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**ARTICLE TOPIC: COMPREHENSIVE ASSESSMENT OF SOIL AND FLORA
CONTAMINATION BY HEAVY METALS IN THE ZONE OF INFLUENCE OF THE
NIKOLAEVSKAYA ENRICHMENT PLANT**

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Abstract. Agricultural lands in East Kazakhstan region cover a significant area, with large portions of pasture and cropland situated in close proximity to operating industrial facilities. Despite this, no comprehensive integrated assessment combining remote sensing, ground-based soil monitoring, and flora survey had previously been conducted for the zone of influence of the Nikolaevskaya enrichment plant. This study aimed to fill that gap by a 40-year land cover analysis (1985-2024) using publicly available satellite data processed in Google Earth Engine with soil sampling and vegetation surveys across 17 sites. Soil analyses revealed not only elevated heavy metal concentrations but also a sharp pH decrease, conditions under which heavy metals become significantly more mobile and available for plant uptake. Technosol formation was observed at multiple sampling points, indicating a permanent transformation of the natural soil profile. The flora survey recorded 72 species from 62 genera, with ruderal and synanthropic species dominating disturbed habitats and native species persisting only at control points more distant from the facility. Taken together, these findings point to ongoing ecosystem degradation and raise concrete concerns for the regional food chain given the pastureland and cropland adjacent to the plant.

Keywords: heavy metals, soil contamination, East Kazakhstan, technogenic soil, remote sensing.

INTRODUCTION

The environment has a significant impact on human living conditions. Long-term exposure to anthropogenic factors ultimately leads to the destruction of the natural ecosystem and the formation of a technogenic environment, which is characterized by a deterioration in the qualitative properties of environmental objects. Environmental monitoring is necessary to identify environmental risks that local populations and living organisms may face [1]. Previous studies have proven that high concentrations of Zn, Pb, Cd, As, and Cu are found in plants growing near heavy industrial enterprises [2]. This creates a certain food chain for the transfer of heavy metals (HMs) from environmental elements to the human body [3]. Most HMs have carcinogenic and embryogenic effects

on humans and plants [4]. This includes the effects of Cd, Pb and As, which are associated with harmful effects on the cardiovascular, nervous, reproductive and renal systems, and can lead to the development of cancer [5].

Soils significantly impacted by anthropogenic factors differ highly from normal soils. They exhibit a shift in pH toward alkalinity, a reduced oxidation-reduction potential, and high levels of organic matter, N, K, and P [6]. Urban soils accumulate pollutants, including HMs, and contain large quantities of foreign materials. Soil plays an important role in the ecological balance but can pose a health hazard due to the high concentrations of heavy metals [7]. Agricultural land in Kazakhstan occupies 114 million hectares, accounting for 43% of the country's total

land area, of which 12.3% (14 million hectares) is located in the East Kazakhstan region (EKR) [8].

This is the third-largest amount of land in the country used for agricultural purposes. The EKR's agricultural lands are primarily pastures, as the sown area, according to the Kazakhstan Statistics Agency, is 642,000 hectares. This means that in addition to the transfer of HMs along the soil-plant-human chain, this leads to HM intoxication in grazing livestock, which then enters the human body via livestock products along the soil-plant-animal-human chain. According to mapping data from the FAO [9] and the USDA Foreign Agricultural Service [10], the Nikolaevskaya enrichment plant is located throughout EKR's agricultural lands. Given this, the need for research is urgent.

Ground-based monitoring of soil pollution with HM is based on the study of wind patterns, the particle size of sludge waste, and the organic and mineral composition of the soil (to study the capture of heavy metals in the crystalline structure of the soil) [11]. This allows to determine the horizontal and vertical migration of HMs relative to the source, which is used to provide an ecological assessment of the soil condition [12]. However, comprehensive, large-scale monitoring of the impact of man-made sources of air pollution in the EKR has not been conducted yet.

The use of remote sensing provides significant support for environmental and agricultural monitoring. The size of large areas can be estimated based on the visual interpretation of satellite images and the obtained biophysical variables. Reliable information on the environmental situation in the EKR is essential for municipal authorities, as well as the ministries of agriculture, ecology, and health, to make decisions and develop strategies for environmental stabilization, sustainable agricultural development, and improving the health of the region's population. In addition, such studies reveal the impact of

anthropogenic sources on wild flora, enabling measures to conserve the biodiversity of this unique region.

In this article, the object of the study is the soil cover, including arable land, adjacent to the "Nikolaevskaya enrichment plant" industrial facility, located in the EKR. The research was structured around three objectives: 1) conducting environmental monitoring using modern GIS and remote sensing methods and technologies to support short-, medium-, and long-term planning and adaptation measures to natural and anthropogenic changes and consequences; 2) studying the impact of technogenic zones on the environment using ground-based monitoring methods; 3) studying the species composition and dominant species of wild flora in zones affected by identified hazardous pollution sources.

MATERIALS AND METHODS

Study site and industrial facility

The study object is the soil cover and arable lands adjacent to the Nikolaevskaya enrichment plant, located near the village of Ust-Talovka, Shemonakhinskiy district, East Kazakhstan region. The plant is operated by KazMinerals LLP, a subsidiary of Vostoktsvetmet LLP. It was commissioned in 1980 and processes ores from the Artemyevsky, Orlovsky, and Irtyshsky mines, with a capacity of approximately 2.2 million tonnes of ore per year. The main products are copper, zinc, and lead concentrates. The primary pollutants emitted by the facility are copper, lead, zinc, and sulfuric acid vapour used in lead processing.

Physical-geographical characteristics

The study area is located in the north-eastern part of the Kazakhstani Altai and the Irtysh River basin. The terrain includes mountains, foothills, plains, and depressions. Soils range from chernozems to dark and light chestnut soils. The climate is sharply continental, with large daily and annual temperature swings.

Remote sensing and land-use mapping

Biophysical parameters and land-use data were collected as key inputs for

ecological assessment. A regionally adapted soil-vegetation cover classification was developed to distinguish arable and anthropogenically affected lands from natural cover types [13]. Various input data options were tested, including multi-

spectral bands, vegetation indices, water and soil indices, and radar polarisation indices. A pixel-based random forest classifier with 100 decision trees was used for this purpose (figure 1).

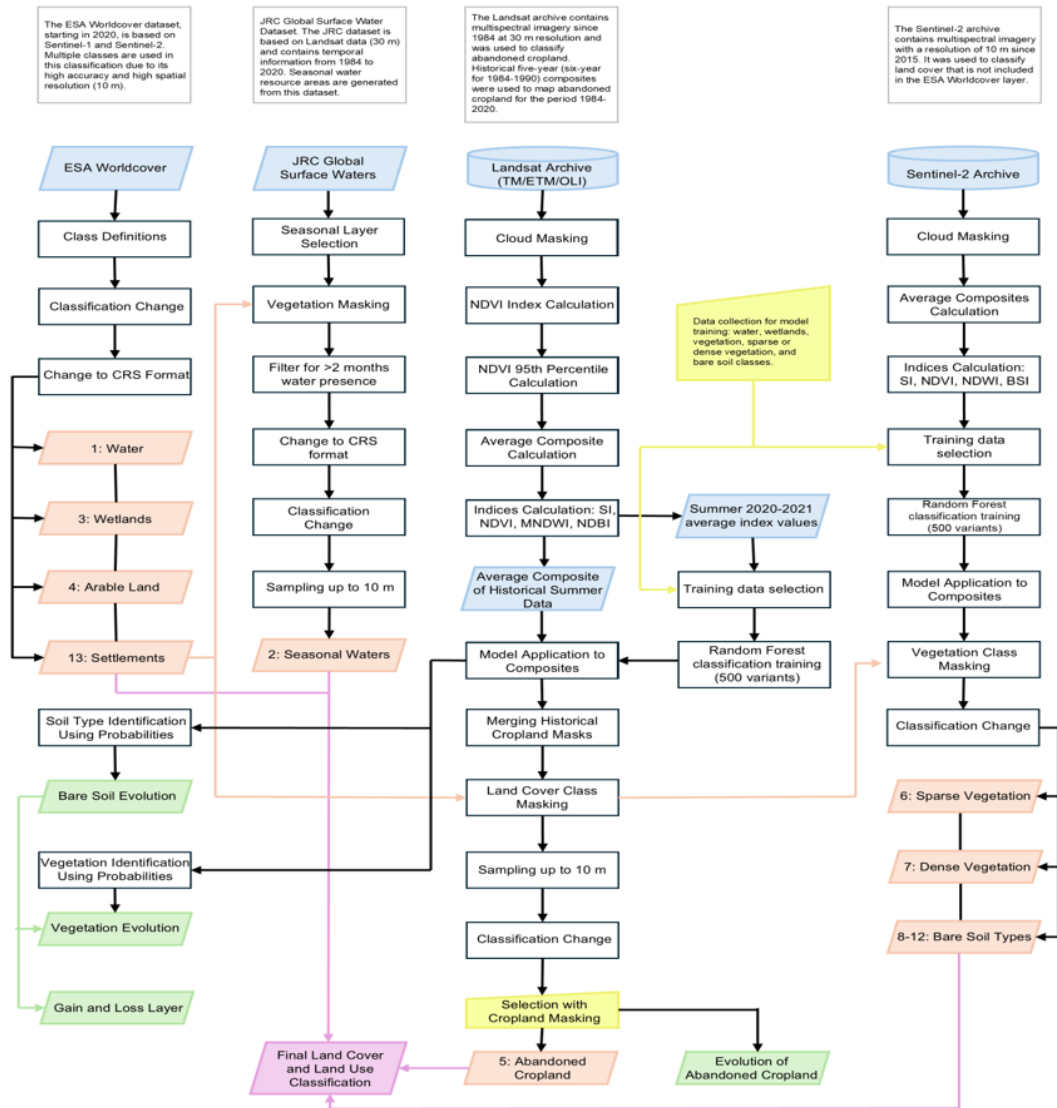


Figure 1 - Classification scheme of regional vegetation cover, considering the specification and classes of vegetation of interest in the area of interest

The resulting classification was used to identify agricultural areas and to map crop types in greater detail, as well as to assess soil-vegetation cover for signs of anthropogenic disturbance.

A temporal analysis covering approximately 40 years (1985-2024) was con-

ducted to track environmental and anthropogenic changes in EKR. Maps from earlier periods were combined with regional expert knowledge to evaluate trends in agriculture, soil degradation, water availability, and air quality. Particular attention was paid to abandoned fields and their

subsequent trajectories, such as full degradation, conversion to pasture, or recovery of natural vegetation. A dedicated mapping workflow was developed for this purpose.

For soil-vegetation cover mapping and the identification of cultivated lands during cropping seasons from 2020 to 2024, a dynamic code was written in Google Earth Engine [14] using Sentinel-2 time-series data. For the 1985-2024 period, Landsat archive data were used. Five-year composites were applied in the time-series analysis to produce more stable results, as the area of interest is frequently cloud-covered.

Figure 1 shows the data sources and all necessary pre-processing steps, as well as the classification steps.

Soil sampling design and field procedures

The field survey was conducted by interpreting map-based versions obtained

using GPS receivers. On this basis, soil profiles were established and soil samples were collected. The survey also included a reconnaissance phase, and profile and description point locations were selected to achieve maximum spatial coverage of the study area.

Soil samples were collected from all study sites in accordance with the Soil Sampling Standard Operating Procedure ENV 3.13. Systematic random sampling was used, dividing the study area into smaller sampling zones using a square grid with 500 m spacing. The number of samples was determined by the size of the area, with a minimum of 30 samples per land-use category to support subsequent statistical analysis. Sampling points were set in eight directions around the plant, at two distance ranges: within 500 m and more than 500 m away (figure 2).



Figure 2 - Soil sampling points at the Nikolaevskaya enrichment plant and zone of influence

Soil samples were collected at two depths, 0-10 cm and 30-40 cm, for chemical analysis.

During an expedition in October 2024, agricultural areas within the zone of technogenic influence of the Nikolaevskaya enrichment plant were monitored. The geolocations of croplands were recorded using a Garmin GPSMAP 66s.

The following GPS coordinates correspond to the two sampling points at the Nikolaevskaya enrichment plant, Shemonaikhinskiy District:

Point 1: N 50°35.4176, E 81°53.2148.

Point 2: N 50°35.4892, E 81°52.8846.

GPS coordinates of vegetation survey locations (17 sites including control points) are listed in table 1.

Table 1 - GPS coordinates of vegetation survey locations at the Nikolaevskaya enrichment plant

№	Location	Latitude	Longitude
1	GPS №26	50°35.9075	81°53.2816
2	GPS №27	50°35.4892	81°52.8846
3	GPS №28	50°35.4176	81°53.2148
4	GPS №29	50°35.4212	81°53.2949
5	GPS №30	50°35.3408	81°54.9838
6	GPS №31	50°35.4328	81°54.2778
7	GPS №0172	50°35.2602	81°53.1613
8	GPS №0173	50°35.1113	81°53.0591
9	GPS №0174	50°35.2001	81°52.5524
10	GPS №0175	50°35.0398	81°52.6439
11	GPS №0176	50°33.9831	81°51.9451
12	GPS №0177	50°33.0830	81°51.8720
13	GPS №0178	50°33.0139	81°50.8734
14	GPS №0179	50°32.6072	81°51.2286
15	GPS №0180	50°33.4568	81°50.8376
16	GPS №0194	50°31.1753	81°55.5703
17	GPS №0195	50°29.9037	81°54.0129

Laboratory analytical methods

Soil chemical analysis was carried out using standard methods accepted in soil science, agrochemistry, and ecology. Aggregate composition was determined by sieve analysis. Cation exchange capacity was measured by the method of E.V. Bobko and D.L. Askinazi, as modified by P.G. Grabarov and Z.A. Uvarova. The sum of exchangeable bases was determined by the Kappen method. Carbonates were measured by the method of E.V. Arinushkina, as modified by P.G. Grabarov. Soil pH was determined by potentiometry. Particle size distribution was determined by the Kachinsk method. Organic matter content

was measured according to GOST 26213-91. Humus composition was determined by the method of V.V. Ponomareva and T.A. Plotnikova [15]. Easily hydrolysable nitrogen was measured by the Tyurin-Kononova method. Mobile forms of phosphorus and potassium were determined by the Machigin method (TsINAO). Heavy metals extractable with an ammonium acetate buffer solution (pH 4.8) were determined by atomic emission spectrometry.

Collection and description of wild flora

Wild flora was collected and described using route-reconnaissance and semi-

stationary methods [16]. Routes were laid out across areas affected by technogenic impact, and annual expeditions were conducted along these routes in five stages, each lasting ten days. Field work included herbarium collection, sample gathering for laboratory analysis, photography, and phytocoenose description. Transects of varying configurations were laid out to assess the current state of populations at the population-organism level.

Plant community descriptions followed the methodology of B.A. Bykov [16]. Geographic, taxonomic, biological, and ecological analyses were conducted according to the methods of A.I. Tolmachev [17], R.V. Kamelin [18], and L.Ya. Kurochkina [19]. Genus and species names follow Plants of the World Online (POWO, 2022), and

authorship follows the International Plant Names Index (IPNI, 2022).

RESULTS AND DISCUSSION

Mapping of agricultural areas and assessment of soil-vegetation cover in East Kazakhstan region

The application of the developed classification workflow to the EKR produced a regionally adapted land-cover map distinguishing agricultural, anthropogenically disturbed, and natural vegetation areas across the study zone (figure 3). The 40-year temporal analysis (1985-2024) confirmed the persistence of agricultural land use in the immediate vicinity of the Nikolaevskaya enrichment plant throughout the observation period, underlining the chronic nature of the exposure risk.

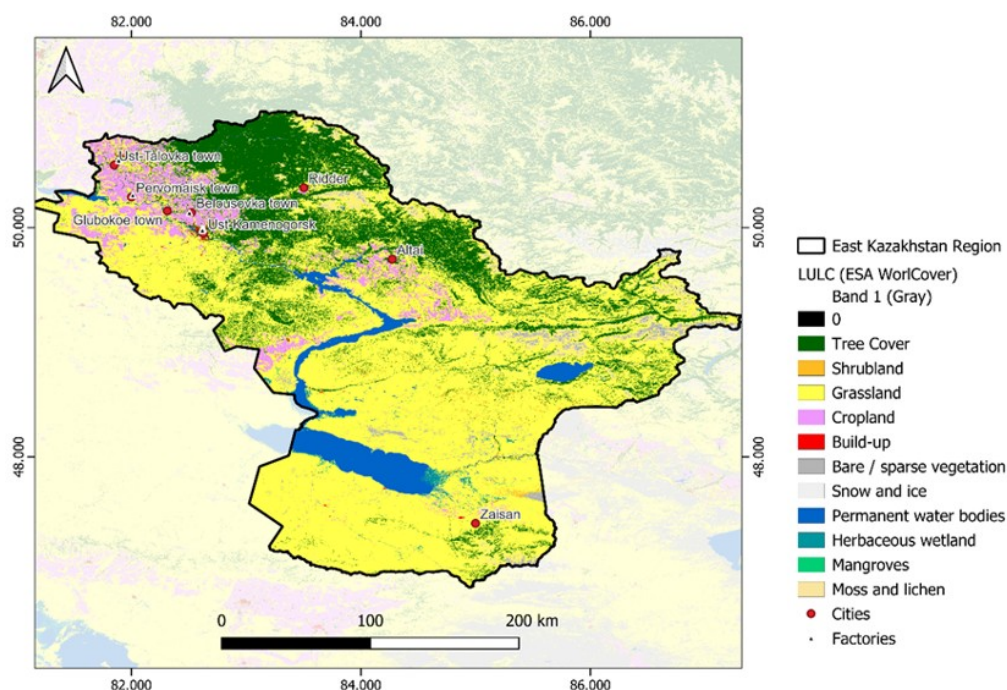


Figure 3 - ESA WorldCover information layer for East Kazakhstan region

Agrochemical and physico-chemical soil properties, background heavy metal content in undisturbed soils, and total and mobile heavy metal content in the zone of influence

The soil profile of undisturbed and uncontaminated soil was sampled and results were entered into a database that

includes the following soil properties: humus, CO₂, Ca, Mg, Na, N, P, K, particle size distribution, and the content of total and mobile forms of heavy metals.

Humus content in the upper soil layers shows relatively low variability. In the 0-5 cm layer it ranges from 1.98% to

8.02%. The content of mobile forms of P and K range from medium to high levels. The soil pH was slightly acidic at the surface, but decreased sharply with depth, reaching very acidic values of 2.51–2.66. Exchangeable Ca is the dominant cation in the soil, which is typical for most fertile soils. Some sampling points showed elevated heavy metal concentrations: Zn at 4510 mg/kg soil, Cd at 36 mg/kg and Cu at

2572 mg/kg (plant territory, point T-33). At several sampling points, the formation of technogenic soil with deposited layers was observed.

Comparison of heavy metal concentrations between uncontaminated reference soil and the most heavily affected sampling points are presented in table 2 and reveal the scale of contamination.

Table 2 - Heavy metal concentrations in reference soil and at maximum contamination point (T-33), mg/kg

Metal	Reference soil 0-20 cm (mean ± SD)	Reference soil 20-40 cm (mean ± SD)	Maximum recorded (point T-33)	Ratio T-33 / reference
Zn	307.3 ± 45.2	245.6 ± 112.3	4510	14.7x
Cu	46.2 ± 5.6	38.6 ± 5.1	2572	55.6x
Cd	4.96 ± 2.69	4.12 ± 2.37	36	7.3x

In reference dark chestnut agricultural soil (sampled from uncontaminated cropland), total Zn stood at 307.3 ± 45.2 mg/kg and total Cd at 4.96 ± 2.69 mg/kg, these values are themselves elevated above typical geochemical background for this soil type, likely reflecting the regional history of diffuse industrial atmospheric deposition in East Kazakhstan. Against this already-elevated baseline, peak concentrations recorded at point T-33 represent exceedances of 14.7-fold for Zn (4510 mg/kg), 55.6-fold for Cu (2572 mg/kg), and 7.3-fold for Cd (36 mg/kg). The spatial pattern of contamination showed a decline with increasing distance from the facility,

consistent with aerial deposition as the primary dispersal pathway.

Species diversity of plant communities at the study sites

The composition of the vegetation cover was surveyed at 17 locations across different parts of the plant territory, including control points. The dominant species recorded at Nikolaevskaya enrichment plant are listed in the Supplementary table 3.

The total number of plant species recorded at the time of the survey at the Nikolaevskaya enrichment plant was 72 species from 62 genera. Of these, 16 were woody species, including 9 trees and 7 shrubs.

Supplementary table 3 - Species recorded at disturbed habitats of the Nikolaevskaya enrichment plant

Genus	Species Name	Common Name
Acer	<i>Acer negundo</i> L.	Box elder
Achillea	<i>Achillea millefolium</i> L.	Common yarrow
Agrimonia	<i>Agrimonia pilosa</i> Ledeb.	Hairy agrimony
Agropyron	<i>Agropyron desertorum</i> (Fisch. ex Link) Schult.	Desert wheatgrass
Arctium	<i>Arctium tomentosum</i> Mill.	Woolly burdock

Continuation of table 3

Artemisia	<i>Artemisia absinthium</i> L.	Common wormwood
	<i>Artemisia austriaca</i> Jacq.	Austrian wormwood
	<i>Artemisia dracunculus</i> L.	Tarragon
	<i>Artemisia gmelinii</i> Weber ex Stechm.	Gmelin's wormwood
	<i>Artemisia vulgaris</i> L.	Common mugwort
Berteroa	<i>Berteroa incana</i> (L.) DC.	Hoary alyssum
Betula	<i>Betula pendula</i> Roth	Silver birch
	<i>Betula pubescens</i> Ehrh.	Downy birch
Bidens	<i>Bidens tripartita</i> L.	Three-part beggarticks
Bromus	<i>Bromus inermis</i> Leyss.	Smooth brome
Bunias	<i>Bunias orientalis</i> L.	Turkish wartycabbage
Calamagrostis	<i>Calamagrostis epigeios</i> (L.) Roth	Wood small-reed
Cannabis	<i>Cannabis ruderalis</i> Janisch.	Wild hemp
Caragana	<i>Caragana frutex</i> (L.) K. Koch	Shrubby caragana
Carduus	<i>Carduus crispus</i> L.	Curly plumeless thistle
Carlina	<i>Carlina biebersteinii</i> Bernh. ex Hornem.	Bieberstein's carline thistle
Carum	<i>Carum carvi</i> L.	Caraway
Chenopodium	<i>Chenopodium album</i> L.	Fat hen
Cichorium	<i>Cichorium intybus</i> L.	Common chicory
Cirsium	<i>Cirsium arvense</i> (L.) Scop.	Creeping thistle
	<i>Cirsium vulgare</i> (Savi) Ten.	Spear thistle
Convolvulus	<i>Convolvulus arvensis</i> L.	Field bindweed
Crataegus	<i>Crataegus chlorocarpa</i> Lenne et K. Koch	Green-fruited hawthorn
	<i>Crataegus sanguinea</i> Pall.	Siberian hawthorn
Dactylis	<i>Dactylis glomerata</i> L.	Cock's-foot
Dracocephalum	<i>Dracocephalum nutans</i> L.	Nodding dragonhead
Echinops	<i>Echinops tricholepis</i> Schrenk	Globe thistle
Echium	<i>Echium vulgare</i> L.	Common viper's bugloss
Elytrigia	<i>Elytrigia repens</i> (L.) Nevski	Common couch grass
Eryngium	<i>Eryngium planum</i> L.	Flat sea holly
Euphorbia	<i>Euphorbia</i> sp.	Spurge
Festuca	<i>Festuca pratensis</i> Huds.	Meadow fescue
Filipendula	<i>Filipendula vulgaris</i> Moench	Dropwort
Fragaria	<i>Fragaria viridis</i> Duchesne	Green strawberry
Geum	<i>Geum urbanum</i> L.	Wood avens
Gypsophila	<i>Gypsophila altissima</i> L.	Tall gypsophila
Heteropappus	<i>Heteropappus altaicus</i> (Willd.) Novopokr.	Altai heteropappus
Hypericum	<i>Hypericum elongatum</i> Ledeb.	Elongated St John's wort
	<i>Hypericum perforatum</i> L.	Common St John's wort
Lavatera	<i>Lavatera thuringiaca</i> L.	Garden tree mallow
Leonurus	<i>Leonurus glaucescens</i> Bunge	Motherwort
Lonicera	<i>Lonicera tatarica</i> L.	Tatarian honeysuckle
Malus	<i>Malus baccata</i> (L.) Borkh.	Siberian crab apple
Matricaria	<i>Matricaria</i> sp.	Chamomile
Melilotus	<i>Melilotus albus</i> Medik.	White melilot
Padus	<i>Padus avium</i> Mill.	Bird cherry
Phlomoides	<i>Phlomoides tuberosa</i> (L.) Moench	Tuberous phlomoides
Plantago	<i>Plantago lanceolata</i> L.	Ribwort plantain
Poa	<i>Poa pratensis</i> L.	Kentucky bluegrass

Continuation of table 3

Populus	<i>Populus balsamifera</i> L.	Balsam poplar
	<i>Populus nigra</i> L.	Black poplar
Rosa	<i>Rosa acicularis</i> Lindl.	Prickly rose
	<i>Rosa spinosissima</i> L.	Burnet rose
Rubus	<i>Rubus caesius</i> L.	Dewberry
Rumex	<i>Rumex confertus</i> Willd.	Russian dock
Salvia	<i>Salvia stepposa</i> Schost.	Steppe sage
Serratula	<i>Serratula coronata</i> L.	Saw-wort
Setaria	<i>Setaria viridis</i> (L.) P. Beauv.	Green bristlegrass
Sonchus	<i>Sonchus arvensis</i> L.	Field milk thistle
Spiraea	<i>Spiraea hypericifolia</i> L.	St John's wort-leaved spiraea
Stipa	<i>Stipa</i> sp.	Feather grass
Tragopogon	<i>Tragopogon orientalis</i> L.	Eastern goat's beard
Trifolium	<i>Trifolium hybridum</i> L.	Alsike clover
Ulmus	<i>Ulmus pumila</i> L.	Siberian elm
Valeriana	<i>Valeriana officinalis</i> L.	Common valerian
Verbascum	<i>Verbascum songaricum</i> Schrenk	Dzungarian mullein
Vicia	<i>Vicia sepium</i> L.	Bush vetch

The soil acidification pattern of near-neutral pH in the upper horizon (6.0–7.5) but a sharp drop to acidic pH (2.51–2.66) at depth, is characteristic of sulfide ore processing environments, where SO₂ emissions and acid leachate from tailings drive progressive subsurface acidification [2, 20]. Under such conditions, the mobility of heavy metals increases substantially. Soil acidification has been shown to increase metal mobility in the order Cd > Zn > Pb, with Cd retaining high mobility at up to 70% of its total concentration even under near-neutral pH conditions [20]. This places the Nikolaevskaya enrichment plant zone in a particularly critical risk category: Cd concentrations at point T-33 (36 mg/kg) already exceed the regional agricultural soil background by 7.3-fold, and continued subsurface acidification is likely to further increase bioavailability over time.

The magnitude of Zn and Cu contamination at peak points is directly comparable to values reported in a parallel assessment of soils adjacent to the Ridder metallurgical complex, another major polymetal-

lic processing facility within the same region, where Zn reached 4415 mg/kg, Cu reached 1177 mg/kg, and Cd reached 179 mg/kg [21]. Taken together, the findings confirm that extreme multi-metal soil contamination is a regional pattern in EKR rather than a site-specific anomaly. Notably, even the reference soils sampled at uncontaminated cropland suggests that diffuse atmospheric deposition from regional industrial activity has already affected the broader agricultural landscape beyond the direct influence zone of individual facilities.

The vegetation data support this picture of broad ecosystem transformation. The dominance of *Artemisia* spp., *Cirsium* spp., and *Bunias orientalis* in disturbed habitats is consistent with patterns documented for industrially impacted landscapes across the region, where ecologically plastic and stress-tolerant ruderal taxa progressively replace native steppe communities under conditions of chronic heavy metal exposure and soil disturbance [21, 22]. The 72 species recorded across 17 sites, while numerically diverse, rep-

resent a functionally impoverished flora dominated by weedy generalists rather than the native meadow-steppe assemblages characteristic of undisturbed EKR landscapes.

The combined soil and vegetation data indicate that the Nikolaevskaya enrichment plant has created a gradient of ecosystem degradation extending beyond its immediate boundaries. The presence of technogenic soils at multiple sampling points, characterized by deposited layers that disrupt the natural soil profile, suggests that these changes are not temporary, but represent long-term, likely irreversible pedogenic transformations driven by sustained industrial activity. Given that agricultural croplands and extensive pasturelands are located adjacent to the affected area, heavy metal contamination through both soil and plant pathways poses tangible risks to the regional food chain, particularly via the soil-plant-livestock-human pathway.

CONCLUSION

The Nikolaevskaya enrichment plant operates within an agricultural landscape that has never previously been subject to a systematic assessment. This study showed that the technogenic influence of the facility has produced measurable and serious

changes to both soil properties and vegetation across the surrounding area.

Ground-based soil sampling confirmed the presence of significant heavy metal contamination in the vicinity of the facility. A sharp decrease in soil pH with depth to values of 2.51-2.66 was recorded, indicating ongoing acidification likely connected to the industrial process. At these pH levels, heavy metals become significantly more mobile and available for plant uptake. The formation of technogenic soil with deposited layers at several sampling points reflects a substantial transformation of the natural soil profile under prolonged technogenic pressure.

The vegetation data confirms this. The 72 species recorded may appear diverse, but the composition is dominated by ruderals and synanthropic species and reflects the replacement of natural plant communities under anthropogenic pressure. Native species held their ground only at control points further from the source.

These findings call for systematic remediation assessment and the establishment of long-term ecological monitoring for the zone, particularly given the scale of adjacent pasturelands used for livestock grazing.

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ТҮЙІН

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COMPREHENSIVE ASSESSMENT OF SOIL AND FLORA CONTAMINATION BY HEAVY METALS IN THE ZONE OF INFLUENCE OF THE NIKOLAEVSKAYA ENRICHMENT PLANT

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Шығыс Қазақстан облысындағы ауылшаруашылық алқаптары айтарлықтай аумақты алып жатыр, сонымен бірге жайылымдық және егістік жерлердің үлкен бөлігі қолданыстағы өнеркәсіптік кәсіпорындарға жақын орналасқан. Осыған қарамастан, Николаев тау-кен байыту комбинатының әсер ету аймағы үшін бұрын қашықтықтан зондтау, жердегі топырақ мониторингі және флораны зерттеуді біріктіретін кешенді интеграцияланған бағалау жүргізілмеген. Бұл зерттеу Google Earth Engine жүйесінде өңделген жалпыға қолжетімді спутниктік деректерді пайдалана отырып, 17 учаскедегі топырақ үлгілерін және өсімдіктерді зерттеу арқылы 40 жылдық (1985-2024) жер жамылғысын талдау арқылы бұл олқылықты толтыруға бағытталған. Топырақ талдаулары ауыр металдардың концентрациясының жоғарылауымен қатар рН деңгейінің күрт төмендеуін, яғни ауыр металдардың өсімдіктерге сіңуі үшін айтарлықтай қозғалмалы және қолжетімді болатын жағдайды көрсетті. Бірнеше сынама алу нүктелерінде техногенді топырақ түзілуі байқалды, бұл табиғи топырақ профиінің қайтымсыз өзгеруін көрсетеді. Флораны зерттеу барысында 62 туыстан 72 түр тіркелді, рудеральды және синантропты түрлер бұзылған тіршілік ету орталарында басым, ал жергілікті түрлер тек нысаннан алыс бақылау нүктелерінде сақталды. Жалпы алғанда, бұл зерттеулер экожүйенің деградациясының жалғасып жатқанын көрсетеді және өсімдікке іргелес жайылымдар мен егістік алқаптарды ескере отырып, аймақтық азық-түлік тізбегіне қатысты нақты алаңдаушылық тудырады.

Түйінді сөздер: ауыр металдар, топырақтың ластануы, Шығыс Қазақстан, техногенді топырақ, қашықтан зондтау.

РЕЗЮМЕ

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КОМПЛЕКСНАЯ ОЦЕНКА ЗАГРЯЗНЕНИЯ ПОЧВ И ФЛОРЫ ТЯЖЁЛЫМИ МЕТАЛЛАМИ В ЗОНЕ ВЛИЯНИЯ НИКОЛАЕВСКОЙ ОБОГАТИТЕЛЬНОЙ ФАБРИКИ

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Сельскохозяйственные земли Восточно-Казахстанской области занимают значительную площадь, при этом большая часть пастбищ и пахотных угодий расположена вблизи действующих промышленных объектов. Несмотря на это, ранее не проводилось

комплексного исследования, объединяющего данные дистанционного зондирования, полевые анализы почв и изучение флоры для зоны влияния Николаевской обогатительной фабрики. Целью данной работы было восполнить этот пробел путём анализа землепользования за 40 лет (1985–2024 гг.) с использованием открытых спутниковых данных, обработанных в Google Earth Engine, а также результатов отбора почвенных проб и геоботанических описаний на 17 участках. Анализ почв показал не только повышенные концентрации тяжёлых металлов, но и заметное снижение pH, при котором металлы становятся более подвижными и легче поглощаются растениями. На ряде участков зафиксировано формирование технозёмов, что указывает на устойчивое изменение природного почвенного профиля. В ходе исследования флоры было выявлено 72 вида из 62 родов; на нарушенных территориях преобладают рудеральные и синантропные виды, тогда как аборигенные виды сохраняются в основном на контрольных участках, удалённых от предприятия. В целом полученные результаты свидетельствуют о продолжающейся деградации экосистем и вызывают обоснованные опасения для региональной пищевой цепи, учитывая расположение пастбищ и сельскохозяйственных угодий в непосредственной близости от предприятия.

Ключевые слова: тяжёлые металлы, загрязнение почв, Восточный Казахстан, техногенная почва, дистанционное зондирование.

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