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АКАДЕМИЯСЫ» РҚБ

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ҰЛТТЫҚ ҒЫЛЫМ АКАДЕМИЯСЫ» РҚБ

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ECOLOGICAL-GEOLOGICAL ASSESSMENT OF TECHNOGENICALLY DISTURBED TERRITORIES OF OIL FIELDS OF THE ATYRAU REGION

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Abstract. In the context of the contemporary development of the oil and gas sector in the Republic of Kazakhstan, it is crucial to possess an understanding of the mechanisms and patterns of distribution of heavy metals in the environment. This circumstance thus necessitates the implementation of a programme of constant monitoring and ecological-geological assessment of the entry of heavy metals into the soils of oil fields. This article addresses the issues of ecological and geological assessment of soil conditions in oil fields in the Atyrau region of the Republic of Kazakhstan. The highest categories of soil contamination with heavy metals were identified in the vicinity of the Iskene and Koschagyl deposits. The findings of the study allow for the accurate determination of the extent and overall category of soil contamination in oil fields. The study was conducted in accordance with the established techniques and methods. The issue of objective ecological-geological assessment of oil fields is addressed through the utilisation of standardised methodologies for the calculation of the total indicator, with due consideration given to the excess of maximum permissible or background concentrations of pollutants. A methodology is proposed for calculating a complex indicator that can take into account the varying dimensions of soil contamination. This includes the frequency of excess of conditionally natural background concentrations, the frequency of exceeding the maximum permissible concentrations of pollutants, and their hazard class. The priority scale of pollutants is based on well-known,

scientifically-based gradations of soil pollution parameters. Using standard and proposed methods for calculating soil pollution, the geo-ecological situation was established at distances of up to 10 km.

Keywords: total pollution category, soil, ecological state, heavy metals, Zhylyoi, Makat, oil fields.

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АТЫРАУ ОБЛЫСЫ МҰНАЙ КЕН ОРЫНДАРЫ ТЕХНОГЕНДІ БҰЗЫЛҒАН ТЕРРИТОРИЯЛАРЫН ЭКОЛОГИЯЛЫҚ-ГЕОЛОГИЯЛЫҚ БАҒАЛАУ

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Аннотация. Қазақстан Республикасының мұнай-газ секторын дамытудың қазіргі жағдайында ауыр металдардың қоршаған ортаға таралу механизмдері мен заңдылықтарын білу маңызды болып табылады. Бұл жағдай мұнай кен орындарының топырақтарына ауыр металдардың түсуін тұрақты бақылау және экологиялық-геологиялық бағалау қажеттілігін анықтайды. Бұл мақалада Қазақстан Республикасы Атырау облысының мұнай кен орындарының топырақтарының жағдайын экологиялық-геологиялық бағалау мәселелері қарастырылған. Топырақтың ауыр металдармен ластануының жоғары санаттары Ескене және Қосшағыл кен орындарының маңында анықталды. Зерттеу нәтижелері мұнай кен орындарындағы топырақтың ластану дәрежесі мен жалпы категориясын сенімді анықтауға мүмкіндік береді. Зерттеуді жүргізу кезінде жалпы қабылданған әдістер мен әдістер қолданылды. Мұнай кен орындарының аумағын объективті экологиялық-геологиялық бағалау мәселесі ластаушы заттардың шекті рұқсат етілген немесе фондық концентрацияларының асып кетуін ескере отырып, жалпы көрсеткішті есептеудің стандартты әдістерін қолдану арқылы қарастырылады. Топырақтың ластануының әртүрлі өлшемді сипаттамаларын есепке алатын кешенді көрсеткішті есептеу әдістемесі ұсынылған: шартты табиғи фондық концентрациядан асып кету жиілігі, ластаушы заттардың шекті рұқсат етілген

концентрациясынан асу жиілігі, олардың қауіптілік класы. Ластаушы заттардың басымдық шкаласы топырақтың ластану параметрлерінің ғылыми негізделген белгілі градацияларына негізделген. Топырақтың ластануын есептеудің стандартты және ұсынылған әдістерін қолдана отырып, 10 км-ге дейінгі қашықтықта геоэкологиялық жағдай белгіленді.

Түйін сөздер: жалпы ластану категориясы, топырақ, экологиялық жағдай, ауыр металдар, Жылыой, Мақат, мұнай кен орындары

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ЭКОЛОГО-ГЕОЛОГИЧЕСКАЯ ОЦЕНКА ТЕХНОГЕННО-НАРУШЕННЫХ ТЕРРИТОРИИ НЕФТЯНЫХ МЕСТОРОЖДЕНИЙ АТЫРАУСКОЙ ОБЛАСТИ

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Аннотация. При современных условиях развития нефтегазового сектора Республики Казахстан важное значение имеет познание механизмов и закономерностей распределения тяжелых металлов в окружающей среде. Это обстоятельство определяет необходимость проведения постоянного мониторинга и эколого-геологической оценки поступления тяжелых металлов в почвы нефтяных месторождений. В данной статье рассмотрены вопросы эколого-геологической оценки состояния почв нефтяных месторождений Атырауской области Республики Казахстан. Наиболее высокие категории загрязнения почв тяжелыми металлами обнаружены вблизи месторождения Искене, Косчагыл. Результаты исследования позволяют достоверно определить степень и суммарную категорию загрязнения почв нефтяных месторождений. При проведении исследования были использованы общепринятые методики и методы. Рассматривается проблема объективной эколого-геологической оценки территории нефтяных месторождений по стандартным методикам расчета суммарного показателя с учетом превышения предельно допустимых или фоновых концентраций

загрязнителей. Предложена методика расчета комплексного показателя, который может учитывать разноразмерные характеристики загрязнения почв: кратность превышения условно-естественных фоновых концентраций, частоту превышения предельно допустимых концентраций загрязнителей, их класс опасности. В основу шкалы приоритетности загрязнителей положены известные научно-обоснованные градации параметров загрязнения почв. С помощью стандартных и предложенной методик расчета загрязнения почв установлена геоэкологическая ситуация на расстоянии до 10 км.

Ключевые слова: суммарная категория загрязнения, почва, экологическое состояние, тяжелые металлы, Жылыой, Макат, нефтяные месторождения

Introduction

The distribution of potentially hazardous pollutants in the soils of oil field zones is contingent upon a number of factors, including the volume of emissions, the dynamics of their entry onto the surface of the soil cover, the degree of its heterogeneity, the characteristics of chemicals and compounds containing pollutants, the transfer and migration of heavy metals, the interaction and mutual influence of various pollutants, and other factors. The underlying soil surface within a radius of up to 9 km from the territory of oil fields and waste storage facilities may receive significant amounts of substances containing potential environmental pollutants, including cadmium, lead, zinc, copper and strontium (Zhukova, Khomyakov, 2016). The soil is in a constant state of change in response to alterations in the surrounding environment, as well as to the impact of human activity and land use, and agricultural processes. Some changes in the soil will be transient and reversible, whereas others will result in a radical alteration of the soil's condition, becoming a permanent feature (Kolesnikov, 2010; Kubrina, 2012). Despite a significant number of studies examining the impact of oil pollution on soil ecology in oil fields in the Atyrau region, there is a paucity of research investigating the behaviour of oil products and the practical aspects of soil reclamation in oil field ecosystems.

The objective of this research is to evaluate the ecological and geological condition of technogenic ally polluted areas within oil fields in the Atyrau region of the Republic of Kazakhstan. The rationale for these objective stems from the fact that the study area is not only affected by oil pollution but also by oil fields, which are widely regarded as one of the most environmentally hazardous forms of oil waste.

Study area

The Makat district is situated in the south-eastern region of the Atyrau district. Its total area extends from north to south for 58 km and from west to east for 124 km. The district is bordered to the north by the Kyzylkoginsky district, to the southeast by the Zhylyoi district, to the southwest by the suburban areas of Atyrau, and to the west by the Makhambet district. The district's total area within administrative boundaries is 487.8 thousand hectares, representing 4.2 % of the Atyrau region's total territory.

The administrative centre of the district is the urban-type settlement of Makat, situated 130 km from the regional centre, the city of Atyrau. The regional economy is primarily based on oil and gas production, with notable contributions from NGDU Makatneft, NGDU Dossorneft, LPU MakatZhaiktransgaz, and the Dossor auto repair plant. The Makat region is characterised by a strong industrial presence. The advancement of the regional economy is contingent upon the growth and utilisation of oil fields. The territory of the Makat region

is geomorphologically characterised as part of the Caspian accumulative Upper Quaternary marine, with localised alluvial lowland features within the marginal trough of the platform, exhibiting evidence of preserved marine salinisation and partial aeolian modelling. The region's topography is characterised by an extremely flat plain, comprising predominantly sandy and partially loamy Upper Khvalynian deposits (Diarov, 2003).

The Zhylyoi district is situated in the southeastern portion of the Atyrau region. The district is bordered to the north by the Kyzyl-Korgansky district, to the north-west by the Makat districts of the Atyrau region, to the west by the Caspian Sea, and to the south by the Aktobe region. The district covers an area of 29,352.2 km². The topography of the Zhylyoi region is characterised by a lack of variation. The region is situated within two distinct geomorphological zones: the Caspian lowland and the Podural chalk plateau. The majority of the region's territory is situated within the first of these regions. The region's economy is primarily based on oil production.

Materials and research methods

In order to conduct an ecological and geological assessment of the current state of the soil cover, oil fields situated within the Atyrau region were selected as the subject of study. The study area is host to a number of oil fields, which have the potential to act as sources of soil contamination.

The methodology comprised an analysis of background soils and soils exposed to oil contamination as a consequence of an oil pipeline rupture. The latter was situated at various distances from the accident site, including the epicentre, impact zone and contamination boundary. In the course of the field survey, a comparative geographical approach was employed with a view to establishing a connection between the structure of soils and the corresponding set of natural conditions (Seredina V.P., Nosova, 2020).

In soil-geographical terms, the study area is situated within the desert subzone, where the predominant zonal soil type is brown desert soil. However, given the relatively recent formation of the territory, the proximity of mineralised groundwater to the surface and the complex influence exerted on the soil-forming process by the Caspian Sea, weakly formed saline soils of the hydromorphic series are predominant (Saparov et al., 2020).

Two samples were taken from each of the two deposits in each region. A total of four points from the Tengiz, Koschagyl, Iskine, and Koshkar Yuzhny oil fields were considered (see Figure 1). Samples were obtained at distances ranging from 0.1 to 10 km from each point of the studied deposits. A total of 22 samples were obtained for each deposit in the Makat and Zhylyoi districts of the Atyrau region. In the absence of natural or anthropogenic sources of chemical elements within a 15 km radius of each deposit, the geochemical background for each deposit was determined.

Figure 1 – Schematic map of soil sampling sites in oil fields of the Zhylyoi and Makat regions.
The oil fields are located in the following regions: 1 – Tengiz, 2 – Koschagyl, 3 – Iskine, 4 – Koshkar Yuzhny
Red dots – indicate the locations of soil sampling.

Soil samples were obtained from the principal soil types and in the vicinity of the oil fields under investigation in the Makat and Zhylyoi districts of the Atyrau region, specifically from the upper horizon at a depth of 0–25 cm. A total of 88 sampling sites (SP) and one conditional background site were established. The upper soil layer, spanning a depth of 0–25 cm, was selected as the focus of the study, encompassing the anticipated area of oil impact within a radius of 0.1–10.0 km from the object of investigation. In order to assess the ecological and geological impact of soil contamination in the region under study, classical analytical techniques were employed. The soil samples were collected in accordance with the requirements of GOST 17.4.3.01–2017. The soil samples were analysed in accordance with the relevant standards and guidelines. The sampling requirements were met in July 2023, with the samples subsequently prepared in accordance with GOST 17.4.4.02–2017. The determination of the content of heavy metals in soil samples was conducted in specialized chemical laboratories using atomic absorption spectroscopy on a spectrophotometer (Izimova et al., 2024).

In addition to the aforementioned multivariate analysis techniques, a set of indicators was employed to characterise geochemical associations and subsequently assess the ecological state of the deposit area. These calculations were performed using the Excel program. The concentration coefficient (CC) of a chemical element is a measure of the level of concentration of the element in the environment (in the contaminated zone) relative to

its background content. The aforementioned coefficient is calculated using the following formula:

$$K_C = \frac{C_i}{C_{b,}} \quad (1)$$

In this context, C_i represents the average concentration of the *i*-th chemical element established for a given geochemical sample. C_b, on the other hand, denotes the background content of this same element.

The total pollution index (Z_c) was calculated using the following formula:

$$Z_c = \sum_{i=1}^{n} K_C - (n-1) \quad , \quad (2)$$

In this context, n represents the number of ingredients under consideration, while Kc denotes the concentration coefficient of a given element. This is defined as the ratio of the element's concentration at the sampling site to that observed in the conventional background (Kc = Kpp / Kfon). The level of pollution was determined in accordance with the gradations set forth in SanPin 2.1.7.1287.03.

The Z_C indicator was employed for the ecological-geological assessment of the total indicator of soil pollution due to technogenic impacts, with the results presented in accordance with the specifications set forth in Table 1. It can serve to reflect the actual influence of the volume and composition of pollutants found in the soil on the composition and quality of the soil.

Table 1. Gradation of the degree of violation by categories of soil pollution

Meaning Z_C	Soil pollution category
–	Clean
8 – 16	Acceptable
16 – 32	Moderately dangerous
32 – 128	Dangerous
>128	Extremely dangerous

The data were subjected to statistical processing using computer programs, specifically MS Excel 2017 and Statistica 8.0.

Results and its discussion

The objective of this study, conducted in the autumn of 2022–2023, was to assess the ecological and geological impact of soil contamination with oil in oil fields situated in the Zhylyoi and Makat regions of the Atyrau region. The primary anthropogenic pathway for the introduction of heavy metals into the soil is through oil. The propagation range and levels of soil contamination are contingent upon the strength of the source, emission conditions, and other parameters. As a consequence of the dissipation of impurities with distance from the sources of pollution, the zone of intense influence, in which the MPC is exceeded, is relatively limited. However, the soil cover

of the studied areas has been found to contain notable quantities of heavy metals. The results of the laboratory analysis of soil samples for the content of heavy metals (HM) revealed the following patterns (Table 2).

Table 2. Average content of heavy metals in soils of the studied oil fields of the Atyrau region, mg/kg

Date	H_{sam}, cm	Heavy metals and their content in soils, mg/kg				
		Cu	Cd	Pb	Zh	Cr
MPC, mg/kg		3,0	0,5	32,0	23,0	6,0
Tengiz oil field (coordinates 46°09'10" 53°23'00")						
Autumn 2022 y.	0-25	2,955	0,056	34,151	21,549	3,15
Autumn 2023 y.	0-25	2,878	0,087	33,112	23,472	4,05
Koschagyl oil field (coordinates 46°49' 53°46')						
Autumn 2022 y.	0-25	2,326	0,026	32,155	23,175	3,21
Autumn 2023 y.	0-25	2,481	0,027	31,231	20,182	2,28
Iskine oil field (coordinates 47°24' 52°42')						
Autumn 2022 y.	0-25	2,258	0,065	31,146	22,184	2,87
Autumn 2023 y.	0-25	2,387	0,042	30,112	22,793	1,11
South Koshkar oil field (coordinates 47°44' 53°45')						
Autumn 2022 y.	0-25	2,974	0,102	32,847	23,487	2,37
Autumn 2023 y.	0-25	2,538	0,075	31,735	21,931	3,99

The data on the content of substances in the soil cover are of the utmost importance for the ecological and geological assessment of the state of soils in oil fields contaminated with oil and oil products in the Makat and Zhylyoi fields of the Atyrau region. Furthermore, they are instrumental in identifying the distribution area of heavy metals. The results of the soil sample analyses revealed that the concentrations of heavy metals, specifically lead, exceeded the maximum permitted concentration (MPC) in 2022. The exceedances were observed at 34.151 MPC in the Tengiz fields, 32.155 in the Koschagyl field, and 32.847 MPC in the South Koshkar field. In 2022, an excess of zinc was recorded in the Koschagyl and South Koshkar deposits, with levels reaching 23.175 MPC and 23.487 MPC, respectively. With regard to other heavy metals, no excess of the MPC was identified in the aforementioned oil fields during the course of the 2022 study.

In comparison to the data collected in spring 2022, the concentrations of all heavy metals detected in soil samples from individual oil fields exhibited a slight decrease. The results of the soil sample analyses indicated a slight increase in the concentration of heavy metals, specifically lead (33.112 MPC) and zinc (23.472 MPC), in the Tengiz fields in 2023 (Figure 2).

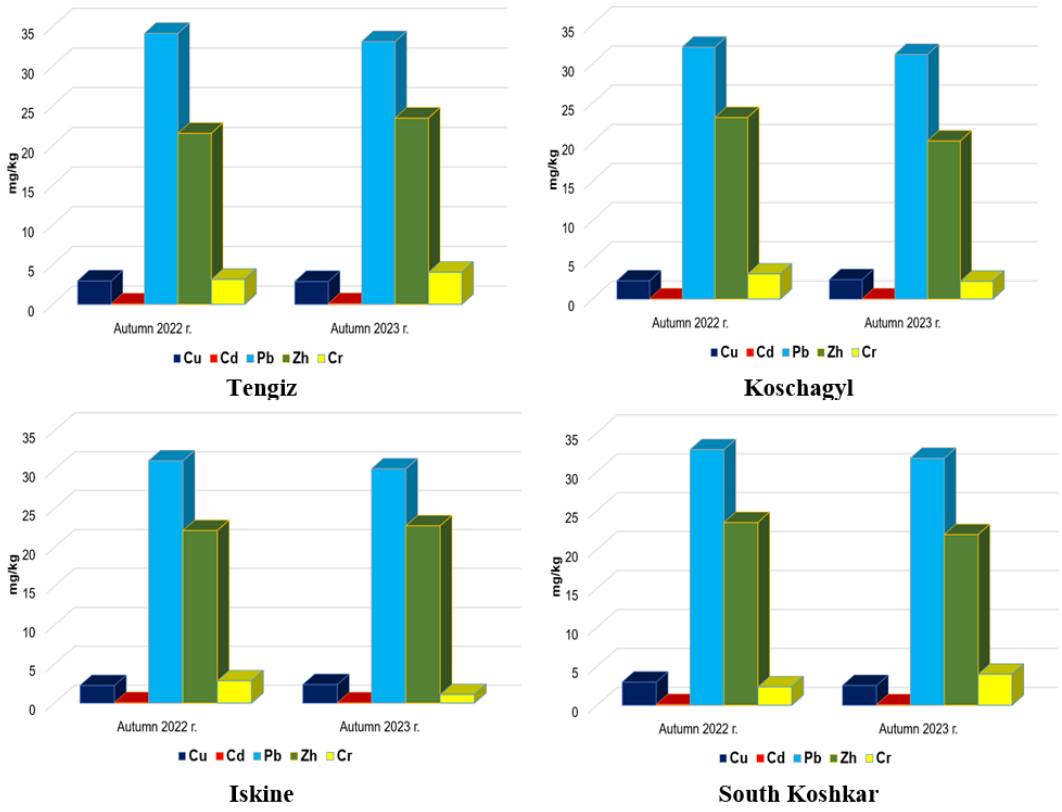

Figure 2. The Dynamics of the Average Content of Heavy Metals in Soils of Oil Fields in the Atyrau Region

The research findings indicate that the concentration of heavy metals in soil samples from the Atyrau region in 2022 is as follows: The order of concentration was Cd > Cu > Cr > Zn > Pb. Cadmium was the initial element in the series, exhibiting a content in soils that did not exceed the established threshold. In 2023, the concentration of heavy metals in soil samples remained consistent with that observed in 2022.

A comparison of the data processing results for the two-year period (2022–2023) (Table 3) reveals that the concentration (mean, minimum, maximum) of heavy metals in the soil cover of the studied oil fields is lower than the mean for 2022.

Table 3. The results of the statistical processing of the soil sample analysis from oil fields in the Atyrau region for the period 2022–2023 are presented in mg/kg.

Element	Годы	Cu	Cd	Pb	Zh	Cr
Tengiz oil field						
Average content	2022	2,955	0,056	34,151	21,549	3,15
	2023	2,878	0,087	33,112	23,472	4,05
Minimum	2022	1,694	0,022	21,289	18,587	1,16
	2023	1,984	0,016	20,548	18,541	1,18

Maximum	2022	3,191	0,121	35,162	26,184	5,36
	2023	3,054	0,154	36,654	24,981	6,11
Number of samples	2022	20	20	20	20	20
	2023	22	22	22	22	22
Geochemical backdrop	2022	1,056	0,021	10,816	9,195	0,87
	2023	1,087	0,017	9,891	11,648	0,92
Koschagyl oil field						
Average content	2022	2,326	0,026	32,155	23,175	3,21
	2023	2,481	0,027	31,231	20,182	2,28
Minimum	2022	1,151	0,018	20,160	17,969	1,02
	2023	1,262	0,011	22,958	18,118	1,11
Maximum	2022	2,985	0,102	34,991	25,598	5,04
	2023	3,002	0,114	35,287	25,547	5,98
Number of samples	2022	20	20	20	20	20
	2023	22	22	22	22	22
Geochemical backdrop	2022	1,025	0,025	10,511	9,088	0,99
	2023	1,082	0,022	10,229	10,878	0,82
Iskine oil field						
Average content	2022	2,258	0,065	31,146	22,184	2,87
	2023	2,387	0,042	30,112	22,793	1,11
Minimum	2022	1,587	0,021	20,298	19,512	1,12
	2023	1,621	0,019	20,121	18,189	1,14
Maximum	2022	3,051	0,098	34,841	26,058	4,69
	2023	2,988	0,101	33,158	25,894	4,75
Number of samples	2022	20	20	20	20	20
	2023	22	22	22	22	22
Geochemical backdrop	2022	0,991	0,020	9,875	8,184	0,22
	2023	1,005	0,011	10,002	8,498	0,19
Oil field South Koshkar						
Average content	2022	2,974	0,102	32,847	23,487	2,37
	2023	2,538	0,075	31,735	21,931	3,99
Minimum	2022	1,874	0,052	20,119	17,916	0,87
	2023	1,765	0,032	20,489	18,089	0,99
Maximum	2022	3,218	0,101	34,596	26,198	4,18
	2023	3,054	0,196	34,165	25,489	4,98

Number of samples	2022	20	20	20	20	20
	2023	22	22	22	22	22
Geochemical backdrop	2022	1,051	0,018	9,987	8,596	0,77
	2023	1,021	0,016	10,098	9,489	0,76

In order to ascertain the concentration coefficient of the element KS in relation to the degree of soil contamination in oil fields, the following formula is employed. Subsequently, the data obtained for each field (Table 4) is subjected to processing. It is notable that for all elements under analysis, there is a considerable discrepancy between the minimum and maximum values of the CS concentration coefficient, with a ratio of up to 6.0 times for Cr and 3.0 times for Pb. The observed scatter in Kc values can be attributed to the presence of isolated anomalies within a relatively limited area in oil fields.

Table 4. The concentration coefficients of heavy metals for deposits in the Atyrau region are presented below

Oil field	Years	Cu	Cd	Pb	Zh	Cr
Tengiz	2022	2,80	2,67	3,16	2,34	3,62
	2023	2,65	5,12	3,35	2,02	4,40
Koschagyl	2022	2,27	1,04	3,06	2,55	3,24
	2023	2,29	1,23	3,05	1,86	2,78
Iskine	2022	2,28	3,25	3,15	2,71	13,05
	2023	2,38	3,82	3,01	2,68	5,84
South Koshkar	2022	2,83	5,67	3,29	2,73	3,08
	2023	2,49	4,69	3,14	2,31	5,25

The application of histograms of heavy metal concentrations and calculated CS concentration coefficients for each element enables the identification of trends in changes in the content of heavy metals.

The total pollution indicator (Zc), defined as the sum of the concentration coefficients (Kc) of elements (minus the background) included in the geochemical association, serves to reflect the excess of the background level by a group of elements and to characterise the level of technogenic pollution of the environment. In order to ascertain the total indicator of heavy metal contamination of soils in oil fields, the following formula (2) is employed. In order to assess the sanitary and toxicological situation, chemical elements of toxicological hazard classes I (Cd, Pb, Zn) and II (Cu, Cr) are employed in the calculation of ZC. The results of the total indicator of heavy metal pollution in oil fields of the study areas are presented in Table 5.

Table 5. The total pollution indicator for oil fields in the Atyrau region is as follows:

Oil field	Years	Z_c
Tengiz	2022	10,59
	2023	13,53
Koschagyl	2022	8,16
	2023	8,21
Iskine	2022	20,44
	2023	13,73
South Koshkar	2022	13,60
	2023	13,88

Table 1 is employed as an assessment scale for the total contamination of soil with heavy metals. As illustrated in Table 1, the soil contamination levels at the Tengiz, Koschagyl and South Koshkar oil fields were deemed to be within the acceptable or low contamination range in 2022. Conversely, the Iskene field exhibited a total pollution indicator value of 20.44, which falls within the moderately dangerous category of soil pollution. In 2023, all oil fields in the Atyrau region that were the subject of study were found to be in the category of acceptable or low degree of soil contamination with heavy metals. Subsequently, trend lines were constructed in order to identify the projected trajectory of soil contamination over the subsequent two-year period (Figure 3).

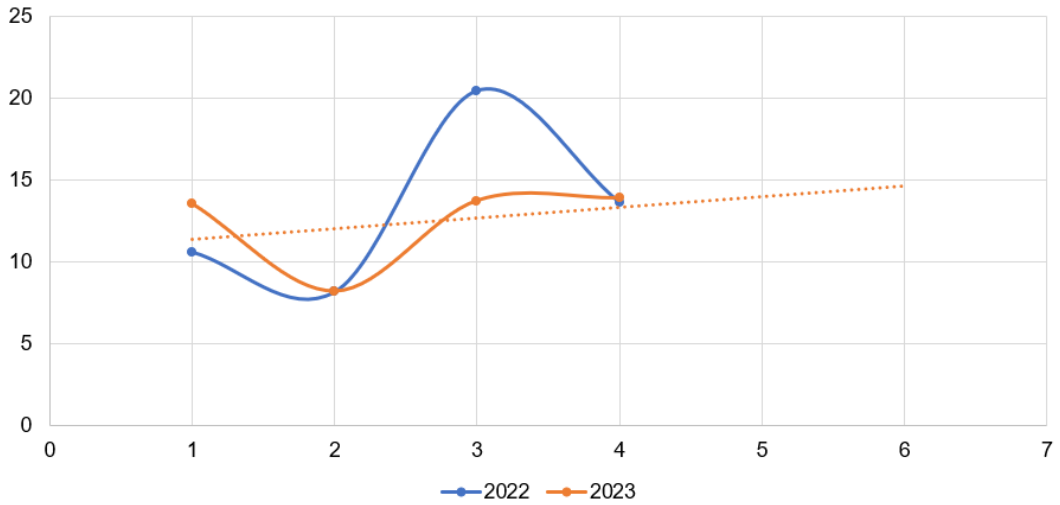

Figure 3. Correlation of trends in total pollution (Zc) of soil cover in oil fields of the Atyrau region

The trends in soil pollution in the region identified during the study indicate a statistically low level of general pollution of the territory of oil fields. This allows for the establishment of a number of anomalies of technogenic origin with significant excesses of the maximum permissible concentrations of heavy metals.

The results of processing the data obtained during the study of soils for the ecological-geological assessment of oil fields in the Zhylyoi and Makat regions of Atyrau for the content of

heavy metals demonstrated that the state of the soil cover during the period of research (2022–2023) was within the acceptable or low degree of pollution category.

In conclusion, the results of the ecological and geological assessment of the soil cover indicate that areas containing elevated concentrations of Cd, Pb, Zn, Cu and Cr can be identified within a radius of up to 4.0 km from the oil fields and 0.5-1.0 km from the object (well). Nevertheless, the concentration of bulk forms of Cd, Pb, Zn, Cu and Cr in the soils of the investigated areas remains below the current regulatory limits for maximum permissible concentrations.

The intensity of migration and accumulation of heavy metals in the studied oil-contaminated soils is contingent upon the concentration of oil products and the distance from the source of pollution. Technogenic pollution affects the morphological appearance of soils, manifesting as an intense specific odour of oil, a change in the colour of the entire soil profile to a darker hue, cementation of soil aggregates with heavy fractions of oil, and the formation of a bituminous crust on the soil surface.

In conclusion, it can be stated that the formation of the oil and gas complex in the areas of the Atyrau region under study has led to a notable increase in the anthropogenic load on the soil cover. The principal causes of soil cover disturbance in the region are anthropogenic disturbances, petrochemical and industrial wastewater, drilling fluids, toxic chemical elements and others. It can also be stated that the most informative approach to the ecological-geological assessment of soil condition is provided by the use of the ZC indicator. Consequently, the ecological and geological state of the soil was evaluated throughout the course of the study based on the composition of a number of polluting heavy metals.

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