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APPLIED GEOGRAPHIES

Spatial distribution of potentially toxic elements in soils and water bodies of the Kostanay region in Kazakhstan

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ABSTRACT

Knowledge of the distribution patterns of potentially toxic elements (PTE) is essential for assessing and predicting the dynamics of landscapes under anthropogenic influences. As a case study, soil-forming rocks, soils and water bodies of the Kostanay region in the Republic of Kazakhstan were studied for the presence of potentially toxic elements (PTE) through analysing concentrations of different chemical elements within them. Study areas were selected across the region - ones with differing natural settings and liable to differing anthropogenic influences from industrial and agricultural landuses - and specific key sites were selected in each area from which soil and water samples were taken. Soil profiles were extracted, with the deepest horizons being taken as indicative of underlying soil-forming rocks, and with the upper horizons being taken as indicative of the soil per se. Soil samples were taken from soil profiles along horizons to study the distribution of chemical elements. These samples were analysed using the atomic absorption method to determine their respective contents of differing chemical elements, and hence PTE. The obtained data suggests the spatial distribution of PTEs across the soils and water bodies of the Kostanay region.

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KEYWORDS
Soil; water bodies; potentially toxic elements; gross content; anthropogenic impact

Introduction

When researching the ecological characteristics of chemical elements, knowledge of their standard or 'background' content in rocks, soils and water bodies is essential, allowing careful assessment of possible anthropogenic pollution by potentially toxic elements (henceforth PTE). Knowledge of the background environmental content of heavy metals, including iron and copper, is hence of practical importance for developing a strategy for rational nature management, as well as for improving the organisation of geochemical monitoring (of rock, soil and water bodies) since the correctness of the assessment of relative degrees of environmental pollution depends upon it. High concentrations of heavy metals are dangerous for living organisms; they can accumulate inside the organism and cause severe poisoning (Avkopashvili et al., 2015; Hanauer et al., 2011).

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Soil and surface water contamination by PTE poses a threat to human life and ecological communities due to their bioaccumulation, toxicity and persistent nature in the ecosystem (Din et al., 2023; Muhammad & Usman, 2022).

The content of chemical elements in the soils and water bodies of the Kostanay region in the Republic of Kazakhstan are considered in Amerguzhin (2004). The soil cover and vegetation of this region differ between landscapes located in forest-steppe, steppe, and semi-desert natural zones, with implications for the distribution of PTE. Agricultural lands occupy some 92.5% of the region's total land area (https://newecodoklad.ecogosfond.kz/2016/kostanajskaya-oblast/) while there are heavy-industrial plants of various sorts found in the region, all with implications for the distribution of PTE and the threats posed by PTE. The chemical element composition of the Kostanay region has been poorly studied to date, and requires further detailed ecological and geochemical research. This study therefore aims to study the spatial distribution of PTE in the soils and water bodies of the region, adding to that knowledge of the distribution patterns of PTE essential for assessing and predicting the dynamics of regional ecosystems under anthropogenic influences.

Material and methods

The objects of the study were samples from soils and water bodies in the Kostanay region, located in the north of the Republic of Kazakhstan. Kostanay city is the administrative centre of this region. In the north and northwest, the Kostanay region borders the Russian Federation, in the west and southwest – with Aktobe in the east – with North Kazakhstan, and Akmola, in the southeast, with the Karaganda regions of Kazakhstan. The intra-continental location determines the natural features of the studied area. The variety of geological and geomorphological, climatic, and soil-plant conditions determines the differentiation of landscapes across forest-steppe, steppe, and semi-desert natural zones. Kostanay region also belongs to an industrial-agrarian part of the country, which contributes to economic development. The manufacturing industry of the Kostanay region is composed by mechanical engineering, the metallurgical industry, the production of building materials, and the development of industry and agriculture, all of which leads to the contamination of soil and water bodies with PTE and other pollutants from various anthropogenic sources.

Industrial enterprises, transportation and various economic objects constantly emit pollutants. It is necessary to understand up to what limit their content does *not* have a negative impact on the environmental situation or human health. In this regard, there is the concept of Maximum Permissible Concentrations (MPCs) of harmful substances, now specified in Kazakhstan by both the Joint Order of the Minister of Health of the Republic of Kazakhstan from January 30, 2004 № 99 and the Minister of Environmental Protection of the Republic of Kazakhstan from January 27, 2004 № 21-p 'On Approval of Norms of maximum permissible concentrations of harmful substances, harmful microorganisms and other biological substances polluting the soil'. For example, the standards for MPC of heavy metals in soil are as follows for: chromium (Cr) – 0.05 mg/kg; copper (Cu) – 33.0 mg/kg; lead (Pb) 32.0 mg/kg; and manganese (Mn) – 1500 mg/kg.

Soil sampling

One of the study's objectives was to select areas within the region for soil sampling, seeking to represent the variable state of the natural environment, capturing variability in both standard or background elemental and chemical properties as well as being located in zones of anthropogenic impact. In an initial survey process, considering types of nature management and using high spatial resolution Landsat 9 satellite imagery for 2022, nine distinct areas were identified, within which specific key sites – point locations – were identified from which soil samples could be taken. The objects of the study were indeed the most common and typical soils on the territory of Kostanay region near anthropogenic sources of pollution. The geographical spread of the areas is shown in Figure 1, with specific key sites – also known as 'sampling locations' or 'selection points' – highlighted with red (brighter) spots, while properties of each key site are listed in Table 1. Field studies were then conducted in July 2022.

Full-profile soil sections were extracted from naturally 'typical' sites in the system of associated landscapes, taking into account the influence of anthropogenic sources. Soil samples were taken according to genetic horizons, including from deeper soil-forming rock horizons. Within each soil profile, samples were taken to identify the difference between the content of heavy metals in the surface soil horizonm, what we call just 'the soils', and in the lower soil horizon, what we call 'the soil-forming rocks'. It is from the latter that soils inherit their mineralogical composition and, consequently, the natural content of most heavy metals.

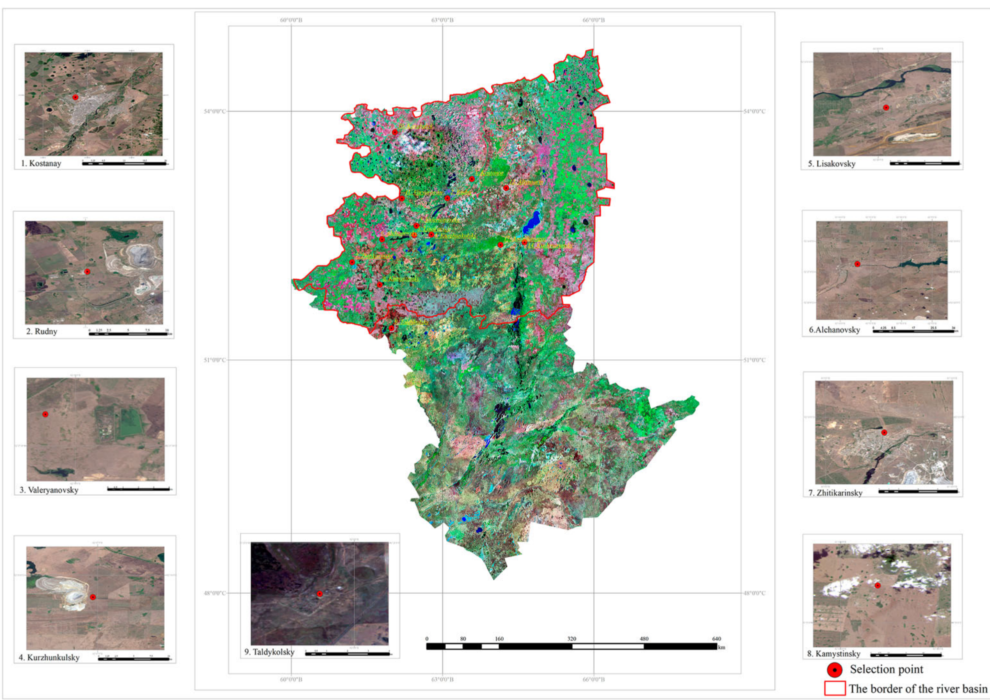

Figure 1. Map of the study region showing selected areas and key sites.

Table 1. Selected areas and key sites in the Kostanay region. (LLP = Limited Liability Partnership; JSC = Joint Stock Company).

№	Selected area	Coordinates of key site	Location of key site	Type of anthropogenic activity	Water temp. °C	Date sampled
1	Kostanay	53.24259, 63.58897	53 m. from Evraz Caspian Steel LLP to the south	Plant for production of small-grade rolled products (Evraz Caspian Steel LLP) on the industrial site with reinforcement shop, welding posts, BSU, crushed stone warehouse, sawmill, and boiler rooms	18°C	05/07/22
2	Rudny	53.02053, 63.00536	300 m. from Kazakh Aluminosilicate Refractories Plant to the south	Kazakh Aluminosilicate Refractories Plant production plant based on its electro-corundum and chamotte	18°C	07/07/22
3	Valer-yanov	52.60913, 62.54584	180 m. from Pervomai Crushed Stone Plant LLP to the southwest	Pervomai Crushed Stone Plant LLP was founded at the Pervomai deposit; extraction and processing of building stone, crushed stone, and gravel	13°C	08/07/22
4	Kurz-hunkul	52.54937, 62.70169	150 m. from Kurzhunkul iron ore deposit to the south	Kurzhunkul iron ore deposit is part of the Sarbay Ore Management of JSC Sokolov-Sarbay Mining and Processing Production Association	15°C	10/07/22
5	Lisakov	52.51835, 62.52562	500 m. from Orken-2 LLP to the south	Orken-2 LLP is the legal successor of the Lisakov Mining and Processing Plant, engaged in the extraction, enrichment, processing, and shipment of iron ore	17°C	11/07/22
6	Alchanov	52.473500, 61.806198	100 m. from the village of Alchanovka to the southeast	Production of agricultural products; production of wheat of hard and soft varieties; cultivation of cattle for meat (Kazakh white-headed breed)	16°C	12/07/22
7	Zhitikarin	52.161118, 61.203895	137 m. from Kostanay Minerals JSC to the west	Kostanay Minerals JSC is a mining company specialising in the extraction of chrysotile asbestos and the production of chrysotile fibre	22°C	13/07/22
8	Kamystin	51.973470, 62.262581	355 m. from Krasnooktyabr field to the southwest	Mining and processing of lead-zinc ore in Shaimerden JSC within the large Krasnooktyabr bauxite deposit; main activity is the crushing and shipment of ore	24°C	07/07/22
9	Taldykol	51.398765, 61.985587	113 m. from the village of Taldykol to the southwest	Production of agricultural products: wheat production, raising cattle for meat	20°C	08/07/22

The selected samples were prepared for examination in the laboratory for the presence of pollutants in them. Soil samples were evenly placed on paper, and to avoid lumpiness of the soil samples entering the crusher large lumps were detected and removed. Visually observed pebbles, insects, debris, and other foreign inclusions were also removed. The purified soil samples were then crushed with a pestle in a mortar and sieved with laboratory sieves.

Water sampling

Water bodies are indicators of anthropogenic changes in the natural environment. Pollution enters natural waters due to both wastewater discharge from urban areas, flushing from agricultural areas, and dry and wet precipitation from the atmosphere to the surface of catchment basins. Pollution and deterioration of water quality are associated with industrial wastewater discharged by mining and processing enterprises, the use of agricultural fertilisers, as well as with PTE entering Tobol from the entire catchment area.

Our research in the Kostanay region allowed us to establish some hydrochemical features of the composition of the waters of the studied area, based on water sampling conducted in July 2022. We collected water samples in three key sites located in Kostanay, Rudnyi and Zhitikara cities. Sampling was carried out in a container made of materials that do not affect the chemical composition of the sample, namely polyethylene containers with tightly closed lids. Sampling and storage tanks were thoroughly washed and dried according to the requirement that there should be no chemical alteration of the samples introduced by the sampling and measuring procedures.

Chemical and statistical analysis

The level of concentrations of chemical elements in the region's soils and soil-forming rocks – iron (Fe), zinc (Zn), lead (Pb), copper (Cu), molybdenum (Mo), and cadmium (Cd) – and the water bodies – iron (Fe), aluminium (Al), barium (Ba), boron (B), vanadium (V), potassium (K), calcium (Ca), cobolt (Co), silicon (Si), lithium (Li), magnesium (Mg), manganese (Mn), molybdenum (Mo), sodium (Na), nickel (Ni), lead (Pb), sulphur (S), strontium (Sr), titanium (Ti), and phosphorus (P) – were established by analysing the derived samples. Analytical studies of potential pollutants, the PTEs, were carried out in the certified laboratory Eco-Nus in Kragandy, the capital of Karaganda region. Concentration levels of chemical elements in both the soil and water samples were determined by the atomic absorption method using the atomic absorption spectrometer MGA-915MD. This spectrometer – with electrothermal atomisation and Zeeman correction of non-selective absorption, with an extended spectral range – is designed to measure the content of elements.

Gross content levels of the different chemical elements in the soil samples – including both the soil-forming rocks (lower horizons) and the soils *per se* (upper horizons) – and also in the water samples were thereby derived. Statistical processing of the soil and water data obtained during the study was then done using the Microsoft Excel programme. The following statistical indicators were deployed in the data processing: n – number of samples; $\bar{X} \pm S\,\bar{x}$ – arithmetic mean and its error (mg/kg); CV – coefficient of variation (%); lim – limits of fluctuations (mg/kg); p – limit difference; σ – standard deviation (mg/kg); r – correlation coefficient.

Results and discussion

Chemical elements in Kostanay's soil-forming rocks and soils

In the studied region, Kostanay, modern Quaternary sediments have a limited distribution. They are represented by alluvial sediments in the floodplain parts of the region's rivers and lakes and estuary-lake sediments in large depressions. Among the Quaternary formations, quite common eluvial-diluvial deposits of loess-like nature are of particular interest. Sedimentation in the Quaternary period occurred under challenging conditions of accumulative and denudational processes in the regional landscapes associated with the activity of glacial waters and the latest tectonics. A relatively small thickness characterises Quaternary deposits throughout the Kostanay region, the exception being the alluvial sediments of the Turgai hollow, the valley of the Turgai, Uly-Zhilanchik, and Tobol rivers, and large drainless depressions formed due to the activity of glacial waters (https://nic-peb.kspi.kz/ru/14-plitki/84-prirodnye-osobennostikostanajskoj-oblasti.html).

The overall picture of levels of concentrations of chemical elements in the in the soil-forming rocks of the Kostanay region, based on the lower soil horizons data, is presented in Table 1. The equivalent picture for the soils of the Kostany region, based on the upper soil horizons data, is presented in Table 2.

A graphic comparison between overall levels of concentration of four selected chemical elements – copper, lead, molybdenum, and zinc – found, respectively, in Kostanay's soil-forming rocks and soils can be seen in Figure 2.

Iron (Fe): Iron is the most essential soil-forming element. Regarding its prevalence in the lithosphere, iron ranks as the second metal after aluminium and fourth among all elements comprising the lithosphere. It is also a biogenic element necessary for living organisms' normal functioning and vital activity, but its increased environmental

Table 2. Variation and statistical indicators of chemical elements in the soils of the Kostanay region in mg/kg.

Elements (alpha-betical)	$X \pm S\ x$	lim	σ	CV, %
Fe	44,006.6 ± 3,687.2	36,234.6–68,222.4	12,772.9	29.03
Cu	32.6 ± 1.8	25.1–41.7	6.3	19.29
Mo	6.4 ± 1.8	1.5–16.4	6.4	91.9
Pb	32.5 ± 1.7	24.0–38.8	5.9	18.2
Zn	59.5 ± 5.1	33.4–83.9	17.8	29.9
Nitrates	46.5 ± 15.9	13.0–110.0	55.02	118.3

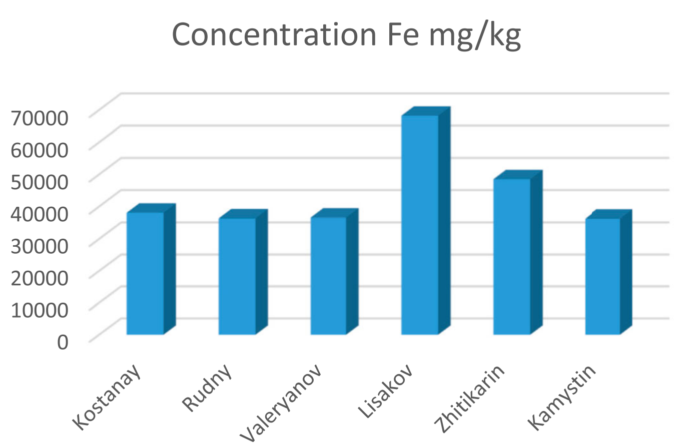

Figure 2. Concentration of iron in soil-forming rocks of the main elements of the Kostanay region, mg/kg.

intake – if too prevalent – can negatively impact all biosphere components. On soil enriched with soluble forms of iron, toxic effects of this element on plants can be observed. Characteristic signs of the harmful effects of iron on plants are the absence of necrotic tissue and the development of chlorosis between the veins of young leaves. In this regard, then, the issue of studying the content of iron ions in some natural objects is quite relevant (Orlov et al., 1991).

The gross iron content in the soil-forming rocks of the studied region varies from 12,248 to 68,222 mg/kg, with an average coefficient of variation of 49%. The average iron content in the whole set of soil-forming rocks is 38,158 mg/kg, equal to the Clarke Index[1] for iron in the earth's crust (c.38;000 mg/kg: Alekseenko, 1990). The lowest levels of iron content are found in light loamy soil-forming rocks, measured as low as 12,481 mg/kg, while the highest iron content is characteristic of earthy, cartilaginous, crushed stone deposits, the heavier loams, measured as high as 68,222 mg/kg.

The gross iron content in the soils of the studied region is equal to 44,006.60 mg/kg, which is more than the Clarke Index noted above. The iron content here varies across the key sites from 36,234.62 to 68,222.37 mg/kg (see Figure 3), with an average coefficient of variation of 29.03%. Table 2. The maximum iron concentration of 68,222.37 mg/kg is found at key site No.5 (Lisakov), with 48,535.97 mg/kg found for key site No.7 (Zhitikarin). The iron content in the soils of key sites No. 5 and 7 obviously exceeds the Clarke Index for iron in the ground. The notable excess at site No.5 is explained by geochemical features with local soils influenced by the underlying rocks, but also by the impact of the enterprise Orken-2 LLP, which is the legal successor of the Lisakov Mining and Processing Plant and is engaged in the extraction, enrichment, and processing of iron ore. At site No.7, a slight excess over the average iron index is due to the influence of the enterprise JSC Kostanay Minerals, which is engaged in extracting asbestos ore.

Zinc: The zinc content in the soil-forming rocks was 51.4 ± 10.6 mg/kg, with a range of limits of 21.3-83.9 mg/kg. The minimum average gross zinc content of 21.3 mg/kg is typical for light loamy soil-forming rocks, while the maximum zinc concentrations of 83.9 mg/kg are characteristic of cartilaginous crushed stone soil-forming rocks.

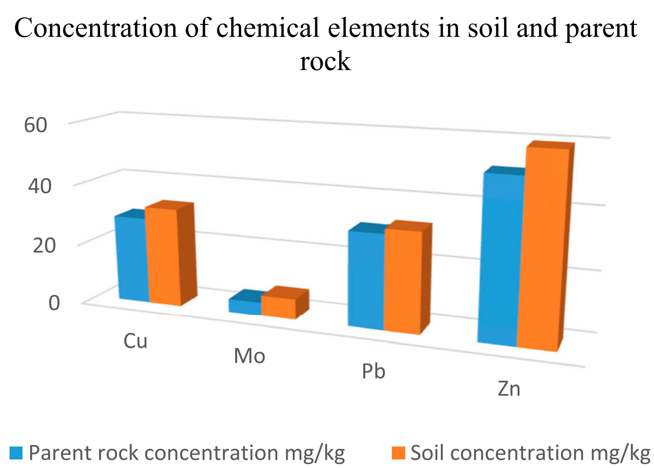

Figure 3. Contents of basic elements in soil-forming rocks and clean soils of the Kostanay region.

The zinc content does not exceed the MPC norm; the average zinc content in the soils was 59.5 ± 5.1 mg/kg, with a range of limits of 33.4-83.9 mg/kg. The minimum average gross zinc content of 33.4 mg/kg is typical for chernozems of southern saline soils (key site No. 2, Ore), while the maximum zinc concentrations of 83.9 mg/kg are characteristic of chernozems of southern saline soils with steppe saline soils (key site No. 7, Zhitikarin).

Lead: The gross lead content in the soil-forming rocks of the region varies from 19.1 to 38.7 mg/kg, with an average coefficient of variation of 24.9%. The average lead content in the whole set of soil-forming rocks is 30.9 ± 3.1.

The average gross content of lead in the soils of the Kostanay region is 32.6 ± 2.6 mg/kg, which is higher than the Clarke Index in the Earth's crust (16 mg/kg). The highest concentrations of lead (41.7 mg/kg), exceeding 1.3 MPC, were found in the upper soil horizon of key site No. 1 (Kostanay production), where southern saline chernozems develop on clays. The lead content increases down the profile. Indeed, data for the city of Kostanay showed that in soil samples taken from various sites the lead content was 3.0-60.3 mg/kg. In the area of the confectionery factory the concentration of lead exceeded 1.9 MPC (*Newsletter on the State of the Environment of Kostanay Region for the First Half of, 2022*). Thus, the results we obtained on the content of lead in the soils of Kostanay are confirmed by the reliability of the data obtained by the branch of RSE Kazhydromet in the Kostanay region for 2022. The results of the study showed that the excess concentration of gross lead is characteristic of light clay chernozems of the southern vital areas No. 1 (Kostanay) at 37.0 mg/kg, No. 3 (Valeryanov) at 38.8 mg/kg, No. 5 (Lisakov) at 35.1 mg/kg, and No. 7 (Zhetikarin) at 33.6 mg/kg.

Copper: The gross copper content in the soil-forming rocks of the region varies from 16.1 to 35.6 mg/kg, with an average coefficient of variation of 23.05%. The average copper content in the whole set of soil-forming rocks is 28.6 ± 2.7 mg/kg, lower than its Clarke Index in the earth's crust (47 mg/kg: Vinogradov, 1957). The lowest levels of copper content is found in light-loamy soil-forming rocks, measured as low as 16.1 mg/kg, while the highest copper content is characteristic of loamy deposits, where the copper content can reach 5.6 mg/kg.

The gross copper content in the soils of the Kostanay region varies from 25.1 to 41.7 mg/kg, with an average coefficient of variation of 19.29%. A slight excess of the maximum permissible concentration (MPC) of the gross copper content in the upper soil horizon (35.6 mg/kg) was established for the southern saline chernozems (key site No. 1). There is an increase in the content of the element down this soil profile from 35.6 to 46.1 mg/kg. The data obtained by us on the excess of copper in the soils of the city of Kostanay are comparable with indicators from the branch of the RSE Kazhydromet in the Kostanay region, which confirms the reliability of the results obtained by us. Indeed, data for the city of Kostanay showed that in soil samples taken from various sites the copper content ranged from 0.4 to 5.0 mg/kg, with measures in the area of the city's confectionery factory exceeding 1.7 MPC (*Newsletter* on the State of the Environment of Kostanay Region for the First Half of 2022).

Lead: The gross lead content in the soil-forming rocks of the region varies from 19.1 to 38.7 mg/kg, with an average coefficient of variation of 24.9%. The average lead content in the whole set of soil-forming rocks is 30.9 ± 3.1.

The lead content increases up the profile. The average gross content of lead in the soils of the Kostanay region is 32.6 ± 2.6 mg/kg, which is higher than the Clarke Index in the

Table 3. Correlation dependences of chemical elements in soils of the Kostanay region

Chemical element	Fe	Cu	Mo	Pb	Zn
Fe	1				
Cu	0.27	1			
Mo	0.34	−0.33	1		
Pb	0.04	−0.02	0.43	1	
Zn	0.72	0.06	0.22	−0.03	1

Earth's crust (16 mg/kg). The highest concentrations of lead (41.7 mg/kg), exceeding 1.3 MPC, were found in the upper soil horizon of key site No. 1 (Kostanay production), where southern saline chernozems develop on clays. Indeed, data for the city of Kostanay showed that in soil samples taken from various sites the lead content was 3.0-60.3 mg/kg. In the area of the confectionery factory the concentration of lead exceeded 1.9 MPC (*Newsletter* on the State of the Environment of Kostanay Region for the First Half of 2022). Thus, the results we obtained on the content of lead in the soils of Kostanay are confirmed by the reliability of the data obtained by the branch of RSE Kazhydromet in the Kostanay region for 2022. The results of the study showed that the excess concentration of gross lead is characteristic of light clay chernozems of the southern vital areas No. 1 (Kostanay) at 37.0 mg/kg, No. 3 (Valeryanov) at 38.8 mg/kg, No. 5 (Lisakov) at 35.1 mg/kg, and No. 7 (Zhetikarin) at 33.6 mg/kg.

Molybdenum: The molybdenum content in the soil-forming rocks of the Kostanay region varies from 1.5 to 11.8 mg/kg, with an average coefficient of variation of 4.5 mg/kg. Gross molybdenum in the soils of the Kostanay region, meanwhile, varies from 1.5 to 16.4 mg/kg, with an average content of 6.9 mg/kg.

Cadmium: The average cadmium content in the soil-forming rocks and soils of the studied region was <3 mg/kg.

According to the values found for the average concentrations of chemical elements (mg/kg) in the soils of the studied region, the elements are arranged in the following decreasing order of prevalence: Fe (44,006.6) > Zn (59.5) > Pb (32.5) > Cu (25.1) > Mo (<6.9), Cd (<3) are arranged in the following decreasing order. Correlational bonds between the chemical elements can also be calculated (see Table 3). A high positive relationship of iron with zinc was established (r = 0.72); a positive weak force relationship was established between iron and molybdenum (r = 0.34) and between iron, and copper (r = 0.27); and negative weak force correlations were found between copper and molybdenum (r = 0.33), copper and lead (r = 0.02), and lead and zinc (r = 0.03).

The issue related to nitrate pollution of soils is becoming increasingly relevant, as too its impact on natural systems, humans and animals is increasing. Nitrates were determined in various types of soils (dark chestnut saline soils, poorly developed chernozems with steppe saline soils), and we found that the nitrate content in the soils of the Kostanay region ranges from 13.0 to 110.0 mg/kg, with an average content of 46.5 mg/kg, not exceeding the MPC (130 mg/kg). The maximum concentration of nitrate is typical for the critical site No. 4 Kurzhunkul, measured at 110 mg/kg, where there are sown fields of grain and oilseed crops.

Chemical elements in Kostanay's water bodies

The overall picture of levels of concentrations of chemical elements in the water bodies of the Kostanay region, based on the study's water samples and analyses, is presented

Table 4. Variation and statistical indicators of the macro-component composition of the waters of the Kostanay region in mg/dm^3.

Parameters	$X \pm S\,x$	lim	p	σ	CV, %
Mineralisation	981 ± 59.6	851–1219	368	206.4	21.04
pH	7.7 ± 0.06	7.5–7.9	0.4	0.2	2.8
Overall rigidity	7.4 ± 0.3	6.7–8.6	1.9	1.02	13.7
Dry residue	859 ± 51.08	747–1063	316	177.0	20.6
HCO_3-	244 ± 16.8	207–311	104	58.1	23.8
H_2CO_3	4 ± 0.3	3.4–5.1	1.7	1.0	23.9
Cl-	289.3 ± 29.7	230–408	178	102.8	35.5
SO_4^{2}-	150 ± 6.2	126–168	42	21.6	14.4
NO_3-	2.8 ± 1.2	0.3–7.7	7.4	4.27	154.4
Ca	57.3 ± 5.3	36–68	32	18.5	32.2
Na + K	181.3 ± 16.4	148–247	99	56.9	31.4
Mg	55.7 ± 6.86	40–83.0	43	23.8	42.7
Nitrates	3.3 ± 1.1	0.3–7.7	7.4	3.9	117.0
Nitrites	0.1 ± 0.03	0.01–0.2	0.2	0.1	121.6
Ammonium nitrogen	0.2 ± 0.02	0.1–0.3	0.1	0.06	30.1
Ammonium ions	0.28 ± 0.02	0.2–0.3	0.2	0.09	30.7

in Table 4. The mineralisation and chemical composition of the river waters of the Tobol River basin depend on the salinity of the soils drained by the rivers. Figure 1. The map shows the boundaries of the Tobol River drainage basin. Mineralisation is a quantitative measure of the dissolved solids content of water, and it is also called soluble solids content or total salt content because dissolved substances in water take the form of salts.

In this regard, the rivers draining the saline Turgai Hollow are distinguished by the most significant mineralisation. The rivers flowing down the Trans-Ural plateau and the Kazakh small hills are the most desalinated. Results show differing extents of mineralisation (Zhetikarin quarry 1219 mg/dm3, Kostanay production 873 mg/dm3, Ore quarry 851 mg/dm3, etc.). The average content of sulphate ions in the studied waters of the basin is 150 ± 6.2 mg/dm^3, with a coefficient of variation of 14.4%, and the range of limits is 126-168 mg/dm^3.

The pH of the aqueous medium determines the probable concentrations of various chemical elements in it, their migration forms, and possible processes of changing concentrations and conditions of elements. According to our studies, the pH of the waters of the Tobol basin averaged 7.7. The value of the total ~~stiffness~~ 'rigidity' lies from 6.7 to 8.6 mg/dm^3, while the average value of the total stiffness is 7.4 ± 0.1 mg/dm^3, with a coefficient of variation of 13.7%. The average ~~moderate~~ hardness is found in the waters sampled at the vital site of Zhitikarin, measured at 8.6 mg-eq/dm^3, and the waters of the critical areas of Kostanay and Rudny, measured respectively at 7.0 and 6.7 mg-eq/dm^3.

The average content of bicarbonate ions in the waters of the Tobol basin iss 244 ± 16.8 mg/dm^3, and variation of this ion measure lies in the range of 207-311 mg/dm^3, with the coefficient of variation at 23.8%. Along with the increased concentration of sulphate ions, chlorine ions are increased (1-1.5 times). The average chloride ion content in the waters of the studied region is 2.8 ± 1.2 mg/dm^3, with fluctuations of 0.3-7.7 mg/dm^3 and the coefficient of variation at 154.4%.

Nitrogen compounds as biogenic components of aquatic ecosystems are indicators of the level of anthropogenic load, and therefore indicators of the content of ammonium nitrogen, nitrates, and nitrites are also used in assessing the quality of the hydro-ecological condition of water bodies. The data obtained on nitrates and nitrous ammonium content in the water bodies of the Kostanay region shows that no excess MPC was detected overall for nitrates, nitrous ammonium, and ammonium ions (see Figure 4). Some individual figures exceeding MPC are nonetheless seen for nitrites, up to 1.25 MPC, with the maximum nitrite content of 0.2 mg/dm^3 found in critical site No.7 (Zhitikarin) due to the influence of the enterprise JSC Kostanay Minerals, which is engaged in extracting asbestos ore. The excess of nitrite indicators is probably due to the industry's impact, and additional monitoring studies are needed to obtain more reliable data.

Concentrations of the PTE Fe, Al, Ba, B, V, K, Ca, Co, Si, Li, Mg, Mn, Mo, Na, Ni, Pb, S, Sr, Ti, and P in the water bodies of the Kostanay region can be determined, as shown in Table 5. As our studies show, the nickel concentration in the surface waters of the region varies from 0.005 to 0.006 mg/dm^3, averaging 0.005 mg/dm^3 and the coefficient of variation at 21.3%. Observations of the branch of RSE Kazhydromet for the quality of surface waters in the Kostanay region reveals a significant excess of nickel. According to previous research (reported in *Newsletter* on the State of the Environment of Kostanay Region for the First Half of 2022) 45 cases of high pollution were detected in the study area: the Zhelkuar River, with 2 cases of high pollution (nickel, chlorides); the Tobyl River, with 20 cases of high pollution (calcium, magnesium, chlorides, sulphates, mineralisation, nickel); and the Obagan River, with 23 cases of high pollution (calcium, magnesium, chlorides, sulphates, mineralisation).

Ions of zinc, copper, cadmium, and lead are among the most dangerous pollutants of the natural environment. Analysis of the obtained data on the concentration of chemical elements in the Kostanay region at the critical sites of Kostanay, Rudny and Zhetikara showed that for these ions no excess of MPC was detected (see Figure 5). Correlations

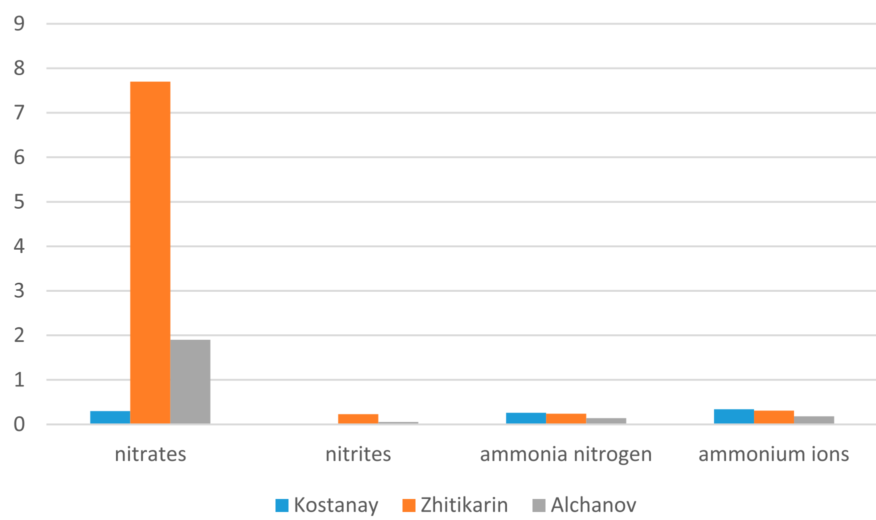

Figure 4. The content of nitrates, nitrites, ammonium nitrogen, and ammonium ions in the water bodies of the study region IN mg/dm^3.

Table 5. Variation and statistical indicators of the distribution of chemical elements in the water bodies of the Kostanay region in 2022mg/dm^3.

Parameters	$X \pm S\ x$	lim	p	σ	CV, %
Fe	0.2 ± 0.02	0.1–0.2490	0.02	0.08	45.2
Al	0.05 ± 0.004	0.04–0.07	0.03	0.01	26.9
Ba	0.06 ± 0.003	0.05–0.07	0.02	0.01	19.9
B	0.2 ± 0.002	0.15–0.16	0.01	0.005	3.09
V	0.005 ± 0.0002	0.004–0.005	0.002	0.0009	19.9
K	7.1 ± 0.7	4.3–8.7	4.5	2.5	34.8
Ca	57.1 ± 5.6	34.8–69.9	35.03	19.4	33.9
Co	0.006 ± 0.0009	0.003–0.009	0.006	0.003	51.1
Si	2.4 ± 0.2	2.0–3.2	1.3	0.7	28.3
Li	0.0105 ± 0.0002	0.01–0.0110	0.001	0.0007	6.7
Mg	50.9 ± 6.3	37.7–75.9	38.2	21.7	42.5
Mn	0.1 ± 0.002	0.02–0.3	0.2	0.0007	86.3
Mo	0.009 ± 0.0006	0.007–0.01	0.004	0.002	25.4
Na	157.97 ± 14.07	128.4–214.2	85.8	48.7	30.9
Ni	0.005 ± 0.0003	0.005–0.006	0.002	0.001	21.4
Pb	0.002 ± 0.0002	0.001–0.003	0.002	0.0008	43.2
S	46.5 ± 1.6	40.9–51.7	10.7	5.4	11.6
Sr	0.7 ± 0.02	0.6–0.7	0.1	0.07	10.2
Ti	0.002 ± 0.0001	0.001–0.002	0.0009	0.0005	32.2
P	0.1 ± 0.03	0.002–0.2	0.2	0.03	93.9
Zn	0.005 ± 0.0001	0.005–0.006	0.2	0.0005	8.8

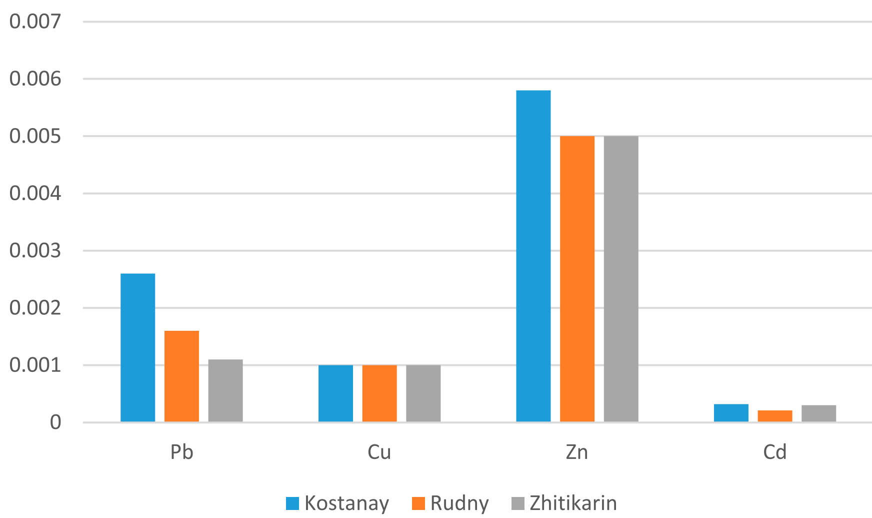

Figure 5. The content of chemical elements (lead, copper, zinc, cadmium) in the water bodies of Kostanay region mg/dm^3.

between trace elements and the main components are very diverse, but some trends can be identified. In most cases the pH and chemical elements are reversed; in strontium, arsenic and copper the relations are unreliable; in nickel and sodium, they are positively vital; between pH and cadmium, they are weak. Overall, it can be assumed that a decrease in pH leads to increased leaching of the studied elements from the water-bearing rocks.

Copper does not have reliable connections with all these components, and its distribution can be explained by the absence of copper contamination of water, suggesting that this element has a natural, non-anthropogenic, distribution. Zinc has a significantly strong and medium relationship with sulphates and calcium, and shows feedback with other macro-components, and so it can be assumed that the zinc content in the studied waters is associated with sulphates. Thus, in sum, and as a result of the conducted monitoring hydrochemical studies, it is found that in the water bodies of the studied region pollutants, maybe PTEs, are exceeding the MPC indicators, the causes of which are associated with industrial, household and agricultural runoff.

Conclusions

The following core findings from this inquiry into the concentrations of chemical elements in the soils and water bodies of the Kostanay region, in the Republic of Kazakhstan, can be listed as follows. There are many implications here for the health of environments and people in the region, with clear indications of anthropogenic influences leading to PTEs in the soils and waters. Continued geochemical monitoring of these concentrations is essential, and the present study has suggested certain critical issues to which future attention should be directed.

1. The average gross content of the chemical elements Zn, Mo, Si, Pb, and nitrates in the soils of the studied area does not exceed the MPC.
2. The average iron content in soils exceeds the Clarke Index for iron in the ground. The maximum iron concentration of 68,222.4 mg/kg is found at the critical site No.5 (Lisakov), associated with an iron ore deposit where iron ore is extracted and processed.
3. The highest concentrations of lead, 41.7 mg/kg, exceeding 1.3 MPC, and of copper, 35.4 mg/kg, exceeding 0.9 MPC, are found in the upper soil horizon of the critical site No. 1, Kostanay production, which is associated with the impact of the city's industrial enterprises.
4. The analysis of the obtained data on the concentration of chemical elements in the Kostanay region's water bodies shows no excess of MPC detected for zinc, cadmium, copper, and lead.
5. The content of nitrates and ammonium nitrogenous in the water bodies of the Kostanay region does not exceed the MPC, but an excess of MPC is detected for nitrites – 1.3 MPC – and is also associated with the impact of industry.
6. Heterogeneity in the content of chemical elements, PTE and pollutants between different soils and water bodies across the studied region is revealed, the spatial distribution here being explained by geographical variability in soil-forming rocks and the landscape-geochemical conditions of migration and accumulation of chemical components, as well as by geographical variability in the influence of mining, industrial and agricultural enterprises.

Note

1. 'Clarks' of different chemical elements means numbers expressing the average content of these elements in the Earth's crust, hydrosphere, Earth as a whole, and cosmic bodies. Generalisation of data on the chemical composition of various rocks composing the Earth's crust, taking into account their distribution to depths of 16 km, was first made by the American scientist F. W. Clark (1889).

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