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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 ғылымиметриялық 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 басылмды 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.

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GEOECOLOGICAL-CHEMICAL ASSESSMENT OF TECHNOGENIC CONTAMINATION OF THE “TUKHLAYA BALKA” FILTRATION FIELDS AREA

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Abstract. Relevance. The “Tukhlaya Balka” evaporation (filtration) fields have received municipal and industrial wastewater of Atyrau since 1945 (476 ha under the city akimat, 860 ha under JSC “Atyrau Refinery”). The unlined bed and more than eighty years of operation create a risk of technogenic contamination of soils, water and air, requiring regular geo-ecological and geochemical assessment as a basis for ecosystem restoration. *Purpose* – to assess the degree of technogenic contamination from seasonal monitoring of sulfur compounds, heavy metals and

petroleum products in water and soil, and to substantiate the need for remediation. *Methods.* Water and soil (0-20 cm) samples were collected at the “Right Bank” point in April-May and June-July 2026 and analysed in an accredited laboratory by certified methods (GOST R 51592-2000, GOST 17.1.5.01-80, etc.). Concentrations were compared with MPC values (GN 2.1.5.1315-03, GN 2.1.7.2041-06); the water pollution index (WPI) and the concentration coefficient (Kc) relative to the urban geochemical background (RSE “Kazhydromet” data) were calculated. *Results.* Petroleum products in water exceeded the MPC in both seasons (9.0- and 5.4-fold) and were 2.3-3.8 times higher than the maximum values in the regional river monitoring network; total iron exceeded the MPC only in spring (1.4-fold). The WPI (2.33 and 1.22) corresponds to quality class III (“moderately polluted”). Hydrogen sulfide occurred in water and soil. The soil is strongly salinized ($\text{Cl}^- + \text{SO}_4^{2-}$ 6,794-6,848 mg/kg), the chloride share rising from 33 to 42% by summer. Petroleum products, copper and zinc in soil do not exceed the standards, yet the copper Kc relative to the urban background reached 3.9-4.2. *Conclusions.* The leading factors of technogenic loading are petroleum contamination of water, soil salinization and copper accumulation; remediation with natural sorbents (diatomite, opoka, Inder deposit borate minerals) and an expanded monitoring network, including groundwater, are substantiated.

Keywords: filtration fields, technogenic pollution, geo-ecological assessment, bottom sediments, petroleum products, soil salinization

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«САСЫҒАН САЙ» БУЛАНУ АЛҚАПТАРЫ АУМАҒЫНЫҢ ТЕХНОГЕНДІК ЛАСТАНУЫН ГЕОЭКОЛОГИЯЛЫҚ-ХИМИЯЛЫҚ БАҒАЛАУ

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Аннотация. *Өзектілігі.* «Тухлая балка» булану (сүзу) алқаптары 1945 жылдан бері Атырау қаласының шаруашылық-тұрмыстық және өндірістік ағынды суларын қабылдайды (476 га – қала әкімдігі, 860 га – «Атырау МӨЗ» АҚ). Ложаның гидрооқшауламасының болмауы және сексен жылдан астам пайдалану мерзімі топырақтың, судың және атмосфералық ауаның техногендік ластану қаупін туғызады, бұл экожүйені табиғи сорбенттермен қалпына келтірудің негізі ретінде тұрақты геоэкологиялық-геохимиялық бағалауды талап етеді. *Мақсаты* – судағы және топырақтағы күкіртті қосылыстардың, ауыр металдардың және мұнай өнімдерінің маусымдық мониторингі деректері бойынша аумақтың техногендік ластану дәрежесін бағалау және рекультивация қажеттілігін негіздеу. *Әдістері.* Су және топырақ (0-20 см қабат) сынамалары «Оң жағалау» нүктесінде 2026 жылдың сәуір-мамыр және маусым-шілде айларында алынып, аккредиттелген зертханада аттестатталған әдістемелер бойынша (ГОСТ Р 51592-2000, ГОСТ 17.1.5.01-80 және т.б.) талданды. Концентрациялар ШРК-мен (ГН 2.1.5.1315-03, ГН 2.1.7.2041-06) салыстырылды; судың ластану индексі (СЛИ) және «Қазгидромет» РМК деректері бойынша қалалық геохимиялық фонға қатысты концентрация

коэффициенті (Кс) есептелді. *Нәтижелері.* Судағы мұнай өнімдерінің мөлшері екі маусымда да ШРК-дан асты (9,0 және 5,4 есе) және өзендерді өңірлік мониторинг желісінде тіркелген ең жоғары мәндерден 2,3-3,8 есе жоғары болды; жалпы темір ШРК-дан тек көктемде асты (1,4 есе). СЛИ (2,33 және 1,22) III сапа класына («орташа ластанған») сәйкес келеді. Күкіртсутек суда да, топырақта да анықталды. Топырақ қатты сортаңданған ($\text{Cl}^- + \text{SO}_4^{2-}$ қосындысы 6794-6848 мг/кг), жазға қарай хлоридтердің үлесі 33-тен 42 %-ға дейін өсті. Топырақтағы мұнай өнімдері, мыс және мырыш нормативтерден аспайды, алайда қалалық фонға қатысты мыстың Кс мәні 3,9-4,2-ге жетті. *Қорытынды.* Техногендік жүктеменің негізгі факторлары – судың мұнаймен ластануы, топырақтың сортаңдануы және мыстың жиналуы; аумақты табиғи сорбенттермен (диатомит, опока, Индер кен орнының боратты шикізаты) рекультивациялау және мониторинг желісін, оның ішінде жерасты суларын қамти отырып, кеңейту қажеттілігі негізделді.

Түйін сөздер: сүзу алқаптары, техногендік ластану, геоэкологиялық баға беру, түптік шөгінділер, мұнай өнімдері, топырақтың сортаңдануы

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ГЕОЭКОЛОГОХИМИЧЕСКАЯ ОЦЕНКА ТЕХНОГЕННОГО ЗАГРЯЗНЕНИЯ ТЕРРИТОРИИ ПОЛЕЙ ФИЛЬТРАЦИИ «ТУХЛАЯ БАЛКА»

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Аннотация. *Актуальность.* Поля испарения (фильтрации) «Тухлая балка» с 1945 г. используются для приема хозяйственно-бытовых и производственных сточных вод города Атырау. Площадь участков, находящихся в ведении акимата города Атырау и АО «Атырауский НПЗ», составляет 476 и 860 га соответственно. Отсутствие гидроизоляции ложа и длительная эксплуатация объектов повышают риск техногенного загрязнения почв, поверхностных и подземных вод, а также атмосферного воздуха. В связи с этим особую значимость приобретает комплексная геоэколого-химическая оценка состояния территории, необходимая для обоснования мероприятий по снижению экологической нагрузки и последующей рекультивации загрязненных участков. *Цель.* Оценить степень техногенного загрязнения территории полей фильтрации «Тухлая балка» на основе сезонного мониторинга содержания соединений серы, тяжелых металлов и нефтепродуктов в воде и почве, а также обосновать необходимость проведения рекультивационных мероприятий. *Методы.* Исследование основано на результатах сезонного отбора и лабораторного анализа проб воды и почвы. Пробы почвы из слоя 0–20 см и пробы воды отобраны в точке наблюдения «Правобережье» в апреле–мае и июне–июле 2026 г. Лабораторные исследования выполнены аккредитованной лабораторией с применением аттестованных методик, включая ГОСТ Р 51592-2000, ГОСТ 17.1.5.01-80 и другие нормативные документы. Полученные концентрации загрязняющих веществ сопоставлены с установленными предельно допустимыми концентрациями (ПДК). Рассчитаны индекс загрязнения воды (ИЗВ) и коэффициент концентрации (Кс) относительно городского геохимического фона, определенного по данным РГП «Казгидромет». *Результаты.* Установлено, что содержание нефтепродуктов в воде превышало ПДК в оба периода наблюдений - в 9,0 и 5,4 раза соответственно. При этом концентрации нефтепродуктов в исследованных пробах превышали максимальные значения, зарегистрированные в региональной сети мониторинга рек, в 2,3–3,8 раза. Превышение ПДК по содержанию общего железа зафиксировано только в весенний период и составило 1,4 раза. Рассчитанные значения ИЗВ - 2,33 и 1,22 - отнесены авторами к III классу качества воды («умеренно загрязненная»). Сероводород обнаружен как в водной, так и в почвенной среде. Исследованные почвы характеризуются высоким содержанием растворимых солей: суммарная концентрация хлоридов и сульфатов составляет 6794–6848 мг/кг. Доля хлоридов в суммарном содержании указанных анионов увеличилась с 33 % весной до 42 % летом. Концентрации нефтепродуктов, меди и цинка в почве не превышали использованных нормативных значений. Вместе с тем коэффициент концентрации меди относительно городского геохимического

фона составил 3,9–4,2, что свидетельствует о ее повышенном содержании по сравнению с фоновыми показателями. *Выводы.* Результаты исследования свидетельствуют о наличии техногенной нагрузки на территорию полей фильтрации «Тухлая балка», основными проявлениями которой являются загрязнение воды нефтепродуктами, повышенное содержание растворимых солей в почве и накопление меди относительно городского геохимического фона. Выявленные особенности подтверждают необходимость дальнейшего комплексного экологического мониторинга и разработки мероприятий по рекультивации загрязненных участков. В качестве потенциальных материалов для снижения подвижности загрязняющих веществ могут рассматриваться природные сорбенты, включая диатомит, опоку и боратное сырье Индерского месторождения. Перспективным направлением дальнейших исследований является расширение сети наблюдений с включением мониторинга подземных вод и экспериментальной оценки эффективности предлагаемых сорбционных материалов.

Ключевые слова: поля фильтрации, техногенное загрязнение, геоэкологическая оценка, нефтепродукты, засоление почв, тяжелые металлы, рекультивация

Introduction. The territory colloquially known as “Tukhlaya Balka” is a system of evaporation (filtration) fields designed to receive and naturally neutralize municipal and industrial wastewater of the city of Atyrau. The facility has been in operation since 1945, i.e. for more than eighty years, making it one of the oldest and, at the same time, most problematic accumulation-type hydraulic structures in the territory of Western Kazakhstan. The total area of the land allotment exceeds 1,300 ha and is divided by ownership: 476 ha are on the balance sheet of the Atyrau city akimat, where municipal wastewater from the city sewerage system is predominantly accumulated, and 860 ha are assigned to JSC “Atyrau Refinery” (ANPZ), which receives industrial wastewater generated, in particular, during oil dehydration and desalting at electric desalting units (Kenzhetayev et al., 2020a).

The absence of continuous sealing of the impoundment bed, the long period of operation, and the practically continuous inflow of fresh effluent without adequate pretreatment create persistent preconditions for the technogenic transformation of the soil cover, contamination of near-surface and groundwater, and emission of volatile compounds, including hydrogen sulfide, into the atmosphere. According to official data from the Atyrau regional branch of RSE “Kazhydromet,” “Tukhlaya Balka” (together with the “Kvadrat” storage pond in the north-western part of the city) is one of two municipal accumulators of industrial and household effluent with a total area of about 1,000 ha, into which effluent flows practically without treatment, making it the principal source of hydrogen sulfide in the city as a result of the decomposition of organic matter in sewage, including petroleum products (Kazhydromet, 2025a). In recent years, environmental measures have been carried

out at the site aimed at draining and subsequently reclaiming individual sections of “Tukhlaya Balka,” with part of the effluent redirected to closed pipelines leading to the municipal wastewater treatment plant; however, as of 2026 the complete closure of the facility as an active evaporation field has not been completed, which confirms the continuing relevance of instrumental monitoring of the site.

Under these conditions, the relevance persists of a systematic geo-ecological and geochemical assessment of the condition of the “Tukhlaya Balka” territory, including regular monitoring of the quality of water, soil and bottom sediments, determination of the multiplicity of exceedance of applicable standards, identification of the leading factors of technogenic loading, and scientific substantiation of priority directions for remediation. The present work is based on the results of instrumental studies carried out by an accredited testing laboratory - the Mobile Environmental Monitoring Centre of the Republican Research Centre for Atmospheric Air Protection LLP (accreditation certificate No. KZ.T.06.0369 dated 29.03.2024) commissioned by NPJSC “Kh. Dosmukhamedov Atyrau University” over two seasonal cycles of 2026 - April-May and June-July. The results obtained are regarded as a scientific basis for the further development of a technology for restoring the ecosystem of the territory using natural sorbents - diatomite, opoka, and borate mineral raw material from the Inder deposit (Atyrau region) - inderite and inyoite.

The purpose of the study is to carry out a geo-ecological and geochemical assessment of the degree of technogenic contamination of the “Tukhlaya Balka” filtration fields based on seasonal monitoring of water and soil quality, including the content of sulfur compounds, heavy metals and petroleum products, and on this basis to substantiate the need for, and priority directions of, remediation of the territory.

To achieve this purpose, the following tasks were addressed: 1) to analyse the chemical composition of water and soil samples collected in two seasonal cycles of 2026 across three groups of indicators - sulfur compounds, heavy metals and petroleum products; 2) to compare the concentrations obtained with applicable maximum permissible concentration (MPC) standards, as well as with independent statistical data from regional environmental monitoring by RSE “Kazhydromet”; 3) to carry out a geo-ecological assessment of the spatio-temporal dynamics of contamination of the territory; 4) to substantiate the need for remediation of the territory as a basis for the subsequent choice of treatment technology.

Literature Review. The problem of accumulation-type evaporator ponds (filtration fields) for wastewater is typical of arid and semi-arid territories of the Republic of Kazakhstan, where the absence of natural receivers for treated effluent makes this method of disposal practically the only alternative. According to K. Ospanov et al. (2020), about 540 such accumulators are in operation in Kazakhstan, located near major cities and industrial centres; using the example of the pond system of the city of Kostanay, the authors established that the efficiency of primary

settling tanks often does not meet the design value, and pollutants (BOD₅, COD, suspended solids, ammonium nitrogen) enter groundwater through infiltration via the impoundment bed, with groundwater quality statistically linked (according to cluster and component analysis) to both the water quality in the ponds and the water quality of adjacent surface watercourses (Ospanov et al., 2020). This conclusion is directly relevant to “Tukhlaya Balka,” since the facility is structurally the same type of unlined earthen accumulator, but has a substantially longer (over 80 years, versus the first few decades) operating life, which potentially increases the risk of accumulated contamination of underground horizons.

Methodological approaches to the geochemical assessment of accumulation-type technogenic water bodies in the arid zone of Kazakhstan have been developed in detail in the work of G.Zh. Kenzhetayev and co-authors. In a study of the wastewater evaporator pond of Caspi Bitum JV LLP (Mangystau region), MPC exceedances were found for a number of indicators ranging from 1.1 to 21.9-fold, including up to 2.8-fold for total iron and up to 1.7-fold for petroleum products; the BOD₅/COD ratio at all sampling points was below 0.5, which the authors interpreted as a sign of supersaturation of the wastewater with poorly oxidisable compounds and a low capacity of the pond for biochemical self-purification (Kenzhetayev et al., 2020a). To reduce the emission of harmful substances from the surface of the evaporator, the authors proposed and tested a heliotechnical system of translucent covers that intensifies the evaporation process in a closed volume while simultaneously preventing the release of petroleum product and hydrogen sulfide vapours into the atmosphere (Kenzhetayev et al., 2020a).

In another work by the same team of authors, an ecological-geochemical assessment was carried out of the wastewater settling pond of the sewage treatment facility of the city of Zhanaozen (Mangystau region) with the aim of selecting an environmentally and economically feasible method of treating this water for subsequent use in irrigating the city's green spaces under conditions of water scarcity (Kenzhetayev et al., 2020b). Water and bottom-sediment sampling was carried out according to the same normative documents (GOST R 51592-2000, GOST 17.1.5.01-80) as in the present study; for the statistical processing of small samples with different distribution laws, the authors applied the non-parametric Kruskal-Wallis test (Statistica 10), and GIS software (Google Maps, SAS Planet) for mapping the area of the settling pond. Based on the results of the contamination assessment, the settling pond, located practically within the city limits, was classified by the authors as a “technogenic” object with an insufficient degree of water treatment; a heliotechnical method of post-treatment was proposed as the most economically and environmentally feasible (Kenzhetayev et al., 2020b). The indicators used in this work - the water pollution index (WPI) and the aggregate pollution index - are also applied in the present study.

The significance of bottom sediments and soils as an indicator of technogenic contamination of filtration fields is emphasised in the work of O.V. Kovaleva and

D.V. Vinogradov (2025), carried out using the example of the filtration fields of a milk-processing enterprise in the Tyumen region. The authors established an exceedance of lithosphere clarke values for iron (6.6-fold) and manganese (89.7-fold), while calculating biological absorption coefficients of elements by the plant *Carex rostrata* Stokes, which made it possible to construct accumulation-intensity series and identify groups of elements with strong and weak biological uptake. It is shown that as the content of heavy metals in bottom sediments increases, the intensity of their uptake by the plant decreases, which is relevant for planning phytoremediation measures at similar facilities (Kovaleva, Vinogradov, 2025).

A separate line of research concerns the improvement of evaporative treatment technologies for mineralised and oil-contaminated effluent. A. Zaro et al. (2023) demonstrated experimentally that the use of a porous layer of carbon foam in the upper part of the evaporator makes it possible to localise thermal energy at the water surface and reduce the share of energy lost to heating the underlying volume of liquid by 90.2% at a porosity of 100 pores per inch; the specific energy consumption for evaporation is thereby reduced from 4.284 to 3.344 kJ/g. Although this work was carried out in relation to industrial wastewater and municipal solid waste landfill leachate, the proposed principle of heat localisation is also of practical interest for intensifying evaporation at facilities of the “Tukhlaya Balka” type.

For a quantitative assessment of the hazard level of soil and bottom sediment contamination, domestic and Russian practice traditionally uses the methodology of the total pollution index Z_c , based on the calculation of concentration coefficients ($K_c = C_i/C_{background}$) relative to the regional geochemical background, with the subsequent identification of contamination categories: not hazardous ($Z_c < 16$), moderately hazardous (16-32), hazardous (32-128) and extremely hazardous (> 128) (Saet et al., 1990). Along with this, the water pollution index (WPI) is used to assess surface water quality, calculated as the average value of the ratios of actual concentrations to MPC for a limited number of priority indicators, with the identification of seven water quality classes - from “very clean” to “extremely dirty” (Kenzhetayev et al., 2020b). Both methodological approaches are used in the present work to interpret the results of chemical analysis.

A synthesis of the sources reviewed shows that, despite the experience accumulated in Kazakhstan in the geo-ecological assessment of individual wastewater accumulators (Kostanay, Zhanaozen, Mangystau region), systematic publications in the peer-reviewed scientific literature devoted specifically to the territory of “Tukhlaya Balka” - one of the largest and oldest such facilities in the country - were not found at the time this article was prepared. This determines the scientific novelty and practical significance of the present study.

Materials and Methods. The object of the study is the “Tukhlaya Balka” evaporation (filtration) fields, located in the immediate vicinity of the city limits of Atyrau and divided into left-bank and right-bank sections (Table 1, Figure 1). Sampling was carried out by the Mobile Environmental Monitoring Centre of the

Republican Research Centre for Atmospheric Air Protection LLP (accreditation certificate No. KZ.T.06.0369 dated 29.03.2024) commissioned by NPJSC “Kh. Dosmukhamedov Atyrau University” at the “Right Bank Tukhlaya Balka” point (coordinates according to the sampling report: 47°05′06.5″ N, 51°58′25.5″ E) over two seasonal cycles: cycle I - April-May 2026 (sampling reports No. 185/B and No. 147/P dated 29.04.2026); cycle II - June-July 2026 (sampling reports No. 262/B and No. 294/P dated 29.06.2026).

Table 1. General characteristics of the study object.

Parameter	Value
Name of the facility	“Tukhlaya Balka” evaporation (filtration) fields
Year operation began	1945
Total area of the land allotment, ha	≈ 1,336 (476 + 860)
incl. on the balance sheet of the Atyrau city akimat, ha	476
incl. on the balance sheet of JSC “Atyrau Refinery,” ha	860
Purpose	Receiving municipal wastewater from the city sewerage system and industrial effluent from the refinery
Monitoring point / coordinates	“Right Bank,” 47°05′06.5″ N, 51°58′25.5″ E*
2026 sampling periods	29.04.2026 (cycle I); 29.06.2026 (cycle II)

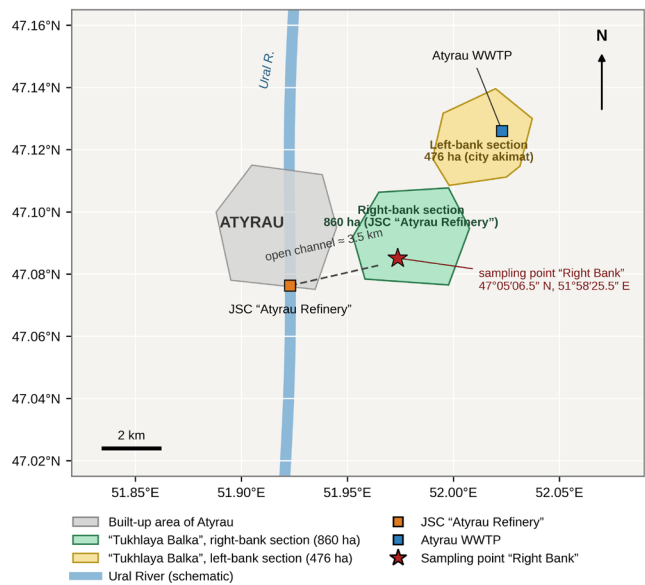


Figure 1. Schematic map of the location of the “Tukhlaya Balka” evaporation fields relative to the city of Atyrau, JSC “Atyrau Refinery” and the Atyrau wastewater treatment plant (KOS); WGS-84 coordinate system. Section boundaries and the course of the Ural River are shown schematically; coordinates of the city of Atyrau, JSC “Atyrau Refinery,” the “Tukhlaya Balka” facility and the KOS are based on mapping services and official documentation of JSC “Atyrau Refinery” (Atyrau Oil Refinery JSC, 2026).

Water sampling, preservation and transport were carried out in accordance with the requirements of GOST R 51592-2000 “Water. General requirements for sampling,” soil sampling (sampling depth 0-20 cm) - in accordance with GOST 17.1.5.01-80 “Nature protection. Hydrosphere. General requirements for sampling of bottom sediments of water bodies for pollution analysis.” Meteorological parameters were recorded during sampling: in April, the air temperature was 17.1°C, atmospheric pressure 758 mmHg, wind direction north-east, wind speed 2.1-3.4 m/s; in June - 27.3°C, 757 mmHg, northerly wind, 2.5-3.4 m/s, respectively. Laboratory tests were carried out using certified methods, a list of which by matrix type and determined indicators is given in Table 2.

Table 2. Sampling programme and normative-methodological basis of the analysis.

Matrix	Indicator	Unit	Normative document for the test method
Water	Petroleum products	mg/dm ³	ST RK 2328-2013
Water	Total iron	mg/dm ³	ST RK ISO 6332-2008
Water	Sulfates	mg/dm ³	ST RK 1015-2000
Water	Hydrogen sulfide	mg/dm ³	ST RK 2874-2016
Water	Sulfides	mg/dm ³	ST RK 2874-2016
Water	Copper, lead, zinc	mg/dm ³	ST RK 2318-2013
Soil (0-20 cm)	Petroleum products	mg/kg	MVI No. 03-03-2012 (KZ.07.00.01668-2022)
Soil (0-20 cm)	Hydrogen sulfide	mg/kg	SanPiN 42-128-4433-87
Soil (0-20 cm)	Phenol	mg/kg	PND F 16.1:2.3:3.44-05
Soil (0-20 cm)	Chlorides	mg/kg	GOST 26425-85
Soil (0-20 cm)	Sulfates	mg/kg	GOST 26426-85
Soil (0-20 cm)	Copper, zinc	mg/kg	ST RK 2.377-2015

To interpret the results, concentrations of pollutants in water were compared with maximum permissible concentrations (MPC) for wastewater discharge into water bodies used for drinking, domestic and cultural purposes (GN 2.1.5.-1315-03) - following the methodological approach tested in the assessment of similar accumulation-type technogenic water bodies in the Republic of Kazakhstan (Kenzhetayev et al., 2020a; Kenzhetayev et al., 2020b). Heavy metal concentrations (Cu, Zn) in soil were compared with the hygienic standards GN 2.1.7.2041-06 “Maximum permissible concentrations (MPC) of chemical substances in soil” (mobile form), since specific regional standards for soils of the arid zone of the Atyrau region are not established in open sources; the general regulatory framework of the Republic of Kazakhstan for chemical substances contaminating soil is set out in the joint order of the Minister of Health of the Republic of Kazakhstan and the Minister of Environmental Protection of the Republic of Kazakhstan dated 2004. For petroleum products in soil, a five-level contamination scale approved by Roskomzem and agreed with the Ministry of Natural Resources of Russia (10-

18.11.1993) was used: less than 1,000 mg/kg - acceptable level; 1,000-2,000 - low; 2,000-3,000 - medium; 3,000-5,000 - high; more than 5,000 mg/kg - very high level of contamination (Roskomzem, 1993); in the absence of an officially approved numerical MPC standard for petroleum products in soil in the regulatory framework of Kazakhstan and the CIS, this scale is widely used in the practice of engineering-environmental surveys.

The following were calculated: the multiplicity of MPC exceedance ($K_p = C_{actual} / MPC$); the relative change in concentrations between seasons $\Delta = (C_{summer} - C_{spring}) / C_{spring} \times 100\%$; the integrated water pollution index $WPI = (1/n) \cdot \sum C_i / MPC_i$ for five regulated indicators (petroleum products, total iron, sulfates, copper, zinc), with subsequent classification into one of seven water quality classes (Kenzhetayev et al., 2020b); and the concentration coefficient $K_c = C_i / C_{background}$ for copper and zinc in soil - relative to the urban geochemical background of the city of Atyrau.

To statistically verify the results obtained and give them regional context, data from official state environmental monitoring were used: information bulletins on the state of the environment for the Atyrau region and for the Republic of Kazakhstan as a whole, published by the Atyrau regional branch of RSE “Kazhydromet” and the Environmental Monitoring Department of RSE “Kazhydromet” on a monthly and semi-annual basis (Kazhydromet, 2025a, 2025b). These bulletins contain, in particular, actual concentrations of copper and zinc in the soils of settlements of the Republic of Kazakhstan, including the city of Atyrau (as of the first half of 2025: copper 0.31-0.35 mg/kg, zinc 2.0-2.4 mg/kg) (Kazhydromet, 2025b), used in the present work as the urban geochemical background $C_{background}$ when calculating concentration coefficients, as well as hydrochemical monitoring data for the Zhaiyk (Ural) River, the Kigash River and the Peretaska, Yaik and Sharonova channels within the city of Atyrau, used for an independent comparison of the actual petroleum product concentrations in the water of the “Tukhlaya Balka” point with the regional monitoring network (Kazhydromet, 2025a). Water quality classification according to Kazhydromet data is carried out according to the “Unified system for classifying water quality in water bodies” in force in the Republic of Kazakhstan, approved by order No. 70 of the Committee for Water Resources and Irrigation of the Ministry of Agriculture of the Republic of Kazakhstan dated 20.03.2024, and includes six classes - from “very good quality” (class 1) to “highly polluted” (class 6) waters; this classification is used in the present work as a system of comparison independent of the WPI.

Results and Discussion. *Chemical composition of water.* The results of the chemical analysis of water at the “Tukhlaya Balka” point (right bank) over two seasonal cycles of 2026 are given in Table 3 and Figures 2-4.

Table 3. Results of the chemical analysis of water and multiplicity of MPC exceedance.

Indicator	Unit	MPC*	Spring (Apr.-May)	Summer (Jun.-Jul.)	Kp, spring	Kp, summer	Δ, %
Petroleum products	mg/dm ³	0.1	0.90	0.535	9.00	5.35	-40.6
Total iron	mg/dm ³	0.3	0.41	0.12	1.37	0.40	-70.7
Sulfates	mg/dm ³	500	404.2	79.0	0.81	0.16	-80.5
Hydrogen sulfide	mg/dm ³	-	0.050	0.02	-	-	-60.0
Sulfides	mg/dm ³	-	0.003	<0.002	-	-	≤-33.3
Copper	mg/dm ³	0.05	0.0173	0.0051	0.35	0.10	-70.5
Lead	mg/dm ³	-	0.003	0.006	-	-	+100
Zinc	mg/dm ³	1.0	<0.1	<0.1	≤0.10	≤0.10	0

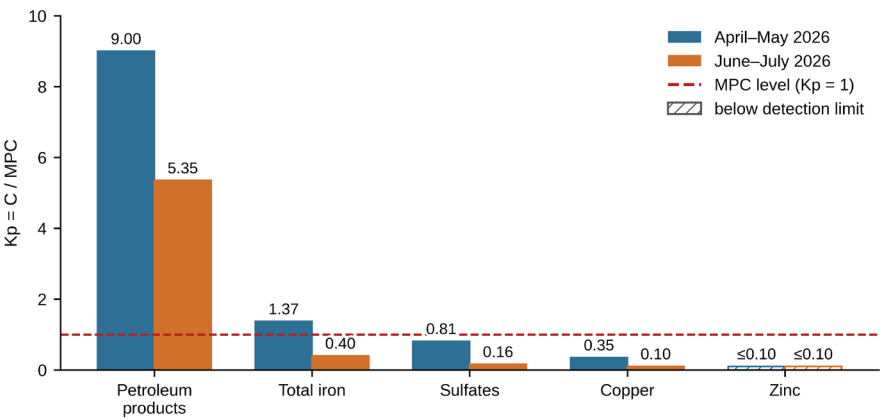


Figure 2. Multiplicity of MPC exceedance for regulated water quality indicators at the “Tukhlaya Balka” point (GN 2.1.5.-1315-03).

As follows from Table 3 and Figure 2, the only indicator for which MPC exceedance was recorded in both seasonal cycles is petroleum products: 9.0-fold in spring and 5.4-fold in summer. The total iron content exceeded the standard in the spring period (1.37-fold), but decreased to 0.40 MPC in the summer period. No exceedances were found for sulfates, copper or zinc in either cycle, despite sulfates being the most abundant impurity by absolute concentration (79-404 mg/dm³). A comprehensive profile of the multiplicity of MPC exceedance for all five indicators simultaneously is presented on the radial diagram (Figure 3): it is clearly visible that the contour for both seasons extends beyond the MPC circle (Kp = 1.0) only along the “petroleum products” axis, while along the other axes the contour lies inside this circle.

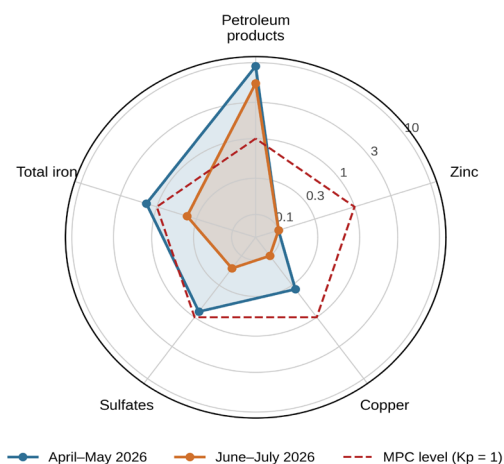


Figure 3. Radial profile of the multiplicity of MPC exceedance (K_p) for regulated water quality indicators (logarithmic scale).

Attention is drawn to a multidirectional seasonal dynamic: concentrations of most regulated indicators (petroleum products, iron, sulfates, copper, hydrogen sulfide) decreased in the summer cycle relative to spring by 40.6-80.5%, whereas the lead content, on the contrary, increased (from 0.003 to 0.006 mg/dm³), while remaining at a level typical of background concentrations (Figure 4). The observed general decrease in concentrations may be due to a combination of factors: seasonal dilution of effluent by flood waters in April-May, intensification of biochemical and physicochemical transformation processes of impurities as water temperature rises in summer (a similar seasonal dependence has been noted for evaporator ponds in the Mangystau region (Kenzhetayev et al., 2020a)), as well as the possible influence of environmental and technical measures carried out at the site during the period under consideration. To unambiguously interpret the seasonal dynamics, continued monitoring over a full annual cycle with quarterly frequency is required.

Comparison with independent data from regional monitoring by RSE “Kazhydromet” confirms the pronounced technogenic nature of the petroleum contamination at the “Tukhlaya Balka” point. According to the bulletin for September 2025, petroleum product concentrations at control cross-sections of the Zhaiyk (Ural) River and its channels (Peretaska, Yaik, Sharonova) within the city of Atyrau were 0.054-0.234 mg/dm³, with the waters classified as quality class 3-4 (“moderately polluted”-“polluted”) according to the current Unified Classification System (Kazhydromet, 2025a; KVR MSKh RK, 2024). Even the lower of the two values recorded in the present study (0.535 mg/dm³, summer) exceeds the maximum value recorded in the regional river network during the same period by 2.3-fold, and the spring value (0.90 mg/dm³) by 3.8-fold, indicating a substantially higher technogenic loading on “Tukhlaya Balka” compared with background water bodies of the same region.

The presence of hydrogen sulfide (0.02-0.050 mg/dm³) and dissolved sulfides (up to 0.003 mg/dm³) in the water indicates the development of sulfate reduction processes in anaerobic microzones within the water column and the near-surface layer of bottom sediments, which is typical of water bodies that have long received effluent with a high concentration of organic matter, and is consistent with the previously established low BOD₅/COD ratio (< 0.5) for similar facilities in Kazakhstan, indicating a low capacity of such ponds for biochemical self-purification (Kenzhetaev et al., 2020a). Given that BOD₅ and COD indicators were not included in the present sampling programme, their inclusion among the determined indicators appears advisable for subsequent monitoring cycles.

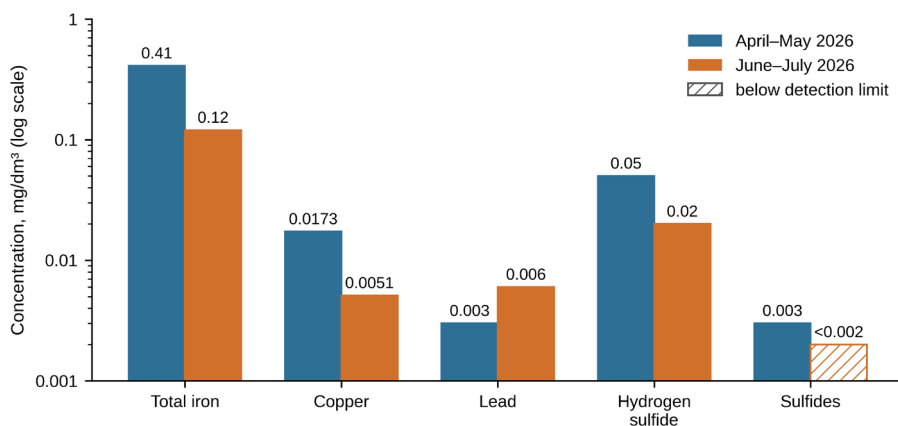


Figure 4. Seasonal dynamics of iron, copper, lead, hydrogen sulfide and sulfide content in the water of the “Tukhlaya Balka” point (logarithmic scale).

Chemical composition of soil. The results of the chemical analysis of soil (0-20 cm layer) are given in Table 4 and Figures 5, 6.

Table 4. Results of the chemical analysis of soil.

Indicator	Unit	Standard*	Spring (Apr.-May)	Summer (Jun.-Jul.)	Δ, %
Petroleum products	mg/kg	<1000 (accept.)	20.9	<5.0	-76.1
Hydrogen sulfide	mg/kg	-	1.93	1.55	-19.7
Phenol	mg/kg	-	<0.05	<0.05	0
Chlorides	mg/kg	-	2236.5	2875.5	+28.6
Sulfates	mg/kg	-	4557.09	3972.75	-12.8
Copper	mg/kg	3.0**	1.3	1.4	+7.7
Zinc	mg/kg	23.0**	<5.0	<5.0	0

* For petroleum products - category according to the contamination-level assessment scale (Roskomzem, 1993); dash - no regulated numerical standard exists. ** GN 2.1.7.2041-06, mobile form.

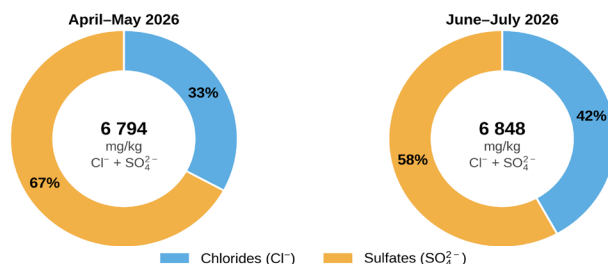


Figure 5. Structure of water-soluble salts in the soil of the “Tukhlaya Balka” point (share of chlorides and sulfates, %, and their total content, mg/kg).

The most pronounced feature of the chemical composition of the soil is the high content of water-soluble salts: chloride concentration was 2,236.5 mg/kg in spring and 2,875.5 mg/kg in summer (an increase of 28.6%), and sulfates - 4,557.09 and 3,972.75 mg/kg, respectively (a decrease of 12.8%). As shown in Figure 5, the total salt loading ($\text{Cl}^- + \text{SO}_4^{2-}$) remained practically unchanged between cycles (6,794 and 6,848 mg/kg, respectively), although the structure of the salt composition shifted: the share of chlorides increased from 33 to 42%, with a corresponding decrease in the share of sulfates from 67 to 58%. Expressed as a mass fraction, the total salt content corresponds to 0.68-0.69% of soil mass, which exceeds levels typical of non-saline soils of the arid zone by one to two orders of magnitude, and indicates the formation of a technogenic salt marsh (solonchak) within the evaporation fields. The shift of the salt composition structure towards chlorides by the summer period may be explained by the different behaviour of these ions as temperature and evaporation intensity increase: highly soluble chlorides continue to accumulate in the upper horizon owing to capillary rise of moisture, whereas part of the sulfates can be removed from solution through precipitation of poorly soluble sulfate minerals (gypsum), which is a typical process for evaporite systems of an arid climate.

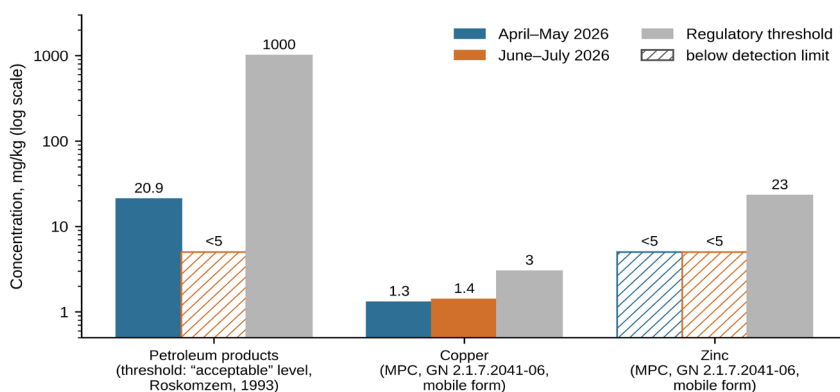


Figure 6. Content of petroleum products, copper and zinc in soil compared with regulatory thresholds (the Roskomzem, 1993 scale and GN 2.1.7.2041-06), mg/kg (logarithmic scale).

Unlike salinization, the content of petroleum products and heavy metals in soil does not exceed applicable standards, although it approaches them for copper. The petroleum product concentration decreased from 20.9 mg/kg in spring to a level below the detection limit (< 5.0 mg/kg) in summer, corresponding to the “acceptable” level of contamination on the scale (Roskomzem, 1993) (two orders of magnitude below the lower boundary of the “low level” category, 1,000 mg/kg). The copper content amounts to 43-47% of the hygienic standard GN 2.1.7.2041-06 (3.0 mg/kg, mobile form), i.e. it remains within the acceptable range but is not negligible and warrants attention in subsequent monitoring; the zinc content does not exceed 22% of the corresponding standard (23.0 mg/kg). Phenol was not detected in any samples at the method’s limit of determination (< 0.05 mg/kg). The hydrogen sulfide content in soil (1.55-1.93 mg/kg) is an additional indicator of locally anaerobic conditions in the near-surface layer, associated with the decomposition of organic matter from the wastewater entering the evaporation fields.

Geo-ecological assessment of the site condition. Calculation of the integrated water pollution index (WPI) for five regulated indicators (petroleum products, total iron, sulfates, copper, zinc) gives a value of 2.33 for the spring cycle and 1.22 for the summer cycle. According to the seven-class scale adopted in hydrochemical practice (I - “very clean,” $WPI \leq 0.3$; II - “clean,” 0.3-1.0; III - “moderately polluted,” 1.0-2.5; IV - “polluted,” 2.5-4.0; V - “dirty,” 4.0-6.0; VI - “very dirty,” 6.0-10.0; VII - “extremely dirty,” > 10.0), the water at the “Right Bank” point belongs to quality class III (“moderately polluted”) in both observation periods, with some improvement of the indicator by the summer cycle - approaching the boundary of class II (Figure 7).

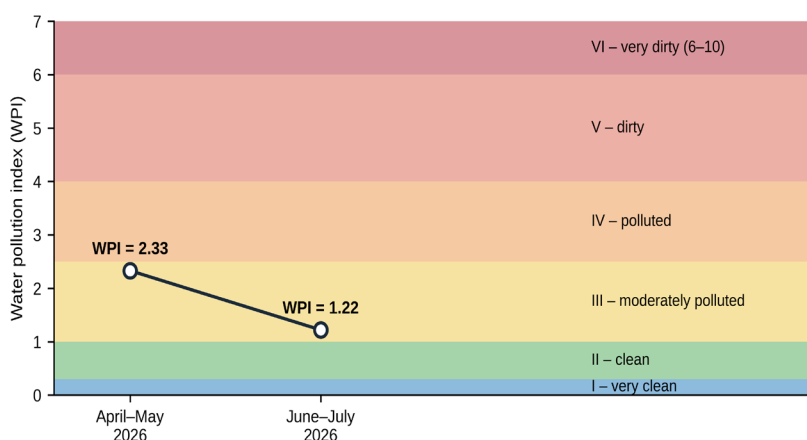


Figure 7. Dynamics of the water pollution index (WPI) at the “Tukhlaya Balka” point against the background of the adopted seven-class water quality scale.

Direct comparison of the copper and zinc concentrations obtained in soil with the hygienic standard GN 2.1.7.2041-06 shows that both metals remain within the

acceptable range - 43-47% and no more than 22% of the standard, respectively. At the same time, comparison with the urban geochemical background of the city of Atyrau, based on semi-annual soil monitoring by RSE “Kazhydromet” (copper 0.31-0.35 mg/kg, zinc 2.0-2.4 mg/kg) (Kazhydromet, 2025b), gives a fundamentally different picture: the copper concentration coefficient K_c is 3.9 in spring and 4.2 in summer, i.e. the copper content in the soil at the “Tukhlaya Balka” point is approximately 4 times higher than the typical urban background (Figure 8), indicating real technogenic enrichment of the soil with copper that is not revealed when comparing only with the sanitary-hygienic standard. For zinc, K_c does not exceed 2.3 (taking into account the detection limit of < 5.0 mg/kg). This discrepancy - exceedance of the background while simultaneously complying with the hygienic standard - emphasises the methodological importance of using both approaches simultaneously: the GN 2.1.7.2041-06 standard answers the question of direct sanitary hazard, whereas the concentration coefficient K_c answers the question of the degree of technogenic change of the territory relative to itself (the urban background), which is more informative for the purposes of geo-ecological monitoring and remediation planning.

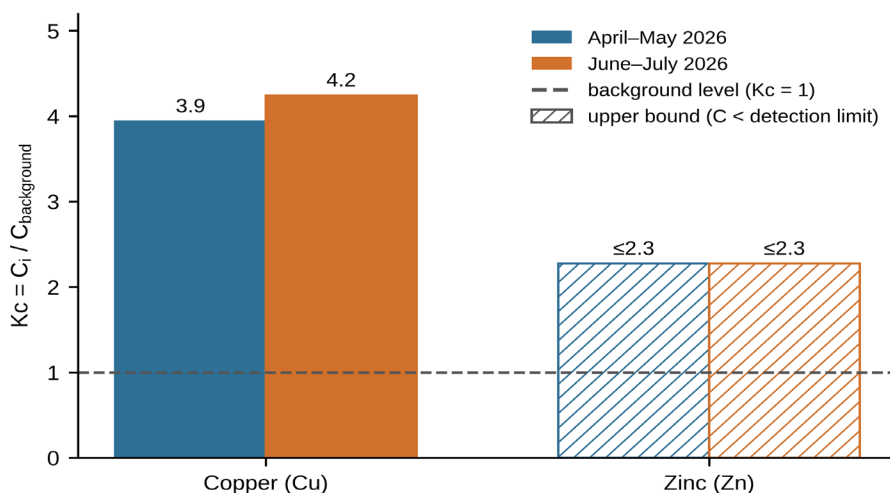


Figure 8. Concentration coefficient of copper and zinc in the soil of the “Tukhlaya Balka” point relative to the urban geochemical background of the city of Atyrau (based on data from RSE “Kazhydromet,” 2025b).

Comparison of the contamination structure of “Tukhlaya Balka” with the previously studied wastewater settling pond of the city of Zhanaozen (Kenzhetayev et al., 2020b) indicates a fundamental similarity between the facilities in type - both are accumulators of municipal and industrial effluent in the arid zone, classified by researchers as “technogenic” objects - and in the proposed method of post-treatment (heliotechnical intensification of evaporation). At the same time, according to the

present study, the leading factors of technogenic loading on “Tukhlaya Balka” are persistent petroleum contamination of water and pronounced salinization of soils; the contribution of heavy metals does not create a direct sanitary hazard (Cu and Zn content below hygienic standards), although significant enrichment relative to the urban background is recorded for copper ($K_c = 3.9-4.2$), whereas for the Zhanaozen settling pond, according to the literature, heavy metals are also among the controlled contamination indicators (Kenzhetayev et al., 2020b). This is consistent with the composition of the bulk of the incoming effluent: municipal sewage from the city sewerage system in the akimat-owned section, and industrial effluent from the refinery associated with oil dehydration and desalting in the plant-owned section, for which a high content of chlorides, sulfates and petroleum products is typical (Kenzhetayev et al., 2020a).

By analogy with methodologically similar studies of accumulation-type technogenic water bodies (Kenzhetayev et al., 2020b; Ospanov et al., 2020), it can be predicted with a sufficient degree of probability that: 1) maximum pollutant concentrations are confined to the zones of direct effluent discharge; 2) the distribution of impurities within the water area has a pronounced wind-related character owing to the “surge” phenomenon of water towards the prevailing wind directions, which for the city of Atyrau are characteristically north-easterly and northerly (also confirmed by the parameters of the present sampling); 3) the most likely risk zone for groundwater quality is the periphery of the accumulators, including the boundary between the left-bank and right-bank sections and the adjacent floodplain of the Ural River - by analogy with the statistical relationship established for the Kostanay ponds between groundwater quality and the water quality in the accumulators, which weakens with increasing distance from the ponds (Ospanov et al., 2020).

Scientific substantiation of the need for remediation and possible treatment technologies. Although MPC exceedances were not found for most regulated indicators at the studied point, the totality of the data obtained substantiates the need to carry out remediation measures on the territory of “Tukhlaya Balka.” This conclusion is based on several grounds: (1) a persistent MPC exceedance for petroleum products in water, maintained in both seasons (5.4-9.0-fold); (2) pronounced technogenic salinization of soils, exceeding levels typical of natural soils of the region by one to two orders of magnitude; (3) continuing emission of hydrogen sulfide, confirmed by the laboratory data of the present study in both water and soil; (4) more than 80 years of facility operation without continuous sealing of the impoundment bed, creating a cumulative risk to groundwater quality by analogy with the documented mechanism of infiltration contamination of the aquifer for the Kostanay ponds (Ospanov et al., 2020); (5) the absence of groundwater quality monitoring within the site perimeter in the current monitoring programme.

Given the chemical composition of the contamination identified (sulfates, sulfides and hydrogen sulfide; petroleum products; copper, enriched relative to the

urban background), the most targeted approach appears to be a sorption treatment method using natural mineral sorbents that we plan to apply at the site - diatomite and opoka, as well as borate mineral raw material from the Inder deposit (inderite, inyoite), which is a regional resource of the Atyrau region. Diatomite and opoka are microporous siliceous sedimentary rocks with a developed specific surface area, cation-exchange capacity, and high sorption capacity for petroleum products and heavy metal ions, which makes them fundamentally suitable for the post-treatment of water containing precisely those groups of pollutants identified as priorities in the present study; a quantitative assessment of their sorption efficiency in relation to the water and soil of “Tukhlaya Balka,” as well as the prospects for using borate raw material from the Inder deposit.

Thus, the results of the contamination assessment of the “Tukhlaya Balka” evaporation fields, located practically within the city limits of Atyrau and receiving effluent practically without treatment, which allows the facility to be classified as “technogenic,” substantiate the choice of natural mineral sorbents - diatomite, opoka and borate raw material from the Inder deposit (inderite, inyoite) - as the most economically feasible and environmentally safe method of water post-treatment for the subsequent restoration of the ecosystem of the territory.

Conclusion. Based on the results of two seasonal sampling cycles (April-May and June-July 2026) at the “Right Bank” point of the “Tukhlaya Balka” evaporation fields, a persistent exceedance of the fishery-water MPC (GN 2.1.5.-1315-03) for petroleum product content was established - 9.0-fold in spring and 5.4-fold in summer; an episodic exceedance (1.4-fold) was recorded for total iron in the spring period. No exceedances were found for sulfates, copper or zinc in either cycle.

The calculated water pollution index (WPI) was 2.33 in spring and 1.22 in summer, corresponding to quality class III (“moderately polluted”) in both observation periods; this assessment is consistent with the independent water quality classification of the Ural (Zhaiyk) River within the city of Atyrau (class 3, “moderately polluted”) carried out by RSE “Kazhydromet” according to the current Unified Classification System. Petroleum product concentrations at the “Tukhlaya Balka” point exceed the maximum values recorded during the same period in the regional surface water monitoring network of the Atyrau region by 2.3-3.8-fold.

The soils of the territory are characterised by pronounced technogenic mineralisation: the total content of chlorides and sulfates was 6,794-6,848 mg/kg (0.68-0.69% of soil mass), with a shift in the structure of the salt composition from a predominance of sulfates (67%) in spring to a more equal ratio with chlorides (42/58%) in summer, exceeding typical background values for non-saline soils of the arid zone by one to two orders of magnitude and indicating the formation of a technogenic salt marsh (solonchak).

The petroleum product content in soil (5.0-20.9 mg/kg) corresponds to the “acceptable” level of contamination; the copper content amounts to 43-47%, and zinc to no more than 22% of the applicable hygienic standard GN 2.1.7.2041-

06, i.e. it remains within the norm. At the same time, comparison with the urban geochemical background of the city of Atyrau (based on RSE “Kazhydromet” data) revealed significant enrichment of the soil with copper ($K_c = 3.9-4.2$) with moderate enrichment with zinc ($K_c \leq 2.3$), which demonstrates the limitations of an assessment based solely on sanitary-hygienic standards without taking the regional geochemical background into account.

The leading factors of geo-ecological risk in the studied territory are persistent petroleum contamination of water, pronounced salinization of soils, accumulation of copper in soil relative to the urban background, and continuing emission of hydrogen sulfide - according to RSE “Kazhydromet,” “Tukhlaya Balka” is the principal source of hydrogen sulfide for the city of Atyrau - which substantiates the need to complete and expand the environmental measures being carried out at the site.

The contamination structure established (sulfur compounds, petroleum products, copper enrichment) confirms the feasibility of the application we plan of natural mineral sorbents (diatomite, opoka, borate raw material from the Inder deposit - inderite, inyoite) for wastewater treatment and the subsequent restoration of the ecosystem of the territory. In addition, the following is recommended: technical remediation of the impoundment bed followed by ameliorative desalinization and biological remediation using salt-tolerant and oil-tolerant plant species.

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