









SOIL CONTAMINATION AND FOOD SAFETY IN NIGERIA: A COMPREHENSIVE ASSESSMENT OF HEAVY METAL DISTRIBUTION AND AGRICULTURAL IMPLICATIONS

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ABSTRACT

Soil heavy metal contamination represents one of the most pervasive environmental and public health challenges confronting Nigeria's agricultural sector. This comprehensive review synthesises published data from 2020 to 2025 on the spatial distribution of key heavy metals, lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), nickel (Ni), mercury (Hg), and copper (Cu), in Nigerian agricultural soils, their transfer into staple food crops, and the resultant human health implications. Evidence indicates that mean soil concentrations of Cr (81.77 mg/kg), Pb (19.91 mg/kg), As (13.23 mg/kg), and Cd (3.25 mg/kg) routinely exceed WHO/FAO permissible limits in many agroecological zones, with the Niger Delta, Kano metropolis, and Kwara State emerging as particularly vulnerable hotspots. Principal contamination drivers include petroleum extraction and oil spills, indiscriminate wastewater irrigation, excessive use of agrochemicals, artisanal mining, and tannery effluents. Bioaccumulation in staple food crops, including rice, cassava, yam, pumpkin leaf, spinach, and maize, confirms a functional soil-to-food contamination pathway with documented exceedances of Codex Alimentarius and European Union limits for Pb and Cd. Children and subsistence farmers represent the most vulnerable population segments through combined dietary and dermal exposure routes. Remediation strategies, including phytoextraction, biochar amendments, lime stabilisation, and microbial bioremediation, are critically evaluated. Policy gaps in regulatory enforcement, environmental monitoring, and food safety governance are identified. The review concludes by proposing an integrated, multi-stakeholder framework for sustainable soil management and food safety assurance in Nigeria.

Keywords: Heavy metal contamination; soil pollution; food safety; Nigeria; bioaccumulation; phytoremediation; Niger Delta; cadmium; lead; agricultural implications.

1. INTRODUCTION

Nigeria, with a population exceeding 220 million and an economy substantially anchored in rain-fed smallholder agriculture, is acutely vulnerable to the cascading effects of soil degradation. Agricultural land covers approximately 70.8 million hectares, supporting the livelihoods of more than 70% of the rural population and generating staple outputs of cassava, yams, rice, sorghum, and diverse vegetables [1]. Against this backdrop, the escalating contamination of arable soils with heavy metals, attributable to rapid industrialisation, petroleum exploitation, artisanal mining, and injudicious agrochemical use, constitutes a growing threat to food safety and national food security [2,3].

Heavy metals are naturally occurring elements with an atomic density greater than 4 g/cm³, encompassing Pb, Cd, Cr, As, Hg, Ni, Cu, zinc (Zn), and manganese (Mn) [4]. Unlike organic pollutants, they are non-biodegradable, persist indefinitely in the soil matrix, and accumulate progressively in living tissues through bioaccumulation and biomagnification [5]. Their toxicological significance is compounded by their capacity to enter the human food chain via plant uptake, contaminating cereals, root crops, and leafy vegetables consumed daily by Nigerian households [6].

Recent studies conducted across geographically diverse Nigerian states, including Kwara, Kano, Rivers, Delta, Imo, and Lagos, consistently report heavy metal concentrations that exceed the maximum permissible levels established by the World Health Organization (WHO), the Food and Agriculture Organization (FAO), and the Codex Alimentarius Commission [6–10]. The Niger Delta remains an exceptional case, where decades of crude oil exploration have deposited an estimated 9–13 million barrels of petroleum into the terrestrial ecosystem, enriching soils with Cd, Hg, Ni, and Pb to ecologically hazardous levels.

Despite the growing body of site-specific investigations, comprehensive national-level synthesis of heavy metal distribution patterns, their primary sources, soil-to-crop transfer dynamics, and effective remediation strategies remain scarce within the peer-reviewed literature. This review addresses that gap by providing a systematic, geographically stratified assessment of heavy metal contamination in Nigerian agricultural soils, drawing on verifiable literature published between 2020 and 2025, and situating findings within the broader context of global food safety frameworks and policy imperatives.

2. SOURCES OF HEAVY METAL CONTAMINATION IN NIGERIAN SOILS

2.1 Petroleum Extraction and Oil Spills

The Niger Delta ecosystem spanning Rivers, Bayelsa, Delta, Akwa Ibom, Cross River, and Ondo states has endured the heaviest toll of petroleum-associated soil contamination in sub-Saharan Africa. Anyanwu et al. [11] reported total petroleum hydrocarbon (TPH) concentrations of up to 889 mg/L and heavy metal concentrations as high as 13.119 mg/L in water samples, with the heavy metal pollution index indicating serious ecological and human health hazards, especially for Cd, Cu, Hg, and Ni. Spill data analysed between 2021 and 2024 identified Rivers, Bayelsa, and Delta states as the most affected, with contamination linked to aging pipeline infrastructure, sabotage, and inadequate spill response [12,13].

Co-elution of crude oil and associated formation water mobilises heavy metals into the vadose zone, where downward percolation contaminates the root zone of food crops. Persistent contamination suppresses soil microbial diversity, disrupts nitrogen cycling, and reduces agricultural productivity, compounding food insecurity in already marginalised farming communities [11,12]. Figure 1 presents the Spatial distribution map of documented heavy metal hotspots in Nigerian agricultural soils.

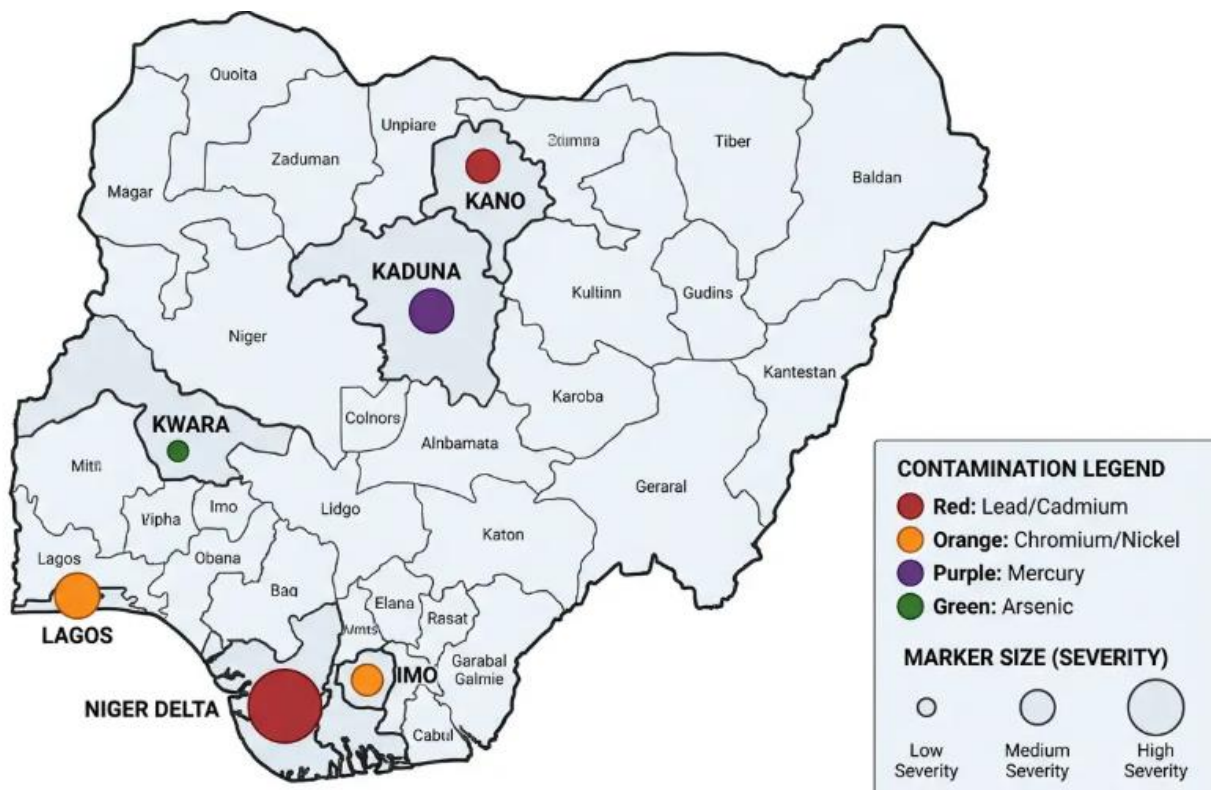


Figure 1. Spatial distribution map of documented heavy metal hotspots in Nigerian agricultural soils, 2020–2025. Size of symbol indicates severity of contamination; colour codes represent the dominant contaminating metal (red: Pb/Cd; orange: Cr/Ni; purple: Hg; green: As). Sources: Data synthesised from references [2,6,11,16].

2.2 Wastewater Irrigation and Industrial Effluents

In peri-urban agricultural zones, particularly around Kano, Abuja, and Ilorin, the pervasive practice of irrigating crops with untreated municipal and industrial wastewater introduces elevated concentrations of Pb, Cd, Cr, and Cu directly into arable soils [6,14]. Orosun et al. [6] documented mean soil Cr concentrations of 81.77 mg/kg and Pb of 19.91 mg/kg in Ilorin, both substantially exceeding WHO recommended soil thresholds, attributing these exceedances primarily to wastewater reuse from textile, tanning, and food-processing industries. In Kano metropolis, heavy metal buildup in soils from decades of irrigation with Challawa and Sharada industrial estate effluents has been well characterised, with the sequence Fe > Zn > Mn > Cu > Ni > Pb > Co > Cr reported across vegetable farms [14].

A recent assessment of effluent-irrigated farmlands in Abuja's industrial corridor confirmed Cr concentrations consistent with tannery and metal-finishing discharges, while wastewater pH in the alkaline range (7.8–8.5) reduced micronutrient bioavailability and further impaired soil health [7]. These findings underscore the dual burden of heavy metal toxicity and nutritional impairment imposed by unregulated effluent irrigation.

2.3 Artisanal and Small-Scale Mining

Artisanal gold mining activities concentrated in Zamfara, Niger, and Kebbi states have precipitated severe lead poisoning outbreaks, with soils in mining communities recording Pb concentrations far exceeding safe thresholds. Mining operations crush ore using rudimentary techniques that release fine lead-bearing dust into the ambient environment, contaminating homestead soils, play areas, and adjacent agricultural land [3,4]. Mercury, used for gold amalgamation, similarly accumulates in soils and sediments, with potential for methylation to the highly neurotoxic methylmercury under anaerobic conditions [11].

2.4 Agrochemical and Fertiliser Use

The widespread and often unregulated application of phosphate fertilisers, pesticides, and herbicides constitutes an underappreciated source of cadmium, arsenic, and lead loading in Nigerian agricultural soils. Phosphate fertilisers manufactured from phosphate rock may contain Cd concentrations of 5–100 mg/kg, and their repeated use gradually enriches the plough layer [15,16]. Bawa [16] demonstrated that pesticide use on farms in Paki, Kaduna State, was associated with bioaccumulation factors (BAF) for Cd of 0.84–3.52 in common food crops, with onion (*Allium cepa*) exhibiting the highest Cd BAF of 3.52 indicating active hyperaccumulation from agrochemical-contaminated soils.

3. REGIONAL DISTRIBUTION AND SPATIAL PATTERNS

Heavy metal contamination in Nigerian agricultural soils exhibits pronounced spatial heterogeneity driven by proximity to pollution sources, soil physicochemical properties (pH, cation exchange capacity, organic matter content), and land-use history [2,3,6]. Table 1 presents a synthesis of reported mean heavy metal concentrations across Nigerian agroecological zones in comparison with WHO/FAO regulatory thresholds.

Table 1. Summary of reported mean heavy metal concentrations in Nigerian agricultural soils compared with WHO/FAO permissible limits.

Heavy Metal	WHO Limit (mg/kg)	Mean Conc. (mg/kg)	Principal Source	Region	Reference
Lead (Pb)	85	19.91	Industrial effluent, vehicular emissions	Kwara State	[6]
Cadmium (Cd)	0.8	3.25	Phosphate	Kano State	[6]

			fertilisers, wastewater irrigation		
Chromium (Cr)	100	81.77	Tanneries, electroplating industries	Kwara State	[6]
Arsenic (As)	20	13.23	Pesticide use, geogenic sources	South-West	[6]
Nickel (Ni)	50	8.40	Oil spills, Niger Delta petroleum	Niger Delta	[11]
Mercury (Hg)	0.3	0.56	Gold artisanal mining, chlor- alkali plants	North- Central	[11]
Copper (Cu)	100	9.15	Agrochemicals, sewage sludge	South-West	[2]

WHO/FAO = World Health Organization/Food and Agriculture Organization permissible soil limits for agricultural land. Values represent means from cited studies.

The Niger Delta zone consistently records the most alarming heavy metal burden, driven by chronic petroleum contamination. In contrast, the northern zones of Kano and Kaduna present elevated Cd, Pb, and Zn concentrations linked to tannery effluents and wastewater irrigation. In south-eastern states such as Imo and Enugu, lead and cadmium accumulations associated with legacy mining and informal industrial activities have been reported to exceed EU agricultural soil limits [10,17]. The south-western states of Ondo and Delta present compound contamination from bitumen mining alongside petroleum-associated metals [18].

Soil pH is a primary modulator of metal bioavailability across all zones; acidic soils (pH < 6.0) prevalent in humid south-eastern Nigeria enhance metal solubility and plant uptake, while the alkaline soils of the arid north tend to immobilise metals in the short term but concentrate them over extended irrigation cycles [6,14]. Soil organic matter content inversely correlates with metal bioavailability through complexation, though organic matter is declining across degraded Nigerian farmlands, further exacerbating contamination risks [2,3].

4. Soil-to-Food Crop Transfer and Bioaccumulation

The translocation of heavy metals from contaminated soil matrices into edible plant tissues is governed by the bioaccumulation factor (BAF) and transfer coefficient (TC), both of which vary substantially by metal species, crop variety, soil pH, and organic matter content [16]. Table 2 summarises documented heavy metal concentrations in key Nigerian staple food crops relative to Codex Alimentarius and WHO/FAO maximum permissible levels, while Figure 2.

Bioaccumulation factor (BAF) values for key heavy metals in commonly consumed Nigerian food crops (rice, cassava, spinach, onion, maize, and fluted pumpkin).

Table 2. Heavy metal concentrations in selected Nigerian staple food crops compared with international regulatory limits.

Food Crop	Metal (mg/kg FW)	Conc. Detected	Regulatory Limit	Reference
Rice (<i>Oryza sativa</i>)	Pb	3.53	0.2 (EU/Codex)	[15]
Rice (<i>Oryza sativa</i>)	Cd	0.034	0.1 (EU/Codex)	[15]
Cassava (<i>M. esculenta</i>)	Pb	19.42	0.1 (WHO/FAO)	[10]
Spinach (<i>A. hybridus</i>)	Cr	81.77*	2.3 (EU) – soil value	[6]
Pumpkin leaf (<i>T. occidentalis</i>)	Cd	0.049	0.05 (WHO/FAO)	[10]
Maize (<i>Z. mays</i>)	Pb	2.80	0.2 (Codex)	[16]
Onion (<i>A. cepa</i>)	Cd	3.52 (BAF)	0.05 (WHO/FAO)	[16]

*FW = Fresh Weight; BAF = Bioaccumulation Factor; *Soil concentration exceeding regulatory limit; EU = European Union; Codex = Codex Alimentarius; WHO/FAO = World Health Organization/Food and Agriculture Organization.*

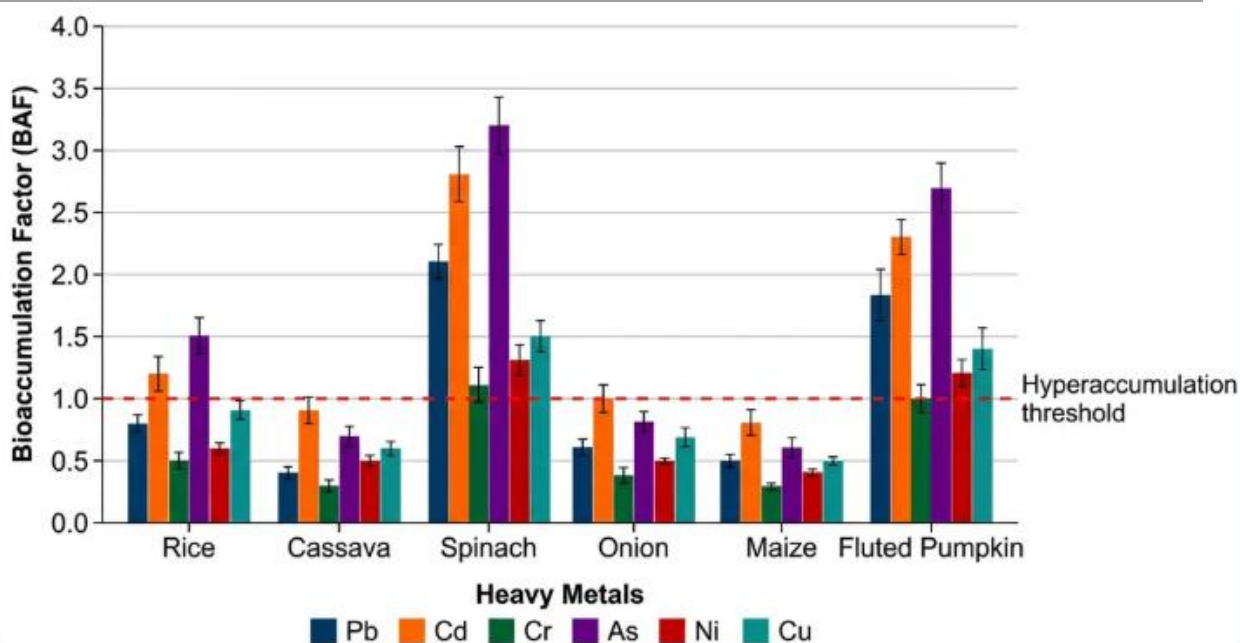


Figure 2. Bioaccumulation factor (BAF) values for key heavy metals in commonly consumed Nigerian food crops (rice, cassava, spinach, onion, maize, and fluted pumpkin). Dashed horizontal line at $BAF = 1.0$ denotes the threshold above which active bioaccumulation is occurring.

Bar chart with error bars representing standard deviation of values synthesised from published studies

Sources: Adapted from references [6,10,15,16].

Leafy vegetables, particularly spinach (*Amaranthus hybridus*) and fluted pumpkin (*Telfairia occidentalis*), demonstrate the highest transfer coefficients for Cd and Pb, owing to their high transpiration rates and expansive root surface areas [6,18]. Orosun et al. [6] confirmed that spinach and cabbage irrigated with wastewater in Ilorin accumulated Cr, Pb, As, and Cd at levels exceeding WHO recommended food safety limits in all sampled plots, with contamination indices corroborating severe-to-extreme pollution risk. Monte Carlo probabilistic health risk assessment models applied in the same study quantified non-carcinogenic hazard quotients substantially above the safe threshold of 1.0 for both adults and children.

Root crops, particularly cassava, Nigeria's most widely cultivated food crop, present a distinct concern. Although tuber tissues exhibit lower BAF values than leafy counterparts, the sheer volume of daily cassava consumption among rural populations results in cumulative Pb and Cd intakes that may exceed provisional tolerable weekly intake (PTWI) values established by the Joint FAO/WHO Expert Committee on Food Additives (JECFA) [10]. Akpan-Ebe et al. [10] documented Pb concentrations of 19.42 mg/kg in cassava tubers from Owerri, nearly 200-fold above the WHO maximum level of 0.1 mg/kg for root vegetables, attributing this primarily to atmospheric deposition rather than direct soil-root transfer.

The quantification of heavy metals in widely consumed Nigerian food crops using atomic absorption spectroscopy (AAS) confirmed the presence of Cd, Pb, Co, Mn, Hg, As, Cr, and Ni across a basket of eight cereals, legumes, tubers, and vegetables, with the majority of values exceeding international maximum permissible limits [15]. Children represent the most vulnerable demographic, as their lower body weight relative to food intake intensifies effective dose exposure, while neurological and developmental consequences of Pb and Hg are disproportionately severe in the neonatal and early childhood periods [3,4].

5. HUMAN HEALTH IMPLICATIONS

Chronic dietary exposure to heavy metals through contaminated food crops engenders a spectrum of adverse health outcomes that impose substantial morbidity burdens on affected Nigerian communities. Lead is established as a potent neurotoxin with no identified safe blood concentration in children; even sub-threshold exposures impair cognitive development, reduce IQ, and cause behavioural disorders [3,4]. Cadmium targets the renal proximal tubule, inducing progressive tubular dysfunction, proteinuria, and, with prolonged exposure, Itai-itai-like osteomalacia [5,6]. Chromium (VI) is classified as a Group 1 human carcinogen by the International Agency for Research on Cancer (IARC), with inhalation and ingestion of Cr-contaminated foodstuffs linked to elevated risks of pulmonary and gastrointestinal cancers [3].

Arsenic, present primarily in inorganic form in soil, is a recognised multi-site carcinogen, associated with cancers of the skin, bladder, lung, and kidney, as well as a potent endocrine

disruptor affecting reproductive outcomes [6]. Mercury, through biotransformation to methylmercury in aquatic and wetland environments adjacent to oil-producing communities, enters the food chain via fish and leafy vegetables irrigated with contaminated water, with severe neurological consequences documented at low chronic exposures [11]. The synergistic toxicity of co-occurring heavy metals further amplifies health risks beyond what individual metal assessments would predict [3,5].

Subsistence farmers who consume crops grown on their own contaminated land, combined with those living in proximity to active pollution sources (oilfield workers' families, tannery communities, artisanal mine workers), face the compound burden of dietary, dermal, and inhalation exposures [2,4,18]. Atikpo et al. [18] calculated target hazard quotients (THQ) for Cd and Pb ingestion from vegetables harvested near Ondo State's bitumen mines that substantially exceeded 1.0 for both adults and children, confirming non-carcinogenic risk. Hazard Index (HI) aggregation across Cd, Zn, Pb, and Cr further classified dietary exposure as posing a significant cumulative health risk.

6. REMEDIATION STRATEGIES AND AGRICULTURAL IMPLICATIONS

The restoration of heavy-metal-contaminated agricultural soils in Nigeria demands the integration of biological, chemical, and physical remediation strategies tailored to local soil conditions, crop systems, and socioeconomic realities. Table 3 presents a comparative summary of principal remediation approaches documented in recent literature, including their target metals, reported efficiencies, and principal advantages and limitations.

Table 3. Comparative assessment of heavy metal remediation strategies applicable to Nigerian contaminated agricultural soils.

Remediation Strategy	Target Metals	Efficiency (%)	Advantages / Limitations	Reference
Phytoextraction (Thlaspi caerulescens)	Cd, Zn, Pb	50–75%	Eco-friendly; slow; requires multiple cycles	[19]
Phytostabilisation (Vetiver grass)	As, Pb, Cu	30–60%	Reduces bioavailability; does not remove metal	[20]
Biochar Amendment	Cd, Pb, Cr	40–85%	Improves soil fertility; cost varies by feedstock	[5]
Lime/Alkaline Amendment	Pb, Cd, Zn	60–90%	Inexpensive; temporary; pH-sensitive	[5]
Microbial Bioremediation	Ni, Cr, Cu	20–55%	Enhances plant uptake; lab-to-	[20]

(PGPR)			field gap remains large	
Soil Washing (EDTA chelation)	Pb, Cd, As	70–95%	High efficacy; expensive; secondary contamination risk	[5]

PGPR = Plant-Growth-Promoting Rhizobacteria; EDTA = Ethylene Diamine Tetra-Acetic Acid. Efficiency ranges represent published field and greenhouse values.

Phytoremediation, encompassing phytoextraction, phytostabilization, phytovolatilisation, and rhizofiltration, is increasingly recognised as the most ecologically appropriate and cost-effective strategy for rural Nigerian settings, given the abundance of tropical hyperaccumulator plant species and the prohibitive cost of conventional ex situ techniques [19,20]. Zhakypbek et al. [19] demonstrated that phytoextraction using *Thlaspi caerulescens* achieved 50–75% reduction in soil Cd and Zn over multiple growing seasons, while phytostabilisation with Vetiver grass effectively immobilised Pb and As in root zones, reducing bioavailable fractions by up to 60%. Sharma et al. [20] further highlighted the role of plant-growth-promoting rhizobacteria (PGPR) in enhancing phytoextraction efficiency by mobilising rhizosphere-bound metals, increasing plant biomass, and reducing phytotoxic stress, an approach of particular relevance in multi-metal contaminated Nigerian soils. Oladosu et al. [21] proposed that the application of smart sensor technologies may improve food safety monitoring by facilitating early detection of heavy metal contamination in agricultural ecosystems Biochar amendment, the incorporation of charred biomass into contaminated soils, represents a promising and scalable intervention for Nigerian smallholders, given the widespread availability of agricultural crop residues as feedstocks [5]. By raising soil pH and providing high-surface-area adsorption sites, biochar reduces the bioavailable fraction of Cd, Pb, and Cr by 40–85%, concurrently improving soil fertility indicators including water retention and microbial biomass carbon [5]. The circular economy potential of converting crop residues (rice husks, groundnut shells, sugarcane bagasse) into biochar is particularly well-suited to Nigeria's agricultural waste streams.

Chemical immobilisation through lime application remains the most widely deployed field-scale intervention across sub-Saharan Africa, primarily by raising soil pH to reduce metal solubility [5]. While cost-effective and rapidly deployable, lime amendment is temporary in acidic, humid environments and must be periodically reapplied, a practical challenge for resource-constrained Nigerian smallholders. Soil washing with EDTA chelation achieves the highest metal removal efficiencies (70–95%) but generates secondary contaminated leachates requiring further treatment, and associated costs prohibit widespread adoption in low-income agricultural settings [5,19]. Figure 3 show the Conceptual framework illustrating the integrated pathway from heavy metal contamination sources through soil accumulation, plant bioaccumulation, and food chain transfer to human health outcomes in Nigeria, with corresponding remediation and policy intervention points.

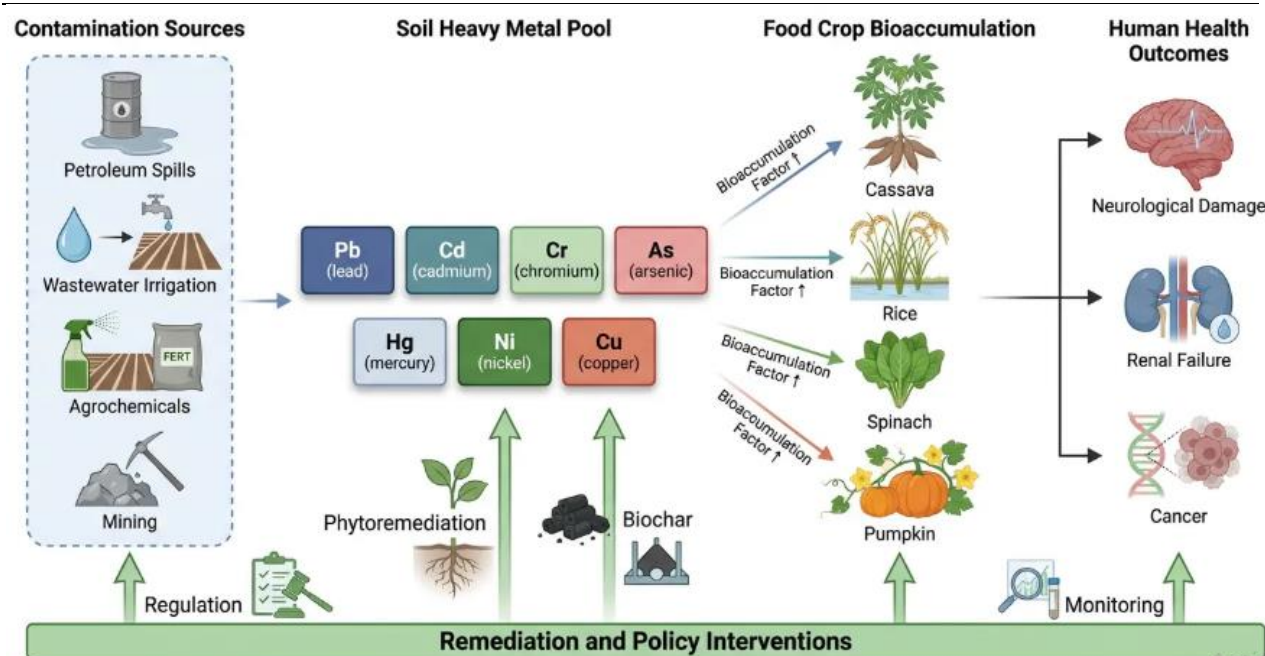


Figure 3. Conceptual framework illustrating the integrated pathway from heavy metal contamination sources through soil accumulation, plant bioaccumulation, and food chain transfer to human health outcomes in Nigeria, with corresponding remediation and policy intervention points.

Sources: Synthesised from reviewed literature references [1–20].

7. POLICY, REGULATORY FRAMEWORK, AND RESEARCH GAPS

Nigeria's regulatory framework for soil and food safety encompasses the National Environmental Standards and Regulations Enforcement Agency (NESREA) Act of 2007, the Harmful Waste (Special Criminal Provisions) Act, the National Agency for Food and Drug Administration and Control (NAFDAC) Act, and the Department of Petroleum Resources (DPR) Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN). However, persistent enforcement gaps, inadequate laboratory infrastructure, and limited routine soil and food quality monitoring have collectively undermined the practical effectiveness of these instruments [1,12,13].

Key regulatory deficiencies include the absence of a comprehensive national soil quality standard applicable to agricultural land, the non-existence of a mandatory crop-level heavy metal maximum residue limit (MRL) framework aligned with Codex Alimentarius, and insufficient intersectoral coordination between NESREA, NAFDAC, the Federal Ministry of Agriculture, and state-level environmental agencies [4,15]. The Petroleum Industry Act of 2021 introduced provisions for environmental remediation bonds in oil-producing communities, yet implementation milestones remain largely unmet [15].

Critical research gaps identified in this review include the near-absence of longitudinal soil monitoring datasets that would allow contamination trends to be tracked over time; limited epidemiological data directly linking heavy metal dietary exposure to specific disease outcomes in Nigerian populations; insufficient investigation of speciation and bioavailability of metals

rather than total metal concentrations; and the very limited number of field-scale remediation trials conducted under Nigerian agroecological conditions [2,3,15]. Future research priorities should encompass: national-scale heavy metal soil mapping using geospatial techniques; biomonitoring programmes measuring blood lead and urinary cadmium in priority exposed populations; and participatory trials of locally adapted remediation technologies with smallholder farmers.

8. CONCLUSION

This review confirms that heavy metal contamination of agricultural soils constitutes a clear, measurable, and escalating threat to food safety and public health across multiple Nigerian agroecological zones. Lead, cadmium, chromium, and arsenic concentrations routinely exceed international permissible thresholds in soils irrigated with wastewater, impacted by petroleum spills, or amended with agrochemicals containing metal impurities. The documented transfer of these metals into Nigeria's most widely consumed staple crops, rice, cassava, fluted pumpkin, and leafy vegetables, establishes a concrete soil-to-food contamination pathway with quantifiable human health consequences, particularly for children and subsistence farming communities.

Effective mitigation requires a paradigm shift from reactive, site-specific interventions toward a proactive, integrated national soil-food safety management system. This should encompass mandatory periodic soil quality surveillance linked to crop safety monitoring; strengthening of NAFDAC's food safety testing capacity to include heavy metal residue screening; community-led adoption of validated low-cost remediation technologies including phytoextraction and biochar amendment; and international capacity-building partnerships to support Nigeria's compliance with Codex Alimentarius food safety standards. Realising these objectives will require sustained political commitment, dedicated research funding, and genuine intersectoral collaboration at both national and subnational levels.

Declarations

Conflict of Interest: The authors declare no conflict of interest.

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Ethical Approval: Not applicable (literature review).

Data Availability: All data cited are available in the referenced peer-reviewed publications.

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