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Ecological-Geochemical Assessment of Elemental Composition, Humus Content and Soil Reaction in Irrigated Dark Sierozems around the Angren Thermal Power Plant

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Abstract This study evaluates the elemental composition, humus content, and soil reaction of irrigated dark sierozems in the vicinity of the Angren Thermal Power Plant (TPP), Uzbekistan. Sampling locations were situated at distances of 1.6, 2.5, 8, 15, and 21 km from the power plant, with a reference site at 24 km. Element concentrations were determined by inductively coupled plasma mass spectrometry (ICP-MS), and the measured values were summarized as arithmetic means. Mean concentrations of Pb, Ni, As, and Sb were 190, 130, 6.2, and 6.7 mg/kg, respectively. Comparison with the provisional allowable concentrations for total element contents specified in Uzbekistan sanitary regulation No. 0112-26 yielded concentration-to-reference ratios of 5.94, 3.71, 3.10, and 1.49, respectively. The soil pH (water) ranged from 6.2 to 7.1 at sampling sites and reached 7.3 at the reference site. Surface-layer (0–5 cm) humus values ranged between 1.09% and 1.45%, decreasing with depth at all five sites. These findings provide an integrated descriptive basis for prioritizing Pb, Ni, As, and Sb in further soil monitoring; the concentration ratios should not be interpreted as direct measurements of bioavailability or evidence of a particular emission source.

Keywords Angren TPP, Irrigated dark sierozem, Potentially toxic elements, ICP-MS, Humus, Soil pH, Environmental geochemistry

1. Introduction

Coal-fired power plants can affect the ecological and geochemical properties of surrounding soils through atmospheric particulate deposition and the storage of ash and slag. The mineral and chemical composition of combustion residues depends on fuel properties, combustion conditions, and particle-control technologies [1,2,3]. Accordingly, the measured concentration of an element in soil must be interpreted in the context of natural geological backgrounds as well as possible anthropogenic inputs.

Fine fly-ash particles may be transported through the atmosphere before being deposited on soil surfaces. However, element concentrations also reflect the composition of parent material, land-use history, irrigation, and local dust sources. Izquierdo and Querol [2] reported that the release of elements from coal ash varies with mineral phases and aqueous conditions. Total concentrations therefore cannot be assumed to represent mobile or biologically available fractions.

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The retention, transport, and bioavailability of potentially toxic elements depend on their chemical forms and on soil physicochemical properties. Soil pH, organic matter, carbonates, clay minerals, and iron and manganese (hydr)oxides can affect sorption and dissolution [4,5,6,7,8]. Metal cations and oxyanion-forming elements such as arsenic do not necessarily exhibit the same geochemical behavior.

The Angren industrial region includes irrigated dark sierozem soils subject to both industrial and agricultural influences. Sampling-site selection considered the location of ash-and-slag facilities and cultivated fields in the northern and northeastern sectors of the area. Previously documented humus profiles provide soil-organic-matter context for the present study [9].

Early studies of fly-ash mineralogy and characterization (Vassilev and Vassileva [1]; Vassilev et al. [3]) established the importance of the composition and mineral phases of coal-combustion residues. Subsequent work on leaching (Izquierdo and Querol [2]) demonstrated that element release depends on the solid phases and contact solution. Research on sorption, pH-dependent dissolution and soil organic matter [4,5,6,7,8] provided the geochemical framework for distinguishing total-element concentrations from mobile fractions. More recent investigations have incorporated

multiple indicators and source-apportionment methods to evaluate fly-ash signals and soil contamination around coal-fired power plants (Wang et al. [10]; Jia et al. [11,12]). These approaches differ in their sampling designs and analytical targets, so reported element concentrations are not necessarily directly comparable.

Regional work supplies an additional historical context. Shukurov et al. [13] examined soil biogeochemical properties in the Angren industrial area; Jabbarov and Begimova [9] reported humus profiles relevant to the present soil setting; and Jobborov et al. [14] discussed chemical properties of industrially affected soils. Together, these studies motivate an integrated description of total-element abundance, soil reaction and organic-matter distribution, while emphasizing that a local reference pH measurement is not an element -specific geochemical background. In contrast to studies employing source-apportionment or bioavailability tests, the present dataset supports a descriptive comparison with specified national screening values, rather than causal attribution to a single emission source.

The objective was to characterize mean concentrations of selected elements in irrigated dark sierozems near the Angren TPP, compare them with the specified national soil screening criteria, and interpret soil pH and humus profiles as complementary physicochemical indicators.

2. Materials and Methods

The study was conducted on irrigated dark sierozem soils surrounding the Angren Thermal Power Plant in the Tashkent region, Uzbekistan. Sampling locations were situated 1.6, 2.5, 8, 15, and 21 km from the plant; a site at 24 km was designated as a reference. Their selection considered the locations of ash-and-slag facilities, irrigated farmland, and the northern to northeastern sectors of the study area. Figure 1 presents a conceptual sampling transect rather than a scale-accurate geographic map.

Soil samples were prepared for elemental analysis by air-drying, removing coarse stones, roots and other extraneous materials, grinding, sieving and homogenizing. The prepared material was subjected to acid digestion to transfer the elements into solution, and elemental concentrations were determined using inductively coupled plasma mass spectrometry (ICP-MS). Instrumental measurements were subject to calibration and analytical quality-control procedures. The reported concentrations were expressed in mg/kg of dry soil. Soil humus content was determined using the Tyurin method, based on oxidation of soil organic carbon with potassium dichromate ($K_2Cr_2O_7$) in sulfuric acid (H_2SO_4) medium, for the 0–5, 5–20 and 20–55 cm intervals [9]. Soil reaction was measured potentiometrically using a pH meter in an aqueous soil suspension and expressed as pH-H_2O. The reported elemental concentrations were summarized as arithmetic means. Since the available dataset does not provide site-specific elemental concentrations, sample counts or dispersion statistics, no inferential tests or site-specific elemental trends were calculated.

Sanitary regulation No. 0112-26, Appendix 11, was used for the comparative evaluation [15]. The regulation differentiates maximum permissible concentrations (MPCs) from provisional allowable concentrations (PACs; ODK/ TREK) for specified analytical fractions. The present comparison uses the provisional values applicable to total soil contents: Pb 32, Ni 35, As 2.0 and Sb 4.5 mg/kg. For each element, the descriptive ratio was calculated as K = C/P, where C is the reported arithmetic mean of the total soil concentration and P is the relevant regulatory reference value (both in mg/kg). Because the individual measurements and sample count were not supplied, this calculation should not be interpreted as a statistical assessment of exceedance prevalence.

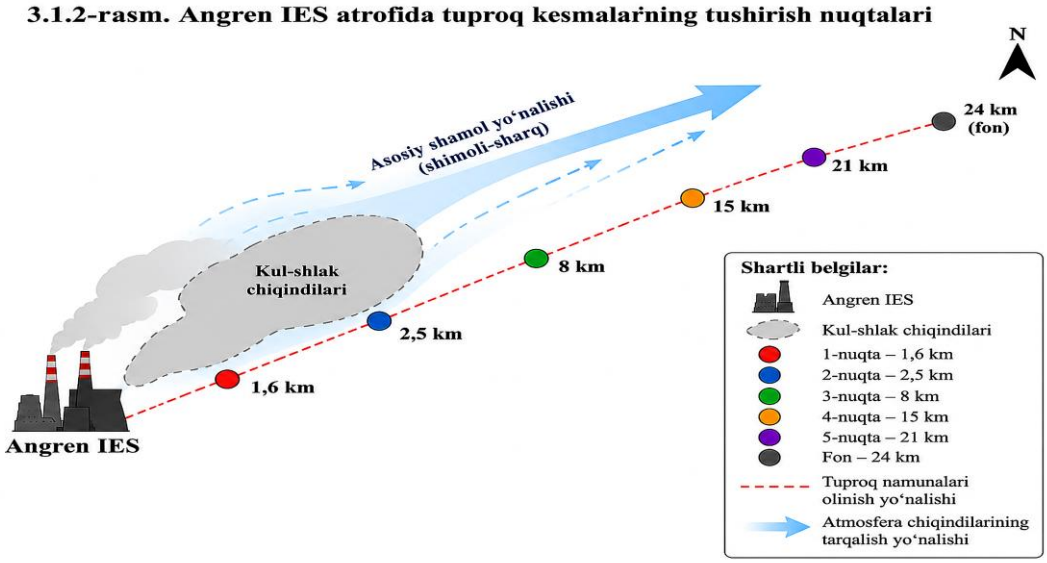

Figure 1. Schematic representation of soil sampling locations around the Angren Thermal Power Plant (TPP). Distances (1.6, 2.5, 8, 15, 21 and 24 km) are measured from the plant; the 24 km location is the reference site. Not drawn to geographical scale

The regulatory ratio was used only as a screening comparison of the reported arithmetic mean with the tabulated total-content criterion. A ratio greater than one refers to that mean and does not imply that every sampling location had the same concentration. Likewise, the sampling-site pH values and profile-specific humus percentages were interpreted descriptively; no statistical relationship between these variables and individual element concentrations was inferred.

3. Results

3.1. Elemental Composition and Regulatory Comparison

ICP-MS analysis showed differences among the arithmetic mean concentrations of soil elements. Notable values included Sr (410 mg/kg), Pb (190 mg/kg), Rb (190 mg/kg), and Ni (130 mg/kg). Pb, Ni, As, and Sb were prioritized for comparison because of their environmental relevance and the availability of regulatory reference values (Table 1).

Table 1. Mean Element Concentrations and Provisional Allowable Values for Total Soil Contents

Element	Mean, mg/kg	PAC, mg/kg	C/P
Pb	190	32	5.94
Ni	130	35	3.71
As	6.2	2.0	3.10
Sb	6.7	4.5	1.49
Cr	48	—	—
Co	10.2	—	—
Sr	410	—	—
Rb	190	—	—

Note: Regulatory values are from sanitary regulation No. 0112-26 [15]. Total Cr was not compared with the Cr(III)-specific criterion; no normative ratio is reported for Co.

The highest arithmetic concentration-to-reference ratio was found for Pb, followed by Ni, As, and Sb. These ratios characterize means across the analyzed samples rather than maxima at individual sites. The total Cr concentration was 48 mg/kg, but it was not directly compared with a Cr(III)-specific limit. Absolute Sr and Rb contents describe the soil elemental composition and do not independently establish the source of these elements.

The resulting ratios indicate elements deserving attention during subsequent soil monitoring; however, they are not equivalent to bioavailable fractions or biological effect measurements [7,16,17].

3.2. Vertical Distribution of Humus

Humus content varied between soil profiles and layers [9]. All five profiles showed greater contents in surface samples than at deeper intervals (Table 2).

Humus in the 0–5 cm layer ranged from 1.09% to 1.45%, compared with 0.85–1.28% in the 5–20 cm layer and 0.48–0.82% in the 20–55 cm layer. The lowest and highest surface values occurred at 1.6 and 8 km, respectively. The distance pattern was nonmonotonic; no direct relationship with the spatial distribution of individual elements is claimed from these data.

Table 2. Humus Content (%) in Soil Layers at Different Distances from the Angren TPP

Depth, cm	1.6 km	2.5 km	8 km	15 km	21 km
0–5	1.09	1.33	1.45	1.27	1.21
5–20	0.92	1.05	1.28	0.85	1.04
20–55	0.48	0.54	0.73	0.67	0.82

Source: Jabbarov and Begimova (2025), p. 164 [9].

The consistency of the vertical humus gradient is more pronounced than the variation among sampling distances: every surface layer exceeds its corresponding 20–55 cm layer. This pattern indicates a depth-dependent distribution of soil organic matter within the irrigated profiles. Differences among distances are nonuniform, however, and cannot independently be treated as a regular gradient arising from industrial deposition [9].

3.3. Variation in Soil Reaction

The pH-H_2O values at the five sampling sites varied from 6.2 to 7.1, compared with 7.3 at the reference location (Table 3).

Table 3. Soil Reaction (pH-H_2O) at the Sampling Locations

Site	Distance, km	pH-H_2O
KA-1.6	1.6	6.3
KA-2.5	2.5	6.2
KA-8	8	6.4
KA-15	15	6.7
KA-21	21	7.1
Reference	24	7.3

The lowest pH was observed at 2.5 km. Values at the 1.6 and 2.5 km sites were 1.0 and 1.1 pH units below the reference, respectively. From 2.5 km toward the reference site, pH increased across the reported sampling points. These observations describe differences in soil reaction and do not by themselves identify their causes.

4. Discussion

4.1. Interpretation of the Regulatory Comparisons

The concentration-to-reference ratio depends on the analytical definition of the measured element and the category of the benchmark. Sanitary regulation No. 0112-26 distinguishes maximum permissible concentrations (MPCs) from provisional allowable concentrations (PACs) [15]. PACs for total soil content were used for the present screening comparisons. These ratios identify priorities for additional monitoring but do not quantify exposure, bioavailability, or ecological risk [7,16].

The elements assessed have distinct geochemical behavior. Pb and Ni can be retained by sorption on mineral and organic surfaces, whereas arsenic commonly occurs as oxyanion species with different redox and oxide-surface interactions. Antimony also has complex aqueous speciation. Consequently, relative total concentrations cannot be used to rank mobility or biological hazard directly [4,5,8].

The contrasting behavior of these chemical groups also explains why the same pH shift need not produce comparable changes in their mobility. Organic functional groups, oxide surfaces and competing solutes may favor retention of one species while increasing the dissolved fraction of another. Thus, the measured soil reaction is best interpreted as a condition influencing potential partitioning, not a direct determination of mobile element fractions [4,5,8,17].

The national screening comparison is especially informative when the denominator is stated explicitly for each element. Because the calculated ratios use the arithmetic means, the ranking Pb > Ni > As > Sb reflects relative positions against their respective benchmarks rather than a ranking of absolute concentrations or toxicity. This distinction matters when communicating findings across elements that have different natural abundances, chemical forms, and regulatory reference values. Consequently, both the original concentration in mg/kg and the dimensionless ratio are retained in Table 1 [7,15,16].

4.2. Role of Organic Matter and Irrigated Soil Conditions

Across all five transect positions, humus content was greater in the surface (0–5 cm) layer than at 20–55 cm. Organic functional groups can contribute to metal retention, whereas dissolved organic ligands can increase the mobility of certain species [4,5,6,18]. Hence, the observed humus profile describes relevant soil conditions but does not establish metal–humus correlations.

Soil pH rose from 6.2 at 2.5 km to 7.3 at the reference site. Such variation can modify the charge and sorptive properties of mineral and organic surfaces, although the direction and magnitude of the response are element-specific [4,8,17]. Irrigation-water chemistry and land management may also contribute to the observed pH differences; the measurements alone do not attribute them to emissions from the power plant.

The pH results show a clear descriptive contrast between the near-plant locations and the 24 km reference location. Since pH is logarithmic, the reported difference in pH units must not be treated as a linear percentage difference. The environmental meaning of this pattern also depends on the soil buffering system, including carbonates, mineral surfaces, and organic matter. The measurements therefore characterize the reaction of the sampled soils without requiring an inference that each element responds proportionally to distance [4,8,17].

4.3. Regional Context and Monitoring Implications

Shukurov et al. [13] investigated elemental and microbiological properties in the Angren industrial area, while Jobborov et al. [14] examined soil chemical characteristics in several industrially affected areas of the Tashkent region. Both investigations provide a relevant regional basis for interpreting soil quality, without implying that their sampling designs or analytical measurements are directly equivalent to those reported here.

Against this regional background, the present study jointly describes ICP-MS-derived mean elemental concentrations, pH observations along the sampling transect, and depth-resolved humus contents in irrigated dark sierozems. This combination permits a complementary description of elemental abundance and soil conditions without emphasizing numerical differences between independent studies.

The datasets resolve different dimensions of soil conditions. Elemental concentrations are arithmetic means, whereas pH is reported at individual sampling locations and humus by soil depth. Therefore, a mean-to-benchmark ratio does not imply the same concentration at every location, and the pH distance pattern should not be taken as the spatial distribution of any individual element. This separation keeps the environmental interpretation consistent with the observations [10,11,12].

For monitoring, Pb, Ni, As, and Sb merit priority because their reported mean concentrations are above the selected national screening benchmarks [15]. Their distinct geochemical behavior calls for element-specific interpretation: Pb and Ni interact with mineral and organic exchange and sorption sites, whereas As and Sb may occur as oxyanion species with different affinities for oxide surfaces [4,5,8,17]. Soil pH and humus provide useful chemical context, but neither is a direct measure of exposure or element mobility.

The 24 km reference location is a comparison point for the pH transect and should not be equated with an independently established elemental background concentration. Thus, the ratios in Table 1 compare arithmetic means with sanitary screening values, not site-by-site enrichment against local geological baselines. This distinction is relevant when interpreting findings from industrial landscapes with heterogeneous soil parent materials and land use [10,15].

For comparison, Wang et al. [10] combined multiple independent tracers to investigate fly-ash contributions to surface soils. That study illustrates why chemical source attribution is a separate analytical objective from a benchmark comparison. The Angren ratios reported here are therefore used to guide monitoring priorities, not to estimate the fractional contribution of individual emissions.

The higher surface-horizon humus contents provide context for retention processes, but neither these profiles nor the pH transect alone demonstrate an element–humus association or identify the origin of measured metals [4,5,6,17,18].

Because the retention and release of coal-combustion -derived elements depend on mineral phases and solution chemistry [1,2,3], future work should include location -specific total concentrations, soil mineralogy, element fractionation and suitable background samples. These additional measurements would permit testing of spatial trends and possible sources rather than assuming an emission

gradient from the available arithmetic means.

Accordingly, the present results should be viewed as a descriptive screening dataset that supports the design of targeted, element-specific monitoring rather than as a quantified assessment of mobility, exposure or source apportionment [16,17,18]. Previous investigations of particle-size effects on the behavior of soil metal(loid)s [19] and of metal contamination near coal-fired power plants [20] further support the value of analyzing multiple soil characteristics; their different study designs do not, however, establish the sources of the Angren measurements.

5. Conclusions

ICP-MS measurements yielded mean Pb, Ni, As and Sb concentrations of 190, 130, 6.2 and 6.7 mg/kg, respectively. Ratios to the applicable provisional allowable concentrations were 5.94, 3.71, 3.10 and 1.49. Soil pH varied among sampling locations and reached 7.3 at the reference site, while humus content decreased with depth across all five profiles. Taken together, these observations support prioritizing Pb, Ni, As and Sb in soil monitoring and provide physicochemical context for interpreting the element concentrations.

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