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Gradient indication and spatial analysis of heavy metal redistribution in soils of the Surgil gas field (Aral sea region, Uzbekistan)

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Abstract

The article discusses the results of research on technogenic soil contamination at the Surgil natural gas field using local and translocal monitoring methods, gradient indication method, GIS technologies, and environmental risk indices. Such features of the Surgil gas fields (SGF) as industrial development on the freshly dried seabed, heterogeneous orography, insufficient phytoremediation conditions, and mesoclimatic changes have been identified. A generalized assessment of technogenic pollution was obtained both for individual drilling wells and for the entire SGF territory. It was established that the soils and ground near boreholes are technically practically uncontaminated by cyanides and biogenic elements, slightly contaminated by mineral salts and trace elements of nickel and chromium, moderately contaminated by arsenic and trace elements of cadmium and zinc. The content of selenium and lead ranges from moderate to severe pollution. Soil-grounds are heavily contaminated with copper microelements. The content of heavy metal microelements in soil and soils on SGF poses a low environmental risk for the environment, except for cadmium, whose RI index increases significantly from 2011 to very high in 2022.

Keywords: Technogenic soil contamination, heavy metals, ecological risk assessment (ERA), gradient-based pollution assessment, GIS analysis, spatio-temporal dynamics, gas field environmental impact, Aral Sea region.

Introduction

Worldwide, the development of oil and gas fields is associated with the greatest environmental burden. Soil, surface and groundwater pollution, and the destruction of soil and vegetation cover are occurring. The migration of pollutants as dust in the air and as soil filtrate leads to the spread of polluents over considerable distances from their sources. The bioaccumulation of pollutants in the population's body in the impact zone of oil and gas fields leads to various diseases.

The numerous studies in global scientific literature on the technogenic pollution of the environment by the gas-producing industry indicate the relevance of environmental research aimed at monitoring and developing measures to mitigate technogenic impacts[1-5]. In these studies, special attention is paid to soil contamination with heavy metals, which pose the greatest danger to health. Differences in geographical conditions lead to a large variation in assessing the impact of gas production facilities on the natural environment, which necessitates the application of a regional approach in research.

In Uzbekistan, a number of environmental protection problems have been supplemented by the discovery of the Western Aral and Surgil natural gas fields, which poses an additional technological stress to the Aral Sea crisis for the ecosystem of the dried seabed. It should be noted that the monitoring conducted by organizations related to the development of these deposits does not have the regularity and detail necessary for a full-fledged study of environmental safety. The above determines the relevance of this research with a regional approach, aimed not only at studying the current ecological situation in the SGF area but also at identifying trends and patterns of spatial distribution of technogenic pollution.

Materials and Methods

Study area: The "Surgil" field, represented by drilling wells NoNo59, 42, 54, 5 and 3, as well as a comprehensive gas treatment plants (CGTP), is located in the southwestern part of the dried bottom of the Aral Sea, as shown in Figure-1, and occupies an area of 3600 hectares.

Drilling wells, as elements of the Surgil Gas Field (SGF) industrial facility, consist of drilling towers and wastewater storage facilities with average dimensions of 70 × 80 × 5 m, as shown in Figure-2. The bottom and side slopes of wastewater storage facilities are covered with waterproof films, which still do not completely exclude infiltration into adjacent soil layers. Furthermore, during prolonged evaporation of wastewater from storage facilities, pollutants can be subjected to weathering, thereby causing translocal soil and ground contamination.

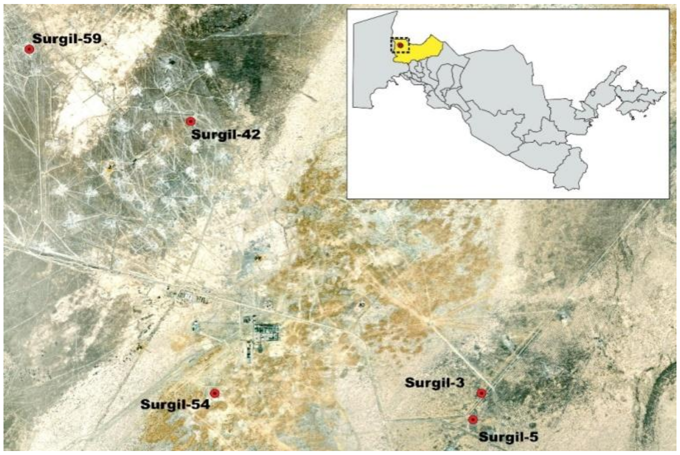

Figure-1: Surgil gas field and explored drilling wells.

Figure-2: Drilling rig and wastewater storage.

The Surgil-54 well, located at the very crest of the Arkhangelsk valley, poses the greatest risk of translocal pollution. The pollution of the soil in this locality is exacerbated by the adjacent CGTP, as shown in Figure-3. Gas processing plant emissions are enriched with SO (46.0-60.8%) and SO (24.4-32.6%), which are formed during the combustion of natural gas in flares.

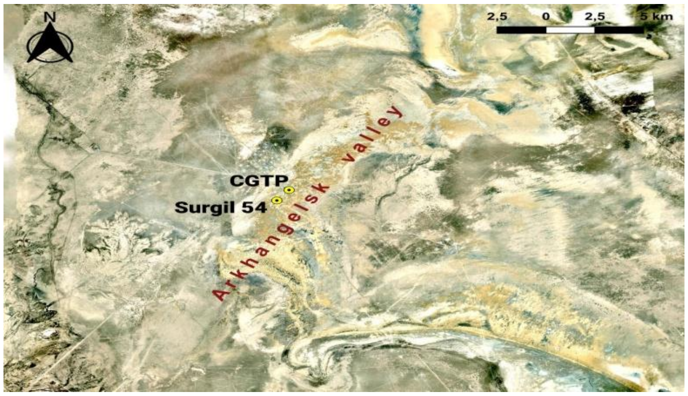

Figure-3: Location of the Surgil-54 well and the CGTP on the Arkhangelsk valley.

Let us note some features of the research area. First of all, this is the uniqueness of developing gas deposits on the freshly dried seabed, combined with the presence of pre-industrial soil pollution by anthropogenic sediments of river waters.

Any research on the geosystem of the Aral Sea and its dried seabed must take into account the dynamism of all processes occurring in this territory. The degree of soil susceptibility to pollution, as is known, significantly depends on the soil-soil composition. The distinctive feature of this research area is the constantly changing salinity of the soils of the dried bottom of the Aral Sea (DBAS), which affects the physicochemical processes in the soils.

Soil self-purification is a positive part of pollution dynamics, as shown in many works[6], occurring due to the presence of surface watercourses and vegetation cover. A characteristic feature of the Surgil deposit is the absence of surface watercourses and the scarcity of vegetation cover, which determines the minimal self-purification of soils.

It is also necessary to take into account the features and patterns of other processes that directly or indirectly affect the technogenic pollution of soils during the development of the Surgil natural gas field. First of all, of course, this is the spatial dynamics of soil-soil composition, which depends on the dynamics of the drying up of the Aral Sea, the dynamics of phytocenoses, climate, as well as the wind-blown displacement of soil-soil particles.

The wind transfer of soil material on the dried bottom of the Aral Sea, and with it, technogenic pollutants, has a tendency to increase, which increases the risks of expanding the territory of technogenic impact on the environment.

Such climatic changes in the geosystem of the Aral Sea and its dried-up bottom as an increase in air temperature and a decrease in its humidity contribute to an increase in the risks of technogenic pollution during the development of gas fields on the dried-up bottom. The specifics of dry and hot climate (annual precipitation of 250 mm, evaporation up to 1000 mm), neutral and alkaline soil reaction (pH=7-10), carbonate and sulfate- and chloride-rich soil (120 mg/eq, saline soils) contribute to the accumulation of pollutants, especially in depressions.

At the initial stage, a local assessment of the physical and chemical state of the soil and groundwater in the Surgil gas field was carried out. Sampling was carried out in zones adjacent to wells No. 3, 5, 42, 54 and 59, at distances of 5 and 10 m, in the surface soil horizon (0-20 cm), as well as at a depth of 1 m.

The next stage of the research was aimed at analyzing the spatial variability of soil and soil physicochemical indicators. The application of translocal monitoring is due to the ability of chemical elements and their compounds to spread beyond the sources of impact as a result of geochemical processes, including horizontal infiltration, sorption interactions, and eol transfer. Within the framework of this stage, the impact zones of the CGTPand the separate Surgil-54 production well were identified. Soil studies were conducted at distances of 100, 500, and 1000 m from sources of influence in various directions, as shown in Figure-4.

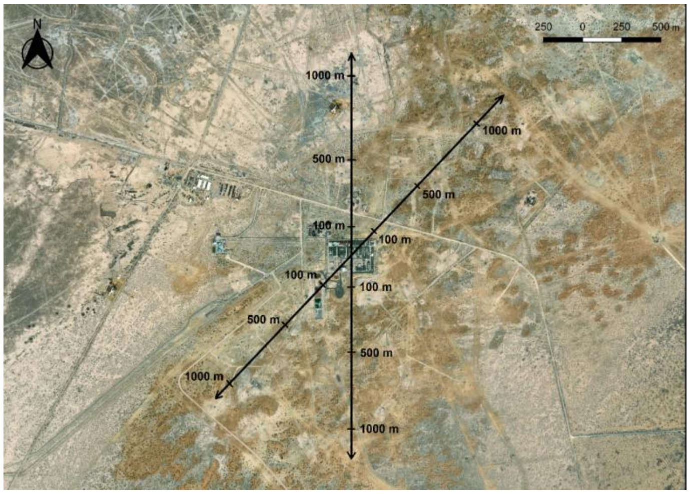

Figure-4: Translocal monitoring route diagram.

The choice of this well for a more detailed examination is due to its proximity to the CGTP and its location on the crest of the Arkhangelsk valley, thereby having the greatest impact zone due to better conditions for the horizontal migration of pollutants, both soil and air.

At the final, third hierarchical level of the study, the analysis focuses exclusively on heavy metals, which are considered as priority polluting components of gas production facilities. Within this stage, a quantitative assessment of the spatio-temporal dynamics of their distribution in soil and ground and atmospheric air is carried out.

Since the main part of technogenic pollution occurs at the short (1-2 years) stage of well drilling in gas field development technology, the 1st and 2nd-level monitoring works performed by M.B.Jollibekov date back to 2011, when the initial wells were drilled. The choice of this period is due to the fact that it is precisely at the initial stage of gas field development that technogenic pollution is most clearly identified. Subsequently, determining the impact of new wells on the environment becomes difficult due to the overlap of their impact zones with existing pollution fields.

At the third level of the research hierarchy, in 2022, translocal monitoring of environmental pollution by heavy metals was additionally conducted along the same routes by the CGTP and the Surgil-54 well to determine the temporal dynamics of this process, as shown in Figure-4.

Methods: The methodological scheme of the study is based on the approach developed by academician V. N. Sukachev, within which the study of natural systems is carried out through a consistent transition from the general level of analysis to a more detailed one, which allows for the phased refinement of the characteristics of the object under study[7].

In this work, to determine the technogenic pollution of soils, along with the qualitative methods described above, quantitative methods in combination with GIS technologies and information technologies were used[8].

Quantitative methods include the method of gradient indication of the degree of pollution developed by the authors[8], based on the analysis of spatial dynamics, assessment of the total concentration of polluents, comparative statistical analysis of technogenic soil pollution in different years, and assessment of environmental risk.

The gradient indication of the degree of contamination by a specific ingredient is based on the analysis of the spatial dynamics of its concentration and is reduced to calculating the average gradient G of the relative value $P = C(x_i)/\Phi$, which reflects the degree of excess of the background concentration at a distance from the source of impact:

$$G = \frac{1}{n}\sum_{i=1}^{n}\frac{C_i - C_{i-1}}{\Phi} \qquad (1)$$

where Φ is the temporal-background value of the pollute, $C(x_i)$ is the pollute concentration measured at the i-th sampling point. The numbering of points increases as distance from the pollution source increases.

Furthermore, the application of the gradient indication method allows for the quantitative determination of the soil contamination radius R_D, which characterizes the spatial impact zone of an industrial facility under the condition of a negative gradient value ($G < 0$). For this, the linear dependence $f(x)$ is approximated from the set of values of the ratio $C(x_i)/\Phi$, after which the point X_k corresponding to the intersection of the trend line with the zero level, i.e., the condition $F(X_k) = 0$, is determined, and it is evident:

$$R_D = \max\{X_k\} \qquad (2)$$

The methodology for assessing environmental risk (ERA) serves to determine potential environmental risks associated with the metal content in the soil[9], and is calculated using the following equation:

$$E_r^i = T_r^i \times (C_i/C_0) \qquad (3)$$

where C_i - denotes the concentration of the corresponding metal in the analyzed sample, and C_0 - the background content[10]. The parameter T_r^i characterizes the toxic response coefficient of the corresponding metal. The values of the toxic response coefficients (TRF) for Cu (5), Cr (2), Pb (5), Zn (1), Ni (5), and As (10) are taken from published sources[9,11,12].

The potential environmental risk (RI) is determined according to the following equation:

$$RI = \sum_{i=0}^{n} E_r^i \tag{4}$$

Based on the calculations of individual values of E_r and the integral indicator RI, the classification of potential environmental risk is performed as follows: the values of $E_r < 40$ and $RI < 150$ correspond to a low level of risk; at $40 \leq E_r < 80$and $150 \leq RI < 300$, the risk is considered moderate; the range of $80 \leq E_r < 160$ and $300 \leq RI < 600$ characterizes a significant risk; at $160 \leq E_r < 320$ and $RI \geq 600$, a high level of risk is observed, and $E_r \geq 320$ corresponds to an extremely high environmental risk.

To assess the degree of technogenic pollution of the SGF area, data obtained during a survey of the soils of the northeastern part of the Ustyurt Plateau in 2006 were used as temporal-background physicochemical indicators[13].

Results and Discussion

The main data are the results of field monitoring performed by M.B. Jollibekov during a number of expeditions in the period 2011-2022. 240 determinations of pollutants in the soil composition were made for 20 names of pollutants belonging to the following groups of pollution agents: heavy metals, poisonous chemicals, mineral salts.

Analytical work was carried out at the State Specialized Inspection for Analytical Control (SIAC) of the Ministry of Ecology, Environmental Protection and Climate Change of the Republic of Karakalpakstan and the State Specialized Inspection for Analytical Control (SSIAC) of the Ministry of Ecology, Environmental Protection and Climate Change of the Republic of Uzbekistan.

Due to the large volume of data obtained, we will present for information on the degree of detail only the results of local monitoring of mineral salts and physical indicators, shown in Table-1, and translocal monitoring of heavy metal content, shown in Table-2, indicating points with maximum values, highlighted in red, and minimum values, highlighted in green, of the measured components.

Table-1: Mineral salts and physical indicators.

Sampling location	Depth, SS	pH	Electrical conductivity	Sulfates (SO_4)	Sulfide (S)	Nitrites (NO_2)	Nitrates (NO_3)	Chlorides (CL)
CGTP	0-20	6.8	0.57	275	0.007	0.026	7	3.0
	100	6.0	0.60	270	0.006	0.02	7	3.0
Surgil-3 (5m)	0-20	5.0	0.53	150	0.003	0.019	5	2.0
	100	5.0	0.86	150	0.013	0.023	7	4.0
Surgil-3 (10m)	0-20	5.0	0.40	150	0.003	0.211	6	4.0
	100	5.0	0.60	150	0.004	0.22	7	3.5
Surgil-5 (5m)	0-20	5.0	0.58	150	0.003	0.023	6	4.0
	100	5.0	0.98	150	0.004	0.023	6	3.5
Surgil –5 (10m)	0-20	5.0	4.0	190	0.003	0.016	6	5.3
	100	5.0	1.83	450	0.003	0.020	6	5.0
Surgil-42 (5m)	0-20	5.0	5.21	1000	0.004	0.016	6	13.0
	100	5.0	2.27	575	0.003	0.026	7	3.5
Surgil-42 (10m)	0-20	5.0	5.20	8.0	0.004	0.011	7	12.0
	100	6.0	2.20	6.5	0.004	0.016	7	7.5
Surgil-59 (5m)	0-20	5.0	8.26	1400	0.002	0.033	7	27.5
	100	6.0	1.72	275	0.004	0.033	8	6.0
Surgil-59 (10m)	0-20	5.0	6.19	825	0.01	0.006	7	9.0
	100	6.0	5.16	1150	0.002	0.029	7	11.0
Surgil-54 (5m)	0-20	5.0	1.50	200	0.002	0.08	7	4.0
	100	6.2	1.58	200	0.005	0.099	7	2.8

Table-2: The content of heavy metals in the soil around Surgil-54 and CGTP.

Wind direction	Sampling location	Pb		Cd		Ni		Zn		Cu	
		MPC-32.0		MPC-2.0		MPC-85.0		MPC-100.0		MPC-3.0	
		2011	2022	2011	2022	2011	2022	2011	2022	2011	2022
North	100m	11.4	9.5	0.5	0.6	2.6	5.9	14.4	9.0	3.2	3.3
	500m	10.1	16.2	0.4	0.4	2.2	8.5	14.8	10.1	2.6	3.0
	1000m	8.8	18.1	0.4	0.6	1.7	7.0	11.5	61.2	3.0	4.0
North-East	100m	26.7	8.3	1.0	1.2	3.0	23.4	18.2	98.0	3.6	3.5
	500m	22.3	8.5	0.8	0.6	1.7	5.4	32.6	9.6	3.0	7.0
	1000m	14.1	16.4	0.8	1.2	2.7	23.0	14.8	88.6	3.0	1.5
South	100m	5.8	20.4	0.3	1.2	4.5	19.5	19.2	58.2	3.0	2.5
	500m	11.2	0.6	0.5	7.1	4.2	9.8	20.2	0.1	3.0	3.3
	1000m	7.5	9.0	0.5	0.6	3.2	5.6	33.5	18.4	3.6	2.0
South-West	100m	10.6	1.2	0.6	1.2	3.0	13.1	17.2	18.5	2.2	3.5
	500m	12.1	9.6	0.7	0.7	3.3	6.2	22.3	10.8	2.6	5.3
	1000m	17.1	9.9	0.8	1.1	3.6	6.0	36.1	7.8	2.6	0.7

The electrical conductivity, sulfate and chloride concentrations vary significantly across SGF wells, which is explained by the localization of drilling operations: in the lowlands, salt accumulation is higher than in the highlands; moreover, the coastal desert-sandy and takyr-like saline soils are slightly saline compared to saline soils.

The table reflects the complex spatial dynamics of heavy metal content in the soils around the Surgil-54 well and the CGTP, explained mainly by microrelief irregularities. The time dynamics are generally positive, due to soil contamination by new wells drilled after 2011. The exception is the negative dynamics of lead, possibly due to this heaviest metal having a greater ability to infiltrate deeper.

In this work, the following classification of technogenic pollution in the fractions of MPCs was adopted: 0-0.01 - no pollution; 0.01-0.5 - slight contamination; 0.5-1 - moderate contamination; more than 1 - severe contamination.

Based on the results of local monitoring, it was established that the soils and ground near drilling wells are technically practically not contaminated with cyanides, biogenic elements, slightly contaminated with mineral salts, microelements of nickel, chromium, moderately contaminated with arsenic, cadmium, and zinc. The content of selenium and lead in soil soils ranges from moderate to severe pollution. Soil-grounds are heavily contaminated with copper microelements.

The results of calculations based on translocal monitoring data using the gradient indexation method are presented in Table-3. In the northern and northeastern directions, a negative pollution gradient prevails, indicating a decrease in the concentration of the substance with increasing distance from the source. This is due to the non-negative gradient of isohypses in these directions (increasing the relief of the Earth's surface).

In the southern and southwestern directions, on the contrary, a positive pollution gradient prevails due to the lowering of the relief towards the source. The identified pattern has a simple explanation according to the laws of soil physics: the dependence of substance migration in the surface layers of the soil on the isohypses gradient. The distribution pattern of pollutants from the source can also be explained by the wind regime in this region. The prevailing winds of the northern half of the Rumb cause the largest outflow of pollutants to the south of the source. Exceptions are heavy metals, which, due to their significant density, are less susceptible to horizontal migration and accumulate near the source.

The spatial distribution of pollutants from their source in soils depends on factors such as the terrain's orography, the mechanical composition of the soil-soil, the reactivity of the substance (interaction with other components), pre-industrial pollution, and soil remediation. These factors create significant noise when determining the spatial picture of technogenic pollution and are manifested in the scattered nature of empirical data. The gradient indexing method allows for a certain degree of suppression of these noises and obtaining a generalized assessment of the spatial distribution of pollutants from the source. When interpreting the calculation results, it is necessary to keep in mind the heterogeneity of the relief and the accumulation of pollutants even in insignificant micro-depressions.

Since the highest technogenic contamination of SGFs occurs due to heavy metal microelements, this article presents the results of graphical representation of the spatiotemporal dynamics of the distribution of the most toxic and carcinogenic lead, shown in Figure-5.

The heterogeneity of the terrain's relief leads to the formation of local maximums of M_i concentrations in depressions and local minimums of Ni in areas with elevated relief, as shown in Figure-5.

Assuming the invariance of the average spatial and temporal pollution gradients for all the wells studied in this work and using GIS technologies, a general picture of the SGF territory's pollution by heavy metals, such as lead, is shown in Figure-6.

The impact of technogenic pollution on the environment is assessed, in particular, by the environmental risk index, calculated using formulas (3) and (4). The histogram in Figure-7 shows the RI values for heavy metals.

Table-3: Average gradient G and radius of action R (km) of technogenic pollution by polluentant groups.

Polyutants		North	North-East	South	South-West
Mineral salts	*G*	0.03	-0.09	0.01	-0.03
	R	3.7	6.4	9.8	3.9
Heavy metals	*G*	-0.43	-0.31	-0.26	-0.15
	R	4.6	5.7	5.9	7.52
Toxic substances	*G*	0.13	0.19	0.57	0.24
	R	3.2	6.8	10.8	7.2

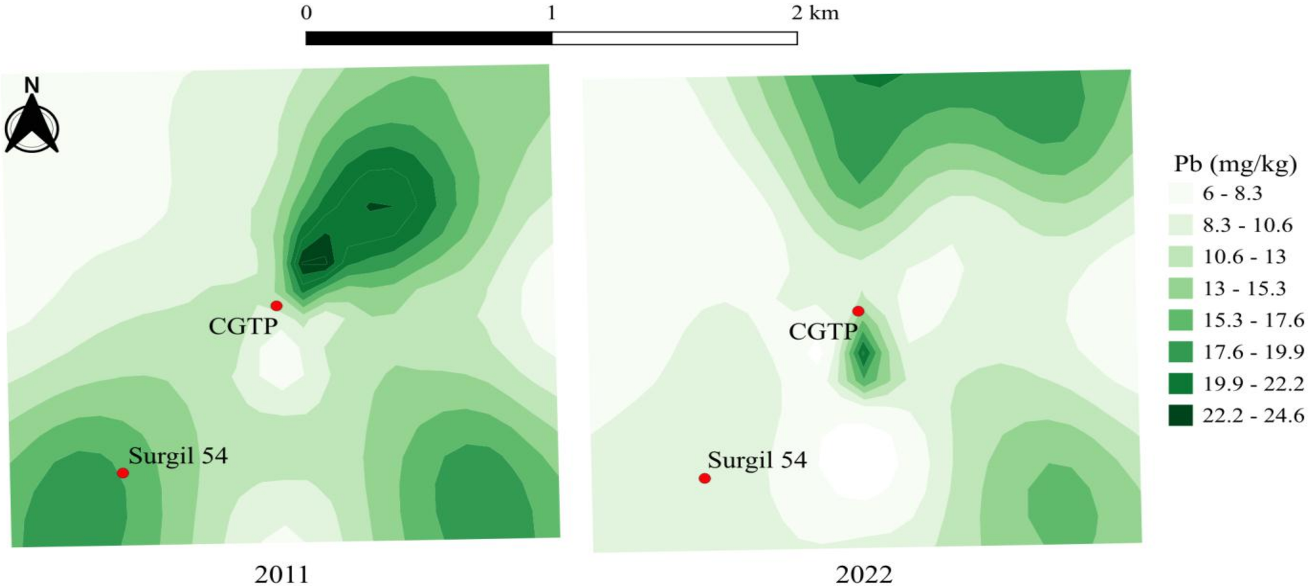

Figure-5: Spatial and temporal dynamics of soil contamination with lead elements in the Surgil-54 and CGTP areas in 2011 and 2022.

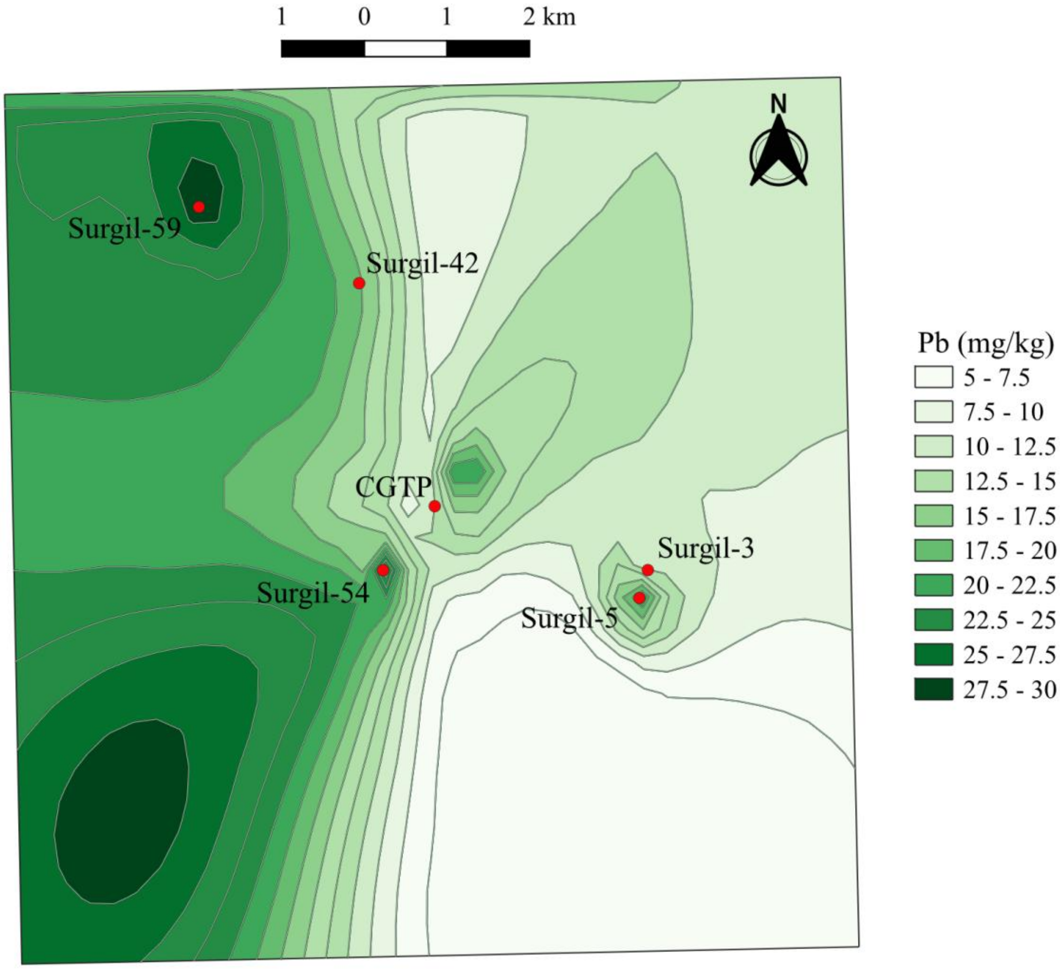

Figure-6: Spatial-temporal dynamics of lead contamination of the SGF territory.

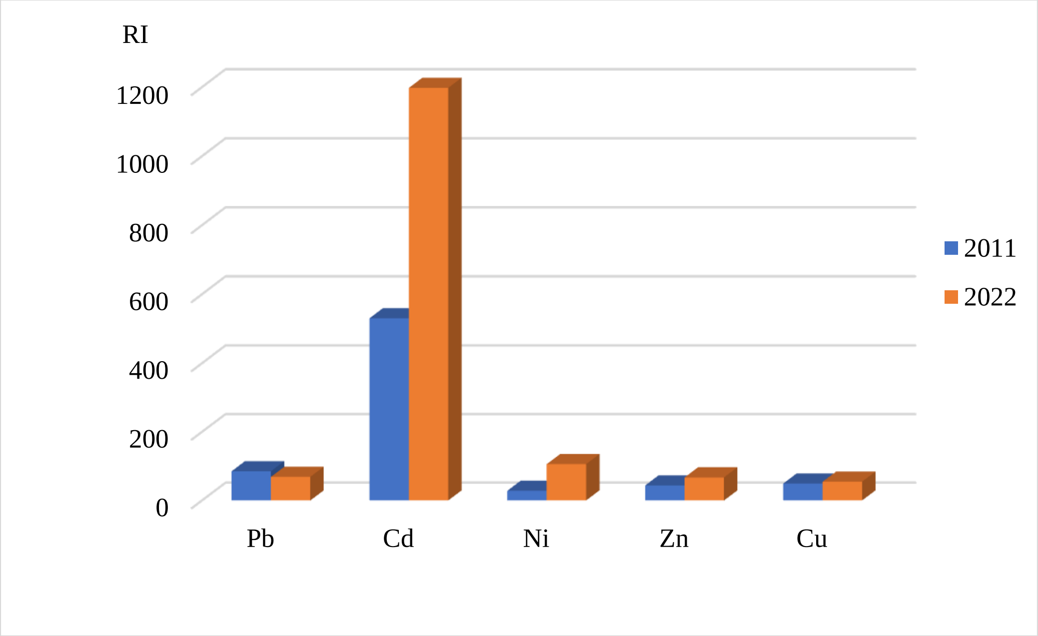

Figure-7: Dynamics of environmental risk for heavy metals in 2011 and 2022.

From the histogram, it can be seen that all metals in SGF, except cadmium, pose a low environmental risk. Cadmium RI increases significantly from 2011 to very high in 2022. For all heavy metal microelements, the environmental risk progresses over time, which is explained by the increase in the number of drilling wells on SGF.

Conclusion

Based on the conducted research, the following conclusions were made. i. The process of technogenic pollution of soil-soil with heavy metals and groundwater can be represented as the transfer of substances from deep layers to surface layers, their migration from the source by horizontal and vertical infiltration, as well as by aeolian transfer in the atmosphere. ii. The strong influence of the heterogeneity of the Orography of the dried-up bottom of the Aral Sea on the spatial distribution of technogenic pollution has been revealed, which determines the presence of local maximums due to the accumulation of pollutants in the lowlands and local minimums in the elevations of the relief. iii. Using the developed method of gradient indication of the degree of environmental pollution by industrial facilities, it has been established that the SGF impact zone, excluding wind transfer, is limited to 15-20 km from each drilling well. iv. It was established that the soils and ground near boreholes are technically practically uncontaminated by cyanides and biogenic elements, slightly contaminated by mineral salts and trace elements of nickel and chromium, moderately contaminated by arsenic and trace elements of cadmium and zinc. The content of selenium and lead ranges from moderate to severe pollution. Soil-grounds are heavily contaminated with copper microelements. v. The content of heavy metal microelements in soil and soils on SGF poses a low environmental risk for the environment, except for cadmium, whose RI index increases significantly from 2011 to very high in 2022.

References

1. Opekunov, A. Y., Mitrofanova, E. S., Sanni, S., Kommedal, R., Opekunova, M. G., & Bagi, A. (2015). Polycyclic aromatic hydrocarbons in the bottom sediments of rivers and canals of Saint Petersburg. *Vestnik Sankt-Peterburgskogo Universiteta Seriya Geologiya Geografiya*, 4, 98-109.
2. Opekunova, M. G., Opekunov, A. Y., Kukushkin, S. Y., & Arestova, I. Y. (2018). Evaluation of environmental transformation in areas of hydrocarbon deposits in the North of Western Siberia. *Contemporary Problems of Ecology*, 11(1), 99-110.
3. Bashkin, V. N., Galiulin, R. V., Galiulina, R. A., & Arabsky, A. K. (2019). Risk of soil contamination by heavy metals through gas-dust emissions. *Issues of Risk Analysis*, 16(1), 42-49.
4. Bogdanov N.A. (2018). Heavy metals in soils as indicator of sanitary state of territories: monitoring of the south of Astrakhan region. *Journal of Health and Environmental Research*, 4(4), 119-129.
5. Tarasova, S. S., & Gaevaya, E. V. (2021). Studies of drilling sludge toxicity and possibilities for its utilization. *Probl. Reg. Ekol*, (3), 75-79.
6. Tangahu, B. V., Sheikh Abdullah, S. R., Basri, H., Idris, M., Anuar, N., & Mukhlisin, M. (2011). A review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation. *International journal of chemical engineering*, 2011(1), 939161.
7. VN, S. (1964). Osnovnye ponyatiya lesnoy biogeotsenologii [Basic concepts of forest biogeocenology]. Osnovy lesnoy biogeotsenologii [Fundamentals of forest biogeocenology].
8. Jollibekov M.B., Tleumuratova B.S. &Urazimbetova E.P. (2026). Metodologiya otsenki tekhnogennogo zagryazneniya okruzhayushchey sredy na neftegazovykh mestorozhdeniyakh. *Vestnik KKO AN RUz*, (1), 54-63.
9. Hakanson L. (1980). An ecological risk index for aquatic pollution control. *A sedimentological approach. Water Research*, 14(8), 975-1001.
10. Loska K., Wiechula D. & Korus I. (2004). Metal contamination of farming soils affected by industry. *Environment International*, 30(2), 159-165.
11. Gope, M., Masto, R. E., George, J., & Balachandran, S. (2018). Tracing source, distribution and health risk of potentially harmful elements (PHEs) in street dust of Durgapur, India. *Ecotoxicology and Environmental Safety*, 154, 280-293.
12. Jiang, Y., Wen, H., Zhang, Q., Yuan, L., & Liu, L. (2022). Source apportionment and health risk assessment of potentially toxic elements in soil from mining areas in northwestern China. *Environmental Geochemistry and Health*, 44(5), 1551-1566.
13. Report (2006). Vedomstvenny monitoring za sostoyaniem okruzhayushchey prirodnoy sredy pri osushchestvlenii neftegazovykh operatsiy na Kungradskom uchastke.. Tashkent.