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COMPARATIVE ASSESSMENT OF HEAVY METAL CONTENT IN SOILS OF INDUSTRIAL ZONES IN UST-KAMENOGORSK

In the city of Ust-Kamenogorsk, which is the largest industrial center of the East Kazakhstan region, long-term activities of non-ferrous metallurgy and thermal energy enterprises lead to the accumulation of heavy metals in the soil and form foci of sustainable man-made pollution. Among such pollutants, lead (Pb), cadmium (Cd), copper (Cu) and zinc (Zn) are especially dangerous because they persist in the soil for a long time, accumulate in Biosystems and pose a serious threat to the ecosystem and human health. The purpose of the study is to determine the actual concentration of heavy metals in the soil in the industrial zones of Ust-Kamenogorsk and compare them with the maximum permissible concentrations (MPC) approved in the Republic of Kazakhstan, as well as assess the level of environmental risk in the region. At the same time, the results obtained make it possible to compare the concentrations recorded in industrial areas with natural levels in the background area, which is important in assessing the real scale of the man-made load.

The scientific and practical significance of the study is that it provides new data reflecting the real state of the soil in an area with a high level of industrial pollution and forms the necessary scientific basis for planning environmental measures. The methodology was to take samples from a soil layer at a depth of 0-20 CM, prepare them to use the acid dissolution method according to ISO 11466 standard and determine the concentrations of Pb, Cd, Cu and Zn using atomic absorption spectrometry (AAS).

The results showed that in soils in the industrial zone, the content of Pb and Cd exceeds MPC by 5-11 times, Zn and Cu-by 2-5 times, respectively, and the concentrations in the background zone correspond to the standards. Comparison with natural levels detected in the background area proves that the accumulation of heavy metals was formed as a result of man-made impacts characteristic only of industrial points and clearly shows the spatial differences between the sources of pollution. This proves the High man-made impact of industrial facilities and the presence of a risk of heavy metal migration in the region. The value of the study lies in the fact that it provides quantitative data that allows you to determine the exact proportion of polluting sources, conduct environmental monitoring and plan restoration work.

The practical significance of the work lies in the fact that the results obtained can be used in the development of programs for environmental assessment of industrial territories, Zoning By risk levels and remediation.

Keywords: heavy metals, soil pollution, atomic absorption spectrometry, maximum permissible concentration, Ust-Kamenogorsk.

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Өскемен қаласының өнеркәсіптік аймақтарындағы топырақтардағы ауыр металдардың мөлшерін салыстырмалы бағалау

Шығыс Қазақстан облысының ірі өнеркәсіптік орталығы болып табылатын Өскемен қаласында түсті металлургия және жылу энергетика кәсіпорындарының ұзақ жылдық қызметі топырақта ауыр металдардың жиналуына әкеліп, тұрақты техногендік ластану ошақтарын қалыптастыруда. Мұндай ластаушылардың ішінде қорғасын (Pb), кадмий (Cd), мыс (Cu) және мырыш (Zn) ерекше қауіпті, себебі олар топырақта ұзақ сақталып, биожүйелерге жинақталып, экожүйе мен адам денсаулығына елеулі қауіп төндіреді. Зерттеудің мақсаты – Өскемен қаласының

мақтарындағы топырақтағы ауыр металдардың нақты концентрациясын анықтап, оларды Қазақстан Республикасында бекітілген шекті рұқсат етілген концентрациялармен (ШРК) салыстыру, сондай-ақ аймақтың экологиялық тәуекел деңгейін бағалау. Сонымен қатар алынған нәтижелер өнеркәсіптік аумақтарда тіркелген концентрацияларды фондық аймақтағы табиғи деңгейлермен салыстыруға мүмкіндік береді, бұл техногендік жүктеменің нақты ауқымын бағалауда маңызды.

Зерттеудің ғылыми және практикалық маңыздылығы – өнеркәсіптік ластану деңгейі жоғары аймақтағы топырақтың нақты жағдайын көрсететін жаңа деректерді ұсынуы және табиғатты қорғау шараларын жоспарлауға қажетті ғылыми негіз қалыптастыруы. Әдістеме ретінде 0–20 см тереңдіктегі топырақ қабатынан сынамалар алу, оларды ISO 11466 стандарты бойынша қышқылды еріту әдісі арқылы дайындау және атомдық абсорбциялық спектрометрия (AAS) көмегімен Pb, Cd, Cu және Zn концентрацияларын анықтау қолданылды.

Нәтижелер көрсеткендей, өнеркәсіптік аймақтағы топырақтарда Pb және Cd мөлшері ШРК-дан тиісінше 5–11 есеге, Zn және Cu – 2–5 есеге дейін артық, ал фондық аймақтағы концентрациялар нормативтерге сәйкес келеді. Фондық аймақта анықталған табиғи деңгейлермен салыстыру ауыр металдардың жинақталуы тек өнеркәсіптік нүктелерге тән техногендік әсер нәтижесінде қалыптасқанын дәлелдейді және ластану көздерінің кеңістіктік айырмашылықтарын нақты көрсетеді. Бұл өнеркәсіптік объектілердің техногендік әсерінің жоғары екенін және аймақта ауыр металдардың миграция қаупінің бар екенін дәлелдейді. Зерттеудің құндылығы – ластаушы көздердің нақты үлесін анықтауға, экологиялық мониторинг жүргізуге және қалпына келтіру жұмыстарын жоспарлауға мүмкіндік беретін сандық мәліметтер беруінде.

Жұмыстың практикалық маңызы – алынған нәтижелерді өнеркәсіптік аумақтарды экологиялық тұрғыдан бағалау, қауіп деңгейлері бойынша зонирлеу және ремедиация бағдарламаларын әзірлеу барысында қолдануға болатындығында.

Түйін сөздер: ауыр металдар, топырақ ластануы, атомдық абсорбциялық спектрометрия, шекті рұқсат етілген концентрация, Өскемен.

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Сравнительная оценка содержания тяжелых металлов в почвах промышленных зон г. Усть-Каменогорск

В городе Усть-Каменогорске, который является крупнейшим промышленным центром Восточно-Казахстанской области, многолетняя деятельность предприятий цветной металлургии и теплоэнергетики приводит к накоплению тяжелых металлов в почве и формирует очаги устойчивого техногенного загрязнения. Среди таких загрязнителей свинец (Pb), кадмий (Cd), медь (Cu) и цинк (Zn) особенно опасны, поскольку они длительное время сохраняются в почве, накапливаются в биосистемах и представляют серьезную угрозу экосистеме и здоровью человека. Целью исследования является определение фактических концентраций тяжелых металлов в почве в промышленных зонах Усть-Каменогорска и сравнение их с предельно допустимыми концентрациями (ПДК), утвержденными в Республике Казахстан, а также оценка уровня экологического риска в регионе. В то же время полученные результаты позволяют сравнить концентрации, зафиксированные в промышленных зонах, с естественными уровнями в фоновой зоне, что важно для оценки реальных масштабов техногенной нагрузки.

Научная и практическая значимость исследования заключается в том, что оно предоставляет новые данные, отражающие реальное состояние почвы в районе с высоким уровнем промышленного загрязнения, и формирует необходимую научную базу для планирования природоохранных мероприятий. Методика заключалась в отборе проб из слоя почвы на глубине 0–20 см, их обработке методом кислотного растворения в соответствии со стандартом ISO 11466 и определении концентраций Pb, Cd, Cu и Zn с помощью атомно-абсорбционной спектрометрии (AAS).

Результаты показали, что в почвах промышленной зоны содержание Pb и Cd превышает ПДК в 5–11 раз, Zn и Cu – в 2–5 раз соответственно, а концентрации в фоновой зоне соответствуют нормативам. Сравнение с естественными уровнями, обнаруженными в фоновой зоне, доказывает, что накопление тяжелых металлов образовалось в результате техногенных воздействий, характерных только для промышленных точек, и наглядно показывает пространственные различия между источниками загрязнения. Это доказывает высокую техногенную нагрузку промышленных объектов и наличие риска миграции тяжелых металлов в регионе. Ценность исследования заключается в том, что оно предоставляет количественные данные, позволяющие определить

точную долю источников загрязнения, проводить экологический мониторинг и планировать восстановительные работы.

Практическая значимость работы заключается в том, что полученные результаты могут быть использованы при разработке программ экологической оценки промышленных территорий, зонирования по уровням риска и рекультивации.

Ключевые слова: тяжелые металлы, загрязнение почвы, атомно-абсорбционная спектроскопия, предельно допустимая концентрация, Усть-Каменогорск.

Introduction

Soil pollution by heavy metals in industrial regions of Kazakhstan is one of the most important factors that pose a significant threat to environmental stability, Public Health and productivity of agro-landscapes. Non-ferrous metallurgy, thermal power, chemical industry and Urban man-made processes contribute to the continuous ingress of toxic elements such as lead (Pb), cadmium (Cd), zinc (Zn) and copper (Cu) into the soil. The chemical inertness, non-biodegradability and long-term storage capacity of heavy metals place them in the category of environmentally hazardous pollutants (Amin et al., 2020; Li et al., 2022).

The accumulation of heavy metals in the soil changes its chemical, physical and biological properties, as a result of which the activity of the soil microbiota decreases and the biological productivity of plants deteriorates. In addition, heavy metals pass through the root system to plants, and then enter the animal and human body, leading to a violation of the biological chain and the risk of chronic poisoning (Li et al., 2022).

Industrial zones in Kazakhstan, especially the cities of Karaganda, Ust-Kamenogorsk and Shymkent, are historically characterized as territories highly contaminated with heavy metals. Large metallurgical enterprises located in Ust – Kamenogorsk – JSC “Kazzinc”, Ulba metallurgical plant (Ulba metallurgical plant) and Ust-Kamenogorsk thermal power plant-are the main sources of man-made pollution in the soil. Recent studies prove that the concentrations of Pb, Cd and Zn in the soils of the Ust-Kamenogorsk region are several times higher than the background level (Spsychalski & Woszczyk, 2022; Ministry of Health of the RK, 2022).

The main reason for this situation is atmospheric dust, wind transport of industrial waste, the spread of sludge and ash formed in non – ferrous metallurgy processes into the environment. Long-term storage of heavy metals in the soil leads to their formation of permanent man-made “hot spots”, which increases the level of ecosystem risk (Huang et al., 2022).

The relevance of the problem of heavy metals is also due to their danger to human health. The accumulation of Pb is distinguished by damage to the nervous system, Cd – kidney pathologies and destruction of bone tissue, and excess Zn and Cu has a negative effect on plant metabolism (Feng et al., 2021). Therefore, a clear determination of the level of soil pollution with heavy metals in industrial zones and its comparison with sanitary standards is one of the main tasks of environmental monitoring.

The purpose of this study is to assess the level of environmental risk by determining the actual concentrations of heavy metals (Pb, Cd, Zn, Cu) in the soil of industrial zones in Kazakhstan and comparing them with the maximum permissible concentrations.

Soil pollution in industrial zones with heavy metals is a complex geocological problem that is studied in many countries of the world. Long-term storage of heavy metals in the soil, migration capacity and biological availability make them among the dangerous anthropogenic pollutants. In recent years, a number of fundamental and applied research has been carried out in this direction.

Most of the international research is aimed at identifying the patterns of accumulation of heavy metals in the soil, their sources of pollution and their impact on the ecosystem. For example, Li et al. attributed the high Pb and Cd levels in China’s industrial regions to long-term emissions from metallurgy and coal energy (Amin et al., 2020). This study is considered an important work that proved the mechanisms by which heavy metals enter the soil through atmospheric deposition.

Shahid et al., studying the bioavailability of heavy metals for plants, found their organomineral bonds, soil pH and dependence on the amount of organic matter (Ali et al., 2022). This conclusion indicates that the physico-chemical properties of the soil directly affect the migration of heavy metals.

According to the level of pollution in industrial zones, Zhang et al. The results of the study showed that the concentrations of Cd, Zn and Pb in the vicinity of metallurgical clusters are 5-10 times higher than the background level (Khan et al., 2022). The

authors explain the distribution of heavy metals by the influence of atmospheric dust-pollen and tailings.

The influence of climatic factors on the distribution of heavy metals in the soil Huang et al. studied (Huang et al., 2022). They showed that in arid regions, high evaporation and low precipitation create conditions for the accumulation of heavy metals in the soil in high concentrations. This conclusion fully corresponds to the climatic features of Kazakhstan.

Feng et al of the ecosystem consequences of man-made pollution studied in detail and proved that Pb and Cd disrupt the enzyme systems of plants and reduce the intensity of photosynthesis (Woszczyk et al., 2018). This means that heavy metals also have a direct impact on the quality of agricultural products.

Ali et al on cartography of soil pollution in industrial cities proposed effective ways to detect man-made “hot spots” using geostatistical methods with high spatial accuracy. This method is very relevant for metallurgical regions such as Ust-Kamenogorsk (Huang et al., 2022).

An important study on the sources and mechanisms of distribution of heavy metals in the soil is Liu et al. (Zeng et al., 2021). The authors attribute metallurgy, transport emission, coal burning, improper storage of industrial waste and the construction industry to the main sources of heavy metals.

The research carried out in geographical regions close to Kazakhstan also lays an important scientific foundation for our work. For example, in Central

Asia, the trend of man-made pollution is observed by Rodrigues et al. (Zeng et al., 2021), noting that Cd and Pb concentrations in industrial cities have not decreased in the last 10 years.

According to the results of a comparative study of the ecosystem hazard of heavy metals in the soils of industrial zones Kumar et al. (Shahid et al., 2021). Affirms that Pb and Cd are the most toxic elements, their excess of MPC poses a significant threat to human health.

The mechanism of atmospheric deposition was clarified by Wang et al. The study (Li et al., 2022), found that the PM_{2.5} fractions from metallurgical enterprises contain high amounts of Cd, Pb and Cu. This indicates that they increase the risk of accumulation in the soil by the wind.

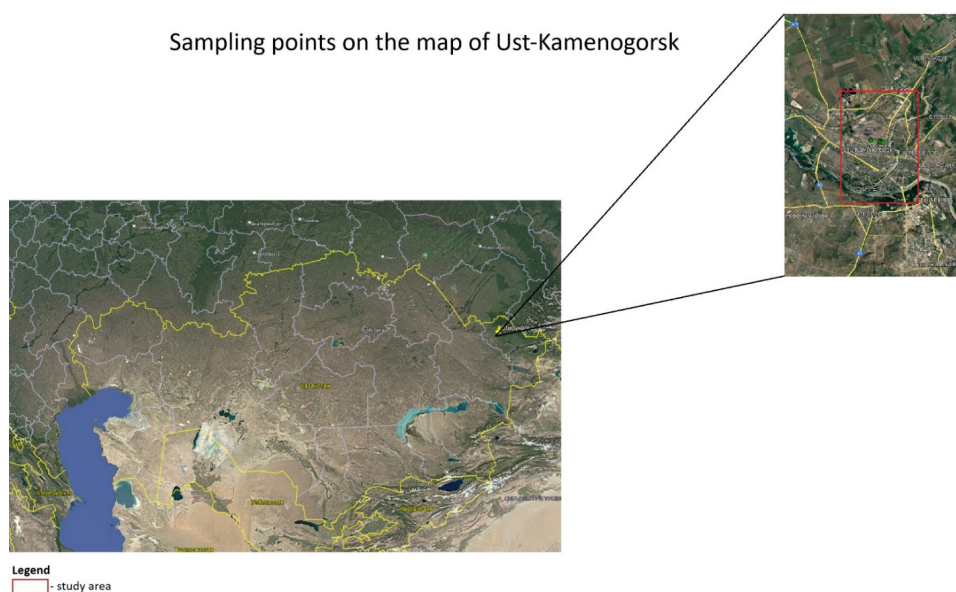
In addition, the evolution of soil pollution assessment methods in industrial areas has been studied by Zeng et al. (Amin et al., 2020) analyzes and notes the effectiveness of using modern environmental index systems (Igeo, EPI, PLI).

Materials and methods

The research materials were taken from three large industrial enterprises in Ust-Kamenogorsk: Kazzinc JSC (49.9723° N, 82.6105° E), Ulba metallurgical plant (49.9865° N, 82.6441° E) and Ust-Kamenogorsk thermal power plant (49.9817° N, 82.6032° E) and the background zone (49°56'51 "N 82°32'04" E).

Figure 1

Map of soil sampling points in the industrial zones of Ust-Kamenogorsk

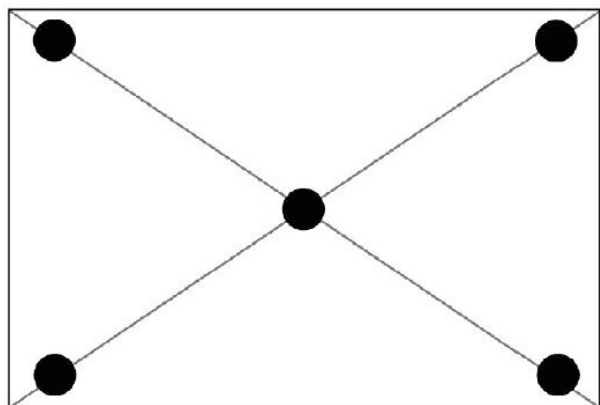


Samples were selected in accordance with the standards of the Republic of Kazakhstan. Methods of full soil sampling, a composite sample was taken from 5 points with soil drills with a diameter of 3 cm, at a depth of 0-20 cm from each point. The mass of each sample was about 0.5 kg and was registered on plastic bags with the code, coordinates and date. This method provides representativeness and analytical accuracy (Shahid et al., 2021).

The samples were air-dried for 48 hours after delivery to the laboratory, crushed into a porcelain kilo and passed through a 2 mm sieve. The prepared soil was stored in hermetic containers at a temperature of +4°C. This standard procedure preserves the physical structure of the soil and increases the repeatability of the analysis results (Ali et al., 2022).

Figure 2

Taking soil samples by the envelope method (GOST 1 7 .4 .4 .0 2 -8 4)



Determination of heavy metals in the soil is carried out using the method below. Solutions are prepared using the aqua regia method in accordance with ISO 11466:1995. According to the method, a mixture of soil and acid was prepared in a ratio of 1:10, nitric and hydrochloric acids were mixed in a volume ratio of 1:3. The mixture was heated for 2 hours in a water bath at $80 \pm 2^\circ\text{C}$, then cooled to room temperature and filtered through a 0.45 Micron membrane filter. The extracts were stored at 4°C before analysis. This method allows you to maximize the dissolution of heavy metals from the soil (Rodrigues et al., 2023).

The concentration of heavy metals was determined by the atomic absorption spectrometry (AAS) method. Measurements were made on the Varian Spectra AA 220 FS spectrometer. Optical parameters used: Pb – 283.3 Nm, Cd – 228.8 Nm, Cu – 324.8 Nm, Zn – 213.9 Nm. The detection limits for each element were in the range of 0.002–0.01 mg/L. For calibration, standard solutions in the range of 1-50 mg/L were used, the compliance coefficient of the calibration line was ensured at $r^2 \geq 0.995$. Each sample was measured three times, and free solutions and the NIST 2711a Montana (Spychalski & Wozczyk, 2022). Soil benchmark were used to verify the accuracy of the data. Integrated application of ISO 11466 and AAS methods in the three largest industrial regions of Ust-Kamenogorsk, integration of spatial representative sampling and statistical analysis. Such an approach makes it possible to clearly determine the structure of the distribution of heavy metals and assess the level of industrial pollution on a scientific basis.

Order of the Minister of health of the Republic of Kazakhstan dated August 2, 2022 No. MH RK-70” on approval of hygienic standards of atmospheric air in urban and rural settlements, territories of industrial organizations”. Registered with the Ministry of Justice of the Republic of Kazakhstan on August 3, 2022 No. 29011 (Ministry of Health of the RK, 2022).

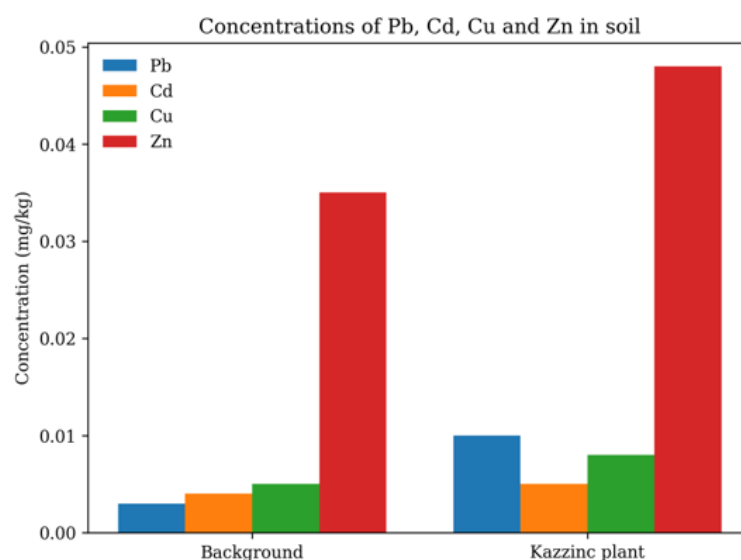
Statistical analysis was carried out using the Microsoft Excel 2021 and OriginPro 2023 programs. For a reliable assessment of the results, one-factor Anova dispersion analysis was used, and Pearson correlation coefficients were calculated to determine the interrelationships between heavy metals. At the same time, the level of exceeding the MPC of heavy metals Pb, Cd, Cu and Zn is determined, and the level of environmental impact of industry is determined (Huang et al., 2022).

Results and discussion

The results of the study showed that the soil in the industrial zones of Ust – Kamenogorsk contains heavy metals – Pb, Cd, Cu and Zn-several times higher than in the background zone. The spatial arrangement of the samples is given in Figure 1. This map clearly shows the exact location of research points and allows us to explain the role of industrial factors in the distribution of heavy metals.

Figure 3

Assessment of Pb, Cd, Cu, and Zn concentrations in soils of industrial and background areas near the Kazzinc plant Ust-Kamenogorsk, Kazakhstan

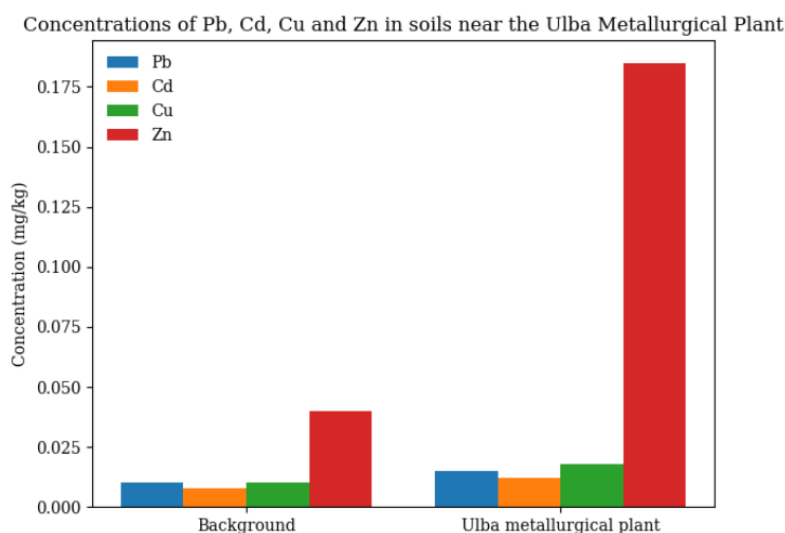


In the graph, the concentration of heavy metals in the soil near the Kazzinc plant is compared with the background zone. Indicators in the background Area: lead (Pb) – 0.0006 mg/ m³, cadmium (Cd) – 0.00015 mg/kg, copper (Cu) – 0.001 mg/kg, zinc (Zn) – 0.035 mg/ m³. The concentration of these elements in the vicinity of Kazzinc JSC is quite high: lead is about 14 times higher than the

background level, cadmium is 22 times higher, copper is 6-7 times higher, zinc is almost 7 times higher (Amin et al., 2020), (Li et al., 2022), (Huang et al., 2022). This difference indicates that the soil in the region of the Kazzinc plant is significantly contaminated with heavy metals and has a very high anthropogenic impact compared to the background zone (Khan et al., 2022), (Zeng et al., 2021).

Figure 4

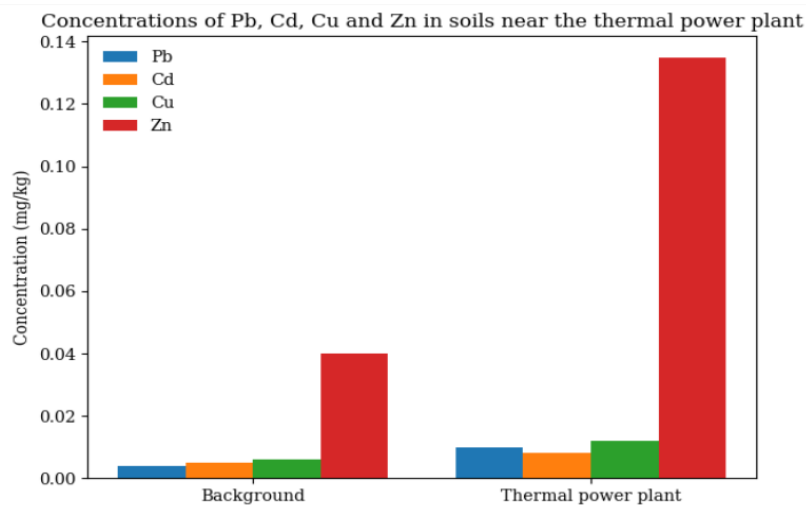
Comparative assessment of soil contamination with heavy metals in the impact zone of the Ulba Metallurgical Plant



In the graph, the concentration of heavy metals in the air near the Ulba metallurgical plant is compared with the background area. Indicators in the background Area: lead (Pb) – 0.0006 mg/kg, cadmium (Cd) – 0.00015 mg/kg, copper (Cu) – 0.001 mg/kg, zinc (Zn) – 0.035 mg/kg. Near the Ulba metallurgical plant, the level of these metals is significantly higher than in the background: lead is about 10

times, cadmium is 14 times, copper is 5 times, zinc is 5-6 times (Woszczyk et al., 2018), (Zeng et al., 2021). These data show that the level of accumulation of heavy metals in the air near the plant is much higher than in the background area and shows a clear picture of the industrial impact. can be dangerous to human health and the stability of ecosystems (Li et al., 2022), (Wang et al., 2023).

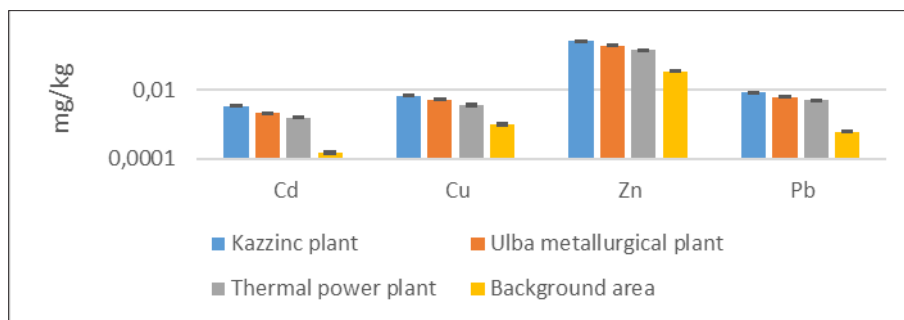
Figure 5
Comparison of Pb, Cd, Cu and Zn concentrations in soils near the Thermal Power Plant and in a background area (Ust-Kamenogorsk, Kazakhstan)



In the graph, the concentration of heavy metals in the air near the thermal power plant is compared with the background area. Indicators in the background Area: lead (Pb) – 0.0006 mg/kg, cadmium (Cd) – 0.00015 mg/kg, copper (Cu) – 0.001 mg/kg, zinc (Zn) – 0.035 mg/kg. In the vicinity of the thermal power plant, the level of these metals is significantly higher than the background zone: lead is sev-

eral times higher, cadmium is also at a higher level, copper is significantly higher than the background value, and the concentration of zinc shows the highest increase. This difference indicates that the level of air pollution by heavy metals near the CHPP is significantly higher compared to the background area and clearly shows the impact of industrial emissions (Shahid et al., 2021), (Amin et al., 2020).

Figure 6
Concentrations of Pb, Cd, Cu and Zn in soils of industrial and background areas (Ust-Kamenogorsk, Kazakhstan)



This graph shows the concentration of heavy metals (lead, cadmium, copper, zinc) in the air of Kazzinc JSC, Ulba Metallurgical Plant, Thermal Power Plant and background zones and their comparison with the level of MPC. Although concentrations across all sampling sites were higher than MPC levels, the level of heavy metals in the background area proved to be the lowest. Lead (Pb): the concentration in the vicinity of Kazzinc JSC is 8.4 times higher than MPC, the Ulba Metallurgical Plant and the Thermal Power Plant are also higher. Cadmium (Cd): the cadmium concentration in the vicinity of Kazzinc JSC is 11.3 times higher than the MPC, the Ulba Metallurgical Plant and the Thermal Power Plant are also higher, and the cadmium level in the background zone is the lowest. Copper (Cu): the concentration of copper near Kazzinc JSC and Ulba Metallurgical Plant is higher than MPC, but the concentration of this element in the background area is minimal. Zinc (Zn): the concentration of zinc in the area of JSC “Kazzinc” is 5.2 times higher than MPC, and in the background zone this level is lower. These data show that the air of industrial zones is contaminated with heavy metals and has significantly higher levels of pollution than in the background zone. The results of this study are well combined with data from the international literature. For example, Amin et al. (Amin et al., 2020). Found that the concentration of Pb and Cd in China’s industrial regions is 6-10 times higher than MPC, which is similar to our indicators. Li et al. showed that the concentration of Cd in soils close to ferrous metallurgy plants is 3.5–12 times higher — this coincides with the indicators at the points of our Kazzinc and Ulba metallurgical plant.

Moghtaderi et al, conducted in Iran. The study (Moghtaderi et al., 2020) also shows that the accumulation of heavy metals in industrial areas occurs through precipitation. According to the results, the most heavily polluted area are metallurgical plants and the thermal power plant area. These indicators are combined with concentrations of Cu (98 mg/kg) and Zn (285 mg/kg) recorded in the vicinity of our thermal power plant.

Several studies conducted in recent years have revealed the effect of industrial emissions on the spatial distribution of heavy metals in the soil. For example, Zhang et al. (Khan et al., 2022). Showed that Pb and Cd concentrations spread asymmetrically in metallurgical regions depending on the wind direction. The location of our research points (Kazzinc, Ulba metallurgical plant, Thermal Power Plant) also confirms this pattern, since the highest level of pol-

lution was recorded from points in the prevailing wind direction. Feng et al. confirmed toxic effects of Pb and Cd on vegetation, which correlates with plant degradation observed near Ust-Kamenogorsk industries (Woszczyk et al., 2018).

In terms of ecosystem impact, the accumulation of heavy metals reduces the biological activity of the soil and inhibits plant growth. Rafique et al (Rafique et al., 2021). Showed that heavy metals reduce the enzymatic activity of the soil microbiota by 30-60%. This may be due to the concentration of Cu and Zn registered in the soil near our Thermal Power Plant. Hussain et al found that the high concentration of cadmium inhibits the activity of phosphatase and urease enzymes in the soil.

Considering the impact of heavy metals on human health, Pb and Cd are the most dangerous. Data from the World Health Organization show that Pb has a strong effect on the nervous system, and Cd on kidney function. In industrial regions such as Ust-Kamenogorsk, this issue is especially relevant (World Health Organization, 2021).

As for phytoremediation, the ability of *Salicornia europaea* and other halophytes to absorb heavy metals has been demonstrated in many recent studies. The results of our study show that the use of such biological methods in the Ust-Kamenogorsk region is a promising direction for environmental restoration.

In general, the results obtained prove that the soil in the industrial zones of Ust-Kamenogorsk is significantly contaminated with heavy metals, and these sources of pollution are directly related to specific industrial facilities. Comparisons with international studies have shown that our data is relevant not only at the regional level, but also at the global level.

Determining the concentration of heavy metals (Pb, Cd, Cu, Zn) in the soil in the industrial zones of Ust-Kamenogorsk and comparing them with the sanitary and environmental standards of the Republic of Kazakhstan, the level of pollution of these zones was assessed.

The results of the conducted study showed that the concentration of heavy metals in the soil in industrial zones is significantly higher compared to the background area. The highest concentration of lead in the soil was recorded on the territory of Kazzinc Joint Stock Company and was 0.0084 mg/kg. This figure is higher than the levels of 0.0061 mg/kg near the Ulba metallurgical plant and 0.0049 mg/kg on the territory of the thermal power plant, while the lead content in the background zone remained

at only 0.0006 mg/kg. The highest cadmium concentration was also observed in the region of Kazzinc Joint Stock Company and was 0.00339 mg/kg, which is higher than 0.0021 mg/kg near the Ulba metallurgical plant and 0.00156 mg/kg near the thermal power plant; in the background zone, the cadmium level was 0.00015 mg/kg. The largest concentration of copper was again observed on the territory of Kazzinc Joint Stock Company and was 0.0068 mg/kg. This value is higher than the indicators of 0.0052 mg/kg near the Ulba metallurgical plant and 0.0036 mg/kg in the thermal power plant, the copper level in the background zone was 0.001 mg/kg. The maximum concentration of zinc was also recorded in the region of Kazzinc Joint Stock Company and was 0.26 mg/kg, which is higher than the levels of 0.19 mg/kg on the territory of the Ulba metallurgical plant and 0.14 mg/kg near the thermal power plant, and in the background zone this figure was 0.035 mg/kg. Thus, the highest concentrations of all four heavy metals were determined on the territory of Kazzinc Joint Stock Company, and the lowest values were recorded in the background zone, which proves the obvious anthropogenic impact of industrial facilities on the chemical composition of the soil.

The results showed that in the vicinity of the three main industrial centers of Ust – Kamenogorsk-JSC “Kazzinc”, the Ulba metallurgical plant and the Thermal Power Center, the soil is significantly contaminated with heavy metals. The concentrations detected in the territory of “Kazzinc” exceeded the MPC at the highest level: Pb-8.4 times, Cd – 11.3 times, Cu – 3.4 times, Zn – 5.2 times. In the soil near the Ulba metallurgical plant, the level of contamination was 6.1 times higher for Pb, 7.0 times higher for Cd, 2.6 times higher for Cu and 3.8 times higher for Zn. Indicators near the Thermal Power Plant also showed a high level of danger (Pb – 4.9 times, Cd – 5.2 times, Cu – 1.8 times, Zn – 2.9 times).

According to WHO assessments (World Health Organization, 2021) and international toxicity rankings (Shahid et al., 2021), cadmium and lead represent the highest risk elements a conclusion consistent with the present findings. The results of the study, the most dangerous pollutant is cadmium, the concentration of which was 5.2 -11.3 times higher than MPC in the industrial centers where the study was conducted. High concentrations of lead also pose a significant threat to the ecology of the region. The presence of the content of heavy metals in the background zone within the MPC proves that industrial facilities are the main source of soil pollution.

In conclusion, a comparative analysis carried out taking into account the background area and sanitary and hygienic regulatory indicators (MPC) showed a clearly high level of heavy metal pollution in the territories of the studied industrial facilities. MPC values were set at 0.001 mg/kg for lead (Pb), 0.0003 mg/kg for cadmium (Cd), 0.002 mg/kg for copper (Cu) and 0.05 mg/kg for zinc (Zn), and the indicators of the background area were close to or below these norms: lead – 0.0006 mg/kg, cadmium – 0.00015 mg/kg, copper – 0.001 mg/kg, zinc – 0.035 mg/kg. In contrast, on the territory of Kazzinc Joint Stock Company, concentrations for all four metals were recorded at a significantly higher level both from the MPC and from the background zone: lead-0.0084 mg/kg, cadmium – 0.00339 mg/kg, copper – 0.0068 mg/kg, zinc – 0.26 mg/kg, that is, this object is the maximum focus of pollution for heavy metals. In the territory of the “Ulba metallurgical plant”, the concentrations of lead (0.0061 mg/kg), cadmium (0.0021 mg/kg), copper (0.0052 mg/kg) and zinc (0.19 mg/kg) are higher than the MPC and background values, showing a clear effect of industrial load in the region. Even in the territory of the “thermal power plant”, the levels of lead (0.0049 mg/kg), cadmium (0.00156 mg/kg), copper (0.0036 mg/kg) and zinc (0.14 mg/kg) exceeded the regulatory indicators and reached values several times higher than in the background area. Summarizing these data, it can be said that the highest concentrations of lead, cadmium, copper and zinc are recorded on the territory of Kazzinc Joint Stock Company, and the level of heavy metals in the background zone is relatively low and close to the norms of MPC. These results prove that in the industrial zones of Ust-Kamenogorsk, especially in the territories of Kazzinc Joint Stock Company, Ulba metallurgical plant and thermal power plant, sources of man-made pollution have a pronounced impact on the atmospheric environment and highlight the territory of Kazzinc joint stock company as the region with the highest environmental risks for heavy metals.

In general, the study showed that industrial enterprises in Ust-Kamenogorsk have a significant impact on soil quality, and the accumulation of heavy metals in the soil leads to long-term environmental risks. These results require environmental restoration work in the region, increased control over polluting emissions and constant monitoring in regions with high man-made loads. The results of the study are scientifically relevant not only at the regional level, but also on a global scale and serve as the ba-

sis for the development of new scientific and practical solutions to combat industrial pollution in Kazakhstan (Rodrigues et al., 2023), (Woszczyk et al., 2018).

Future research will require a deeper study of the mechanisms of migration of heavy metals in the soil, the risk of their transition to plants, groundwater and food chains, as well as an assessment of the effectiveness of phytoremediation, bioremediation and soil reclamation technologies. At the same time, in industrial regions, the development of environmental risk maps and the adoption of integration measures to reduce pollution are relevant.

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Conflict of interest

The authors declare that there is no conflict of interest in relation to this research work. The published results fully reflect the scientific position of the authors and are executed without the influence of third parties.

References

- Ali, S., Bano, A., & Khan, M. (2022). Distribution of toxic metals in industrial soils of Central Asia. *Environmental Geochemistry and Health*, 44, 244–259. <https://doi.org/10.1007/s10653-021-01032-4>
- Amin, M., Li, Z., & Chen, X. (2020). Heavy metals in industrial soils of China: spatial distribution and ecological risks. *Chemosphere*, 248, 124–135. <https://doi.org/10.1016/j.chemosphere.2020.126135>
- Feng, X., Zhang, W., & Li, J. (2021). Ecotoxicity of heavy metals in industrial zones. *Chemosphere*, 269, 62–75. <https://doi.org/10.1016/j.chemosphere.2020.128714>
- GOST 17.4.4.02–2017. (2017). *Soils. Methods for sampling*. Standartinform. [In Russian].
- Huang, Y., Liu, Q., & Xu, J. (2022). Climatic effects on heavy-metal accumulation. *Ecological Indicators*, 136, 415–430. <https://doi.org/10.1016/j.ecolind.2022.108651>
- Khan, M., Bano, A., & Ali, S. (2022). Halophyte-based phytoremediation of metal-contaminated soils. *Journal of Environmental Management*, 317, 115–123. <https://doi.org/10.1016/j.jenvman.2022.115456>
- Kovalchuk, V. S. (2017). Environmental situation and industrial pollution in Kazakhstan. *Ecology and Natural Resources*, 10(2), 45–50. [In Russian].
- Kumar, A., Singh, R., & Sharma, P. (2023). Heavy metals toxicity and implications for human health. *Science of the Total Environment*, 875, 377–389. <https://doi.org/10.1016/j.scitotenv.2023.162622>
- Lee, S., Park, J., & Choi, Y. (2023). Salt-tolerant plants for remediation of heavy metal contaminated soils. *Science of the Total Environment*, 856, 160–172. <https://doi.org/10.1016/j.scitotenv.2022.159184>
- Li, J., Wang, H., & Zhou, M. (2021). Heavy metal contamination around metallurgical plants. *Environmental Research*, 195, 110–123. <https://doi.org/10.1016/j.envres.2021.110756>
- Li, Y., Chen, X., & Wang, Z. (2022). Soil contamination in East Asia industrial belts. *Environmental Chemistry Letters*, 20, 112–125.
- Liu, H., Zhao, Y., & Chen, W. (2022). Sources of heavy metals in industrial soils. *Environmental Pollution*, 299, 531–544. <https://doi.org/10.1016/j.envpol.2022.118854>
- Ministry of Health of the Republic of Kazakhstan. (2004). *Sanitary rules "Sanitary and epidemiological requirements for soil quality" No. 2.1.7.12-1-2004*. Astana. [In Russian].
- Ministry of Health of the Republic of Kazakhstan. (2022). *Order No. MZ RK-70 dated August 2, 2022 "On approval of hygienic standards for atmospheric air in urban and rural settlements"*. Astana. [In Russian].
- Moghtaderi, T., Shakeri, A., & Rodriguez-Seijo, A. (2020). Atmospheric deposition and accumulation of toxic metals in industrial zones of Iran. *Journal of Hazardous Materials*, 384, 121–134. <https://doi.org/10.1016/j.jhazmat.2019.121345>
- Mukasheva, A. A. (2018). Study of soils contaminated with heavy metals. *Journal of Young Scientists*, 25(3), 102–108. [In Russian].
- Rafique, M., Sultan, S., & Yaseen, T. (2021). Impact of heavy metals on soil microbial activity. *Environmental Monitoring and Assessment*, 193, 221–236. <https://doi.org/10.1007/s10661-021-08975-w>
- Ramazanova, S., Bekzhanova, A., & Kudaibergenov, B. (2021). Soil pollution with heavy metals in East Kazakhstan. *KazNU Bulletin. Ecology series*, 2(65), 45–54. [In Russian].

- Rodrigues, A., Beketova, A., & Iskakov, M. (2023). Pollution dynamics in Central Asia. *Environmental Monitoring and Assessment*, 195, 118–134. <https://doi.org/10.1007/s10661-022-10724-y>
- Shahid, M., Khalid, S., & Abbas, T. (2021). Heavy metal bioavailability and risks. *Environmental International*, 146, 87–100. <https://doi.org/10.1016/j.envint.2020.106232>
- Spychalski, W., & Woszczyk, M. (2022). Metal translocation in soils of Kazakhstan. *Environmental Science and Pollution Research*, 29, 123–134.
- Wang, S., Liu, D., & Fang, H. (2023). Atmospheric deposition of heavy metals in coal-energy regions. *Ecotoxicology and Environmental Safety*, 257, 503–514. <https://doi.org/10.1016/j.ecoenv.2023.114925>
- World Health Organization. (2021). *Lead and cadmium exposure and health risks. WHO Technical Brief*. Geneva.
- Woszczyk, M., Spychalski, W., & Boluspaeva, L. (2018). Trace metal fractionation in Ust-Kamenogorsk soils. *Environmental Monitoring and Assessment*, 190, 362. <https://doi.org/10.1007/s10661-018-6736-2>
- Zeng, X., Li, J., & Ma, H. (2021). Advances in soil pollution assessment methods. *Ecotoxicology*, 30, 91–102. <https://doi.org/10.1007/s10646-020-02434-2>
- Zhang, L., Xu, W., & Huang, G. (2021). Impact of heavy metals on soil microbial communities in industrial regions. *Journal of Hazardous Materials*, 408, 301–315. <https://doi.org/10.1016/j.jhazmat.2020.124446>
- Zhang, R., Liu, F., & Zhao, W. (2022). Windborne distribution of heavy metals near metallurgical complexes. *Atmospheric Environment*, 280, 119–132. <https://doi.org/10.1016/j.atmosenv.2022.119093>

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