STUDY ON THE PARTICLE SIZE DISTRIBUTION CHARACTERISTICS OF SOIL AND EVALUATION OF TYPICAL HEAVY METAL CONTAMINATION IN COAL MINING AREAS OF THE LOESS PLATEAU IN CHINA

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Abstract. This study investigates soil reclamation and contamination at coal gangue dumps in China's Loess Plateau. Soil samples from dump sites and adjacent areas (50 m radius) revealed sandy textures (mean sand:75.5%, silt:14.2%, clay:10.39%). Compared to controls, sand content decreased by 5.6% at dumps and 3.3% at 50 m. Soils were acidic with elevated electrical conductivity (dump mean EC:332 μS/cm; 50 m:294 μS/cm) and low organic carbon. Critical heavy metal contamination was observed: average Cd and Zn concentrations exceeded both risk screening and control values (GB 15618-2018), while Pb surpassed screening values (1.06×) but not control thresholds. Heavy metal distribution followed Fe > Mn > Zn > Pb > Cd. Significant positive correlations (Cd-Pb-Zn) indicated homogeneous pollution sources. Findings demonstrate gangue-induced soil degradation and compound heavy metal contamination, necessitating targeted remediation strategies.
Keywords: *Loess Plateau, coal mining area, soil particle size distribution, soil heavy metals, soil reclamation*

Introduction

With the continuous advancement of social industrialization and technology, human beings have carried out unprecedented scales and intensities of mineral resource extraction, which provides important material support for human survival and sustainable development (Zhang et al., 2024) According to statistics, approximately 3 million hectares of land in China have been polluted due to mining activities, with 533,000 hectares of abandoned land resulting annually from mining (The Ministry of Natural Resources' Opinions on Exploring the Use of Market-based Approaches to Promote Mine Ecological Restoration, Policy Interpretation, 2019). The waste residues, waste rock piles, and tailing ponds formed during mineral resource extraction and smelting not only occupy large areas of land but also cause ecological destruction and environmental pollution in mining areas and surrounding regions (Wang et al., 2019). These are one of the primary sources of environmental heavy metal pollution (Fei et al., 2019). Heavy metals entered into the surrounding environment through atmospheric

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deposition, leachate from waste residues, and groundwater runoff, eventually leading to severe contamination of the surrounding soil and crops (Zhang et al., 2023). The fractal dimension of soil is a highly feasible indicator for quantitatively reflecting the shape of soil and soil nutrient content. Moreover, soil fractal theory has become an important tool for researching and quantitatively describing soil structural characteristics and has been widely applied in recent years.

Soil particle composition is the fundamental framework of the soil structure and one of its important physical properties (Mohammadi et al., 2019). It can influence soil structure (Zuo et al., 2020), soil water content (Antinoro et al., 2014), soil nutrient levels (Kome et al., 2019; Ruehlmann et al., 2020; Zhang et al., 2022), soil temperature (Wang et al., 2016), soil tillage performance, and soil erosion resistance (Sun et al., 2015), thereby affecting the migration and transformation of heavy metals in the soil. For example, studies on soil particle composition and carbon sequestration under vegetation restoration in the Mu Us Sandy Land show a significant correlation between soil particle composition and carbon sequestration (Wang et al., 2020). Additionally, heavy metals combine with fine soil particles in various ways, posing potential risks to human health and the environment. Research has shown that fine particles containing heavy metals can become suspended in the atmosphere due to wind, and enter the human body through respiratory and dermal exposure, leading to various diseases (Yamamoto et al., 2006). Furthermore, studies indicate that the adsorption capacity of soil particles for heavy metals varies with particle size. Fine particles, with their larger specific surface area, higher content of soil organic matter (SOM), and metal oxides, tend to contain higher concentrations of heavy metals (Liu et al., 2018; Li et al., 2021).

Soil heavy metals possess significant characteristics such as biological toxicity, concealment, persistence, long-term accumulation, and irreversibility, which can harm plants, animals, and human health through the food chain (Verma et al., 2019; Luo et al., 2020). Studies have shown that wild animals living in polluted areas accumulate large amounts of heavy metals in their bodies (Pogányová et al., 2022; Lima et al., 2023). Vegetables grown in polluted irrigation areas also have higher heavy metal concentrations than the limits recommended by the World Health Organization (Abbas et al., 2023). In coal mining areas, the average concentrations of Cd, Cr, and Ni in vegetable garden soils are significantly higher than background levels (Ahmad et al., 2020), and these heavy metals enter higher trophic levels through the food chain (Gavri et al., 2019). Moreover, heavy metals combine with proteins containing hydroxyl and amino groups and various enzymes in the human body, affecting normal physiological and biochemical functions. In some cases, they may even lose biological activity, leading to metabolic disorders of proteins and carbohydrates, as well as changes in DNA and neurotransmitters (Chen et al., 2016). Studies show that the accumulation of Cd and Pb in the human body can damage the nervous system, lead to kidney failure, respiratory diseases, cardiovascular diseases, and other health issues (Adimalla et al., 2020; Wang et al., 2024). Currently, heavy metals, particularly Cd and Pb, are the primary pollutants affecting soil environmental quality. Therefore, investigating and controlling the risks of Cd and Pb is an urgent issue. Furthermore, exploring the relationship between soil texture, fractal dimension, and heavy metals will provide a theoretical foundation for further developing an ecological restoration model for mining area land reclamation.

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Research methods and materials

Study area overview

The Shigetai Coal Mine is located approximately 55 kilometers northwest of Shanjiaocheng, Shenmu County, on the northeastern side of the Ulanmulun River, China. Administratively, it is under the jurisdiction of Daliuta Town, Shenmu County. To the west of the mining area lies the Ulanmulun River, to the south is the Halaogou coal mine, and to the north it borders the Batuta coal mine. The eastern boundary is defined by the Qigai Gully and the Shaanxi-Mongolia border, while the western boundary is also marked by the Ulanmulun River. The geographic coordinates of the coal mine are between 110°09′41″ to 110°18′35″ E and 39°17′02″ to 39°35′16″ N. The Shigetai Coal Mine spans approximately 8.4 km in length from north to south and about 8.5 km in width from east to west, covering an area of 65.25 km^2. The mining area is situated in the northern part of the Loess Plateau in northern Shaanxi and the southeastern edge of the Maowusu Desert, characterized by a semi-arid continental monsoon climate in the northern temperate zone. The geomorphological units can be divided into two categories: windblown sand is found in the northern part of the mining area, with dunes stretching in a continuous wave-like form, and the terrain is relatively flat, with undeveloped water systems. The area has an average annual temperature of 8.7°C, with an extreme maximum temperature of 41.2°C and an extreme minimum temperature of -29°C. The average annual precipitation is 405.6 mm.

The Shigetai Coal Mine is one of the main production mines of the Shenhua Dongbei Coal Group. It officially commenced production on January 15, 2006, with geological reserves of 893 million tons and recoverable reserves of 657 million tons. The coal quality is characterized by low ash, low sulfur, low phosphorus, and medium to high calorific value. It primarily consists of high-volatile long flame coal and non-caking coal, making it a high-quality coal suitable for power generation, chemical, and metallurgical industries. The mine is now closed.

Sample collection

This study investigated the concentrations of Cd, Pb, Zn, Fe, and Mn in the soils of the Shige Tai mining area and its surrounding environment (within 50 meters of the slag pile). To establish a more robust control baseline, the reference sampling area was strategically relocated to a non-contaminated zone situated 2–3 km from the waste repository. The samples were collected between July and August 2021. The mining area was divided into six equal strata, and soil samples were collected from the 0-15 cm and 15-30 cm soil layers using a stainless steel soil auger. Four composite samples were obtained for each stratum by collecting two composite samples from the top and bottom of the slag pile. A composite sample was prepared by randomly collecting three subsamples at each sampling point, and these subsamples were then mixed together. In total, 16 composite samples were collected from the slag piles. Additionally, 8 composite soil samples were collected from 500 meters away from the slag pile (*Figure 1*).

Detection methods

After naturally air-drying, soil samples were ground and sieved through a 2 mm polyethylene sieve to obtain uniform soil particles for further use. A portion of the prepared soil samples was sieved through a 0.5 mm sieve. Soil pH, EC, %OC, and soil

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texture were determined following the methods described by Prasetyo et al. (2010), Dawaki et al. (2013), and Maguire and Heckendorn (2011). The determination of soil Zn, Pb, and Cd concentrations followed the testing methods recommended by the "Soil Environmental Quality-Soil Pollution Risk Control Standards for Land Use (Trial)" (GB36600-2018). For soil Fe and Mn, HNO_3–H_2O_2–HCl digestion was performed, and the concentrations were measured using a Flame Atomic Absorption Spectrophotometer (AAS). During the analysis, national standard soil samples and blank control samples were used as quality controls, with spiked recovery rates maintained within the range of 90%–110% (*Table 1*).

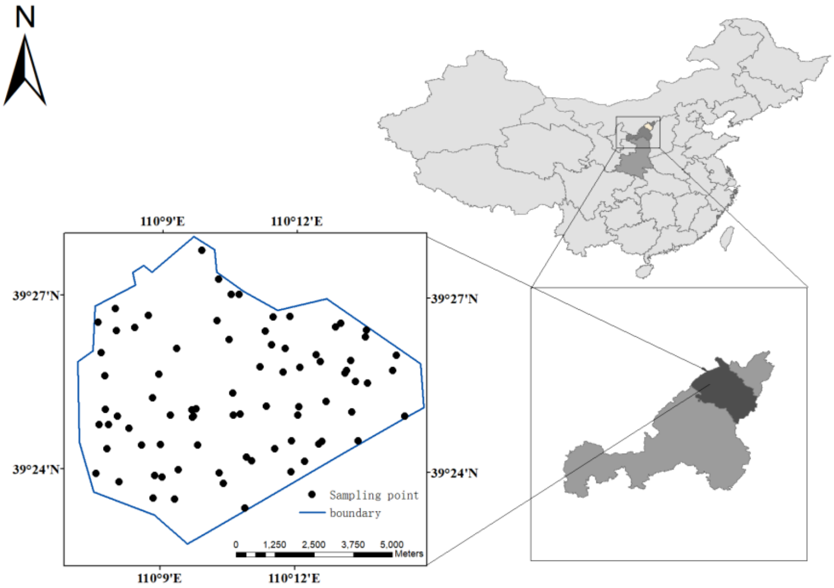

Figure 1. *Sampling point location map*

Table 1. *Soil heavy metal pollution evaluation standard limits (mg/kg)*

Elements	Risk screening value				Risk control value				Soil background values of Shaanxi Province	WHO limit values
	pH≤5.5	5.5<pH≤ 5.5	6.5<pH≤ 7.5	pH>7.5	pH≤5.5	5.5<pH≤ 5.5	6.5<pH≤ 7.5	pH>7.5		
Cd	0.3	0.3	0.3	0.6	0.5	2.0	3.0	4.0	0.76	3
Pb	70	90	120	170	400	500	700	1000	21.4	100
Zn	200	200	250	300	/	/	/	/	69.4	300
Fe	/	/	/	/	/	/	/	/	/	50000
Mn	/	/	/	/	/	/	/	/	/	2000

Data analysis

The concentrations of heavy metals are presented as the mean ± standard deviation (SD). One-way analysis of variance (ANOVA) and correlation analysis were performed to assess the statistical significance of the results and the relationships between the parameters.

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Results and discussion

Soil texture distribution

The soil texture distribution map (*Figure 2*) indicates that the soil in the study area is sandy. As shown in *Table 2*, the clay content in the soil at the tailings pile ranges from 1.3% to 31.4%, with an average value of 10.39%, while the silt content ranges from 1.4% to 37.8%, with an average of 14.2%, and the sand content ranges from 56.0% to 97.3%, with an average of 75.5%. At a distance of 50 m from the tailings pile, the clay content ranges from 4.6% to 20.2%, with an average value of 11.6%, the silt content ranges from 4.3% to 17.5%, with an average of 11.2%, and the sand content ranges from 64.7% to 85.3%, with an average of 77.3%. Compared to the control (CK) samples, the average sand content in the soils at the tailings pile and at a distance of 50 m decreased by 5.6% and 3.3%, respectively.

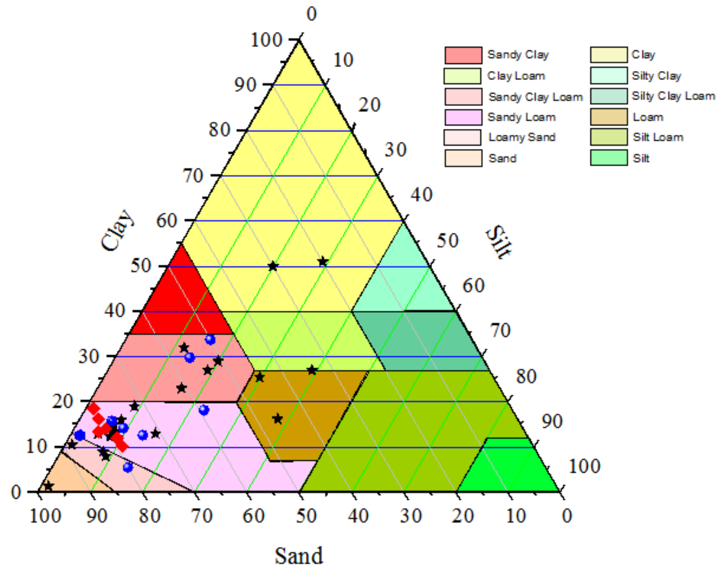

***Figure 2.** Soil texture distribution map*

The pH values of the soils in the study area range from 5.20 to 6.91 at the tailings pile and from 5.58 to 5.91 at a distance of 50 m, with average values of 6.17 and 5.77, respectively (*Table 2*). This indicates that the soils in the study area are generally acidic, likely due to the prior use of nitrogen-containing fertilizers in land conversion processes, which, through nitrification, produce nitric acid, leading to soil acidification (Okonkwo et al., 2021). The electrical conductivity (EC) of the soils in the study area ranges from 261 to 445 μS/cm at the tailings pile and from 145 to 399 μS/cm at a distance of 50m, with average values of 332 μS/cm and 294 μS/cm, respectively. The relatively high EC values may be attributed to increased metal content due to mining activities, which is leached into the soil, thus raising the ion concentration in the soil (Wang et al., 2024). The soil organic carbon (OC%) content in the tailings pile and the 50m distance zone ranges from 0.23% to 0.87% and from 0.25% to 0.81%, with average values of 0.44% and 0.46%, respectively. The organic carbon content is relatively low, which may be due to the loss of surface soil caused by mining activities in the region (Boateng et al., 2012).

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Table 2. *Physicochemical parameters of soil samples*

No.	pH	EC µS/cm	%OC	Sand% 50-2000µm	Silt% 2-50µm	Clay% <2µm
T1	5.77±0.03a	358±1.2c	0.23±0.04a	97.30±0.77e	1.35±0.01a	1.35±0.06a
T2	5.82±0.40a	301±0.02b	0.33±0.52b	88.20±0.20d	10.50±0.02de	1.30±0.11a
T3	6.06±1.10ab	261±0.07a	0.25±0.23a	78.40±0.01c	13.30±1.11ef	8.30±1.11d
T4	6.04±0.03ab	364±1.01c	0.67±1.20c	85.00±0.06d	10.50±1.02de	4.50±0.18b
T5	5.78±0.07a	299±0.01b	0.63±1.11c	57.60±0.05a	37.80±0.05i	4.60±0.26b
T6	5.92±0.22a	380±1.32c	0.38±0.12b	63.20±1.21b	5.40±1.12b	31.40±0.25j
T7	6.11±0.13ab	365±0.06c	0.87±0.03d	59.09±0.25a	18.18±0.22gh	22.73±0.22i
T8	6.91±0.05b	333±0.04c	0.53±0.11b	75.90±1.18c	15.90±0.36f	8.20±0.31d
T9	5.91±0.11a	266±0.17b	0.67±0.22c	56.00±2.20a	25.70±0.45h	18.30±0.45g
T10	6.82±0.09a	399±1.20c	0.51±0.22c	85.60±0.02cd	12.60±0.55e	1.80±0.66a
T11	6.86±1.17ab	445±0.03c	0.44±0.03c	73.60±0.12c	12.60±1.13e	13.80±0.71ef
T12	6.53±0.34ab	262±1.16a	0.33±0.03c	77.82±0.03c	15.73±0.17f	6.45±0.10c
T13	5.62±0.08a	269±0.01b	0.27±0.10a	76.50±0.25c	14.20±2.12ef	9.30±0.25de
T14	6.73±0.16ab	288±0.01b	0.24±0.01a	76.20±0.28c	7.80±0.10c	16.00±0.20f
T15	5.20±0.18a	362±0.04c	0.53±0.03c	79.00±0.32cd	9.00±0.25d	12.00±0.19ef
T16	6.65±0.15b	366±0.18c	0.45±0.02b	77.95±0.41c	15.77±1.25f	6.28±0.88c
Mean value	6.17±0.27ab	332±0.90c	0.46±0.02c	75.46±0.55c	14.15±0.89ef	6.28±0.20c
S1	5.91±0.03a	145±0.17c	1.25±0.02e	82.00±0.25d	8.00±1.21c	10.0±0.17de
S2	5.85±1.12ab	272±2.10c	1.09±1.18e	77.4±0.29cd	8.81±0.58c	13.8±0.57ef
S3	5.84±0.05ab	399±0.07c	0.48±0.01d	85.3±1.17d	4.32±1.11b	10.4±0.38de
S4	5.58±0.12a	266±0.01c	0.45±0.31c	77.9±1.02cd	17.51±1.21gh	4.6±0.06b
S5	5.71±0.22ab	315±0.08bc	0.27±0.09a	83.4±1.05d	11.21±0.22de	5.4±0.10bc
S6	5.62±0.06ab	350±0.70c	0.81±0.11d	64.7±2.02b	15.10±0.31f	20.2±0.18h
S7	5.72±0.07ab	336±1.04c	0.49±0.12c	75.9±0.05cd	8.22±0.52c	15.9±0.20ef
S8	5.91±0.21ab	267±0.38i	0.25±1.12a	71.4±0.05c	16.31±0.25g	12.3±0.30ef
Mean value	5.77±0.24ab	294±1.13b	0.44±0.15c	77.25±0.74cd	11.22±0.08de	11.6±0.30e
CK1	5.88±0.22ab	281±0.92bc	0.21±0.02a	78.81±0.21cd	12.01±0.12e	9.18±0.20de
CK2	5.62±0.23ab	326±0.08bc	0.22±0.81a	78.73±0.45cd	10.23±0.23de	11.04±0.06e
CK3	5.81±0.15ab	303±0.10c	0.24±0.22a	81.73±0.56d	13.37±1.15ef	4.90±0.19b
CK4	5.77±0.09ab	320±1.11bc	0.23±0.16a	80.28±0.22d	16.27±2.23g	3.45±0.06ab
CK5	5.74±0.17ab	315±0.15bc	0.22±0.05a	80.02±0.25d	18.56±0.18gh	1.42±0.50a
Mean value	5.76±0.22ab	309±0.05bc	0.22±0.26a	79.91±0.36cd	14.09±0.21ef	6.00±0.40c

Characteristics of soil heavy metal concentrations

As shown in *Figure 3*, the concentrations of heavy metals (Cd, Pb, Zn, Fe, Mn) near the slag heap ranged from 2.18 to 4.80 mg/kg, 70.7 to 223.8 mg/kg, 109.28 to 484.0 mg/kg, 7594.48 to 26970.67 mg/kg, and 1379.17 to 3124.67 mg/kg, respectively, with corresponding mean values of 3.01 mg/kg, 127.31 mg/kg, 275.15 mg/kg, 15793.22 mg/kg, and 2230.76 mg/kg. At a distance of 50 meters from the slag heap, the concentrations of Cd, Pb, Zn, Fe, Mn ranged from 2.18 to 3.68 mg/kg, 57.42 to 94.62 mg/kg, 132.87 to 445.83 mg/kg, 5919.25 to 27462.53 mg/kg, and 1321.70 to 2885.67 mg/kg, respectively, with mean values of 2.77 mg/kg, 74.63 mg/kg, 295.26 mg/kg, 11523.64 mg/kg, and 1956.55 mg/kg.

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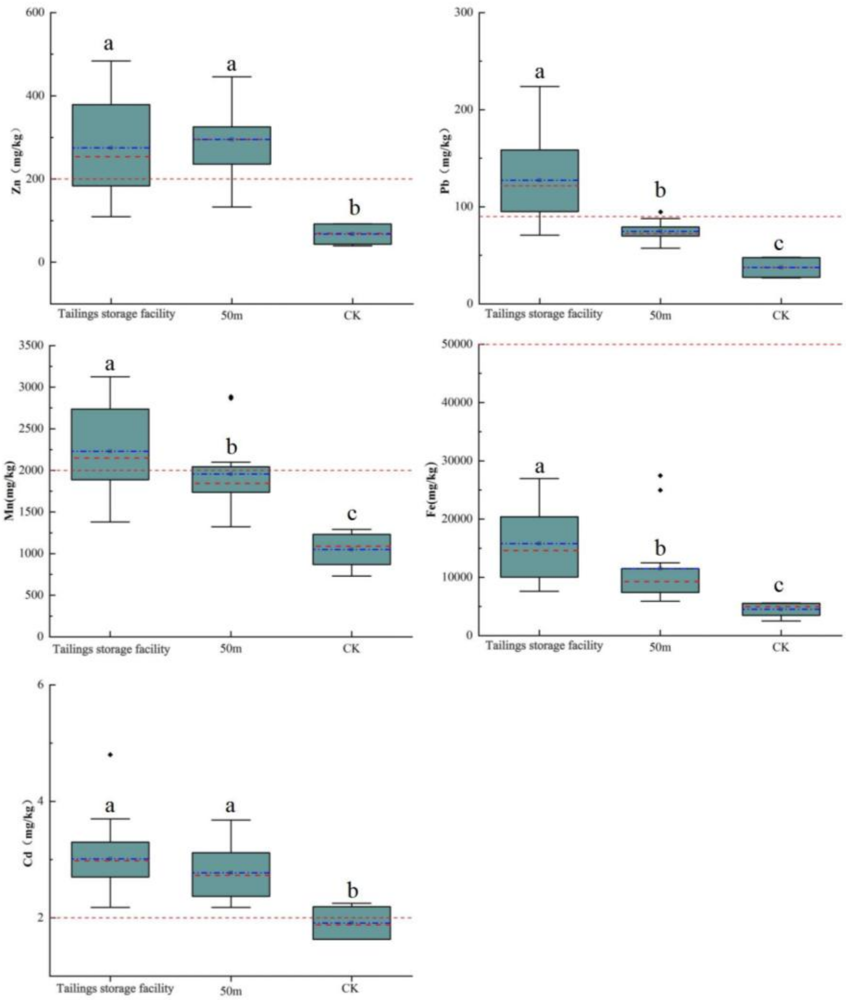

Figure 3. *Heavy metal content distribution*

The pH values of the soil samples from the slag heap ranged from 5.20 to 6.91, indicating a typical mildly acidic soil. According to the comparison analysis of the soil pollution risk screening and control values from GB 15618—2018 (pH ≤ 5.5 and 5.5 < pH ≤ 6.5), the mean concentration of Cd exceeded the soil pollution risk screening and control values in GB 15618—2018 (*Table 1*), with exceedance factors of 10.3 and 1.0, respectively. The mean concentration of Pb exceeded the risk screening value but did not exceed the risk control value, with an exceedance factor of 1.06. The mean concentration of Zn exceeded both the risk screening and control values, with exceedance factors of 1.4 and 1.1, respectively. At a distance of 50 meters from the slag heap, the mean concentration of Cd exceeded the risk screening and control values, with exceedance factors of 4.16 and 1.4, respectively. The mean concentration of Zn also exceeded both the risk screening and control values, with exceedance factors of 1.5 and 1.2, respectively.

According to the interpretation of the soil pollution risk control values for agricultural land in GB 15618—2018, when the concentration of Cd exceeds the risk control value, the soil pollution risk for agricultural land is high, which could lead to the non-compliance of edible agricultural products with quality safety standards. Such risks are difficult to mitigate through safety measures (Nuralykyzy et al., 2021). Studies have

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shown that acidic soils facilitate the migration of heavy metal Zn, which may be the primary reason for the elevated Zn concentrations in the study area. Pb concentrations greater than 1.0 mg/kg in soil typically indicate the presence of local pollution sources. The elevated Cd concentrations in the study area are attributed to the introduction of cadmium from the parent rock due to anthropogenic mining activities. According to reports by Chiroma et al. (2014), the concentrations of Pb and Mn in slag heaps greatly exceed the soil permissible limits set by the World Health Organization, while the concentrations of Cd, Fe, and Zn remain within the permissible limits. In contrast, the concentrations of heavy metals (Cd, Pb, Zn, Fe, Mn) in the surrounding environment of the slag heap are below the permissible limits, suggesting that they may not pose an immediate environmental threat. However, these metals may migrate within the soil and affect soil organisms and plants. The distribution pattern of heavy metal concentrations in the soil around the slag heap is in the decreasing order of Fe > Mn > Zn > Pb > Cd, which further confirms that mining activities have a negative impact on the local and surrounding ecosystems, and are a major source of environmental heavy metal pollution. These findings are consistent with the research results of Mani et al. (2022).

Soil treatments significantly altered physicochemical properties vs. controls. T7 and S1 exhibited organic carbon enrichment (>0.87%), while T6 and S6 showed clay accumulation (>20%), impacting hydraulic and nutrient retention. Elevated pH in T8/T16 (6.65–6.91) and EC in T11 (445 μS/cm) suggest potential alkalinity/salinity management needs. Texture shifts from sandy (T1: 97.3% sand) to clayey (T6: 31.4% clay) underscore site-specific intervention requirements.

Correlation analysis

The correlation analysis between the physicochemical parameters and heavy metal concentrations shows that pH is strongly correlated with EC, OC, and most heavy metals, except for Zn and Pb (*Figure 4*).

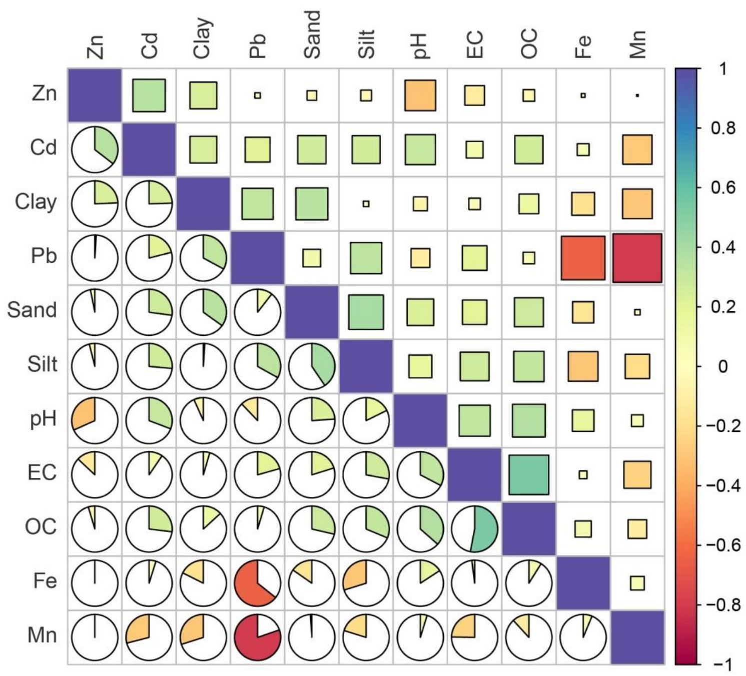

Figure 4. *Correlation analysis chart*

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Additionally, EC exhibits a close correlation with OC, Cd, and Pb. Furthermore, a strong relationship between OC and Cd, Pb, and Fe was observed (see *Figure 3*), suggesting that they may have a common source. The three elements, Cd, Pb, and Zn, show highly significant positive correlations with each other, which is consistent with the findings of Chakraborty et al. (2021) and Zhao et al. (2020) in lead-zinc mining areas. On one hand, this indicates that the three elements have similar geochemical behaviors (migration and enrichment), often occurring in association or symbiosis, with highly homologous sources (Liu et al., 2022). On the other hand, it highlights the close connection between the exceedance of Cd levels in the study area and lead-zinc smelting activities.

Conclusion

The soil texture in the study area is sandy, and the overall soil environment is acidic. Within the tailings heap and a 50-meter radius, the soil EC values are relatively high, while the organic carbon content is comparatively low. The average concentrations of soil heavy metals, Zn and Cd, exceed the soil pollution risk screening values and risk control values for Cd in GB 15618—2018, with exceedance factors of 10.3 and 1.0, respectively. The average concentration of Pb also exceeds the soil pollution risk screening value for Pb in GB 15618—2018, but does not surpass the risk control value. Correlation analysis shows that pH is strongly correlated with EC, OC, and most heavy metals, except for Zn and Pb. Additionally, EC is closely correlated with OC, Cd, and Pb. Furthermore, Cd, Pb, and Zn exhibit highly significant positive correlations with each other, indicating that these three heavy metals often occur in association or symbiosis, with highly homologous sources.

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REFERENCES

[1] Abbas, T. M., Wadaan, A. M., Ullah, H., Farooq, M., Fozia, F., Ahmad, I., Khan, M. F., Baabbad, A., Ullah, Z. (2023): Bioaccumulation and Mobility of Heavy Metals in the Soil-Plant System and Health Risk Assessment of Vegetables Irrigated by Wastewater. – Sustainability 15: 121452.

[2] Adimalla, N., Chen, J., Qian, H. (2020): Spatial characteristics of heavy metal contamination and potential human health risk assessment of urban soils: A case study from an urban region of South India. – Ecotoxicology and Environmental Safety 194: 110406.

[3] Ahmad, I., Ansari, T. M. (2020): An assessment of toxic heavy metals in soil and plants (*Allium cepa* and *Daucus carota*) by GFAAS. – International Journal of Environmental Analytical Chemistry 102: 1029-1048.

[4] Antinoro, C., Bagarello, V., Ferro, V., GIordano, G., Iovino, M. (2014): A simplified approach to estimate water retention for Sicilian soils by the Arya-Paris model. – Geoderma 213: 226-234.

[5] Boateng, E., Dowuona, G. N., Nude, P. M., Foli, G., Gyekye, P., Jafaru, H. M. (2012): Geochemical assessment of the impact of mine tailings reclamation on the quality of soils at AngloGold Concession Obuasi, Ghana. – Research Journal of Environmental and Earth Sciences 4: 466-474.
[6] Chakraborty, B., Bera, B., Roy, S., Adhikary, P. P., Sengupta, D., Shit, P. K. (2021): Assessment of non-carcinogenic health risk of heavy metal pollution: evidences from coal mining region of eastern India. – Environmental Science And Pollution Research 28: 47275-47293.
[7] Chen, Y. F., Liu, D. X., Ma, J. H., Jin, B. Y., Peng, J. B., He, X. L. (2021): Assessing the influence of immobilization remediation of heavy metal contaminated farmland on the physical properties of soil. – Science of The Total Environment 781: 146773.
[8] Chiroma, T. M., Ebewele, R. O., Hymore, F. K. (2014): Comparative assessment of heavy metal levels in soil, vegetables and urban grey waste water used for irrigation in Yola and Kano. – International Refereed Journal of Engineering and Science 3: 1-9.
[9] Dawaki, U. M., Dikko, A. U., Noma, S. S., Aliyu, U. (2013): Heavy metals and physicochemical properties of soils in Kano urban agricultural lands. – Nigerian Journal of Basic and Applied Science 21: 239-246.
[10] dos Santos Lima, G., Menegario, A. A., Suarez, C. A., Kamazuka, S. H., Gemeiner, H., Sánchez-Sarmiento, A. M., Ferioli, R. B., Barreto, A. S. (2023): Pelagic and estuarine birds as sentinels of metal(loid)s in the South Atlantic Ocean: Ecological niches as main factors acting on bioaccumulation. – Environmental Pollution 326: 121452.
[11] Fei, X., Chrisstakos, G., Xiao, R., Ren, Z. Q., Liu, Y., Lv, X. (2019): Improved heavy metal mapping and pollution source apportionment in Shang hai City soils using auxiliary information. – Science of the Total Environment 661: 168-177.
[12] Gavri, J., Despotovi, S., Prokic, M., Gavrilovi, B., Saii, Z. (2019): Do different diets affect oxidative stress biomarkers and metal bioaccumulation in two snake species? – Comparative Biochemistry and Physiology Part C Comparative Pharmacology 223: 26-34.
[13] Kome, G. K., Enang, R. K., Tabi, F. O., Yerima, B. P. K. (2019): Influence of clay minerals on some soil fertility attributes: A review. – Open Journal of Soil Science 9: 155-188.
[14] Li, Y., Padoan, E., Ajmone-Marsan, F. (2021): Soil particle size fraction and potentially toxic elements bioaccessibility: A review. – Ecotoxicology and Environmental Safety 209: 111806.
[15] Li, X. Y., Liang, H. B., Zeng, Y., Zheng, X. B., Ren, Z. L., Mai, B. X. (2023): Trophic transfer of heavy metals in a wetland food web from an abandoned e-waste recycling site in South China. – Science of the Total Environment 890: 164327.
[16] Liu, G., Wang, J., Liu, X., Liu, X., Li, X., Ren, Y., Wang, J., Dong, L. (2018): Partitioning and geochemical fractions of heavy metals from geogenic and anthropogenic sources in various soil particle size fractions. – Geoderma 312: 104-113.
[17] Liu, X. Y., Jing, M., Bai, Z. K. (2022): Heavy metal concentrations of soil, rock, and coal gangue in the geological profile of a large open-pit coal mine in China. – Sustainability 14: 1020.
[18] Luo, X., Ren, B., Hursthouse, A. S., Jiang, F., Deng, R. J. (2020): Potentially toxic elements (PTEs) in crops, soil, and water near Xiangtan manganese mine, China: potential risk to health in the foodchain. – Environ Geochem Health 42: 1965-1976.
[19] Maguire, R. O., Heckendorn, S. E. (2011): Laboratory Procedures: Virginia Tech Soil testing laboratory. – VCE Publications 452: 452-881.
[20] Mani, M., Altunisik, A., Gedik, K. (2022): Bioaccumulation of trace elements and health risk predictions in edible tissues of the marsh frog. – Biological Trace Element Research 200: 4493-4504.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_95919602

[21] Mohammadi, M., Shabanpour, M., Mohammadi, H. M., Davatgar, N. (2019): Characterizing Spatial Variability of Soil Textural Fractions and Fractal Parameters Derived from Particle Size Distributions. – Pedosphere 29(2): 224-234.

[22] Nuralykyzy, B., Wang, P., Deng, X. Q., An, S. S., Huang, Y. M. (2021): Heavy metal contents and assessment of soil contamination in different land-use types in the Qaidam Basin. – Sustainability 13: 12020.

[23] Okonkwo, S. O., Jacob, J. O., Iyaka, Y. A., Inobeme, A. (2021): Assessment of selected heavy metal concentrations in soils from a mining area in Minna, Niger state. – Environmental Monitoring and Assessment 193(3): 140.

[24] Pogányová, A., Haas, M., Solár, J. (2022): Lead content in soil，plants，rodents，and amphibians in the vicinity of a heating plant's ash waste. – Environmental Monitoring and Assessment 194: 21.

[25] Prasetyo, B., DewiKrisnayanti, B., Utomo, W. H., Anderson, C. W. N. (2010): Rehabilitation of artisanal mining gold land in West Lombok, Indonesia: Arbuscular Mycorrhiza Status of Tailings and Surrounding Soils. – Journal of Agricultural Science 2: 202-209.

[26] Ruehlmann, J. (2020): Soil particle density as affected by soil texture and soil organic matter: 1. Partitioning of SOM in conceptional fractions and derivation of a variable SOC to SOM conversion factor. – Geoderma 375: 114542.

[27] Sun, M., Huang, Y. X., Sun, N., Xu, M. G., Wang, B. R., Zhang, X. B. (2015): Advance in Soil Pore and its Influencing Factors. – Chinese Journal of Soil Science 46(1): 233-238. (in Chinese).

[28] The Ministry of Natural Resources' Opinions on Exploring the Use of Market-based Approaches to Promote Mine Ecological Restoration (2019). – Policy Interpretation. https://www.gov.cn/zhengce/2019-12/25/content_5463897.htm.

[29] Verma, A., Kumar, R., Yadav, S. (2019): Distribution, pollution levels, toxicity, and health risk assessment of metals in surface dust from Bhiwadi industrial area in North India. – Human and Ecological Risk Assessment: An International Journal 26: 2091-2111.

[30] Wang, J. J., Huang, Y. F., Long, H. Y. (2016): Water and salt movement in different soil textures under various negative irrigating pressures. – Journal of Integrative Agriculture 15: 1874-1882.

[31] Wang, N., Han, J. C., Wei, Y., Li, G., Sun, Y. Y. (2019): Potential ecological risk and health risk assessment of heavy metals and metalloid in soil around Xunyang mining areas. – Sustainability 11: 4828.

[32] Wang, L. M., Zhang, Q., Bai, L. H., et al. (2020): Effect of three vegetation type on soil particle composition and carbon fixation in the Mu Us sand land. – Research of Soil and Water Conservation 27: 88-94. (in Chinese).

[33] Wang, N., Liu, Z., Sun, Y. Y., Lu, N., Luo, Y. H. (2024): Analysis of soil fertility and toxic metal characteristics in open-pit mining areas in northern Shaanxi. – Scientific Reports 14: 2273.

[34] Yamamoto, N., Takahashi, Y., Yoshinaga, J., Tanaka, A., Shibata, Y. (2006): Size distributions of soil particles adhered to children' s hand. – Archives of Environmental Contamination and Toxicology 51(2): 157-163.

[35] Zhang, J. H., Li, G. D., Ding, S. Y., Tian, H. W., Ren, X. J., Liu, M., Zheng, Y. P. (2022): Distribution characteristics of soil particles and their relationships with soil organic carbon components in the alluvial/sedimentary zone in the lower reaches of the Yellow River. – Frontiers in Environmental Science 10: 849565.

[36] Zhang, Y., Song, B., Zhou, Z. (2023): Pollution assessment and source apportionment of heavy metals in soil from lead– zinc mining areas of south China. – Journal of Environmental Chemical Engineering 11: 109320.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/2305_95919602

[37] Zhang, S., Cao, Y., Gao, C. F., Meng, T., Li, Q. (2024): Pollution Characteristics, Risk Assessment, and Source Analysis of Heavy Metals in Soil from a Typical Abandoned Antimony Smelting Factory. – Environmental Science 45: 6171-6184.
[38] Zhao, K., Zhang, L. Y., Dong, J. Q., Wu, J. S., Ye, Z. Q., Zhao, W. M., Ding, L. Z., Fu, W. J. (2020): Risk assessment, spatial patterns and source apportionment of soil heavy metals in a typical Chinese hickory plantation region of southeastern China. – Geoderma 360: 114011.
[39] Zuo, F. L., Li, X. Y., Yang, X. F., Wang, Y., Ma, Y. J., Huang, Y. H., Wei, C. F. (2020): Soil particle-size distribution and aggregate stability of new reconstructed purple soil affected by soil erosion in overland flow. – Journal of Soils and Sediments 20: 272-283.