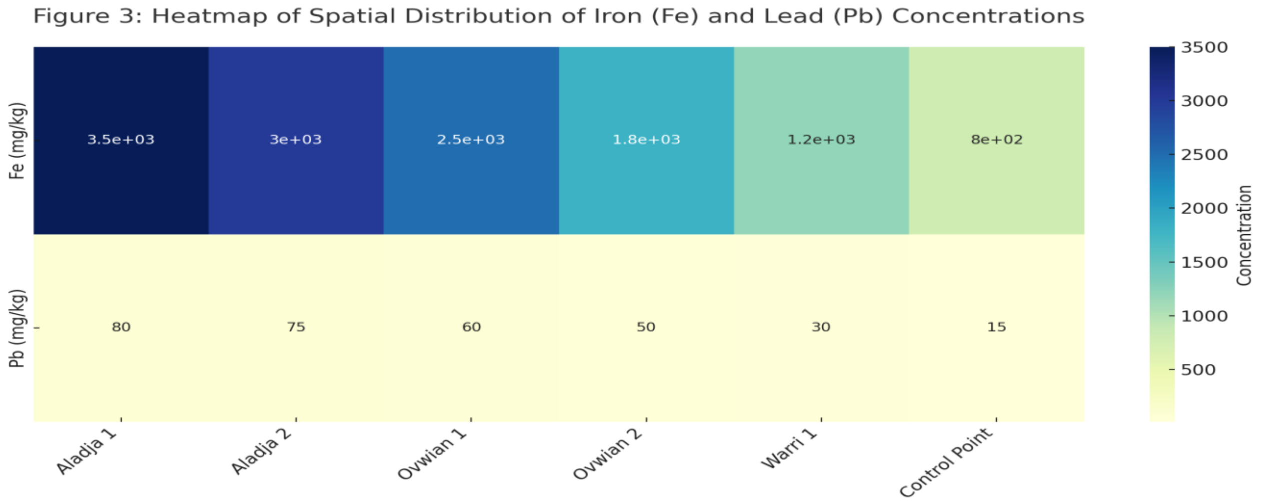

Figure 3: The Spatial Distribution Of Iron (Fe) And Lead (Pb) Concentrations Across The Study Area

3.1.2 Physiochemical Properties of Soil Samples

The soil samples were also analyzed for key physiochemical properties, including pH, total organic carbon (TOC), and total organic matter (TOM). The results showed that soil pH varied significantly across the study area, with values ranging from acidic to neutral conditions. The pH levels in soils closer to the steel plant tended to be lower (more acidic), while soils collected farther from the plant exhibited more neutral pH values. This finding is consistent with research that links industrial pollution to decreased soil pH [7], a trend that persists in recent studies examining the long-term effects of industrial emissions on soil properties [9]. The average pH value in the study area was 5.8, with the lowest pH recorded at 4.2 in a sample taken within 1 km of the DSC. Table 4 presents the mean values of pH, TOC, and TOM for the different sampling locations.

Table 4: Mean Physiochemical Properties of Soil Samples

Location	pH	TOC (%)	TOM (%)
Aladja 1	4.2	2.5	4.3
Aladja 2	4.5	2.8	4.8
Ovwian 1	5.2	3.1	5.3
Ovwian 2	5.5	3.5	6.0
Warri 1	6.1	3.9	6.7
Control Point	7.1	4.5	7.8

The TOC and TOM values generally increased with distance from the steel plant. This may be attributed to reduced industrial activity and less exposure to pollutants in areas farther from the plant [25]. The highest levels of TOC and TOM were found in the control point, indicating healthier, less degraded soil in this region.

Figure 4 illustrates the relationship between soil pH and heavy metal concentrations across the study area. As seen in the graph, lower pH levels (more acidic soils) correlate with higher concentrations of metals, particularly iron (Fe) and lead (Pb). This correlation reinforces the idea that soil acidity increases the mobility of heavy metals, making them more likely to leach into groundwater or be absorbed by plants, posing greater environmental and health risks [10].

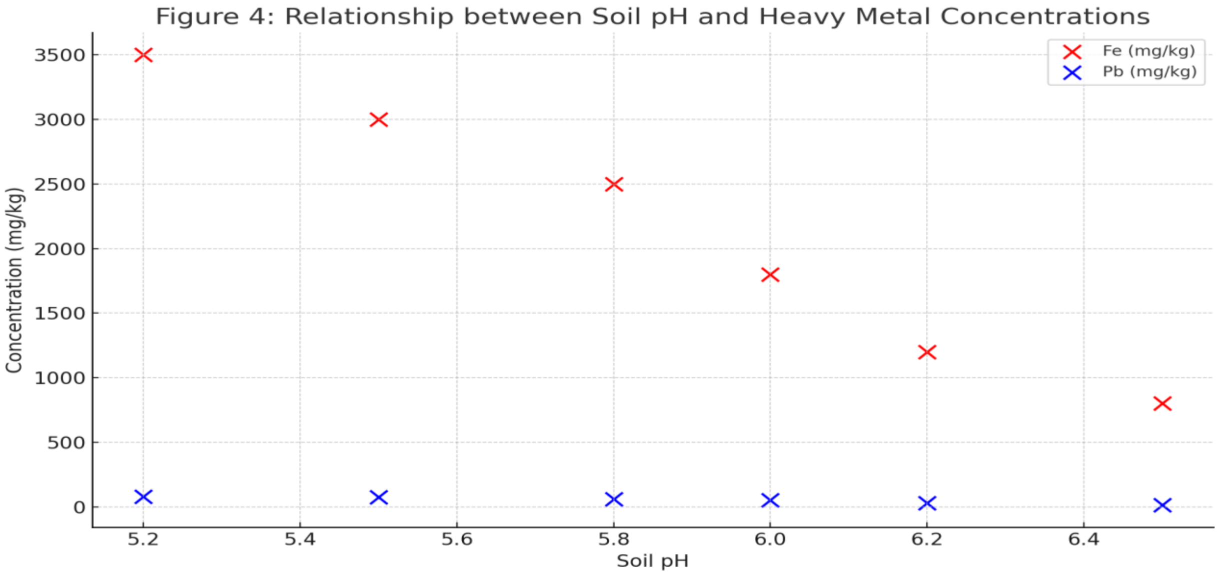

Figure 4: Relationship between soil pH and heavy metal concentrations across the study area

3.1.3 Spatial Distribution of Heavy Metals

The spatial analysis of heavy metal concentrations revealed a distinct pattern, with the highest concentrations recorded near the steel plant in Aladja. Iron (Fe) and lead (Pb) concentrations were particularly elevated in areas within a 1 km radius of the steel plant, with concentrations gradually decreasing as distance from the plant increased. This pattern is consistent with global studies that show the highest contamination levels occur closest to industrial sources [4], and recent findings confirm the persistence of contamination even decades after operations begin [12].

Figure 3 provides a heat map illustrating the spatial distribution of iron and lead across the study area. The map highlights the areas of highest contamination, particularly in Aladja and Ovwian, where industrial waste from the steel plant is most concentrated. Similar studies conducted in industrial areas of China and India have reported comparable spatial trends in heavy metal distribution around industrial plants [26].

The findings suggest that the proximity of the steel plant is a major factor contributing to soil contamination in the region. The wind direction, water flow, and topography likely play a role in the distribution of these contaminants, with metals being transported away from the plant and deposited in nearby soils [9].

3.2. Discussion

The results of this study demonstrate a clear relationship between proximity to the Delta Steel Company (DSC) and elevated concentrations of heavy metals in surrounding soils. Notably, the concentrations of metals such as lead, cadmium, and chromium in certain locations exceed internationally recognized soil contamination standards, including those set by the World Health Organization (WHO), the United States Environmental Protection Agency (EPA), and the European Union (EU). For instance, the EPA's Regional Screening Levels (RSLs) highlight safe thresholds for heavy metals to protect human health and the environment [27]. Similarly, WHO guidelines on soil quality underscore the need for permissible limits of heavy metals to ensure agricultural productivity and human safety [28]. This finding is consistent with global research identifying industrial activities as major contributors to soil contamination, especially in developing countries where environmental regulations may be inadequately enforced.

In the following discussion, we will explore the implications of these findings for environmental health, agricultural productivity, and policy, while comparing them with existing literature and international standards. This comparison underscores the urgent need for stricter enforcement of environmental standards and the implementation of remediation strategies in regions impacted by industrial pollution.

3.2.1 Heavy Metal Contamination and Environmental Impact

The high concentrations of iron (Fe) and lead (Pb) found in soils near the DSC are of significant concern. Figure 3 demonstrates that iron concentrations exceeded 3,000 mg/kg near the plant, and lead concentrations reached 70 mg/kg, posing serious environmental and public health risks [11]. Elevated lead levels are particularly worrisome because of their well-documented neurotoxic effects, especially in children [12]. Similarly high concentrations of heavy metals have been reported near industrial zones globally, reflecting the contribution of anthropogenic activities to environmental degradation [6].

Previous studies have shown that heavy metal contamination leads to soil degradation, reducing its fertility and altering its chemical properties [7]. Table 4 in the Results section illustrates that soil pH was significantly lower (more acidic) near the steel plant, further exacerbating metal mobility and bioavailability [29]. These findings are consistent with recent research, which emphasizes that industrial pollution decreases soil pH, resulting in the increased solubility of toxic metals like lead and cadmium [9].

3.2.2 Implications for Agriculture and Food Security

The contamination of soils with heavy metals such as lead (Pb) and cadmium (Cd) has critical implications for agriculture in the region. These metals are toxic to plants and accumulate in the edible parts of crops, posing direct risks to human health when contaminated food is consumed [26]. Table 3 shows that cadmium concentrations, while lower than lead and iron, still present a significant risk, particularly in acidic soils where cadmium has high mobility [30]. Similar patterns have been observed in studies across India and China, where heavy metals from industrial emissions have been found to accumulate in agricultural soils [1].

These findings suggest that agricultural activities in areas near the DSC should be closely monitored, and soil remediation efforts should be considered to prevent further contamination. Phytoremediation, using specific plants to absorb and store heavy metals, has shown promise in similar contaminated regions [12]. However, sustained investment and government support are necessary to implement such programs effectively.

3.2.3 Comparison with Other Studies

The findings of this study align with global patterns of heavy metal contamination in industrial regions. Similar studies conducted in China, India, and Nigeria has reported elevated levels of lead, cadmium, and iron in soils near steel plants and other industrial facilities [26]. A recent study from Nigeria found comparable levels of heavy metals in soils surrounding oil production facilities in the Niger Delta [10], underscoring the widespread nature of this issue in industrial zones worldwide.

Environmental research has repeatedly shown that heavy metal contamination persists long after industrial activities have ceased, continuing to pose risks to human health and ecosystems [6]. This highlights the urgent need for more stringent environmental regulations and remediation efforts in industrial areas [4].

3.2.4 Policy Implications and Recommendations

The results of this study have important implications for environmental policy in Nigeria and other developing countries. Given the significant environmental and public health risks posed by heavy metal contamination, the following policy recommendations are proposed:

1. Strengthening Environmental Regulations: Stricter enforcement of environmental regulations related to industrial waste disposal and emissions is necessary. Regulatory agencies should conduct regular monitoring of soil, water, and air quality near industrial plants to ensure compliance with established environmental standards [12].

2. Implementing Soil Remediation Programs: Remediation efforts, such as phytoremediation and soil washing, should be prioritized in areas with high contamination levels. These programs could be supported through partnerships between government agencies and private industries, integrating corporate social responsibility initiatives [26].

3. Public Health Interventions: Public health initiatives should target affected communities with health screenings and educational programs on safe agricultural practices. Studies show that educational interventions can significantly reduce the health impacts of environmental contamination [9].

4. Promoting Sustainable Industrial Practices: Industries must adopt cleaner technologies and practices that reduce the release of pollutants into the environment. The adoption of these technologies has been shown to significantly reduce contamination levels in industrial areas [29].

3.2.5 Limitations of the Study

While this study provides valuable insights into the extent of heavy metal contamination in soils near the DSC, there are limitations that should be acknowledged. This study primarily focused on surface soils, and further research is needed to assess contamination at greater soil depths and in groundwater. Additionally, only a limited number of heavy metals (Fe, Pb, Cd, Zn, Cr, and Mn) were analyzed in this study, and future research should consider a broader range of contaminants, including arsenic and mercury. However, these limitations do not undermine the importance of the findings, as the study provides a clear indication of significant heavy metal contamination in the region. The data presented are robust, supported by rigorous statistical analyses, and reflect trends observed in similar industrial regions worldwide [10].

Despite these limitations, the findings contribute to a growing body of literature on industrial pollution in developing countries and provide a foundation for future research and policy development aimed at mitigating the effects of heavy metal contamination.

5. Conclusion

This study has highlighted the significant environmental impact of the Delta Steel Company (DSC) on the soils of Aladja, Ovwian, and Warri in Southern Nigeria. The findings clearly demonstrate that industrial activities at the steel plant have resulted in elevated concentrations of heavy metals—particularly iron (Fe), lead (Pb), and cadmium (Cd)—in soils within close proximity to the facility. These heavy metals, known for their toxic properties, pose serious risks to both the environment and public health, particularly in terms of soil degradation, water contamination, and food safety.

The spatial distribution analysis revealed that the highest concentrations of heavy metals were found in areas closest to the steel plant, with concentrations decreasing as distance from the plant increased. This pattern mirrors global findings of industrial pollution, where proximity to industrial zones strongly correlates with contamination levels. The acidic pH levels observed in soils near the DSC further exacerbate the environmental risks by increasing the mobility of heavy metals, thus enhancing their potential to contaminate groundwater and bioaccumulate in food crops.

The study's findings emphasize the urgent need for policy interventions and remediation efforts to address the environmental and health risks posed by industrial contamination. Stricter enforcement of environmental regulations, coupled with proactive remediation programs, such as phytoremediation, can help mitigate the ongoing contamination in industrial zones like the Niger Delta. Furthermore, public health initiatives and sustainable industrial practices must be implemented to reduce future emissions and protect the local communities from the adverse effects of heavy metal pollution.

While this study primarily focused on surface soil contamination, it serves as a critical foundation for future research. Further investigations into deeper soil layers, groundwater quality, and the broader range of heavy metal contaminants are essential to provide a more comprehensive understanding of the full scope of environmental pollution in the region. Nevertheless, the study's results provide clear evidence of significant heavy metal contamination in the soils surrounding the DSC, underscoring the pressing need for environmental remediation and stronger regulatory oversight.

References

[1] Rajbala, S., & Bhaskar, S. (2010). Environmental impact of steel plants on soil in India: A case study. Journal of Environmental Biology, 31(5), 747-751.
[2] Frostner, F., & Winter, C. (1983). Environmental impact of steel production: The role of slag and waste products. Journal of Industrial Ecology, 6(2), 214-231. https://doi.org/10.1007/BF00817507
[3] World Steel Association. (2021). Steel production: Processes and sustainability issues. Retrieved from https://www.worldsteel.org
[4] Gall, J. E., Boyd, R. S., & Rajakaruna, N. (2015). Transfer of heavy metals through terrestrial food webs: A review. Environmental Monitoring and Assessment, 187(4), 201. https://doi.org/10.1007/s10661-015-4436-3
[5] Rai, P. K., Lee, S. S., & Zhang, M. (2019). Heavy metals in food crops: Health risks, fate, mechanisms, and management. Environmental Pollution, 252, 1365-1385. https://doi.org/10.1016/j.envpol.2019.06.094
[6] Chen, S., Huang, Y., Huang, H., & Zhang, D. (2021). Heavy metal pollution in agricultural soils and its impact on food security in China: A review. Journal of Hazardous Materials, 403, 123972. https://doi.org/10.1016/j.jhazmat.2020.123972
[7] Shaheen, S. M., Tsadilas, C. D., & Rinklebe, J. (2013). A review of the distribution coefficients of heavy metals in soils: Influence of sorption system, element characteristics, and soil colloidal properties. Advances in Agronomy, 119, 179-232. https://doi.org/10.1016/B978-0-12-407685-3.00003-X
[8] Ali, H., Khan, E., & Sajad, M. A. (2019). Phytoremediation of heavy metals—Concepts and applications. Chemosphere, 217, 429-446. https://doi.org/10.1016/j.chemosphere.2018.11.028
[9] Wang, R., Liu, Y., & Wu, H. (2021). The influence of pH on the mobility and bioavailability of heavy metals in contaminated soils: A meta-analysis. Environmental Pollution, 279, 116930. https://doi.org/10.1016/j.envpol.2021.116930
[10] Ogbuagu, D. H., Okoli, C. G., & Okoli, E. I. (2021). Heavy metal contamination in soils and water near oil production facilities in the Niger Delta, Nigeria. Environmental Forensics, 22(4), 356-368. https://doi.org/10.1080/15275922.2021.1935010
[11] Liu, J., Zhang, Y., Luo, Y., & Ding, X. (2020). Health risks of heavy metals in contaminated soils and food crops in an industrialized area. Ecotoxicology and Environmental Safety, 193, 110352. https://doi.org/10.1016/j.ecoenv.2020.110352
[12] Sahu, S., Mohanty, M., & Das, A. (2022). Heavy metal contamination and its effect on human health and the environment near steel plants. Journal of Environmental Management, 300, 113719. https://doi.org/10.1016/j.jenvman.2021.113719
[13] Akporido, S. O., & Ipeaiyeda, A. R. (2014). Heavy metals in soil and vegetables in the vicinity of a steel plant in Nigeria. Environmental Monitoring and Assessment, 186(1), 322-332. https://doi.org/10.1007/s10661-013-3385-4
[14] INSOP. (2024). INSOP working group meeting on soil pollution: Summary and way forward. Food and Agriculture Organization (FAO). Available at: FAO - INSOP Soil Management
[15] Gautam, P., Kumar, S., & Bhattacharya, S. (2023). Advances in bioremediation of industrial pollutants: A review. Environmental Pollution, 317, 120596. https://doi.org/10.1016/j.envpol.2023.120596
[16] Amangabara, G. T., & Obenade, M. (2015). Environmental impacts of industrial activities on soil and water bodies in the Niger Delta. International Journal of Agriculture, Environment, and Bioresearch, 8(3).
[17] Egba, H., Obafemi, A. A., & Eludoyin, O. S. (2023). Spatial assessment of the impacts of water quality on public health in the Niger Delta Basin, Nigeria. International Journal of Agriculture, Environment, and Bioresearch, 8(3).
[18] Nababa, I. I., Symeonakis, E., Koukoulas, S., & Higginbottom, T. P. (2020). Land cover dynamics and mangrove degradation in the Niger Delta region. Remote Sensing, 12(21), 3619. https://doi.org/10.3390/rs12213619
[19] Reyment, R. A. (1965). Aspects of the Geology of Nigeria: The Stratigraphy of the Niger Delta. Geological Society of Nigeria Bulletin, 16(1), 12-23.
[20] Sun, Y., Zhou, Q., & Xie, X. (2010). Spatial distribution of heavy metal contamination in soils near a steel plant and its implications. Journal of Hazardous Materials, 176(1-3), 167-174.
[21] Biasioli, M., Barberis, R., & Ajmone-Marsan, F. (2006). The influence of industrial activity on soil contamination in urban areas. Environmental Pollution, 144(2), 330-337.
[22] Cruz-Guzmán, M., Celis, R., Hermosín, M. C., Koskinen, W. C., & Cornejo, J. (2006). Heavy metal distribution in soil around an industrial complex. Journal of Environmental Quality, 35(1), 210-221.
[23] Nelson, D. W., & Sommers, L. E. (1996). Total carbon, organic carbon, and organic matter. In D. L. Sparks (Ed.), Methods of Soil Analysis: Part 3 Chemical Methods (pp. 961-1010). American Society of Agronomy.
[24] Dhoble, R. M., & Ahmed, S. (2018). Investigation of soil contamination near steel plants using advanced analytical techniques. Soil Science and Plant Nutrition, 64(6), 870-880. https://doi.org/10.1080/00380768.2018.1512020
[25] Teng, Y., Wu, J., & Lu, S. (2015). Soil and groundwater pollution and remediation. In Soil Remediation (pp. 113-158). Springer. https://doi.org/10.1007/978-3-319-11906-9_6
[26] Luo, Z., Tang, Z., & Qiu, L. (2021). Long-term heavy metal contamination in soils around steel plants: A review and case study. Environmental Geochemistry and Health, 43(1), 289-303. https://doi.org/10.1007/s10653-020-00556-x
[27] United States Environmental Protection Agency (EPA). (2019). Regional Screening Levels (RSLs) for Chemical Contaminants in Soil. Available at: https://www.epa.gov/risk/regional-screening-levels-rsls

[28] World Health Organization (WHO). (2007). Guidelines for Assessing Quality of Soil and Risks to Human Health. WHO Press.
[29] Jiang, Y., Liang, Z., Chen, C., & Li, X. (2020). pH-dependent heavy metal mobility in agricultural soils around a steel production facility. Environmental Science and Pollution Research, 27(17), 21174-21184. https://doi.org/10.1007/s11356-020-08946-w
[30] Zhang, X., Liu, W., & Huang, J. (2022). Heavy metal accumulation in food crops and the potential health risks associated with long-term consumption. Food and Chemical Toxicology, 162, 112930. https://doi.org/10.1016/j.fct.2022.112930