ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

№2
2026

ISSN 2518-170X (Online)
ISSN 2224-5278 (Print)

CENTRAL ASIAN ACADEMIC
RESEARCH CENTER

N E W S
OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES

2 (476)

MARCH – APRIL 2026

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, 2026

The scientific journal News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences has been indexed in the international abstract and citation database Scopus since 2016 and demonstrates stable bibliometric performance.

The journal is also included in the Emerging Sources Citation Index (ESCI) of the Web of Science platform (Clarivate Analytics, since 2018).

Indexing in ESCI confirms the journal's compliance with international standards of scientific peer review and editorial ethics and is considered by Clarivate Analytics as part of the evaluation process for potential inclusion in the Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI), and Arts & Humanities Citation Index (AHCI).

Indexing in Scopus and Web of Science ensures high international visibility of publications, promotes citation growth, and reflects the editorial board's commitment to publishing relevant, original, and scientifically significant research in the fields of geology and technical sciences.

«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылыметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

Индексирование в Scopus и Web of Science обеспечивает высокую международную востребованность публикаций, способствует росту цитируемости и подтверждает стремление редакционной коллегии публиковать актуальные, оригинальные и научно значимые исследования в области геологии и технических наук.

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Owner: «Central Asian Academic Research Center» LLP (Almaty).
The certificate of registration of a periodical printed publication in the Committee of information of the Ministry of Information and Communications of the Republic of Kazakhstan № KZ50VPY00121155, issued on 05.06.2025
Thematic scope: *geology, hydrogeology, geography, mining and chemical technologies of oil, gas and metals*
Periodicity: 6 times a year.
http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Меншіктеуші: «Орталық Азия академиялық ғылыми орталығы» ЖШС (Алматы қ.).
Қазақстан Республикасының Ақпарат және коммуникациялар министрлігінің Ақпарат комитетінде 05.06.2025 ж. берілген № KZ50VPY00121155 мерзімдік басылым тіркеуіне қойылу туралы куәлік.
Тақырыптық бағыты: *геология, гидрогеология, география, тау-кен ісі, мұнай, газ және металдардың химиялық технологиялары*
Мерзімділігі: жылына 6 рет.
http://www.geolog-technical.kz/index.php/en/

News of the National Academy of Sciences of the Republic of Kazakhstan. Series of geology and technology sciences.
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)
Собственник: ТОО «Центрально-Азиатский академический научный центр» (г. Алматы).
Свидетельство о постановке на учет периодического печатного издания в Комитете информации Министерства информации и коммуникаций и Республики Казахстан № KZ50VPY00121155, выданное 05.06.2025 г.
Тематическая направленность: *геология, гидрогеология, география, горное дело и химические технологии нефти, газа и металлов*
Периодичность: 6 раз в год.
http://www.geolog-technical.kz/index.php/en/

CONTENTS

NEWS OF THE NATIONAL ACADEMY OF SCIENCES OF THE REPUBLIC
OF KAZAKHSTAN, SERIES OF GEOLOGY AND TECHNICAL SCIENCES
ISSN 2224–5278
Volume 2.
Number 476 (2026), 253–271

https://doi.org/10.32014/2026.2518-170X.627

UDC: 504.53
IRSTI: 87.21.91

©Madibekov A.[1,2], Opp Christian[3], Karimov A.[1], Ismukhanova L.[1,2], Zhadi A.[1,2*], 2026.
[1]JSC Insitute of geography and water security, Almaty, Kazakhstan;
[2]Kazakh National University named after Al-Farabi, Almaty, Kazakhstan;
[3]Philipps-Universität Marburg, Marburg, Germany.
E-mail: askhat.zhadi@mail.ru

REGULARITIES OF DISTRIBUTION AND ACCUMULATION FACTORS OF HEAVYMETALS IN SOILS OF THE ZHETYSU REGION (KAZAKHSTAN)

Madibekov Azamat — PhD, Associate Professor, Chief researcher, JSC «Institute of Geography and Water Security», Almaty Kazakhstan; Senior lecturer, Al-Farabi Kazakh National University, Almaty, Kazakhstan;
E-mail: a.s.madibekov@gmail.com, https://orcid.org/0000-0001-9303-6640;
Opp Christian — Professor, Philipps-Universität Marburg, Faculty of Geography, Marburg, Germany;
E-mail: opp@geo.uni-marburg.de, https://orcid.org/0000-0003-0683-3890;
Karimov Alibek — Researcher, JSC «Institute of geography and water security», Almaty, Kazakhstan;
E-mail: karalik0@mail.ru, https://orcid.org/0000-0003-0797-6252;
Ismukhanova Laura — PhD, Senior researcher, JSC «Institute of geography and water security», Senior lecturer, Al-Farabi Kazakh National University, Almaty, Kazakhstan,
E-mail: ismukhanova@ingeo.kz, https://orcid.org/0000-0001-6421-8621;
Zhadi Askhat — PhD, Researcher, JSC «Institute of geography and water security», Almaty, Kazakhstan, Senior lecturer, Al-Farabi Kazakh National University, Almaty, Kazakhstan,
E-mail: askhat.zhadi@mail.ru, https://orcid.org/0000-0001-7044-3454.

Abstract. The Zhetysu region of Kazakhstan is characterized as a partially metal-rich territory due to both natural ore-bearing conditions and anthropogenic impacts. Despite the significant industrial and technogenic pressure in the region, systematic studies on the spatial distribution of heavy metals in soils have not previously been conducted. Therefore, a first grid-based monitoring study was carried out to assess the distribution of heavy metals in surface soils. Soil samples were collected from the upper layer (0–5 cm) at 52 monitoring points. The concentrations of heavy metals were determined using the flame atomic absorption spectrometric method with a spectrophotometer.

Results. The copper (Cu) concentrations in soils ranged from 0.003 to 0.037 mg kg^{-1}, while zinc (Zn) concentrations varied from 0.006 to 0.195 mg kg^{-1}. Soil lead (Pb) concentrations ranged between 0.0002 and 0.0110 mg kg^{-1}. Cadmium (Cd) content was detected at levels of 0.001–0.009 mg kg^{-1}. Nickel (Ni) concentrations ranged from 0.0081 to 0.0240 mg kg^{-1}, and cobalt (Co) concentrations from 0.015 to 0.030 mg kg^{-1}. Higher copper and cobalt concentrations were mainly observed in heavy loams and sandy loams due to their higher sorption capacity. Zinc distribution showed spatial similarity with copper. Low lead concentrations were recorded in sandy soils, which promote metal leaching. Elevated nickel concentrations were associated with clay soils capable of retaining metal particles. In addition to natural background levels and anthropogenic sources, wind transport was identified as an important factor influencing the accumulation of heavy metals in soils.

Scientific novelty. The study provides the first grid-based monitoring assessment of heavy metal distribution in surface soils of the Zhetysu region, revealing the combined influence of soil types, natural geochemical background, and aeolian transport processes.

Practical value. The obtained results form a baseline dataset for environmental monitoring and assessment of soil contamination in the region and can support environmental management and soil protection strategies in industrial areas.

Keywords: heavy metals, soil, anthropogenic load, maximum permissible concentration, distribution by wind

Funding: *The work was carried out in the framework of grant funding by the Committee of Science of the Ministry of Science and Higher Education of the Republic of Kazakhstan No. AP23488902 "Ecosystem Sustainability of Zhetysu Region: Geo-environmental analysis of depositing environments and recommendations for sustainable development".*

For citations: *Madibekov A., Christian Opp., Karimov A., Ismukhanova L., Zhadi A. Regularities of distribution and accumulation factors of heavymetals in soils of the Zhetysu region (Kazakhstan). News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. 2026. No.2. Pp. 253–271. DOI: https://doi.org/10.32014/2026.2518-170X.627*

©Мадибеков А.С.[1,2], Опп К.[3], Каримов А.[1], Исмуханова Л.Т.[1,2], Жәди А.Ө.[1,2*], 2026.
[1]«География және су қауіпсіздігі» АҚ, Алматы, Қазақстан;
[2]Әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан;
[3]Марбург қаласындағы Филипп университеті, Марбург, Германия.
E-mail: askhat.zhadi@mail.ru

ЖЕТІСУ ӨҢІРІНІҢ ТОПЫРАҚТАРЫНДА АУЫР МЕТАЛДАРДЫҢ ТАРАЛУ ЗАҢДЫЛЫҚТАРЫ МЕН ЖИНАҚТАЛУ ФАКТОРЛАРЫ (ҚАЗАҚСТАН)

Мадибеков Азамат — PhD, қауымдастырылған профессор, бас ғылыми қызметкер, «География және су қауіпсіздігі институты» АҚ; аға оқытушы, әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан,
E-mail: a.s.madibekov@gmail.com, https://orcid.org/0000-0001-9303-6640;
Опп Кристиан — профессор, Марбург атындағы Филиппс университеті, Марбург, Германия,
E-mail: opp@geo.uni-marburg.de, https://orcid.org/0000-0003-0683-3890;
Каримов Алибек — ғылыми қызметкер, «География және су қауіпсіздігі институты» АҚ, Алматы қ., Қазақстан,
E-mail: karalik0@mail.ru, https://orcid.org/0000-0003-0797-6252;
Исмуханова Лаура — PhD, аға ғылыми қызметкер, «География және су қауіпсіздігі институты» АҚ, аға оқытушы, әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан,
E-mail: ismukhanova@ingeo.kz, https://orcid.org/0000-0001-6421-8621;
Жәди Асхат — PhD, ғылыми қызметкер, «География және су қауіпсіздігі институты» АҚ, Алматы, Қазақстан, аға оқытушы, әл-Фараби атындағы Қазақ ұлттық университеті, Алматы, Қазақстан,
E-mail: askhat.zhadi@mail.ru, https://orcid.org/0000-0001-7044-3454.

Аннотация. Қазақстанның Жетісу өңірі табиғи кенді жағдайлар мен антропогендік әсерлерге байланысты металдарға салыстырмалы түрде бай аймақ ретінде сипатталады. Аймақта өнеркәсіптік және техногендік жүктеме жоғары болғанымен, топырақтағы ауыр металдардың кеңістіктік таралуы жүйелі түрде бұрын зерттелмеген. Осыған байланысты жер үсті топырақтарындағы ауыр металдардың таралуын бағалау мақсатында алғашқы торлы мониторингтік зерттеу жүргізілді. Топырақтың жоғарғы қабатынан (0–5 см) 52 нүктеден үлгілер алынды. Ауыр металдардың мөлшері жалынды атомдық-абсорбциялық спектрометрия әдісімен анықталды.

Нәтижелер. Нәтижелер бойынша Cu мөлшері 0,003-0,037 мг/кг, Zn – 0,006-0,195 мг/кг, Pb – 0,0002-0,0110 мг/кг, Cd – 0,001-0,009 мг/кг, Ni – 0,0081-0,0240 мг/кг, Co – 0,015-0,030 мг/кг аралығында анықталды. Cu және Co жоғары концентрациялары сорбциялық қабілеті жоғары ауыр және құмдақ саздақ топырақтарда байқалды. Zn таралуы Cu-мен ұқсас. Құмды топырақтарда Pb мөлшері төмен болды, бұл металдардың шайылуына байланысты. Ni мөлшері көбіне сазды топырақтарда жоғары болды. Сонымен қатар ауыр металдардың жиналуына жел арқылы тасымалдану маңызды фактор болып табылады.

Ғылыми жаңалығы. Зерттеу Жетісу өңірінің жер беті топырақтарындағы ауыр металдардың таралуын торлы мониторинг негізінде алғаш рет бағалап, топырақ типтері, табиғи геохимиялық фон және эолдық тасымал процестерінің бірлескен әсерін көрсетті.

Практикалық маңызы. Алынған нәтижелер өңірдегі топырақтың ластануын бағалау және экологиялық мониторинг жүргізу үшін бастапқы деректер базасын қалыптастырады, сондай-ақ өнеркәсіптік аймақтарда қоршаған ортаны басқару мен топырақты қорғау стратегияларын әзірлеуге негіз бола алады.

Түйін сөздер: ауыр металдар, топырақ, антропогендік жүктеме, шекті рұқсат етілген концентрация, жел арқылы таралу

©Мадибеков А.С.[1,2], Опп К.[3], Каримов А.[1], Исмуханова Л.Т.[1,2], Жәди А.Ө.[1,2*], 2026.

[1]АО «Институт географии и водной безопасности», Алматы, Казахстан;
[2]Казахский национальный университет имени аль-Фараби, Алматы, Казахстан;
[3]Университет Филиппа в Марбурге, Марбург, Германия.
E-mail: askhat.zhadi@mail.ru

ЗАКОНОМЕРНОСТИ РАСПРЕДЕЛЕНИЯ И ФАКТОРЫ АККУМУЛЯЦИИ ТЯЖЕЛЫХ МЕТАЛЛОВ В ПОЧВАХ ЖЕТЫСУСКОГО РЕГИОНА (КАЗАХСТАН)

Мадибеков Азамат — PhD, ассоциированный профессор, главный научный сотрудник, АО «Институт географии и водной безопасности»; Старший преподаватель, Казахский национальный университет имени аль-Фараби, Алматы, Казахстан,
E-mail: a.s.madibekov@gmail.com, https://orcid.org/0000-0001-9303-6640;
Опп Кристиан — профессор, Филиппс-университет Марбурга, Марбург, Германия,
E-mail: opp@geo.uni-marburg.de, https://orcid.org/0000-0003-0683-3890;
Каримов Алибек — научный сотрудник, АО «Институт географии и водной безопасности», Алматы, Казахстан,
E-mail: karalik0@mail.ru, https://orcid.org/0000-0003-0797-6252;
Исмуханова Лаура — PhD, старший научный сотрудник, АО «Институт географии и водной безопасности»; Старший преподаватель, Казахский национальный университет имени аль-Фараби, Алматы, Казахстан;
E-mail: ismukhanova@ingeo.kz, https://orcid.org/0000-0001-6421-8621;
Жәди Асхат — PhD, научный сотрудник, АО «Институт географии и водной безопасности», Алматы, Казахстан, Старший преподаватель, Казахский национальный университет имени аль-Фараби, Алматы, Казахстан;
E-mail: askhat.zhadi@mail.ru, https://orcid.org/0000-0001-7044-3454.

Аннотация. *Актуальность.* Жетысуская область Казахстана характеризуется как территория с повышенным содержанием металлов, обусловленным как природными рудоносными условиями, так и антропогенным

воздействием. Несмотря на значительное промышленное и техногенное давление, систематические исследования пространственного распределения тяжёлых металлов в почвах ранее практически не проводились. В связи с этим выполнено первое сеточное мониторинговое исследование распределения тяжёлых металлов в поверхностных почвах региона. Образцы почв верхнего слоя (0–5 см) были отобраны в 52 точках. Концентрации металлов определялись методом пламенно-атомно-абсорбционной спектрометрии. *Результаты*. Установлено, что содержание Cu варьирует в пределах 0,003–0,037 мг/кг, Zn - 0,006–0,195 мг/кг, Pb - 0,0002–0,0110 мг/кг, Cd - 0,001–0,009 мг/кг, Ni - 0,0081–0,0240 мг/кг, Co - 0,015–0,030 мг/кг. Повышенные концентрации Cu и Co отмечены в тяжёлых и супесчаных суглинках, что связано с их высокой сорбционной способностью. Пространственное распределение Zn в целом коррелирует с распределением Cu. Низкие значения Pb характерны для песчаных почв, способствующих вымыванию металлов. Повышенные концентрации Ni приурочены к глинистым почвам. Важным фактором формирования геохимических аномалий также является ветровой (эоловый) перенос. *Научная новизна*. В работе представлена первая оценка пространственного распределения тяжёлых металлов в поверхностных почвах Жетысуского региона на основе сеточного мониторинга, что позволило выявить совокупное влияние типов почв, природного геохимического фона и эоловых процессов переноса. *Практическая значимость.* Полученные результаты формируют базовую информационную основу для экологического мониторинга и оценки загрязнения почв региона и могут быть использованы при разработке мер экологического управления и стратегий защиты почв в промышленных и природно-антропогенных системах.

Ключевые слова: тяжелые металлы, почва, антропогенная нагрузка, предельно допустимая концентрация, ветровое распределение

Introduction. Zhetysu region of Kazakhstan, located in a favorable natural and climatic zone, possesses significant natural resources, including fertile lands and water sources. The region has strategic importance as a key transit corridor of the Silk Road project “Western Europe – Western China” and serves as one of the major business and transport hubs of Central Asia, acting as a bridge between Europe and Asia. The regional economy is primarily based on agricultural and industrial sectors, which ensures economic stability but simultaneously increases anthropogenic pressure on the environment. At the same time, the region faces infrastructural limitations related to waste treatment and environmental protection.

The main sources of atmospheric air pollution in the region include heat and power stations, automobile transport, and facilities of the agricultural and construction sectors. In recent years, environmental protection measures have been introduced to reduce emissions, including modernization of treatment facilities and improvement of technological processes aimed at lowering concentrations of

inorganic dust, soot, hydrocarbons and heavy metals. In addition, the territory of Zhetysu region and adjacent areas includes several geochemical provinces, zones of geochemical associations and metallogenic complexes (Kravchenko et al, 2024).

According to RSE "Kazhydromet", over the past five years the atmospheric pollution index (API) indicates elevated air pollution levels. Exceedances of maximum allowable concentrations (MAC) were recorded for PM-10 (568 cases), carbon monoxide (538 cases), PM-2.5 (240 cases) and hydrogen sulfide (50 cases). Pollution intensifies mainly during the cold season due to emissions from heat and power plants and automobile transport. The MAC values are 0.06 mg m^{-3} for PM-10, 0.035 mg m^{-3} for PM-2.5 and 0.008 mg m^{-3} for hydrogen sulfide (Order of the Minister of Health of the Republic of Kazakhstan, 2022).

The main sources of water pollution in the region are public utilities, mining and the food industry (Kumari et al, 2021). Municipal utilities account for about 95% of pollutant discharges, while mining and the food industry contribute 3.3% and 1.5%, respectively. Major polluters include SCP VH "Karatalirrigation", "Zhetysu Vodokanal" and other municipal enterprises. According to RSE "Kazgidromet" monitoring data for 2023, water bodies in the region correspond to class 2 of the Unified Classification System, with the main pollutants being suspended solids, nitrite anions and total phosphorus exceeding MAC levels.

Anthropogenic soil pollution, particularly in Taldykorgan, Tekeli and Zharkent, is characterized by elevated concentrations of heavy metals (lead and zinc), largely related to the activities of the Tekeli Lead-Zinc Combine. Such contamination negatively affects soil physical and biological properties, reduces fertility and poses risks to human health (Tőzsér et al, 2023; Angon et al, 2024).

Agricultural lands are economically important for the region; however, soil degradation caused by anthropogenic impacts reduces their productivity (Angon et al, 2024; Rashid et al, 2023). Earlier studies conducted in the Ile River delta and the State National Reserve "Ile-Balkash" revealed soil and vegetation degradation associated with industrial emissions (Performed within the framework, 2023; Madibekov et al, 2023; Madibekov, 2023). Exceedances of maximum permissible concentrations (MPC) were recorded for copper, zinc, cadmium, cobalt and nickel, indicating significant accumulation of pollutants in soils (Fang et al, 2024). The MPC values (mg kg^{-1}) are: Cu – 3.0, Zn – 23.0, Pb – 6.0, Cd – 0.5, Co – 5.0 and Ni – 4.0 (Order of the Minister of Health of the Republic of Kazakhstan, 2021)

The development of the region contributes to the growth of prosperity and cultural diversity. But this development is accompanied by significant anthropogenic pressure on the natural environment. Urbanization, as well as intensive activities of energy and agricultural enterprises lead to desertification, reduction of biodiversity, degradation of water resources and soils in this area (Li et al, 2019, Kumar et al, 2024). This situation requires attention to the ecological conditions of the region and strengthening of measures to control and reduce anthropogenic pressure and impact on the environment.

The analysis of the current state of the region's depositing environments has shown that the main pollution factors are industrial emissions, transportation and public utilities. The environmental situation is characterized by the accumulation of pollutants in the atmosphere, water bodies and soils, which requires strengthened monitoring and modernization of environmental protection measures at enterprises. The introduction of a systematic approach to assessing and reducing anthropogenic pressure, together with effective natural resource management strategies, is essential for ensuring the environmental sustainability of the region (González Henao, 2021). Data on the distribution and accumulation of heavy metals in soils are fundamental for establishing an effective environmental monitoring system aimed at assessing and reducing environmental pressure; however, such systematic baseline data are still lacking for the Zhetysu region.

Therefore, a sampling system based on geographical and geochemical analysis was developed to comprehensively assess and monitor environmental conditions. The territory of the region was divided into equal areas of approximately 250 km², forming a grid of 52 squares. This approach ensures systematic and uniform spatial coverage while minimizing the risk of missing zones with potential contamination anomalies. Sampling sites were selected to represent the diversity of natural and anthropogenic environments of the region.

The key sampling sites were determined considering:

1. the regional geochemical background, which allows identification of anomalous concentrations of metals and toxicants and evaluation of anthropogenic impacts;

2. the degree of anthropogenic load, including industrial zones, agricultural areas and populated territories;

3. the spatial and functional diversity of ecosystems, taking into account relief, soil types and water resources to assess factors influencing pollutant distribution.

Such structured division of the territory allows us to achieve high accuracy and reproducibility of data, providing objective information on the nature and extent of pollution at the region level.

Materials and Methods. A field expedition for sampling was carried out from September 25 to October 25 2024 at established permanent points distributed over the study area (Figure 1) to assess the chemical-toxicological state of soils in the Zhetysu region. The purpose of this work was to obtain original data on heavy metal concentrations in soils.

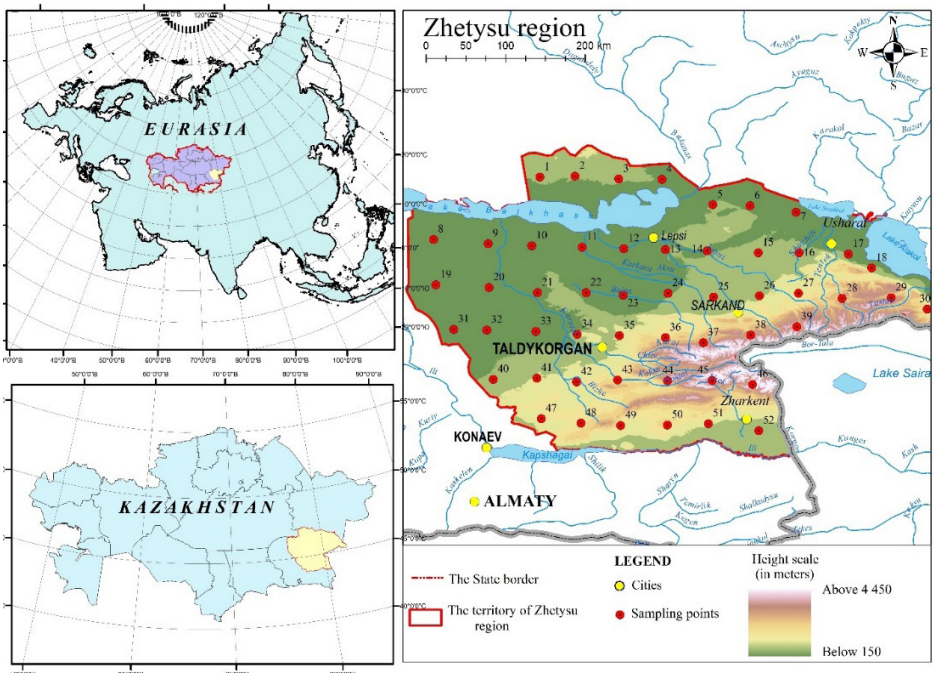

Figure 1. Location of the Zhetysu region and soil sampling points of the present study.

Soil sampling was carried out using the envelope method with diagonal crossing of the site to ensure representativeness. Sampling locations were selected based on analysis of the regional geochemical background, which allowed identification of areas with anomalous concentrations of the studied parameters. Each sample therefore reflects the characteristics of the soil cover and genetic horizons typical for the site.

According to the regulations (Water quality, 2005), each composite sample was formed from point samples collected at the same site. A pooled sample consisted of at least five-point samples with a total mass of not less than 1 kg, ensuring reliable analytical results. Sampling was performed carefully to avoid contamination, and metal-free tools were used.

To assess soil contamination by heavy metals, samples were taken from the surface layer (0–5 cm), each weighing up to 200 g. The samples were air-dried (Water quality, 2005) and stored in cloth bags, cardboard boxes or glass containers. For chemical analysis, air-dried samples were cleaned of large inclusions, reduced by the quartering method to 0.2 kg, ground and sieved through a 1 mm sieve. Approximately 5 g of soil was used for laboratory analysis.

Mobile forms of metals were extracted according to RD 52.18.289-90 (Guiding document, 1990) using an acetate-ammonium buffer solution (pH 4.8). Metal concentrations in the extracts were determined by atomic absorption analysis, allowing assessment of the mobile fraction of metals and their potential

bioavailability.

The concentration of heavy metals such as Cu, Zn, Pb, Cd, Co and Ni in soil samples was determined by flame atomic absorption spectrometric method using a Shimadzu AA-7000 spectrophotometer (Japan) (Kumari et al, 2021). The method is based on the measurement of light absorption by metal atoms at specific wavelengths, which allows the determination of the concentration of each metal in the samples (e.g., for copper – 324.7 nm, for zinc – 213.9 nm, etc.). For calibration purposes, State Standard Reference Materials (SSM) with correlation r = 0.99 were used, which guarantees the reliability of the results.

The organization of field and laboratory studies on the basis of modern methods allows us to ensure high accuracy and reproducibility of data on soil contamination of the region. The application of atomic absorption analysis methods for heavy metals determination allows to obtain reliable data necessary for the further assessment of the technogenic impact degree (Kumari et al, 2021).

When analyzing the prevailing wind directions, the period from the beginning of complete melting snow cover (April 27, 2024) to the first day of sampling soil probes on September 25, 2024 was taken.

Results and discussion. *Change in air temperature.* In consequence of the chemical-toxicological analyses of soils in the region the following regularities and peculiarities of distribution of heavy metals and other chemical indicators were founded. Based on these new results the determination of the state of ecosystems in the region (Campillo-Cora et al, 2024) became possible.

Soil pH values vary from 5.7 to 8.1. This indicates a diverse range of soil acidity in the region. Most of the studied soils have neutral or slightly alkaline reactions, which is common for soils in Central and East Kazakhstan with normal biological activity and the maintenance of a healthy microbiological composition. Soil mineralization varies in a wide range – from 20 to 3240 mg/L. High mineralization levels indicate significant salt content, which may contribute to the accumulation of heavy metals, especially in soils with heavier granulometric structure.

The soils of the region are represented by a wide range of granulometric types, from sands and sandy loams to heavy loams and clays. Clay and loam soils have a high sorption capacity and therefore retain pollutants, including heavy metals, more effectively. In contrast, sandy soils are more permeable and prone to metal leaching, which reduces their ability to accumulate contaminants over long periods (Opp et al, 1999).

Copper concentrations in soils range from 0.003 to 0.037 mg kg^{-1}. The highest values were recorded in heavy loam and sandy loam soils at sampling points 24 and 26 (up to 0.037 mg kg^{-1}) and point 28 (up to 0.036 mg kg^{-1}), which may be associated with local anthropogenic sources and the high sorption capacity of these soil types. The lowest copper content (0.003 mg kg^{-1}) was observed in sandy loam soils, for example at point 46 (Explanatory note, 2023). The classification of soil granulometric composition follows Lomtadze V. D. (Lomtadze, 1990).

The source of soil contamination with copper and zinc in the town of Tekeli is of natural-anthropogenic origin. The area is associated with mining and processing of polymetallic ores, while the geological structure of the Tekeli deposit itself creates an elevated natural background of heavy metals in soils (National conditions and resources, 2010; Emami et al., 2023). In addition, copper, lead and zinc deposits are located near the regional center. Metal-processing enterprises such as “Kainar”, “Ger-power”, “Velund-steel” and the “Miras” plant operate in Taldykorgan (Madibekov et al., 2023). Local wind conditions promote the transport of metal particles mainly in the southern direction.

Figure 2 shows the spatial distribution of copper concentrations in surface soils (0–5 cm) of the Zhetysu region together with wind roses indicating the frequency of wind directions. Wind roses were constructed using data from the Internet resource https://rp5.ru and the Climate Handbook (Weather Schedule, 2024; Reference book on climate of Kazakhstan, 2025). The rp5.ru dataset includes statistical wind direction distribution from the date of complete snow cover melt (or establishment of stable positive daily temperatures) until September 25, 2024, when soil sampling began. Climate Handbook data were used to determine the average annual repeatability of wind directions. Additional information was taken from the “Results of Environmental Impact Assessment” for the Sayak field (Explanatory note, 2023).

Analysis of wind flows near areas with elevated heavy metal concentrations shows that these zones often coincide with prevailing wind directions. Geochemical analysis allowed identification of two main sources of soil contamination: technogenic (industrial emissions) and natural (ore deposits). Elevated copper concentrations are mainly associated with the Zhetysu Alatau mountain region (1600–4622 m a.s.l.), although air transport from this area indicates that it is not a major accumulation zone of heavy metals. Zinc and cadmium show similar spatial distribution patterns.

Zinc concentrations range from 0.006 to 0.195 mg kg^{-1}. The highest values (up to 0.195 mg kg^{-1}) occur in the eastern and southeastern parts of the region, including areas near Sarkand and Zharkent, indicating strong local contamination likely related to industrial and agricultural activities. Lower zinc concentrations (around 0.008 mg kg^{-1}) are typical for the central and western parts of the region.

In the Bezhintau Ridge area, a polymetallic mining province explains the similar distribution of elevated copper and zinc concentrations in soils, especially north-north-east of Zharkent. Part of this province extends into the territory of the People's Republic of China (PRC) (Explanatory note, 2023). Data on metallogenic complexes and geochemical associations were obtained from the Geochemical and Metallogenic Maps of the National Atlas of the Republic of Kazakhstan (Natural conditions and resources, 2010). The distribution of metals is strongly influenced by mountain-valley wind circulation in the western Boro-Khoro Ridge and air flows from the Zharkent area.

The northern slopes of the Tastau Ridge belong to a quartz-vein geochemical association of copper and zinc, forming a zone of relatively high copper (0.013 mg kg^{-1}) and maximum zinc concentrations (0.195 mg kg^{-1}) south of Lepsinsk (point 39). Another accumulation zone occurs near the Dostyk railway station in the Alakol district, where wind erosion and transport of particles from the eastern Tastau Ridge increase copper (0.032 mg kg^{-1}) and zinc (0.149 mg kg^{-1}) concentrations in soils (point 30) (Emami et al, 2023). The same area also shows the highest lead (0.011 mg kg^{-1}) and cadmium (0.009 mg kg^{-1}) values. Prevailing winds from the south and north-west (Figure 2) indicate possible transboundary transport of heavy metal particles from the PRC through the "Dzhungarian Gate", one of the windiest inland regions in the world.

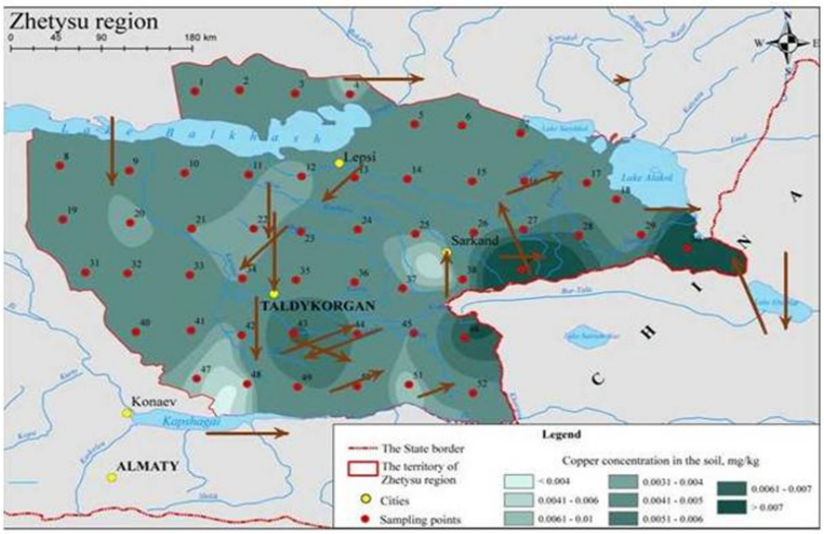

Figure 2. Distribution of copper (Cu) concentrations in surface soils of the Zhetysu region. The prevailing wind directions shown by arrows within the studing territory and outside areas. The arrows length is proportional to the maximum repeatability.

Another accumulation zone is observed on the eastern shore of Lake Sasykkol (point 7), where elevated concentrations of zinc (0.030 mg kg^{-1}), cadmium (0.006 mg kg^{-1}), cobalt (0.023 mg kg^{-1}) and nickel (0.014 mg kg^{-1}) are recorded. This is likely related to the transport of metal particles from the Aktogay deposit. Further east, along the northern shore of Lake Balkash, the Sayak group of deposits forms a slightly elevated background of heavy metals (except cobalt) in the north-western soils of the Zhetysu region.

The main zones of high zinc concentrations generally coincide with areas of elevated copper content, indicating common sources of pollution. Since large industrial enterprises are absent in most of these areas, except for the highly polluted zone around Tekeli, the elevated zinc levels are mainly associated with natural sources. As shown in Figure 3, the principal zones of increased zinc concentrations

are located in the mountainous regions of the Zhetysu Alatau, where copper- and zinc-bearing ores are widespread. The relatively high zinc concentration near Tekeli (point 43 – 0.052 mg kg^{-1}) may also be related to the wind transport of weathered rock particles from ore deposits and mining waste. In addition, the western shore of Lake Sasykkol shows elevated zinc levels due to the transport of heavy metal particles from the Aktogay deposit. On the northern shore of Lake Balkash, in the western part of the Zhetysu region, relatively high zinc concentrations (point 1 – 0.023 mg kg^{-1}) are associated with the Sayak group of deposits, where ores also contain cadmium, cobalt, nickel and lead.

Low concentrations of lead were noted in sandy surface soils in the northern and central parts, especially near Lake Balkash (point 9) and south of the cities of Taldykorgan and Sarkand (0.006-0.007 mg kg^{-1}). In the eastern and south-eastern parts, near the border to China and Zharkent, there were recorded high concentrations of lead, which may be related to transboundary transport of pollutants and industrial activity near the border.

Along the Aksu River, the Zhetysu–Alatau–Balkhash structural block of the metallogenic collision zone is located. Although this block does not contain known lead inclusions, the presence of local centers with elevated lead concentrations suggests possible lead occurrence in the Earth's crust. The source of lead input to the southern shore of Lake Balkash remains unclear. Wind conditions around the Zhamanzhal sands (point 11 – 0.008 mg kg^{-1}) do not allow the identification of a specific emission area. In the western part of the Zhetysu region (point 19 – 0.008 mg kg^{-1}), lead particles are likely transported from the Ile River delta area, north of the Zhideli channel, where a lead ore source is located in the western part of the Saryesik-Atyrau sand massifs.

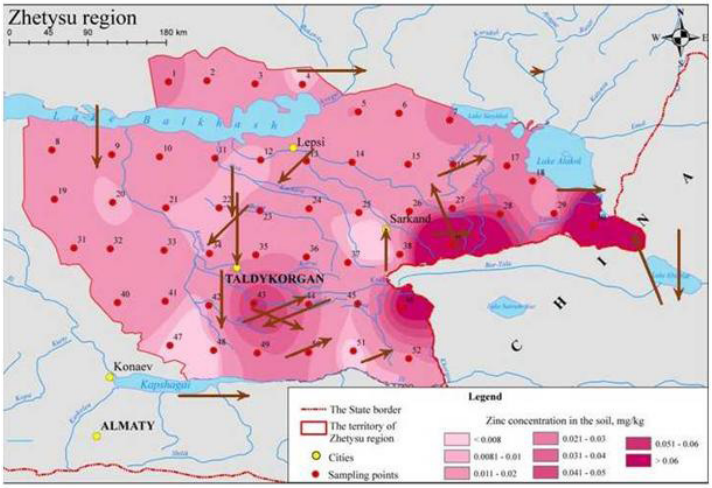

Figure 3. Distribution of zinc (Zn) concentrations in surface soils of the Zhetysu region. The prevailing wind directions shown by arrows within the studing territory and outside areas. The arrows length is proportional to the maximum repeatability.

At the latitude of Sarkand city, a lead accumulation zone has been identified. Elevated lead concentrations here are mainly associated with wind transport. At point 19 (0.0121 mg kg^{-1}), lead is transported from the geochemical province located between the Ile River delta and the Zhetysu region. Northeast of Taldykorgan, another geochemical province forms an elongated zone of high lead concentrations in the southwest–northeast direction (point 24 – 0.0162 mg kg^{-1}). In addition, a center of increased lead concentration is observed northeast of Sarkand (point 26 – 0.0164 mg kg^{-1}), where the anomaly is of natural origin and not related to anthropogenic sources.

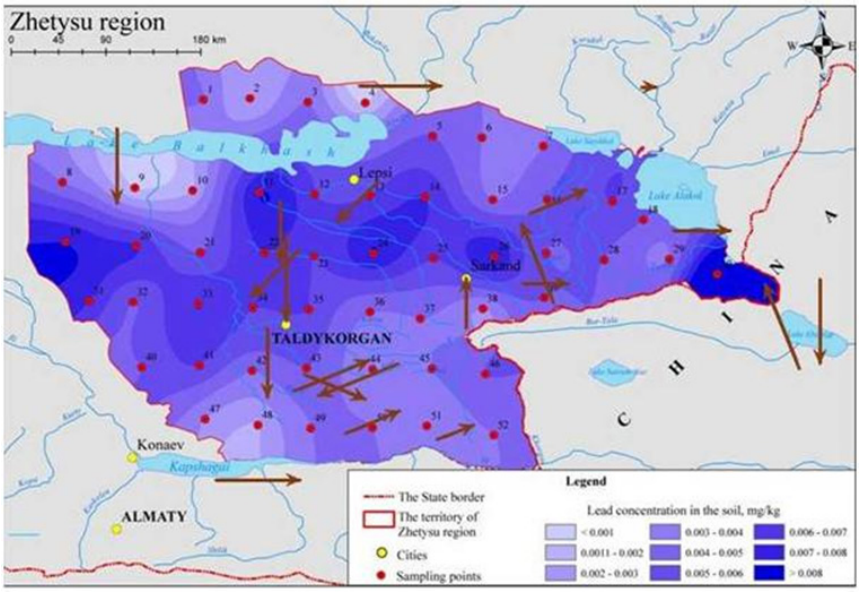

Figure 4. Distribution of lead (Pb) concentrations in surface soils of the Zhetysu region. The prevailing wind directions shown by arrows within the studing territory and outside areas. The arrows length is proportional to the maximum repeatability.

Cadmium concentrations range from 0.001 to 0.009 mg kg^{-1}. Elevated levels are observed in highly mineralized soils near Sarkand (point 26 – 0.0055 mg kg^{-1}), Taldykorgan (point 34 – 0.006 mg kg^{-1}) and near Lake Zhalanashkol (points 29 and 30), where increased soil mineralization likely promotes cadmium retention. Additional accumulation zones occur near the Sayak group of deposits (points 1 and 3 – both 0.005 mg kg^{-1}) and along the northern bank of the Ile River upstream of the Kapshagai reservoir (point 50 – 0.005 mg kg^{-1}) (Figure 5).

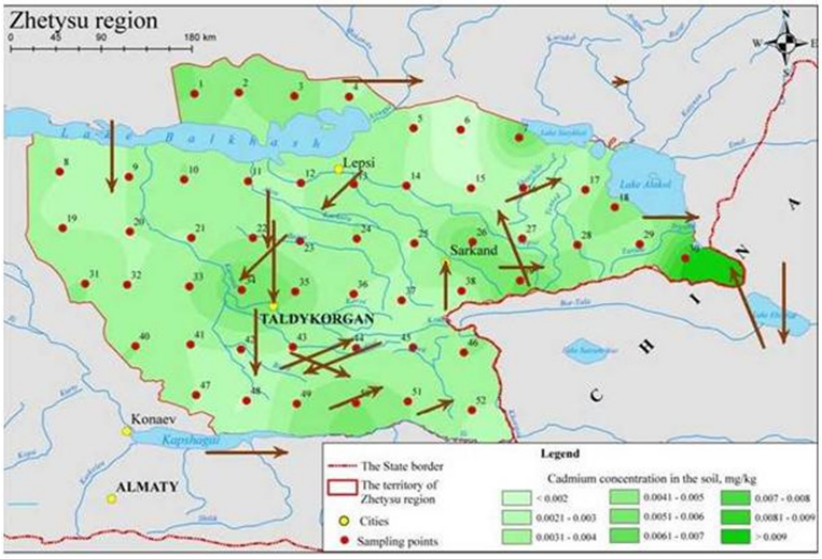

Figure 5. Distribution of cadmium (Cd) concentrations in surface soils of the Zhetysu region. The prevailing wind directions shown by arrows within the studing territory and outside areas. The arrows length is proportional to the maximum repeatability.

In the areas near Sarkand (point 26 – 0.006 mg kg^{-1}) and Taldykorgan (point 34 – 0.006 mg kg^{-1}), cadmium input is associated with a porphyry quartz-vein geochemical zone extending from Tekeli toward the Kazakhstan–PRC border and possibly into the Xinjiang Uyghur Autonomous Region of China. The Sayak and Aktogay deposits also form local zones of elevated heavy metal concentrations in soils of the Zhetysu region. The cadmium anomaly along the northern bank of the Ile River (point 50 – 0.005 mg kg^{-1}) coincides with a geochemical association zone of heavy metals in the southern part of the region, where cadmium-bearing rocks are transported by prevailing winds.

Nickel and cobalt are commonly associated elements in the Earth's crust. Nickel concentrations range from 0.0081 to 0.024 mg kg^{-1}, with the highest values recorded at points 26 and 28 in the eastern part of the study area, likely due to clay soils capable of retaining metals. Lower concentrations occur in the central and western parts of the region. The main zone of nickel and cobalt accumulation is located on the northern slopes of the Zhetysu Alatau (point 28: Ni – 0.024, Co – 0.030 mg kg^{-1}), corresponding to metallogenic complexes situated away from major industrial sources.

Nickel anomalies near Lepsinsk are associated with a nickel-bearing metallogenic complex. In the western part of the region, nickel is transported from the metallogenic zone of the Shu-Ilei Mountains (Gagarinskoye, Shokpar and Kepken deposits) and recorded at points 19 and 40 (0.012 and 0.014 mg kg^{-1}), while wind transport can carry nickel and cobalt particles over distances of several hundred kilometers.

The northern coast of Lake Balkash represents a heavy metal accumulation zone influenced by the Sayak deposit. Elevated concentrations on the eastern coast (point 5: Ni – 0.007 mg kg^{-1}, Co – 0.018 mg kg^{-1}) reflect the influence of the Aktogay deposit, while increased nickel levels on the northeastern coast (point 2 – 0.018 mg kg^{-1}) are associated with the Sayak group of deposits (Madibekov et al, 2023).

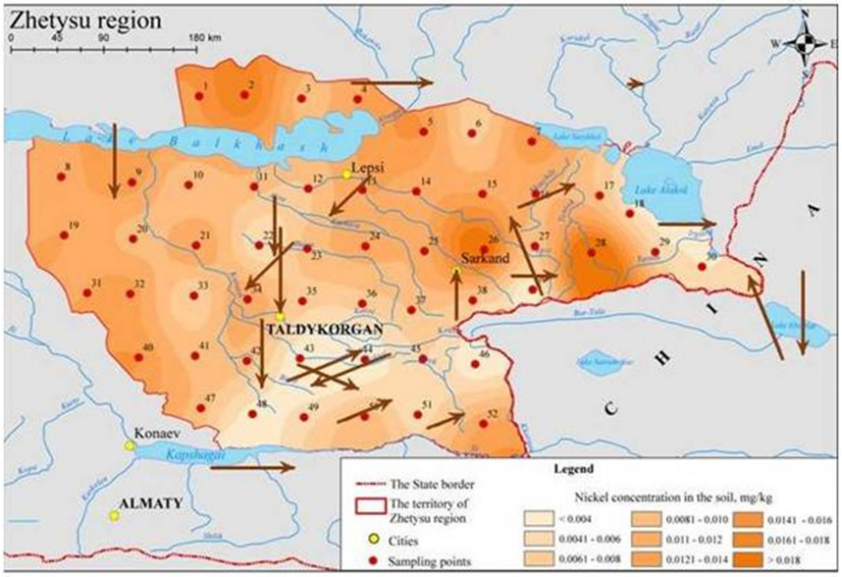

Figure 6. Distribution of nickel (Ni) concentrations in surface soils of the Zhetysu region. The prevailing wind directions shown by arrows within the studing territory and outside areas. The arrows length is proportional to the maximum repeatability.

High concentrations of zinc (0.030 mg kg^{-1}), cadmium (0.006 mg kg^{-1}), cobalt (0.023 mg kg^{-1}) and nickel (0.014 mg kg^{-1}) are recorded in soils on the western shore of Lake Sasykkol (point 7). The distribution of heavy metals in the north-eastern soils of the Zhetysu region suggests a natural source west of Urzhar village, likely related to metal-bearing rocks of the south-western part of the Tarbagatai Ridge.

Analysis of local zones with high heavy-metal concentrations shows that the isolines of maximum values often form ellipsoidal contours. The major axis of these ellipsoids generally coincides with prevailing wind directions, indicating the location of emission sources. At the same time, terrain features can modify the trajectory of dust and weathered rock particles, since air flows may rise above natural obstacles several times their height.

Cobalt concentrations vary from 0.015 to 0.030 mg kg^{-1}, with the highest values observed in heavy loams (up to 0.030 mg kg^{-1} at point 28), reflecting the ability of these soils to accumulate cobalt, particularly in central and southern parts of the study area near the PRC border. In the Bestas sands area, a zone of elevated cobalt

concentrations in surface soils is also observed. Although the prevailing wind direction near Balkash, the Sayak field and the "Algazy Island" weather station follows a northeast–southwest axis, the cobalt anomaly southeast of Balkash (point 8 – 0.025 mg kg^{-1}) indicates accumulation of emissions mainly from the Sayak group of deposits, with a possible additional influence from the Balkhash industrial hub.

Based on the analysis of heavy metal distribution in the soils of the Zhetysu region, geological features make a significant contribution to the observed levels of contamination.

Copper and zinc show similar spatial patterns of high concentrations, indicating common emission sources. On the northern slopes of the Zhetysu Alatau, the zone of elevated copper and zinc concentrations lies west of the zones with high nickel and cobalt contents. This difference may be related to variations in particle transport distances or to the presence of weathered rocks containing these metals in adjacent areas of the south-western shore of Lake Alakol and the PRC.

On the western shore of Lake Sasykkol (point 7), a deposition zone of heavy metals is observed: zinc (0.030 mg kg^{-1}), cadmium (0.006 mg kg^{-1}), cobalt (0.023 mg kg^{-1}) and nickel (0.014 mg kg^{-1}). The source of these emissions is likely located west of Urzhar village, on the western slopes of the Tarbagatai Ridge.

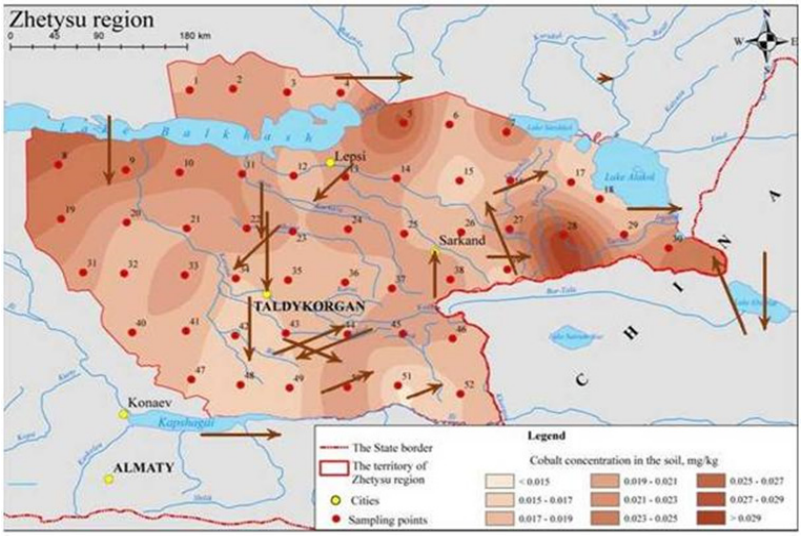

Figure 7. Distribution of cobalt (Co) concentrations in surface soils of the Zhetysu region. The prevailing wind directions shown by arrows within the studing territory and outside areas. The arrows length is proportional to the maximum repeatability.

The contours of maximum concentration isolines often have an ellipsoidal shape, with the major axis generally coinciding with prevailing wind directions. Such orientation indicates the probable location of emission sources of heavy metal particles.

Conclusions. The results of the study indicate that soil contamination of the Zhetysu region by heavy metals (Cu, Zn, Pb, Cd, Co and Ni) is determined by a combination of natural geochemical conditions and anthropogenic influences. The highest concentrations of heavy metals were recorded in the areas adjacent to Tekeli city, the Aktogay and Sayak ore deposits, and on the eastern shore of Lake Alakol. Elevated levels of cadmium, lead, cobalt and nickel were also detected along the northern shore of Lake Balkash and in the valley of the Ile River. The spatial distribution of metals in soils shows a clear relationship with prevailing wind directions, forming elongated zones of increased concentrations with a gradual decrease from the central parts to the periphery. The analysis also demonstrates that natural geochemical provinces generally create higher background levels of heavy metals in soils than technogenic sources. An exception to this trend was identified for cobalt in the northwestern part of the Zhetysu region. The obtained results provide a basis for further investigations of the vertical distribution and migration of heavy metals in soils and for the development of a regional monitoring system for soil contamination.

References

Kravchenko E., Minkina T., Mandzhieva S., Bauer T., Lacynnik E., Wong M.H., Nazarenko O. (2024) Ecological and health risk assessments of heavy metal contamination in soils surrounding a coal power plant. Journal of Hazardous Materials. – Vol. 484. – P. 136751. https://doi.org/10.1016/j.jhazmat.2024.136751. (in English).

Internet resource (2022) Ob utverzhdenii gigienicheskikh normativov k atmosfernomu vozdukhu v gorodskikh i sel'skikh naselennykh punktakh, na territoriyakh promyshlennykh organizatsii [On approval of hygienic standards for atmospheric air in urban and rural settlements and in industrial areas]. Order of the Minister of Health of the Republic of Kazakhstan No. ҚР ДСМ-70. https://adilet.zan.kz/rus/docs/V2200029011. (in Russian).

Kumari S., Mishra A. (2021) Heavy Metal Contamination. IntechOpen. Threats and Sustainable Solutions. IntechOpen. – No. 93412. https://doi.org/10.5772/intechopen.93412. (in English).

Tőzsér D., Horváth R., Simon E., Magura T. (2023) Heavy metal uptake by plant parts of Populus species: a meta-analysis. Environmental Science and Pollution Research. – Vol. 30. – P. 69416-69430. https://doi.org/10.1007/s11356-023-27244-2. (in English).

Angon P.B., Islam M.S., Kc S., Das A., Anjum N., Poudel A., Suchi S.A. (2024) Sources, effects and present perspectives of heavy metals contamination: Soil, plants and human food chain. Heliyon. – Vol. 10. https://doi.org/10.1016/j.heliyon.2024.e28357. (in English).

Rashid A., Schutte B.J., Ulery A., Deyholos M.K., Sanogo S., Lehnhoff E.A., Beck L. (2023) Heavy metal contamination in agricultural soil: Environmental pollutants affecting crop health. Agronomy. – Vol. 13. – Art. 1521. https://doi.org/10.3390/agronomy13061521. (in English).

Research Report (2023) Geo-ecological monitoring of depositing environments of the Ile River delta and the State Natural Reserve "Ile-Balkash" (Final report). Grant financing IRN No. AR09260361. KN RK MNVO RK. – Almaty. – 106 p. – No. 0121RKK00433. (in English).

Madibekov A., Ismukhanova L., Opp C., Saidaliyeva Z., Zhadi A., Sultanbekova B., Kurmanova M. (2023) Spatial distribution of Cu, Zn, Pb, Cd, Co, Ni in the soils of Ili River delta and State Natural Reserve Ili-Balkhash. Applied Sciences. – Vol. 13(10). – Art. 5996. https://doi.org/10.3390/app13105996. (in English).

Madibekov A. (2023) Heavy metals in depositing environments of the territory of the Ile River delta and the State Natural Reserve "Ile-Balkash". Monograph. Almaty: Smart University Press. – 210 p. (in English).

Fang S., Hua C., Yang J., Liu F., Wang L., Wu D., Ren L. (2024) Combined pollution of soil by heavy metals, microplastics, and pesticides: Mechanisms and anthropogenic drivers. Journal of Hazardous Materials. – Vol. 485. – 136812. https://doi.org/10.1016/j.jhazmat.2024.136812. (in English).

Internet resource (2021) Ob utverzhdenii gigienicheskikh normativov k bezopasnosti sredy obitaniya. [On approval of hygienic standards for environmental safety]. Order of the Minister of Health of the Republic of Kazakhstan. – No. KR DCM-32. https://adilet.zan.kz/rus/docs/V2100022595. (in Russian).

Li C., Zhou K., Qin W., Tian C., Qi M., Yan X., Han W. (2019) A review on heavy metals contamination in soil: Effects, sources, and remediation techniques. Soil and Sediment Contamination: An International Journal. – Vol. 28(4). – P. 380-394. https://doi.org/10.1080/15320383.2019.1592108. (in English).

Kumar U., Kumar Singh P., Kumar I., Kumar Sharma R. (2024) Heavy metal accumulation, yield and health risk assessment of wheat crop grown in contaminated soil amended with bio ash for sustainable agriculture. Journal of Food Composition and Analysis. – Vol. 139. – 107140. https://doi.org/10.1016/j.jfca.2024.107140. (in English).

González Henao S., Ghneim-Herrera T. (2021) Heavy metals in soils and the remediation potential of bacteria associated with the plant microbiome. Frontiers in Environmental Science. https://doi.org/10.3389/fenvs.2021.604216. (in English).

ST RK ISO 8288-2005 (2005) Water quality. Determination of cobalt, nickel, copper, zinc, cadmium and lead. Flame atomic absorption spectrometric methods (ISO 8288:1986). Committee on Technical Regulation and Metrology of the Ministry of Industry and Trade of the Republic of Kazakhstan. – P. 23. (in English).

RD 52.18.289-90 (1990) Methodology for measuring the mass fraction of mobile forms of metals (Cu, Pb, Zn, Ni, Cd, Co, Cr, Mn) in soil samples by atomic absorption analysis. USSR State Committee on Hydrometeorology. – P. 37. (in English).

Campillo-Cora C., Rodríguez-Seijo A., Pérez-Rodríguez P., Fernández-Calviño D., Santás-Miguel V. (2024) Effect of heavy metal pollution on soil microorganisms: Influence of soil physicochemical properties. A systematic review. European Journal of Soil Biology. – Vol. 124. – 103706. https://doi.org/10.1016/j.ejsobi.2024.103706. (in English).

Opp C. (1999) Schwermetalle. In: Bastian O., Schreiber K.F. (Eds.) Analyse und ökologische Bewertung der Landschaft. 2nd edition [Analysis and Ecological Assessment of the Landscape. 2nd Edition]. Spektrum Academic Publishing, Heidelberg, Berlin. – P. 239-246. (in German).

Lomtadze V.D. (1990) Fiziko-mekhanicheskie svoystva gornykh porod. Metody laboratornykh issledovaniy [Physical and mechanical properties of rocks: Methods of laboratory research]. – 328 p. (in Russian).

Tarasevich G. (1961) Teksturno-strukturnye osobennosti rud Tekeliyskogo mestorozhdeniya [Textural and structural features of ores of the Tekeli deposit. Proceedings of the Mineralogical Museum named after A.E. Fersman]. – Vol. 12. – P. 108-122. (in Russian).

Internet resource (2005) Spravochnik Contact Plus. Spravochnyy portal «Ves' Kazakhstan» [Directory Contact Plus. Reference portal “All Kazakhstan”]. https://www.kps.kz/taldyikorgan/promyishlennost_proizvodstvo. Date of access: 10.11.2024. (in Russian).

Internet resource (2024) Prognoz pogody [Weather schedule]. https://rp5.ru/. Date of access: 21.11.2024. (in Russian).

Spravochnik po klimatu Kazakhstana [Reference Book on Climate of Kazakhstan] (2010) Multiyear data. RSE “Kazgidromet”, Information-analytical center “RFGZ”. Almaty. – Vol. I–XIV. Section 5: Wind. – 337 p. (in Russian).

Okhrana okruzhayushchey sredy» k proektu rekultivatsii narushennykh zemel' pri razrabotke poleznykh iskopaemykh iz tekhnogennykh mineral'nykh obrazovaniy gruppy Sayak (Sayak-1) v Karagandinskoy oblasti [Section of Environmental Protection to the project of reclamation of disturbed lands at mining of minerals from technogenic mineral formations of Sayak group (Sayak-1)

in Karaganda region] (2023) Explanatory note. Edited by T.N. Obzhorina. LLP “Sary-Arka Ecology”. Karaganda. – P. 61. (in Russian).

Natsional'nyy atlas Respubliki Kazakhstan [National Atlas of the Republic of Kazakhstan] (2010) Scientific edition. Natural conditions and resources. Chief editor A.R. Medeu. – Almaty. – Vol. 1. – 149 p. (in Russian).

Emami H., Memarzadeh M. (2023) Spatial monitoring of wind erosion and some heavy metals in suspended load of Tabas city. Journal of Water and Soil. – Vol. 37(2). – P. 219-235. https://doi.org/10.22067/jsw.2023.78876.1204. (in English).

Madibekov A., Karimov A., Ismukhanova L., Zhadi A. (2023) Heavy metals in the snow cover and soil of the Ile River delta. News of the National Academy of Sciences of the Republic of Kazakhstan. Geology and Technical Sciences Series. – No. 6(462). – P. 125-144. https://doi.org/10.32014/2023.2518-170X.354. (in English).

Publication Ethics and Publication Malpractice
in the journals of the Central Asian Academic Research Center LLP

For information on Ethics in publishing and Ethical guidelines for journal publication see http://www.elsevier.com/publishingethics and http://www.elsevier.com/journal-authors/ethics.

Submission of an article to the journals of the Central Asian Academic Research Center LLP implies that the described work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis or as an electronic preprint, see http://www.elsevier. com/postingpolicy), that it is not under consideration for publication elsewhere, that its publication is approved by all authors and tacitly or explicitly by the responsible authorities where the work was carried out, and that, if accepted, it will not be published elsewhere in the same form, in English or in any other language, including electronically without the written consent of the copyright-holder. In particular, translations into English of papers already published in another language are not accepted.

No other forms of scientific misconduct are allowed, such as plagiarism, falsification, fraudulent data, incorrect interpretation of other works, incorrect citations, etc. The Central Asian Academic Research Center LLP follows the Code of Conduct of the Committee on Publication Ethics (COPE), and follows the COPE Flowcharts for Resolving Cases of Suspected Misconduct (http://publicationethics. org/files/ u2/New_Code.pdf). To verify originality, your article may be checked by the Cross Check originality detection service http://www.elsevier.com/editors/plagdetect.

The authors are obliged to participate in peer review process and be ready to provide corrections, clarifications, retractions and apologies when needed. All authors of a paper should have significantly contributed to the research.

The reviewers should provide objective judgments and should point out relevant published works which are not yet cited. Reviewed articles should be treated confidentially. The reviewers will be chosen in such a way that there is no conflict of interests with respect to the research, the authors and/ or the research funders.

The editors have complete responsibility and authority to reject or accept a paper, and they will only accept a paper when reasonably certain. They will preserve anonymity of reviewers and promote publication of corrections, clarifications, retractions and apologies when needed. The acceptance of a paper automatically implies the copyright transfer to the Central Asian Academic Research Center LLP.

The Editorial Board of the Central Asian Academic Research Center LLP will monitor and safeguard publishing ethics.

Requirements for articles design for publication in the journal are available on the websites:

www:nauka-nanrk.kz
http://www.geolog-technical.kz/index.php/en/
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Managing Editor: *T. Apendiev*
Editors: *D.S. Alenov, A.Shormakova*
Computer layout: *G.D. Zhadyranova*

Signed for print: April 10, 2026
Format: 70×90 1/16. 26.5 printed sheets. Order No. 2.

«Central Asian Academic Research Center» LLP
Almaty, Shevchenko Street, 28