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«ҚАЗАҚСТАН РЕСПУБЛИКАСЫ
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АКАДЕМИЯСЫ» РҚБ

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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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ИЗВЕСТИЯ

РОО «НАЦИОНАЛЬНОЙ
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Y.Kh. Kakimzhanov[1], *K.T. Kyrgyzbay[1], S.M. Zhumatayev[2], T.A. Bazarbayeva[1], G.T. Kunypiyaeva[3], 2025.
[1]Al-Farabi Kazakh National University, Almaty, Kazakhstan;
[2] K.I. Satbayev Kazakh National Research Technical University, Almaty, Kazakhstan;
[3]Kazakh Research Institute of Agriculture and Plant Growing, Almaty region, Kazakhstan.
E-mail: kyrgyzbay.kudaibergen@gmail.com

ASSESSMENT OF SOIL CONTAMINATION OF THE WEST KAZAKHSTAN REGION WITH HEAVY METALS AS A RESULT OF INDUSTRIAL ACTIVITY

Kakimzhanov Y.Kh. – PhD, Acting Associate Professor, Al Farabi Kazakh National University, Almaty, Kazakhstan, Email: erkinkakimzhanov@gmail.com; https://orcid.org/0000-0001-6454-681X;
Kyrgyzbay K.T. – PhD, lecturer, Al Farabi Kazakh National University, Almaty, Kazakhstan, Email: kyrgyzbay.kudaibergen@gmail.com; https://orcid.org/ 0000-0002-4279-6436;
Zhumatayev S.M. – PhD student, Senior lecturer, K.I. Satbayev Kazakh National Research Technical University, Almaty, Kazakhstan, Email: serikzhumatayev@gmail.com; https://orcid.org/0009-0008-1618-7881;
Bazarbayeva T.A. – Head of department UNESCO Chair in Sustainable Development, Candidate of Geographical Sciences, Docent, Al Farabi Kazakh National University, Almaty, Kazakhstan, Email: tursynkul.bazarbayeva@gmail.com; https://orcid.org/0009-0008-5685-5215**;**
Kunypiyaeva G.T. – candidate of agricultural sciences, senior researcher, Kazakh Research Institute of Agriculture and Plant Growing, Almaty region, Kazakhstan, Email: kunypiyaeva_gulya@mail.ru; https://orcid.org/0000-0001-8606-765X.

Abstract. The study is devoted to the analysis of soil pollution in the West Kazakhstan region with heavy metals and hydrocarbons as a result of intensive activities of the oil and gas and mining industries. The main attention is paid to the determination of pollutant concentrations, their spatial distribution and the impact on ecosystems. It has been established that the region's soils are long-term accumulators of man-made pollutants, including heavy metals (lead, cadmium, arsenic, chromium, nickel) and hydrocarbons. Key industrial zones of the region, such as Khromtau, Aktobe, Karachaganak field and oil refineries, have been selected as objects of study.

Field and laboratory studies were carried out using generally accepted sampling methods (GOST 17.4.4.02-2017) and chemical analysis (atomic absorption spectrophotometry, X-ray fluorescence analysis). Geostatistical data analysis was carried out using GIS technologies (ArcGIS), which made it possible to create spatial maps of the distribution of pollutants. The results showed that the concentrations of heavy metals in the studied soils exceed the maximum permissible values (MPC). For example, near large industrial facilities, the concentration of chromium reaches 7333.6 mg/kg, nickel – 2213.1 mg/kg, and arsenic – 19 mg/kg.

It has been revealed that soil pollution is accompanied by a deterioration of their physico-chemical characteristics, a decrease in fertility and a threat to ecosystems. The problem is aggravated by the migration of toxic substances into reservoirs and their accumulation in biota, which poses a danger to public health. Monitoring methods, including chemical, bioindication, and geostatistical approaches, as well as innovative soil purification technologies such as bioremediation and the use of nanotechnology, are proposed to minimize environmental damage.

The results of the study are important for the development of state programs for the restoration of polluted lands, reducing anthropogenic pressure and ensuring sustainable development of the region.

Keywords: soil pollution, heavy metals, geostatistical analysis, GIS technologies, oil and gas and mining industries.

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Е.Х. Какимжанов[1], *Қ.Т. Қырғызбай[1], С.М. Жуматаев[2], Т.А. Базарбаева[1], Г.Т. Куныпияева[3], 2025.

[1]Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан;

[2]Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті, Алматы, Қазақстан;

[3]Қазақ егіншілік және өсімдік шаруашылығы ғылыми-зерттеу институты, Алматы обл., Қазақстан.

E-mail: kyrgyzbay.kudaibergen@gmail.com

БАТЫС ҚАЗАҚСТАН ӨҢІРІНІҢ ТОПЫРАҒЫНЫҢ ӨНЕРКӘСІПТІК ҚЫЗМЕТ НӘТИЖЕСІНДЕ АУЫР МЕТАЛДАРМЕН ЛАСТАНУЫН БАҒАЛАУ

Какимжанов Е.Х. – Ph.D, доцент міндетін атқарушы, Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан, Email: erkinkakimzhanov@gmail.com, https://orcid.org/0000-0001-6454-681X;

Қырғызбай Қ.Т. – Ph.D, оқытушы, Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан, Email: kyrgyzbay.kudaibergen@gmail.com, https://orcid.org/ 0000-0002-4279-6436;
Жуматаев С.М. – Ph.D студент, аға оқытушы, Қ.И. Сәтбаев атындағы Қазақ ұлттық техникалық зерттеу университеті, Алматы, Қазақстан, Email: serikzhumatayev@gmail.com, https://orcid.org/0009-0008-1618-7881;
Базарбаева Т.А. – Тұрақты даму бойынша ЮНЕСКО кафедрасының меңгерушісі, г.ғ.к., доцент, Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан, Email: tursynkul.bazarbayeva@gmail.com, https://orcid.org/0009-0008-5685-5215**;**
Куныпияева Г.Т. – ауыл шаруашылығы ғылымдарының кандидаты, аға ғылыми қызметкер, Қазақ егіншілік және өсімдік шаруашылығы ғылыми-зерттеу институты, Алматы облысы, Қазақстан, Email: kunypiyaeva_gulya@mail.ru, https://orcid.org/0000-0001-8606-765X.

Аннотация. Зерттеу мұнай-газ және тау-кен өнеркәсібінің қарқынды қызметі нәтижесінде Батыс Қазақстан өңірінің топырақтарының ауыр металдармен және көмірсутектермен ластануын талдауға бағытталған. Ластаушы заттардың концентрациясын анықтауға, олардың кеңістіктік таралуына және экожүйелерге әсеріне назар аударылды. Аймақтың топырақтары ауыр металдарды (қорғасын, кадмий, мышьяк, хром, никель) және көмірсутектерді қоса алғанда, техногендік ластаушы элементтердің ұзақ мерзімді жинақтаушылары болып табылады. Зерттеу объектілері ретінде Хромтау, Ақтөбе, Қарашығанақ кен орны және мұнай өңдеу зауыттары сияқты өңірдің негізгі өнеркәсіптік аймақтары таңдалды.

Далалық және зертханалық зерттеулер сынамаларды іріктеудің жалпы қабылданған әдістерін (ГОСТ 17.4.4.02-2017) және химиялық талдауды (атомдық-абсорбциялық спектрофотометрия, рентген-флуоресцентті талдау) қолдана отырып жүргізілді. Деректерді геостатистикалық талдау ГАЖ технологияларын (ArcGIS) қолдана отырып жүргізіліп, ластаушы заттардың кеңістіктік таралу карталарын жасауға мүмкіндік берді. Нәтижелер зерттелетін топырақтарда ауыр металдардың концентрациясы шекті рұқсат етілген мәндерден (ШРК) асатынын көрсетті. Мысалы, ірі өнеркәсіптік нысандардың жанында хром концентрациясы 7333,6 мг/кг, никель – 2213,1 мг/кг, ал мышьяк – 19 мг/кг жетеді.

Топырақтың ластануы олардың физикалық-химиялық сипаттамаларының нашарлауымен, құнарлылығының төмендеуімен және экожүйелерге қауіп төндірумен қатар жүретіні анықталды. Мәселе улы заттардың су объектілеріне қоныс аударуымен және олардың биотада жиналуымен күрделене түседі, бұл халықтың денсаулығына қауіп төндіреді. Экологиялық зиянды азайту үшін химиялық, биоиндикациялық және геостатистикалық тәсілдерді, сондай-ақ биоремедиация және нанотехнологияларды қолдану сияқты топырақты тазартудың инновациялық технологияларын қамтитын мониторинг әдістері ұсынылған.

Зерттеу нәтижелері ластанған жерлерді қалпына келтіру, антропогендік жүктемені азайту және аймақтың тұрақты дамуын қамтамасыз ету бойынша мемлекеттік бағдарламаларды әзірлеу үшін маңызды.

Түйін сөздер. топырақтың ластануы, ауыр металдар, геостатистикалық талдау, ГАЖ технологиялары, мұнай-газ және тау-кен өнеркәсібі.

Е.Х. Какимжанов[1], *К.Т. Кыргызбай[1], С.М. Жуматаев[2], Т.А. Базарбаева[1], Г.Т. Кунылияева[3], 2025.
[1]Казахский национальный университет имени аль-Фараби, Алматы, Казахстан;
[2]Казахский национальный исследовательский технический университет им. К.И. Сатпаева, Алматы, Казахстан;
[3]Казахский НИИ земледелия и растениеводства, Алматинская область, Казахстан.
E-mail: kyrgyzbay.kudaibergen@gmail.com

ОЦЕНКА ЗАГРЯЗНЕНИЯ ПОЧВЫ ЗАПАДНО-КАЗАХСТАНСКОГО РЕГИОНА ТЯЖЕЛЫМИ МЕТАЛЛАМИ В РЕЗУЛЬТАТЕ ПРОМЫШЛЕННОЙ ДЕЯТЕЛЬНОСТИ

Е.Х. Какимжанов – PhD, исполняющий обязанности доцента, Казахский национальный университет имени аль-Фараби, Алматы, Казахстан, Email: erkinkakimzhanov@gmail.com, https://orcid.org/0000-0001-6454-681X;
К.Т. Кыргызбай – PhD, преподаватель, Казахский национальный университет имени аль-Фараби, Алматы, Казахстан, Email: kyrgyzbay.kudaibergen@gmail.com, https://orcid.org/ 0000-0002-4279-6436;
С.М. Жуматаев – PhD студент, старший преподаватель, Казахский национальный исследовательский технический университет им. К.И. Сатпаева, Алматы, Казахстан, Email: serikzhumatayev@gmail.com, https://orcid.org/0009-0008-1618-7881;
Т.А. Базарбаева – заведующий кафедрой ЮНЕСКО по устойчивому развитию, к.г.н., доцент, Казахский национальный университет имени аль-Фараби, Алматы, Казахстан, Email: tursynkul.bazarbayeva@gmail.com, https://orcid.org/0009-0008-5685-5215**;**
Г.Т. Кунылияева – кандидат сельскохозяйственных наук, старший научный сотрудник, Казахский НИИ земледелия и растениеводства, Алматинская область, Казахстан, Email: kunypiyaeva_gulya@mail.ru, https://orcid.org/0000-0001-8606-765X.

Аннотация. Исследование посвящено анализу загрязнения почв Западно-Казахстанского региона тяжёлыми металлами и углеводородами в результате интенсивной деятельности нефтегазовой и горнорудной промышленности. Основное внимание уделено определению концентраций загрязнителей, их пространственному распределению и влиянию на экосистемы. Установлено, что почвы региона являются долговременными аккумуляторами техногенных загрязнителей, включая тяжёлые металлы (свинец, кадмий, мышьяк, хром, никель) и углеводороды. В качестве объектов изучения выбраны ключевые промышленные зоны региона, такие как Хромтау, Актобе, Карачаганакское месторождение и нефтеперерабатывающие заводы.

Полевые и лабораторные исследования проводились с применением общепринятых методов отбора проб (ГОСТ 17.4.4.02-2017) и химического анализа (атомно-абсорбционная спектрофотометрия, рентгенофлуоресцентный анализ). Геостатистический анализ данных осуществлялся с использованием ГИС-технологий (ArcGIS), что позволило создать пространственные карты распределения загрязняющих веществ. Результаты показали, что в исследуемых почвах концентрации тяжёлых металлов превышают предельно-допустимые значения (ПДК). Например, вблизи крупных промышленных объектов концентрация хрома достигает 7333,6 мг/кг, никеля – 2213,1 мг/кг, а мышьяка – 19 мг/кг.

Выявлено, что загрязнение почв сопровождается ухудшением их физико-химических характеристик, снижением плодородия и угрозой для экосистем. Проблема усугубляется миграцией токсичных веществ в водоёмы и их накоплением в биоте, что представляет опасность для здоровья населения. Для минимизации экологического ущерба предложены методы мониторинга, включающие химический, биоиндикационный и геостатистический подходы, а также инновационные технологии очистки почв, такие как биоремедиация и применение нанотехнологий.

Результаты исследования имеют важное значение для разработки государственных программ по восстановлению загрязнённых земель, снижению антропогенной нагрузки и обеспечению устойчивого развития региона.

Ключевые слова: загрязнение почв, тяжёлые металлы, геостатистический анализ, ГИС-технологий, нефтегазовая и горнодобывающая промышленность

Introduction. The increasing anthropogenic impact on soil resources in the West Kazakhstan region requires a comprehensive study due to the growing environmental problems. In recent decades, the active industrial development of the region, especially in the oil and gas and mining industries, has led to a deterioration in soil conditions, changes in their physico-chemical properties and a decrease in biological activity. The region's soils are long-term accumulators of man-made pollutants, which makes them an important indicator of the ecological state of the natural environment.

The West Kazakhstan region, including Aktobe, Atyrau and Mangystau regions, plays a key role in the economy of Kazakhstan due to the extraction of oil, natural gas, as well as the processing of non-ferrous and polymetallic ores. However, intensive industrial activity is accompanied by man-made disturbances, leakage of petroleum products and accumulation of heavy metals in soils. The main pollutants include hydrocarbons such as polycyclic aromatic hydrocarbons (PAHs), benzenes and xylenes, as well as heavy metals such as lead, cadmium, arsenic and mercury. These substances have a toxic effect on the soil horizons, water systems and biota of the region (Korabayev, et al. 2024; Bazarbayeva, 2024).

The purpose of the study is to assess the level of soil pollution in the West Kazakhstan region with heavy metals and petroleum products, to study their impact on ecosystems and to identify existing monitoring methods to prevent soil degradation.

The relevance of research. The problem of soil pollution is especially relevant for the western regions of Kazakhstan, where the accumulation of toxic substances has reached critical levels. Oil spills, drilling waste, and mining tailings lead to changes in soil properties, including reduced fertility, secondary salinization, and vegetation degradation (Wang, et al. 2021). The complexity of the situation is compounded by the lack of systematic monitoring and control over the condition of polluted lands. As a result, the quality of agricultural land is deteriorating, the risk of groundwater contamination is increasing, and the region's biodiversity is being disrupted.

The main sources of pollution. *Oil and gas industry*. The extraction, processing and transportation of oil is accompanied by hydrocarbon leaks and emissions of toxic substances such as PAHs and petroleum products that penetrate into the soil and water horizons (Korabayev, et al. 2024; Bazarbayeva, 2024). An example is the Emba River, where an excess concentration of petroleum products leads to ecosystem degradation and soil quality degradation (Dahl and Kuralbayeva, 2001).

Mining industry. Mining and processing of polymetallic ores leads to the accumulation of heavy metals (lead, cadmium, arsenic, zinc). (Y. Wang et al. 2021) in soil horizons and water systems. Toxic waste in tailings dumps often becomes a source of pollution due to leaks and insufficient controls (Korabayev, et al. 2024).

Environmental consequences. Soil pollution leads to degradation of their structure (C. Wang et al. 2020, Tan et al. 2020), deterioration of physico-chemical characteristics and decrease in biological activity. Heavy metals, penetrating into soil horizons, are adsorbed on soil particles and accumulate in plants, which disrupts food chains and reduces the productivity of agricultural land. In addition, toxic substances affect the soil biota (Tan, et al. 2021), disrupting microbiological processes and the nutrient cycle.

Migration of heavy metals and hydrocarbons into groundwater is particularly dangerous (Taghizadeh-Mehrjardi, et al. 2021), which poses a threat to the water supply of the local population and worsens the quality of life in the region (Tan et al. 2021). Degradation of pastures contaminated with lead and cadmium makes them unsuitable for grazing, which affects agricultural production and food security (Boiko, et al. 2023).

The significance of this study will contribute to the development of effective measures to control and monitor the state of the soil cover of the West Kazakhstan region. The proposed approaches will minimize the negative impact of industrial activity on soils, preserve biodiversity and improve the ecological situation of the region, which is the basis for sustainable development and ensuring public health.

Objects of research. The objects of the study are the western regions of Kazakhstan: Aktobe, West Kazakhstan, Atyrau and Mangystau regions (Figure 1). These territories are of particular interest due to their geographical location, natural conditions and economic importance to the country (Committee on Ecology of the Republic of Kazakhstan, 2022).

Geographical location and climate. The western regions of Kazakhstan are located at the junction of Europe and Asia, bordering Russia, Uzbekistan, Turkmenistan and the Caspian Sea. The region covers the Caspian lowlands, Mugodzhary and the Ustyurt desert. The climate is sharply continental: hot summers with temperatures up to +40 °C and cold winters up to -20 °C. Low rainfall (150-300 mm per year) causes the aridity of the territory (Kazhydromet, https://kazhydromet.kz).

Figure 1 – Map of the Western regions of Kazakhstan administrative divisions

Soils and vegetation. The soil cover of the region is diverse. The northern part (Aktobe and West Kazakhstan regions) is dominated by chestnut and gray-earth soils suitable for pasture and agriculture. In the southern regions (Mangystau region), desert sandy and clay soils are common, as well as salt marshes characterized by low fertility. Vegetation is represented by steppe (kovyl, tipchak) and desert communities (saksaul, solyanka, wormwood) (Academy of Sciences of the Republic of Kazakhstan 2018).

Industrial activity. The western regions of Kazakhstan play a strategic role due to large oil and gas deposits (Tengiz, Kashagan), as well as polymetallic ores (United Nations Environment Programme (UNEP). 2020). More than 90% of the country's proven hydrocarbon reserves are concentrated here, which is accompanied by intense anthropogenic impact. The main pollutants are petroleum products, heavy metals and wastewater, which degrade the soil cover and disrupt ecosystems (Salikhov, et al, 2018; Baykov, et al, 2022).

Environmental issues. Key environmental issues in the region include:

– contamination of soil and water resources as a result of oil leaks and industrial waste;

Desertification and land degradation, especially in the Mangystau region;

– decrease in biodiversity due to intensive industrial development.

Thus, the object of the study is man-made changes in the soil cover of the western regions of Kazakhstan caused by the activities of the oil and gas and mining industries (Salikhov, 2018).

Materials and methods. The research was conducted on the territory of the West Kazakhstan region in June 2024. The main types of soils in the dry-steppe zone of the West Kazakhstan region were studied: dark chestnut, meadow chestnut and salt marsh. To ensure a comprehensive analysis, both natural undisturbed areas and anthropogenic-disturbed territories were selected.

Selection of soil samples. Soil samples were taken along the middle part of the soil profile horizon in accordance with generally accepted methods and the envelope method. Cotton bags were used to collect samples, which ensures the preservation of the chemical composition of the soil. The selection procedure was carried out in accordance with GOST 17.4.4.02-2017 "Nature protection. Soils. Methods of sampling and preparation of samples for chemical, bacteriological and helminthological analysis" (INTERSTATE STANDARD 2017). The selection was carried out according to the genetic profile, taking into account the characteristics of each soil horizon.

Organization of field work. Field research was conducted in four regions of the West Kazakhstan region. Field and camera studies of soils in the West Kazakhstan region included the collection of quantitative data from monitoring sites, the analysis of stock and cartographic materials, as well as the decryption of remote sensing data (including the processing of satellite images). Additionally, meteorological information was collected, which made it possible to clarify the current boundaries of the spread of degraded lands and other relief formation processes. This made it possible to clarify the contours of the spread of degraded lands and other relief-forming processes.

Laboratory methods of soil analysis. Laboratory studies were carried out using traditional methods: granulometric and microaggregate compositions – according to N.A. Kachinsky; total humus, group and fractional composition of humus – according to I. Tyurin; total nitrogen – according to Kjeldahl; carbon dioxide of carbonates – according to Geisler-Maximyuk; gypsum – according to Giedroyc; metabolic capacity – according to Giedroyc; absorbed calcium and magnesium –

according to Giedroyc; absorbed sodium and potassium – on a flame photometer; water extraction analysis – according to Arinushkina; pH of soil suspension – calorimetrically; aggregate analysis – according to Savvinov; maximum hygroscopicity – according to Mitcherlich; the mass of the solid phase of the soil is pycnometrically; the volume mass is by the Nekrasov borax; soil moisture is by the weight method; water permeability is by the N.S. Nesterov device with an area of 0.1 m2 with a water pressure of 5 cm; field moisture capacity is at the flooded sites with humidity determination after 3 days; mobile iron is by Kirsanov; mobile phosphorus – according to Machigin; mobile potassium – according to Protasov; hydrolyzable nitrogen – according to Tyurin and Kononova; gross phosphorus – according to Pamberton; gross potassium – according to Smith; gross soil analysis – according to Giedroyc. Biological (soil fauna) research will be conducted in spring – summer – autumn (October); Gilyarov method research.

Monitoring methods were also used, including physico-chemical analysis, geostatistical and modern technological approaches.

Methods of monitoring and chemical analysis. Chemical analysis is one of the key methods for monitoring contaminated soils. Atomic absorption spectrophotometry (AAS) was used to determine concentrations of heavy metals such as lead, cadmium, mercury, and arsenic (Enuneku, et al, 2021; Bhardwaj, et al, 2017; Mmolawa, et al, 2013). This method provides highly accurate identification of even minimal concentrations.

To study the assessment of soil pollution with heavy metals in the territory of the West Kazakhstan region, the following objects were selected for the Aktobe region (1. Khromtau Artificial upland mountains from spent rock, 2. Khromtau Artificial upland mountains from spent rock, 3. Alley of Miners, 4. Central City Park in the city of Khromtau, 5. Zhaman Kargaly River, 6. Aktobe Ferroalloy plant, 7. Kenkiyak deposit); Mangystau region (1. Zhangyrlau village, 2. Turysh village, 3. LLP “JV “CASPI BITUMEN industrial zone, 4. Sulfuric acid plant (Aktau), 5. Zhetibai field, JSC Mangistaumunaigas, 6. Kyzylsai, 7. Central Park in Zhanaozen) in Atyrau region (1.Kosshagyl settlement, 2. 40 km east of Atyrau, 3. Akystau field, 4. Atyrau Oil Refinery (ANPZ)); in West Kazakhstan regions (1. Karachaganak oil and gas condensate field, 2. Karashyganak village, 3. Park of Culture and Recreation. Uralsk, 4. Uralskaya CHPP thermal power plant industrial zone).

GIS technologies and geostatistical analysis. The ArcGIS 10.6 software was used for data processing and map creation. Geostatistical methods such as kriging interpolation and the inversely weighted distance (IDW) method have been used to analyze the spatial distribution of pollutants. The IDW method makes it possible to visualize the spread of pollutants and identify “hot spots” where concentrations of heavy metals are highest.

The formula of the IDW method:

$$\hat{y}(S_0) = \sum_{i=1}^{n} \frac{d_{oi}^{-\propto}}{\sum_i^n d_{oi}^{-\propto}} y(S_i) \qquad (1)$$

In equation (1), the numerator is the inverse of the distance (d0i) between S0 and Si with degree a, and the denominator is the sum of all weights of the inverse distance for all locations i, so the sum of all li for a point without sampling will be one (George Y. Lu and David W. Wong. 2008; Shepard 1968; Berndt and Haberlandt 2018).

The IDW method allows to visualize the distribution of heavy metals based on the created raster surface.

Based on the results of the GIS analysis, they provide a reliable assessment of the soil cover and contamination of the territory. Comparative analysis with remote sensing data will allow for more accurate mapping of degraded and polluted soils in the West Kazakhstan region.

The research was conducted on the territory of the West Kazakhstan region in June 2024. The main types of soils in the dry-steppe zone of the West Kazakhstan region were studied: dark chestnut, meadow chestnut and salt marsh. To ensure a comprehensive analysis, both natural undisturbed areas and anthropogenic-disturbed territories were selected.

Results and discussion. During the field soil expedition, soil samples were taken in accordance with GOST 17.4.4.02–2017 "Nature protection. Soils. Methods of sampling and preparation of samples for chemical, bacteriological, and helminthological analysis" (INTERSTATE STANDARD 2017). The work was carried out at facilities located in various regions of the West Kazakhstan region and other industrial zones of Kazakhstan.

To determine the impact of the Donskoy Mining and quarries on soil pollution, a soil section was laid and soil samples were taken using the envelope method in the south–east and north–west directions according to the wind rose, at a distance of 100 m, 250 m, 500 m, 1000 m and 5000 m, as well as on the territory of urban parks (Alley of Miners and Central Khromtau City Park). A total of 18 samples were taken from the study area (Figure 2): Section No. 1 (0-8 cm); 100 m, 250 m, 500 m to the southeast of Section No. 1; The foot of the dump; 100 m, 250 m, 500 m, 1000 m and 5000 m to the northwest of the dump; The Central Park and the Alley of miners of the city of Khromtau, the border of the city of Khromtau.

Sample names	Indicators of the elements in the soil, in mg/kg													
	Nickel	Molybdenum	Cobalt	Chromium	Arsenic	Mobile Zinc	Mobile Copper	Mobile Cadmium	Mobile lead	Mobile boron	Gross zinc	Gross copper	Gross Cadmium	Gross lead
Section No. 1 (0-8 cm)	19	124	7	1550	16	0.9	0.7	0.5	0.9	0.22	91.2	22.8	1.2	5.6
100 m south-east of Section No. 1	739	5	56	2434	12	0.6	0.4	1.5	1.1	0	87.2	28.4	0.8	7.2
250 m south-east of Section No. 1	2225	0	134	3307	9	0.5	0.2	0.9	1.4	0.14	146	26.4	3.6	6
500 m south-east of Section No. 1	487	11	0	2849	13	0.5	0.1	1.1	1.5	0.01	72.4	21.2	3.2	3.6
Foot of the dump	1971	10	176	1416	6	1.4	1	0.1	0.7	0.07	60.8	18.8	3.6	2.4
100 m northwest of the dump	1718	13	165	1479	0	1.1	0.7	0.6	0.7	0.13	68.8	15.2	1.2	3.6
250 m northwest of the dump	1738	12	132	1171	0	0.3	0.6	0.6	0.6	0.11	64	17.2	2.4	2
500 m northwest of the dump	52	8	17	180	0	1.7	0.5	0.8	1.1	0.15	65.2	17.6	2	5.6
1000 m northwest of the dump	321	6	66	2205	11	0.6	0.3	0.8	0.7	0.08	74.4	16.4	2.4	3.6
Khromtau Central Park	71	0	0	485	14	7.3	0.4	1.3	1.8	0.22	72.8	20.4	4.8	9.2
Alley of miners, Khromtau city	563	10	51	3708	11	1.2	0.5	0.9	1.7	0.1	87.6	26.8	2	4.8
The border of the city of Khromtau	537	13	0	7335	10	5	0.6	1.1	1.3	0.38	99.2	21.6	3.6	5.6
5000 m northwest of the dump	714	4	0	2524	12	0.2	0.5	0.9	0.6	0.17	66.4	18.4	1.6	5.2

Figure 2 – Results of laboratory studies of soil samples in the territory of the Donskoy Mining and Processing Complex, Khromtau

A soil section was laid on the border of the industrial zone of the Aktobe Ferroalloy plant and soil samples were taken in the sanitary protection zone and beyond it at a distance of 100 m, 250 m, 500 m and 1000 m in the western and northern directions, as well as in the territory of the Central Park of Aktobe. A total of 9 samples were selected (Figure 3): Section–3; 100 m, 250 m, 500 m and 1000 m west of the SPZ; 100 m, 250 m and 500 m north of the SPZ; Aktobe Central Park.

Sample number	Sample names	Indicators of the elements in the soil, in mg/kg												
		Nickel	Molybdenum	Chromium	Arsenic	Mobile Zinc	Mobile Copper	Mobile Cadmium	Mobile lead	Mobile boron	Gross zinc	Gross copper	Gross Cadmium	Gross lead
23	Section	114	12	25165	4	1.4	0.6	0.3	0.3	0.06	55.6	22	0.4	4.4
26	100 m west of sanitary protection zone	110	17	16863	11	5.1	1.4	1.6	1.2	0.28	94.4	21.6	3.2	7.2
27	250 m west of sanitary protection zone	49	19	14197	14	6.6	1.1	1.6	1.3	0.21	150.8	21.2	5.2	7.2
28	500 m west of sanitary protection zone	68	20	2851	9	3.2	0.6	0.9	0.5	0.21	94.4	23.6	3.2	4.8
29	1000 m west of sanitary protection zone	76	11	3238	5	1.6	0.6	0.8	0.2	0.15	84.8	21.6	2.4	4.4
30	100 m north of the sanitary protection zone	84	11	10655	10	4	1.2	1.5	0.6	0.13	83.2	19.6	4	3.6
31	250 m north of the sanitary protection zone	80	5	9231	15	4.9	1.2	1.5	0.8	0.12	132	19.2	1.6	4
32	500 m north of the sanitary protection zone	83	9	6029	4	4.4	0.8	1	0.4	0.03	90.4	18.4	2.4	5.6
34	Aktobe Central Park, 8000 m	0	0	0	0	3.7	0.7	0.9	0.4	0.42	102	23.2	1.2	4

Figure 3 – Comparison of the results of laboratory studies of soil samples in the territory of the Aktobe Ferroalloy Plant

Sampling sites on the territory of the Kenkiyak oil field SPZ (Figure 4): 37 sample is a gas station site, 35 sample is along the road in a northwesterly direction at 1000 m and 36 sample is 5000 m.

Sample number	Sample names	Indicators of the elements in the soil, in mg/kg										
		Nickel	Chromium	Arsenic	Mobile Zinc	Mobile Copper	Mobile Cadmium	Mobile lead	Gross zinc	Gross copper	Gross Cadmium	Gross lead
35	1000 m north of the sanitary protection zone	49	157	10	0.7	1.4	0.9	1.4	40.4	14	2.8	6.4
36	5000 m north of the sanitary protection zone	25	209	7	0.6	1.9	1	1.3	20	4.8	0.4	6.4
37	gas station of terratoria villages	22	102	8	4.7	1.6	1.2	2.3	47.6	10.4	0.8	9.2

Figure 4 – Comparison of the results of laboratory studies of soil samples in the Kenkiyak oil field

The Karachaganak oil field and the city of Uralsk were selected as sites on the territory of the West Kazakhstan Region. 5 samples were selected at the SPZ of the Karachyganak oil field (Figure 5): No. 103 – section No. 12, No. 109 – the border of the SPZ, No. 110 – 1,500 m to the southwest of the SPZ, No. 111 – 1,500 m to the northeast of the SPZ, No. 112 – the village of Karashyganak. 3 samples were selected at the Uralsk city border (Figure 6): No. 113 – Central Park, No. 114 – Central Park Industrial Zone, No. 115 – 7,500 m from the industrial zone.

Sample number	Sample names	Indicators of the elements in the soil, in mg/kg												
		Nickel	Cobalt	Chromium	Arsenic	Mobile Zinc	Mobile Copper	Mobile Cadmium	Mobile lead	Mobile boron	Gross zinc	Gross copper	Gross Cadmiu	Gross lead
103	Incision No. 12	67	0	163	9	1.3	0.7	0.9	1	0.06	220	22	3.2	3.2
109	SPZ border	74	0	264	9	1.8	0.9	0.6	0.6	0.01	54.8	25.2	4.8	4
110	1 500 m south-west of the sanitary protection zone	71	74	240	11	1.6	0.8	0.9	0.7	0.04	58.4	21.6	3.2	2.8
111	1 500 m north-east of the sanitary protection zone	73	55	168	10	1.8	0.9	0.6	1.2	0.01	60.8	23.6	4.4	5.2
112	Karashyganak village	64	0	147	9	2.9	1.2	1.2	1.5	0.13	71.6	22.4	5.2	3.2

Figure 5 – Comparison of the results of laboratory studies of soil samples in the territory of the Karachyganak oil field

Sample names	Indicators of the elements in the soil, in mg/kg											
	Nickel	Chromium	Arsenic	Mobile Zinc	Mobile Copper	Mobile Cadmium	Mobile lead	Mobile boron	Gross zinc	Gross copper	Gross Cadmium	Gross lead
Central Park	92	299	9	32.8	0.9	1	1.5	0.37	216	32.4	4.4	5.6
Central Park Industrial Zone	96	317	10	5	1.8	1.1	0.6	0.14	54.8	25.6	4.8	4
7 500 m south of the industrial zone	54	437	7	1.1	0.7	0.4	0.7	0.13	24.4	12.4	4	3.2

Figure 6 – Comparison of the results of laboratory studies of soil samples in the city of Uralsk

Atyrau Oil Refinery (ANPZ), Koschagylskoye and Martyshinskoye oil fields were selected as sites for soil research in Atyrau region (Figures 7, 8, 9). The following points have been selected on the territory of the ANPZ: No. 93 – 5000 m east of the SPZ, No. 94 – 1000 m east of the SPZ, No. 95 – 500 m east of the SPZ, No. 96 – 250 m east of the SPZ, No. 97 – 250 m south of the SPZ, No. 98 – 500 m south of the SPZ and No. 99 – 1000 m south of the SPZ. The Koschagylskoye oil field facility covers the following points: No. 71 – section No. 8, No. 73 – section No. 9, No. 77 – 1000 m south – east of section No. 8, No. 78 – 5000 m south – east of section No. 8, No. 79 – 500 m south–east of section No. 8, No. 80 – 500 m to the northwest and No. 81 – Kosachagyl settlement.

Sample number	Sample names	Indicators of the elements in the soil, in mg/kg											
		Nickel	Cobalt	Chromium	Arsenic	Mobile Zinc	Mobile Copper	Mobile Cadmium	Mobile lead	Gross zinc	Gross copper	Gross Cadmium	Gross lead
93	5000 m east of SPZ	54	0	211	7	6.7	3.6	1.4	2.2	31.2	16.4	2.4	8
94	1000 m east of SPZ	87	57	529	9	21.1	5.6	1.8	3.6	133.6	38	2	10
95	500 m east of SPZ	72	0	303	12	12.8	4.6	1.7	3.2	68.4	25.6	3.6	9.6
96	250 m east of SPZ	66	0	209	7	7.3	4.4	1.5	2.1	46.4	23.2	2.4	10.4
97	250 m south of the SPZ	0	61	189	10	19.4	5.1	2.7	2.8	68.8	33.2	4.4	8.8
98	500 m south of the SPZ	82	0	159	11	2.3	3.8	1.5	2.4	98.4	20.4	3.6	6.8
99	1000 m south of the SPZ	79	75	165	7	6.5	3.9	1.4	2.3	51.6	19.6	4.4	7.2

Figure 7 – Comparison of the results of laboratory studies of soil samples in the territory of the Atyrau Oil Refinery

Sample number	Sample names	Indicators of the elements in the soil, in mg/kg											
		Nickel	Molybdenum	Chromium	Arsenic	Mobile Zinc	Mobile Copper	Mobile Cadmium	Mobile lead	Gross zinc	Gross copper	Gross Cadmium	Gross lead
71	Section No. 8	21	0	98	6	1.7	1.8	1	1.9	16	10.4	3.2	6
73	Section No. 9	16	0	57	5	3.7	2.4	1	2	26.4	7.2	4.8	6.8
77	1000 m southeast of section No. 8	18	0	102	4	0.8	2.8	1.3	2	12	8.4	1.2	5.6
78	5000 m southeast of section No. 8	22	0	135	4	1.3	2.6	1.1	1.4	19.2	6	1.6	6
79	500 m southeast of section No. 8	0	0	0	0	1.2	2.6	0.8	1.5	29.6	9.6	1.2	7.2
80	500 m northwest of section No. 8	0	0	0	0	0.7	2.7	1.1	1.6	11.2	9.6	1.2	8
81	Kosshagyl, a settlement	0	13	60	4	2.1	2.9	0.9	1.6	16.4	7.2	0.01	9.6

Figure 8 – Comparison of the results of laboratory studies of soil samples in the territory of the Koschagyl oil field

Sample number	Sample names	Indicators of the elements in the soil, in mg/kg												
		Nickel	Molybdenum	Cobalt	Chromium	Arsenic	Mobile Zinc	Mobile Copper	Mobile Cadmium	Mobile lead	Gross zinc	Gross copper	Gross Cadmium	Gross lead
89	Martyshi Section-11	78	4	96	147	12	4	3.1	1.8	2.4	48	23.2	0.8	11.2
90	Martyshi to the north 250 m	37	10	0	100	15	2.6	4	1.7	2.7	28.8	9.2	0.4	8.8
91	Martyshi 1000 m	46	0	0	165	7	3	3.5	1.7	2.6	23.2	9.2	1.6	6.8

Figure 9 – Comparison of the results of laboratory studies of soil samples in the territory of the Martyshinsky oil field

Laboratory tests. The selected samples were sent to certified laboratories for chemical analysis for the content of heavy metals:

• Ecoservice–S LLP

• Kazakh Research Institute of Soil Science and Agrochemistry named after U.U. Uspanov

Applied laboratory instruments:

1. Specord 210 PLUS
2. Ionometer I–160
3. FLAPHO–4 flame photometer
4. AR 2140 and Scout SPS202F electronic scales
5. Portable XRF analyzer for X-ray fluorescence spectrometry

Laboratory results showed concentrations of heavy metals (mg/kg), shown in Figures 3 and 4.

An integrated approach using GIS and chemical analysis allowed us to obtain accurate and reliable results for assessing the state of the soil cover of the West Kazakhstan region and other industrial regions of Kazakhstan.

Soil pollution in the western regions of Kazakhstan is a serious environmental problem associated with the intensive activities of the oil and mining industry. The accumulation of heavy metals, oil and its derivatives in soils has a significant negative impact on ecosystems, reduces land fertility and threatens public health.

The main criteria for assessing polluted soils. The main indicator of the environmental danger of soil pollution is the excess of the maximum permissible concentrations (MPC) of toxic substances. The analysis showed that intensive development of natural resources in Kazakhstan is often carried out without due consideration of environmental consequences, which leads to significant accumulation of heavy metals, pesticides and petroleum products in the soils. Soil pollution is the entry into its composition of solid, liquid and gaseous substances that have harmful effects both directly and indirectly through their impact on other components of the ecosystem.

In Kazakhstan, there is a lack of systematic research on the content of toxic substances in soils and vegetation of natural areas, especially pastures and forage lands. Data on pollution are fragmentary, focusing mainly on the sources of pollution rather than its effects on the soil cover.

Sources of soil pollution. The main anthropogenic sources of soil pollution are:

Industrial enterprises (metallurgy, mining and oil refining industries);

– energy (thermal power plants);

– motor transport;

– agricultural waste (chemical plant protection products);

– household and industrial waste.

Enterprises associated with the extraction and processing of polymetallic ores pose a special environmental danger, as heavy metals enter the soil: lead (Pb), cadmium (Cd), mercury (Hg), arsenic (As), zinc (Zn), copper (Cu), nickel (Ni).

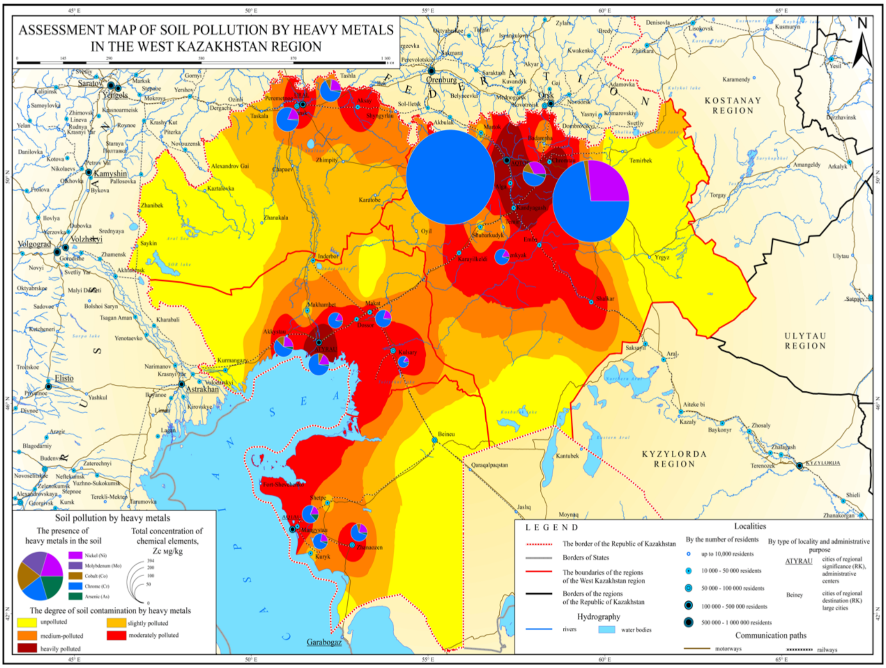

Рисунок 10 – Оценочная карта загрязнения почв тяжелыми металлами Западно-Казахстанского региона

Geographical specifics of soil pollution. Foci of heavy metal pollution in Kazakhstan are concentrated in areas of large industrial zones and cities: Khromtau, Atyrau, Aktau, Karachaganak oil and gas condensate field. In the vicinity of these settlements, concentrations of lead, copper, zinc, and cadmium in the soil significantly exceed the maximum permissible concentration (Figure 10), which poses a threat to ecosystems and public health.

Features of migration and accumulation of heavy metals. Heavy metals have the ability to accumulate and migrate in the soil (Figure 11). The main mechanisms of their movement and accumulation include:

1) the transfer of toxic substances in the form of dust for tens of kilometers from the source of pollution, especially in the dry season;

2) the formation of insoluble compounds with humus, which leads to their fixation in the upper soil layer, mainly at a distance of 1-3 km from the source;

3) increased anthropogenic impact on urban soils due to the proximity of industrial enterprises, transport infrastructure and urbanization.

Environmental hazards of soil pollution. Heavy metals, accumulating in soils, pose a serious threat to ecosystems and human health. The main consequences include:

- The transfer of toxic substances into plants, animals and further along the food chain, which contributes to their accumulation in human and animal organisms;

- High toxicity of certain metals (for example, lead and mercury), leading to serious illnesses and even deaths;
- Accumulation of a billion tons of industrial waste annually, which causes irreversible changes in the soil cover.

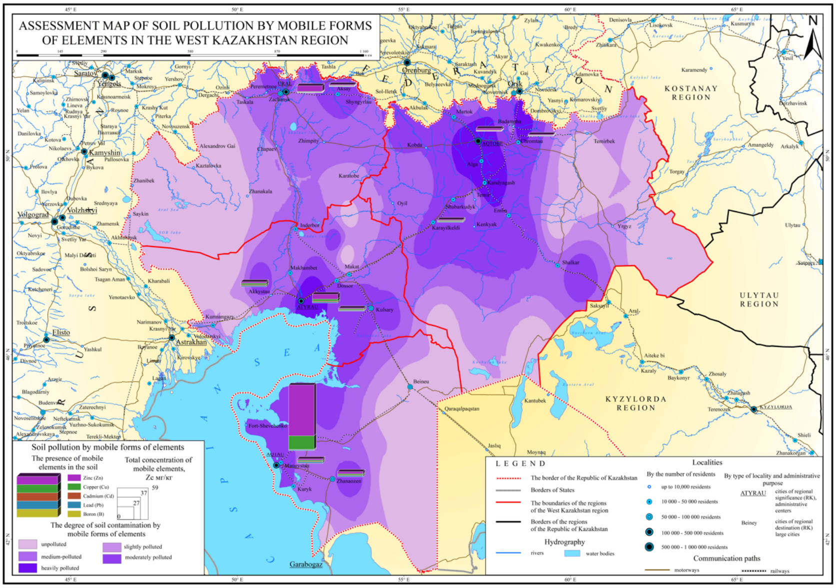

Figure 11 – Estimated map of soil pollution by mobile forms of elements in the West Kazakhstan region

Characteristics of the soils of the studied territories. The soils of the cities of Khromtau and Aktobe are dark chestnut, carbonate.

Mechanical composition: medium loamy.

The addition density of horizon A is 1.08 g/cm3, the density of the solid phase is 2.46 g/cm3.

Porosity: 56%.

Humus content:

- Upper horizon (A_1): 2.80 %;
- Horizon A_2: 1.91 %;
- AB horizon: less than 1 %.

The reaction of the medium (pH): slightly alkaline in the upper horizons (7.3–7.6) and strongly alkaline in the lower horizons (8.0–9.0).

Salinity: the upper horizons are unsalted, the middle part is medium salinity, the lower part is strong (1.02–1.60%).

Heavy metal content. In the territories of Donskoy GOK and the city of Khromtau, there is a significant excess of the maximum permissible concentration for a number of heavy metals.:

1. Arsenic (6.0–19.0 mg/kg), MPC: 2 mg/kg.
2. Nickel (above 4.0 mg/kg at all points).
3. Molybdenum (at some points up to 10-fold excess).
4. Cobalt and chromium (excess at all sampling points).
5. Zinc (up to 146 mg/kg at individual points).

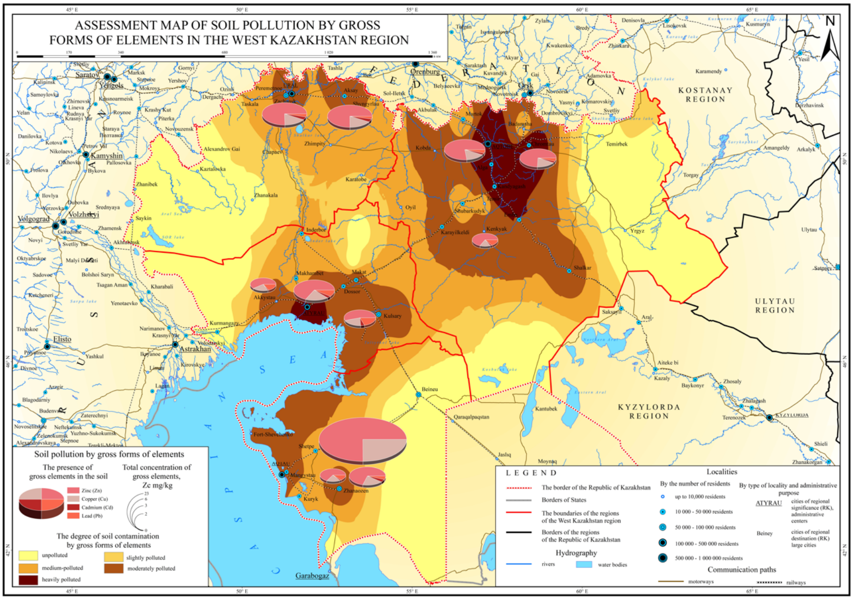

Figure 12 – Estimated map of soil pollution by gross forms of elements in the West Kazakhstan region

Spatial distribution of heavy metals (Figure 12). Geospatial analysis using the IDW interpolation method in ArcGIS showed:

– The city of Khromtau: the main pollutants are nickel, cobalt, chromium, zinc, cadmium. The highest concentrations are recorded in the landfill sites and the central part of the city.

– Aktobe city: high concentrations of nickel, chromium, arsenic, cadmium and zinc. The greatest pollution was recorded in the northeastern and southern parts of the city.

– Kenkiyak deposit: exceeding the maximum permissible concentration for chromium, copper, arsenic and cadmium.

– The city of Uralsk: the maximum permissible concentrations for chromium (up to 436.9 mg/kg), arsenic (9.9 mg/kg), cadmium and copper have been exceeded.

– Karachaganak deposit: soil pollution is associated with chromium, arsenic, zinc and cadmium.

– Koschagylskoye and Martyshinskoye deposits: the maximum permissible concentrations for arsenic, chromium, cadmium and copper were exceeded.

The most polluted territories are associated with the location of industrial facilities, landfills, and mining areas.

The main pollutants of soils are chromium, nickel, arsenic, cadmium, copper and zinc, the concentrations of which are many times higher than the MPC.

The results emphasize the need to implement systematic monitoring of soil pollution, develop methods for their purification and restoration.

The data obtained are of high practical importance for the development of environmental measures to restore polluted territories and include them in agricultural turnover, which will ensure the sustainable development of the region.

Conclusion. Soil pollution in the western regions of Kazakhstan continues to be a significant environmental concern due to the extensive activities of the oil and mining industries. The primary contaminants include heavy metals, petroleum, and its derivatives, all of which severely impact ecosystems, degrade soil fertility, and pose considerable risks to public health.

The major sources of contamination are industrial emissions, mining and mineral processing activities, and vehicular emissions. Areas with the highest concentrations of toxic substances are located near major industrial facilities, such as the cities of Khromtau, Aktobe, and Uralsk, as well as the Karachaganak oil and gas condensate field and other prominent oil fields.

Research findings highlight that the soils in the affected regions are characterized by low humus and phosphorus levels, moderate nitrogen content, and elevated potassium levels, which collectively signal reduced soil fertility. This situation underscores the urgent need for soil restoration measures to ensure long-term land productivity.

To assess soil contamination, chemical, bioindication, geostatistical, and cartographic methods were employed. Geographic Information System (GIS) technologies facilitated the development of information and assessment maps that visualize pollutant dispersion. The key indicator of contamination is the exceedance of maximum permissible concentrations (MPC) for heavy metals, such as chromium, nickel, cadmium, and arsenic.

To mitigate environmental damage, the following integrated approaches are recommended:

1. Continuous Monitoring: Regular monitoring of soil pollution using advanced analytical techniques to identify trends and risks.

2. Remediation Technologies: Implementation of soil purification methods, including bioremediation, chemical treatments, and thermal processing.

3. Innovative Solutions: Adoption of cutting-edge technologies, such as nanotechnology, to enhance the efficiency and effectiveness of soil restoration.

The research outcomes have significant practical value and can inform government policies aimed at reducing anthropogenic pressures, restoring soil fertility, and reintegrating polluted lands into agricultural production. This will enhance regional livestock and feed production, contributing to the sustainable economic development of the region.

Achieving environmental safety in western Kazakhstan necessitates strengthening the environmental control system, prioritizing soil condition assessments, and fostering collaboration between research institutions and industrial enterprises. Such partnerships can facilitate the implementation of innovative environmental protection strategies and promote the rational use of natural resources.

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