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S.O. Kozhagulov*, V.G. Salnikov

Non-profit joint stock company «Al-Farabi Kazakh National University», Almaty, Kazakhstan
*e-mail: s_kozhagulov@mail.ru

THE IMPACT OF METEOROLOGICAL AND CLIMATIC CONDITIONS ON THE POTENTIAL FOR SELF-PURIFICATION OF ATMOSPHERE ON THE INDUSTRIAL REGION

The article discusses spatiotemporal changes in the main climatic indicators in the period 1941-2020, their impact on the possibilities of the atmospheric self-purification of a lead-zinc mine. The study of changes in air temperature showed the presence of long-term trends, and the climatic potential parameters of the dissipative capacity of the mine atmosphere were calculated. It was found that the average monthly air temperature increases with the rate of warming of 0.19 to 0.34 °C every 10 years. Moreover, a relatively greater increase in temperature occurs in winter, and a smaller increase in summer. Determined that the anomalous air temperature field is large in the study area both in winter and summer months. Based on the calculations, data on the spatiotemporal variability of the climatic potential of the dissipation capacity and the coefficient of atmospheric self-purification were obtained. This made it possible to establish that throughout the entire annual cycle, unfavorable conditions are observed for the dispersion of polluting particles in the atmospheric air, and to a greater extent during the cold period of the year. The results indicate the manifestations of natural and anthropogenic atmospheric processes that prevent the dispersion of pollution in the atmosphere. The performed research is significant for the practical use. Since data on the spatial and temporal variability of the dispersion potential of atmospheric air must be previously assessed when implementing measures to manage air quality in an industrial region.

Key words: atmospheric pollution, climate change, climatic potential of atmospheric dispersal ability, coefficient of the atmosphere's self-purification, aridization, lead-zinc mine.

С.О. Кожагулов*, В.Г. Сальников

Әл-Фараби атындағы Қазақ ұлттық университеті КеАҚ, 050040, Алматы қ., Қазақстан
*e-mail: s_kozhagulov@mail.ru

Өнеркәсіптік аймақ атмосферасының өзін-өзі тазалау әлеуетіне метеорологиялық-климаттық жағдайлардың әсерін талдау

Негізгі климаттық көрсеткіштердің кеңістіктік-уақыттық өзгерістері және олардың 1941-2020жж. кезеңіндегі қорғасын-мырыш кеніші ауданындағы атмосфераның өзін-өзі тазарту әлеуетіне әсері мақалада қаралады. Ауа температурасының зерттеу ұзақ мерзімді тенденциялардың болуын көрсетті.Ауаның орташа айлық температурасы әр 10 жыл сайын 0,19-дан 0,34 °С-қа дейін жылыну жылдамдығымен көтерілетіні анықталды. Сонымен қатар, температураның ең үлкен өсуі қыста, ал ең азы жазда болады. Аномальды ауа температурасы өрісі зерттелетін аумақта қыста да, жазда да үлкен болатыны көрсетілген.Атмосфераның шашырату қабілеттілігінің климаттық әлеуетінің және өзін-өзі тазарту коэффициентінің кеңістіктік-уақыттық өзгермелілігінің деректері алынған. Бүкіл жылдық цикл бойы атмосфералық ауада ластаушы бөлшектердің дисперсиясы үшін қолайсыз жағдайлардың және көбінесе суық мезгілдерде болатыны анықталды. Алынған нәтижелер атмосфераның ластануының таралуы болдырмайтын табиғи және антропогендік атмосфералық процестердің көріністерін көрсетеді. Жүргізілген зерттеулер практикалық қолдану үшін маңызды. Себебі атмосфералық ауаның шашрау әлеуетінің кеңістіктік және уақыттық өзгермелілігі туралы мәліметтерді өнеркәсіптік аймақта ауаның сапасын басқару шараларын жүзеге асыру кезінде алдын ала бағалау қажет.

Түйін сөздер: атмосфераның ластануы, климаттың өзгеруі, атмосфераның шашырату қабілетінің климаттық әлеуеті, атмосфераның өзін-өзі тазарту коэффициенті, аридизаттау, қорғасын-мырыш кеніші.

С.О. Кожагулов*, В.Г. Сальников

НАО «Казахский национальный университет имени аль-Фараби», г. Алматы, Казахстан
*e-mail: s_kozhagulov@mail.ru

Влияние метеорологических и климатических условий на потенциал самоочищения атмосферы промышленного региона

В статье рассматриваются пространственно-временные изменения основных климатических показателей в период 1941-2020гг, их влияние на потенциал самоочищения атмосферы в районе свинцово-цинкового рудника. Изучение изменения температуры воздуха показало наличие долгопериодных тенденций. Установлено, что среднемесячная температура воздуха увеличивается со скоростью потепления от 0,19 до 0,34 °С каждые 10 лет. Причем, наибольшее повышение температуры приходится на зимний период, а наименьшее на лето. Показано, что аномальность поля температуры воздуха велика в районе исследования как в зимние, так и летние месяцы. На основании расчетов получены данные пространственно-временной изменчивости климатического потенциала рассеивающей способности и коэффициента самоочищения атмосферы. Установлено, что в течение всего годового хода отмечаются неблагоприятные условия для рассеивания загрязняющих частиц в атмосферном воздухе, при этом в большей степени в холодный период года. Полученные результаты свидетельствуют о проявлениях природных и антропогенных атмосферных процессов, препятствующих рассеиванию загрязнений атмосфере. Выполненные исследования имеют важное значение для практического использования. Поскольку данные о пространственной и временной изменчивости рассетвающего потенциала атмосферного воздуха необходимо предварительно оценивать при реализации мероприятий по управлению качеством воздуха промышленного региона.

Ключевые слова: загрязнение атмосферы, изменение климата, климатический потенциал рассеивающей способности атмосферы, коэффициент самоочищения атмосферы, аридизация, свинцово-цинковый рудник.

Introduction

The atmosphere is characterized by unlimited capacity, high mobility, variability constituent components, the uniqueness of physical, chemical processes and transformations. The specific features of these transformations are associated with both natural and anthropogenic factors (Morozov A.E., Starodubzeva N., 2020:123). The intra-annual atmosphere course and the underlying surface thermal state is the most important elements in all Earth's atmosphere models of the general circulation, which determines climate change (Perevedentsev Yu.P., Khabutdinov Yu.G., 2012:23). Climate, as a dynamic form, has constantly changed in the historical past, is changing now and is predicted to change in the future (NRC, 2020). Over the past few decades research on climate change (Kogan F, Guo W, 2014:127 ; Alexander L, 2016:4) has shown that the Central Asia region has warmed faster than other regions (Santer B et al., 2018:6399). Among these mechanisms, solar activity is the main natural factor driving the climate change.

Nowadays, climate change is accelerating the depletion of natural resources, as production and consumption amid ongoing pollution require more energy and materials. The anthropogenic factor is responsible for the greenhouse effect which linked to an increase in the concentration of carbon dioxide and other small gas components in the atmosphere (Belousova E.P., et al, 2023:73). According to the UN, air pollution is recognized as the most important environmental contributor to the global burden of diseases, causing millions of premature deaths and large economic losses every year (Asrar G.R. et al, 2019). This work aimed at studying of spatiotemporal changes in the main climatic indicators in the period 1941-2020, their impact on the potential for atmospheric self-purification in the area of the lead-zinc mine.

The aim of the study is to analyze the impact of meteorological and climatic conditions on air pollution levels, and the spatiotemporal variability of lead-zinc mine's surface atmosphere self-purification (using the Shalkiya mine as example).

Research methods

Study Area

The state of atmospheric air in the mining area is determined by a combination of natural and anthropogenic impacts. JSC "ShalkiyaZinc LTD" is an enterprise for the extraction and processing of Pb/Zn ore at the Shalkiya deposit, which is located in the southeast of Kyzylorda, in the northeast, 17 km from the city of Zhanakorgan, at

67°25’00»E east longitude and 44°01’20»N latitude (Figure 1).

According to the research company BrookHunt (2006), the total Zn reserves of the Shalkiya deposit account for more than 30% of Kazakhstan’s total reserves and are the 5th largest deposit in the world with proven and probable reserves about 6.5 million tons of Zn. (Salnikov V. et al, 2024:71). The Pb content ranges from 0.9 to 1.67%, Zn- from 3.8 to 4.36%, averaging 1.30 and 4.28%, respectively. The host rocks of the deposit are classified as low- and medium-abrasive. The average content of silica in the ores and rocks of the deposit is 41-50%. JSC “ShalkiyaZinc LTD” plans to build an enrichment plant with a capacity of 4 million tons per year. Now at the main industrial site of the mine at the border of the sanitary protection zone and in settlements, the atmospheric pollutants concentrations from stationary sources do not exceed the established limits, comply with applicable standards, except for the increased dust content (Salnikov V. et al, 2024:71). But dust particles may contain heavy metals pose hazard during the operation of the concentrator, both in the working area and in the open tailings. Due to exposure to oxidizing agents and weather conditions, they are potentially hazardous (Whaley P., et al, 2021; Golokhvast K.S., et al, 2012:5; Punia A. 2021:4056).

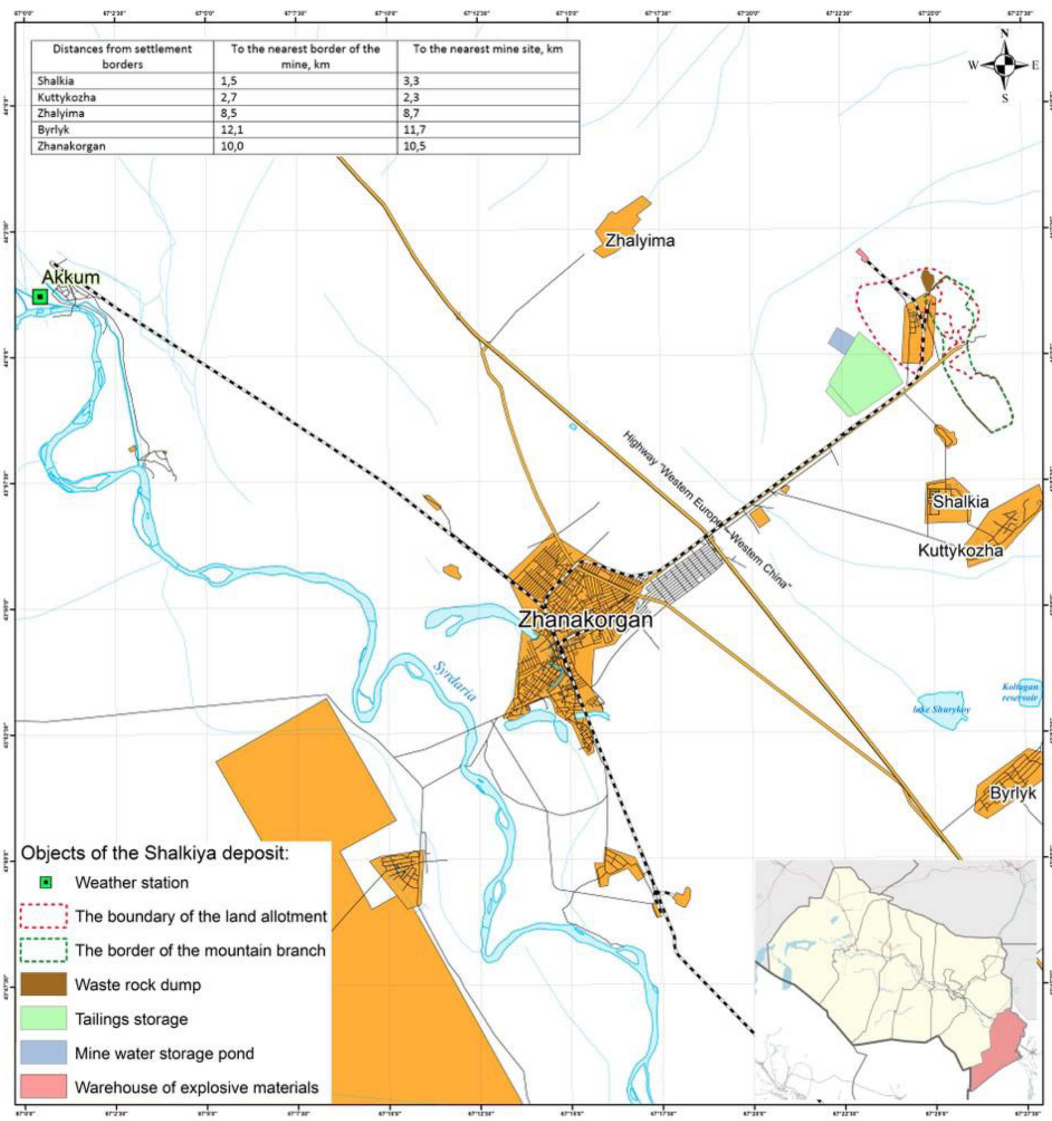


Figure 1 – Map showing the location of the Shalkiya mine in South Kazakhstan, as well as adjacent settlements and other objects. Source: Compiled by the authors based on https://www.ebrd.com

The objectives of the study on the Shalkiya mine are:

- meteorological and climatic conditions;
- the potential of self-purification;
- the spatiotemporal variability of lead-zinc mine's surface atmosphere.

Information database

When assessing the potential for atmospheric pollution, it is advisable to use, instead of individual meteorological elements, complex parameters that characterize a specific meteorological situation and conditions (Morozov A.E., Starodubtseva N.I., 2020:123). As the information base for the study of the meteorological characteristics influence and calculations of the potential for atmospheric air dispersion and self-purification there were used data of the average long-term meteorological parameter's values for the meteorological station Akkum (Figure 1). It is located in close proximity to the object of study (hereinafter for brevity Akkum). These data taken from the reference books on Kazakhstan's climate (Spravochik po klimatu Kazakhstana, 2003:04, 05,16), which will allow us to determine the meteorological and climatic potential of atmospheric pollution (MPAP, CPAP) in the study area. According to the methodology (Selegey T.S., et al, 2015:725), MPAP, (CPAP) calculated by the formula:

$$CPAP = \frac{(R_c + R_f)}{(R_p + R_w)} \quad (1)$$

where: R_c – repeatability of weak wind speeds 0-1 m/s;

R_f is the repeatability of the number of days with fog;

R_p is the repeatability of the number of days with precipitation ≥ 0.5 mm;

R_w – repeatability of wind speeds ≥ 6 m/s. (Kabdykadyrov A.A., et al, 2021:308)

This indicator is characterized in such a way that the larger the MPAP(CPAP) index, the worse the conditions for the dispersion of impurities (Table 1).

Table 1 – Criteria for dispersion conditions in terms of CPAP (Selegey T.S. et al., 2015:725)

Gradation number	CPAP value	Characteristics of dispersion conditions
1	<0.8	Favorable
2	0.8-1.2	Intermediate (buffer zone)
3	1.2-2.4	Adverse
4	>2.4	Extremely unfavorable

Atmosphere self-purification coefficient K, inverse CPAP, taking into account the conditions of dispersion (Lapina S.N. et al., 2008:8; Stambekov M.D., Turulina G.K., 2016:7)

$$K = \frac{1}{CPAP} \quad (2)$$

The coefficient of the atmosphere self-purification (K) is calculated as the ratio of the repeatability of processes that positively affect the removal of impurities from the atmosphere, to the repeatability of processes that contribute to the accumulation of air pollutants (Krymskaya O.V, et al, 2016:124).

The study of large anomalies of air temperature fields in this work was carried out according to the Bagrov criterion (Bagrov N.A., Myakisheva N.N., 1966:53). Bagrov's anomaly index (K_b) is calculated using the formula:

$$K_b = \frac{1}{N}\sum_{i=1}^{N}\left(\frac{\Delta T_i}{\sigma}\right)^2 \quad (3)$$

where:

ΔT_i – anomaly of average monthly air temperature at a point at the i-th station

σ – standard deviation of temperature;

N – number of stations.

Threshold values for the K_B index: when $K_B \geq 1.15$ the field anomaly is large, when $K_B \leq 0.75$ there is a slight anomaly and when $0.75 < K_B < 1.15$ the anomaly has medium intensity (Bagrov N.A., Myakisheva N.N., 1966:53; Stambekov M.D., Turulina G.K., 2016:7).

Literature review

In the modern world, lead and zinc are widely used in the construction and automotive industries of the world. However, the global assessment of Pb-Zn mineral resources clearly reflects the environmental challenges facing the lead-zinc (Pb-Zn) ores mining sector. A great risk to the environment, especially atmospheric air, is the huge amount of uncontrolled waste (tailings) of Pb/Zn mines located in tailings (Mohr S. at.al, 2018:17; Tao Chen, et.al, 2022:120328). Sustainable environmental management is becoming important due to both natural causes of climate change on Earth, and increased impact of anthropogenic factors (Gazaryan V.A., et al, 2022:1). At least 226.1 million tons Pb and 610.3 million tons Zn are shown to be present in 851 individual mineral deposits and waste treatment projects in 67 countries at an average grade of 0.44% Pb and 1.20% Zn, (Mudd G.M. et al., 2017:1160). Moreover, only China produces most of the used Pb, Zn in the world. At the same time, a large amount of waste (tailings) of Pb/Zn mines is placed in tailings without proper management, which poses a significant risk to the local ecosystem and residents of mining areas around the world (Mohr S, et al, 2018:17). Tailings are known to be potentially hazardous due to exposure to oxidants and weather conditions. Thus, according to the mining industry operating data, the amount of tailings generated is estimated at about 0.26-2.5 tons for each ton of Pb/Zn ore processed. It is estimated that there are more than 8100 tailings dumps worldwide with a release volume of 10 billion m^3 (Chen et al, 2022: 120328). Containing Pb, Zn, Cd, and other heavy metals suspended particles can pose a hazard during the operation of the concentrator, both in the working area and in the open tailings, as they are potentially hazardous due to exposure to oxidizing agents and weather conditions (Whaley P. et al., 2021; Golokhvast K.S. et al., 2012:5).

Atmospheric synoptic weather parameters play a significant role in determining the transportation, dispersion, and concentration of air pollutants in different geographical areas (Demuzere M., et al, 2009:2695). Meteorological elements are a general name for a number of characteristics of the atmospheric air state and some atmospheric processes. These include characteristics of the atmosphere state and atmospheric processes that are directly observed at meteorological stations: atmospheric pressure, air temperature and humidity, wind (horizontal air movement), cloudiness (in terms of quantity and form), amount and type of precipitation, visibility, fogs, blizzards, etc. (Morozov A.E., Starodubtseva N.I., 2020:123).

Meteorological conditions influence the processes of accumulation and dispersion of the atmospheric impurities (Assanov D., et al, 2021:200663). The atmospheric dispersion is the main process that governs the transfer of a pollutant within the atmosphere. The dispersion of a pollutant is strictly related to the atmospheric condition in which it is diluted. The atmospheric turbulence is a complex phenomenon to study and to analyze (Adami L., Boffadossi M., 2020). The authors (Lai et al., 2023:406) assessed the influence of atmospheric synoptic weather conditions and the transfer of air masses over long distances. The long-term weather shifts have been observed to positively impact reducing the concentration of PM_{10} extreme events.

The studies (Selegey T.S. et al., 2015:725) of the meteorological potential of atmospheric pollution for 196 weather stations of Western Siberia from 1986 to 2010, analyzing the meteorological potential of pollution from 1986 to 2010. revealed a change in meteorological conditions for dispersing impurities in the surface layer of the atmosphere almost throughout the region for the worse due to an increase in the repeatability of weak winds 0 – 1 m/s, with a simultaneous decrease in the repeatability of winds ≥ 6 m/s.

There is an extensive literature devoted to the study of the climatic factors role and the assessment of the atmospheric air surface layer state in the mining industry (Prabhakar G., et al., 2014:339; Punia A., 2021:4056; Kozhagulov S.O., Salnikov V.G., 2023). The study (Prabhakar G. et al., 2014:339) a spatial and temporal trends in the concentration of airborne solid particles of metals and metalloids in southern Arizona, characterized by a high density of active and abandoned mines, it was found that periods with a high concentration of fine soil coincide with a higher concentrations of metals in the atmosphere, with higher increases in urban areas. The arid climate favors dust emissions from natural and human activities.

The review (Punia A., 2021:4056) also shows that climatic factors such as temperature, precipitation and wind significantly affect the distribution of pollutants in arid, semi-arid regions; wind, water and pollute the environment. In study (Wang H., 2022:119529), precipitation was identified as the most important driving force for the migration of heavy metals in Pb-Zn tailings, which are hazardous wastes generated after ore crushing, magnetic separation, differential flotation and Pb-Zn recovery from production Pb -Zn concentrates.

Kazakhstan's atmospheric air, in general, has an uneven predisposition to pollution according to climatic conditions. The physical-geographical and climatic features of Kazakhstan include, firstly, the fact that lightly dispersed soils prevail on its territory (Ershibulov A.K., 2016:125). If there is dry and hot weather most of the year in desert, semi-desert and steppe areas poor in vegetation, these soils create favorable conditions for the formation of increased background of natural dust pollution atmosphere. In addition, high intensity solar radiation contributes to the formation of secondary harmful substances (with presence of pollutants).

They may be more toxic than the original products. This is due to photochemical reactions associated with formation of photochemical smog (Salnikov V.G., 2006:230). In addition, due to natural and climatic conditions, the territory is characterized by a significant predominance of evaporation over precipitation, which has formed highly saline lands. Similar loose and overdried soil low organic matter layers are easily exposed to wind (Geldiyeva G.V. et al., 2004:236; Omuto C.T. et al., 2023:13157). Apparently, dry and hot weather in most of the year due to favorable conditions are created for the formation of an increased natural pollution of the atmosphere background with dust. Thus, the meteorological parameters are one of the important indicators in the study of atmospheric air pollution. In this aspect, the study of spatial and temporal variability of climatic conditions, assessment the potential scattering ability of the atmosphere becomes unprecedentedly relevant.

Results and the discussion

The initial indicators for the temperature regime analysis were the data of the average annual monthly values of air temperature at Akkum. Table 2 shows the data on the average monthly and annual norms of air temperature and the amount of precipitation. The "norm" in the current work refers to the long-term average value of the considered climate variable for the period 19812010 (Kabdykadyrov A.A. et al., 2021:308).

Table 2 – Annual norm and average monthly air temperature (T, °C), the amount of precipitation (R,mm) at Accum for the period 1981-2010

Month	11	22	43	64	85	76	77	88	99	110	111	112	Year
T, °C	-4,6	-1,6	5,8	14,4	20,9	26,8	28,7	26,7	19,8	11,1	3,7	-2,7	12,4
R,mm	21	21	23	21	21	8	7	1	2	9	25	21	180

Source: Compiled by the authors based on Handbook on the climate of Kazakhstan (Spravochik po klimatu Kazakhstana, 2011)

Analysis of Figure 2 shows that in the annual course, the minimum average monthly air temperature falls on January – minus 4.6 °C, and the maximum in July -plus 28.7 °C. The annual amplitude of fluctuations in air temperature is 33.3 °C. The average annual air temperature is positive and amounts to 12.4°C. From January to February, there is a slight increase in the average annual air temperature due to the fact that the radiation and circulation conditions of these months are similar to each other. Further, with an increase in the influx of solar radiation, from February to March, an increase in air temperature is observed. Then, during the complete transition from negative to positive radiation balance (Stambekov M.D., Turulina G.K., 2016:7), the largest increase in temperature in a year is noted. Further, from July to August, a slow decrease in temperature begins. Then, due to the change and restructuring of the circulation, as well as the transition of the radiation balance to a negative value, the largest decrease in air temperature is observed, this strong drop is observed from September to December.

One of the meteorological phenomena that favors the purification of atmospheric air from pollutants is precipitation. When the atmosphere is cleaned, pollutants are washed out and enter the soil, vegetation cover and water.

Average monthly amount and repeatability (%) of the days' number with precipitation ≥ 0.5 mm at Akkum is shown in Figure 2 and Table 3. Two maxima (in November and March) can be observed 25 mm and 23 mm respectively. In August, vice versa, can be noted the minimum precipitation (1 mm). It can be observed that from January to May precipitation varies slightly (from 21 to 23 mm), and there is a significant drop to 7 mm in June, then in August can be noted a minimum dropping. There is a slowly increase (to 9 mm) from September to October, then in November there is a rapid increase in precipitation up to 25 mm, which is the second maximum. Then there is a slight decrease in December. The annual amount of precipitation is 180 mm.

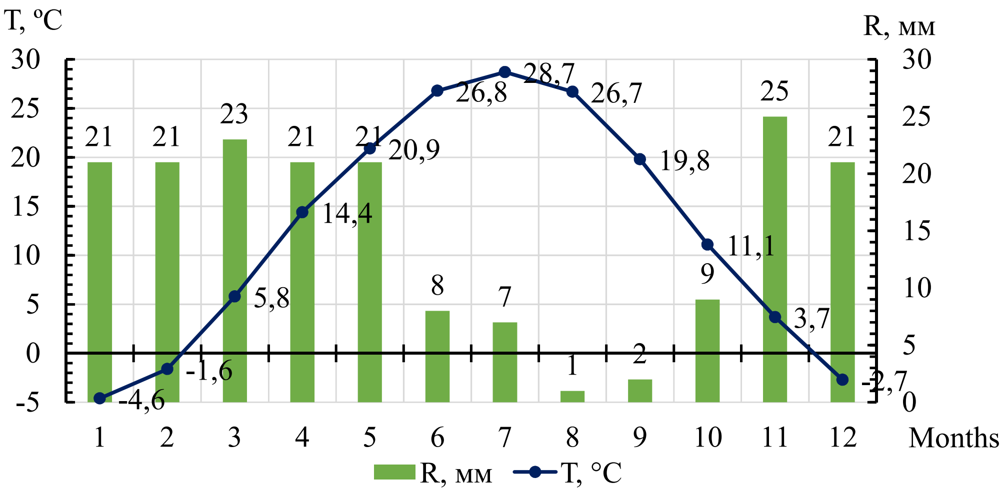


Figure 2 – The annual course of the average monthly air temperature and the amount of precipitation at the Akkum (Source: Compiled by the authors based on (Spravochik po klimatu Kazakhstana, 2003:04, 05,16; ND RK, 2022))

Table 3 – Average monthly amount and repeatability (%) of the days' number with precipitation ≥ 0.5 mm at Akkum

Month												**Year**
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	
1,5	1,3	2,0	2,1	1,8	0,7	0,6	0,1	0,1	1,0	1,5	1,6	14,3
21	21	23	21	21	8	7	1	2	9	25	21	180

As a rule, to characterize the intensity of change in temperature (or other meteorological element) for a selected period of years, the value of the linear trend slope (rate of change) in the time course of air temperature is used (Perevedentsev Yu. P., et al, 2019:32; ND RK, 2022). Figure 3 (a, b, c, d) shows graphs of the average monthly temperature time course for winter, spring, autumn and summer, respectively, according to the Akkum data for the period 1941-2020, from which you can see that the trend lines everywhere have positive trends. Thus, in winter air temperature rises at a rate of 0.34 ºC every 10 years, in spring – 0.28 ºC / 10 years, in summer – 0.19 ºC / 10 years, in autumn – 0.27 ºC / 10 years.

Thus, in the specified area in the time course for the period 1941-2020 there is an increase in air temperature with a rate of warming from 0.19 to 0.34°C every 10 years. The data obtained are consistent with the changes of Kyzylorda region air temperature from 1961 to 2020. based on the nonparametric statistical method of Mann-Kendall. It was noted that over the selected period, average annual temperature changes increased by 0.02...0.05°C (Abdullah N. et al., 2024:65). Moreover, the greatest increase in temperature is observed in winter, and the least in summer. Positive trends in the trend lines of average monthly temperatures are associated with an increase in greenhouse gas concentrations. Elevated temperatures are accompanied by a loss of soil moisture and further drying. Current trends promote aridization, which leads to the process of desertification of the territory, as a result of which increased concentrations of suspended particles in the atmospheric air can be observed (Salnikov V. et al, 2024:71).

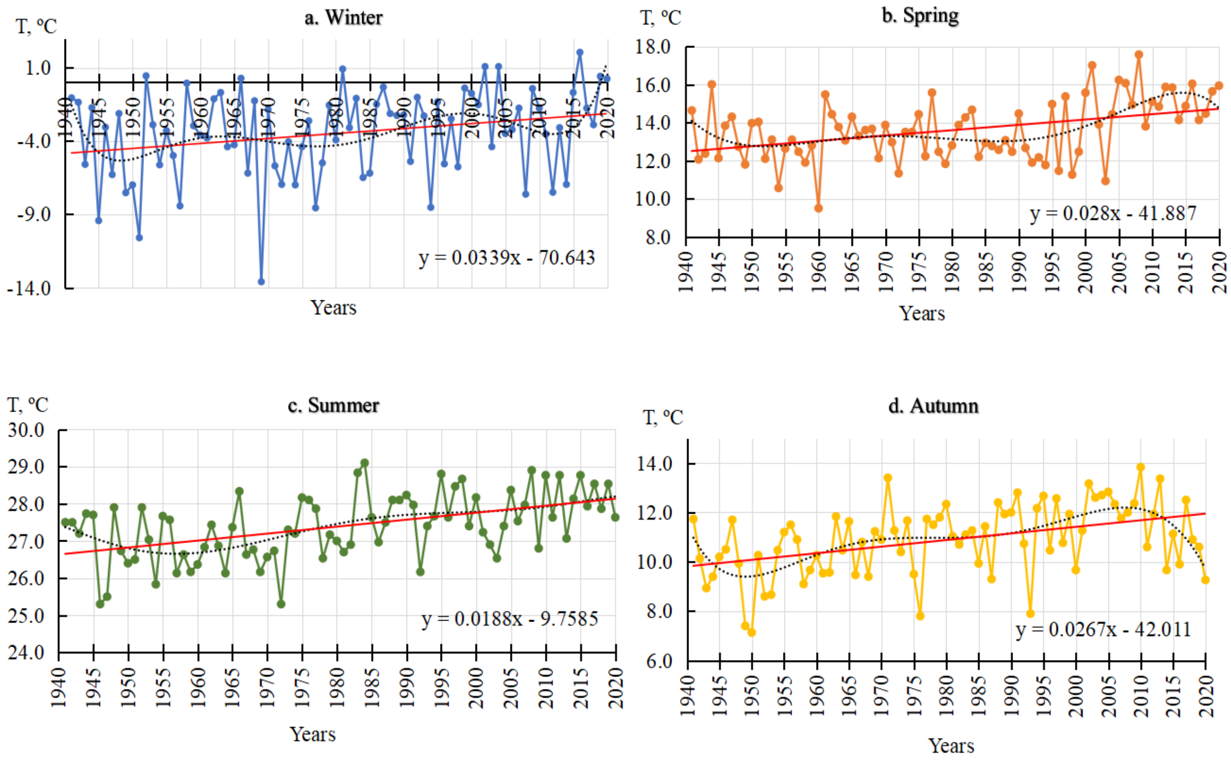


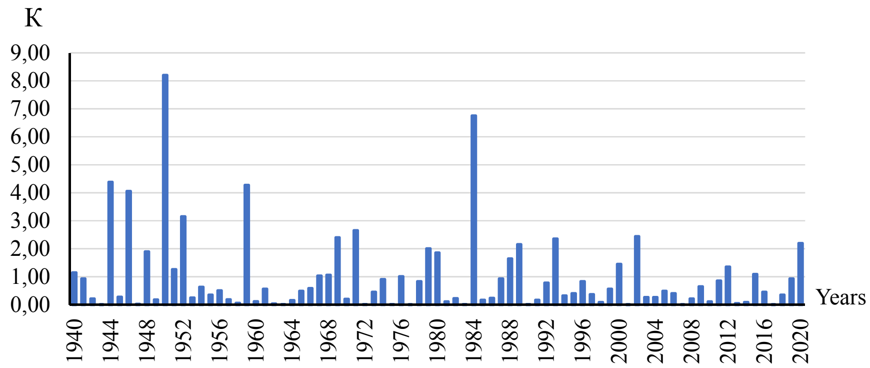
Figure 3 – Average monthly air temperature at MS Akkum for the period 1941-2020

As an indicator of anomaly in climate studies, deviations of meteorological values from average long-term values or their ratio to the average standard deviation are widely used (Gruza G.V., Rankova E.Ya., 2012:194). A comprehensive assessment of the degree of anomaly of the temperature field is the Bagrov anomaly index (K_B), which allow to quantitatively reflect the duration and temporal distribution of air temperature extremes. In this work, the K_B index is calculated for winter and summer (Figure 4 and Figure 5).

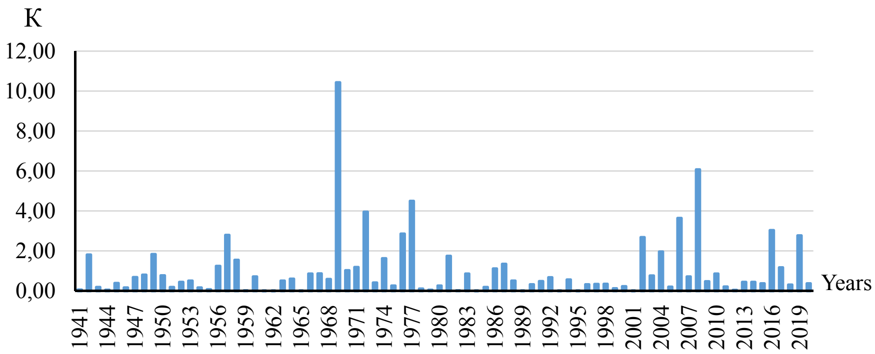
Based on the calculated values of the Bagrov index ($K_B \geq 1.15$), a catalog of extremely cold (EC) and warm (EW) months for winter and summer was compiled. According to MS Akkum for the study period 1941-2020. 63 cases with deviations of air temperature from the norm in winter were identified, including 33 cases with EC and 30 EW years, and in the summer 74 cases with anomalies were identified: 36 cases of EC and 38 cases of EW.

The atmospheric air purification from pollutants largely depends on the precipitation's amount and intensity. According to studies, during precipitation, there is a decrease in the concentrations of sulfur dioxide and nitrogen dioxide. After rain in summer tropospheric ozone and other impurities are removed from the atmosphere almost in full (Kabdykadyrov A.A. et al, 2021:308; Korotkova N.V., Semenova N.V., 2014:194).

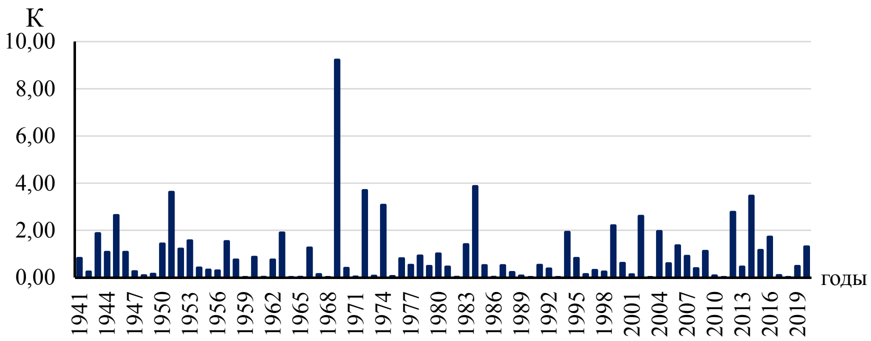
An important role in leaching pollutants from the atmosphere plays the precipitation duration. It significantly influences in washing pollutants out of the atmosphere. During precipitation with a duration of 6 hours or more, a reduced level of air pollution is formed. Restoration and return of the initial level of air pollution is carried out gradually, within 12 hours. The described dependence refers to concentrations that are formed outside the direct impact of sources, while during the direct transfer of emissions from pollution sources, the effect of removing atmospheric impurities is manifested to a lesser extent. The influence of liquid and solid precipitation on the purification of the atmosphere is taken into account through the repeatability of the number of days with precipitation more than or equal to 0.5 mm per day. A number of researchers suggest that this amount of precipitation is capable of depositing roadside dust and other impurities in the air (Lapina S.N. et al., 2008:8; Korotkova N.V., Semenova N.V., 2014:194). Table 3 shows the repeatability (%) of the days' number with precipitation ≥ 0.5 mm at Akkum.



a. December

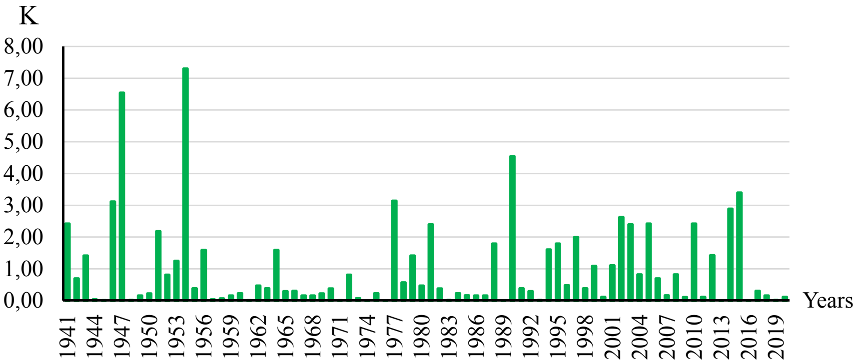


b. January

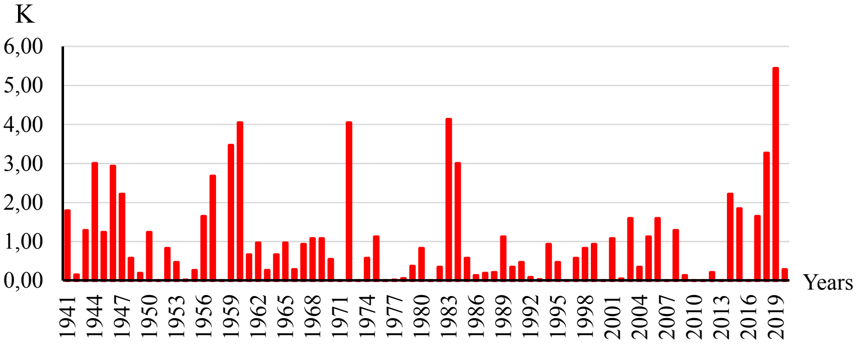


c. February

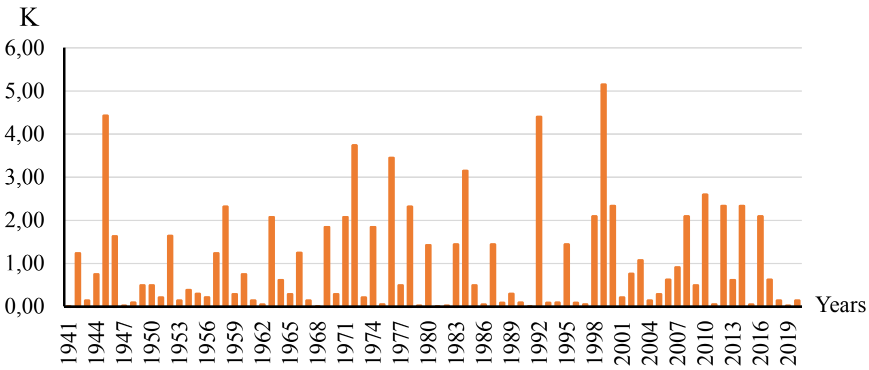
Figure 4 – $K_{\text{в}}$ index values for winter for the period 1941-2020



a. June



b. July



c. August

Figure 5 – K_B index values for summer for the period 1941-2020

Analysis (Table 3) shows that in the long-term regime for the meteorological station Akkum, the highest repeatability of precipitation with a gradation of ≥ 0.5 mm is observed in the spring season from March to May within 1.8-2.0%, and the lowest in August and September is 0.1%, while the average annual the repeatability value of this gradation is only 14.3%. Very low precipitation and high evaporative capacity of the day surface determine the intensity and direction of the biological and geological circulation of water and chemicals. Fog formation causes an increase in ground-level concentrations of pollutions, as water droplets tend to absorb harmful chemical concentrates. After that, toxic impurities begin to settle in the surface layers of the atmosphere, which leads to an increase in total concentrations. Due to the accumulation of significant concentrations (outside water droplets), pollutants are transferred from the surrounding space to the area of fog formation. Above the fog zone, a significant risk is the presence of smoke plumes, under the influence of which pollution spreads into the surface air layer (Lapina S.N. at al, 2008:8). Repeatability data (%) of the days' number with fogs in the area of meteorological station Akkum are presented in Table 4.

Table 4 – Average monthly repeatability of the days' number of with fogs at Akkum

Month												Year
1	2	3	4	5	6	7	8	9	10	11	12	
1,1	0,6	0,4	0,1	0,0	0,0	0,0	0,0	0,0	0,1	0,5	1,3	4,0

The number of days with fogs (Table 4) is small in the study area. The presence of days with fogs is noted in the cold period, where the highest repeatability in December reaches only 1.1%, and the minimum in October and April is 0.1%. In the warm season (from May to August) foggy days are completely absent.

Table 5, according to the climate reference book, shows the average monthly and average annual repeatability (%) of wind directions at Akkum (Spravochik po klimatu Kazakhstana, 2005).

According to Table 5, the average annual frequency of calms on Akkum is 38%, the highest level is observed in the autumn season within 44-50%, and the lowest from January to March -20-22% respectively.

The Figure 6 shows the wind rose, built on the average annual repeatability of wind directions, in accordance of which the most predominant direction is the northeast wind – 30%.

In Table 6, the repeatability (%) of wind directions were calculated for the seasons of the year at Akkum.

Table 5 – Average Akkum's wind directions monthly repeatability (%)

Month	Wind direction								Calm
	N	NE	E	SE	S	SW	W	NW	
1	8	8	12	31	14	5	7	15	22
2	9	8	13	26	12	7	8	17	20
3	11	11	11	16	11	9	11	20	20
4	12	28	24	4	5	8	11	8	32
5	15	26	19	3	4	7	14	12	36
6	18	28	16	3	2	4	10	19	34
7	25	26	11	2	1	3	10	22	34
8	23	36	13	1	1	2	8	16	36
9	18	33	16	2	2	5	10	14	45
10	14	28	15	3	5	10	15	10	50
11	11	29	22	4	6	12	9	7	44
12	8	27	23	5	8	15	10	4	43
Year	15	30	19	3	4	8	10	11	38

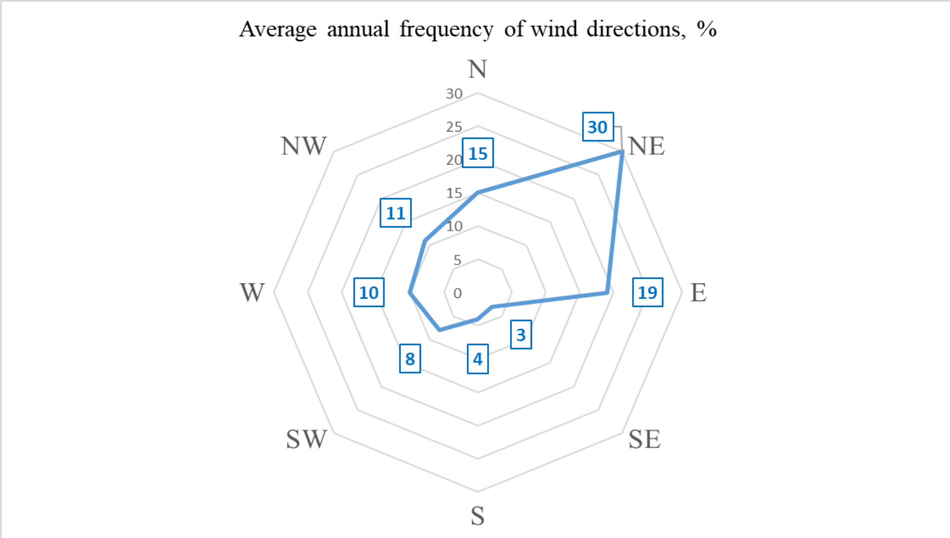


Figure 6 – Wind rose of average annual repeatability (%) of wind directions at Akkum
(Source: Compiled by the authors based on (Spravochik po klimatu Kazakhstana, 2005))

Table 6 – Repeatability (%) of wind directions by seasons at Akkum

Season	Wind direction								Calm
	N	NE	E	SE	S	SW	W	NW	
Winter	20	25	33	59	29	17	18	33	56
Spring	13	22	18	8	7	8	12	13	29
Summer	22	30	13	2	1	3	9	19	35
Autumn	14	30	18	3	4	9	11	10	46
Year	15	30	19	3	4	8	10	11	38

Figure 7 shows a wind rose constructed from the seasonal frequency of wind directions at Akkum.

According to the analysis of Table 6 and Figure 7 in spring, summer and autumn, the northeast wind direction is predominant, with a repeatability of 22-30%, respectively and in winter, southeastern directions prevail – 59%. Thus, the potential emissions of pollutants from the planned production at the Shalkiya field will be mostly transferred to the southwest of the Kyzylorda region. Table 7 shows the average monthly repeatability of occurrence (%) of weak (0-1 m/s) and strong (≥ 6 m/s) winds at Akkum.

According to the climatic data (Table 7), at Akkum, in the warm season observed the wind speeds repeatability with a gradation of ≥ 6 m/s, in particular from April to August, up to 10.7%. The number of days with weak winds repeatability (with a gradation of 0-1 m/s) occurs on the cold period of the year, from September to March, ranging from 45.4% (in March) to 58.5% (in November).

a b c d

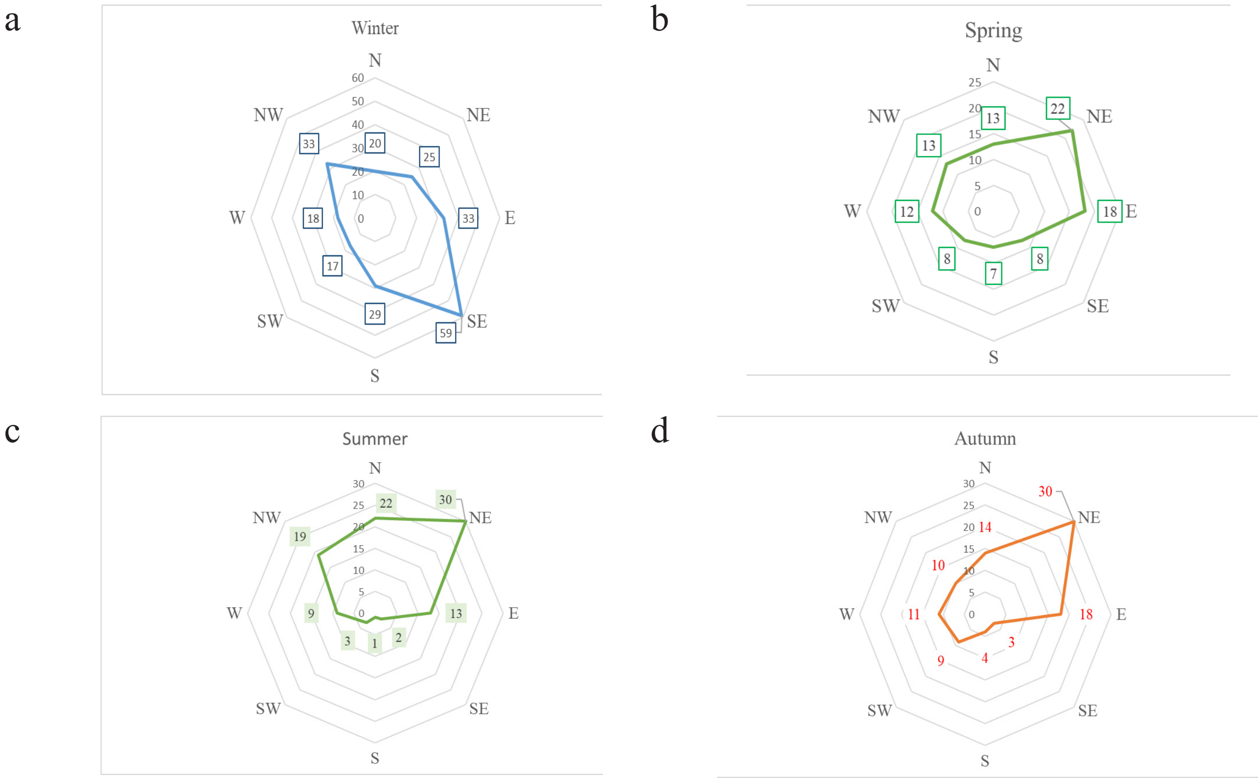


Figure 7 – Wind rose of repeatability (%) of wind directions by seasons at Akkum (Spravochik po klimatu Kazakhstana, 2005).

Table 7 – Average monthly repeatability (%) of weak (0-1 m/s) and strong (≥ 6 m/s) winds at Akkum

Wind speed gradation, m/s	Month												Year
	1	2	3	4	5	6	7	8	9	10	11	12	
0-1	50,2	48,7	45,4	40,0	36,9	35,6	32,9	36,2	51,3	56,9	58,5	55,6	45,7
≥ 6	6,8	6,6	6,7	10,0	9,0	9,1	10,7	9,5	5,1	4,4	3,9	3,9	7,2

One of the important points in the method of analyzing of the potential for the atmospheric air self-purification is the calculation of the repeatability of the surface delaying layers of atmosphere (R_{in}). The obtained value will allow us to estimate the coefficient of atmospheric self-purification (K) (Kabdykadyrov A.A. et al, 2021:308).

As a rule, an example of unfavorable meteorological conditions are surface temperature inversions. Taking into account the stable stratification of the atmosphere, they are retaining layers that prevent the dispersion and transfer of impurities in atmospheric air layers. Similar methods were used in the works (Arguchintseva A.V., Kochugova E.A., 2019:3; Perevedentsev Yu.P. et al., 2012:32; Belousova E.P. et al., 2023:73; Teterin A.F. et al, 2015).

Repeatability (R_{in}) is calculated using the regression equation. This equation for continental regions has the form:

$$R_{in}=31{,}4+0{,}29R_c, \qquad (4)$$

In accordance with equation (4) and the climatic data of the Akkum, the surface delaying layers of atmosphere (R_{in}) were calculated (Table 8).

Table 8 – Average monthly repeatability of the surface delaying layers (R_{in}) on Akkum

Month												Year
1	2	3	4	5	6	7	8	9	10	11	12	
46,0	45,5	44,6	43,0	42,1	41,7	40,9	41,9	46,3	47,9	48,4	47,5	44,7

It can be seen (Table 8), that in Akkum, Rin is ranges from 40.9% (in July) to 48.4% (in December). In the cold period, the values of R_{in} are slightly higher than in the warm season. In the average annual value, R_{in} is 44.7%. Under these conditions, elevated levels of surface air concentrations may be observed.

In accordance with the values of R_{in} and based on long-term climatic data from Akkum, according to formulas (1) and (4), the indicators of the climatic potential of atmospheric pollution and the coefficient of atmospheric self-purification (K) (Kabdykadyrov A.A. et al, 2021:308; Gazaryan, V.A. et al., 2022:1) were calculated, the calculation results of which are given in Table 9. Since in the study area the repeatability of fogs (R_f) is low, instead of the value of R_f, the indicator (R_{in}) was used, according to the methodology (Selegey T.S. et al., 2015:725).

Table 9 – Indicators of CPAP and K for the area of Akkum

Indicators	Month												Year
	1	2	3	4	5	6	7	8	9	10	11	12	
CPAP	6,2	6,2	5,2	3,3	3,4	3,6	2,9	3,8	9,9	10,5	10,9	10,3	6,4
K	0,09	0,08	0,10	0,15	0,14	0,13	0,15	0,12	0,05	0,05	0,05	0,05	0,10

For a visual representation of the results of calculations, in Figures 8 graphs of the annual variation of the coefficients of CPAP and K are plotted on Akkum.

An analysis of Figure 8a and Table 8 indicates that in the long-term aspect, the indicators of the CPAP in the entire annual course have a degree of extremely unfavorable conditions (CPAP > 2.4) for the atmospheric pollutants dispersion. The highest indicators of unfavorable weather conditions are observed in the cold period of the year (September-March), the coefficient is 5.2-10.9. In the warm season (April-August), this indicator is kept in gradations of 2.9-3.8. The generalizing provision on extremely unfavorable conditions shows the average annual value of the CPAP equal to 6.4.

According to Figure 8b and Table 9, the inverse CPAP self- purification coefficient K, which determines the conditions for the pollutant particles dispersion, also characterizes unfavorable conditions for the pollutant's dispersion throughout the entire annual cycle with the range from 0.05 to 0.15. Similarly to the CPAP indicator the cold period has more unfavorable conditions for dissipation in comparison with the warm period.

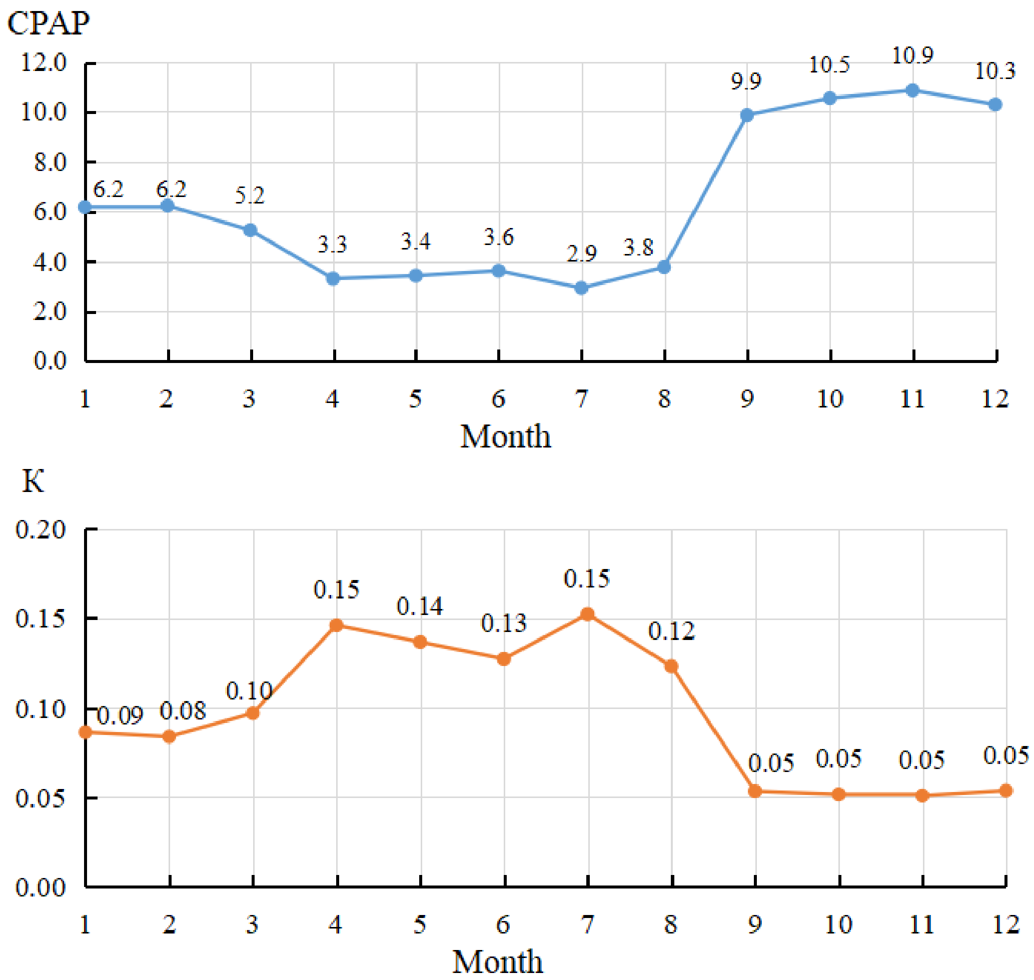


Figure 8 – Graph of the annual course of the CPAP coefficient and self-cleaning coefficient K at the meteorological station Akkum (Source: Compiled by the authors based on Akkum data (Spravochik po klimatu Kazakhstana, 2005, Selegey T.S.,et al, 2015:725))

Thus, during the study, the set goal was achieved and the hypothesis put forward was confirmed. It was noted that in the mine area in the period 1941-2020. observed an increase in average monthly air temperature with a warming rate of 0.19 to 0.34 °C every 10 years. The results of the analysis made it possible to identify unfavorable conditions for the dispersion of polluting particles in the atmospheric air throughout the entire annual cycle, which is associated with the processes of soil salinization and aridization. Taking into account the data obtained in the work in the future, when designing a tailing dump, it is important to assess the role of climatic factors in the distribution of heavy metals in the environment in the area of lead-zinc ore mining.

Conclusion

1. The analysis of changes in the meteorological and climatic factors' complex and their impact on the potential for atmospheric self-purification in the area of a lead-zinc mine indicates manifestations of atmospheric processes (natural and anthropogenic) that prevent the atmospheric pollutants dispersion.

2. It was noted that in the mine area in in the time course (1941-2020) every 10 years observed an increase in average monthly air temperature with a warming rate of 0.19 to 0.34 °C. At the same time, the greatest increase in temperature was noted in winter, and the smallest in summer.

3. It is shown that the anomalous air temperature field is large in the study area both in winter and summer months.

4. The data obtained according to the assessment of the spatiotemporal variability of CPAP (the climatic potential of atmospheric pollution) and the self-purification coefficient in the meteorological station Akkum, indicate unfavorable conditions for the dispersion of polluting particles in the atmospheric air throughout the entire annual cycle, which is associated with the aridization and soil salinization.

5. The obtained data should be taken into account in implementation of the air quality management in the industrial region.

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Information about authors:

Kozhagulov Saken Oralbaevich – doctoral student of the Department of Meteorology and Hydrology, Faculty of Geography and Nature Management, Al-Farabi Kazakh National University (Almaty, Kazakhstan, e-mail: s_kozhagulov@mail.ru);

Salnikov Vitaly Grigorievich – Professor, Doctor of Geographical Sciences, Department of Meteorology and Hydrology, Al-Farabi Kazakh National University (Almaty, Kazakhstan, e-mail: vitali.salnikov@kaznu.edu.kz);

Авторлар туралы мәлімет:

Кожагулов Сакен Оралбаевич – Әл-Фараби атындағы ҚазҰУ география және табиғатты пайдалану факультеті метеорология және гидрология кафедрасының докторанты (Алматы, Қазақстан, e-mail: s_kozhagulov@mail.ru);

Сальников Виталий Григорьевич – Әл-Фараби атындағы ҚазҰУ метеорология және гидрология кафедрасының профессоры, география ғылымдарының докторы. (Алматы, Қазақстан, e-mail: vitali.salnikov@kaznu.edu.kz);

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