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ANTHROPOGENIC IMPACT ON SOIL AND VEGETATION IN TURKISTAN REGION: CHEMICAL COMPOSITION AND HEAVY METAL CONTAMINATION

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Abstract: The main purpose of this study is to analyze the anthropogenic impact on the soil and vegetation cover of the landscapes of the Turkistan region (southern part of Kazakhstan), and to investigate the chemical composition of elements and pollutants. The current state of landscapes with patterns of distribution of chemical elements and the influence of anthropogenic activity have been revealed. Quantitative indicators of the content of chemical elements (carbon, oxygen, sodium, magnesium, aluminum, silicon, potassium, calcium, titanium, iron, lead, arsenic, copper, zinc, nickel, cobalt, vanadium, thallium, manganese, and strontium) were studied based on soil samples. The levels of concentration of chemical elements of vegetation cover, aboveground and underground parts (carbon, oxygen, sodium, magnesium, aluminum, silicon, phosphorus, sulphur, chlorine, potassium, calcium, iron and copper) were assessed. The results of the chemical analysis of the soil cover revealed an excess of the maximum permissible concentration of chemical elements (lead, copper, zinc, arsenic, and chromium), while elevated levels of insoluble ash were observed in plants.

Keywords: chemical composition; environmental impact; anthropogenic activities; land resources

1. Introduction

As a result of scientific and technological progress, evolving social relations, and human impact on the environment at a global scale, landscapes have undergone structural changes (Wolf et al., 2023). Landscape pollution refers to the excessive concentration of certain substances or energy in the environment, surpassing permissible levels, and the infiltration of toxic substances into the landscape due to both human activities and natural processes (Kolluru et al., 2023; Panfilova et al., 2019). Understanding the level of these substances in soil and vegetation plays an important role in developing a strategy for the rational use of the environment and improving the system of soil and geochemical monitoring (Komilova et al., 2021; Ozgeldinova et al., 2019; Raj et al., 2022).

Anthropogenic activities significantly impact soil and vegetation, altering their chemical composition and introducing pollutants (Lyubchik et al., 2008; Tikhonova et al., 2008). Abera

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et al. (2023) highlighted how land cover and management changes in Southeastern Kenya affect environmental conditions, which is relevant to the Turkistan region where similar practices may influence soil and vegetation composition. Dağyeli (2023) discussed the long-term effects of agro-pastoralist livelihoods in Central Asia, providing context for understanding anthropogenic pressures in the Turkistan region and their impact on soil and vegetation. Wang et al. (2023) demonstrated how land use changes in China's karst regions affect ecosystem services, offering parallels for assessing the impact of similar processes in the Turkistan region on chemical composition and contamination levels. These studies collectively emphasize the need to understand and mitigate the environmental impacts of human activities.

According to Khodjimatov and Bajmurotov (2023), the study of the impact of anthropogenic activities on the soil and vegetation cover in Turkistan region is an important task from the standpoint of assessing the ecological state of the region. Currently, there is an impact of human activity, including industry and agriculture, on the soil composition, which is manifested in the introduction of a variety of chemicals into the soil. Problems of soil pollution are associated with the appearance of heavy metals, pesticides, fertilizers, and other chemical compounds in it. Following Alikulov et al. (2023) and Valeyev et al. (2023), a qualitative study of the chemical composition of the soil will help to assess the level of pollution and its effect on vegetation. Due to the increase in anthropogenic load, this study focuses on the chemical composition of soils and vegetation of the Turkistan region and assesses the impact of anthropogenic factors on ecosystems.

According to Zhumanov (2022), anthropogenic impacts such as deforestation, land misuse, and construction can lead to increased soil erosion. However, it is necessary to consider in more detail the fact that the study of the aspect of deforestation is key to fully understand the long-term consequences of their impact on landscape sustainability. Shamshiev et al. (2022) note that the study of the current state of landscapes includes the analysis of patterns in the distribution of chemical elements and the impact of human activity on the environment. It is important to note that a comprehensive investigation of the landscape condition requires analyzing the chemical elements present in the soil. These elements include heavy metals (e.g., lead, cadmium, mercury), minerals, and other chemical compounds. High concentrations of heavy metals are very dangerous for living organisms, as they accumulate inside the body and cause severe poisoning (Mukayev et al., 2019; Ozgeldinova et al., 2015; Ozgeldinova et al., 2019).

The primary aim of this study is to analyze the impact of human activities on the soil and vegetation cover in the Turkestan region. The specific objectives are as follows:

- to analyze the chemical composition of elements and pollutants in the soil and vegetation cover of the region, while also assessing the heterogeneity of concentrations; and
- establishing a framework to devise efficient soil remediation techniques for minimizing heavy metal contamination in the Turkistan area, focusing on specific locations in Shymkent and Turkistan, to meet regulatory standards for enhancing soil quality.

2. Materials and methods

The research focuses on the Turkistan region, an administrative area in the southern part of Kazakhstan. This region is located geographically in the middle latitudes of Central Eurasia, encompassing the eastern part of the Turan Lowland and the western slopes of the Tien Shan mountains. In the north, the territory is in contact with the Ulytau region, in the west it is bounded by the Kyzylorda region, in the east it borders with the Jambyl region, and in the south, it adjoins Uzbekistan. The study area is characterized by a variety of topography and landscapes formed by various geological and geomorphological processes. Turkistan region is one of the regions where industry and agriculture are closely interconnected (Huang & Yu, 2023). The impact of anthropogenic activity, due to the dynamic development of the economy, is continuously increasing from year to year. As a result of this action, various toxic substances penetrate into the soil cover and vegetation, which leads to types of chemical pollution (Guo et al., 2024).

At the stage of the preliminary study, nine key sites were identified for field work, considering the possible impact of anthropogenic factors on the natural landscapes of the main zones of Turkistan region. The high spatial resolution Landsat 9 satellite images for the year 2023 were utilized to assess the state of the environment for the chosen locations (U.S. Geological Survey, 2023). These satellite images provide detailed visual data, offering insights into land use, vegetation cover, changes in landscape patterns, and potentially identifying areas affected by anthropogenic activities (Table 1). Field studies of soil cover and vegetation were conducted in July and August 2023.

Table 1. The main information related to key sites of the Turkistan region

No.	Coordinate	Location	Types of anthropogenic activities	Sampling date
1	**Arys** 42°30′17.80″N 68°48′45.34″E	3.9 km south of the city of Arys, the southern slope of the Arys River, alluvial plain.	**Urban industrial:** production facilities in the food industry include a meat processing plant, a dairy processing plant, and enterprises in the flour and bakery industries. **Mining industry:** non-metallic ores (bentonite clay, limestone-shell deposit). **Agriculture:** cattle breeding, grass cutting; plant cultivation pastures (pastures 426,643 ha).	07/21/2023
2	**Zhetisay** 40°48′2.85″N 68°21′7.73″E	Hilly relief formations extend toward the northeast from the settlement of Zhetisay, on the left bank of the Dostyk Canal, in the catchment area of the Syr Darya River.	**Urban industrial:** food industry (beef processing plant, starch and citric acid production from maize); light industry (cotton processing, cotton cleaning factories). **Agriculture:** cattle breeding, grass cutting; plant cultivation; pastures (pastures 1,487 ha).	07/22/2023
3	**Zhuantobe** 44°42′14.13″N 68°47′17.39″E	4 km south of the village of Zhuantobe, south of the Shu River, there is a slightly crossed flat plain with temporary riverbeds.	**Communications and transport:** oil pipelines (outside the city). **Agriculture:** cattle breeding, grass cutting; plant cultivation (irrigated crops 442 ha); pastures (pastures 380,137 ha).	07/23/2023

Table 1. The main information related to key sites of the Turkistan region (*continued*)

No.	Coordinate	Location	Types of anthropogenic activities	Sampling date
4	**Shymkent** 42°25′58.90″N 69°42′53.48″E	Located in the foothills of the Tien Shan Mountains, Shymkent city is 3 km northeast of its center. Located on the watershed between the Sayram and Badam rivers, the city is represented by arid and erosive hill forms, being at an altitude of 506 meters above sea level.	**Urban industrial:** food industry (vegetable oils, flour, milk, pasta, confectionery); light industry (garment factory, manufacturing company); construction industry (factory for the production of porcelain stoneware and ceramic plates); metalworking industry (metallurgical plant).	07/30/2023
5	**Kazygurt** 41°48′44.70″N 69°23′49.73″E	5.9 km north of the village of Kazygurt, on the southern slope of Mount Kazygurt, on the right bank of the Keles River, bumpy hills.	**Urban industrial:** food industry (instant pasta, beverages, natural juice, milk powder and butter); construction industry (enterprise for the production of "Reinforced concrete products"). **Agriculture:** cattle breeding, grass cutting; plant cultivation; pastures (pastures 133,460 ha).	07/31/2023
6	**Saryagash** 41°48′41.73″N 69°23′48.52″E	At a distance of 1.6 km south and west of the city of Saryagash, in the basin of the Keles and Kurkeles rivers, hilly areas rise high, which represent an area with numerous elevations.	**Urban industrial:** food industry (mineral water bottling, production of high-quality wine products, wheat flour products); light industry (production of cotton fiber). **Recreational:** recreation areas (sanatoriums). **Agriculture:** cattle breeding, grass cutting); plant cultivation; pastures (pastures 294,579 ha).	08/01/2023
7	**Karabulak** 42°32′4.20″N 69°42′38.07″E	At a distance of 5.8 km to the southeast of the village of Karabulak, the alluvial and proluvial plain stretches, bounded by the Aksu and Arys rivers.	**Agriculture:** cattle breeding, grass cutting; plant cultivation; pastures (remote lands—8,234 ha).	08/02/2023
8	**Shubarsu** 42°30′46.12″N 69°22′28.03″E	The alluvial and proluvial plain, which is a riverine area, is located on the Western bank of the Shubarsu River and is a tributary of the Arys River, just 4 km northwest of the village of Shubarsu.	**Transport infrastructure and communication system:** communications and transport (international transit corridor); roads, pipes, gas pipeline (outside the city).	08/04/2023

Table 1. The main information related to key sites of the Turkistan region (*continued*)

No.	Coordinate	Location	Types of anthropogenic activities	Sampling date
9	**Turkistan** 43°16′9.60″N 68°21′40.72″E	8.9 km southeast of the city of Turkistan, south of Mount Karatau, there is an alluvial and proluvial plain.	**Urban industrial:** light industry (sewing workshop). Mining industry: non-metallic ores (clay-gypsum deposit).	08/06/2023

Note. Compiled by the author based on U.S. Geological Survey (USGS). (2023). Landsat 9 imagery, Scene ID for the Turkistan region, Kazakhstan. Available at: https://earthexplorer.usgs.gov/

Measuring concentrations of chemical elements in soil sections involves collecting soil samples at various depths to determine the content of different elements. This method includes analyzing the presence of elements such as carbon (C), oxygen (O), sodium (Na), magnesium (Mg), aluminum (Al), silicon (Si), potassium (K), calcium (Ca), titanium (Ti), iron (Fe), lead (Pb), arsenic (As), copper (Cu), zinc (Zn), nickel (Ni), cobalt (Co), vanadium (V), thallium (Tl), manganese (Mn), phosphorus (P) sulphur (S) chlorine (Cl), and strontium (Sr). After collection, samples undergo processing in the lab, which includes drying, crushing, and homogenizing to ensure uniformity and representativeness. Laboratory techniques such as atomic absorption spectroscopy and inductively coupled plasma are employed to measure element concentrations (Kolluru et al., 2023). The resulting data are interpreted to identify patterns in element distribution across soil depths, aiding in understanding processes like element migration and the impact of human activities or natural processes on soil chemistry. Considering the impact of human activity in various typical natural areas of integrated landscapes, soil sections were created. Samples were taken from these sections to analyze the chemical composition of the soil cover and the dominant plants (aboveground and underground parts) in accordance with the genetic horizons.

The received analytical test samples were investigated in the certified regional engineering and testing laboratory in Shymkent. In addition, special research focus is directed at two key sites, Shymkent and Turkistan, to evaluate contamination levels. Soil samples were collected to a depth of 30 cm from several points within each study area to account for spatial variability. Sampling points were located at a distance of 1 to 5 m from each other, depending on the terrain. Plant samples were collected for analysis of heavy metals and other pollutants accumulated in plants, which are highly sensitive to pollution. The number of chemical elements in soil and vegetation samples was measured based on physicochemical methods by the Spectroscan MAX GF–2E X-ray spectroscope. The data obtained during the study were statistically processed using the Microsoft Excel software suite. Plant samples were collected from field conditions, washed with water, dried, ground into powder, and analyzed for heavy metal concentration.

3. Results

The geological structure of the area under study includes sedimentary rocks of different ages, from Proterozoic to modern Quaternary deposits. The most common are Proterozoic and Paleozoic deposits. The area encompasses excavation, landform modifications, and the construction of artificial hills or reservoirs (Duan et al., 2023). This study found that at a depth of 0.3 m from the ground surface, there were no significant changes in the chemical composition of the soil. The number of elements associated with the distribution of chemical elements in the soil, and variational and statistical indicators in soils relative to the physicochemical properties were determined during the study (Table 2).

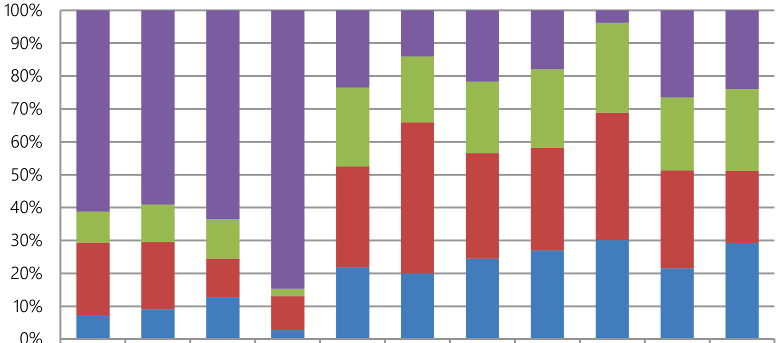
Table 2. Statistical indicators of the soil macro-component obtained from samples collected at nine key sites in the Turkistan region

Parameters	*X±Sx*	*lim*	*p*	*σ*	*CV*	*mass*
Humus	0.71±0.06	0.99—0.51	0.48	0.2	27.99	–
C	5.56±0.39	7.24—3.57	3.67	1.34	24.05	2
O	52.43±0.22	53.66—51.37	2.29	0.76	1.45	55
Na	0.65±0.04	0.81—0.4	0.41	0.15	22.76	0.63
Mg	1.63±0.05	1.95—1.44	0.51	0.17	10.64	0.63
Al	5.9±0.23	7.42—5.25	2.17	0.8	13.55	7.13
Si	19.11±0.54	21.6—16.44	5.16	1.87	9.81	33
K	2.1±0.08	2.55—1.89	0.66	0.28	13.54	1.36
Ca	7.85±0.63	10.61—4.81	5.8	2.17	27.72	1.37
Ti	0.36±0.01	0.39—0.31	0.08	0.03	9.72	0.46
Fe	4.3±0.18	5.45—3.8	1.65	0.61	14.22	3.8
P	0.03±0.02	0.2—0	0.2	0.08	244.95	0.08

Note. *X±Sx* (mg/kg except for humus in %)—mean value (*X*) ± standard error of the mean (*Sx*); *lim (%)*— range of values observed (maximum—minimum); *p*—the probability value, often indicating the significance of differences or variations; *σ*—standard deviation; *CV (%)*—coefficient of variation; *mass* (%)—average chemical elemental composition of soils

The study found that the humus content in all soil samples does not exceed 1%, which is considered a very low level. Soil fertility largely depends on the amount of organic matter, particularly humus. The level of soil fertility increases with an increase in humus content. Humic substances reduce soil wear, that is, they improve its water-physical, water-temperature, physicochemical, and other properties (Li et al., 2023). Anthropogenic changes, such as land development and landscape modification, are closely linked to low soil humus content. When natural habitats such as forests, marshes, and coastal areas are destroyed, the amount of organic material that accumulates in the soil in the form of humus decreases. The loss of vegetation associated with these changes leads to a decrease in organic residues that form humus. In addition, anthropogenic activities, including agriculture, can cause soil erosion, which reduces the topsoil where humus typically accumulates. These changes can also affect the chemical composition of the soil, which impairs humus formation. Thus, anthropogenic changes directly and indirectly reduce the humus content of the soil (Wolf et al., 2023).

The content of heavy metals in the soil at key site 4, Shymkent, exceeds the norms set by the On Approval of Hygienic Standards for the Safety of the Living Environment (2015), by more than several times, according to chemical analysis of samples taken in areas with significant sources of pollution and high population density. According to this Order, the maximum permissible concentrations for heavy metals in soil are as follows: Pb—32 mg/kg, As—2 mg/kg, Cu—3 mg/kg,Zn—23 mg/kg, and Ni—4 mg/kg. In Kazakhstan, as in many countries, specific limits and thresholds are set for various pollutants, including heavy metals like Pb, As, Cu, Zn, Ni, and others.These limits are established to protect environmental quality and human health from the adverseeffects of pollution. For instance, the permissible levels of these heavy metals in soil are defined based on scientific assessments of their toxicity and environmental impact. These legislative normsin Kazakhstan might align with international standards, guidelines recommended by organizations such as the World Health Organization, and/or environmental directives from bodies like theEuropean Union. For site No. 4, the observed concentrations of several heavy metals exceed permissible limits by several times, especially for Pb (Figure 1).



	Pb	As	Cu	Zn	Ni	Co	V	Tl	Mn	Fe	Sr
Shymkent No. 4-4	1288.00	276.59	344.13	7164.35	36.15	2.80	63.01	0.37	107.00	4.15	273.30
Shymkent No. 4-3	199.39	53.17	65.77	193.61	37.00	4.01	63.00	0.50	764.39	3.47	285.00
Shymkent No. 4-2	462.00	96.00	63.00	871.50	47.30	9.15	93.47	0.65	1084.00	4.67	250.00
Shymkent No. 4-1	154.68	42.40	69.60	233.00	33.56	4.00	71.00	0.56	843.55	3.38	333.45

Figure 1. The concentration of heavy metal ions (mg/kg) at sampling locations of the key site No. 4 in Shymkent.

It has been proven that heavy metals are released into the air in particularly high quantities and are contaminated with heavy metal salts (Zhang et al., 2023). The sizes of variational and statistical indicators of chemical elements in the soils of the key site No. 4 in Shymkent are given in Table 3.

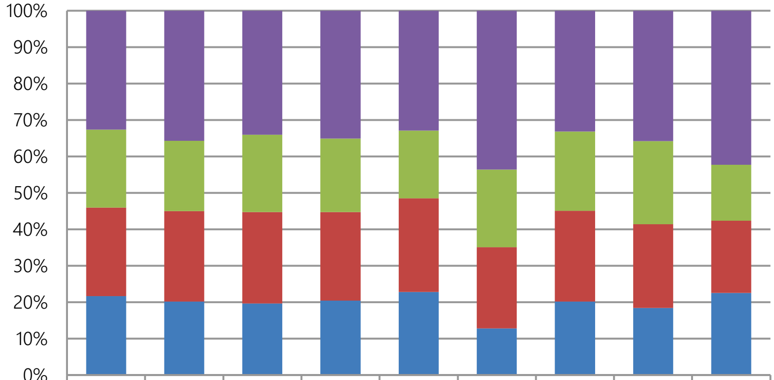
Table 3. Statistical characteristics of the variation in the distribution of heavy metal ions in the soil at thekey site No. 4 in Shymkent

Parameters	*X*±*Sx*	*lim*	*p*	*σ*	*CV*
Pb	526.02±151.78	1,288—154.68	1,133.32	525.77	99.95
As	117.04±31.42	276.58—42.4	234.18	108.85	93.01
Cu	135.62±40.13	344.13—63	281.13	139.03	102.51
Zn	2,115.62±975.76	7,164.35—193.61	6,970.74	3,380.13	159.77
Ni	38.5±1.75	47.3—33.56	13.74	6.05	15.7
Co	4.99±0.82	9.15—2.8	6.35	2.83	56.72
V	72.62±4.16	93.47—63	30.47	14.4	19.83
Tl	0.52±0.03	0.65—0.37	0.28	0.12	22.18
Mn	699.74±120.63	1,084—107	977	417.87	59.72
Fe	3.92±0.18	4.67—3.38	1.29	0.61	15.5
Sr	285.44±10.15	333.45—250	83.45	35.16	12.32

Note. *X*±*Sx* (mg/kg)—mean value ± standard error of the mean; *lim* (%)—range of values observed (maximum—minimum); *p*—the probability value, often indicating the significance of differences or variations; *σ* —standard deviation; *CV* (%)—coefficient of variation.

In the average condition, the concentration of As in the soil varies from 0.3 to 12.9 mg/kg. It is carried in the soil to a depth of up to 60 cm and accumulates in the treated layer. The average As content in the soil of the world is 5 mg/kg (U.S. Environmental Protection Agency, 2005). The main sources of soil contamination with As are herbicides, insecticides, and other pesticides used systematically in agriculture (Kumar et al., 2023). Road construction and development can change water flows, affect the hydrological regime of rivers and streams, and lead to a decrease in the area of natural reservoirs (Assede et al., 2023). In the studied soils, the average content of total As in the surface layer is 117.04±31.42 mg/kg. And in the soil samples taken from areas with a high concentration of population, the size limits are lower (Abera et al., 2023; Huang & Yu, 2023; Vinogradov, 2020).

The samples taken from the main production facilities, park areas, and other points at the key site No. 9 in Turkistan, found that the Al content in these samples exceeds the maximum permissible norms by 3–4 times (Figure 2). The average Ni content in the soil of the world is 40 mg/kg (Zhang et al., 2023). Toxic substances, entering the soil and water, can penetrate into plants and animals. This leads to toxins entering the food chain, eventually reaching human levels and affecting health (Kolluru et al., 2023; Li et al., 2023).



	Mn	Zn	Al	Ni	Pb	Cd	Cr	Cu	Fe
Turkestan No. 9-4	652.35	66.85	33194.02	27.25	16.53	0.41	57.85	43.93	25.36
Turkestan No. 9-3	426.30	36.04	20670.62	15.62	9.35	0.20	37.93	28.06	9.21
Turkestan No. 9-2	486.32	46.38	24368.28	18.85	12.89	0.21	43.42	28.23	11.92
Turkestan No. 9-1	431.96	37.72	19138.49	15.81	11.47	0.12	35.17	22.57	13.52

Figure 2. The concentration of heavy metal ions (mg/kg) at the sampling points of the key site No. 9 in Turkistan

The variational and statistical characteristics of the soils at the key site No. 9 are presented in Table 4. Information on transformed species is needed to assess and characterize the hazard of compounds ingested as plant products grown on contaminated soils. The more mobile types of these elements are, the faster they move from soil to plants, that is, because of this, their danger increases. Toxic substances can have harmful effects on animals and plants in natural ecosystems, which can lead to a decrease in biodiversity and even to the extinction of individual species (Abera et al., 2023; Du et al., 2023; Huang & Yu, 2023).

Table 4. Characteristics of variations and distribution of heavy metals in the soil at the key site No. 9 in Turkistan

Parameters	*X*±*Sx*	*lim*	*p*	*σ*	*CV*
Mn	499.23±30.49	652.35—426.3	226.05	105.6	21.15
Zn	46.75±4.08	66.85—36.04	30.81	14.15	30.26
Al	24,342.85±1,817.47	33,194.02—19,138.49	14,055.53	6,295.88	25.86
Ni	19.38±19.38	27.25—15.62	11.63	5.45	28.12
Pb	12.56±0.87	16.53—9.35	7.18	3.02	24.04
Cd	0.24±0.04	0.41—0.12	0.29	0.12	52.52
Cr	43.59±2.92	57.85—35.17	22.68	10.1	23.18
Cu	30.7±2.66	43.93—22.57	21.36	9.21	29.99
Fe	15±2.06	25.36—9.21	16.15	7.13	47.53

Note. *X*±*Sx* (mg/kg)—mean value (*X*) ± standard error of the mean (*Xs*); *lim* (%)—range of values observed (maximum—minimum); *p*—the probability value, often indicating the significance of differencesor variations; *σ*—standard deviation; *CV* (%)—coefficient of variation.

The plants of the Turkistan region are represented by meadow and meadow steppe associations. The soil cover in the flat part forms grey, saline, pale grey, and sandy soil. Meadow, mountain brown soils are common in the foothills. Vegetation typical of the desert belt is mainly formed (Zhou et al., 2024). Saxaul, juzgun, wormwood, saltwort, cockspur grass, cheegrass, camel's-thorn, wheat grass; jujube, tamarisk, willow grow in the valleys of the Syr Darya, Chu rivers; oatmeal and wormwood steppes grow in the foothills, fruit trees, junipers, alpine meadows grow in the mountains (Wang et al., 2023). The intense impact of human activity has a significant impact on the vegetation cover of the Turkistan region, leading to negative changes in the species composition, structure, and productivity of ecosystems.

Plants act as a key indicator of pollution by industrial emissions into the environment, as they are the first to respond to man-made pressure due to their increased sensitivity to anthropogenic impact (Gorshkov, 1982). Toxic substances can accumulate in plant and animal tissues, which can lead to long-term consequences for ecosystems and consumer health (Wang et al., 2023). In an area with a high content of pollutants, plants accumulate them in maximum (marginal) amounts in the middle of the growing season. Toxic substances can cause various diseases and environmental problems (Sofi et al., 2023). Under the influence of pollutants, the soil cover is transformed, and the composition of soil microorganisms changes. These changes are manifested in a decrease in the diversity of species affecting the biochemical activity of soils and an increase in the proportion of microorganisms resistant to pollution. In the fight against landscape pollution, control and monitoring measures are being taken, such as the collection of the data on air, water, and soil quality and the introduction of technologies and practices to reduce emissions of harmful substances (Dağyeli, 2023). A study of the vegetation cover in key sites of the Turkistan region was conducted in order to ensure comparability of the indicator characteristics of plants depending on the natural impact and the form of anthropogenic impact on them.

The dominant vegetation of the study area includes *Psoralea*, a shrub of the legume family associated with high desertification, and is characterized by a desert natural zone consisting predominantly of perennial herbaceous plant species. *Psoralea* is a shrub of the legume family, whose plants are associated with high desertification of the relief of this natural ecosystem, and belongs to a desert natural zone consisting of a predominance of perennial herbaceous plant species (Wang et al., 2023). The vegetation cover of pastures is represented by camel's-thorn (*Alhagi*), a perennial plant association belonging to the legume family, as well as Austrian wormwood (*Artemisia austriaca*), a perennial shrub belonging to the genus wormwood of the aster family, and wild carrot (*Daucus*), a genus of dicotyledonous, monocotyledonous or perennial herbaceous plants of the celery family, and redshank (*Persicaria maculosa*) is an annual herbaceous plant of the buckwheat family. Due to some anthropogenic actions, the vegetation cover undergoes changes in the size of its normal shape, which indicates excessive grazing on pasture lands (Aslam et al., 2024).

Fieldwork conducted in July 2023 showed that the humus content in the soil is sharply decreasing from top to bottom. This indicates the spread of plants within 30 cm from the base of the roots. The chemical composition of dominant plants (aboveground and underground parts) was assessed based on the content of macro components and heavy metals in conditions of contamination of vegetation cover in the area. The results did not reveal an excess of the maximum permissible concentration of heavy metal ions in the composition of plants. The number of elements related to the distribution of chemical elements of the vegetation cover and the variational and statistical indicators of plants relative to the physicochemical properties determined by the study are given in Table 5.

Table 5. Statistical indicators of the macro-component composition of aboveground and underground vegetation cover in the Turkistan region

Parameters	*X±Sx*	*lim*	*p*	*Σ*	*CV*
Ash	9.12±0.54	11.26—6.51	4.75	1.86	20.41
C	13.39±0.51	15.16—11.36	3.8	1.78	13.31
O	43.27±0.93	48.84—40.96	7.88	3.23	7.46
Na	1.58±0.54	3.74—0.26	3.48	1.89	119.36
Mg	3.83±0.66	6.65—1.34	5.3	2.27	59.38
Al	1.49±0.2	2.05—0.52	1.53	0.71	47.66
Si	3.93±0.79	6.96—0.58	6.38	2.75	69.94
P	2.75±0.71	6.96—1.07	5.89	2.47	89.93
S	1.82±0.36	3.43—0.51	2.92	1.23	67.87
Cl	1.33±0.34	2.99—0.18	2.81	1.19	89.79
K	16.46±1.78	27.27—11.73	15.97	6.18	37.52
Ca	13.60±1.64	22.45—8.19	10.72	5.69	41.86
Fe	1.26±0.17	1.74—0.45	1.29	0.59	47.07
Mn	0.11±0.07	0.56—0	0.56	0.25	223.61
Cu	0.07±0.05	0.37—0	0.37	0.17	223.61

Note. *X±Sx* (mg/kg)—mean value ± standard error of the mean; *lim* (%)—range of values observed (maximum—minimum); *p*—the probability value, often indicating the significance of differences or variations; *σ*—standard deviation; *CV* (%)—coefficient of variation.

According to the data obtained, Mg and Cu concentrations were below the detection level. It was also revealed that plants in key sites No. 1 in Arys and No. 4 in Shymkent exhibit high "dustiness". Thus, chemical monitoring studies of the plants revealed that the concentrations of pollutants in the vegetation cover do not exceed the permissible maximum levels (following the same norms as for soil).

4. Discussion

This study highlighted that in areas heavily populated and near major pollution sources, including emissions from a metallurgical enterprise in Shymkent, soil heavy metal ion concentrations exceed established standards by more than 2.5 times on average. Pb content, in particular, surpasses standard values by several times. Figure 2 illustrates the concentration of heavy metal ions at sampling points at key site No. 4 in Shymkent, depicting the extent of contamination. There is a metal mining and processing enterprise ("Yuzhpolymetal") in this area that is involved in the extraction and processing of metal ores, which can result in significant emissions of heavy metals and toxic gases into the environment. This is the primary source of heavy metal and toxic gas emissions into the local environment. Analysis revealed that Pb ion content, the most toxic element among those studied, exceeds standards by nearly five times. This underscores the profound impact of industrial emissions on soil quality in the region. Soil contamination with heavy metals like Pb carries severe consequences for ecosystems and human health. Pb, known for its extreme toxicity, especially affects children and can lead to various metabolic disorders. Its high mobility in soils allows for accumulation in plants, potentially entering the food chain and thereby affecting the health of those who consume contaminated plants (Guo et al., 2024).

Measuring the concentration of chemical elements in vegetation, including aboveground and underground parts, is an important aspect of ecosystem research (Glibovytska & Shkitsa, 2020; Fedoniuk et al., 2024; Semak & Mylenka, 2024). The choice of specific plant species depends on the research objectives. Different plants may have different levels of adaptation to soil and climatic conditions, which affects their chemical composition. Plant samples are collected in various parts of the ecosystem, including aboveground parts (leaves, stems, flowers) and underground parts (roots, tubers, bulbs) (Illienko et al., 2023; Shaforost et al., 2024). This may also include collecting samples from different areas of the soil around the plants.

The results of the studies conducted by Zhou et al. (2024) and Franco-Rozo et al. (2024) demonstrate a common emphasis on the use of atomic absorption for the analysis of elements in soil and plants, but they focus on different aspects of this approach. Zhou et al. (2024) note the method's high sensitivity and accuracy, which make it ideal for detecting even low concentrations of elements. They emphasize the importance of these characteristics to ensure effective environmental pollution monitoring.

On the other hand, the study by Franco-Rozo et al. (2024) focuses on the use of standards with known elemental concentrations as a key element in calibration and ensuring the accuracy of analytical results. They point out the importance of using certified reference materials to ensure the reproducibility and reliability of analyses, which is critical in ensuring that elemental concentrations in real soil samples are correctly determined. Both studies demonstrate the importance of using modern analytical methods and standards in studying the impact of human activity on the environment. The use of the atomic absorption method in conjunction with certified standards is a critical step toward improving the quality and reliability of scientific research in the field of natural resource protection.

Ahmad et al. (2024) determined that increased concentrations of Pb in the soil may be associated with industrial emissions, transport pollution, or the use of lead compounds in agriculture. This metal can accumulate in the soil cover and pose a danger to plants, animals, and humans. Elevated levels of Cu and Zn may be associated with the use of fertilizers, pesticides and other chemicals. Furthermore, according to this study, insufficient attention is paid to the importance of maintaining balance and stability in the soil ecosystem. Cu and Zn, inexcessive amounts, can also have toxic effects on plants and microorganisms in the soil. The significance of information regarding the increase of As levels in the soil is often overstated. Thisincrease may be due to natural processes such as mineral weathering, as well as human activities such as industrial emissions and the use of As compounds in agriculture.

Aslam et al. (2024) note that manufacturing enterprises, especially those engaged in metallurgy, mining, or other processes related to the use of Zn, can release significant amounts of Zn into the atmosphere in the form of aerosols or gases. These emissions can settle on the soil surface near enterprises and lead to an increase in the Zn content in the soil. The use of fertilizers, pesticides, and herbicides containing zinc in agriculture can become a source of its accumulation in the soil.

As noted by Guo et al. (2024), the high-temperature combustion process can be used forvarious purposes, such as analyzing the composition of a sample, evaluating its mineral composition, or determining the content of insoluble residues. Insoluble ash includes minerals, metal oxides, and other inorganic compounds that remain after the burning of organic components. Determination of insoluble ash content in a sample is an important parameter in various fields, such as the analysis of soils, fuels, mineral materials, and industrial waste.

All previously mentioned confirm the importance and necessity of monitoring and managing soil quality in regions with a high degree of anthropogenic impact. The obtained results of the analysis of the chemical composition of soils in the Turkistan region, where the maximum permissible levels of heavy metals were found to be exceeded, indicate environmental pollution problems. The findings can provide information about the mineral composition and overall purity of the sample, and can also be practically applied to monitor production processes and ensure the quality of various materials. Exceeding the maximum permissible concentrations of the above chemical elements may indicate potential problems of soil contamination in the area under study.

5. Conclusion

The obtained conclusions indicate that the chemical study of the soil cover in the considered key sites demonstrates an excess of the maximum permissible concentrations of chemical elements such as Pb, Ni, Cu, and Zn. The industrial and livestock operations have resulted in elevated levels of insoluble ash in plants. In two key sites, No. 4 and No. 9 (Shymkent and Turkistan), significant contamination of heavy metal ions was found in the observed soil samples: the concentration of Ni exceeds the maximum permissible level by 3–4 times, Cu by 7–14 times, Zn by 1.5–3 times, and Cr by 5–9 times. The Pb concentrations in Shymkent exceed the national legislation norm by over ten times.

The limitations of the present study include a restricted sample size and geographic scope, which may not fully capture the variability of soil and vegetation contamination across the entire region. In the course of the conducted research, the set goals were successfully achieved, including the analysis of methods, the study of the impact of anthropogenic activities on the soil and vegetation cover of the landscapes of the Turkistan region, and the analysis of the chemical composition. All these actions are aimed at increasing the potential, competitiveness, and quality of services provided under the influence of pollutants. In the future, scientific research will focus on the development and implementation of innovative mechanisms for accurately measuring the concentration levels of chemical elements in vegetation in order to advance the field of ecology.

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