UDC 504.054; 504.056
IRSTI 87.21.09
DOI 10.37238/2960-1371.2960-138X.2025.97(1).39

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THE LEVEL OF SOIL CONTAMINATION WITH HEAVY METALS IN THE TERRITORY OF THE BALKHASH MINING AND METALLURGICAL COMBINE

Annotation. Contamination of soil covered with heavy metals in places where industrial centers are concentrated is an urgent problem for many countries, including Kazakhstan. The main sources of heavy metal elements in the soil are metallurgical production, and heavy metal contamination of the soil around the metallurgical enterprise threatens human health and causes various pathologies in the development of living organisms. As a result of migration processes, toxicants in the soil enter the surface and underground waters. In this study, the environmental condition of soil contaminated with heavy metals in the territory of the metallurgical enterprise of Central Kazakhstan "Kazakhmys" Industrial Union (Balkash Mining and Metallurgical Combine) was evaluated. The soil cover in the industrial territory of Central Kazakhstan was found to be contaminated with different concentrations of heavy metals. Eleven heavy metals were detected in the soil samples, and the following heavy metals were found in dissolved form: TiO_2, MnO, and Fe_2O_3. It is known that the concentration of the heavy metals Pb, Zn, Cu, and Sr in the obtained soil samples is significantly higher. It was established that the concentration of heavy metals increases in the following order: Pb>Zn>Cu>Sr>Cr>As>V>Ni>Cd>Co>Hg. Three points, №1, №2, and №5, were identified with the highest levels of pollution. The highest concentration of lead was 901.1±0.05 mg/kg ($p<0.05$), the highest concentration of zinc was 647.3±0.05 mg/kg ($p<0.05$), the high concentration of copper was 376.3±0.05 mg/kg ($p<0.05$), and the highest concentration of strontium was 432.6±0.05 mg/kg ($p<0.05$). This study provides a comprehensive assessment of soil cover contamination with heavy metals in areas where industrial centers are concentrated, while also suggesting the adoption of topical solutions for pollution reduction and environmental management.

Keywords: Balkhash mining and metallurgical plant; soil pollution; heavy metals; soil cover; ferrous and non-ferrous metallurgy; atomic-adsorption method; ecosystem.

Introduction

Heavy metals are common pollutants in the soil environment, namely arsenic (As), cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb), copper (Cu), zinc (Zn), and nickel (Ni). This type of contamination is biologically toxic, widely distributed, and persists long-term in the soil environment. With the rapid development of the economy and society, a variety of heavy metal-contaminated soil threatens the environment and public health [1].

The soil contamination with these heavy metal ions introduces significant environmental hazards, ranging from soil and water pollution to the disruption of ecosystems and the release of potentially deleterious substances into the environment [2]. The mining processes associated with copper, zinc, lead, manganese, and iron, extensively utilized in industrial applications, have been identified as primary contributors to soil contamination [3]. Systematically elevated levels of these heavy metals have consistently surfaced in soil samples collected from mining sites, necessitating a thorough investigation into their intricate environmental impacts. The soil contamination with these heavy metal ions not only poses significant ecological hazards on land but also extends its effect on the surrounding air and water ecosystems. The mining processes associated with copper, zinc, lead, manganese, and iron, are widely employed in industrial applications, potentially leading to air pollution. Additionally, the leaching of heavy metals into water sources exacerbates water pollution concerns, posing threats to aquatic life and potentially impacting human health [4].

Soil is the main component of the ecosystem, but recently, due to the rapid development of industrialization and urbanization, significant problems of environmental pollution have arisen [5]. It is known that the earth, as the main part of the terrestrial ecosystem, plays a very important role in the existence of various types of living organisms. Heavy metals in the soil (HM) accelerate their accumulation in the soil due to their biotoxicity accumulation and non-degradable properties [6]. Heavy metals that accumulate in the soil, even in small quantities, are very toxic, particularly dangerous pollutants of the natural environment, and even at low concentrations, they cause various pathologies in the development of living organisms [7]. An increase in the level of accumulation of heavy metals leads to many physical, chemical, and biological changes in the environment. The nature and extent of these changes depend on the amount and form of heavy metals in natural objects [8]. The group of heavy metals includes the following chemical elements: Cr, Mn, Fe, Co, Ni, Cu, Zn, Ga, Ge, Mo, Cd, Sn, Sb, Te, W, Hg, Tl, Pb, Bi. Dangerous toxic heavy metals include Pb, Cd, Hg, Zn, Mo, Ni, Co, Sn, Cu, V, Sb, As [9].

High concentrations of non-biodegradable metals are extremely dangerous for living organisms. Cadmium (Cd), chromium (Cr), lead (Pb), zinc (Zn), iron (Fe), and copper (Cu) are heavy metals that are particularly dangerous and are found in contaminated soil [10]. Heavy metals such as Cd, Cu, Pb and Zn are known as potentially toxic elements (PUEs) due to their increased toxicity and are also used in metallurgy, mining, waste incineration, road infrastructure, smelting and fossil fuel combustion industries [11].

Due to the specific surface area of heavy metals, most of the particles in the atmosphere come from coal, fuel and industrial pollutants such as iron (Fe), chromium (Cr), lead (Pb), cadmium (Cd), zinc (Zn) and copper (Cu) [12]. Increasing industrialization, exploitation of natural and mineral resources, and unstable social conditions have led to widespread environmental degradation on a global scale.

Environmental and subsoil pollution is the result of direct dumping of urban and industrial pollutants into landfills [13].

The environment is affected by various anthropogenic factors, namely industrial wastes, mining wastes, combustion processes, smelter wastes, traffic emissions, etc. [14]. Consequences of the introduction of toxic substances into the environment contribute to the occurrence of various diseases in organisms as a result of deterioration and change of natural ecosystems, stability, bioaccumulation and biomagnification of heavy metals [15]. Eating vegetables contaminated with toxic elements can lead to various pathological diseases. In particular, Cd, Pb and As are carcinogenic and cause neurological abnormalities or kidney, bone and cardiovascular system diseases [16, 17]. Other heavy metals, such as Cu and Zn, are considered non-carcinogenic, but their increased content causes liver failure, stomach pain, and changes in the immune system, which can harm human health [18, 19]. Metals also affect aquatic life, damage many parts of the body, and cause endocrine disorders and immunological abnormalities [20]. It also causes an imbalance in the ecosystem, putting pressure on the health of certain species. The major components of pollutants are anthropogenic sources, although various pollutants occur naturally in the soil as mineral constituents and are usually toxic at high levels. Soil pollution is usually not overtly measured or observed, but it is a serious problem.

Factories and industrial areas emit large amounts of pollutants into the environment and also reduce the quality of the environment. The health conditions of residents in industrial cities with poor ecological conditions may show dangerous indicators. Metals and metalloids enter the human body through drinking water, food and food additives, inhalation, absorption through the skin, and accidental ingestion [21, 22]. In modern society, due to the development of agrochemistry and industry, the amount of pollutants is increasing day by day. Thus, the complex nature of their decomposition and accumulation at different rates makes soil studies difficult and expensive to determine the exact extent of pollutant exposure. Toxic chemical effects and their possible environmental consequences require the development of technologies for the removal of environmental pollutants [23]. Industrial waste increases the greenhouse effect, acid rain, and the concentration of suspended substances in the air [24]. The mining industry plays an important role in the development of the world economy by supplying necessary materials to various industries. However, mining is a concern due to its significant environmental impacts, including pollution, habitat destruction, and greenhouse gas emissions [25]. Lands around metallurgical plants are constantly exposed to waste containing various atmospheric emissions, including harmful heavy metals. Heavy metals are among the most toxic substances for living organisms, including plants [26]. They cause direct damage to plants, including woody plants, accelerating their decline and eventually causing death [27]. Therefore, the purpose of the work is to determine the composition of heavy metals in the soil cover of the industrial areas of Central Kazakhstan.

Research Objects and Methods

Heavy metals are the main pollutant of the natural environment that harms the biosphere and is known to be dangerous to the human body. Due to the large number of industrial establishments, some areas are turning into ecological disaster zones.

Although heavy metals are second only to pesticides in terms of danger, they are more toxic than the more widely known pollutants such as carbon dioxide and sulfur. In the future, they are considered to be more dangerous than nuclear power plant waste and solid household waste [28]. The study area is located in the Central regions of the Republic of Kazakhstan, Karaganda Region, the Industrial Association "Kazakhmys" (Balkash Mining and Metallurgical Combine) is shown in Figure 1. The presented maps were created using ArcGIS 10.6.

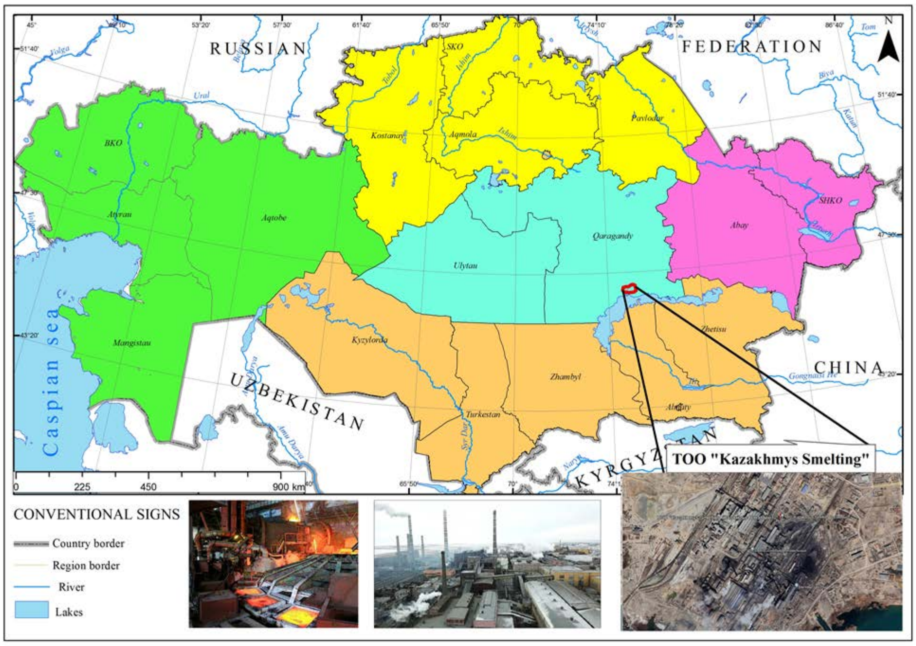

Figure 1. Map of the territory where the "Balkash Mining and Metallurgical Combine" Industrial Union is located. Note: created based on the author.

The industrial enterprise "Kazakhmys" Industrial Union is located in the southwestern part of the city. To the west of the plant, there is a waste storage facility with a total area of 40 km^2. There is a thermal power plant in the southeast.

The geolocation of soil sampling points is shown in Figure 2. The coordinates of the soil sampling points are: 46.83'20"31N and 74.94'46"26E. In October 2023, soil samples were taken from the industrial areas of Central Kazakhstan from the depth of 25-30cm of the root layer using the "envelope method". The soil sampling process was carried out according to GOST 17.4.4.02-2017 [29].

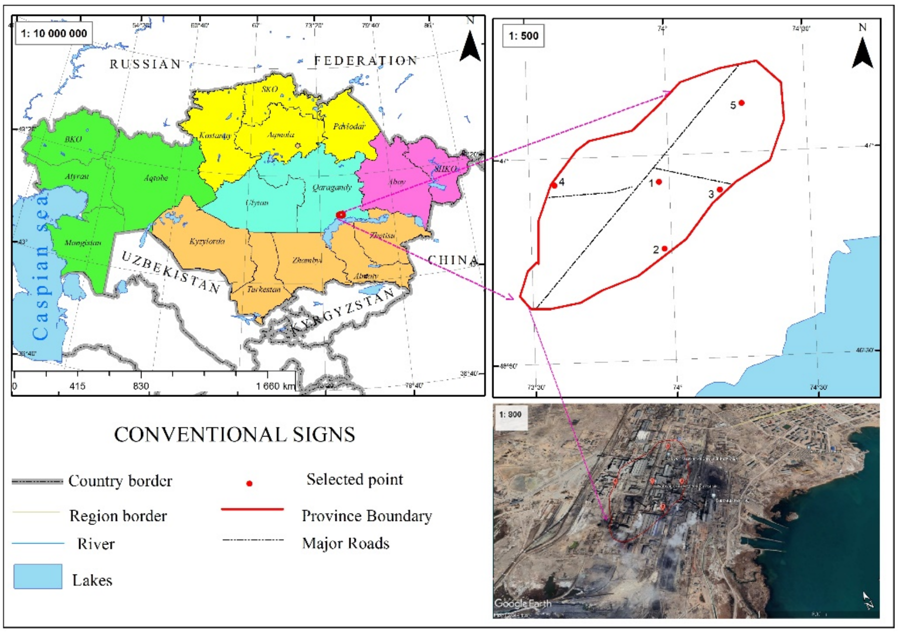

Figure 2. Location map of the study area with sampling points. Note: created based on the author.

Soil samples were taken from five points on the territory of the "Kazakhmys" Industrial Union from different distances. Four points were marked in the corners of the test areas and one in the middle. From the point in the middle of the first sample and this first point, the second point sample is ±866m, the third point sample is ±784m, the fourth point sample is ±546m, the fifth point sample is ±1160m (five samples in total The sixth soil sample was taken from the clean area for control purposes. Samples were collected in clean plastic bags weighing approximately 1.0kg. The collected samples were sequentially numbered and delivered to the laboratory. Based on the certified laboratory of "Ekoexpert" LLP, laboratory analysis of soil samples was carried out to determine heavy metals. Atomic absorption and X-ray fluorescence spectroscopy methods were used in the work.

Research results and their analysis.

As a result of experimental studies, the concentrations of heavy metals in soil samples taken near this production area are shown in Figures 3, 4, 5, 6, 7, and 8. The distribution of the concentration of heavy metals in soil samples is shown in the histogram. The vertical axis shows heavy metals, and the horizontal axis shows the concentration of metals in mg/kg. Blue columns represent soil samples taken from five points on the territory of the "Kazakhmys" production association, and orange represents soil samples taken from a clean area for control purposes.

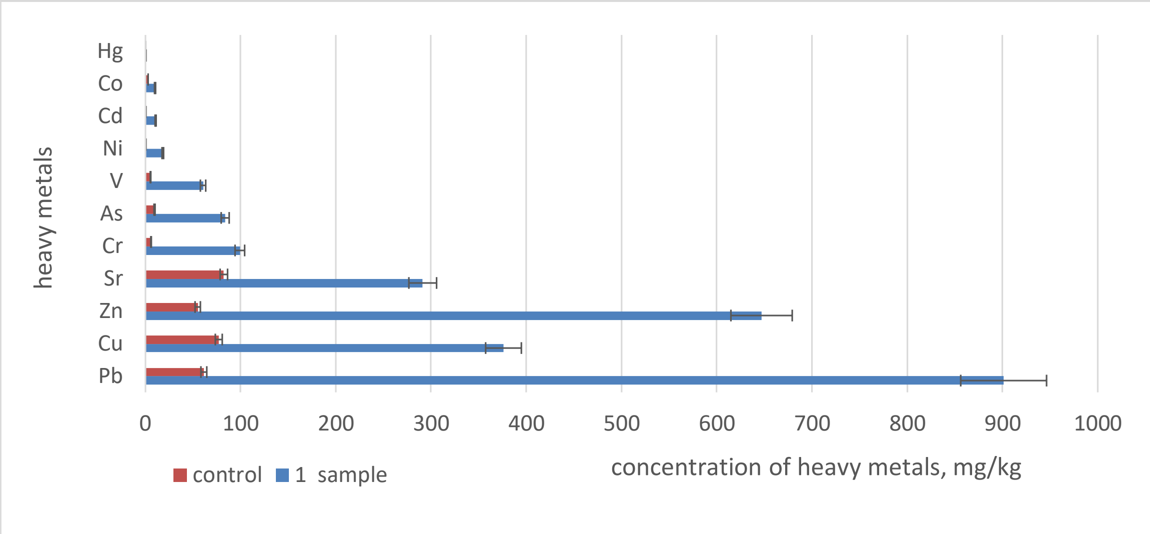

Figure 3. Amount of heavy metals (mg/kg) in the soil taken from the first point.

In Figure 3, the highest Pb in the soil sample from the first point (sample) is 901.1±0.05 mg/kg ($p<0.05$), which is about fourteen times more than the lead in the soil sample from the clean area (control). Zn is 647.3±0.05 mg/kg ($p<0.05$), which is about eleven times higher than the amount of Zn in the sample from the clean area compared to the soil in the control sample. Cu is 376.3±0.05 mg/kg ($p<0.05$), which is about five times higher than the amount of copper in the soil sample from the control area. Sr 291.2±0.05 mg/kg ($p<0.05$), about three times more than the amount of strontium in the soil from the control area.

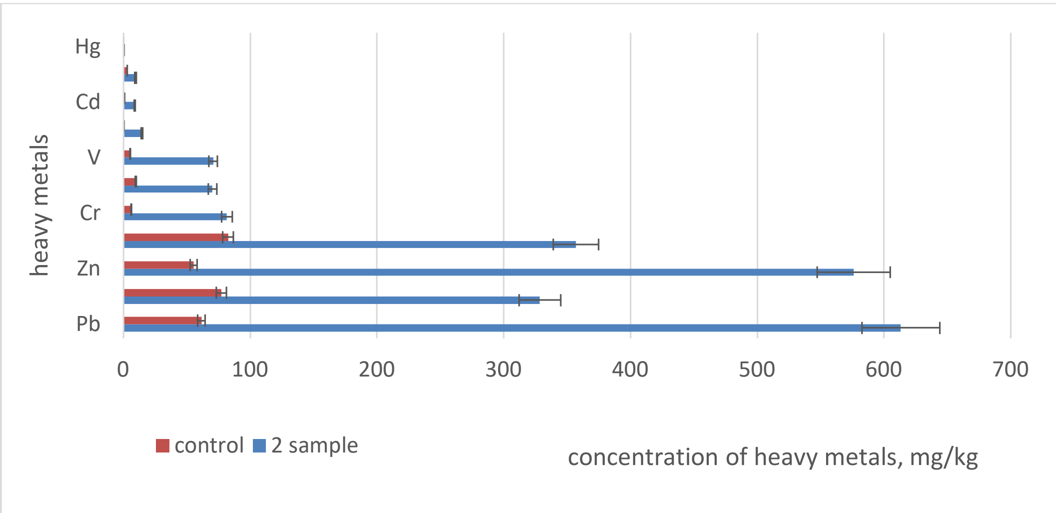

Figure 4. Amount of heavy metals (mg/kg) in the soil taken from the second point.

As shown in Figure 4, the maximum concentration of heavy metals Pb, Zn, Sr and Cu (mg/kg) is observed in the soil sample taken from the second point (sample). Accordingly, the values of these metals are 613.2±0.05 mg/kg ($p<0.05$), about ten times more than lead in the soil sample taken from the clean area (control). 576.3±0.05 mg/kg ($p<0.05$), which is about eleven times more than the amount of zinc in the sample from the clean area compared to the soil in the control area. 357.05±0.05 mg/kg ($p<0.05$), which is four times higher than the amount of strontium in the soil sample from the control area. 328.5±0.05 mg/kg ($p<0.05$), which is about four times more than the amount of copper in the soil from the control area.

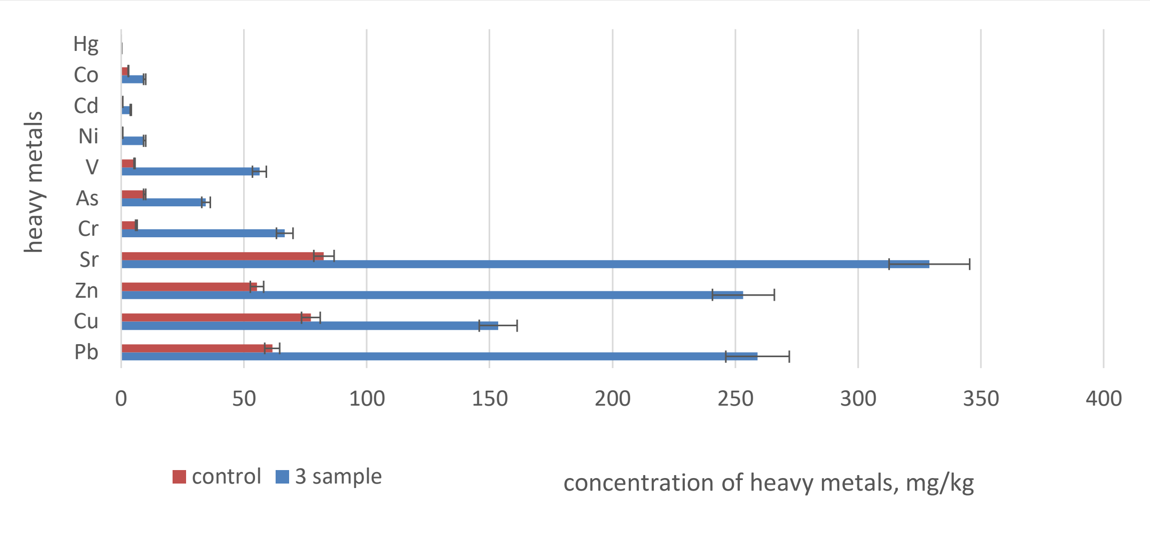

Figure 5. Amount of heavy metals (mg/kg) in the soil taken from the third point.

Figure 5 shows that at the third point, the highest index of heavy metals increased in the following order: Sr>Pb>Zn>Cu. Strontium is 329.05±0.05 mg/kg ($p<0.05$), which is about 4 times higher than the amount of strontium in soil from the control area. Lead is 259.1±0.05 mg/kg ($p<0.05$), which is about 4.2 times higher than the lead concentration in the soil sample taken from the clean area. Zinc is 253.3±0.05 mg/kg ($p<0.05$), which is about 4.6 times higher than soil zinc from the control area. Copper is 153.5±0.05 mg/kg ($p<0.05$), the amount of copper in the soil is about 2 times higher than in the control area.

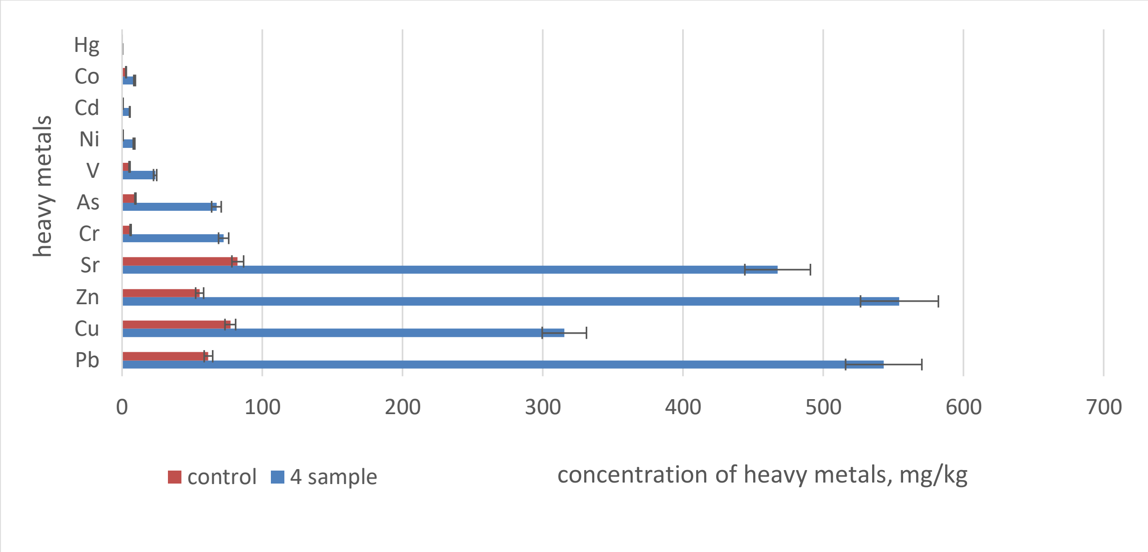

Figure 6. Amount of heavy metals (mg/kg) in the soil from the fourth point.

In figure 6, the levels of heavy metals in the soil sample taken from the fourth point increase in the following order: Zn > Pb > Sr > Cu. Zn is 554.4±0.05 mg/kg ($p<0.05$), approximately ten times higher than the zinc content in the control area soil. Pb is 543.1±0.05 mg/kg ($p<0.05$), approximately 8.8 times higher than the lead content in the soil sample from the clean area. Sr is 467.3±0.05 mg/kg ($p<0.05$), 5.6 times higher than the strontium level in the soil sample from the control area. Cu is 315.3±0.05 mg/kg ($p<0.05$), four times higher than the copper concentration in the soil sample from the control area.

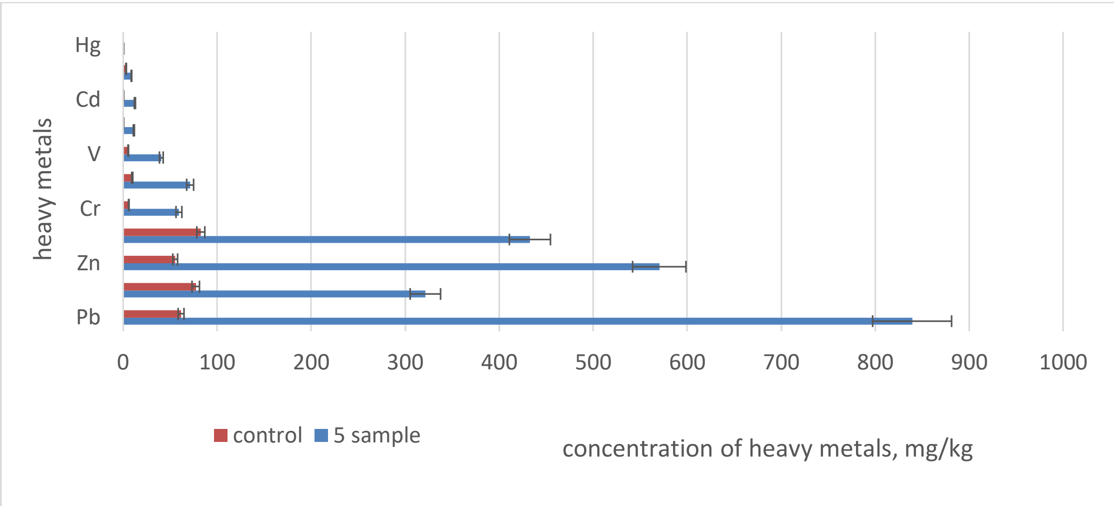

Figure 7. Amount of heavy metals (mg/kg) in the soil from the fifth point.

In figure 7, the levels of heavy metals in the soil sample taken from the fifth point increase in the following order: Pb > Zn > Sr > Cu. Pb is 839.3±0.05 mg/kg ($p<0.05$), approximately 14 times higher than the lead level in the soil sample from the control area. Zn is 570.3±0.05 mg/kg ($p<0.05$), about 10 times higher than the zinc content in the soil sample from the control area. Sr is 432.6±0.05 mg/kg ($p<0.05$), five times higher than the strontium level in the control area. Cu is 321.35±0.05 mg/kg ($p<0.05$), and the copper concentration in the sample was found to be four times higher than in the control.

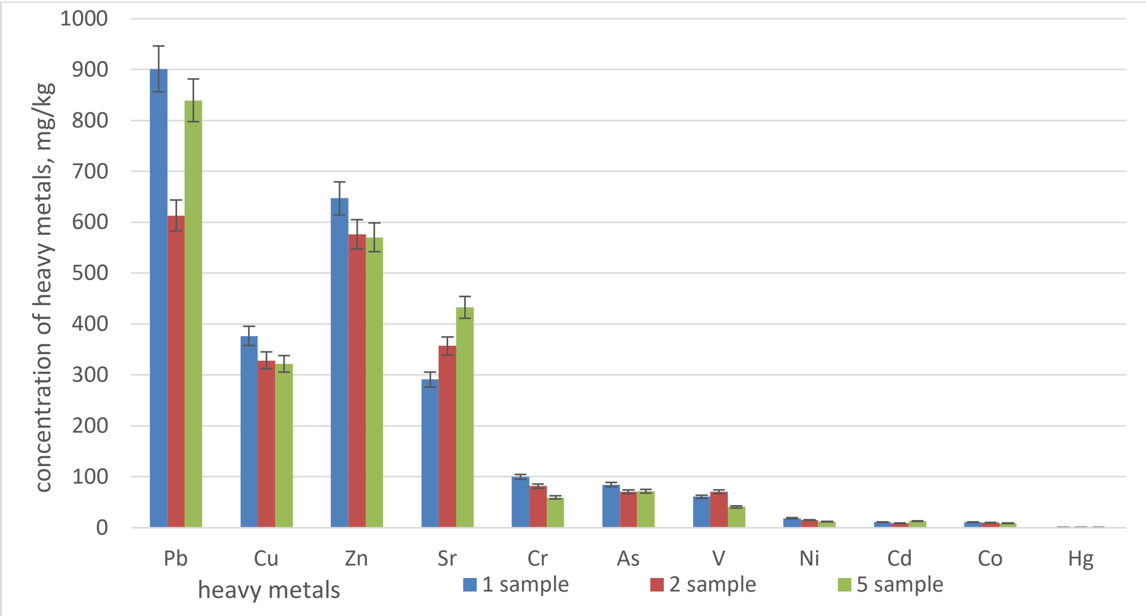

Figure 8. Amount of heavy metals (mg/kg) in the soil obtained from points №1, №2, and №5.

The results of the comparison of the three points with the highest level of pollution are shown below. The highest concentration of lead in the first point is 901.1±0.05 mg/kg ($p<0.05$), in the fifth point 839.3±0.05 mg/kg ($p<0.05$), in the second point 613.2±0.05 mg/kg ($p<0.05$). The highest concentration of zinc in the first point is 647.3±0.05 mg/kg ($p<0.05$), in the second point 576.3±0.05 mg/kg ($p<0.05$), and in the fifth point 570.3±0.05 mg/kg ($p<0.05$) is observed. The highest concentration of copper in the first point is 376.3±0.05 mg/kg ($p<0.05$), in the second point 328.5±0.05 mg/kg ($p<0.05$), in the fifth point 321.35±0.05 mg/kg ($p<0.05$). The highest concentration of strontium was 432.6±0.05 mg/kg ($p<0.05$) at the fifth point, 357.05±0.05 mg/kg ($p<0.05$) at the second point, and 291.2±0.05 mg/kg ($p<0.05$) at the first point. The order of growth of elements in the soil was determined: lead (Pb) > zinc (Zn) > copper (Cu) > strontium (Sr).

Discussion

Soil contamination due to heavy metal ions such as lead, zinc, manganese, iron, and copper can have a significant impact on water and aquatic ecosystems [30]. These metals infiltrate into groundwater, causing contamination of these water sources

(Ahmed et al., 2021). Additionally, precipitation can transport heavy metals from the soil to rivers and lakes, leading to pollution that affects life in water bodies, including various organisms such as plants and animals. Some heavy metals like manganese, iron, and copper may be absorbed as nutrients by certain plants, but in cases like lead and zinc, these metals can be absorbed in excess, causing harm to plants [31]. This pollution can directly impact aquatic animals and create changes in the food chain. Water contaminated with heavy metals can also harm humans through the consumption of water or direct consumption of contaminated fish. Sustainable use of resources and materials, optimal land management, and the use of water treatment technologies can contribute to reducing pollution and protecting aquatic ecosystems.

In the soil, heavy metals enter as ions e.g., Pb (II), Zn (II). The ion exchange process in the soil with various ions, such as hydrogen ions H+ and aluminum ions Al (III), causes the migration of metal ions from the soil to the aqueous solution [32]. Ju et al. conducted a comprehensive review with a focus on sea cucumbers as bioindicators of heavy metal contamination and toxicity [33]. The most commonly observed heavy metals reported included Fe, Zn, As, Cu, Hg, Pb, Mn, Cr, Ni, and Cd, with specific species such as Eupentacta fraudatrix and Holothuria mammal showing elevated levels of arsenic, and Stichopus Herrmann raising concerns about mercury. Human activities such as cultivation, fishing, and shipping release heavy metals into free marine ecosystems, posing a threat to oceans and coastal environments.

During rainfall or irrigation, soil particles containing metal ions move with water toward surface waters [34]. Vineetha et al. studied the effects of a catastrophic flood on heavy metal pollution and the benthopelagic community in the Cochin estuary, India. The 2018 flood led to decreased nutrients and heavy metal concentrations in water and sediments [35]. Pre-flood, phytoplankton abundance, mainly Cerataulina bicornis, dropped significantly post-flood. Conversely, zooplankton and macrobenthos responded positively to flood-induced habitat changes. Sediment heavy metal levels decreased, promoting higher macrobenthic diversity, shifting from pollution-indicator polychaetes to healthier mollusks and crustaceans. It can be concluded that heavy metal ions have been transported by soil particles from the bed to other locations by floods, potentially leading to increased pollution in other areas.

The metallurgy industry plays a crucial role in soil contamination with ions of lead, zinc, manganese, iron, and copper. Metal production and processing, waste management, and atmospheric deposits are the primary sources of contamination. These pollutants have extensive effects on soil, water, plants, wildlife, and human health. To address this issue, effective monitoring and assessment are essential to comprehend the precise dimensions of the problem and present necessary strategies for reduction and remediation. While traditional soil purification methods, such as physical, chemical, and biological approaches, have limitations, the utilization of emerging technologies and approaches is imperative for pollution control. The metallurgy industry is progressively embracing green chemistry and sustainable practices to diminish environmental impacts and enhance efforts in addressing the issue. In general, managing pollution with ions of lead, zinc, manganese, iron, and copper is vital for preserving both human health and the environment.

Conclusion

The leading industries in the industrial production of Central Kazakhstan are ferrous and non-ferrous metallurgy, which account for more than 50% of the region's total potential. The results of the research showed that heavy metals accumulate in the soil at almost all sampling points, regardless of the distance. The soil samples taken from industrial areas showed higher accumulation of Pb, Cu, Zn, and Sr compared to the samples taken from the clean area. Mercury (Hg) and cobalt (Co) were found to be uniformly distributed in very low concentrations across all soil samples.

When comparing the three points with the highest pollution levels, the highest concentration of lead was observed at point 1, with 901.1±0.05 mg/kg ($p<0.05$). The highest concentration of zinc was 647.3±0.05 mg/kg ($p<0.05$) at point 1. The highest concentrations of copper were 376.3±0.05 mg/kg ($p<0.05$) at point 1, and the highest concentration of strontium was observed at point 5, with 432.6±0.05 mg/kg ($p<0.05$). Based on the results of the research, a comparison of the three points with the highest levels of Pb, Cu, Zn, and Sr pollution in the area of the metallurgical enterprise "Kazakhmys" (Balkhash Mining and Metallurgical Plant) showed the following results: Pb, №1>№5>№2, Cu, №1>№2>№5, Zn, №1>№2>№5, and Sr, №5>№2>№1. Based on this result, it was determined that the soil of the area closest to the Balkhash Mining and Metallurgical Plant has a high level of contamination with heavy metals. The political and legal implications of this matter are significant due to the widespread effects of pollution with ions of lead, zinc, manganese, iron, and copper on the territory of the Production Association "Kazakhmys" (Balkhash Mining and Metallurgical Plant) of the metallurgical enterprise of Central Kazakhstan. Governments and regulatory bodies must implement and enforce stricter environmental standards and more effective regulations to prevent pollution from metal production facilities. This includes enhancing waste management methods, employing gas control technologies, and establishing more efficient mechanisms for monitoring and enforcement. Furthermore, increased financial support for research into innovative techniques and methods for pollution control and remediation is necessary.

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БАЛҚАШ КЕН-МЕТАЛЛУРГИЯЛЫҚ КОМБИНАТЫ АУМАҒЫНДАҒЫ ТОПЫРАҚТЫҢ АУЫР МЕТАЛДАРМЕН ЛАСТАНУ ДЕҢГЕЙІ

Аңдатпа. Индустриалды орталықтар шоғырланған жерлердегі топырақ жамылғыларының ауыр металдармен ластануы әлемнің көптеген елдері үшін, соның ішінде Қазақстанда да өзекті мәселе болып табылады. Топырақтағы ауыр металл элементтерінің негізгі көздері металлургия өндірісі болып, металлургиялық кәсіпорын айналасындағы топырақтың ауыр металдармен ластануы адам денсаулығына қауіп төндіреді және тірі организмдердің дамуында әртүрлі патологияларды тудырырады. Миграциялық процестердің нәтижесінде топырақтағы токсиканттар жер үсті және жер асты суларына түседі. Бұл зерттеуде Орталық Қазақстанның металлургиялық кәсіпорыны «Қазақмыс» Өндірістік бірлестігі (Балқаш кен-металлургиялық комбинаты) аумағындағы ауыр металдармен ластанған топырақ жамылғысының экологиялық жағдайы бағаланды. Орталық Қазақстанның өндірістік аумағындағы топырақ жамылғысының әртүрлі ауыр металдардың ұқсамаған концентрациялармен ластану жағдайы анықталды. Алынған топырақ сынамаларында 11 ауыр металдар анықталды және еріген күйінде мына ауыр металдар кездесті TiO_2, MnO, және Fe_2O_3. Мына ауыр металдардың Pb, Zn, Cu және Sr концентрациясының анағұрлым жоғары екендігі белгілі болды. Ауыр металдардың концентрациясының өсуі Pb>Zn>Cu>Sr>Cr>As>V>Ni>Cd>Co>Hg ретпен болатындығы айқындалды.

Ластану деңгейі ең жоғары болған үш нүкте №1, №2, №5 анықталды. Қорғасынның ең жоғары концентрациясы 901,1±0,05 мг/кг ($p<0,05$), мырыштың ең жоғары концентрациясы 647,3±0,05 мг/кг ($p<0,05$), мыстың жоғары концентрациялары 376,3±0,05 мг/кг ($p<0,05$) және стронций ең жоғары концентрациясы 432,6±0,05 мг/кг ($p<0,05$) болғандығы анықталды. Бұл зерттеу өндірістік орталықтар шоғырланған аумақтардағы топырақтың ауыр металдармен ластануын кешенді бағалауды қамтамасыз етеді, сонымен қатар ластануды азайту және қоршаған ортаны ұтымды басқару бойынша ағымдағы шешімдерді ұсынады.

Кілт сөздер: Балқаш кен-металлургиялық комбинаты; топырақ ластануы; ауыр металдар; топырақ жамылғысы; қара және түсті металлургия; атомно-адсорбциялық әдіс; экожүйе.

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УРОВЕНЬ ЗАГРЯЗНЕНИЯ ПОЧВ ТЯЖЕЛЫМИ МЕТАЛЛАМИ НА ТЕРРИТОРИИ БАЛХАШСКОГО ГОРНО-МЕТАЛЛУРГИЧЕСКОГО КОМБИНАТА

Аннотация. Загрязнение почвенных покровов тяжелыми металлами в местах сосредоточения промышленных центров является актуальной проблемой для многих стран мира, в том числе и Казахстана. Основными источниками элементов тяжелых металлов в почве являются металлургические производства, а загрязнение тяжелыми металлами почвы вокруг металлургического предприятия угрожает здоровью человека и вызывает различные патологии в развитии живых организмов. В результате миграционных процессов токсиканты, находящиеся в почве, попадают в поверхностные и подземные воды. В данном исследовании оценено экологическое состояние почвы, загрязненной тяжелыми металлами, на территории металлургического предприятия Центрально-Казахстанского производственного объединения «Казахмыс» (Балкашский горно-металлургический комбинат, или БГМК). Установлено, что почвенный покров на промышленной территории Центрального Казахстана загрязнен различными концентрациями тяжелых металлов. В пробах почвы обнаружено 11 тяжелых металлов, а в растворенном состоянии обнаружены следующие тяжелые металлы: TiO_2, MnO и Fe_2O_3. Известно, что концентрация этих тяжелых металлов Pb, Zn, Cu и Sr в полученных образцах почвы значительно выше. Установлено, что концентрация тяжелых металлов увеличивается в ряду Pb>Zn>Cu>Sr>Cr>As>V>Ni>Cd>Co>Hg. Три точки №1, №2, №5 были выявлены с наибольшим уровнем загрязнения. Наибольшая концентрация свинца 901,1±0,05 мг/кг ($p<0,05$), а наибольшая концентрация цинка составила 647,3±0,05 мг/кг ($p<0,05$), высокие концентрации 376,3±0,05 мг/кг ($p<0,05$) и установлено, что наибольшая концентрация стронция составила 432,6±0,05 мг/кг ($p<0,05$). Данное исследование дает комплексную оценку загрязнения почвенного покрова тяжелыми металлами в районах сосредоточения промышленных центров, а также предлагает актуальные решения по снижению загрязнения и рациональному природопользованию.

Ключевые слова: Балхашский горно-металлургический комбинат; загрязнение почв; тяжелые металлы; почвенный покров; черная и цветная металлургия; атомно-адсорбционный метод; экосистема.