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

№6
2025

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

6 (474)

NOVEMBER – DECEMBER 2025

THE JOURNAL WAS FOUNDED IN 1940

PUBLISHED 6 TIMES A YEAR

ALMATY, 2025

«Central Asian Academic Research Center» LLP is pleased to announce that "News of NAS RK. Series of Geology and Technical sciences" scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of Geology and Technical Sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

«Орталық Азия академиялық ғылыми орталығы» ЖШС «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Web of Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

ТОО «Центрально-азиатский академический научный центр» сообщает, что научный журнал "Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

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 Nº 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/

«ҚР ҰҒА» РҚБ Хабарлары. Геология және техникалық ғылымдар сериясы».
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/

«Известия РОО «НАН РК». Серия геологии и технических наук».
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 6. Number 474 (2025), 230–245

https://doi.org/10.32014/2025.2518-170X.582

УДК: 551.4.02
UDC: 551.4.02

© D.Kh. Sunakbaeva[1], D.Kh. Yuldashbek[*1], K. Aitekova[2], Y.T. Ergashev[3], 2025.

[1]Khoja Akhmet Yassawi International Kazakh-Turkish University, Turkestan, Kazakhstan;

[2]International Taraz university named after Sherkhan Murtaza, Taraz, Kazakhstan;

[3]Tashkent State Technical University, Tashkent, Uzbekistan.
E-mail: davlat.yuldashbek@ayu.edu.kz

BIOLOGICALLY ACTIVE SUBSTANCES FOR REDUCING HEAVY METAL MIGRATION IN CONTAMINATED SOILS

Sunakbaeva Dilara — Candidate of Technical Sciences, Khoja Akhmet Yassawi International Kazakh-Turkish University, Turkestan, Kazakhstan,
E-mail: dilara.sunakbayeva@ayu.edu.kz, https://orcid.org/0009-0006-3727-4891;
Yuldashbek Davlat — Master of Chemistry, Khoja Akhmet Yassawi International Kazakh-Turkish University, Turkestan, Kazakhstan,
E-mail: davlat.yuldashbek@ayu.edu.kz, https://orcid.org/0000-0001-9342-7502;
Aitekova Kuralay — Candidate of Technical Science, International Taraz university named after Sherkhan Murtaza, Taraz Kazakhstan,
E-mail: Aytekova1972@mail.ru, https://orcid.org/0000-0001-8439-944X;
Ergashev Yorqinjon — Associate Professor of the Tashkent State Technical University,
E-mail: comfort_oil@mail.ru, https://orcid.org/0000-0002-5332-5752.

Abstract. With increasing anthropogenic pressure on the lithosphere and rising soil contamination by heavy metals (Pb, Cd, Zn, Cu, As), developing environmentally safe land-rehabilitation methods has become a key task in geotechnical and engineering geology. This study examines the influence of biologically active substances (Alt-6, Alt-7, Alt-S, Bentaktiv-alt-S) on heavy-metal mobility and uptake in the "soil–plant" system under controlled laboratory and micro-field conditions. The research focuses on surface soil horizons (0-20 cm), the upper layer of the lithogenic profile where contamination processes are most active. The effectiveness of biostimulants was assessed using atomic absorption spectrophotometry and stripping voltammetry. Results showed that applying these substances reduced the mobility and bioavailability of heavy metals, lowering their accumulation in edible plant parts by 10-86%, depending on the element and

treatment. The greatest effect was achieved through combined pre-sowing seed treatment and foliar spraying, which also decreased soil toxicity and increased yields by 25-61%. The chemical composition of the tested substances was additionally considered: humic-containing regulators were characterized by humic acid fraction (52-58%), fulvic acids (12-15%), pH 6.5-7.2 and medium-molecular polymer structure, which determines their chelating ability. These findings are valuable for professionals in environmental monitoring, geoecology, soil protection, reclamation, and bioremediation. The study highlights the potential of biotechnological approaches in engineering-geological practices aimed at restoring agricultural productivity in areas affected by industrial activity, including mining and processing zones. The proposed methods can help mitigate environmental risks and enhance agroecosystem resilience in contaminated regions.

Keywords: heavy metals, soil contamination, biologically active substances, phytotoxicity, environmental remediation

© Д.К. Сунакбаева[1], Д.Х. Юлдашбек*[1], К.У. Айтекова[2], Е.Т. Ергашев[3], 2025.

[1]Қожа Ахмет Ясауи атындағы Халықаралық қазақ-түрік университеті, Түркістан, Қазақстан;

[2]Шерхан Мұртаза атындағы Халықаралық Тараз университеті, Тараз, Қазақстан;

[3] Ташкент мемлекеттік техникалық университеті, Ташкент, Өзбекстан.

E-mail: davlat.yuldashbek@ayu.edu.kz

ЛАСТАНҒАН ТОПЫРАҚТАРДАҒЫ АУЫР МЕТАЛДАРДЫҢ МИГРАЦИЯСЫН ТӨМЕНДЕТУГЕ АРНАЛҒАН БИОЛОГИЯЛЫҚ БЕЛСЕНДІ ЗАТТАР

Сунакбаева Дилара — техника ғылымдарының кандидаты, Қожа Ахмет Ясауи атындағы Халықаралық қазақ-түрік университеті, Түркістан, Қазақстан,
E-mail: dilara.sunakbayeva@ayu.edu.kz, https://orcid.org/0009-0006-3727-4891;
Юлдашбек Давлат — химия магистрі, Қожа Ахмет Ясауи атындағы Халықаралық қазақ-түрік университеті, Түркістан, Қазақстан,
E-mail: davlat.yuldashbek@ayu.edu.kz, https://orcid.org/0000-0001-9342-7502;
Айтекова Куралай — техника ғылымдарының кандидаты, Шерхан Мұртаза атындағы Халықаралық Тараз университеті Тараз, Қазақстан,
E-mail: Aytekova1972@mail.ru, https://orcid.org/0000-0001-8439-944X;
Ергашев Ерқинжон — доцент, Ташкент мемлекеттік техникалық университеті, Ташкент, Өзбекстан,
E-mail: comfort_oil@mail.ru, https://orcid.org/0000-0002-5332-5752.

Аннотация. Литосфераға антропогендік әсердің артуы және топырақтың ауыр металдармен (Pb, Cd, Zn, Cu, As) ластануы жағдайында бүлінген жерлерді экологиялық тұрғыдан қайта қалпына келтіру әдістерін әзірлеу геотехникалық инженерия мен инженерлік геологияның басым

міндеттерінің бірі болып табылады. Бұл зерттеу биологиялық белсенді заттардың (Alt-6, Alt-7, Alt-S, Bentaktiv-alt-S) ауыр металдардың «топырақ–өсімдік» жүйесіндегі қозғалғыштығы мен сіңірілуіне лабораториялық және микродалалық жағдайларда әсерін зерттейді. Зерттеу ластану процестері ең қарқынды жүретін литогендік профильдің жоғарғы бөлігі болып табылатын 0–20 см аралығындағы топырақтың беткі горизонттарына бағытталған. Биостимуляторлардың тиімділігін бағалау үшін атомдық-абсорбциялық спектрофотометрия және инверсиодық-вольтамперометрия әдістері қолданылды. Алынған нәтижелер биологиялық белсенді заттарды қолдану ауыр металдардың қозғалғыштығы мен биожетімділігін төмендететінін, олардың өсімдіктердің өнімді бөлігінде жиналуын 10-86%-ға азайтатынын көрсетті. Ең айқын әсер тұқымды себу алдында өңдеу мен өсімдіктерді жапырақ арқылы бүркуді қоса қолданғанда байқалады, бұл топырақтың уыттылығын азайтып, дақылдардың өнімділігін 25-61%-ға арттырады. Сынақтан өткен заттардың химиялық құрамы да қарастырылды: гуминдік қосылыстардан тұратын реттегіштер гумин қышқылдарының мөлшері (52-58%), фульвоқышқылдар (12-15%), pH 6,5-7,2 және олардың хелат түзу қабілетін айқындайтын орта молекулалы полимерлі құрылымымен сипатталды. Алынған деректер экологиялық мониторинг, геоэкология, топырақты қорғау, бүлінген жерлерді рекультивациялау және биоремедиация саласындағы мамандар үшін жоғары практикалық маңызға ие. Бұл зерттеу жұмыстары ауыл шаруашылығы әлеуетін, соның ішінде минералды шикізатты өндіру және өңдеу аймақтарын қоса алғанда, техногендік жүктемеге ұшыраған аумақтарды қайта қалпына келтіруге бағытталған инженерлік-геологиялық шараларға биотехнологиялық тәсілдерді біріктірудің перспективалы екенін көрсетеді. Әзірленген әдістерді экологиялық тәуекелдерді азайту және ластану жағдайында агроэкожүйелердің тұрақтылығын арттыру үшін пайдалануға болады.

Түйін сөздер: ауыр металдар, топырақтың ластануы, биологиялық белсенді заттар, фитоуыттылық, экологиялық қалпына келтіру

© Д.К. Сунакбаева[1], Д.Х. Юлдашбек*[1], К.У. Айтекова[2], Е.Т. Ергашев[3], 2025.

[1]Международный казахско-турецкий университет имени Ходжи Ахмеда Ясави, Туркестан, Казахстан;

[2]Международный Таразский университет им. Шерхана Муртазы, Тараз, Казахстан;

[3]Ташкентский государственный технический университет, Ташкент, Узбекистан.

E-mail: davlat.yuldashbek@ayu.edu.kz

БИОЛОГИЧЕСКИ АКТИВНЫЕ ВЕЩЕСТВА ДЛЯ СНИЖЕНИЯ МИГРАЦИИ ТЯЖЁЛЫХ МЕТАЛЛОВ В ЗАГРЯЗНЁННЫХ ПОЧВАХ

Сунакбаева Дилара — кандидат технических наук, Международный казахско-турецкий университет имени Ходжи Ахмеда Ясави, Туркестан, Казахстан,
E-mail: dilara.sunakbayeva@ayu.edu.kz, https://orcid.org/0009-0006-3727-4891;
Юлдашбек Давлат — магистр химии, Международный казахско-турецкий университет имени Ходжи Ахмеда Ясави, Туркестан, Казахстан,
E-mail: davlat.yuldashbek@ayu.edu.kz, https://orcid.org/0000-0001-9342-7502;
Айтекова Куралай — кандидат технических наук, Международный Таразский университет им. Шерхана Муртазы. Тараз, Казахстан,
E-mail: Aytekova1972@mail.ru, https://orcid.org/0000-0001-8439-944X;
Ергашев Еркинжон — доцент, Ташкентский государственный технический университет, Ташкент, Узбекистан,
E-mail: comfort_oil@mail.ru, https://orcid.org/0000-0002-5332-5752.

Аннотация. Усиление антропогенной нагрузки на литосферу и рост загрязнения почв тяжёлыми металлами (Pb, Cd, Zn, Cu, As) делают актуальной разработку экологически безопасных методов реабилитации нарушенных земель. В работе исследовано влияние биологически активных веществ (Alt-6, Alt-7, Alt-S, Bentaktiv-alt-S) на миграцию и биодоступность тяжёлых металлов в системе «почва–растение» в лабораторных и микрополевых условиях. Исследование выполнено на поверхностном горизонте почв (0–20 см), наиболее подвержённом техногенному загрязнению. Для анализа использованы методы атомно-абсорбционной спектрофотометрии и инверсионно-вольтамперометрии. Установлено, что применение биологически активных веществ снижает подвижность и доступность тяжёлых металлов, уменьшая их накопление в растениях на 10–86 %. Наиболее выраженный эффект достигается при сочетании предпосевной обработки семян и внекорневого опрыскивания, что одновременно снижает фитотоксичность почвы и повышает урожайность культур на 25–61 %. Химический анализ исследуемых веществ показал, что гуматсодержащие регуляторы характеризуются высоким содержанием гуминовых кислот (52–58 %), фульвокислот (12–15 %), pH 6,5–7,2 и средне-молекулярной полимерной структурой, что определяет их выраженные хелатирующие свойства. Полученные данные имеют

практическое значение для экологического мониторинга, рекультивации нарушенных земель, инженерно-геологических мероприятий и повышения устойчивости агроэкосистем в условиях техногенной нагрузки, включая территории добычи и переработки минерального сырья. Представленные методы могут быть использованы для минимизации экологических рисков и восстановления продуктивности почв.

Ключевые слова: тяжёлые металлы, загрязнение почв, биологически активные вещества, фитотоксичность, экологическая реабилитация

Introduction. The 20th century was marked by rapid scientific and technological progress, which brought many benefits to humanity but simultaneously pushed life on Earth to the brink of ecological catastrophe. Population growth, intensified resource extraction, and increased emissions of pollutants have led to profound changes in nature, negatively affecting human existence. Global environmental problems include air, water, and soil pollution, acid rain, radioactive contamination of territories, loss of biodiversity, depletion of biological resources, deforestation, and desertification. These issues arise from the excessive anthropogenic pressure on ecosystems determined by technological factors and population density exceeding their ecological capacities, which depend on the natural resource potential and landscape resilience (Kabysheva et al., 2020; Kurdyukov et al., 2012; Yerkinbek et al., 2024).

Environmental protection has become the social challenge of the century, requiring responsible policies based on reliable data on the state of the environment and the interactions of ecological factors. However, existing solutions fail to yield sustainable results due to internal conflicts within human society, national disunity, and uneven regional development. Humanity often chooses destruction over creation, disregarding ecological consequences, as seen in the actions of industrial enterprise owners who neglect safety regulations and the demands of organizations like Greenpeace (Strelnikov et al., 2023; Syam et al., 2025).

The green cover of the planet is one of evolution's greatest achievements, but its condition is deteriorating due to pathological changes in plants caused by environmental pollution. Plants play a crucial role in maintaining the biosphere, acting as the planet's "green lungs" and "green liver," regulating natural processes such as photosynthesis, nitrogen exchange, and nutrient cycles. Soil pollution – especially by chemical substances like heavy metals and pesticides, as well as by physical, mechanical, and biological agents disrupts plant ontogenesis, leads to species extinction, and impoverishes the gene pool. Soil acts as a depository for anthropogenic pollutants, accumulating heavy metals (Cu, Ni, Co, Pb, Zn, Cd, etc.), which affect physiological processes, photosynthesis, and plant productivity (Bhat et al., 2025; Belbel et al., 2025; Tamma et al., 2025; Afzal et al., 2024).

Chemical pollution of soils by heavy metals is one of the most acute environmental problems, as these elements, although essential in trace amounts,

become toxic in excess and disrupt biogeochemical cycles according to the laws of V. I. Vernadsky. This results in abnormalities in plant development, reduced yields, and health risks for humans through the food chain. In urbanized and industrial regions such as Zhezkazgan, Balkhash, and Ust-Kamenogorsk in Kazakhstan, pollution is exacerbated by emissions from metallurgical and energy enterprises, causing soil degradation and loss of species diversity (Rakhimbekova et al., 2024; Bitmanov et al., 2022; Daurov et al., 2023; Tazitdinova et al., 2019).

The path out of the environmental crisis lies in changing the nature of industrial activity, developing zero-waste technologies, and raising the level of environmental awareness in society. A new civilization must be based on an understanding of humanity's place in nature and the formation of a new morality aimed at the co-evolution of nature and society. States that ignore environmental issues deprive themselves of a future (Kazazoglu et al., 2025; Padthar et al., 2024; Mamytova et al., 2024).

This article is devoted to analyzing the processes of heavy metal uptake by agricultural crops and determining the conditions necessary for obtaining environmentally friendly products on contaminated soils. This, in turn, will contribute to the improvement of the biosphere and the achievement of sustainable development goals.

It should be noted that the present work does not address deep geological formations (aquifers, clay strata, low-permeability horizons). The processes of metal diffusion, retention and desorption in such media differ significantly from those in upper soil layers. Therefore, the conclusions of this study apply specifically to surface soils subject to anthropogenic contamination.

Objects and Methods of Research. The study focused on soils and agricultural plants to assess the uptake of heavy metals (HM) from contaminated areas. Soil samples consisted of composite specimens collected according to standard procedures. Plant samples included 5-10 specimens of crops, separated into above-ground and root parts. All analytical work was carried out in the laboratory of Khoja Akhmet Yassawi International Kazakh-Turkish University.

Soil sampling and preparation. Soil samples (500-1000 g) were dried, cleared of foreign inclusions, sieved through a 1 mm mesh, and stored in paper bags. The humus content was determined using the Tyurin method, followed by spectrophotometric analysis. To verify accuracy, standard soil reference samples were used. Additionally, soil moisture, pH, and other agro-physical and chemical properties were determined (Sunakbaeva et al., 2025).

Determination of humus content. According to the Tyurin method: 0.5 g of soil was treated with a potassium dichromate solution, then the mixture was boiled, brought to a volume of 100 ml, and left to stand overnight. The optical density of the solution was measured at a wavelength of 590 nm. Calculations were carried out according to methodological guidelines (Sainova et al., 2023).

$$\% C = 0{,}86\ D / m, \quad (1)$$

where, D – is the optical density and m is the sample weight (g).

Determination of heavy metals in soil. The content of metals (As, Zn, Cu, Pb, Cd, Ni) was determined using atomic absorption spectrophotometry. Concentrations were calculated using the following formula:

$$C = a \cdot V_1 / b \cdot V_2 \quad (2)$$

where, a – the amount of metal found from the calibration curve, mkg/cm³;
V_1 – total volume of the digest, cm³;
V_2 – volume of the digest used for analysis, cm³;
b – weight of the soil sample, g.

Determination of heavy metals in plants. The plants were pre-washed, after which biometric parameters were measured. The samples were crushed and ashed at a temperature of 450 °C. Extraction was performed using a 1 M HCl solution. The content of heavy metals was determined by the method of inverse voltammetry (IV) using the Khan-2 device.

$$X_1 = \frac{I_1 \cdot C_d \cdot V_d \cdot V_{min}}{(I_2 - I_1) \cdot m_{sample} \cdot V_{al}} \quad (3)$$

X_1 – content of the element in the analyzed sample, mg/kg;
C_d – concentration of the certified element mixture used as an additive to the sample, mg/dm³;
V_d – volume of the certified element mixture added, cm³;
V□ᵢ□ – total volume after mineralization;
I_1 – peak anodic current of the element in the analyzed sample, A;
I_2 – peak anodic current of the element in the sample with the added certified mixture, A;
m_{sample} – weight of the analyzed sample, g;
V_{al} – volume of the aliquot taken for analysis, cm³.

Characteristics of biologically active substances. The biologically active substances used in the study included humate-based growth regulators Alt-6, Alt-7, Alt-S and Bentaktiv-alt-S. Their characteristics provided by the manufacturer are as follows:

– humic acids: 52-58%;
– fulvic acids: 12-15%;
– molecular-weight distribution: predominantly medium-molecular organic polymers (5-25 kDa);

– pH of the working solution: 6.5-7.2;

– functional groups: carboxyl (–COOH), phenolic (–OH), low content of quinone structures.

These parameters determine the chelating activity and ability to bind Pb, Cd, Zn and Cu ions, thus affecting metal mobility in soil.

Statistical processing. Statistical processing of the results was carried out according to the methodology of N.V. Sadovsky using variation statistics (Peters' formula and Moldenhauer's constant). To assess the significance of differences between means, analysis of variance was applied, which allows isolating the residual variation associated with experimental error. The experimental error (S_x) and the least significant difference (LSD_{05}) were calculated using the following formulas:

$$S_x = \sqrt{(C_z / n(l-1)(n-1)}, \quad (4)$$

where, C_z – is the residual error ($C_z = C_y – C_r – C_v$), C_y is the total sum of squares, C_r is the sum of squares of repetitions, C_v is the sum of squares of treatments, n – is the number of repetitions, l – is the number of treatments.

$$LSD_{05} = C_{05} \cdot S_x, \quad (5)$$

where, C_{05} is the coefficient corresponding to the 5% significance level. This allowed establishing the limits of random fluctuations and assessing the reliability of the results at a 5% risk level.

Limitations of the study. The study was carried out under controlled laboratory and micro-field conditions. Therefore, long-term stability of metal-humate complexes, seasonal transformations, and environmental safety of the applied substances under real field conditions were not evaluated. Further full-scale field trials and multiyear monitoring are required to assess long-term efficiency and ecological safety.

Results and Discussion. Amid increasing anthropogenic pressure on agricultural lands, the issue of rational land use and soil protection from contamination becomes especially relevant. One of the most dangerous factors is heavy metal (HM) pollution, which, when released into the atmosphere and settling as dust, accumulates in soils and plants. This leads to soil degradation, reduced crop yields, and lower product quality.

Heavy metals enter the environment from both natural sources (volcanoes, wildfires, weathering) and anthropogenic sources (industrial emissions, transportation, fertilizers, pesticides). Cd, Hg, Pb, and Zn are particularly hazardous to human health, as they cause serious pathologies including mutations, cancers, and reproductive disorders. These elements accumulate in the body, exerting long-term toxic effects, including on offspring.

Lead is one of the most widespread heavy metals. Its primary source is exhaust

gases. Although plants absorb Pb poorly, it can still accumulate, especially in leaves and roots, where it is partially retained as insoluble compounds. Some plants, such as Sarépta mustard, are capable of accumulating lead in significant amounts, particularly when exposed to chelating agents like ethylenediaminetetraacetic acid (EDTA).

The bioavailability of heavy metals depends on soil composition, plant properties, and rhizosphere microorganisms. Soil contamination leads to suppression of microflora, decreased biological activity, and reduced fertility. Elevated Pb concentrations (>350 mg/kg) inhibit plant growth, while levels above 1600 mg/kg adversely affect trees and lead to accumulation of heavy metals in the edible parts of crops.

Plants can produce compounds that bind heavy metals (phenols, thiols, etc.), regulating their transport. However, biological tolerance varies significantly among species: for example, wheat is sensitive to Cd at levels as low as 0.7 mg/kg, while peas show sensitivity at 1 mg/kg. Interactions between metals, such as antagonism or synergism, can also influence their migration.

In these circumstances, it is important to develop effective methods to reduce heavy metal content in agricultural products. One approach is the use of biologically active substances that regulate physiological and biochemical processes in plants and reduce the uptake of toxicants.

In this regard, studying the effects of growth regulators Alt-6, Alt-7, Alt-S, and Bentaktiv-alt-S on the accumulation of lead, cadmium, and zinc in potato tubers is of interest.

The effect of growth regulators Alt-6, Alt-7, Alt-S, and Bentaktiv-alt-S on potato development in heavy metal-contaminated soil. Field experiments conducted on serozem soils with high levels of heavy metal contamination (Pb – 200 and 500 mg/kg, Cd – 10 mg/kg, Zn – 300 mg/kg, Cu – 200 mg/kg) showed that the application of growth regulators had a pronounced positive effect on the morphological development of potatoes. All tested products (Alt-6, Alt-7, Alt-S, and Bentaktiv-alt-S) contributed to increased plant height, number of stems per bush, quantity and mass of tubers, as well as accelerated phenological phase development compared to the control (water treatment).

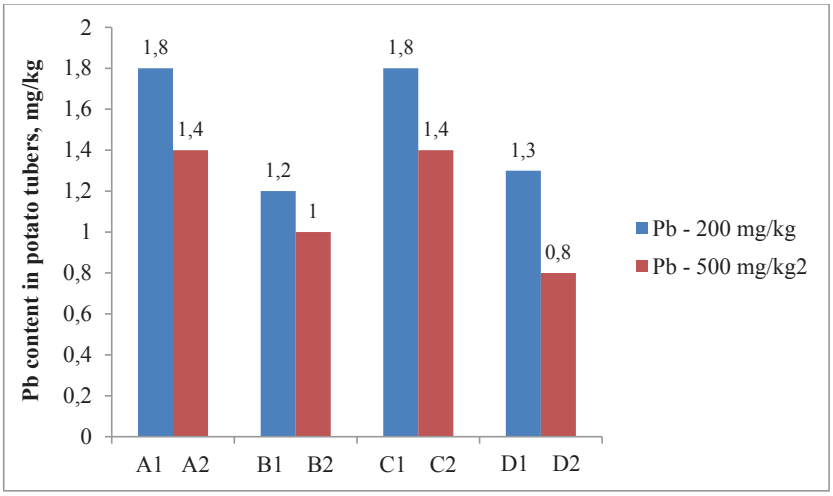
The most stimulating effect across all measured parameters was observed with Bentaktiv-alt-S: plant height reached 59.0 cm versus 42.4 cm in the control; the number of stems per bush was 5.6 (53% higher); tuber mass was 522 g (compared to 415 g in the control). Similar positive effects were also noted for Alt-6, Alt-7, and Alt-S: tuber mass increased by 20 to 25%, and tuber number increased by 20 to 40%, depending on the product (Table 1).

It is important to note that combined application of the products (pre-sowing treatment of tubers and foliar spraying at the budding phase) provided the most pronounced effect both on biometric parameters and on the reduction of lead content in the tubers.

Table 1 – The effect of Alt-6, Alt-7, Alt-S, and Bentaktiv-alt-S on the growth and development of seed potato tubers in heavy metal-contaminated soil

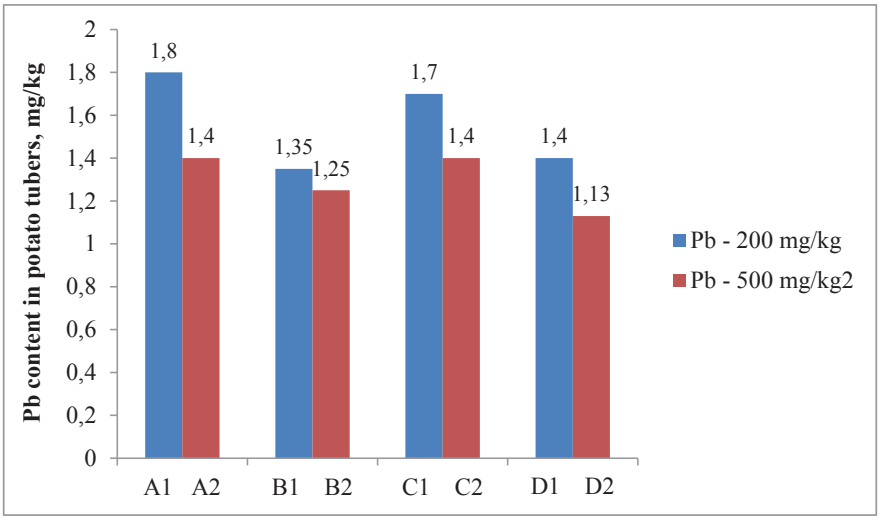
Treatment	Phenological development				Plant height, cm	Stems per bush, pcs	Tubers per bush, pcs	Tuber Mass, g
	planting date	emergence start	budding	flowering				
Control	20.04. 2025	10.05. 2025	28.06. 2025	09.07. 2025	42,4±2,9	3,6±0,2	10±0,4	415±18
Alt-6	20.04. 2025	06.05. 2025	24.06. 2025	05.07. 2025	57,8±3,3	5,5±0,3	13±0,5	502±19
Alt-7	20.04. 2025	06.05. 2025	24.06. 2025	05.07. 2025	56,9±3,0	5,4±0,3	13±0,5	507±19
Alt-S	20.04. 2025	06.05. 2025	24.06. 2025	04.07. 2025	58,1±3,2	5,5±0,3	12±0,5	499±18
Bentaktiv-alt-S	20.04. 2025	06.05. 2025	24.06. 2025	04.07. 2025	59,0±3,2	5,6±0,3	14±0,5	522±20

Reduction of heavy metal translocation. A comparative analysis of Pb content in potato tubers (Figures 1-4) shows that all treatments to some extent inhibited the migration of lead from the soil to the productive parts of the plant. The most effective was the combined application method (variant 4), which significantly reduced lead content in the tubers at both moderate and high contamination levels (500 mg/kg).



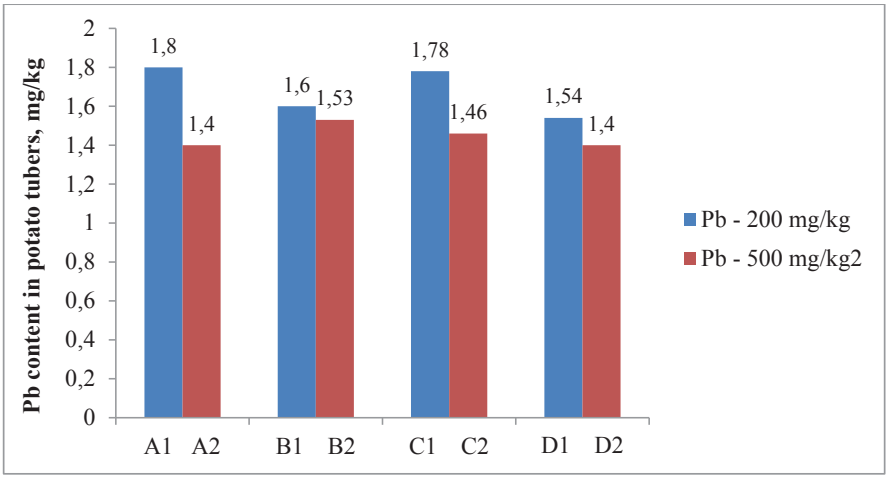
A1, A2 – treatment of seed material with water;
B1, B2 – pre-sowing treatment of tubers with Alt-6;
C1, C2 – foliar spraying at the budding stage with Alt-6;
D1, D2 – pre-sowing treatment of tubers plus foliar spraying at the budding stage with Alt-6.

Figure 1 – Effect of 0.001% Alt-6 solution on Pb content in harvested potato tubers at different heavy metal soil concentrations



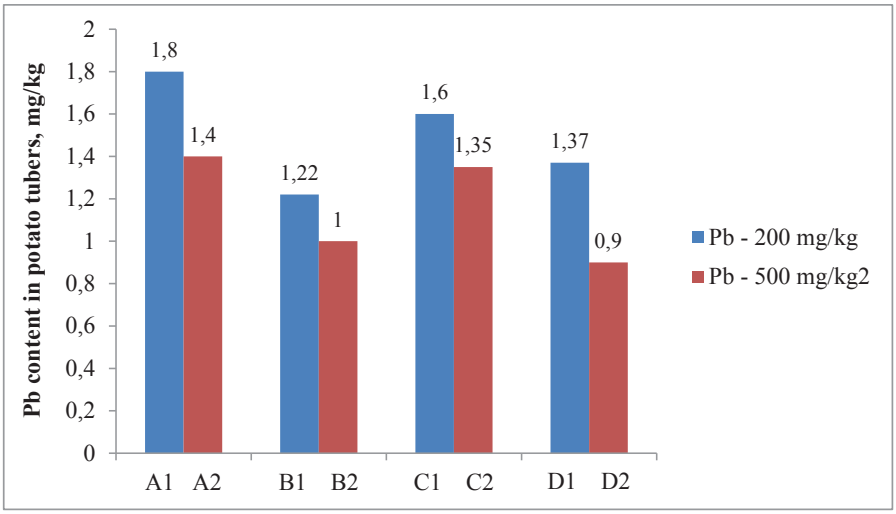
A1, A2 – treatment of seed material with water;
B1, B2 – pre-sowing treatment of tubers with Alt-7;
C1, C2 – foliar spraying at the budding stage with Alt-7;
D1, D2 – pre-sowing treatment of tubers plus foliar spraying at the budding stage with Alt-7.

Figure 2 – Effect of 0.001% Alt-7 solution on Pb content in harvested potato tubers at different heavy metal soil concentrations



A1, A2 – treatment of seed material with water;
B1, B2 – pre-sowing treatment of tubers with Alt-S;
C1, C2 – foliar spraying at the budding stage with Alt-S;
D1, D2 – pre-sowing treatment of tubers plus foliar spraying at the budding stage with Alt-S.

Figure 3 – Effect of 0.001% Alt-S solution on Pb content in harvested potato tubers at different heavy metal soil concentrations



A1, A2 – treatment of seed material with water;
B1, B2 – pre-sowing treatment of tubers with Bentaktiv-alt-S;
C1, C2 – foliar spraying at the budding stage with Bentaktiv-alt-S;
D1, D2 – pre-sowing treatment of tubers plus foliar spraying at the budding stage with Bentaktiv-alt-S.

Figure 4 – Effect of 0.001% Bentaktiv-alt-S solution on Pb content in harvested potato tubers at different heavy metal soil concentrations

In particular, at a soil Pb concentration of 200 mg/kg, pre-sowing treatment followed by foliar spraying with Alt-6 reduced the lead content in tubers from 10.5 mg/kg (control) to values below 9 mg/kg. At a contamination level of 500 mg/kg, the reduction exceeded 20%.

Similar results were obtained for the other treatments. When using Bentaktiv-alt-S, the reductions in lead, zinc, cadmium, and copper content were 11.4%, 35.3%, 86.6%, and 29.9%, respectively (Table 2). Application of Alt-S resulted in decreases of 9.5%, 25%, 80%, and 27.9%, respectively. The concentrations of toxicants in potato tubers for all treatment variants were below the maximum allowable limits (MAL).

Table 2 – Effect of pre-sowing treatment of seed material with 0.001% solutions of growth-stimulating preparations Alt-S and Bentaktiv-alt-S on the translocation of heavy metals into the productive parts of potatoes

Treatment	Heavy metal content, mg/kg			
	Pb	Zn	Cd	Cu
	soil plant	soil plant	soil plant	soil plant
Control (water)	200±7,8 10,5±0,5	300±8,0 30,0±0,7	10±0,5 1,5±0,1	200±5,6 11,1±0,5

Alt-S	200±7,8 9,5±0,5	300±7,6 22,5±0,8	10± 0,3 0,3±0,01	200±6,1 8,0±0,4
Bentaktiv-alt-S	200±7,9 9,3±0,4	300±6,6 19,4±0,6	10±0,3 0,2±0,01	200±5,9 7,8±0,4
MAL, mg/kg dry weight (for potatoes)	0,4	10,0	0,03	5,0

Thus, the preparations exhibit not only growth-stimulating effects but also the ability to suppress the translocation of toxic elements within the "soil–plant" system, demonstrating multifunctionality and potential environmental significance.

Effect of growth regulators on the translocation of arsenic and cadmium in the soil–radish system. The results of microfield experiments with radish confirmed the effectiveness of the growth regulator Alt-7 under soil contamination conditions. In the experiments where radish seeds were treated with a 0.001% solution of Alt-7, there was a significant improvement in plant morphological characteristics and an increase in yield, even in the presence of toxicants in the soil.

Under arsenic contamination (2 and 20 mg/kg), Alt-7 contributed to an increase in root length, diameter, and weight. Yield increased from 3.7-4.2 kg/m² (untreated) to 6.0-6.1 kg/m² (treated), indicating a protective effect of the preparation (Table 3).

Alt-7 had a particularly pronounced effect in reducing cadmium translocation. At soil Cd levels of 2 and 20 mg/kg, its content in the roots decreased from 0.1-0.6 mg/kg (control) to 0.02-0.3 mg/kg (treated), which in most cases was below the maximum allowable limits (0.05 mg/kg). A similar effect was observed under lead contamination: Pb content in roots after Alt-7 treatment remained within sanitary limits.

Table 3 – Effect of pre-sowing seed treatment with Alt-7 under ecotoxicant exposure on radish yield and root structure

Treatment variant and contamination level, mg/kg length, cm		Root characteristics			Yield, kg/m² Cd	Heavy metal content in roots, mg/kg		
		diameter, cm	weight, g			As	Pb	
Untreated, clean background (control)	-	14,2	5,3	290	3,8	-	-	-
Untreated, arsenic background	2	15,3	4,8	301	3,7	-	0,3	-
	20	17,0	5,0	304	4,2	-	1,0	-
Untreated, cadmium background	2	13,3	3,8	275	3,2	0,1	-	-
	20	12,8	4,4	284	3,5	0,6	-	-
Treated, clean background	-	18,7	6,5	358	5,7	-	-	-

Treated, arsenic background	2	19,5	6,4	329	6,1	-	0,1	-
	20	19,7	6,6	364	6,0	-	0,7	-
Treated, cadmium background	2	17,0	5,9	348	5,2	0,02	-	-
	20	17,2	5,5	319	5,4	0,3	-	-
Treated, lead background	30	16,3	5,2	338	5,3	-	-	0,3
	100	15,6	5,1	320	5,3	-	-	4,2

Thus, the preparations exhibit not only growth-stimulating activity but also the ability to suppress the translocation of toxic elements within the soil–plant system, demonstrating multifunctionality and potential environmental significance.

The obtained results describe metal behavior exclusively in surface soil layers (0–20 cm). These mechanisms cannot be directly extrapolated to deeper geological formations, where sorption, redox conditions, and hydraulic conductivity differ substantially.

Conclusions. The conducted research confirmed the high effectiveness of growth regulators Alt-6, Alt-7, Alt-S, and Bentaktiv-alt-S in increasing the yield and quality of agricultural crops (potatoes and radish) under soil contamination with heavy metals (Pb, Cd, Zn, Cu, As). The preparations contributed to improved biometric parameters of plants, including plant height, number of stems, tuber number and mass in potatoes, as well as root length, diameter, and mass in radish.

The growth regulators had a stimulating effect on the phenological development of plants, accelerating the onset of emergence, budding, and flowering by 4–5 days compared to the control. The most pronounced effect was observed with combined treatment (pre-sowing treatment of planting material and foliar spraying at the budding stage), especially with Bentaktiv-alt-S, which increased potato tuber mass by 25% and radish yield by 43–61%.

The preparations demonstrated multifunctional activity, not only stimulating plant growth and development, but also significantly reducing the translocation of heavy metals from soil to the productive parts of crops. For example, under contamination with Pb (200-500 mg/kg), Cd (10 mg/kg), Zn (300 mg/kg), and Cu (200 mg/kg), the content of these elements in potato tubers was reduced by 9.5-11.4% (Pb), 80.0-86.6% (Cd), 25.0-35.3% (Zn), and 27.9-29.9% (Cu) compared to the control. In radish, Alt-7 treatment reduced Cd content from 0.6 to 0.3 mg/kg and As from 1.0 to 0.7 mg/kg at a soil concentration of 20 mg/kg.

The content of heavy metals in the productive parts of plants remained below the maximum allowable concentrations (MAC) when growth regulators were used, confirming the possibility of obtaining environmentally safe products on contaminated soils. This is particularly important for minimizing human health risks associated with the accumulation of toxicants in food chains.

It was established that the bioavailability of heavy metals depends on soil properties, plant species characteristics, and the biologically active substances

applied. Alt-7 showed high efficiency in reducing the phytotoxic effects of Cd and As in radish. However, the ambiguous effect of As (growth stimulation at high concentrations) requires further investigation.

The use of growth regulators is a promising approach for sustainable agriculture under anthropogenic contamination. However, further research is needed to optimize their use, including the study of molecular mechanisms of action and the effects of different concentrations and application methods on various crops and soil types.

The obtained results emphasize the importance of developing and implementing environmentally safe technologies based on the use of biologically active substances to minimize the negative impact of heavy metals and ensure food security.

The conclusions of this study apply to agricultural topsoils and do not describe metal migration in deeper geological horizons. The long-term environmental stability of the immobilized metals requires additional field verification. The chemical composition of the used biologically active substances plays a key role in determining their efficiency, and further research should evaluate molecular-level mechanisms of metal binding.

References

Afzal M., Muhammad S., Tan D., Kaleem S., Khattak A.A., Wang X., Chen X., Ma L., Mo J., Muhammad N., Jan M., & Tan Z. (2024) The Effects of Heavy Metal Pollution on Soil Nitrogen Transformation and Rice Volatile Organic Compounds under Different Water Management Practices. Plants, 13(6). — P. 871. https://doi.org/10.3390/plants13060871 (in English)

Belbel F., Boukheroufa M., Micle V., Sur I. M., Sakraoui F., & Smical I. (2025) Heavy Metal Accumulation (Cd, As, Zn, Cu, Cr) in Hair and Bones of Small Mammal Prey of the Sentinel Species Common Genet (Genetta genetta) in an Anthropogenic Environment of Edough Mountain Forest, Northeastern Algeria. Animals, 15(1). — P. 114. https://doi.org/10.3390/ani15010114 (in English)

Bhat B.A., Rather M.A., Bilal T., Nazir R., Qadir R.U., Mir R.A. (2025) Plant hyperaccumulators: a state-of-the-art review on mechanism of heavy metal transport and sequestration Front Plant Sci. 16:1631378. https://doi.org/10.3389/fpls.2025.1631378 (in English)

Bitmanov Y., Abzhalelov A., & Boluspayeva L. (2022) The content of heavy metals in the soil of Central Kazakhstan. Reports of NAS RK, (3). — P. 5-14. https://doi.org/10.32014/2022.2518-1483.156 (in English)

Daurov D, Zhambakin K, Shamekova M. (2023) Phytoremediation as a way to clean technogenically polluted areas of Kazakhstan. Braz J Biol. 83:e271684. https://doi.org/10.1590/1519-6984.271684 (in English)

Kabysheva K., Bakirova L., Asakeeva R., Imamova B. Semej қalasynyң ekozhүjesindegi topyraқtyң zhaj-kүji [The state of soils in the ecosystem of the city of Semey]. (2020) Bulletin of Shakarim University. Technical Sciences. (4(92)) — P. 211-214. (In Kazakh)

Kazazoglu S. (2025) Environmental Education Through Eco-Literacy: Integrating Sustainability into English Language Teaching. Sustainability. 17(5). — P. 2156. https://doi.org/10.3390/su17052156 (in English)

Kurdyukov V.N. (2012) O novom podhode k ocenke ekologicheskogo ushcherba v ramkah koncepcii ustojchivogo razvitiya [On new approach to environmental damages estimation under sustainable development concept]. Vestnik of Don State Technical University. 12(1-1). — P. 133-140. (In Russian)

Mamytova N., Turakkazy A., Salibayeva E. (2024) Environmental literacy of the population of Astana city. Bulletin of the l.N. Gumilyov Eurasian National University. Chemistry. Geography.

Ecology series. Vol.146, No.1. — P. 85-95. https://doi.org/10.32523/2616-6771-2024-146-1-85-95 (in English)

Padthar S., Naruetharadhol P., Srisathan W.A., & Ketkaew C. (2024) From Linear to Circular Economy: Embracing Digital Innovations for Sustainable Agri-Food Waste Management among Farmers and Retailers. Resources, 13(6). — P. 79. https://doi.org/10.3390/resources13060079 (in English)

Rakhimbekova F., Kaidarova D.R., Orazgaliyeva M., Ryspambetov Zh., Buzdin A., Anapiyayev B. (2024) Cancer Incidence Relation to Heavy Metals in Soils of Kyzylorda Region of Kazakhstan. Asian Pac J Cancer Prev. 25(6). — P. 1987–1995. https://doi.org/10.31557/APJCP.2024.25.6.1987 (in English)

Sainova G.A, Kaliyeva N.A, Yuldashbek D.K, Akbasova A.D. (2023) The Influence of Vermicompost and Various Concentrations of Lead on the Enzymatic Activity of Sierozem Soils of Kazakhstan. Scientifica (Cairo). 2023:8490234. https://doi.org/10.1155/2023/8490234 (in English)

Strelnikov V.V., Frantseva T.P. (2023) Social'naya ekologiya [Social ecology]. Textbook. Moscow: INFRA M. — P. 214 (In Russian)

Sunakbaeva D.Kh., Yuldashbek D.Kh., Aitekova K., Nurmakova S.M., Waris M. (2025) Assessment of the effectiveness of biostabilization in improving the geotechnical properties of degraded soils in the arid regions of Kazakhstan. News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences. Vol.4. (472). — P. 295–311. https://doi.org/10.32014/2025.2518-170X.545 (in English)

Syam R. (2025) Research trends in environmental sociology: A bibliometric analysis of scientific publications from 1976 to 2024. International Journal of Environmental Impacts, Vol. 8, No. 3. — P. 423-433. https://doi.org/10.18280/ijei.080301 (in English)

Tamma A.A., Lejcuś K., Fiałkiewicz W., & Marczak D. (2025) Advancing Phytoremediation: A Review of Soil Amendments for Heavy Metal Contamination Management. Sustainability, 17(13). — P. 5688. https://doi.org/10.3390/su17135688 (in English)

Tazitdinova R.M., Beisenova R.R., Grigoryev A.I., Issayenko O.P. (2019) Contamination of soil with heavy metals in industrial districts of Kokshetau. Fundamental and Experimental Biology. (94) 2. — P. 93-98. https://doi.org/10.31489/2019bmg2/93-98 (in English)

Yerkinbek N.Y., Kozybaeva F.E. (2024) Қazfosfat kəsiporny zauyttarynyң shyғaryndylarynan zardap shekken topyrақ zhamylғysynyң topyrақ-ekologiyalyқ zhaғdajy [Soil-ecological condition of the soil cover affected by the emissions of the factories of the Kazphosphate enterprise]. Soil Science and Agrichemistry. (4). — P. 54-71. https://doi.org/10.51886/1999-740X_2024_4_54 (In Kazakh)

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.

Правила оформления статьи для публикации в журнале смотреть на сайтах:
www:nauka-nanrk.kz
http://www.geolog-technical.kz/index.php/en/
ISSN 2518-170X (Online),
ISSN 2224-5278 (Print)

Ответственный редактор *А. Ботанқызы*
Редакторы: *Д.С. Аленов, Т. Апендиев*
Верстка на компьютере: *Г.Д. Жадырановой*

Подписано в печать 15.12.2025.
Формат 70x90$^{1}/_{16}$. 20,5 п.л.
Заказ 6.

«Central Asian Academic Research Center» LLP
Алматы, Қонаев к-сі, 142