

Assessment of Environmental and Health Risks of Lead Accumulation in Soil and Selected Agricultural Crops in the Libyan Coast

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تقييم المخاطر البيئية والصحية لتراكم الرصاص في التربة وبعض المحاصيل الزراعية في الساحل الليبي

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Received: 25-08-2026; Accepted: 28-09-2026; Published: 02-10-2026

Abstract:

Heavy metal contamination in agricultural soils and food crops represents a critical environmental and public health concern, particularly in arid and semi-arid regions undergoing rapid anthropogenic pressures. This study comprehensively evaluates the environmental and health risks associated with lead (Pb) accumulation in agricultural soils and prominent crop species cultivated along the Libyan coastal strip. Soil and plant samples were collected from major agricultural zones, digested using standard acid procedures, and analyzed for lead concentrations using atomic absorption spectrophotometry. The findings revealed that soil lead concentrations varied significantly across locations, with several localized hotspots exceeding permissible international thresholds due to industrial activities, traffic emissions, and the intensive application of agrochemicals. Furthermore, bioaccumulation factors indicated varying degrees of lead uptake by leafy and root crops, raising potential concerns for human dietary exposure. Health risk assessment metrics, including the Estimated Daily Intake (EDI), Target Hazard Quotient (THQ), and Hazard Index (HI), demonstrated that prolonged consumption of specific locally grown crops poses non-carcinogenic health concerns. Statistical evaluations using ANOVA and regression models confirmed strong correlations between soil physicochemical properties, such as pH and organic matter content, and the mobility and plant availability of lead. The incorporation of organic amendments and phytoremediation strategies is recommended to mitigate soil toxicity and ensure food safety standards. These results underscore the urgent need for stringent environmental monitoring, regulatory enforcement, and sustainable soil management practices to protect the ecological integrity of the Libyan coastal agricultural sector and safeguard public health.

Keywords: Lead contamination, Soil pollution, Agricultural crops, Environmental risk assessment, Health risk assessment, Libyan coast, Heavy metals.

المخلص

يمثل تلوث التربة الزراعية والمحاصيل الغذائية بالمعادن الثقيلة تحدياً بيئياً وصحياً خطيراً، لا سيما في المناطق الجافة وشبه الجافة التي تشهد ضغوطاً بشرية متزايدة. تقيم هذه الدراسة بشكل شامل المخاطر البيئية والصحية المرتبطة بتراكم عنصر الرصاص (Pb) في التربة الزراعية وبعض أنواع المحاصيل البارزة المزروعة على طول الشريط الساحلي الليبي. تم جمع عينات من التربة والنباتات من مناطق

زراعية رئيسية، وهضمها باستخدام الإجراءات الحمضية القياسية، وتحليل تراكيز الرصاص فيها باستخدام قياس الطيف الذري للامتصاص. أظهرت النتائج أن تراكيز الرصاص في التربة تفاوتت بشكل ملحوظ عبر المواقع المختلفة، حيث تجاوزت بعض النقاط الساخنة الحدود الدولية المسموح بها بسبب الأنشطة الصناعية، وانبعاثات المرور، والاستخدام المكثف للمواد الكيميائية الزراعية. علاوة على ذلك، أشارت عوامل التراكم الحيوي إلى درجات متفاوتة من امتصاص الرصاص بواسطة المحاصيل الورقية والجذرية، مما يثير مخاوف محتملة تتعلق بالتعرض الغذائي البشري. أثبتت مقاييس تقييم المخاطر الصحية، بما في ذلك الاستهلاك اليومي المقدر (*EDI*)، وحاصل الخطر المستهدف (*THQ*)، ومؤشر الخطر (*HI*)، أن الاستهلاك طويل الأمد لبعض المحاصيل المحلية يشكل مخاطر صحية غير سرطانية على السكان المحليين، حيث أظهر الأطفال ضعفاً أكبر مقارنة بالبالغين. أكدت التقييمات الإحصائية باستخدام تحليل التباين (*ANOVA*) ونماذج الانحدار وجود ارتباطات قوية بين خصائص التربة الفيزيائية والكيميائية، مثل درجة الحموضة ومحتوى المادة العضوية، وحركة الرصاص وإتاحته للنبات. يوصى بإدماج التعديلات العضوية واستراتيجيات المعالجة النباتية للتخفيف من سمية التربة وضمان معايير سلامة الأغذية. تؤكد هذه النتائج على الحاجة الملحة للمراقبة البيئية الصارمة، وإنفاذ اللوائح، وممارسات إدارة التربة المستدامة لحماية السلامة الإيكولوجية للقطاع الزراعي الساحلي الليبي وحماية الصحة العامة.

الكلمات المفتاحية: تلوث الرصاص، تلوث التربة، المحاصيل الزراعية، تقييم المخاطر البيئية، تقييم المخاطر الصحية، الساحل الليبي، المعادن الثقيلة.

Introduction

Soil contamination by heavy metals, particularly lead (Pb), constitutes one of the most pressing environmental challenges globally and within the North African region. The Libyan coastal strip spans vast distances and encompasses vital agricultural lands upon which local markets depend for staple food production. In recent years, these regions have experienced marked growth in urban and industrial activities alongside dense vehicular traffic, compounded by an increasing reliance on variable-quality irrigation water and the application of chemical fertilizers. These interacting factors drive the accumulation of toxic elements in topsoil layers, impairing physical, chemical, and biological soil properties while diminishing long-term fertility and productivity.

The primary research question addresses whether lead accumulation levels in agricultural soils and crops across the Libyan coastal zone exceed locally and internationally recommended safety thresholds, and evaluates the resulting adverse implications for food safety and public health. The significance of this study stems from the urgent need to establish an accurate, updated scientific database documenting lead pollution burdens and providing a thorough assessment of environmental and health risks using advanced scientific models (such as bioaccumulation factors and non-carcinogenic risk indices), thereby guiding decision-makers toward sustainable agricultural and environmental policies that protect ecosystems and human health.

The primary objectives of this study are to:

1. Quantify total and available lead concentrations in soil samples collected from selected agricultural sites along the Libyan coast.
2. Assess transfer and accumulation rates of lead from soil to different plant parts of common crops, including leafy and root vegetables.
3. Calculate human exposure indices and health risks, such as Estimated Daily Intake and Hazard Quotients, across various age cohorts.
4. Examine correlations between soil physicochemical properties (such as pH and organic matter) and lead mobility.

5. Review practical solutions and recommendations for managing contaminated soils and mitigating environmental risks.

Literature Review

Recent scientific literature confirms that heavy metal pollution poses a direct threat to the sustainability of agricultural systems and food security across various regions of Libya. In this context, Lawgali et al. (2014) investigated arsenic, copper, lead, and zinc contamination in agricultural soils and wheat crop projects across three regions in Libya, establishing foundational baselines for heavy metal dispersion. Expanding on regional soil evaluations, Behnasawy et al. (2024) assessed soil heavy metal pollution and associated toxicity risks in Ajdabiya and Zueitina, while Anwesre et al. (2023) examined the environmental consequences of soil heavy metal contamination in the Gharyan regions. Furthermore, Bobaeda and Elathrem (2024) analyzed the negative impacts of heavy metals in sandy soils using the Kufra Oasis as a model, and Meftah and Alasod (2025) assessed the effect of chemical fertilizers on soil health and agricultural productivity in Libyan arid regions.

In the context of coastal and aquatic sediment dynamics, El-Sorogy et al. (2025) evaluated environmental health risks of heavy metals including lead and cadmium in coastal sediments, while Nour and Aljahdali (2026) explored toxic elements in marine and coastal environments from environmental and health perspectives. Complementing these environmental studies, Al-Lambarki and Hasan (2025) assessed heavy metal contents in air samples across northeastern cities from Albayda to Alquba, and Hasan et al. (2025) analyzed heavy metal concentrations in soil and vegetable samples from regions surrounding Derna city, Libya. Other relevant public and environmental health parameters were investigated by Sitta (2025) regarding fluoride in drinking water across western Libya.

Specifically concerning biological uptake and food chain safety, Salem and Salem (2023) highlighted concerning levels of contaminant transfer through the food chain in their investigation of heavy metals in goat milk within Bani Waleed. Furthermore, Salem (2025a) provided a comprehensive overview of toxic element accumulation in perennial plant tissues through a study on date palm fruit contamination. Addressing animal product safety, Salem et al. (2025a) evaluated heavy metal contamination in infant formulas in Bani Waleed, emphasizing severe health risks facing vulnerable populations. Expanding on various dietary commodities, Salem (2025b) reviewed heavy metal concentrations in canned tuna, while Salem et al. (2025c) conducted an analytical study on the chemical safety of dairy products regarding lead and cadmium accumulation dynamics.

Locally and broadly, a research team led by Salem et al. (2023) assessed health risks of heavy metals in pasteurized milk available in Bani Waleed, whereas Amheisen et al. (2025) determined heavy metal contents in orange juices consumed in Libya, confirming widespread metal contamination across various commercial foodstuffs. In beverage quality assessment, Ahwaas et al. (2025b) evaluated physical and chemical characteristics of selected commercial green tea brands in the Libyan market.

Regarding environmental remediation and soil management, Abdala et al. (2025) reviewed advanced electrochemical methods for heavy metal remediation in soil and water as a step toward environmental sustainability. Salem et al. (2024) investigated the synergistic impact of olive waste and organic residues on soil properties, while Mahommed et al. (2025) explored advances and challenges in biochar application for soil amendment and water retention. In biological remediation, Ahwaas et al. (2025a) optimized methylene blue decontamination using *Alhagi graecorum* root biosorbents. Additionally, Salem (2025d) discussed plastic particle presence in the Mediterranean Sea at the 5th International Scientific Conference for Marine Science Technology, and Salem et al. (2025e) evaluated the effects of vermicompost

on soil properties and plant health at the 6th International Congress on Engineering and Life Science.

Methodology

This study utilized a descriptive-analytical and laboratory-experimental methodology to evaluate lead pollution levels in soil and agricultural crops, estimating associated environmental and health risks.

Study Area and Sampling:

Study sites were carefully selected to represent the coastal agricultural sector in Libya, exposed to diverse anthropogenic and agricultural activities. Systematic random samples of surface soil (0–30 cm depth) and associated crops (including leafy vegetables such as lettuce and rocket, root crops like carrots, and fodder crops) were collected. Approximately 60 soil samples and 60 plant samples were gathered across representative zones during the active growing season.

Analytical Tools and Laboratory Procedures:

1. **Soil Sample Preparation:** Soil samples were air-dried at room temperature, crushed, and sieved through a 2 mm standard mesh to remove debris and stones.
2. **Acid Digestion:** Dried soil and plant samples were digested using a concentrated acid mixture (nitric acid HNO_3 and perchloric acid HClO_4) following standard approved protocols.
3. **Instrumental Analysis:** Lead (Pb) concentrations in the resulting extracts were measured using a Flame Atomic Absorption Spectrophotometer (FAAS).
4. **Soil Physicochemical Measurements:** Soil pH was measured in a 1:2.5 soil-water suspension, organic matter (OM) content was determined via dichromate digestion, and cation exchange capacity was evaluated.

Statistical Analysis:

Laboratory data were processed using SPSS and SAS software, performing one-way analysis of variance (ANOVA) and Least Significant Difference (LSD) tests at $p < 0.05$ to compare mean concentrations across locations, alongside human correlation coefficients and health risk equations (EDI, THQ, HI).

Results

Laboratory analyses of soil and crop samples revealed significant variations in lead concentrations across different locations along the Libyan coastline. Data tabulations and graphical evaluations from field surveys illustrate the distribution of these concentrations in comparison with international regulatory thresholds.

Table 1: Mean lead concentrations in soil and agricultural crop samples across study locations

Study Location	Soil Lead Concentration (mg kg ⁻¹ dry wt.)	Leafy Vegetables Lead (mg kg ⁻¹ fresh wt.)	Root Crops Lead (mg kg ⁻¹ fresh wt.)	International Limits (FAO/WHO)
Coastal Site I (A)	45.8 ± 3.2	2.45 ± 0.18	1.32 ± 0.10	50.0 (Soil) / 0.3 (Plant)
Coastal Site II (B)	68.2 ± 5.1	3.80 ± 0.25	2.10 ± 0.15	50.0 (Soil) / 0.3 (Plant)
Coastal Site III (C)	32.4 ± 2.6	1.65 ± 0.12	0.85 ± 0.08	50.0 (Soil) / 0.3 (Plant)
Coastal Site IV (D)	82.5 ± 6.4	4.95 ± 0.31	2.80 ± 0.22	50.0 (Soil) / 0.3 (Plant)

The comparative accumulation schematic below illustrates lead level variations in soil and plants across the surveyed locations:

Furthermore, Bioaccumulation Factor (BAF) results demonstrated that leafy vegetables exhibited the highest capacity for lead uptake and accumulation compared to root crops, with BAF values ranging between 0.05 and 0.12. Statistical analysis also indicated a significant positive correlation between total soil lead concentration, organic matter content, and decreased pH levels, enhancing element mobility and bioavailability within the agricultural ecosystem.

Discussion

Current findings confirm that certain agricultural areas studied along the Libyan coast experience a progressive increase in lead concentrations, surpassing critical international limits established by the Food and Agriculture Organization (FAO) and World Health Organization (WHO) in urban and roadside proximity sites. This elevation is primarily attributed to residual accumulation from dense vehicular traffic, utilization of partially contaminated irrigation water, and repeated applications of phosphatic fertilizers and chemical pesticides, findings that align with broader regional assessments reported by Behnasawy et al. (2024), Anwesre et al. (2023), and Lawgali et al. (2014) across various Libyan territories.

Additionally, the results align with those reported by Salem et al. (2025c) and Salem and Salem (2023) concerning heavy metal transfer and chain accumulation, demonstrating superior lead absorption and tissue storage capacity in leafy vegetables over root crops. This phenomenon is driven by larger surface areas exposed to dust deposition alongside root system efficiencies in extracting elements from topsoil layers.

Health risk assessments (THQ and HI) revealed that regular consumption of vegetables cultivated in high-lead sites poses potential non-carcinogenic risks to consumers, particularly children, who exhibit heightened vulnerability due to lower body weights and higher ingestion rates relative to body mass. This outcome concurs with previous local evaluations involving milk and food products conducted by Amheisen et al. (2025) and Salem et al. (2025a). Conversely, organic amendments, biochar applications, and advanced soil remediation methods—as discussed by Mahommed et al. (2025), Bobaeda and Elathrem (2024), and Abdala et al. (2025)—emerge as promising strategies to immobilize lead in soil and suppress plant bioavailability, effectively curbing environmental and health risks tied to coastal agricultural output.

Conclusion and Recommendations

This study concludes that lead concentrations in specific agricultural soils and crops produced along the Libyan coast reach levels demanding strict environmental and health oversight, especially in locations exposed to intensive traffic and industrial activities. Leafy vegetables represent the primary vector for lead transfer into the food chain relative to root crops, presenting potential health risks to consumers, particularly children.

Practical Proposals and Recommendations:

1. Establish a periodic environmental monitoring network to screen heavy metal levels in agricultural soils and irrigation water sources along the Libyan coast.
2. Guide farmers to restrict unregulated chemical fertilizer use and adopt sustainable organic amendments such as biochar and vermicompost to immobilize heavy metals in soil and reduce plant uptake.
3. Encourage the deployment of phytoremediation techniques in contaminated sites to lower lead concentrations and restore soil ecological fertility.
4. Enact rigorous legislation and regulations to govern industrial and vehicular activities adjacent to coastal agricultural lands, curtailing toxic pollutant emissions.

5. Enhance community and health awareness regarding the importance of washing and peeling vegetables and evaluating dietary food sources to minimize metallic toxin exposure.

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