

Heavy Metal Contamination and Human Health Risk Assessment of Farmland Soils in Ndele, an Oil-Producing Community in the Niger Delta, Nigeria

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Abstract

Agricultural soils in oil-producing regions of the Niger Delta may receive persistent trace-metal inputs from petroleum-related activities and other anthropogenic sources, creating potential implications for soil quality, crop production and human exposure. This study assessed cadmium (Cd), lead (Pb) and arsenic (As) concentrations and associated human health risks in farmland soils of Mgbu-Oluwa and Mgbu-Ela communities in Ndele, Emohua Local Government Area, Rivers State, Nigeria. Composite topsoil samples (0–15 cm) were collected monthly from four farmland locations for six months (March–August 2025), giving 24 composite samples. Soil pH and temperature were measured in situ, while Cd, Pb and As were determined after acid digestion using atomic absorption spectrophotometry. Data were summarized using descriptive statistics and compared between communities using an independent-samples t-test. Human health risks were evaluated using a United States Environmental Protection Agency (USEPA)-based framework for adult (dermal exposure) and child (soil-ingestion plus dermal exposure). Cadmium was the dominant contaminant, with mean concentrations of 2.19 and 2.77 mg/kg in Mgbu-Oluwa and Mgbu-Ela, respectively. Corresponding mean concentrations were 0.32 and 0.89 mg/kg for Pb and 0.30 and 0.35 mg/kg for As. Differences between communities were not statistically significant for Cd ($p=0.64$), Pb ($p=0.38$) or As ($p=0.84$). Soil pH remained slightly acidic (5.95–6.25), while temperature declined during the sampling period. Using Nigerian petroleum-sector target values and FAO/WHO soil benchmarks, Cd exceeded the Nigerian target value in 17 of 24 samples, whereas Pb and As remained within the comparison values. Non-carcinogenic hazard quotients and hazard indices were below unity for both population groups; child HI values were 0.0425 and 0.0537 in Mgbu-Oluwa and Mgbu-Ela, respectively. Arsenic cancer-risk estimates were within the USEPA acceptable range. The findings indicate localized cadmium contamination without evidence of unacceptable health risk under the assessed exposure assumptions, emphasizing the need for continued soil monitoring, pollution prevention and crop-safety surveillance in Ndele.

Keywords: Cadmium, Lead, Arsenic, Agricultural soil, Health risk assessment, Niger Delta, Ndele, Petroleum pollution

1. Introduction

Soil is a critical component of terrestrial ecosystems, supporting plant production, nutrient cycling, water regulation and microbial processes. It also functions as a major environmental sink for potentially toxic elements released from both natural and anthropogenic sources. Unlike many organic contaminants, heavy metals do not readily degrade and may persist in soils, where their mobility and bioavailability are controlled by factors including pH, organic matter, mineral composition, redox conditions and temperature (Brady & Weil, 2016; FAO, 2021). Their accumulation in agricultural soils is therefore important not only for soil quality but also for food safety and human health. Cadmium (Cd), lead (Pb) and arsenic (As) are among the elements of particular concern because of their toxicity and potential for long-term human exposure. Cadmium can persist in soil and is generally more mobile under acidic conditions, increasing the possibility of plant uptake. Lead is strongly associated with soil particles but remains important because chronic exposure can produce neurological, renal and cardiovascular effects, particularly in children. Arsenic is a recognized human carcinogen and can occur in soils as a consequence of both geogenic processes and anthropogenic activities. Agricultural contamination may therefore create exposure pathways through direct soil contact and importantly, transfer to crops. (Chinedu & Chukwuemeka, 2018; Onyedikachi et al., 2018) The Niger Delta of Nigeria is particularly vulnerable to environmental contamination because petroleum exploration, production, transportation and associated infrastructure occur alongside densely settled communities and agricultural activities. Previous studies have documented heavy metals in soils, vegetation and food systems across the region. Iwegbue et al. (2019) reported heavy-metal contamination around oil facilities in the Niger Delta, while Okoye et al. (2021, 2022) demonstrated contamination of soil and biota across several Niger Delta locations. In Port Harcourt and surrounding areas, agricultural-soil studies have also reported the occurrence of potentially toxic elements and associated exposure concerns (Nwankwola et al., 2017; Iwegbue et al., 2019; Ohiagu et al., 2020; Iyama et al., 2022). Ndele in Emohua Local Government Area is an oil-producing community in Rivers State where agriculture remains important and farmland occurs in proximity to petroleum infrastructure. Despite the environmental significance of the Niger Delta and the evidence from other oil-producing locations, published information specifically describing Cd, Pb and As in Ndele farmland soils remains limited. Establishing site-specific baseline information is necessary because contamination can vary substantially over short distances according to land use, pollution sources and environmental conditions. The present study therefore assessed Cd, Pb and As concentrations in farmland soils of two Ndele communities, examined soil pH and temperature, evaluated compliance against selected Nigerian petroleum-sector and international comparison values and estimated potential human health risks using a USEPA-based exposure framework. The study provides community-level evidence that can support environmental monitoring and agricultural risk management in Ndele and comparable oil-producing communities of the Niger Delta.

2. Materials and Methods

2.1. Study area

Ndele is a community located in Emohua Local Government Area of Rivers State, one of the major oils producing States of the Niger Delta region of southern Nigeria (Figure 1). Two communities, Mgbu-Oluwa and Mgbu-Ela, were selected. Mgbu-Oluwa is located at latitude 4.96478°N and longitude 6.73931°E while Mgbu-Ela is located at latitude 4.96633°N and longitude 6.73553°E,

at an altitude range of 28-32 feet above sea level. The area lies within the humid tropical rainforest zone of the Niger Delta characterized with high rainfall and pronounced wet and dry seasonal conditions. The community is majorly agrarian, with agricultural activities occurring in the vicinity of petroleum infrastructure, making the area relevant for investigation of soil contamination.

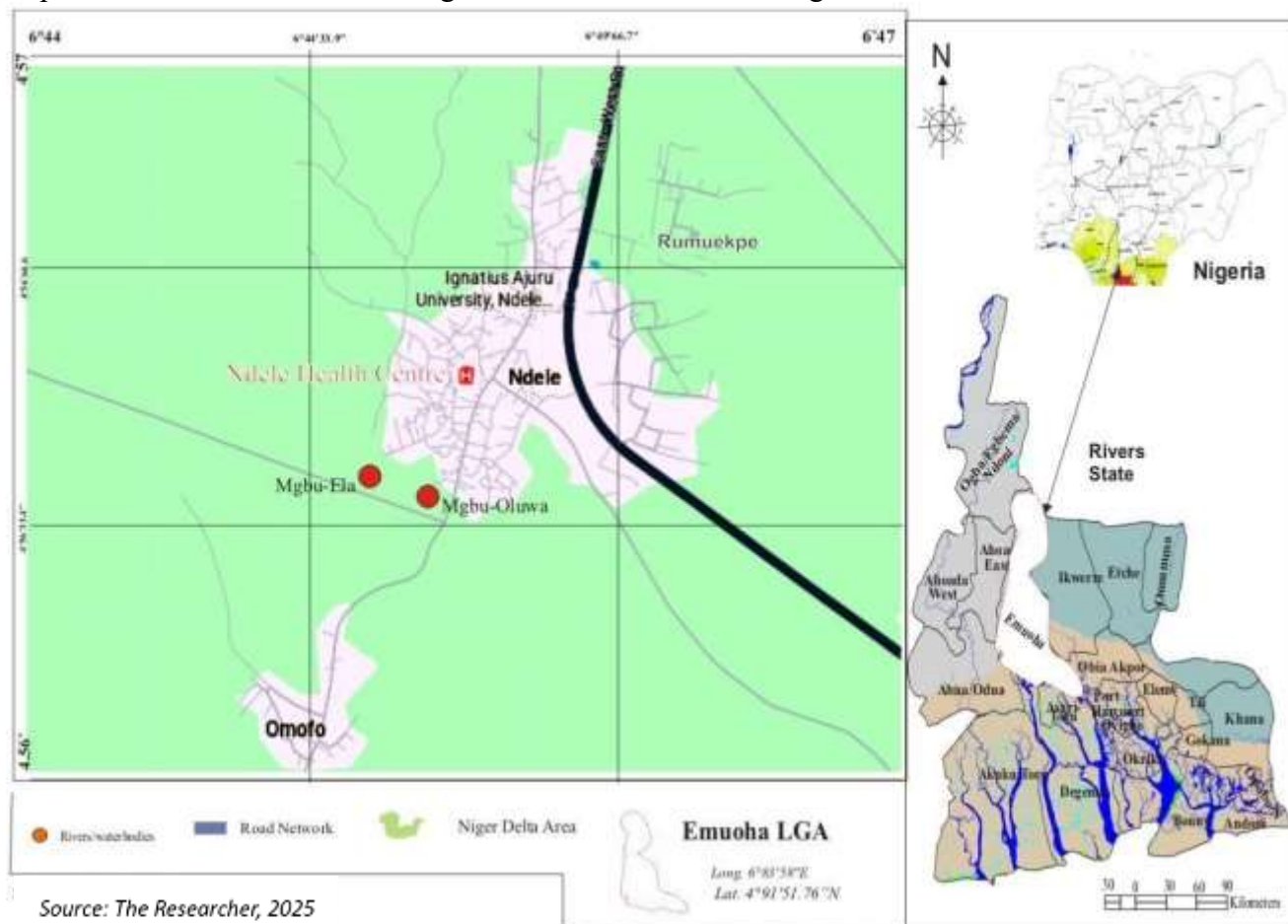


Figure 1: Map of Study Area showing Mgbu-Ela and Mgbu-Oluwa Communities, Ndele, Emohua, Rivers State

2.2. Study design and sampling

A field-based cross-sectional designed environmental assessment was conducted from March to August, 2025. Two farmland locations were selected in each community. At each location, five sub-samples were collected from the topsoil layer (0–15 cm) using a sterile hand auger and homogenized to get a composite sample. One composite sample was obtained per location for each month, giving a total of four composite samples per month and 24 composite samples for the six-month study period. Sampling was undertaken during the early hours of the day, between 06:00 am and 10:00 am. Samples were placed in clean and well labeled black polythene bags and transported for laboratory analysis.

2.3. Heavy-metal analysis

Soil samples were prepared by wet acid digestion and analysed for Cd, Pb and As using atomic absorption spectrophotometry (AAS). 0.5 g of sieved soil was put into a digestion flask and a mixture of concentrated nitric acid and perchloric acid (3:1) was added. The sample was heated gently to 120 °C for complete digestion and a clear solution was obtained. The digest was allowed to cool, filtered through Whatman No. 42 filter paper and made up to 50ml with distilled water. Metal contents were analysed by Atomic Absorption Spectrophotometer with element specific hollow cathode lamps. Calibration curves were prepared with certified standard solutions and reagent blanks were checked for analytical accuracy. Measurements were performed in duplicate and mean values were recorded. Analytical concentrations were derived from calibration curves prepared from certified standards. Values reported as <0.001 mg/kg were treated as below the analytical detection limit. The analytical approach followed standard procedures described in APHA (2017).

2.4. Soil physicochemical measurements

Soil temperature was measured in situ from the topsoil layer (0–15 cm), using a soil thermometer (Model number: TP 101). The temperature values were recorded after stabilization of the reading. Soil pH was measured in situ using a portable soil pH meter (SGS 01) after preparing a representative soil interface and the pH values were recorded after allowing the reading to stabilize. Measurements were taken during the morning sampling period to reduce the influence of direct solar heating.

2.5. Standards and compliance assessment

Observed concentrations were compared with Nigerian petroleum-sector target values, associated with the Department of Petroleum Resources (DPR) and the Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN), and with the FAO/WHO soil comparison values. The Nigerian target values used were 0.8 mg/kg for Cd, 85 mg/kg for Pb and 20 mg/kg for As. The FAO/WHO comparison values were 3 mg/kg for Cd, 50 mg/kg for Pb and 20 mg/kg for As.

2.6. Human health risk assessment

Potential non-carcinogenic and carcinogenic risks were estimated using a USEPA (1997) based soil exposure framework. Adults were evaluated for dermal contact during farming, while children were evaluated for incidental soil ingestion and dermal contact. The exposure factors used included 70 kg adult body weight, 15 kg child body weight, 350 exposure days/year, 24-year adult exposure duration, 6-year child exposure duration, 200 mg/day child soil ingestion rate, 3300 cm² adult exposed skin area and 2800 cm² child exposed skin area. A soil adherence factor of 0.2 mg/cm², dermal absorption fraction of 0.001 and the conversion factor $CF=10^{-6}$ were incorporated in the dermal chronic daily intake (CDI) calculations. Non-carcinogenic risk was expressed as hazard quotient (HQ) and hazard index (HI). Cancer risk was calculated using a lifetime averaging time of 25,550 days. (USEPA, 1997; USEPA, 2011)

The carcinogenic assessment was restricted to arsenic because risk-characterization text identifies an arsenic cancer slope factor of 1.5 (mg/kg-day)⁻¹, and Cd and Pb were excluded from the carcinogenic assessment because suitable slope factors for the adopted exposure scenario were unavailable.

2.7. Statistical analysis

Heavy-metal and physicochemical data were summarized using means, standard deviations, medians, ranges and percentiles. Mean concentrations between Mgbu-Oluwa and Mgbu-Ela were compared using an independent-samples t-test at $\alpha=0.05$. Microsoft Excel was used for data processing and graphical presentation.

3. Results

3.1. Heavy-metal concentrations

Cadmium was the dominant metal and showed the greatest temporal variability. In Mgbu-Oluwa, monthly mean Cd concentrations ranged from 0.15 mg/kg in August to 7.55 mg/kg in May, 2025. In Mgbu-Ela, concentrations increased from 0.45 mg/kg in March to 4.00 mg/kg in August, 2025. The community comparison was not statistically significant ($p=0.64$).

Lead concentrations were generally low. Mgbu-Oluwa increased from below detection in March to 0.68 mg/kg in August, 2025, whereas Mgbu-Ela recorded a localized increase in May to 5.00 mg/kg and remained below detection in June–August, 2025. The difference between communities was not significant ($p=0.38$). Arsenic was detected mainly in March–May, 2025, with the highest monthly means in May (1.55 mg/kg in Mgbu-Oluwa and 1.90 mg/kg in Mgbu-Ela); values were below detection from June to August, 2025. The community difference was not significant ($p=0.84$) (Table 1). The distribution and variability of the heavy metals in all soil samples was summarized using descriptive statistics. Amongst the three metals, cadmium showed the highest variability as revealed by its standard deviation. Lead showed variability but to a lesser extent while arsenic showed the least variability, revealing relative consistency across all samples.

The average concentrations of cadmium, lead and arsenic were 2.40 mg/kg, 0.59 mg/kg, and 0.34 mg/kg respectively. Minimum and maximum values for the three metals ranged from below analytical detection limit (0.001 mg/kg) to 12.70 mg/kg, 7.30 mg/kg and 2.30 mg/kg for cadmium, lead and arsenic respectively (Table 2).

Table 1: Monthly mean concentrations of Cd, Pb and As in farmland soils (mg/kg)

Month	Cd Mgbu-Oluwa	Cd Mgbu-Ela	Pb Mgbu-Oluwa	Pb Mgbu-Ela	As Mgbu-Oluwa	As Mgbu-Ela
March	1.75±1.06	0.45±0.15	<0.001±0.001	0.20±0.14	<0.001±0.001	0.016±0.01
April	2.05±0.77	2.95±0.45	0.27±0.05	0.14±0.02	0.25±0.07	0.20±0.00
May	7.55±7.28	2.25±0.17	<0.001±0.001	5.00±3.25	1.55±0.49	1.90±0.56
June	1.05±0.74	3.30±0.77	0.41±0.07	<0.001±0.001	<0.001±0.001	<0.001±0.001
July	0.60±0.42	3.65±1.09	0.55±0.10	<0.001±0.001	<0.001±0.001	<0.001±0.001
August	0.15±0.10	4.00±1.41	0.68±0.12	<0.001±0.001	<0.001±0.001	<0.001±0.001

Key: <0.001 denotes values below the analytical detection limit.
Community comparisons: Cd $p=0.64$; Pb $p=0.38$; As $p=0.8$

Table 2: Descriptive statistics of the heavy metals across the 24 composite soil samples.

Parameter	n	Mean (mg/kg)	Median (mg/kg)	Minimum	Maximum	SD	25th Percentile	75th Percentile
Cd	24	2.40	2.05	<0.001	12.70	2.72	0.60	2.52
Pb	24	0.59	0.14	<0.001	7.30	1.53	0.001	0.46
As	24	0.34	0.001	<0.001	2.30	0.67	0.001	0.20

3.3. Soil physicochemical properties

Soil pH remained slightly acidic throughout the study. Mgbu-Oluwa ranged from 5.95 in March to 6.25 in August, 2025, while Mgbu-Ela ranged from 6.00 to 6.20.

Soil temperature showed a stronger temporal decline in Mgbu-Oluwa, from 32.0 °C in March to 19.95 °C in August; Mgbu-Ela declined from 29.0 °C to 25.85 °C (Table 3).

Table 3: Monthly Mean Soil Temperature and pH.

Month	Temperature Mgbu-Oluwa (°C)	Temperature Mgbu-Ela (°C)	pH Mgbu-Oluwa	pH Mgbu-Ela
March	32.00±2.82	29.00±0.00	5.95±0.07	6.00±0.00
April	27.65±0.35	28.30±0.28	6.05±0.07	6.10±0.00
May	27.00±0.14	27.75±0.35	6.10±0.00	6.10±0.00
June	23.90±1.55	27.10±0.56	6.15±0.07	6.10±0.00
July	21.42±2.96	26.45±0.77	6.15±0.07	6.20±0.00
August	19.95±2.75	25.85±0.91	6.25±0.07	6.10±0.00

3.4. Compliance with Comparison Values

Cadmium was the principal compliance concern. From the sample-level data, 17 of 24 samples exceeded the Nigerian petroleum-sector target value of 0.8 mg/kg and the FAO/WHO comparison value of 3 mg/kg for Cd (observed range: <0.001–12.70 mg/kg).

Pb (observed range: <0.001–7.30 mg/kg) remained below both comparison values (85 mg/kg and 50 mg/kg for the Nigerian petroleum-sector target value and the FAO/WHO limits respectively), while As (observed range: <0.001–2.30 mg/kg) remained below the 20 mg/kg comparison value for both bodies (Table 4).

Table 4: Comparison of Observed Concentrations with Selected Nigerian Petroleum-Sector and FAO/WHO Soil Benchmarks.

Metal	Nigerian petroleum-sector target (mg/kg)	FAO/WHO comparison (mg/kg)	Observed range (mg/kg)	Main interpretation
Cd	0.8	3.0	<0.001–12.70	17 out of 24 samples exceeded both limits
Pb	85	50	<0.001–7.30	Within both comparison values
As	20	20	<0.001–2.30	Within comparison value

3.5. Human Health Risk Assessment

3.5.1. Non-Carcinogenic Risk Assessment

Adult dermal CDI values were low for all three metals (Table 5). Adult dermal HI values were 2.97×10^{-5} in Mgbu-Oluwa and 3.78×10^{-5} in Mgbu-Ela (Table 8). For children, combined ingestion and dermal exposure produced higher CDI values and HI values of 4.25×10^{-2} and 5.37×10^{-2} in Mgbu-Oluwa and Mgbu-Ela, respectively (Tables 6, 7 and 8 respectively). All HQ and HI values were below unity.

Table 5: Adult Dermal Chronic Daily Intake (CDI_{der}) for Cd, Pb and As

Community	Cd (CDI_{der})	Pb (CDI_{der})	As (CDI_{der})
Mgbu-Oluwa	1.98×10^{-8}	2.89×10^{-9}	2.71×10^{-9}
Mgbu-Ela	2.50×10^{-8}	8.05×10^{-9}	3.16×10^{-9}

Table 6: Child Soil Ingestion Chronic Daily Intake (CDI_{ing}) for Cd, Pb and As

Community	Cd (CDI_{ing})	Pb (CDI_{ing})	As (CDI_{ing})
Mgbu-Oluwa	2.80×10^{-5}	4.09×10^{-6}	3.84×10^{-6}
Mgbu-Ela	3.54×10^{-5}	1.14×10^{-5}	4.47×10^{-6}

Table 7: Child Dermal Chronic Daily Intake (CDI_{der}) for Cd, Pb and As

Community	Cd (CDI_{der})	Pb (CDI_{der})	As (CDI_{der})
Mgbu-Oluwa	7.83×10^{-8}	1.14×10^{-8}	1.07×10^{-8}
Mgbu-Ela	9.91×10^{-8}	3.18×10^{-8}	1.25×10^{-8}

Table 8: Non-carcinogenic risk indicators

Key: HI values are <1

Population/commu nity	Cd HQ	Pb HQ	As HQ	Total HI
Adult dermal – Mgbu-Oluwa	1.98×10^{-5}	8.26×10^{-7}	9.03×10^{-6}	2.97×10^{-5}
Adult dermal – Mgbu-Ela	2.50×10^{-5}	2.30×10^{-6}	1.05×10^{-5}	3.78×10^{-5}
Child – Mgbu- Oluwa	2.81×10^{-2}	1.17×10^{-3}	1.32×10^{-2}	4.25×10^{-2}
Child – Mgbu-Ela	3.55×10^{-2}	3.27×10^{-3}	1.49×10^{-2}	5.37×10^{-2}

3.5.2. Carcinogenic Risk Assessment

For carcinogenic risk assessment, arsenic (As) was retained as the carcinogenic contaminant because an arsenic cancer slope factor (CSF) of $1.5 \text{ (mg/kg-day)}^{-1}$ was available from the USEPA-based guideline while Cd and Pb were excluded as suitable slope factors for the adopted exposure scenario were not available. For cancer risk, the CDI was averaged over the lifetime cancer averaging time ($A_{tc} = 25,550$ days). Thus, the cancer-adjusted CDI is obtained from the corresponding pathway CDI by applying A_{tc} , after which $CR = CDI_{\text{cancer}} \times CSF$. This produces consistent cancer-risk estimates from the same exposure concentrations and pathways used for the non-carcinogenic assessment. The resulting arsenic cancer-risk values are presented in Table 9. For children, ingestion and dermal cancer-adjusted CDI components are shown separately and then summed because the adopted exposure scenario includes both pathways.

Using the stated exposure parameters and a 70-year lifetime averaging time, the arsenic cancer risks were approximately 1.39×10^{-9} for adult dermal exposure and 4.95×10^{-7} for child ingestion plus dermal exposure in Mgbu-Oluwa, and 1.63×10^{-9} and 5.77×10^{-7} , respectively, in Mgbu-Ela. These values are below the 10^{-6} – 10^{-4} risk management range. (USEPA, 2011)

Table 9: Arsenic Cancer-adjusted CDI and Carcinogenic Risk for the Assessed Exposure Pathway

Community	Adult cancer CDI	As Adult CR	As Child ingestion cancer CDI	As Child dermal cancer CDI	As Child combined CR	CCR
Mgbu-Oluwa	9.29×10^{-10}	1.39×10^{-9}	3.29×10^{-7}	9.17×10^{-10}	4.95×10^{-7}	4.95×10^{-7}
Mgbu-Ela	1.08×10^{-9}	1.63×10^{-9}	3.83×10^{-7}	1.07×10^{-9}	5.76×10^{-7}	5.76×10^{-7}

4. Discussion

The present study identified Cd as the dominant heavy metal in the farmland soils of Ndele. The mean concentration across all 24 samples was 2.40 mg/kg, compared with 0.59 mg/kg for Pb and 0.34 mg/kg for As. The temporal pattern of Cd differed between the two communities: Mgbu-Oluwa recorded a pronounced May peak, whereas Mgbu-Ela showed a gradual increase toward

August. The absence of a statistically significant difference between communities suggests that the observed spatial variation is influenced by local environmental factors and human activities. The predominance of Cd is environmentally important because cadmium is persistent and can be relatively mobile in acidic soils. The slightly acidic pH recorded in both communities (5.95–6.25) provides conditions that may favour greater Cd solubility and plant availability. This is relevant for agricultural systems because soil-to-plant transfer can provide a pathway from contaminated soil to food. Previous studies in the Niger Delta have similarly documented heavy metal occurrence in agricultural soils and vegetation, although concentrations vary substantially among locations (Chinedu & Chukwuemeka, 2018; Iyama et al., 2022; Okoye et al., 2022; Imoni & Jonathan, 2025). The Pb concentrations were comparatively low. The localized May spike of 5.00 mg/kg in Mgbu-Ela did not translate into a significant community-level difference and remained far below the Nigerian petroleum-sector target value of 85 mg/kg. Similar evidence of relatively low Pb levels in agricultural systems of Rivers State has been reported by Ohiagu et al. (2020). Nevertheless, low soil concentrations should not be interpreted as absence of health significance because Pb is a potent neurotoxicant and exposure of children warrants particular attention (Okorosaye-Orubite & Igwe, 2017).

Arsenic showed a more episodic pattern, with measurable concentrations concentrated in March–May and non-detectable values from June to August. The maximum observed concentration (1.90 mg/kg) was well below the 20 mg/kg comparison value. Nevertheless, As warrants inclusion in risk assessment because of its carcinogenicity. The calculated cancer-risk values under the adopted exposure assumptions were low, indicating no unacceptable carcinogenic risk from the assessed soil pathways at the time of the study (Felagha et al., 2025)

The soil pH findings are consistent with the generally acidic character of humid tropical soils. Soil acidity can modify metal adsorption and desorption processes and may increase the mobility of metals such as Cd. Temperature also varied during the six-month sampling period, particularly in Mgbu-Oluwa. However, the relatively stable pattern between communities and the absence of significant differences in metal concentrations indicate that temperature alone is unlikely to explain the observed contamination patterns. Local anthropogenic inputs, land-use practices and proximity to petroleum infrastructure are more plausible contributors.

The health-risk assessment provides an important qualification to the contamination findings. Although Cd concentrations exceeded the Nigerian petroleum-sector target value in most samples, non-carcinogenic risk estimates remained below unity. Children had substantially higher HI values than adults because their exposure assessment included incidental soil ingestion and used a lower body weight. This finding is consistent with the general principle that children can have higher exposure per unit body weight than adults. USEPA risk-assessment guidance emphasizes that risk characterization depends on the exposure assumptions and toxicity values used; therefore, the present estimates should be interpreted as screening-level estimates rather than direct predictions of disease. (USEPA, 1997; USEPA, 2011)

The distinction between environmental contamination and current estimated health risk is important. The presence of Cd above a soil target value indicates a soil quality concern even when the modeled HI remains below one. Continued deposition or accumulation could alter future exposure concentrations, while crop uptake was not measured in the present study. Studies from the wider Niger Delta have demonstrated that metals present in soil can enter vegetation and food systems, reinforcing the need for crop-based follow-up studies (Okoye et al., 2021, 2022).

5. Conclusion

Farmland soils in Mgbu-Oluwa and Mgbu-Ela, Ndele contained detectable Cd, Pb and As, with Cd clearly representing the principal contaminant of concern. Cadmium showed the highest mean concentration and greatest temporal variability, while Pb and As occurred at substantially lower concentrations. Soil pH remained slightly acidic and may favour Cd mobility and plant availability. The concentrations of Pb and As were below the selected comparison values, whereas Cd exceeded both the Nigerian petroleum-sector target value and the FAO/WHO acceptable risk range in most samples. Despite the Cd contamination, the modeled non-carcinogenic risks were below the USEPA threshold of unity for both adults and children. Children had higher estimated risks than adults, reflecting their greater relative exposure through soil ingestion. Arsenic cancer-risk estimates were also below the USEPA acceptable risk range. These findings indicate that the present exposure scenarios do not suggest unacceptable modeled human-health risk, but they do not remove the need for environmental management and monitoring.

6. Recommendations

The findings of this study have led to the following recommendations:

- I. Establish periodic monitoring of Cd, Pb and As in agricultural soils of Ndele, with particular attention to Cd hotspots.
- II. Extend future investigations to crop tissues to determine soil-to-plant transfer and dietary exposure.
- III. Investigate additional contaminants, including Ni, Cr, Hg, Cu, Zn and petroleum hydrocarbons, to provide a broader pollution profile.
- IV. Maintain pollution-prevention and environmental-management measures around petroleum infrastructure and other potential contaminant sources.
- V. Provide farmer-focused awareness on soil contamination, safe agricultural practices and the importance of periodic soil testing.

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