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Assessment of Heavy Metals with Soil Physical and Chemical Properties in Ogbomoso Farm Settlement, Oyo State.

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ABSTRACT

Heavy metal contamination of agricultural soils threatens soil health and food safety, however, sitespecific data for Ogbomoso farm settlements is scarce. This study characterized the physical and chemical properties alongside the heavy metal status of soils in Ogbomoso agricultural settlement, Oyo State. Thirty topsoil samples (0–30 cm) were collected from six farm holdings. Physical and chemical properties were determined by standard methods, and heavy metals such as Cu, Pb, As, Zn, Cd, Cr and V were determined by atomic absorption spectrometry. Concentrations were compared with permissible limits and evaluated with contamination factor, geo-accumulation index (I_{geo}), pollution load index (PLI) and potential ecological risk, using a local geochemical background. The soils were sandy (mean sand is 78.6%), moderately acidic (mean pH 5.87) and dense (mean bulk density 1.73 g/cm^3), with low cation exchange capacity (7.11 cmol/kg) and available phosphorus (6.55 mg/kg). Mean metal concentrations (mg/kg) followed the order Cr (71.9) > V (49.5) > Pb (36.6) > Zn (35.5) > Cu (27.6) > As (8.2) > Cd (2.9). Mean Cu, Pb, Zn and Cr were below their permissible limits, but Cd exceeded its limit of 3 mg/kg in 9 of 30 samples, mainly in holdings H5 and H6, and Cr exceeded its limit in two samples, one reaching 390 mg/kg. Cd dominated the pollution indices (mean contamination factor 95; mean I_{geo} 5.7), and every sample had a PLI above 1 (mean 2.5). The soils combine low nutrient-retention capacity with localized but significant Cd contamination; review of agrochemical inputs (fertilizers, herbicides and pesticides), liming, organic amendment and routine monitoring are recommended.

Keywords: heavy metals, cadmium, pollution indices, soil properties, agricultural soils, Ogbomoso

INTRODUCTION

Heavy metals are persistent soil contaminants. When their concentrations exceed acceptable levels, they impair soil microbial communities and enzyme activity (Liu *et al.,* 2018), accumulate in crops and enter the food chain, where they cause toxic effects in humans (Tchounwou *et al.,* 2012). Heavy metal pollution of agricultural soil has therefore become a significant global concern for food production and food safety (Tchounwou *et al.,* 2012; Liu *et al.,* 2018).

The fate of metals in soil depends strongly on soil properties. Texture, organic matter, pH and cation exchange capacity (CEC) determine how strongly metals are adsorbed, how readily they move through the profile and how available they are to plants, while physical properties such as bulk density and porosity control water movement and root growth (Ewetola *et al.,* 2015). Assessment of soil quality should therefore consider physical and chemical properties together with metal concentrations (Zhang *et al.,* 2025).

In Nigeria, metal contamination of soils has been reported around cement factories (Olatunde *et al.,* 2020), active dumpsites (Eze *et al.,* 2020) and mining-affected villages (Yahaya *et al.,* 2021). Soils of Ogbomoso have been assessed for degradation status (Ewetola *et al.,* 2015), but information linking soil properties with heavy metal concentrations and pollution status in the farm settlements of the area is lacking. Without such baseline data, soil fertility, contamination risk and crop safety cannot be properly assessed. This study therefore aimed to determine the physical and chemical properties and the heavy metal concentrations of soils in an agricultural settlement in Ogbomoso, Oyo State.

METHODOLOGY

Study area

The study was conducted in Ogbomoso agricultural settlement in Ogbomoso South local government area, Oyo State, south-western Nigeria (latitudes 8°2′46.7″–8°2′58.5″ N; longitudes 4°8′00″– 4°9′15″ E; Fig. 1), at an elevation of about 347 m above sea level.

Rainfall is moderate to heavy between March and July and averages 1,247 mm per year. The area lies on the Precambrian Basement Complex, with quartzite and sparsely distributed pegmatite (Adagunodo *et al.*, 2018)

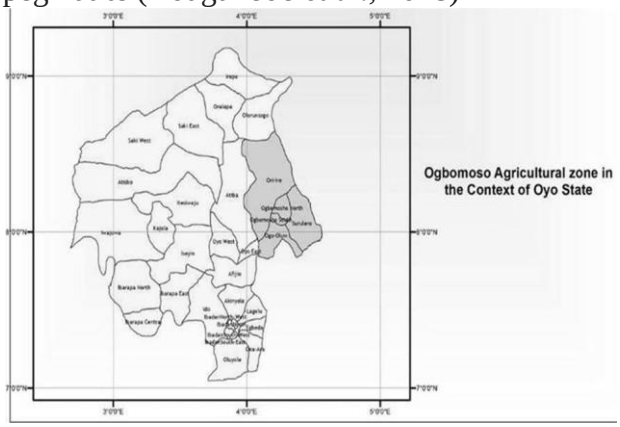


Fig. 1: Map of Oyo State showing Ogbomoso Farm Settlement (shaded) where the study was conducted.

Soil sampling and preparation Topsoil (0–30 cm) was collected with a stainlesssteel auger from six farm holdings (H1–H6), each of about 3 acres. Five sampling points per holding (A–E, about 100 m apart) gave 30 samples, coded H1A–H6E. The auger was rinsed with distilled water between samples to avoid cross-contamination. Samples were air-dried, crushed and passed through a 2 mm sieve; subsamples for chemical and metal analysis were further sieved through 0.5 mm.

Laboratory analyses

Bulk density was determined by the core method on oven-dried (105 °C, 24 h) cores of known volume (Blake and Hartge, 1986). Intact cores were taken at all 30 sampling points. The bulk density first recorded for core H5A (2.79 g/cm^3) exceeded the assumed particle density, which is physically impossible, and was replaced by the verified value of 1.79 g/cm^3. Total porosity (%) was calculated as [1 − (bulk density/particle density)] × 100, assuming a particle density of 2.65 g/cm^3. Gravimetric moisture content (GMC) was determined by oven-drying, and volumetric moisture content (VMC) was calculated as GMC × bulk density. Particle-size distribution was determined by the hydrometer method

(Bouyoucos, 1951).

Soil pH was measured in 1:1 soil:water and 1:1 soil:1 M KCl suspensions with a glass-electrode pH meter, and electrical conductivity (EC) in the soil–water extract with a conductivity meter. Organic carbon was determined by the Walkley–Black wet-oxidation method (Walkley and Black, 1934), total nitrogen by the microKjeldahl method (Bremner, 1960) and available phosphorus by Bray extraction and molybdenum-blue colorimetry (Bray and Kurtz, 1945). Exchangeable bases were extracted with 1 M ammonium acetate (pH 7.0); Ca and Mg were measured by atomic absorption spectrophotometry and Na and K by flame photometry. Exchangeable acidity was extracted with unbuffered 1 M KCl (1:10 m/v) and titrated with 0.05 M NaOH to pH 8.2, and exchangeable Al was determined in the same extract by precipitating Al with NaF and titrating the remaining acidity (Kabala and Jędrzejewski, 2024). CEC was calculated as the sum of the exchangeable bases and exchangeable acidity, and base saturation as the exchangeable bases expressed as a percentage of CEC.

Total Cu, Pb, As, Zn, Cd, Cr and V were extracted from 2 g of oven-dried soil with 10 ml of aqua regia (HCl and HNO_3, 3:1 v/v) heated at 90 °C for 20–25 min. The digest was filtered (Whatman No. 42) and made to volume with distilled water. Concentrations were measured in triplicate by atomic absorption spectrometry (AA-6300, Shimadzu, Japan), and mean values were used. ***Pollution assessment***

Contamination factor (C_f), geo-accumulation index (I_{geo}), pollution load index (PLI) and potential ecological risk (E) were calculated for each sample:

$$C_f = C/B_i \quad (1)$$

$$I_{geo} = \log_2[C/(1.5\,B)]_i \quad (2)$$

$$PLI = (C_{f1} \times C_{f2} \times \ldots \times C_{fn})^{1/n} \quad (3)$$

$$E = T_r \times C_f;\ RI = \Sigma E_r \quad (4)$$

where C is the measured concentration of metal i, B_i its background concentration, n the number of metals and T_r the toxic response factor. Background concentrations (mg/kg: Cu 9.14, Pb

28.37, As 2.40, Zn 31.17, Cd 0.03, Cr 81.20 and V 47.70) were taken from agricultural topsoil at Odo-Oba, south-western Nigeria, on the same Basement Complex geology (Adagunodo *et al.*, 2018). The constant 1.5 in Equation 2 accounts for natural fluctuations in background values (Müller, 1969). T values were Zn 1, Cr 2, V 2, Cu $_r$ 5, Pb 5, As 10 and Cd 30 (Håkanson, 1980; T = 2 $_r$ was adopted for V, as for Cr). I_{geo} was classed as ≤0 unpolluted; 0–1 unpolluted to moderately polluted; 1–2 moderately polluted; 2–3 moderately to strongly polluted; 3–4 strongly polluted; 4–5 strongly to extremely polluted; and >5 extremely polluted. C was classed as <1 low, $_f$ 1–3 moderate, 3–6 considerable and ≥6 very high contamination. A PLI >1 indicates deterioration of soil quality (Tomlinson *et al.*, 1980). E was $_r$ classed as <40 low, 40–80 moderate, 80–160 considerable, 160–

320 high and ≥320 very high risk, and RI as <150 low, 150–300 moderate, 300– 600 considerable and ≥600 very high risk. Measured concentrations were also compared with the FAO/WHO (2001) permissible limits for soils. No limit was available for V.

Statistical analysis

Descriptive statistics (mean, standard deviation, range and coefficient of variation, CV) were calculated. Normality was tested with the Shapiro–Wilk test; most metals were nonnormally distributed. Relationships among variables were examined by Pearson correlation, with Spearman rank correlation as a check. Analyses were done with SPSS version 20.

RESULTS AND DISCUSSION

Soil physical properties

Table 1 summarises the physical properties. Mean bulk density was 1.73 ± 0.25 g/cm³ (range 1.04–2.22), and 22 of the 30 cores exceeded 1.6 g/cm³. Mean total porosity was 34.8 ± 9.5%, and mean GMC and VMC were 4.9% and 8.2%, respectively. Holding means ranged from 1.51 (H6) to 1.92 g/cm³ (H4) for bulk density and from

27.7% (H4) to 43.1% (H6) for porosity, so that H4 was the densest holding and H6 the most porous. The differences among holdings were, however, not statistically significant (bulk density, $F_{5,24}$ = 1.64, P = 0.188; porosity, F = 1.64, P = 0.188; GMC, P = 0.517; VMC, P = 0.820), showing that variation within holdings was as large as variation between them. Table 1: Physical properties of the soils by farm holding (means; overall mean ± standard deviation).

Holding	n	Bulk density (g/cm³)	Total porosity (%)	GMC (%)	VMC (%)
H1	5	1.70	35.8	4.24	7.27
H2	5	1.79	32.4	5.09	9.15
H3	5	1.67	36.9	5.50	9.05
H4	5	1.92	27.7	4.27	7.96
H5	5	1.78	33.0	3.91	6.94
H6	5	1.51	43.1	6.54	9.08
Overall mean	30	1.73 ± 0.25	34.8 ± 9.5	4.9	8.2
Range	30	1.04–2.22	16.3–60.8	1.53–13.16	3.39–15.02
P (ANOVA)		0.188	0.188	0.517	0.820

GMC, gravimetric moisture content; VMC, volumetric moisture content; ANOVA, analysis of variance. Holding values, means of five samples. Overall mean, ± standard deviation. P, probability from one-way ANOVA among the six holdings (not significant at P > 0.05).

Sand averaged 78.6% (65.2–88.6%), silt 9.3% and clay 12.1% (1.4–25.4%; Table 2), so the soils are predominantly loamy sand to sandy loam with a few clay enriched pockets. These textures agree with the sandy to sandy-loam soils reported for degraded soils elsewhere in Ogbomoso (Ewetola *et al.*, 2015). The combination of coarse texture and high bulk density implies rapid drainage, low water-holding capacity and a risk of compaction-related root restriction, especially in H4.

Soil chemical properties

Soil reaction was moderately acidic on average (pH in water 5.87, range 4.90–7.00; Table 2); nine samples had a pH below 5.5, four of them below 5.0. The pH in KCl was lower than the pH in water in every sample (mean difference −0.74), indicating a net negative surface charge. EC was low (mean 31 µS/cm; maximum 110 µS/cm), so salinity is not a constraint. Organic carbon averaged 1.40% (0.56–2.74%) and total nitrogen 0.33% (0.14–0.66%); only two samples exceeded 2% organic carbon, whereas six had less than 1%. Available P was low (mean 6.55 mg/kg; 25 of 30 samples below 10 mg/kg). The organic carbon to nitrogen ratio was very narrow (mean 4.2; range 4.0–5.3), well below the 8–15 usually found in cultivated mineral soils. This suggests that total N may be overestimated, or that Walkley–Black organic carbon is underestimated because the method oxidizes only part of the organic carbon, so the total N values should be interpreted with caution.

Table 2: Chemical properties and texture of the soils (n = 30)

Parameter	Mean	SD	Min.	Max.	CV (%)
pH (H_2O)	5.87	0.64	4.90	7.00	10.9
pH (KCl)	5.13	0.62	4.20	6.30	12.2
Electrical conductivity (µS/cm)	31.0	19.0	10.0	110.0	61.3
Organic carbon (%)	1.40	0.51	0.56	2.74	36.2
Total nitrogen (%)	0.33	0.13	0.14	0.66	37.7
Available P (mg/kg)	6.55	3.52	1.88	18.42	53.8
Exchangeable Ca (cmol/kg)	3.33	3.23	0.74	10.90	96.8
Exchangeable Mg (cmol/kg)	0.97	0.68	0.32	2.50	70.9
Exchangeable Na (cmol/kg)	1.06	0.31	0.80	2.15	29.2
Exchangeable K (cmol/kg)	0.17	0.17	0.05	0.85	104.5
Exchangeable acidity (cmol/kg)	1.71	1.21	0.40	3.80	70.8
Exchangeable Al (cmol/kg)	0.68	0.94	0.00	2.60	138.7
CEC (cmol/kg)	7.11	4.02	2.94	16.02	56.5
Base saturation (%)	71.8	20.5	34.7	97.5	28.6
Sand (%)	78.6	6.7	65.2	88.6	8.6
Silt (%)	9.3	4.2	5.4	24.4	45.0

SD, standard deviation; CV, coefficient of variation; EC, electrical conductivity; CEC, cation exchange capacity. Base saturation, the sum of exchangeable bases expressed as a percentage of CEC. All values are based on the 30 samples (n = 30).

Exchangeable cations were dominated by Ca (3.33 cmol/kg), followed by Na (1.06), Mg (0.97) and K (0.17); K was the scarcest base, and Na exceeded K in every sample. CEC was low (mean 7.11 cmol/kg; 24 of 30 samples below 10 cmol/kg), and mean base saturation was 71.8%. The nine samples with pH below 5.5 (H1B, 5.2; H1D, 4.9; H2A, 4.9; H2C, 4.9; H2E, 5.2; H3A, 5.1; H4C, 5.1; H4D, 4.9; and H6D, 5.1) had the lowest CEC (5.35 cmol/kg) and base saturation (47.1%) and appreciable exchangeable Al (mean 1.91 cmol/kg, against 0.15 cmol/kg in the other 21 samples), a pattern that signals aluminium toxicity risk and poor availability of basic cations. Overall, the sandy texture and low organic matter explain the low CEC, so the soils can hold few nutrients and few metal cations and are vulnerable to leaching losses.

Heavy metal concentrations

Mean metal concentrations followed the order Cr (71.9 mg/kg) > V (49.5) > Pb (36.6) > Zn (35.5) > Cu (27.6) > As (8.2) > Cd (2.9) (Table 3). Variability was high: CV exceeded 40% for all metals except Zn (30%), and the distributions of Cr (CV 90%; maximum 390 mg/kg) and Cd (CV
73%) were right-skewed (skewness 4.30 and 1.31), a pattern typical of a few localised hotspots superimposed on a lower background.

Table 3: Total heavy metal concentrations (mg/kg) in the soils compared with permissible limits (n = 30)

Metal	Mean ± SD	Range	CV (%)	Permissible limit	Samples above limit
Cu	27.6 ± 16.9	6.3–65.8	61.3	100	0 / 30
Pb	36.6 ± 15.8	7.9–88.9	43.1	100	0 / 30
As	8.2 ± 4.1	2.6–20.1	49.6	20	1 / 30
Zn	35.5 ± 10.7	20.0–71.4	30.3	300	0 / 30
Cd	2.9 ± 2.1	0.5–8.0	72.8	3	9 / 30
Cr	71.9 ± 64.9	24.8–390.0	90.4	100	2 / 30
V	49.5 ± 22.0	25.8–134.0	44.4	–	–

SD, standard deviation; CV, coefficient of variation; –, not available (no permissible limit was available for V). Permissible limits are the FAO/WHO (2001) limits for agricultural soils.

Mean concentrations of Cu, Pb, Zn and Cr were below the permissible limits (Fig. 2), and no sample exceeded the limits for Cu, Pb or Zn. Arsenic exceeded its limit (20 mg/kg) marginally in one sample (20.1 mg/kg, H4E). Chromium exceeded its limit in two samples: soil 8 (H2C; 390 mg/kg, nearly four times the limit, together with the highest V, 134 mg/kg) and soil 9 (H2D; 130.5 mg/kg). Cadmium was the main exception. Its mean (2.9 mg/kg) was just below the limit of 3 mg/kg, but nine of the 30 samples (30%) exceeded the limit, with a maximum of 8.0 mg/kg, 2.7 times the limit (Fig. 3). The exceedances were concentrated in holding H5 (four of five samples; mean Cd 6.1 mg/kg) and H6 (three of five samples; mean 3.4 mg/kg), whereas H1 and H2 had no exceedance (mean Cd 1.5 mg/kg in each), which points to managementrelated rather than uniform enrichment. For comparison, agricultural soil amended with dumpsite compost contained 6.4 mg/kg Cd
(Elhalim *et al.*, 2025), higher than the settlement mean but similar to the H5 values.

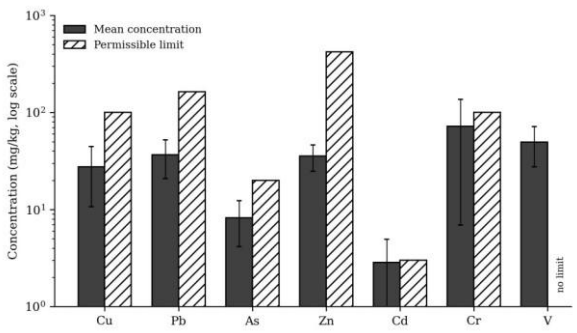


Fig. 2: Mean (± standard deviation) heavy metal concentrations in the soils compared with permissible limits (logarithmic scale). No permissible limit was available for V.

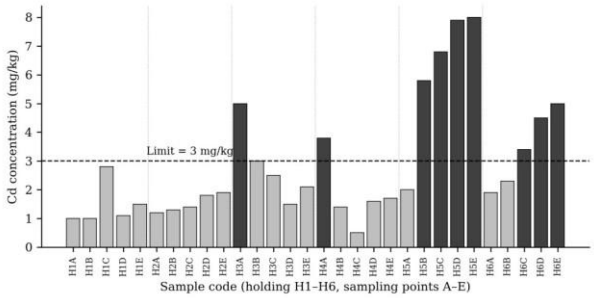


Fig. 3: Cadmium concentration in each soil sample relative to the permissible limit of 3 mg/kg (dark bars exceed the limit).

No permissible limit was available for V. Its maximum (134 mg/kg) coincided with the Cr hotspot at soil 8, and because high Cr and V values were also reported in agricultural topsoils at Odo-Oba on the same geology (Adagunodo *et al.*, 2018), a lithogenic contribution is likely.

Pollution status and ecological risk

Cd was by far the most enriched metal (mean C_f 95.2, maximum 266.7; Table 4). Cu (mean C_f 3.0) and As (3.4) were in the considerablecontamination class on average, with maxima of 7.2 and 8.4 (very high) at individual points, whereas Pb (1.3), Zn (1.1) and V (1.0) were in the moderate class, and the mean for Cr (0.88) was below background, although the Cr hotspot at soil 8 (H2C) reached 4.8. I_{geo} gave the same ranking. The mean I_{geo} of Cd was 5.7 (extremely polluted): 22 of the 30 samples had values above 5, seven between 4 and 5, and one between 3 and 4. Mean I_{geo} for Cu (0.71) and As (1.01) corresponded to unpolluted-to-moderately and moderately polluted soil, respectively, and was negative for Pb, Zn, Cr and V.

Table 4: Contamination factor (C_f), geoaccumulation index (I_{geo}) and potential ecological risk (E_r) of the soils (n = 30)

Metal	Background (mg/kg)	Mean C_f (maximum)	Mean I_{geo} (maximum)	Mean E_r
Cu	9.14	3.02 (7.20)	0.71 (2.26)	15.1
Pb	28.37	1.29 (3.13)	−0.36 (1.06)	6.5
As	2.40	3.42 (8.38)	1.01 (2.48)	34.2
Zn	31.17	1.14 (2.29)	−0.46 (0.61)	1.1
Cd	0.03	95.22 (266.67)	5.66 (7.47)	2,857
Cr	81.20	0.88 (4.80)	−1.03 (1.68)	1.8
V	47.70	1.04 (2.81)	−0.63 (0.91)	2.1

C_f contamination factor; I_{geo}, geo-accumulation index; E_r potential ecological risk factor; values in parentheses are maxima.

Background values are from Odo-Oba, south-western Nigeria (Adagunodo *et al.*, 2018). The pollution load index (PLI) ranged from 1.49 to 3.88 (mean 2.52) and the potential ecological risk index (RI) from 589 to 8,066 (mean 2,917); Cd contributed 98% of RI. All 30 samples had a PLI above 1 (mean 2.5; range 1.5–3.9), the highest values occurring at soil 8 (H2C; 3.9), soil 23 (H5C; 3.6) and soil 28 (H6C; 3.6), so soil quality in the settlement as a whole shows deterioration. Potential ecological risk was also dominated by Cd, which contributed 98% of the risk index (mean RI 2,917; 29 of 30 samples above 600).

Because C_f, I_{geo} and E_r for Cd depend heavily on its very low local background (0.03 mg/kg), the indices were also recalculated against a more conservative set of reference values (mg/kg: Cu 36, Pb 85, As 20, Zn 50, Cd 0.8 and Cr 100). Under this alternative baseline, Cd remained the only enriched metal (mean C_f 3.6, maximum 10.0; E_r = 107, considerable risk), all other metals had mean C_f below 1, and the PLI was lower (mean 0.71; 3 of 30 samples above 1). The conclusion that Cd is the priority contaminant is therefore robust to the choice of baseline, although its severity is not. Cd was likewise a major contributor to ecological risk in soils of mining-affected villages in Zamfara State (Yahaya *et al.*, 2021).

Relationships between soil properties and metals

Soil pH was not significantly correlated with any metal ($|r| \leq 0.24$, $P > 0.2$; Table 5). Three correlations were significant at $P < 0.05$: Cd with organic carbon ($r = 0.37$) and with clay ($r = -0.37$), and As with CEC ($r = 0.39$). With 28 tests, none would remain significant after correction for multiple comparisons, so they are indicative only. The positive Cd–organic carbon relationship, together with the negative Cd–clay relationship, suggests that Cd distribution in these coarse-textured soils reflects inputs at individual sampling points rather than retention by clay.

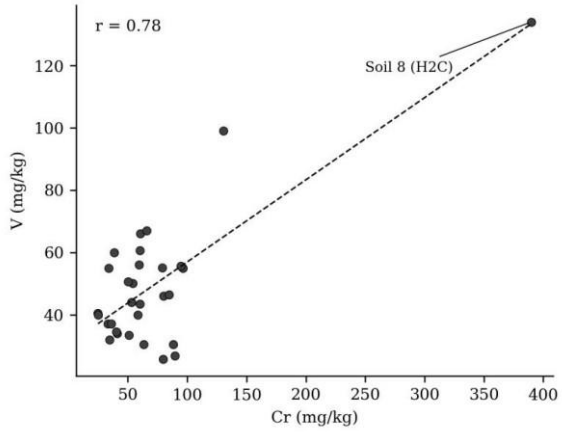
Table 5: Pearson correlation coefficients (r) between soil properties and heavy metal concentrations (n = 30)

Property	Cu	Pb	As	Zn	Cd	Cr	V

pH (H_2O)	0.03	−0.01	0.07	−0.24	0.24	−0.23	−0.22
Organic carbon	0.13	−0.09	0.09	0.07	0.37*	0.04	0.09
CEC	0.13	−0.13	0.39*	−0.12	0.28	0.00	−0.15
Clay	−0.01	0.23	−0.04	0.09	−0.37*	0.29	0.25

An asterisk marks a coefficient significant at $P < 0.05$. Chemical and metal data were paired by sample code.

Among the metals, Cr and V were strongly correlated ($r = 0.78$, $P < 0.001$; Fig. 4), which would normally point to a shared lithogenic source. However, the relationship was driven largely by the single hotspot at soil 8 ($r = 0.41$ without it;
Spearman $\rho = 0.28$, $P = 0.14$), so a common geogenic origin is plausible but not established. Cd was unrelated to Cr and V ($r = −0.24$ and $−0.13$), which supports a different source for Cd, and was correlated only with Cu ($r = 0.42$, $P = 0.02$).



5 **Fig. 4:** Relationship between Cr and V concentrations in the soils (n = 30). The dashed line is the least-squares regression line.

Because the soils are acidic in places, low in CEC and organic matter, and coarse textured, their capacity to immobilize Cd is limited, and Cd is more mobile and more available to plants under such conditions. The localized Cd exceedances in H5 and H6 therefore deserve priority attention. The source of Cd could not be identified: phosphate fertilizers and other agro-allied products such as herbicides and pesticides are plausible candidates, but agrochemical use history and Cd in crop tissue were not measured. The results are also based on a single sampling of 30 points and on total, not bioavailable, metal concentrations.

CONCLUSION

The soils of the agricultural settlement are sandy, dense and moderately acidic, with low CEC, available phosphorus and organic matter, so their capacity to retain nutrients and metals is limited. Mean concentrations of Cu, Pb, Zn and Cr were below permissible limits, but Cd exceeded its limit in 30% of the samples (mainly in holdings H5 and H6), Cr and As exceeded their limits in two samples and one sample, respectively, and Cd dominated the contamination and ecologicalrisk indices under both a local and a conservative baseline.

It is recommended that (i) agrochemical (fertilizer, herbicide and pesticide) sources and application rates, particularly in H5 and H6, be reviewed and the Cd content of inputs checked; (ii) acidic holdings be limed and organic amendments added to raise CEC, buffer pH and reduce metal mobility; (iii) the Cr hotspot at sample 8 be verified by resampling and Cr speciation; (iv) soil, irrigation water and crops, especially leafy vegetables, be monitored periodically for Cd; and (v) future work include crop tissue analysis, Cd speciation and source apportionment.

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