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Study of heavy metals presence in both Irish potatoes and soils collected from an abandoned mining site in plateau state

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Abstract

This study assessed elemental concentrations in Irish potatoes and soils from farmlands in the ex-mining area of Dahwol-vwana village, Jos South L.G.A, Plateau State, Nigeria. Total heavy metal concentrations (Pb, Cd, Zn) in soil and potato samples were measured using Atomic Absorption Spectrometry (AAS). Soil concentrations ranged: Pb 0.0445–3.9343 ppm, Cd 0.0086–0.1200 ppm, and Zn 0.0751–39.0302 ppm, higher than control values (Pb 0.0088 ppm, Cd 0.0029 ppm, Zn 0.0101 ppm) but below international limits (EU: Pb 300 ppm, Cd 3 ppm, Zn 300 ppm; USA: Pb 300 ppm, Cd 3 ppm, Zn 250 ppm; UK: Pb 70 ppm, Cd 1.4 ppm, Zn 200 ppm). Irish potato concentrations ranged: Pb 0.0741–1.5042 ppm, Cd 0.0081–0.0931 ppm, Zn 0.1038–88.0503 ppm. A modified Tessier sequential extraction fractionated metals into exchangeable/carbonate, Fe/Mn oxides, organic, and residual fractions. Most metals were in the residual fraction (Zn 138.85 ppm, Pb 55.59 ppm, Cd 2.5 ppm), suggesting soils are largely unpolluted. Pollution indices showed minimal contamination, with Cd enrichment factor 15.4 and I-geo 4. The predominance of metals in the residual fraction indicates a lithogenic origin, implying low risk of transfer to crops under normal farming. However, soil disturbance, such as mining, could mobilize metals, contaminating soils and water, enhancing plant uptake, and increasing biomagnification risk.

Keywords: Heavy metal, contamination, irish potatoes, soils, abandoned mining site

Introduction

Heavy metal contamination has become a major environmental and public health concern worldwide, particularly in regions with a history of intensive industrial and mining activities (Odimgbe. 2023) [16]. Heavy metals such as lead (Pb), cadmium (Cd), zinc (Zn), copper (Cu), chromium (Cr), and arsenic (As) are naturally occurring elements in the earth's crust, but anthropogenic activities have significantly increased their concentration in soils, water, and agricultural systems (Obruche *et al*., 2019) [13]. Unlike organic pollutants, heavy metals are non-biodegradable, persist in the environment for long periods, and can accumulate in living organisms through processes such as bioaccumulation and biomagnification. This persistence makes them particularly hazardous, as even low concentrations can pose serious ecological and human health risks over time (Odimgbe. 2025) [14]. Agricultural soils are especially vulnerable to heavy metal contamination due to their direct exposure to various pollution sources, including industrial emissions, waste disposal, use of agrochemicals, and mining activities. Mining, in particular, is recognized as one of the most significant contributors to heavy metal pollution. During mining operations, large quantities of waste materials, including tailings and overburden, are generated and often left exposed to environmental conditions (Yohanna *et al*., 2025) [29]. These materials can release heavy metals into surrounding soils and water bodies through processes such as weathering, leaching, and erosion. Even after mining activities have ceased, abandoned mining sites continue to act as long-term sources of contamination, posing environmental challenges for decades. The impact of heavy metal contamination in agricultural soils extends beyond environmental degradation to food safety concerns (Okpanachi *et al*., 2025) [10]. Crops grown on contaminated soils can absorb heavy metals through their root systems, leading to the accumulation of toxic elements in edible plant tissues. This creates a direct pathway for human exposure through dietary intake. Studies have shown that the consumption of crops cultivated in contaminated areas can lead to various health problems, including kidney damage, neurological disorders, and increased risk of cancer (Odimgbe *et al*., 2025) [12]. Therefore, monitoring and assessing heavy metal levels in both soils and food crops are essential for ensuring food safety and protecting public health. Among staple food crops, Irish potato (Solanum tuberosum) is of particular importance due to its widespread consumption and nutritional value. Potatoes are a major source of carbohydrates, vitamins, and minerals, and they play a significant role in food security in many parts of the world, including Nigeria (Ekpo *et al*., 2023) [18]. However, their ability to absorb and accumulate heavy metals from the soil makes them a potential vector for transferring contaminants into the human food chain. The extent of heavy metal uptake by potatoes depends on several factors, including soil properties, metal concentration, plant species, and environmental conditions (Abah *et al*., 2025)[1]. In Nigeria, especially in the Plateau State region, mining activities have historically been extensive, particularly for tin and associated minerals. Areas such as Jos-South Local Government Area have numerous abandoned mining sites, where excavation pits and mine tailings are still visible across the landscape. Over time, many of these abandoned sites have been converted into farmlands by local communities due to increasing pressure on land resources (Obruche *et al*., 2025) [7]. However, the soils in these areas may still contain elevated levels of heavy metals, posing potential risks to both crop quality and human health. Previous studies conducted in Jos-South have revealed significant concentrations of heavy metals in soils around abandoned mining sites (Umudi *et al*., 2025) [20]. For instance, soil samples analyzed from such areas showed elevated levels of metals like lead, cadmium, chromium, and copper, with some concentrations reaching very high values due to mining-related activities (Okano *et al*., 2012; Itodo *et al*., 2021) [6, 8]. These findings highlight the long-term environmental impact of mining and the need for continuous monitoring of contaminated sites (Erienu *et al*., 2022) [4]. Additionally, the use of mining ponds and residual soils for irrigation and farming has been linked to increased metal accumulation in agricultural fields, further exacerbating the risk of contamination in crops. Specific investigations into Irish potatoes cultivated in ex-mining areas of Jos-South have also demonstrated the presence of heavy metals in both soil and crop samples. Analytical techniques such as Atomic Absorption Spectrometry (AAS) and X-ray Fluorescence (XRF) have been used to quantify the concentrations of metals like Pb, Cd, and Zn. Results indicate that while metal concentrations in soils from mining areas are higher than those from control (uncontaminated) sites, they may still fall below certain international permissible limits. However, even when concentrations are within regulatory thresholds, continuous exposure and accumulation can pose long-term health risks, particularly when such crops are consumed regularly. Furthermore, studies have shown that the distribution and mobility of heavy metals in soils depend on their chemical forms and interactions with soil components. In some cases, a significant proportion of metals may be bound to less bioavailable fractions, reducing immediate risk (Ekpo *et al*., 2025) [3]. However, environmental changes such as soil disturbance, changes in pH, or agricultural practices can increase the bioavailability of these metals, leading to enhanced uptake by plants. This dynamic nature of heavy metal behavior underscores the importance of not only measuring total metal concentrations but also understanding their speciation and potential bioavailability (Ogwuche and Obruche, 2020) [15]. Given the reliance of local populations on agricultural produce from these areas, there is a critical need to assess the extent of heavy metal contamination in both soils and crops cultivated on abandoned mining sites. Such assessments provide essential baseline data for environmental management, risk evaluation, and policy formulation. They also help in identifying potential remediation strategies, such as phytoremediation, soil amendments, or land-use restrictions, to mitigate contamination and safeguard public health (Festus-Amadi *et al*., 2021; Oladosu *et al*., 2026) [5, 17].

Therefore, this study focuses on the assessment of heavy metal contamination in Irish potatoes and soils from an abandoned mining site in Jos-South, Plateau State, Nigeria. By analyzing the concentrations of selected heavy metals in both soil and crop samples, and comparing them with established safety standards, the study aims to evaluate the level of contamination and the potential risks associated with the consumption of these crops. Ultimately, the findings will contribute to a better understanding of the environmental and health implications of farming in post-mining landscapes and provide a scientific basis for sustainable land management practices in the region.

Materials and Method

Sample Collection

The methods for sample collection were similar to those of Ugochukwu *et al*. (2025) [18] and Ekpo *et al*. (2023) [21], with a few minor changes. The samples collections was done in farms that surrounded three abandon mining holes in Dahwol Vwana village, in Kuru district, Jos-south L.G.A., Plateau state. This was done after the ridges formed and the Irish potatoes (as shown in figure 1) stems that have been transplanted grown, then the Irish potatoes and their surrounding soil on the farms closer to the ex-mining holes were dug with a clean machete and samples were collected, even as the distance covered in each cases were measured. In each case, the soil samples collected were those around the Irish potatoes immediately when dug (i.e. ranging 10-20cm depth from the top of the ridge). Furthermore, horizontal spacing range of distances were covered and measured, even as both the Irish potatoes and the soil around them were collected as shown IN table 1-3.

Fig 1: Irish Potatoes, with Nature of Its Leaves

Table 1: Sample of the First Ex-Mining Hole Area

North- ward	Distance covered	East- ward	Distance covered	West- ward	Distance covered	South- ward	Distance covered
A_1	2.3m	A_3	8.1m	A_4	3.4m	A_6	5.8m
B_1	2.3m	B_3	8.1m	B_4	3.4m	B_6	5.8m
A_2	12.0m	Hip of Sand		A_5	10.0m	A_7	14.2m
B_2	12.0m			B_5	10.0m	B_7	14.2m

Where sample A is the soil sample and sample B is the Irish potatoes sample.

Table 2: Sample of the Second Ex-Mining Hole Area

North-ward	Distance covered	East-ward	Distance covered	West-ward	Distance covered	South-ward	Distance covered
A_8	1.8m	No Farm		A10	3.1m	A12	9.2m
B_8	1.8m			B10	3.1m	B12	9.2m
A_9	8.5m			A11	11.2m	A13	15.1m
B_9	8.5m			B11	11.2m	B13	15.1m

Where sample A is the soil sample and sample B is the Irish potatoes sample.

Table 3: Sample of the Third Ex-Mining Hole Area

North-ward	Distance covered	East-ward	Distance covered	West-ward	Distance covered	South-ward	Distance covered
Hip of Sand		Stagnate Water		No Farm		A14	19.4m
						B14	19.4m
						A15	28.5m
						B15	28.5m

Where sample A is the soil sample and sample B is the Irish potatoes sample.

These samples were obtained, then carefully separated each in polythene bags to avoid mixing and further labeled with cellulose tape to avoid mistaken identity.

Sample collection at control area

The samples collections (the control) was done in a virgin area (N09041.062‶E008045.003‶) in Trade-Centre village, along Vom road, in Kuru district, Jos-south L.G.A., Plateau state. The expected processes were carried out even as Irish potatoes and soil samples were collected at the end.

Samples Preparation

The preparation was carried out according to the procedures described by (USEPA, 2005; Obruche *et al*., 2019 and Umudi *et al*., 2025) [26, 13, 22]. Each of both samples (soils and Irish potatoes) was taken to the laboratory. Each composite sample for both the Irish potatoes and the soils were spread on a tray and subjected to quartering process to obtain a laboratory sample which was reasonably representative of the composite sample. The representative of these samples was again individually dried to a constant weight. Other parts that will not be able to be crushed into powdery form were manually removed from the sample and about 0.5 g of each of the samples were subsequently homogenized in an agate mortar and then formed into stable pallets using hydraulic press equipped with diameter of 2.5 cm at a compressive force of 10tons.

Digestion both Irish Potatoes and Soil samples

The methods for sample digestion analysis were similar to those of Udom *et al*. (2004) [23] and Umanah *et al*. (2025) [25], with a few minor changes. 1.0g of each of the samples were accurately weighed and transferred into digestion tubes, 30ml of the wet digestion acid mixture were added to each sample in the digestion tubes, the digestion tube containing acid mixture was placed on the digestion apparatus, which was allowed to digest for about 1½ hours until a clear solution is obtained. The end of the digestion was marked by the evolution of a white dense fume of percholoric acid (HCL0$_4$) and the reduction of volume to about 5ml, and then the digestion process was discontinued. The digest was allowed to cool and transferred quantitatively in a 100cm3 volumetric flasks, then was made up to the mark with distilled water. The digest of each sample was transferred into different well stopper rubber container which was made ready for atomic absorption spectroscopic analysis.

Sequential Extraction

The sequential extraction method modified was derived from the procedure detailed by (Obruche *et al*., 2025) [7] to separate Pb, Cd and Zn into four (4) operationally defined fractions: exchangeable and carbonate (EXCH + CARB; 1 M NaOAc+ HOAc at pH 5.0), Fe and Mn oxides (OX; 0.04 M NH2OH.HCl in acetic acid), organic matter (OM; 0.02M HNO^{3+} 20% H2O2), and residual (RES) fractions. The concentration of Pb, Cd, and Zn in solution of each fraction was determined in AAS.

AAS Analysis

Total concentrations of Pb, Cd and Zn in the soils and Irish potatoes were determined using shimadzu Model 650 AAS equipped at a time when each of the lamps below: - Hollow cathode lead lamp Hollow cathode cadmium lamp Hollow cathode zinc lamp, are fixed on the AAS machine and each of these processes was done with a flame type consisting of air/acetylene and stoichiometric flue flow at 0.9-1.2 L/min.

Geochemical Accumulation pollution Indexes

Metal enrichment factor (EF) for Pb, Cd and Zn was calculated based on the following relation, as proposed by Obruche (2018) [11]:

EF =(Msoil)/(Mearth crust)……………………………1

where Msoil is the metal concentration in the soil and Mearth-crust is the average metal concentration in the earth crust, which is approximately 14.0, 0.2 and 75.0ppm for Pb, Cd and Zn respectively.

The geoaccumulation index (I-geo), as proposed by Obruche (2018) [11], was calculated by computing the base 2 logarithm of the measured total concentration of the metal over its background concentration using the following mathematical relation (Umudi *et al*., 2025) [24]:

$I\text{-}geo=\log_2 (Cn/1.5Bn)$……………………………2

Where Cn is the concentration of metal n in the soil, Bn is the soil background concentration of heavy metal n and 1.5 is a factor compensating the background data (correction factor) due to lithogenic effects.

Metal Enrichment

Measurements of metal pollution in soils and sediments by Banat et. al., (2005), was used as standard to ascertain the pollution intensity of metals.

Table 4: Measurements of metal pollution in soils and sediments

Index of geochemical accumulation	I-geo Class	Designation of soil quality
10-5	6	Extremely contaminated
4-5	5	Strongly/extremely contaminated
3-4	4	Strongly contaminated
2-3	3	Moderately contaminated
1-2	2	Uncontaminated/moderately contaminated
0-1	1	Contaminated
0-0	0	Uncontaminated
Obruche *et al.*, 2018		

Statistical Analysis

Analysis of variance (ANOVA) was used to determine significant differences for zinc and in total extractable metal concentrations; the relationships among the various metal fractions and soil properties were determined using correlation analysis, and the sample means were compared using Fisher‟s Least Significant Difference (LSD0.05). All statistical data analyses were performed using SAS V 9.0

Results and Discussion

This section discussed the total elemental concentrations of Zn, Pb and Cd, in both soils and Irish potatoes of the study were analyzed based on the international threshold values for heavy metals concentration in soils (ppm) by (Umudi *et al*.,, 2025) [27]. The mean, standard deviation and range of extractable concentration of Pb, Cd, and Zn were calculated. Conclusively, the mean concentration from the fractionation analyses and background concentration were used for the calculation of enrichment factor and I-geo index of study area according to (Ugboma, 2024) [19]. The findings from this study were compared to the World Health Organization (WHO) recommended standards.

Table 5: Total elemental concentrations of Zn, Pb and Cd, in both soils and Irish Potatoes

Sample Type	Zn(ppm)		Pb(ppm)		Cd(ppm)	
	Sample A	Sample B	Sample A	Sample B	Sample A	Sample B
Control (Average)	0.0101	0.0213	0.0088	0.0041	0.0029	0.0017
1.	2.1204	1.0011	1.0080	0.7400	0.0113	0.0102
2.	1.0964	0.1038	0.5807	0.3932	0.0138	0.0094
3.	0.0751	-	1.1201	-	0.0086	-
4.	7.1509	4.0755	0.1483	0.7415	0.0102	0.0090
5.	4.4004	3.0621	0.8801	0.5721	0.0120	0.0093
6.	1.0466	0.3640	0.6783	0.3815	0.0194	0.0154
7.	5.0583	0.5210	1.0113	0.7223	0.0087	0.0081
8.	0.1528	-	0.0445	-	0.0138	-
9.	8.0601	-	0.5542	-	0.0157	-
10.	2.0587	0.2063	0.7661	0.5114	0.0242	0.0182
11.	1.1862	0.5906	1.0084	0.7414	0.0165	0.0138
12.	13.3446	59.0830	2.5932	0.3411	0.1200	0.0931
13.	31.1962	55.0503	3.9343	1.5042	0.0124	0.0110
14.	28.1887	84.0125	1.8008	0.4152	0.0344	0.0117
15.	39.0302	88.0503	0.4597	0.0741	0.0317	0.0145
WHO		15.0		0.1		3.0

Where sample A is the soil sample and sample B is the Irish potatoes sample.

Table 6: Mean and standard deviation and range of extractable concentration (ppm) of Pb, Cd, and Zn

Heavy Metal		Sequential	Extraction	
	Fraction 1: Exchangeable+ Carbonate bound	Fraction 2: Reducible	Fraction 3: Oxidizable	Fraction 4: Residual
Zn Mean, SD	5.92± 3.65b	5.42±2.62b	4.49± 0.99a	138.85±34.33a
Range	(3.95-7.30)	(2.40-6.99)	(3.39-5.32)	(116.93-178.41)
PbMean, SD	6.04± 3.73a	6.31 ± 4.56c	9.86 ± 6.97b	55.59 ± 6.78b
Range	(3.85-9.59)	(2.21-11.23)	(4.67-17.79)	(48.81-62.37)
Cd Mean, SD	0.23± 0.12c	0.20± 0.18b	0.13 ± 0.07c	2.51 ± 0.09a
Range	(0.09-0.44)	(0.09-0.44)	(0.09-0.20)	(2.40-2.56)

Table 7: Average concentration, enrichment factor, calculated I-geo index, and grade of pollution intensity of Pb, Cd and Zn

Heavy metal	Average value (ppm)	Background Concentration (ppm)	EF	I-geo	I-geo grade	Pollution intensity
Pb	77.8	14.0	5.6	1.9	2	Moderately contaminated
Cd	3.07	0.2	15.4	3.4	4	Strongly contaminated
Zn	154.7	75.0	2.1	0.5	1	Contaminated

Discussion

Total Metal Content

The total concentrations of Pb, Cd and Zn are presented in the soils of Dahwol-vwana village, are shown in Table 5. It can be seen from the data that the concentrations of the three metals of soils varied as follows: Cd, 0.0086-0.1200 ppm; Pb, 0.0445-3.9343 ppm; Zn, 0.0751-39.0302 ppm. The values show a significant range. These observations indicate that all sample values of soils are lower than the recommended international threshold of 300 ppm for Pb, 300 ppm for Zn and 3 ppm for Cd in arable soils set by European Union. But for Irish potatoes sample values (table 5), Pb, and Zn in some samples were higher than that of metal values from control. World Health Organization (WHO) recommended threshold values (table 5) can also be compared based on the same unit. However, the elemental concentrations recorded can be worrisome if accumulated with time. The values indicate relatively low level of contamination when compared with the standard thresholds for arable soils. The absence of local threshold figures necessitated comparisons only with thresholds set by international regulators. Despite the minimal values recorded for the heavy metals studied which are all higher than elemental values from the control, it is tenuous to conclude metal relative pollution of the farmlands, except a fractionation procedure partitions a larger proportion of the total metal onto the readily available fraction.

Extractable Concentration of Pb, Cd, and Zn

The amounts of metals extractable by 0.01M $CaCl_2$ represent quantities exchangeable and carbonate bound with Ca and the portion that form complexes with chloride ions. These forms of metals are labile and readily available for soil biota and uptake. The concentrations of extractable Zn, Pb, and Cd ranged from (3.95-7.30) ppm, (3.85-9.59) ppm and (0.09-0.44) ppm. The difference in these extractable among the various soil samples grouped based on the three abandon mining hole extracted was not statistically significant (Table 6). The percentage of the total extractable of Zn, Pb, and Cd by $CaCl_2$ ranged from (0.03-0.05), (0.05-0.12) and (0.03-0.14). These low levels of extractable in the soils indicate high insolubility of the metal. Therefore, the leaching of Zn, Pb, Cd and potential uptake of the metals by plants are highly limited. Likewise, the potential for each of these metals accumulation in the food chain is relatively low. The low level of extractables implies bulk partitioning of the metals to the non-exchangeable fractions of the soil and it also indicates a lithogenic origin of the contaminant (Table 6).

Enrichment and Accumulation of Pb, Cd and Zn

The EF is the ratio of soil to crustal rock concentration of an element. It gives a quantitative measure of the relative enrichment (or depletion) of an element in soil as compared with rock. Umudi *et al.* (2025) [28] gave metal enrichment factor values of between 2 and 10 as indication of some enrichment of the element under consideration while EF values of < 0.5 and >10 would indicate significant depletion and strong enrichment respectively. The calculated metal EF (according to Table 7) for Pb for the soils of Dahwol-vwana village is 5.6 across the study area. This means that there is some superficial enrichment of the element. Similarly observation was made for Cd, in which the metal gave EF of 15.4 that indicated strong superficial enrichment of the element as a result of anthropogenic activities. While Zn just as Pb indicated some level of enrichment compared to the average rock concentration. The calculated value for Zn is 2.1. The calculated I-geo index (Table 7) for the soils of this study is 2 for Pb; 4 for Cd; and 1 for Zn. These indices were interpreted according to Table 7. The highest grade, 4, means that the soil matrix is strongly contaminated, and it also reflects a relative metal concentration relative to background values (Yohanna et. al., 2025) [29]. Although EF and I-geo allow for quick inferences on the status of a metal relative to mean soil and lithosphere concentration, it is important to point out that these indices are based solely on total concentration of a metal in the environment which is a poor indicator of pollution; therefore EF and I-geo are not strong indicators for making inferences on pollution or risk assessment. A summary of the mean Pb, Cd, and Zn concentration including their EF and I-geo index is presented in table 7. These results agreed with the work of Abeokuta *et al*., (2025) [2] he carried out in same area.

Conclusion

Results of this research showed that the soils of the farmlands are not contaminated with Pb, Cd, and Zn. However, the bulk of the metals were partitioned to the residual fraction. This implies that the soils of the farmlands are not polluted by any of the metals studied. Therefore, there is a low risk of metal transfer from the soil to the growing crops. The enrichment level of the metals as calculated from the enrichment factor and I-geo factor only indicate the buffering of soil solution metal concentration through the slow process of weathering. Observations from this study reflects that, except for geological time, the total metal concentrations recorded for these soils would not play a significant role with respect to the Irish potatoes and other plants‟ growth or in terms of most environmental processes. However, in order to establish more definitive inference on the risk of metal transfer to the food chain, further research is needed on the effect of the protons released by the organic acids produced in the rhizosphere on the solubilization of metals bound to the residual fractions of the soil. This is of concern in soils such as those of this study with metals concentrations derived from parent materials and which also have relatively high metal enrichment factors.

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