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CURRENT ASSESSMENT OF ATMOSPHERIC POLLUTION BY INDUSTRIAL ENTERPRISES IN UST-KAMENOGORSK BASED ON GIS TECHNOLOGIES

ABSTRACT

The article discusses the engineering geological conditions for the cadastral assessment of urban lands, in value terms, the calculation of the area of distribution of hazardous substances in the atmosphere from industrial and other waste sources. The method of zoning territories by pollution level and a cartogram of distribution of hazardous substances in the atmosphere by allocated territories were provided. The following factors and their influence were studied in detail: spatial planning, zoning, cost of land development, engineering and transport infrastructure, physical properties of land, environmental conditions of air, water, soil, nature of construction, nature of the settlement, wind direction. The basis of obtained quantitative, qualitative data, determination in specific territories using geoinformation systems technology (GIS) was considered. The algorithm for assessing the state of atmospheric air in real time includes the integration of the obtained data and modeling the current state of the atmosphere. The study was conducted in the city of Ust-Kamenogorsk, where there are several industrial plants, such as Kazzinc, Ulba Metallurgical Plant (UMP), Titanium Magnesium Plant (TMP). The study results and the calculated coefficients for assessing the atmospheric pollution allow us to draw individual conclusions on the territory of a zoned city. The practical value of the work is providing an algorithm for assessing the state of atmospheric air in real time using the presented results, modeling the state of atmospheric air in each point of the city and qualitative assessment of regions for environmental friendliness in the cadastral system.

KEYWORDS: land assessment zoning, QGIS, ecology, atmospheric air pollution, emissions, estimated coefficients

INTRODUCTION

Due to the increased intensity of urbanization in recent years, determining the market value of land plots in industrial cities has become one of the main criteria in the urban cadastre system, and rationing based on environmental monitoring, developed to assess air pollution, has become one of the rational assessment methods [*Kolankov* et al., 2018]. In this work, the distribution of heavy metals in the atmosphere [*Toguzova* et al., 2016], distance to the source of pollution and directions of transfer of pollution in air basins by wind, etc.[*Daumova* et al., 2018], were analyzed by determining the coefficients for assessing atmospheric pollution by regions. For a qualitative assessment of the urban cadastre system, the unity of atmospheric air in it is one of the vital elements of the environment [*Kenesary* et al., 2019]. In this case, a qualitative assessment of the

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state of the air is considered from the point of view of its anthropogenic pollution and, ultimately, the impact of this factor on the cost of land [*Muter* et al., 2024]. Indicators for assessing degree of pollution in the city's air basin include the ratio of actual pollution levels to sanitary and hygienic standard[1] for the permissible concentration of pollutants in the atmosphere. Maximum permissible concentrations (MPC) determine limits in terms of time, composition, and number of emissions into the atmosphere, ensuring the prevention of negative effects of various substances on humans and the environment.

In several works, atmospheric air pollution in urbanized areas is indicated as the main environmental factor that poses a high risk to health [*Kozlov* et al., 2022]. Currently, the air basin of any industrial city is contaminated with hundreds of chemicals, the level of which partially exceeds the permissible limits in the respective territories, and this is a prerequisite for assessing land plots in the cadastral system, and choosing a location for the type of construction [*Badmaeva* et al., 2021].

In fact, air pollution in the air basin of the Ust-Kamenogorsk city, taken for the study, is caused by many factors [*Seraya* et al., 2023]. At the top of the list are mineral extraction and processing plants, including those producing lead, zinc, phosphorus and chromium, and industries such as Kazzinc, UMP and TMP [*Ramazanova* et al. 2021]. Mineral extraction produces a huge amount of waste. This waste pollutes the air every day [*Zakonov* et al., 2021]. Domestic mining companies update their cleaning systems every year. However, the assessment mapping according to the level of air pollution provides the result of a rational determination of the cost of a plot of land.

Additional factors, such as increasing the number of small production facilities in the city, are the second cause of air pollution. This is accompanied by soot emissions, which contribute to air pollution with carbon dioxide [*Aubakirova* et al., 2020].

The next factor is a major source of air pollution — petrol and diesel cars. An increase in the number of cars due to urbanization, especially in large cities, leads to high levels of air pollution with nitrogen dioxide, carbon monoxide, and organic substances [*Abedzhanova* et al., 2023].

The next factor is the distribution of emissions from industrial companies as a result of the production processes during the combustion of industrial products. In addition to these influencing factors, the location of the study area on the banks of flowing water sources as well as their complex terrain should be noted, since during spring and autumn floods, the landscape changes [*Apshikur* et al., 2023]. This change produces wastewater with the addition of ore residues washed out of open deposits developed in the mineral-rich foothills. This increases the release of harmful gases into the air at certain times during the evaporation of water [*Rakhymberdina* et al., 2022].

Zoning by level of air pollution developed during the study considered all the issues mentioned in this section. The basics of the architectural layout of the city or landscape features were also studied, bearing in mind the fact that insufficient ventilation of the atmospheric space causes the accumulation of pollutants in the surface layer of the atmosphere, and their concentration may vary [*Kulenova* et al., 2022].

The purpose of this study is to improve the methodology of cadastral valuation of urban land by developing a system of valuation indicators based on the consideration of environmental factors with zoning of atmospheric air basins by levels of pollution in the city, for subsequent adjustment of the cadastral value of land plots, and zoning by estimated coefficients of atmospheric pollution determined during the study of pollution level.

RESEARCH MATERIALS AND METHODS

The following series of data were considered to be necessary for the presentation of the study as part of the baseline data:

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[1] Web resource: https://online.zakon.kz/Document/?doc_id=39768520 (accessed 03.02.2024)

- a city with known sources emitting pollutants into the atmosphere and a map of its geographic location obtained from the OSM map by making a query in QGIS (Fig. 1);
- environmental passports of the enterprises polluting the atmospheric air;
- a brief description of the natural conditions underlying the distribution of pollutants in the atmosphere;
- the list of substances that have the greatest impact on the pollution of territories;
- description of the degree of danger posed by the pollutants;
- retrospective analysis, development trends, and scientific and technical forecasting of the air pollution problem;
- data on the effects of air pollution on public health and the environment.

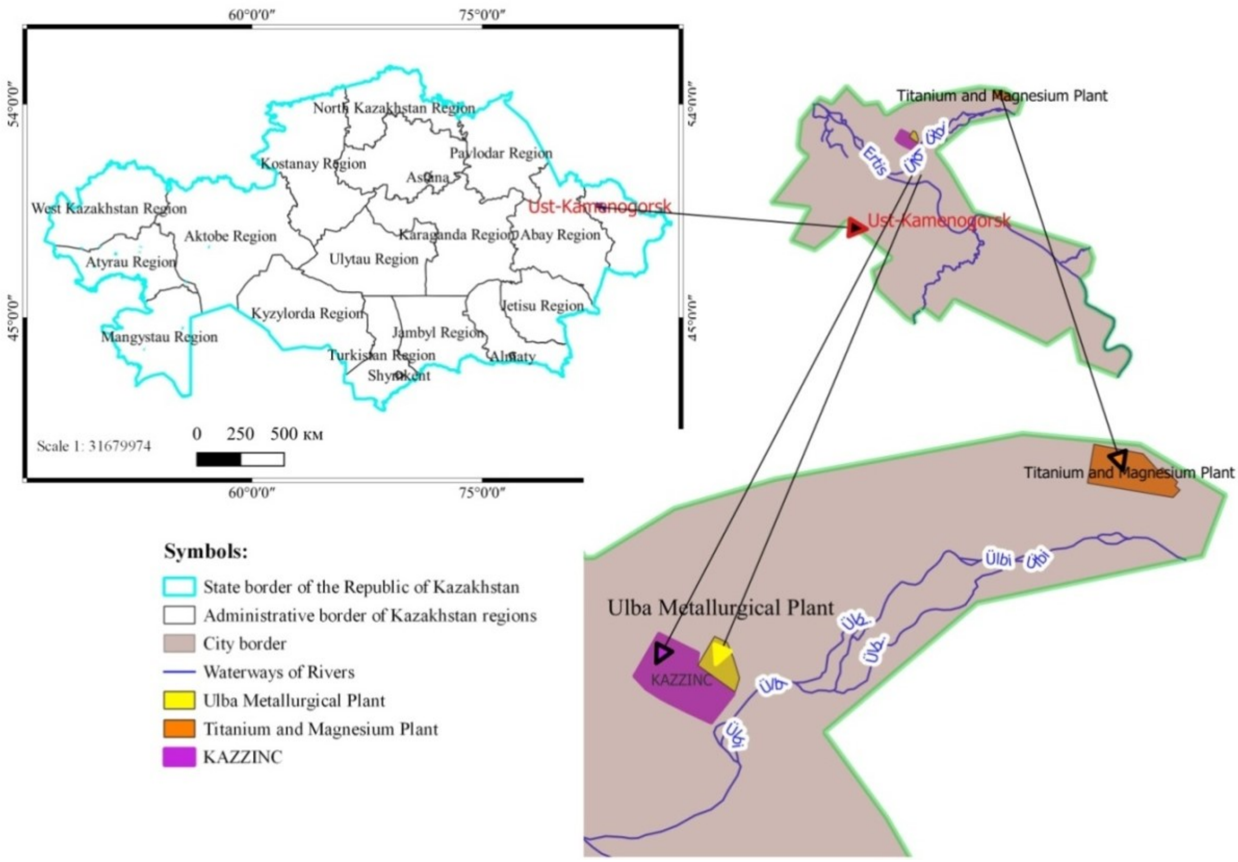

Fig. 1. The object of the study and the location of pollution sources in it

The research data were obtained from the results of the work of scientists from the Ust-Kamenogorsk Road Construction Institute in the 1990s, as well as the results of traditional studies conducted in 2018 by the Department of Environmental Protection of EKTU, as well as the satellite data for the corresponding years.

To assess the pollution of the atmosphere in the city of Ust-Kamenogorsk, all the necessary information was obtained from the results of a comprehensive study conducted by the Ust-Kamenogorsk Road Construction Institute in the 1990s [*Maksimov* et al., 1992]. And in 2018, along with the study conducted by the Department of Environmental Protection of the EKTU, the results of other environmental studies were compared [*Daumova* et al., 2018].

The version of the reports on “Development of the total volume of the maximum allowable emissions” and “Protection of the atmosphere” approved by the City Executive Committee and those accepted by the state supervisory authorities as regulatory documents have been obtained.

The free open-source geographic information system QGIS v. 3.34 was used for the identification of data integrated into areas by the distribution area of numerical data.

Cumulative indicators of the level of pollution for individual elements of the environment have been established in Kazakhstan and abroad for a long time [*Zaghloul* et al., 2020]. In practice, such indicators allow to identify facilities that primarily need air pollution control measures. In addition, a comprehensive indicator of air pollution can be used to establish relationship between changes in the state of the air and the public health in the study area, as well as dependencies between the dynamics of production and the state of the atmosphere. Indicators allow to make an integral assessment of the state of atmospheric air, on the basis of which it is possible to compare the pollution level of several settlements, evaluate the change of the state of the atmosphere for one settlement in dynamics [*Wang* et al., 2023].

The pollution of the atmospheric air is determined by the values of the measured concentration of pollutants (mg/m^3). To assess the degree of pollution, in accordance with the Annex to the order of the Minister of Ecology, Geology and Natural Resources of the Republic of Kazakhstan dated September 14, 2021 No. 375 “Rules for Determining the Standards of Permissible Anthropogenic Impact On Atmospheric Air”[1], the measured concentration of the mixture is compared with the maximum permissible concentration (MPC). The SI (Standard Index) is the highest time concentration of any mixture measured in a city. It is divided by the corresponding MPC. Maximum Repeatability (MR) — Maximum repeatability (%) of *MPC* exceedance for each urban pollutant. The degree of pollution is estimated at the highest value of these indicators if *SI* and *MR* fall into different gradations. For a single concentration of the mixture — the concentration of the mixture measured for 20-30 minutes is taken [*Abikenova* et al., 2023].

$MPC_{o.t.}$ — the maximum allowable one-time concentration of the mixture. The average daily concentration of the mixture is the arithmetic mean of the single concentrations obtained at equal time intervals, including the mandatory periods of 1, 7, 13, 19 hours, as well as the concentration value obtained from continuous registration data 24 hours a day.

$MPC_{a.d.}$ — the maximum allowable concentration of the mixture on a daily average.

For the preparation of the report, the values of the maximum permissible concentrations by the Order of the Minister of Health of the Republic of Kazakhstan of August 2, 2022, No. MH70 “On approval of hygienic standards for atmospheric air in urban and rural settlements, territories of industrial organizations”[2] were used. Calculation of complex indicators of the degree of atmospheric air pollution, hazard classes at sampling points, and the main pollutants of the atmosphere according to their MPC was made.

The degree of contamination of the atmosphere by more than one substance at the same time is estimated by the coefficient of combined action using the following equation (1):

$$K_{s.s.} = \frac{C_1}{MPC_1} + \frac{C_2}{MPC_2} + \dots \frac{C_n}{MPC_n} \quad (1),$$

where C_1, C_2, C_n — the concentration of the substances in the atmosphere;

MPC_1, MPC_2, MPC_n — the maximum allowable concentration of the same substances.

The values of the pollutant indicators at the “nodes” where the study was carried out were obtained using interpolation and extrapolation methods in accordance with the generally accepted rules.

[1] Web resource: https://adilet.zan.kz/rus/docs/V2100024462/compare (accessed 12.02.2024)

[2] Web resource: https://adilet.zan.kz/rus/docs/V2200029011 (accessed 15.02.2024)

The article discusses comparative methods of comprehensive assessment of air pollution in Ust-Kamenogorsk in connection with the activities of industrial enterprises. The methods are based on Geographic Information Systems (GIS). This is due to the integration of many key factors and the use of GIS technologies. The effectiveness of using the method of complex classification of the results of determining atmospheric pollution in the assessment of cadastral land using the corresponding combination of satellite channels in GIS applications was demonstrated.

RESEARCH RESULTS AND DISCUSSION

Approaches to valuation would vary depending on the functional purpose of the land plot. In recent times, it has been used intensively in this direction for the monitoring and evaluation of earth remote sensing data on various land division issues [*Rakhymberdina* et al., 2022]. Among the items listed is the cost of land, which is determined based on topographical, geological, soil, biological, environmental, and other studies. However, it is possible to determine the prices for using and selling land plots to private owners, as well as the price of land tax in municipalities, using the proposed and developed valuation method and the comprehensive valuation method. This makes it clear that not only the value of land, but also the price of land varies depending on the purpose for which it is used.

An analysis of air basin pollution with emissions from 3 enterprises and 100 boilers, whose emissions account for 95 % of the total input of pollutants into the atmosphere, was proposed in the "Summary of the maximum permissible emissions for the city of Ust-Kamenogorsk" [*Maksimov*, 2000].

Annually, 197.9 thousand tons of hazardous substances are released into the atmosphere of the city. Of these, 87.2 % of industrial facilities account for 12.8 % of motor vehicles (Fig. 2).

Pollutants of 61 types are released into the atmosphere (Table 1). In particular, it is possible to ignore the fact that the composition of substances for which there is no information on the MPC and the estimated safe exposure level was significantly lower than the normative values when calculated in quantitative terms. In this list of substances with MPC standards, four are classified as the hazard class 1, and twenty as the 2, twelve, and seven, respectively — the 3 and 4 classes [*Maksimov,* 2000].

There are no MPC standards for 19 substances, 8 of them are determined by the pollution assessment, the estimated safe level of exposure. The composition of suspended matter found in the atmosphere includes solid particles of organic and inorganic origin. The maximum permissible one-time concentration of chemicals in the air of settlements is up to 0.5 mg/m^3.

The maximum permissible concentrations of pollutants in the air of the settlements from the most important air pollutants according to the hazard classes and their MPC, are taken from the officially regulated standards.

In the course of the study, the concentration fields of eighteen substances that form the zones of active air pollution in the residential areas of the city were calculated and a territorial zoning map was generated. Calculations were carried out in the territory of sources of pollution with a mesh density of 1x1 km (between "nodal points"), groups of buildings and land plots united by a common infrastructure were taken for territory with quarters. Seasonality plays an important role in the distribution of air pollution, in particular, the increased use of heating systems in winter and weak ventilation can lead to an increase in the concentration of pollutants, while high temperatures and increased solar radiation in summer can contribute to photochemical reactions by increasing the level of ozone and other pollutants. Wind can transfer pollution over considerable distances by spreading it to different parts of the city. Proximity to water bodies can contribute to changes in local climatic conditions, affecting the distribution of pollutants. In addition, the evaporation process of rivers can contribute to the evaporation of pollutants. Depending on the degree of probability of adverse effects, due to the increased concentration of pollutants in the air, four classes of hazard of substances have been obtained: 4 — very dangerous, 3 — high danger, 2 — medium dangerous, and 1 — low dangerous (Fig. 2).

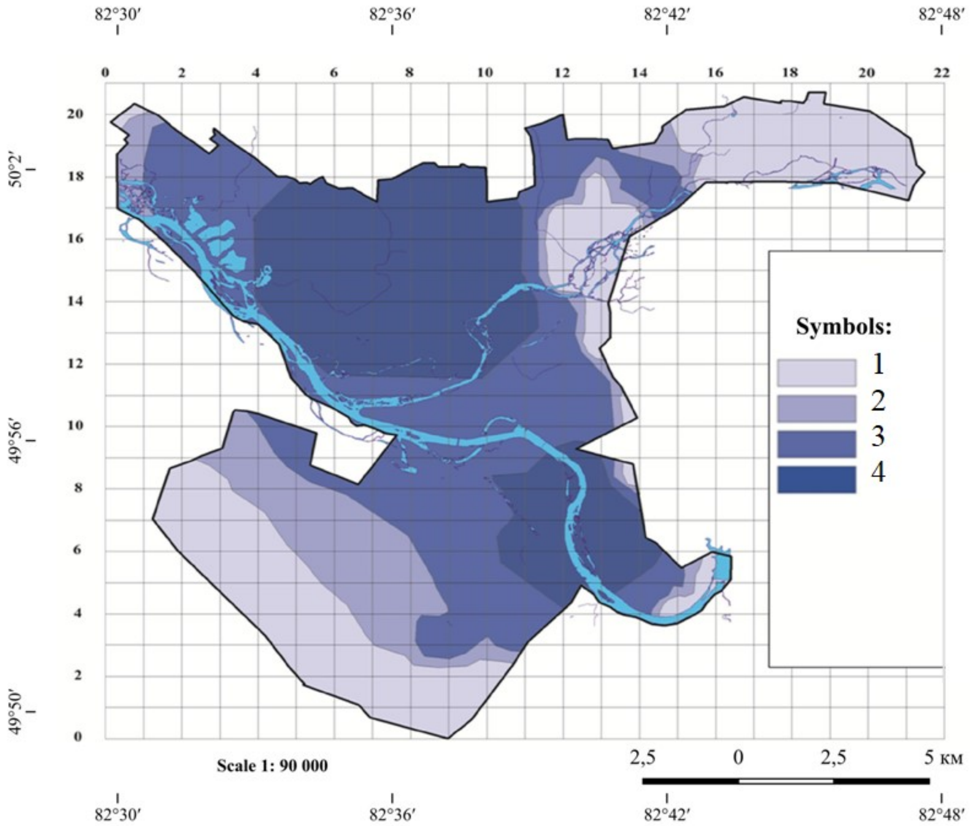

Fig. 2. Map of the distribution of the concentrations of the pollutants in the air according to the classes

Table 1. List of the substances that are emitted into the atmosphere of the city

Name of substances	**MPC mg/m^3**	**Hazard class**	**Emissions t/Year**
1	2	3	4
Sulfur dioxide	0,5	3	87318,31
Carbon monoxide	5	4	39099,18
Suspended solids	0,5	3	32648,79
Nitrogen dioxide	0,085	2	8270,19
Soot	0,15	3	561,31
Zinc	0,15	3	518,17
Chlorine	0,1	2	234,00
Plumbum	0,003	1	179,79
Gasoline	5	4	136,00
Toluene	0,6	3	108,43
Lead sulfide	0,0017	3	65,99
Hydrochloric acid	0,2	4	48,75
Sulfuric acid	0,3	2	51,85
Ethyl alcohol	5	2	45,66
butyl acetate	0,1	4	36,48

Ethyl Acetate	0,1	4	31,26
Phenol	0,1	4	28,22
Arsenic	0,003	2	19,47
Butyl acetate	0,1	2	24,49
Trichlorodiphenyl	0,001	3	11,14
Cadmium	0,001	2	7,44
Formaldehyde	0,035	2	12,95
Benzol	1,5	2	5,40
Ammonia	0,2	4	3,45
Styrene	0,01	2	3,14
Methyl alcohol	1	3	2,85
Chromium anhydride	0,0015	1	1.95
Manganese oxides	0,01	2	2,28
Nitric acid	0,4	2	0,27
Nitric oxide	0,6	3	183,93
Soluble fluorides	0,003	2	0,21
Silicon compounds	0,15	3	0,21
ferric oxide	0,04	3	1,94
Dichloroethane	3	2	1,76
Vanadium pentoxide	0,002	2	13,00
Total			169777,68
Total from industrial enterprises			172615,17
Vehicles			19540,50
Carbon monoxide		4	1265,57
Nitric oxide		2	4570,73
Total			25382,97
Total by city			197998,14

According to the nature of the environmental impact, the indicators of the degree of total atmospheric air pollution are divided into five levels (Table 2).

Table 2. Indicators of total air pollution level

Pollution level	**The magnitude of the pollution index is the specific weight in the total area of the land-assessment area by the number of substances**			
	from 2 to 4	**from 5 to 9**	**up to 10–20**	**more than 20**
Permissible	2	3	4	5
1 level	> 2–4	> 3–6	> 4–6	5–6 >
2 level	> 4–6	> 6–12	> 8–16	10–20 >
3 level	> 8–16	> 12–24	> 16–32	> 20–40
4 level	16 >	> 24	32 >	> 40

The complex indicator of the total pollution of the atmosphere, Z_a, was determined by the following formula (2)

$$Z_a = \sqrt{\Sigma K_{ai}^2} \quad (2),$$

where K_{ai} — indicators of multiples of the exceedance of the MPC for individual substances in the third hazard class.

Since the degree of pollution of the fourth degree within the city limits has a wide range following the value of the complex indicator Z_a, it was divided into four additional zones based on the principle of doubling the Z_a values in each subsequent group (Table 3).

Table 3. Indicators of the level of the very serious pollution of the air

Pollution	The value of the Z_a complex indicator for the number of pollutants in the air			
	from 2 to 3	from 4 to 9	from 10 to 20	more than 20
4 degree				
4a	16–32	24–48	32–64	40–80
4b	32–64	48–96	64–128	80–160
4c	64–128	96–192	128–256	160–320
4d	128–256	192–384	256–512	320–640
4e	256	384	512	640

The concentration of heavy metals in the air, gases, and all the data in table 3 were compared with the permissible limit of MPC in settlements. In any case, agreeing with the theory is not ideal. However, all specific general patterns can be traced in the general air pollution scheme (Fig. 3).

The results of the analysis of the cartogram showed, which are considered sources of pollution that Heat Power Plant (HPP) located on both ends of the city, and Kazzinc, UMP, TMP correspond to the class of indicators of the level of high-risk pollution (Table 3).

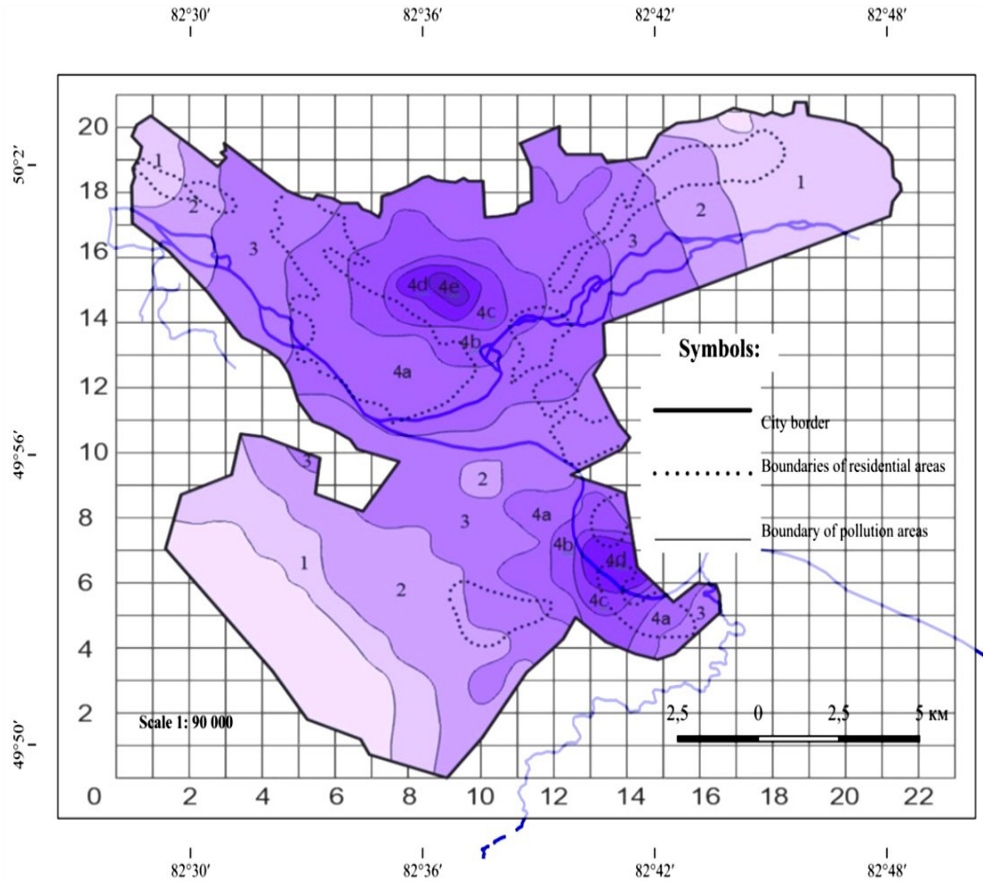

Fig. 3. Integrated map of total air pollution

However, factors such as industrial activity, transportation emissions, urbanization, geography, weather conditions, and regulatory measures to control pollution can cause the overall level of air pollution to vary widely. In addition, ongoing monitoring and emission reduction activities can lead to periodic regulation of air pollution in the criterion areas in the study. The maximum level of pollution by areas of pollution zones is observed more intensively in the vicinity of pollution sources and in the regions of the wind direction (Table 4).

Taking into account all factors and air basin conditions influencing the process of pollution spreading in the atmosphere, the pollution calculation and assessment coefficients are determined according to the distributed classes (Table 5).

Table 4. Area of total pollution of the urban atmosphere by classes

Designation	Pollution level								
	Permissible	1	2	3	4				
					a	b	c	d	e
Total area of pollution areas, ha	2459,5	2663,1	3360,4	4418,3	4734,1	1578,9	457,9	602,6	55,2

By pollutant distribution areas (Table 4), a small percentage of areas in the first three hazard classes can be seen in the first three hazard classes compared to the total study area. For example, the area in moderate amounts is 2459.5 hectares, and in the highest class according to the level of very strong pollution-55.2 hectares, i.e. the main urban territory does not significantly exceed the limits. But in the integrated pollution map (Fig. 4), determined by the results of calculating the assessment coefficients of air pollution, calculated from a comprehensive study of the factors influencing the dispersion of pollutants in the atmospheric air (Table 5), integration into areas by distribution sizes, it is shown that the volume of high-risk areas of the 4th class is quite high, which in turn shows that in this method, along with quantitative determination of areas, drawing a color map by integration with GIS increases the reliability of the result.

Table 5. Result of the calculation of the atmospheric pollution assessment coefficients

Numbers of assessment areas	Complex indicators of pollution	Pollution coefficients
1	28,33	0,24
2	43,93	0,36
3	36,25	0,30
4	120,38	1,00
5	30,73	0,26
6	19,99	0,17
7	3,30	0,03
8	1,92	0,02
9	18,94	0,16
10	5,44	0,05
11	104,82	0,87
12	23,57	0,20
13	12,50	0,10
14	13,22	0,11
15	23,98	0,20
16	15,17	0,13
17	9,10	0,08
18	11,08	0,09

A somewhat more specific solution is to maintain Geographic Information Systems (GIS) for air pollution dispersion zone zoning by air cleanliness for cadastral land assessment with clear quantitative data listed above in specific land conditions. Pollutant dispersion zone modeling, is an effective tool for predicting and analyzing the spread of pollutants in the environment. GIS plays a key role in each of these steps by providing an environment for integration, analysis, and visualization of the data needed for pollutant distribution modeling. GIS allows natural and anthropogenic factors to be incorporated into the modeling. Combining these natural and anthropogenic factors in GIS allows for more accurate modeling and prediction of pollution distribution, which is important for effective management and minimization of negative impacts on the environment and human health (Fig. 4).

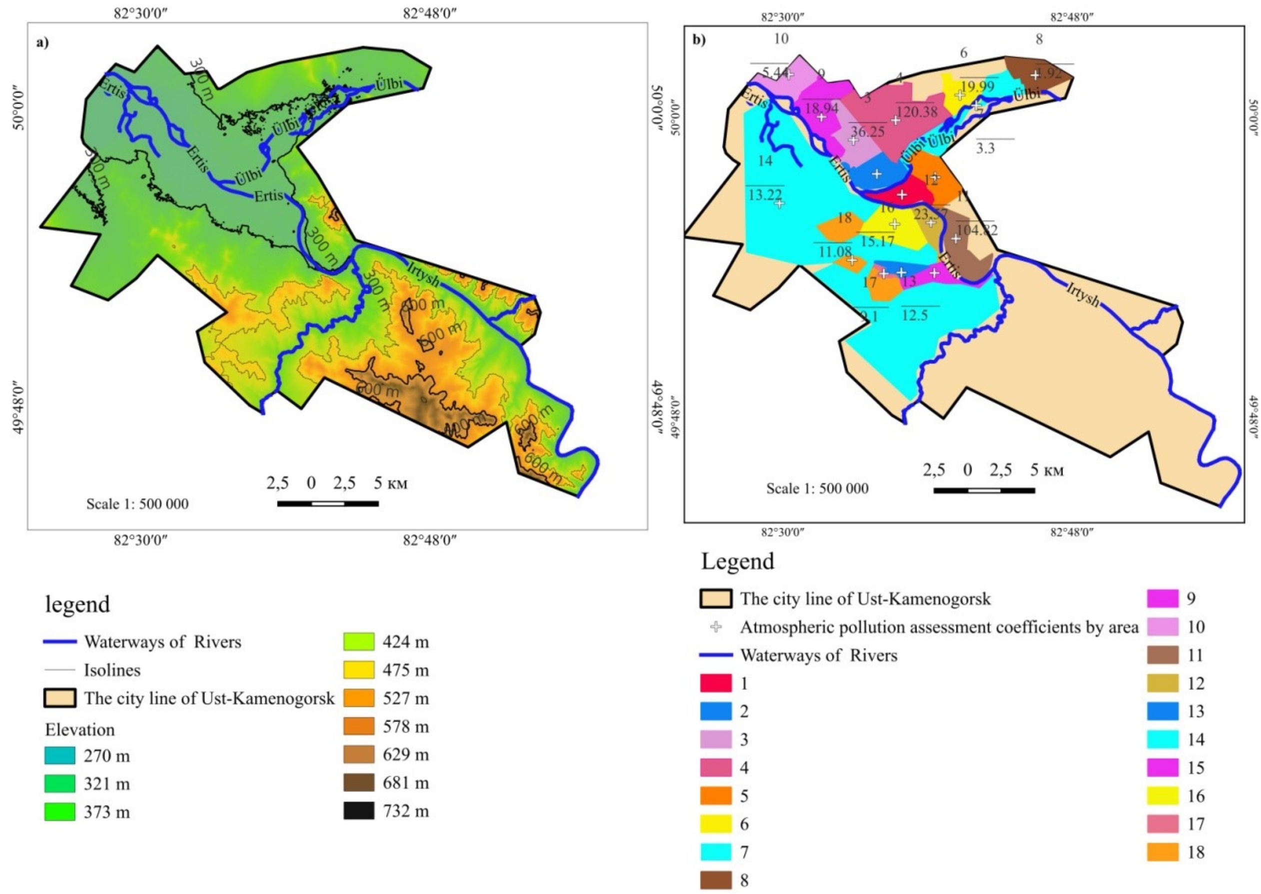

Fig. 4. Map of zoning by complex indicators of atmospheric pollution:
a) relief of the study area;
b) districts by pollution indicators

Application of the results of air pollution assessment in industrial enterprises of Ust-Kamenogorsk allows to significantly improve the process of cadastral value estimation of land plots. Taking into account environmental factors helps to determine the value of real estate more accurately. This is important both for landowners and city authorities. There are also positive results in the determination of environmental risk zones, adjustment of market value of real estate, consideration of sanitary protection zones, planning and development of urban infrastructure, social and economic aspects, etc.

CONCLUSIONS

The zones of distribution of polluting wastes from the main sources of atmospheric air pollution in the study area KAZZINC, UMP, TMP and Heat Power Plant (HPP), which located on two outskirts of the city, differ in territorial remoteness. On the Left Bank areas of the Irtysh River, despite the fact that the assessment area of Land number 7 is located 1.5 kilometers from the sources of pollution in the villages of Staraya Sogra and Novaya Sogra, the pollution factor is 0.03, and the assessment area of Land number 11 is located at a distance of 5–7 kilometers from the sources of pollution, but the pollution factor is 0.87 (Table 5). Levels of atmospheric air pollution in the right-bank areas of the Irtysh generalized within the single-level 0.08–0.11. In the analysis, the wind direction and the architecture of vortex circle formation of urban structures showed that the distribution of polluting waste is independent of the distance from pollution sources, and proved that visual, theoretical evaluation of the atmospheric pollution criterion of land evaluation for cadastral purposes leads to gross errors. It is necessary to take into account the results of a complex geo-ecological survey of lands in the system of urban cadastre, i.e. determination of mechanical properties of soils, factors of hydrogeological conditions and geological processes, and assessment of their impact, peculiarities of the architectural location of buildings and structures, their wind impact of the air basin (settling distance from harmful emissions carried by the wind to the surface), etc. In this case, the use of direct engineering survey results as input material is effectively integrated. In industrial areas, air pollution coefficients are no different from some designated areas over long distances. To avoid such errors, when carrying out the determination of atmospheric pollution in the cadastral land assessment, the use of the method of complex classification of quantitative pollution data with GIS applications gives a reliable assessment result.

National and international air quality standards set by relevant organizations and government agencies are often used to define normal pollution levels. These standards define permissible concentrations of pollutants in ambient air that are considered safe for human health and the environment. According to the country's environmental assessment and monitoring indicators, the city’s pollution from hazardous waste polluting the industrial and air environment remained at normal levels.

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