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Baseline-Referenced Changes in Potentially Toxic Element Concentrations in Mining-Affected Soils after Maize and Tomato Cultivation in Ijesha, Osun State, Nigeria

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ABSTRACT

This study describes potentially toxic element (PTE) concentrations in composite soils from five artisanal gold-mining communities in Atakunmosa West Local Government Area, Osun State, Nigeria, before and after 90 days of maize (Zea mays L.) or tomato (Solanum lycopersicum L.) cultivation. Cr, Cd, Cu, Pb, Zn and As were measured by atomic absorption spectrometry. Each community was represented by one field composite, and the three reported values for each site-treatment combination were treated as repeat analytical readings rather than independent field observations. Final measurements from the unplanted control pots were unavailable. Initial concentrations were heterogeneous across sites. Relative to the initial means, maize-associated decreases occurred in 28 of 30 site-metal combinations and ranged from 16.8% to 95.8%; tomato-associated decreases occurred in 29 of 30 combinations and ranged from 8.9% to 96.4%. Concentrations increased for Cu in maize-treated Ibodi soil and for Zn in both treated Igila soils. These values are descriptive baseline-to-day-90 changes, not control-adjusted removal efficiencies. Without final unplanted controls, independently traceable pot-level data, plant-tissue concentrations, biomass measurements and a soil-plant mass balance, the observed changes cannot be attributed specifically to plant uptake or used to establish phytoremediation performance. The dataset therefore supports a preliminary description of concentration changes after cultivation and identifies requirements for a confirmatory experiment.

Keywords: artisanal gold mining; potentially toxic elements; maize; tomato; soil concentration; experimental controls

I. INTRODUCTION

Artisanal and small-scale gold mining supports livelihoods in many regions, but excavation, ore processing and waste disposal can disturb soil geochemistry and introduce potentially toxic elements into agricultural land and nearby ecosystems. Studies in Ijesha, Osun State, have reported mining-related environmental degradation and site-specific metal contamination, with implications for soil quality and exposure risk (Adegbite et al., 2023; Kyowe et al., 2024).

Potentially toxic elements are not destroyed by biological mineralization. Their environmental behavior depends on redistribution among mineral, organic, aqueous and biological pools. Total concentration alone is therefore an incomplete measure of ecological risk because pH, organic matter, cation-exchange capacity, texture, redox conditions and mineralogy influence solubility, sorption and plant availability (Deng et al., 2024; Parida et al., 2024).

Plants and rhizosphere processes may contribute to contaminant extraction, stabilization or transformation. Demonstrating phytoextraction, however, requires more than a decline in total soil concentration. Time-matched unplanted controls, plant-tissue concentrations, biomass measurements and a soil-plant mass balance are needed to distinguish plant uptake from leaching, redistribution and analytical or sampling variation. These requirements are especially important when food crops such as maize and tomato are evaluated, because contaminated biomass must not enter the human or animal food chain (Anggraini et al., 2025).

This study describes the initial distribution of Cr, Cd, Cu, Pb, Zn and As in five mining-affected soil composites and the concentrations reported after 90 days of maize or tomato cultivation. It also calculates baseline-referenced percentage changes and defines the limits on interpreting those changes in the absence of final unplanted-control and plant-tissue mass-balance data.

II. MATERIALS AND METHODS

2.1 Study area

The study involved soils from Igila, Itagunmodi, Gbodo-Araromi, Ibodi and Fadugba in Atakunmosa West Local Government Area, Osun State, southwestern Nigeria. The reported sampling coordinates were Igila (7.579451° N, 4.658164° E), Itagunmodi (7.542335° N, 4.669324° E), Gbodo-Araromi (7.585937° N, 4.655039° E), Ibodi (7.581959° N, 4.674359° E) and Fadugba (7.598227° N, 4.657849° E).

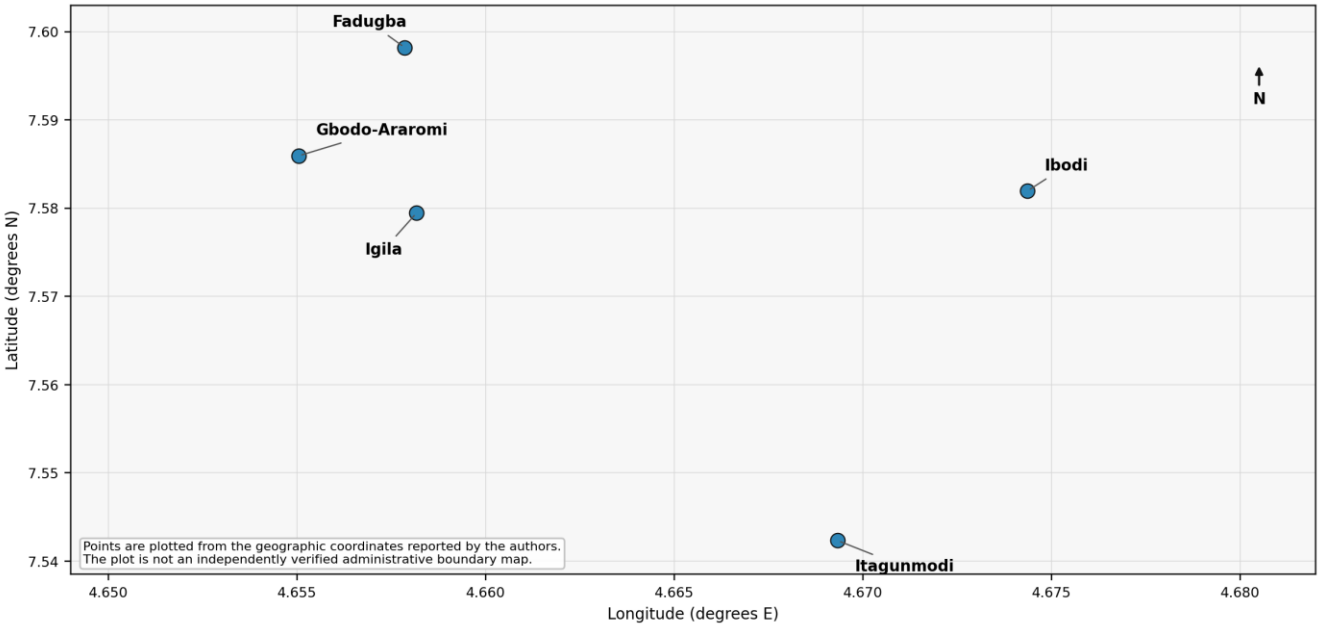


Figure 1. Sampling locations plotted from the geographic coordinates reported for the five Ijesha communities. The plot shows point locations only and does not represent a verified administrative boundary.

2.2 Soil sampling and preparation

At each location, five subsamples were collected within an approximately 20 m radius of the designated point with a cleaned stainless-steel auger and homogenized to form one composite sample. The samples were transported in labeled polyethylene bags, air-dried, cleared of stones and plant residues, gently disaggregated and passed through a 2 mm stainless-steel sieve. This sequence is consistent with the general pretreatment steps in ISO 11464 (ISO, 2006). Each community was represented by one field composite; the design therefore does not estimate within-community spatial variability.

2.3 Experimental design and analytical unit

Maize-planted, tomato-planted and unplanted conditions were reportedly established for each soil, with three 10 L pots containing 5.0 kg of soil per condition. One plant was maintained in each planted pot for 90 days under outdoor conditions. No day-90 results were available for the unplanted pots. The baseline values are initial measurements and are not time-matched controls.

The analytical results contain three readings for each site-treatment combination but do not link those values to individually identified pots. The readings were therefore treated as repeat AAS measurements associated with a single composite soil for descriptive summaries. They were not treated as independent field or pot-level replicates.

2.4 Cultivation and post-cultivation soil preparation

Seeds of maize and tomato were obtained from a local commercial market and established in the prepared soils. Pots were exposed to natural sunlight and rainfall for 90 days. Post-cultivation soil concentrations were reported for the maize and tomato treatments. Plant-tissue results and biomass records were unavailable and are not analyzed here.

2.5 Soil physicochemical characterization

One set of values per location was available for pH, electrical conductivity, organic matter, organic carbon, cation-exchange capacity, bulk density, particle-size fractions and moisture content. Soil pH was measured potentiometrically with a calibrated pH meter following ASTM D4972. These values are reported descriptively because replicate-level physicochemical records were unavailable.

2.6 Determination of potentially toxic elements

Approximately 5.00 g of homogenized soil was acid-digested with analytical-grade nitric and hydrochloric acids, heated at 95 ± 5°C for approximately 3-4 h, cooled and filtered through Whatman No. 42 paper before instrumental analysis. The reported acid volumes and final digest volume could not be reconciled and are not stated here.

Pb, Cd, Cr, As, Zn and Cu were measured with a PG Instruments PG990 atomic absorption spectrometer at reported wavelengths of 217.0, 228.8, 357.9, 193.7, 213.9 and 324.7 nm, respectively. Calibration standards were reported at 0.5, 1.0, 2.0, 5.0 and 10.0 mg L^{-1}, with calibration curves accepted at $R^2 \geq 0.995$. The available method record did not specify the flame and fuel settings, the arsenic atomization or accessory configuration, dilution factors or method detection limits.

2.7 Quality assurance and quality control

The study record states that blanks, calibration-verification standards, reference materials and matrix spikes were used. Numerical blank results, reference-material identifiers, recoveries, duplicate precision, spike recoveries and detection or quantification limits were unavailable. Analytical performance therefore could not be independently assessed.

2.8 Data handling

For each site-treatment combination, the arithmetic mean and sample standard deviation were recalculated directly from the three reported AAS readings. No ANOVA, Tukey test or other inferential test was applied because the readings were not documented as independent field or pot-level observations. Baseline-referenced percentage change was calculated as: $\Delta C\ (\%) = [(C_0 - C_{90}) / C_0] \times 100$, where C_0 is the mean initial concentration and C_{90} is the mean concentration after cultivation. Positive values denote a decrease relative to baseline; negative values denote an increase. The statistic is not a control-adjusted removal efficiency.

III. RESULTS

3.1 Initial concentrations

The initial composite soils differed markedly in their reported PTE concentrations. Itagunmodi had the highest Cr and As means,

Fadugba the highest Cu and Zn means, Gbodo-Araromi the highest Cd mean, and Igila the highest Pb mean (Table 1). These comparisons describe the five sampled composites and cannot be generalized to the corresponding communities.

Table 1. Initial PTE concentrations in the five composite soils (mg kg⁻¹).

Location	Cr	Cd	Cu	Pb	Zn	As
Ibodi	2.299 ± 0.014	1.143 ± 0.004	0.079 ± 0.003	0.097 ± 0.005	0.228 ± 0.007	1.225 ± 0.004
Fadugba	1.199 ± 0.009	1.141 ± 0.005	3.096 ± 0.006	1.515 ± 0.004	1.131 ± 0.004	0.055 ± 0.004
Gbodo-Araromi	0.084 ± 0.005	1.832 ± 0.004	0.216 ± 0.004	1.426 ± 0.004	0.075 ± 0.004	0.095 ± 0.004
Itagunmodi	2.711 ± 0.009	0.085 ± 0.003	0.236 ± 0.004	0.106 ± 0.004	0.134 ± 0.004	1.366 ± 0.003
Igila	1.279 ± 0.007	0.091 ± 0.003	1.523 ± 0.006	1.706 ± 0.005	0.091 ± 0.003	1.004 ± 0.004

Values are recalculated mean ± sample SD of three AAS readings. The readings are treated as analytical repeats of one field composite per location.

3.2 Concentrations after maize cultivation

After maize cultivation, reported concentrations decreased relative to baseline in 28 of 30 site-metal combinations. The positive decreases ranged from 16.8% for Pb at Ibodi to 95.8% for Cd at Gbodo-Araromi. Two combinations increased: Cu at Ibodi rose from 0.079 to 1.341 mg kg⁻¹, corresponding to a baseline-referenced change of -1597.5%, and Zn at Igila rose from 0.091 to 0.430 mg kg⁻¹, corresponding to -370.8%. These large increases warrant source-record verification and illustrate why the changes should not be interpreted as plant uptake or removal.

Table 2. PTE concentrations after 90 days of maize cultivation (mg kg⁻¹).

Location	Cr	Cd	Cu	Pb	Zn	As
Ibodi	1.869 ± 0.007	0.598 ± 0.008	1.341 ± 0.008	0.080 ± 0.005	0.113 ± 0.007	0.762 ± 0.007
Fadugba	0.859 ± 0.009	0.618 ± 0.009	1.341 ± 0.007	1.122 ± 0.008	0.534 ± 0.007	0.039 ± 0.005
Gbodo-Araromi	0.052 ± 0.003	0.077 ± 0.043	0.121 ± 0.006	0.867 ± 0.009	0.033 ± 0.005	0.045 ± 0.004
Itagunmodi	1.699 ± 0.008	0.045 ± 0.006	0.105 ± 0.005	0.065 ± 0.006	0.085 ± 0.008	0.923 ± 0.009
Igila	1.035 ± 0.008	0.061 ± 0.006	0.931 ± 0.009	1.296 ± 0.008	0.430 ± 0.001	0.789 ± 0.012

Values are recalculated mean ± sample SD of three AAS readings.

Table 3. Baseline-referenced percentage change after maize cultivation.

Location	Cr	Cd	Cu	Pb	Zn	As
Ibodi	18.7	47.6	-1597.5	16.8	50.7	37.8
Fadugba	28.4	45.8	56.7	25.9	52.8	29.1
Gbodo-Araromi	38.1	95.8	43.9	39.2	56.0	52.8
Itagunmodi	37.3	47.1	55.4	38.5	36.6	32.4
Igila	19.1	33.2	38.9	24.0	-370.8	21.4

Positive values indicate a decrease from the initial mean; negative values indicate a higher day-90 mean. Values are not adjusted against a day-90 unplanted control.

3.3 Concentrations after tomato cultivation

After tomato cultivation, reported concentrations decreased relative to baseline in 29 of 30 site-metal combinations. The positive decreases ranged from 8.9% for Pb at Ibodi to 96.4% for Cd at Gbodo-Araromi. Zn at Igila increased from 0.091 to 0.635 mg kg⁻¹, corresponding to a baseline-referenced change of -595.3%. As at Fadugba decreased by 18.2%.

Table 4. PTE concentrations after 90 days of tomato cultivation (mg kg⁻¹).

Location	Cr	Cd	Cu	Pb	Zn	As
Ibodi	2.038 ± 0.002	0.825 ± 0.006	0.062 ± 0.004	0.088 ± 0.003	0.156 ± 0.002	0.957 ± 0.001
Fadugba	1.006 ± 0.007	0.855 ± 0.005	2.105 ± 0.010	1.355 ± 0.005	0.899 ± 0.006	0.045 ± 0.004
Gbodo-Araromi	0.061 ± 0.002	0.066 ± 0.005	0.179 ± 0.005	0.821 ± 0.006	0.052 ± 0.003	0.068 ± 0.004
Itagunmodi	2.011 ± 0.007	0.066 ± 0.005	0.167 ± 0.002	0.085 ± 0.005	0.075 ± 0.004	1.143 ± 0.006
Igila	1.150 ± 0.004	0.071 ± 0.004	1.122 ± 0.003	1.398 ± 0.005	0.635 ± 0.005	0.892 ± 0.006

Values are recalculated mean ± sample SD of three AAS readings.

Table 5. Baseline-referenced percentage change after tomato cultivation.

Location	Cr	Cd	Cu	Pb	Zn	As
Ibodi	11.3	27.8	21.5	8.9	31.5	21.9
Fadugba	16.1	25.1	32.0	10.6	20.5	18.2
Gbodo-Araromi	27.4	96.4	17.0	42.4	30.7	28.7
Itagunmodi	25.8	22.4	29.1	19.6	44.0	16.3
Igila	10.0	22.3	26.3	18.1	-595.3	11.2

Positive values indicate a decrease from the initial mean; negative values indicate a higher day-90 mean. Values are not adjusted against a day-90 unplanted control.

3.4 Reported soil physicochemical characteristics

The physicochemical values indicate mildly acidic composite soils, with reported pH values from 5.45 to 6.25. The remaining properties also varied among the five composites (Table 6). These single reported values are descriptive and were not used for inferential or multivariate analysis.

Table 6. Reported physicochemical characteristics of the five composite soils.

Location	pH	EC (dS m-1)	OM (%)	OC (%)	CEC (cmol(+) kg-1)	Bulk density (g cm-3)	Sand (%)	Silt (%)	Clay (%)	Moisture (%)
Ibodi	6.25	0.33	2.14	1.25	9.85	1.33	71.5	14.2	14.2	11.9
Fadugba	5.93	0.38	2.42	1.41	10.62	1.39	69.8	15.6	14.3	12.5
Gbodo-Araromi	5.77	0.49	2.87	1.66	11.83	1.41	67.9	16.9	15.5	13.3
Itagunmodi	5.45	0.56	3.25	1.87	13.23	1.47	64.9	17.6	17.2	14.1
Igila	6.15	0.35	2.35	1.38	10.42	1.35	70.5	14.5	15.1	12.2

EC, electrical conductivity; OM, organic matter; OC, organic carbon; CEC, cation-exchange capacity. Replicate-level records were unavailable.

IV. DISCUSSION

The baseline results show strong heterogeneity among the five composite soils. The element-specific maxima at different sites are consistent with spatially uneven mining inputs, ore processing and waste deposition. Similar site dependence has been reported in mining-affected soils in Ibodi-Ijesa and supports the need for location-specific assessment (Kyowe et al., 2024). Because only one field composite represented each community, however, the present data do not quantify local spatial variability.

Most day-90 concentrations were lower than the corresponding initial means, but three site-metal-treatment combinations showed large increases. Such increases may reflect heterogeneity within the composite soil, redistribution during cultivation, concentration effects, contamination, transcription problems or analytical variability. The available data cannot distinguish among these explanations. The anomalous values should be checked against sample identifiers, dilution factors, calibration records and instrument output before publication.

A decline in total soil concentration is not sufficient evidence of phytoextraction. A valid plant-attributable estimate requires a time-matched unplanted control and a metal mass balance that links changes in the soil to measured concentrations and dry biomass in roots and shoots. Bioaccumulation factors are not reported because the underlying plant-tissue concentrations, tissue fractions, soil denominator and biomass records were unavailable. Multivariate and inferential claims are likewise not reported because the required numerical outputs and independent experimental units were unavailable.

Soil properties may influence metal availability and movement, but the five single-composite values in this study do not support a multivariate causal interpretation. The physicochemical data are therefore reported only as site descriptions. A follow-up experiment should use multiple independent field composites per location, traceable pot-level measurements, measured day-90 controls, soil speciation or bioavailable fractions, plant-tissue concentrations and biomass-based mass balances.

Maize and tomato are food crops. Any biomass grown in contaminated soil should be excluded from human and animal food chains unless safety has been demonstrated. If future work confirms metal accumulation, harvested biomass will require controlled management to prevent re-entry of contaminants into the environment (Anggraini et al., 2025).

4.1 Study limitations

This study has five principal limitations: one field composite represented each community; the three analytical readings were not traceable to independent pots; no day-90 unplanted-control results were available; plant-tissue and biomass data were unavailable for mass-balance analysis; and the available method and QA/QC records did not permit verification of digestion volumes, arsenic measurement conditions, detection limits and analytical performance. These constraints limit the report to a descriptive comparison of initial and post-cultivation concentrations.

V. CONCLUSION

The five sampled soil composites differed in their initial Cr, Cd, Cu, Pb, Zn and As concentrations. After 90 days of maize or tomato cultivation, most reported means were lower than baseline, but Cu in maize-treated Ibodi soil and Zn in the Igila soils increased substantially. These are baseline-referenced concentration changes rather than control-adjusted remediation efficiencies. The available evidence does not establish phytoextraction or comparative phytoremediation performance. A confirmatory study with independent field and pot replication, time-matched controls, verified analytical QA/QC and a complete soil-plant mass balance is required before remediation claims can be made.

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Conflict of interest

The authors declare that they have no conflict of interest.

Data availability

The triplicate AAS readings used for the descriptive calculations are available from the corresponding author on reasonable request.

Author contributions

B. A. Esho: conceptualization, methodology, investigation, writing - original draft and supervision. W. A. Ibraheem: conceptualization, investigation and supervision. A. A. T. Taleat: data analysis, interpretation and writing - review and editing. A. A. Ewuola: supervision and validation. M. Animashahun: data analysis and validation. All authors are responsible for approving the final manuscript and author list.

Ethics statement

Not applicable. The reported study involved soil and plant materials and did not involve human participants or vertebrate animals.

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