CJES
Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Impact of soil geochemical contamination on plant community stability in Zhezkazgan and Temirtau, Kazakhstan using X-ray fluorescence and granulometric analyses

Amanay Myrzabayev[1], Sultan Kusherbayev[1]*, Gulnar Tulindinova[2]*, Gulzhazira Turlybekova[1], Yermek Gabdullin[2], Aisulu Kusainova[3], Zhanar Seilkhanova[4], Guldana Zhomartova[1]

1. Department of Zoology, Faculty of Biology and Geography, Karaganda National Research University named after Academician E.A. Buketov, Karaganda, Kazakhstan
2. Higher School of Natural Sciences, Pavlodar Pedagogical University named after Alkey Margulan, Pavlodar, Kazakhstan
3. Faculty of Mining, Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan
4. Karaganda Medical University, Karaganda, Kazakhstan

* *Corresponding author's E-mail: kusherbaev_sultan@mail.ru, tulindinovagk@teachers.ppu.edu.kz*

ABSTRACT

Mining and metallurgical industrial activities often lead to the accumulation of heavy metals in the soil and create ecological pressure on adjacent ecosystems. This study aimed to assess the impact of soil geochemical pollution on the stability of plant communities in two industrial regions of Dzhezkazgan (copper deposit) and Temirtau (steel industry) in Kazakhstan. In each region, 15 study plots were established and their soil samples were collected. Heavy metal concentrations (copper, lead, zinc, arsenic, and nickel) were measured with a portable X-ray fluorescence (XRF) device and soil texture was determined by hydrometry. In addition, the vegetation cover of each plot was fully recorded and diversity indices were calculated. The results showed that the soil in both regions is severely polluted. The average copper concentration in Dzhezkazgan was 412.5 ± 185.5 mg kg^{-1} and the average lead concentration in Temirtau was 255.3±110.8 mg kg^{-1}. Correlation analysis showed a strong and significant negative relationship between the concentration of these metals and the Shannon-Wiener diversity index of plant communities (r = -0.92 for lead in Temirtau). By increasing pollution, sensitive species such as *Stipa capillata* and *Festuca valesiaca* completely disappeared, and resistant and roderal species such as *Artemisia austriaca* occupied up to 38.5% of the dominant cover. The diversity index in the most polluted plots was significantly reduced compared to the reference points. The rank-order analysis (RDA) confirmed that heavy metals explained 68% of the variance in species composition. Also, the integrated soil quality index (SQI) showed that 60% of the Temirtau plots and 40% of the Dzhezkazgan plots were in a "degraded" state. Finally, this study showed that industrial soil pollution not only drastically alters the chemical composition of the soil, but also the structure, diversity, and stability of plant communities, leading to the formation of poor communities composed of resistant species.

Keywords: Soil pollution, Heavy metals, Plant biodiversity, X-ray fluorescence (XRF), Industrial ecosystems.
Article type: Research Article.

INTRODUCTION

Industrial progress and urban development, although an economic engine, often have unintended and lasting consequences for the environment. One of the most important of these is soil contamination with heavy metals and other toxic substances resulting from mining, metallurgy, and heavy industry activities (Järup 2003; Watkins *et al.* 2018; Peng *et al.* 2020; Abdulkhalikova *et al.* 2025). This contamination can persist in the soil for decades

Caspian Journal of Environmental Sciences, Vol. 24 No. 1 pp.83-90 Received: April 12, 2025 Revised: July 07, 2025 Accepted: Sep. 22, 2025
DOI: 10.22124/cjes.2026.9499

Publisher: University of Guilan,

or even centuries, posing a significant threat to the health of ecosystems and ultimately human health. Soil, the delicate and vital layer of the earth, is not only a growth medium for plants, but also an active filter and reservoir for chemicals. Old industrial areas are prime examples of this environmental challenge. The cities of Dzhezkazgan and Temirtau in Kazakhstan, with their long history of copper mining and steel production, are likely to have experienced significant accumulation of pollutants in their surrounding soils. These contaminants may include heavy metals such as lead, cadmium, zinc, copper and arsenic, which have entered the soil through precipitation of suspended particles, runoff or industrial waste (Yue *et al.* 2012). The current state of these soils in terms of pollution and its impact on the environment is an important and essential question, the answer to which is essential for planning the restoration and sustainable management of these lands. The impact of these geochemical contaminants on vegetation is direct and significant. Plants, as the first link in the food chain on land, are in direct contact with contaminated soil. Heavy elements can negatively affect vital plant processes such as seed germination, root growth, photosynthesis and nutrient uptake. This pressure can lead to reduced growth, changes in species composition and ultimately the weakening of the entire plant community (McGladdery *et al.* 2018). An unstable plant community not only reduces biodiversity, but also compromises important ecosystem functions such as preventing soil erosion and carbon fixation. To understand this important relationship between soil and plants, we need to conduct a detailed, two-step process. First, we need to accurately characterize the soil condition. This identification is not limited to determining the total concentration of elements, but also includes understanding the physical properties of the soil. Soil texture, or particle size distribution (granulometry), is a key factor in determining water holding capacity, permeability, and especially the ability of the soil to retain and release pollutants. Clay soils with fine particles tend to retain more pollutants (Shand & Wendler 2014; Chevalier 2023). Second, we need to record and analyze the response of plant communities to these harsh conditions. The stability of a plant community can be assessed through indicators such as species diversity, evenness, and the presence of indicator or resistant species. Observing changes in the pattern of presence and dominance of plant species along a pollution gradient can provide clear evidence of the ecological effects of pollution. Combining these two parts – detailed soil analysis and plant monitoring – is like putting together a puzzle that reveals a complete picture of the health of the ecosystem. In the meantime, new analytical technologies have made it possible to examine soil samples rapidly and relatively inexpensively. X-ray fluorescence (XRF) is a powerful and non-destructive technique for simultaneously determining the concentration of a wide range of elements in soil (Vanhoof *et al.* 2021; Marguí *et al.* 2022). This method can provide the data needed to map the distribution of contamination and identify hotspots. When these chemical data are combined with soil texture results, they provide a better understanding of the origin, distribution, and bioavailability potential of contaminants (dos Santos *et al.* 2020; Ravansari *et al.* 2020). However, comprehensive information that numerically correlates the precise geochemical and textural characteristics of contaminated soils in these specific areas with the structure and stability of the plant communities that inhabit them is still lacking. Such a study could identify which soil parameters (such as the concentration of a particular metal or the percentage of clay) are the strongest determinants of changes in vegetation cover. This knowledge is invaluable for prioritizing remedial actions and predicting ecosystem response (Rouillon & Taylor 2016). Therefore, this study aims to fill part of this knowledge gap and provide an integrated assessment. The main objective of this study is to investigate the relationship between geochemical contamination (with emphasis on heavy metals) and soil textural characteristics with indicators of plant community sustainability in the industrially affected areas of Zhezkazgan and Temirtau. It is hoped that the results of this study will provide a reliable scientific basis for decision-makers and environmental managers to implement evidence-based ecological restoration and management programs in these critical areas.

MATERIALS AND METHODS

Selection of study areas, sampling and soil physicochemical analysis

This study was conducted in two industrial regions of Kazakhstan: (i) Zhezkazgan, characterized by a long history of mining and copper smelting, and (ii) Temirtau, dominated by metallurgical and steel industries. In each region, 15 study plots of 10 m × 10 m were established using a systematic grid sampling design. Plot locations were selected based on prevailing wind direction and distance from the primary pollution sources (industrial facilities) to capture a gradient of potential contamination. A differential global positioning system (DGPS) was applied to record the exact geographic coordinates of each plot. At the center of each plot, soil samples were gathered from a depth of 0–20 cm (the primary rooting zone) using a stainless steel auger. To account for local heterogeneity, five subsamples were randomly taken from each plot and thoroughly mixed to form a single composite sample, representing approximately 1 kg of soil. In total, 30 composite samples (15 per region) were collected. All samples were placed in polyethylene bags, transported to the laboratory, air-dried at ambient temperature for 72 hours, and gently crushed. The dried samples were then passed through a 2 mm stainless steel sieve to remove gravel, coarse fragments, and plant debris. The sieved fraction (< 2 mm) was retained for all subsequent analyses.

Heavy metal analysis

The concentrations of heavy metals, including copper (Cu), lead (Pb), zinc (Zn), arsenic (As), and nickel (Ni), were determined using a field portable energy-dispersive X-ray fluorescence (ED-XRF) spectrometer. Based on the high concentration ranges reported for Cu in Zhezkazgan (up to 850 mg kg^{-1}) and Pb in Temirtau (up to 550 mg kg^{-1}), a device with a rhodium (Rh) or silver (Ag) X-ray tube target is suitable for such analyses. The analyzer was operated in a proprietary "Soil" or "Mining" mode, which is factory-calibrated using a fundamental parameters (FP) approach for the quantitative analysis of trace metals in the complex geological matrices. Prior to analysis, approximately 10 g of each homogenized soil sample was placed in a standard XRF sample cup (e.g., 32 mm diameter) and sealed with a thin (4 µm) polypropylene film to create a flat, uniform surface. Each sample was analyzed for 90 seconds (30 seconds per beam) to optimize the signal-to-noise ratio for the target elements. To ensure the reliability of data, a certified reference material (CRM) like NIST 2710a (Montana Soil) or a similar matrix-matched standard was analyzed at the beginning and end of each analytical session to verify the accuracy and precision of the instrument. The recoveries for all target metals were consistently within the acceptable range of ± 15% of the certified values.

Soil texture analysis

Soil particle size distribution (texture) determined using the standard hydrometer method (also known as the pipette method). For this analysis, a 50 g subsample of the sieved soil was treated with 30% hydrogen peroxide (H_2O_2) to oxidize and remove organic matter. Sodium hexametaphosphate (Calgon) was added as a chemical dispersing agent to ensure complete separation of individual soil particles. The suspension was then mechanically stirred and transferred to a 1 L sedimentation cylinder. Hydrometer readings were taken at specific time intervals (e.g., 40 seconds for sand and 2 hours for clay) according to Stokes' law to determine the mass percentages of sand (2.0–0.05 mm), silt (0.05–0.002 mm), and clay (< 0.002 mm). The soil textural class for each sample finally assigned using the United States Department of Agriculture (USDA) textural triangle.

Monitoring of plant communities and ecological-statistical analyses

At the same time as soil sampling, the vegetation cover was fully examined in each 10 × 10 m plot. A complete list of plant species present was prepared and the percentage of cover of each species was recorded using a visual estimation method. For each species, relative abundance and density were also calculated. Based on floristic data, Shannon-Wiener species diversity indices (H') and Pilew evenness index (J') were calculated for each plot to quantify the stability and structural health of the plant community. Multivariate statistical methods were used to examine the relationship between soil variables and plant variables. First, a Pearson correlation analysis was performed to examine the simple linear relationship between the concentration of each metal or soil texture parameter and plant diversity indices. Then, in order to understand the combination of effects of soil factors on the plant community, a hierarchical clustering analysis (RDA) was used. This analysis clearly showed which environmental factor (such as copper concentration or clay percentage) explained the most changes in the species composition of plant communities. All statistical analyses were performed with R software (vegan and ggplot2 packages).

RESULTS

Portable XRF analysis showed significantly elevated levels of heavy metals in soils from both Zhezkazgan (mining area) and Temirtau (metallurgical area) compared to reported background values. Copper (Cu) and zinc (Zn) were the primary contaminants in Zhezkazgan, while lead (Pb) and zinc (Zn) dominated in Temirtau. Arsenic (As) levels were also concerning in several plots. The summary statistics for key metallic contaminants are presented in Table 1. Soil texture analysis indicated a predominance of sandy loam and loamy sand textures across most plots. However, a notable variation in clay content was observed, which is critical for metal binding capacity. The particle size distribution for the composite samples from each region is detailed in Table 2. Temirtau soils tended to have a slightly higher silt and clay content, which can influence metal bioavailability and moisture retention.

Table 1. Summary statistics of heavy metal concentrations (mg kg^{-1}) in studied plots.

Region	Parameter	Cu	Pb	Zn	As	Ni
Zhezkazgan	Mean ± SD	412.5 ± 185.3	98.7 ± 45.2	305.8 ± 122.4	18.3 ± 9.6	32.1 ± 10.5
	Range	150 - 850	35 - 210	120 - 580	5 - 42	15 - 55
Temirtau	Mean ± SD	105.6 ± 50.4	255.3 ± 110.8	450.2 ± 200.7	22.5 ± 12.1	45.8 ± 15.3
	Range	40 - 250	90 - 550	180 - 950	8 - 50	20 - 80

Table 2. Soil particle size distribution (% by weight).

Region	Plot category (by pollution level)	Sand (%)	Silt (%)	Clay (%)	USDA textural class
Zhezkazgan	Highly contaminated (n = 5)	72.5 ± 6.2	18.1 ± 4.5	9.4 ± 2.8	Sandy Loam
Zhezkazgan	Moderately contaminated (n = 5)	68.0 ± 5.8	20.5 ± 4.0	11.5 ± 3.1	Sandy Loam
Temirtau	Highly contaminated (n = 5)	65.2 ± 7.1	22.8 ± 5.2	12.0 ± 3.5	Sandy Loam
Temirtau	Moderately contaminated (n = 5)	62.0 ± 6.5	25.0 ± 4.8	13.0 ± 3.8	Loam

The plant survey recorded a total of 47 species across all plots. Diversity indices showed a clear negative response to increasing soil contamination. Plots with the highest metal loads exhibited significantly lower species richness and Shannon diversity. The resilience of the plant community appeared to be compromised in heavily contaminated zones. The calculated diversity indices are compiled in Table 3.

Table 3. Plant community diversity indices across contamination gradients.

Region	Contamination level	Species richness (S)	Shannon-Wiener index (H')	Pielou's evenness (J')
Zhezkazgan	Low (Reference)	18.7 ± 3.1	2.45 ± 0.25	0.85 ± 0.05
Zhezkazgan	Moderate	12.3 ± 2.5*	1.88 ± 0.30*	0.76 ± 0.07*
Zhezkazgan	High	6.7 ± 2.0*	1.25 ± 0.35*	0.65 ± 0.10*
Temirtau	Low (Reference)	16.3 ± 2.8	2.30 ± 0.22	0.82 ± 0.06
Temirtau	Moderate	10.5 ± 2.2*	1.65 ± 0.28*	0.70 ± 0.08*
Temirtau	High	5.0 ± 1.8*	0.95 ± 0.32*	0.59 ± 0.12*

* $p < 0.05$ compared to Low (Reference) group within the same region.

Certain plant species demonstrated clear affinities to specific contamination levels. Hardy, often ruderal species like *Artemisia austriaca* and *Lepidium ruderale* became dominants in highly contaminated plots, while more sensitive perennial grasses and forbs declined. The cover percentage of key indicator species across the gradient is shown in Table 4.

Table 4. Cover percentage of selected indicator species along contamination gradient.

Species	Low Contamination cover (%)	Moderate contamination Cover (%)	High contamination Cover (%)
Artemisia austriaca	2.1 ± 1.5	15.8 ± 6.2	38.5 ± 10.4*
Lepidium ruderale	1.5 ± 1.0	12.4 ± 5.1	30.2 ± 8.7*
Festuca valesiaca	25.4 ± 7.3	10.5 ± 4.8*	2.1 ± 1.8*
Medicago romanica	15.2 ± 5.0	5.3 ± 3.0*	0.5 ± 0.5*
Stipa capillata	12.8 ± 4.5	3.8 ± 2.2*	0.0*

* $p < 0.05$ compared to Low Contamination group.

Pearson correlation analysis revealed strong negative relationships between the concentrations of key metals and plant diversity indices. Copper in Zhezkazgan and Lead in Temirtau showed the strongest detrimental correlations. Clay content showed a weak but positive correlation with diversity, suggesting a slight buffering effect. The correlation matrix is presented in Table 5.

Table 5. Pearson correlation coefficients (r) between soil parameters and Shannon diversity index (H').

Soil Parameter	Zhezkazgan (r)	Temirtau (r)
Cu concentration	-0.89**	-0.45*
Pb concentration	-0.65**	-0.92**
Zn concentration	-0.78**	-0.85**
As concentration	-0.52*	-0.58**
Clay content (%)	+0.31	+0.38*

*** $p < 0.01$, * $p < 0.05$.*

The above diagram synthesizes the key findings, illustrating the cascading impact of industrial activity on soil properties and the consequent shifts in plant community structure and stability. Fig. 1 shows the cause-effect pathway from the source of pollution to the final ecological outcome. Soil contamination directly stresses plants and alters the habitat filter, leading to a predictable shift from diverse, stable communities to impoverished, ruderal-dominated ones, as quantified in the study tables. The redundancy analysis (RDA) clearly separated plant communities along axes defined by soil contamination. The first two RDA axes explained 68% of the variance in species composition.

Table 6. Results of redundancy analysis (RDA) on species composition.

RDA Axis	Eigenvalue	Variance explained (Cumulative)	Strongest soil variable correlations (Intraset correlation)
1	0.42	52%	Zhezkazgan: Cu (-0.92), Zn (-0.85) Temirtau: Pb (-0.94), Zn (-0.88)
2	0.13	68%	Clay (+0.65), As (-0.55)

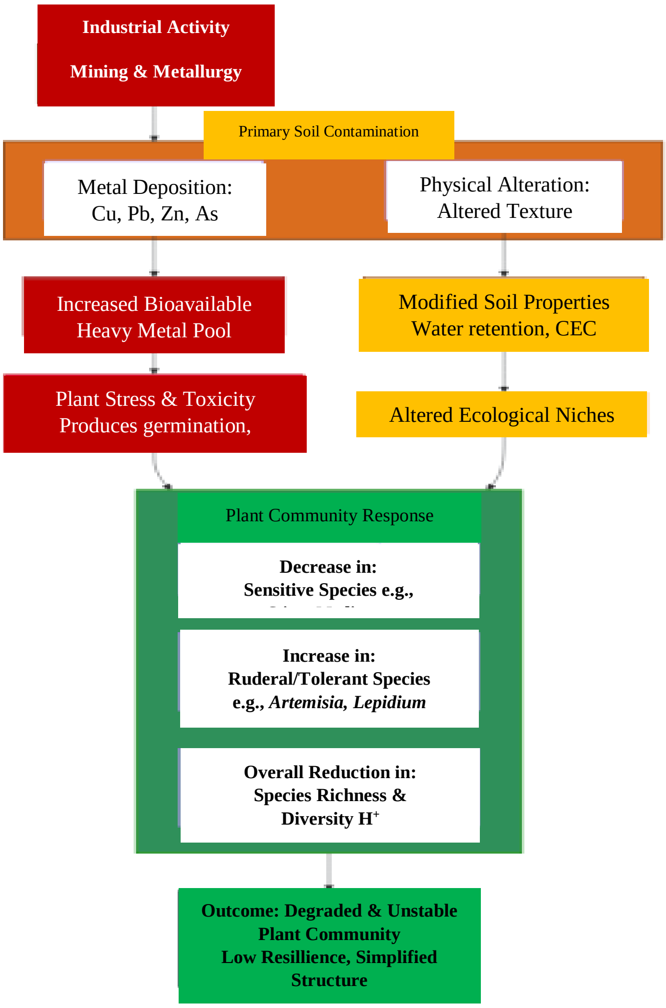

Fig. 1. Conceptual model of industrial impact on soil and plant community stability.

The ordination biplot (summarized in Table 6) showed that Cu and Pb were the strongest drivers in Zhezkazgan and Temirtau, respectively, pulling communities towards a state dominated by tolerant species like *A. austriaca*. A simplified soil quality index (SQI) was calculated for each plot by integrating metal pollution indices and key diversity metrics.

The SQI confirmed that plots in Temirtau experienced a slightly more severe overall degradation, likely due to the combined pressure of multiple metals and finer soil texture. The comparative summary is shown in Table 7. In summary, the study confirmed a strong, quantifiable link between soil geochemical contamination from industrial sources and the degradation of plant community stability, characterized by loss of diversity and a shift towards stress-tolerant, ruderal species.

Table 7. Comparative soil quality index (SQI) and degradation status.

Region	Average SQI (0-1 scale)	Standard deviation	Rate (%) of plots in "Degraded" status (SQI < 0.4)	Dominant degradation factor
Zhezkazgan	0.45	0.18	40%	Copper (Cu) Toxicity
Temirtau	0.38	0.21	60%	Lead (Pb) & Zinc (Zn) Toxicity

DISCUSSION

The findings of this study clearly show that industrial activities in the Dzhezkazgan and Temirtau regions have not only led to soil geochemical contamination, but also have profound ecological consequences on the sustainability of plant communities. The data in Table 1 clearly show very high concentrations of heavy metals, especially copper in Dzhezkazgan and lead and zinc in Temirtau, compared to natural background levels. These concentrations are in some places so high that they can be toxic to many sensitive plants. Soil texture analysis (Table 2) also showed that although the dominant texture in both regions is sandy loam, the presence of even moderate amounts of clay (9-13%) can play an important role in the retention and exchange of these metals, although it seems to have a negligible protective effect at these levels of contamination. The strong and significant negative correlation between metal concentrations and plant diversity indices (Tables 3 and 5) forms the core of the findings of this study. Strong Pearson correlation coefficients (e.g., -0.92 for lead in Temirtau) indicate that increasing soil pollution can be a quantitative predictor of decreasing biodiversity. This decrease in diversity does not only mean a loss of species, but also, as the Pilau evenness index decreases, indicates the dominance of a limited number of species in the community and the loss of the balanced structure of plant communities. Such a community will be much more vulnerable to subsequent disturbances. Changes in species composition are another strong confirmation of the impact of pollution. As seen in Table 4, By increasing pollution, sensitive and dominant native species such as *Festuca valesiaca* and *Stipa capillata*, which usually form the mainstay of healthy pastures, are severely reduced or disappear. In contrast, stress-tolerant species such as *Artemisia austriaca* and *Lepidium ruderale* become significantly more dominant. This pattern suggests an ecological succession under pollution pressure, in which the harsh environmental filter (high metal concentrations) allows only species with tolerant mechanisms to survive. The results of the redistribution analysis (RDA) in Table 6 confirm and quantify these observations in a robust multivariate framework. The 68% explanation of the variance in species composition by the first two axes alone, which were mainly related to heavy metals and clay content, suggests that these soil factors are the main predictors of the observed pattern in vegetation cover. This analysis clearly showed how plant communities shift along pollution gradients in ecological space, forming “different” communities at the polluted end of the spectrum. The differences observed between the two regions are also noteworthy. The lower soil quality index (SQI) in Temirtau (Table 7) is likely due to the toxic polymetallic composition (lead, zinc, and arsenic) combined with the relatively clayier texture, which may result in greater persistence of contaminants. In contrast, in Dzhezkazgan, copper acts as the dominant toxicity factor. This difference is likely to be due to different physiological responses of plants as well as to the remediation priorities for each region. Finally, these findings provide a serious warning for the management of ecosystems affected by industry. The reduction in the diversity and dominance of terrestrial species not only reduces the conservation and rangeland value of the land, but also weakens services such as soil stabilization and nutrient cycling. The model presented in Fig. 1 summarizes these causal relationships well. The next step is to more precisely determine the concentration thresholds at which severe diversity declines occur, as well as to study the possibility of using these resistant species as pioneer species in bioremediation programs.

CONCLUSION

This study clearly showed that the geochemical contamination of soil resulting from mining and metallurgical activities in the Dzhezkazgan and Temirtau regions has exhibited a direct and profound impact on the stability of plant communities. The increase in the concentration of heavy metals in the soil has led to a significant reduction in species diversity and uniformity of the plant community and has caused an ecological succession in favor of the tolerant and stress-resistant species. Statistical analyses confirmed the strong correlation between these two groups of variables, and the classification analysis has also introduced lead and copper as the main environmental factors shaping the species composition. In addition, the present study showed that the combination of rapid and field methods such as XRF with laboratory soil texture analyses and standard ecological monitoring can be an effective tool for the integrated and quantitative assessment of the health of environments under pollution stress. This approach allows the identification of critical points, determination of the dominant stress factors, and monitoring of the change process at a relatively reasonable cost and time. Finally, the findings of this study emphasize the need for proactive management strategies for these areas. These strategies should include continuous soil and vegetation monitoring, defining protected areas with prioritization based on soil quality indices, and exploring the feasibility of implementing bioremediation projects using native resistant species. Such measures are essential to prevent further degradation, partially restore ecosystem function, and protect plant genetic resources in these old industrial areas.

REFERENCES

Abdulkhalikova, JR, Balyanin, DP, Dudaeva, AE, Gabovakhova, NG, Gamidov, MG, Urusova, DB & Umalatov, A I 2025, Heart failure in middle biological age: diagnostic methods and therapeutic approaches. *Revista Latinoamericana de Hipertensión*, 20(2): 165-173, https://doi.org/10.5281/zenodo. 14911431.

Chevalier, R 2023, The effect of soil grain size and organic matter content variability on portable X-ray fluorescence analysis: A review of P-XRF application to monitoring stormwater basin sediment contamination in Fresno, USA, CA, MSc. Dissertation, California State University, Fresno, USA.

Costa, YT, Ribeiro, BT, Curi, N, Guilherme, LRG & Lopes, G 2019, Organic matter removal on oxide determination in Oxisols via portable X-ray fluorescence. *Communications in Soil Science and Plant Analysis, 50*(6): 673-681, https://doi.org/10.1080/00103624.2019.1589479.

de Almeida, E, Montanha, GS, Pereira de Carvalho, HW & Marguí, E 2020, Evaluation of energy dispersive X-ray fluorescence and total reflection X-ray fluorescence spectrometry for vegetal mass-limited sample analysis: Application to soybean root and shoots. *Spectrochimica Acta Part B: Atomic Spectroscopy,* 170: 105915, https://doi.org/10.1016/j.sab.2020.105915.

de Freitas, MG, dos Santos, FR, Parreira, PS & Melquiades, FL 2021, Influence of soil sample grain size on energy dispersive X-ray fluorescence analysis: A comparative study case with three spectrometers. *Spectroscopy Letters,* 54(7): 560-570, https://doi.org/10.1080/00387010.2021.1957941.

dos Santos, FR, de Oliveira, JF, Bona, E, dos Santos, JVF, Barboza, GMC & Melquiades, FL 2020, EDXRF spectral data combined with PLSR to determine some soil fertility indicators. *Microchemical Journal,* 152: 104275, https://doi.org/10.1016/j.microc.2019.104275.

dos Santos, FR, de Oliveira, JF, Barbosa, GMC & Melquiades, FL 2021, Comparison between energy dispersive X-ray fluorescence spectral data and elemental data for soil attributes modelling. *Spectrochimica Acta Part B: Atomic Spectroscopy,* 185: 106303, https://doi.org/10.1016/j.sab. 2021.106303.

Huang, F, Peng, SY, Yang, H, Zhang, H, Li, F, Gu, X, Zhang, Y, Lu, Q & Zhang, X 2022, Development of a novel and fast XRF instrument for large area heavy metal detection integrated with UAV. *Environmental Research,* 214: 113841, https://doi.org/10.1016/j.envres.2022.113841.

Järup, L 2003, Hazards of heavy metal contamination. *British Medical Bulletin,* 68(1): 167-182, https:// doi.org/10.1093/bmb/ldg032.

Marguí, E, Queralt, I & de Almeida, E 2022, X-ray fluorescence spectrometry for environmental analysis: Basic principles, instrumentation, applications and recent trends. *Chemosphere,* 303: 135006, https://doi.org/10.1016/j.chemosphere.2022.135006.

McGladdery, C, Weindorf, DC, Chakraborty, S, Li, B, Paulette, L, Podar, D, Pearson, D, Kusi, NYO & Duda, B 2018, Elemental assessment of vegetation via portable X-ray fluorescence (PXRF) spectrometry. *Journal of Environmental Management,* 210: 210-225, https://doi.org/10.1016/ j.jenvman.2018.01.003.

Peng, L, Li, X, Sun, X, Yang, T, Zhang, Y, Gao, Y, Zhang, X, Zhao, Y, He, A, Zhou, M, Cao, Y & Mielke, HW 2020, Comprehensive Urumqi screening for potentially toxic metals in soil-dust-plant total environment and evaluation of children's (0–6 years) risk-based blood lead levels prediction. *Chemosphere,* 258: 127342, https://doi.org/10.1016/j.chemosphere.2020.127342.

Pessanha, S, Marguí, E, Carvalho, ML & Queralt, I 2020, A simple and sustainable portable triaxial energy dispersive X-ray fluorescence method for in situ multielemental analysis of mining water samples. *Spectrochimica Acta Part B: Atomic Spectroscopy,* 164: 105762, https://doi.org/10.1016/ j.sab.2019.105762.

Ravansari, R, Wilson, SC & Tighe, M 2020, Portable X-ray fluorescence for environmental assessment of soils: Not just a point and shoot method. *Environment International,* 134: 105250, https://doi.org/ 10.1016/j.envint.2019.105250.

Rodrigues, ES, Montanha, GS, de Almeida, E, Fantucci, H, Santos, RM & de Carvalho, H W P 2021, Effect of nano cerium oxide on soybean (*Glycine max* L. Merrill) crop exposed to environmentally relevant concentrations. *Chemosphere*, 273: 128492, https://doi.org/10.1016/j.chemosphere.2020. 128492.

Rouillon, M & Taylor, MP 2016, Can field portable X-ray fluorescence (pXRF) produce high quality data for application in environmental contamination research? *Environmental Pollution*, 214: 255–264, https://doi.org/10.1016/j.envpol.2016.03.055.

Shand, CA & Wendler, R 2014, Portable X-ray fluorescence analysis of mineral and organic soils and the influence of organic matter. *Journal of Geochemical Exploration,* 143: 31–42, https://doi.org/ 10.1016/j.gexplo.2014.03.005.

Shuttleworth, EL, Evans, MG, Hutchinson, SM & Rothwell, JJ 2014, Assessment of lead contamination in peatlands using field portable XRF. *Water, Air, & Soil Pollution*, 225(2): 1844, https:// doi.org/10.1007/s11270-013-1844-2.

Tavares, TR, Nunes, LC, Alves, EEN, de Almeida, E, Maldaner, LF, Krug, FJ, de Carvalho, HWP & Molin, JP 2019, Simplifying sample preparation for soil fertility analysis by X-ray fluorescence spectrometry. *Sensors,* 19(23): 5066, https://doi.org/10.3390/s19235066.

Tavares, TR, Molin, JP, Javadi, SH, de Carvalho, HWP & Mouazen, AM 2020, Combined use of vis-NIR and XRF sensors for tropical soil fertility analysis: Assessing different data fusion approaches. *Sensors,* 21(1): 148, https://doi.org/10.3390/s21010148.

Vanhoof, C, Bacon, JR, Fittschen, UEA & Vincze, L 2021, Atomic spectrometry update – a review of advances in X-ray fluorescence spectrometry and its special applications. *Journal of Analytical Atomic Spectrometry,* 36(9): 1797-1812, https://doi.org/10.1039/D1JA90033A.

Watkins, M, Ziyadin, S, Imatayeva, A, Kurmangalieva, A & Blembayeva, A 2018, Digital tourism as a key factor in the development of the economy. *Economic Annals-XXI*, 169: 40-45.

Yue, T, Wang, F, Han, B J, Chen, ZY & Wang, L 2012, Analysis on Pb, Cd, Cr, As, Mn emission and control technology of typical industries. *Advanced Materials Research,* 610-613: 1176-1187, https://doi.org/10.4028/ www.scientific.net/AMR.610-613.1176.

Bibliographic information of this paper for citing:

Myrzabayev, A, Kusherbayev, S, Tulindinova, G, Turlybekova, G, Gabdullin, Y, Kusainova, A, Seilkhanova, Z, Zhomartova, G 2026, Impact of soil geochemical contamination on plant community stability in Zhezkazgan and Temirtau, Kazakhstan using X-ray fluorescence and granulometric analyses. Caspian Journal of Environmental Sciences, 24: 83-90.