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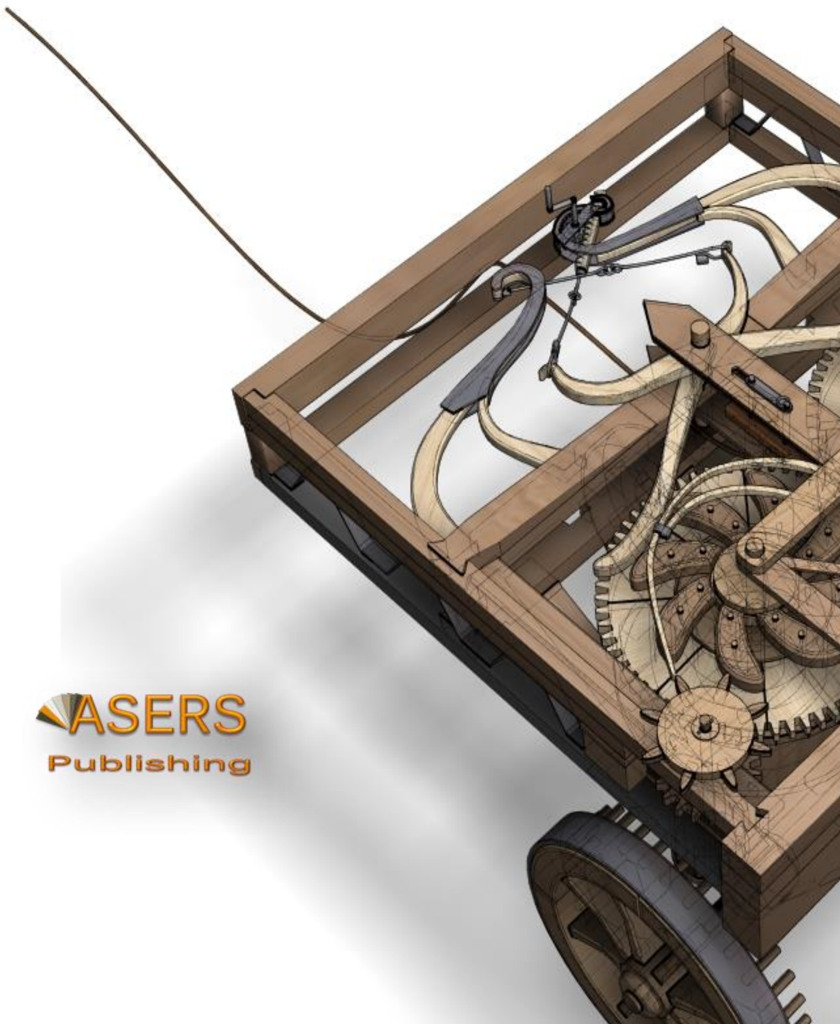

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Table of Contents:

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Assessment and Forecast of Atmospheric Air Quality at the Regional Level. Example of Central Kazakhstan

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Abstract. One of the main issues of environmental protection is the quality of atmospheric air. The reason for this is that all life on Earth, first of all, needs air, which affects all climatic and biological processes in general. Harmful and dangerous impurities can be transferred alongside the movement of air masses. These problems are especially acute in industrialized regions, where the level of anthropogenic impact is increasing. These regions include Central Kazakhstan.

When studying the issues of ecological and economic development of such regions, it is necessary to consider all possible consequences of anthropogenic impact that affect or may affect the atmospheric air. The main factor which plays a key role in this is strengthening the forecasting functions of environmental monitoring services, in our case, in relation to atmospheric air, and, when drawing up a plan for the infrastructure of the territories, taking into account the level of anthropogenic impact.

Keywords: air pollution; indicator; anthropogenic impact, environmental protection; the infrastructure; public health; concentration; pollutants; sulfur dioxide; particulate matter.

JEL Classification: Q53; Q52; I18; R11.

Introduction

One of the main issues of environmental protection is the quality of atmospheric air. The reason for this is that all life on Earth, first of all, needs air, which affects all climatic and biological processes in general. Harmful and dangerous impurities can be transferred alongside the movement of air masses. These problems are especially acute in industrialized regions, where the level of anthropogenic impact is increasing.

Rising levels of pollution, both indoors and outdoors, are the result of industrial growth and many other undesirable human activities. These contaminants are harmful for both humans and the environment. The constant release into the environment of numerous chemical pollutants such as NO_x, NH_3, C_2H_5OH, CO and fluorocarbons from industrial emissions, vehicle exhaust and household waste cause many problems (Deekshitha *et al.* 2021).

1. Literature Review

Air pollution affects public health and was responsible for an estimated 6.7 million deaths worldwide in 2019 and 197,000 deaths in the United States (Landrigan *et al.* 2022). The main source of it is the burning of fossil fuels. Mapping the health impact of air pollution at the community level using publicly available data and open source software will provide a reproducible strategy for pollution prevention. Research led by US scientists quantifies the impact of fine particulate (PM2.5) air pollution on disease, mortality, and child cognitive performance (IQ loss) in every city in Massachusetts. According to the researchers, air pollution-related illnesses, mortality, and IQ loss were most severe in low-income minority communities but were found in every city and town in Massachusetts, regardless of location, demographics, or average household income.

Air pollution is one of main causes of death worldwide and continues to have detrimental effects on our health. In the context of these impacts, researchers have developed statistical modeling approaches to better understand air pollution statistics. However, the time-varying statistics of different types of air pollutants is far from being fully studied. The observed probability density functions of concentrations are strongly dependent on the spatial position and on the pollutant.

In their article, European scientists analyzed a large amount of data from various monitoring points and showed that the concentrations of nitric oxide (NO), nitrogen dioxide (NO2) and particulate matter (PM10 and PM2.5) usually vary greatly for different spatial positions. For each substance there are different propagation models in the plane. They depend on the type of pollutants and environmental characteristics (urban/suburban/rural/transport/industrial/background).

Also, some data from foreign researchers have shown a relationship between exposure to air pollution and the development of interstitial lung diseases. The study aimed to evaluate the effect of long-term exposure to ambient air pollution on the rate of change in total lung capacity, residual volume, and diffusing capacity in the elderly, and showed that long-term exposure to atmospheric NO2 is associated with an accelerated decline in static lung volume and diffusive capacity in the elderly. Air pollution associated with NO2 may be a risk factor for restrictive lung diseases (Chen *et al.* 2022).

For developing countries such as Kazakhstan, where most of the industry is extractive, this issue is particularly acute. In different regions of Kazakhstan, due to the fact that different minerals, polluted with their own particular pollutants, are mined, the problems of atmospheric air in each region are also different. One of such regions contaminated specifically by stationary sources is Central Kazakhstan, which is one of the leading industrial regions of the republic, a territorial manufacturing complex with a developed heavy industry. These are the coal mining, metallurgical and chemical-engineering industries of the republic. All of the most important branches of heavy industry are associated primarily with the mining of coking coal, the processing of ores of non-ferrous, ferrous and rare metals and auxiliary types of raw materials necessary for metallurgy (Zhakataeva 2005). Therefore, the main factors of the negative impact on the atmospheric air of this region are the enterprises of the manufacturing industry and thermoelectric power engineering, which are among the most environmentally «dirty» industries in the world. In Central Kazakhstan, there has been a steady increase in the number of atmospheric emissions from about 1 million tons to 1.4 million tons from 1998 to 2004, and since 2005 - a decrease in emissions to 1.27 million tons.

Atmospheric air quality is understood as a set of atmospheric properties that determine the degree of impact of physical, chemical and biological factors on people, flora and fauna, as well as on materials, structures and the environment as a whole. The degree of impact depends on the quantitative characteristics of said factors and the duration of their impact (https://apps.who.int/iris/bitstream/handle/10665/276929/9789289056199-rus.pdf?sequence=5andisAllowed=y).

When studying the issues of ecological and economic development of such regions, it is necessary to consider all possible consequences of anthropogenic impact that affect or may affect the atmospheric air. The main factor which plays a key role in this is strengthening the forecasting functions of environmental monitoring services, in our case, in relation to atmospheric air, and, when drawing up a plan for the infrastructure of the territories, taking into account the level of anthropogenic impact

The purpose of the work is to assess the quality of atmospheric air in Central Kazakhstan (using the example of Astana, Karaganda and Zhezkazgan), to forecast changes in atmospheric air parameters, spread of pollutants and their impact on the environment and human health.

To assess the quality of atmospheric air, it is necessary to consider both environmental and social indicators. In this paper, among the environmental indicators, we will consider API (Atmospheric Pollution Index), indicators of the highest concentration, PM (suspended matter), SO2, CO2, NO2 levels; among social indicators, we will show the level of mortality by main classes of death causes by regions over the past 5 years.

Object of study and source of data. The study used information from the official statistics of the National Hydrometeorological Service of the Republic of Kazakhstan, the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan.

Using the ArcGIS program, ecological maps were made based on the analysis of pollutant emissions into the atmosphere, as well as indices for assessing the state of the environment by mapping on the maps of the Republic of Kazakhstan.

2. Method also Called Materials and Methods or Experimental Methods

Method of statistical analysis. In the process of studying the quality of atmospheric air at the regional level, various methods were used, including the method of statistical analysis, the mapping method, mathematical methods of data analysis and the method of correlation.

Statistical research and analysis of statistical information is carried out using the following common methods:

- Statistical observation
- Summary of materials, grouping of statistical observation data
- Relative or absolute statistics
- Variation rows
- Selection
- Analysis - correlative and regressive
- Dynamic series

Mapping method. Based on databases, material was collected for the analysis and cartographic presentation of information about the state of the human habitat and other biological species, i.e. about the ecological situation. The method of ecological mapping shows the analysis of the ecological situation and its dynamics, the identification of spatial and temporal variability of environmental factors affecting human health and the state of ecosystems. In our case, indicators of air pollution in the Republic of Kazakhstan were shown.

When studying the dynamics of pollutant emissions into the atmosphere throughout Kazakhstan, statistical observation and grouping methods were used via selection. Since among the environmental criteria such environmental indicators as the Atmospheric Pollution Index (API) were chosen - a complex index of atmospheric pollution that takes into account several impurities, the greatest repeatability (GR) - the greatest repeatability (%) of exceeding the MPC according to observations at one post for one impurity or at all posts of the district for all impurities per month or per year, below are the criteria for assessing the degree of atmospheric pollution (Table 1).

Table 1 Assessment of the atmospheric pollution degree

Degree		API	СИ	GR
Of gradation	Pollution of atmospheric air			
I	Low	from 0 to 4	from 0 to 1	0
II	Higher	from 5 to 6	from 2 to 4	from 1 to 19
III	High	from 7 to 13	from 5 to 10	from 20 to 49
IV	Very high	≥ 14	> 10	> 50

Note – The table was composed by the author based on the data https://www.kazhydromet.kz/ru/ecology/ezhemesyachnyy-informacionnyy-byulleten-o-sostoyanii-okruzhayuschey-sredy

One of the important environmental indicators is the level of pollutants in the air. In Table 1, we considered such indicators as the content of PM (2.5) dust in the atmospheric air and the presence of pollutants SO2, CO2, NO2 in the studied regions. This analysis was made using the method of statistical observation, sampling and comparison. Among the environmental criteria, we took the above-mentioned indicators of the greatest repeatability (GR), the atmospheric pollution index (API), as well as the content in the atmospheric air of such pollutants as PM (2.5) dust, the level of sulfur dioxide (SO2), nitrogen dioxide (NO2) and carbon monoxide (CO2), and the level of maximum permissible concentration (MPC). The analysis of contamination with certain substances was done by the ratio of the MPC level with the indicators of contamination (Table 2).

Table 2. Pollution indicators

Name of impurities	Indicators of API, mg/m^3		Hazard Class
	Maximum single concentration	Average daily	
Nitrogen dioxide	0,2	0,04	2
Nitric oxide	0,4	0,06	3
Suspended matter (particles)	0,5	0,15	3
Suspended matter of PM 10	0,3	0,06	-
Suspended matter of PM 2,5	0,16	0,035	-
Sulfur dioxide	0,5	0,05	3
Carbon monoxide	5,0	3	4

Note – «Hygienic standard for atmospheric air in urban and rural settlements» (SanRandN №168 of February 28, 2015)

Further, when analyzing the data, the standard deviation for the regions for 2017-2021 was calculated, methods of statistical analysis and the mathematical method of standard deviation were applied. The standard deviation method is the most common indicator of the dispersion of the values of a random variable relative to its mathematical expectation (an analogue of the arithmetic mean with an infinite number of outcomes). Usually, it means the square root of the dispersion of a random variable, but sometimes it can mean one or another variant of estimating this value.

Method of modelling – calculation of the Pearson correlation index.

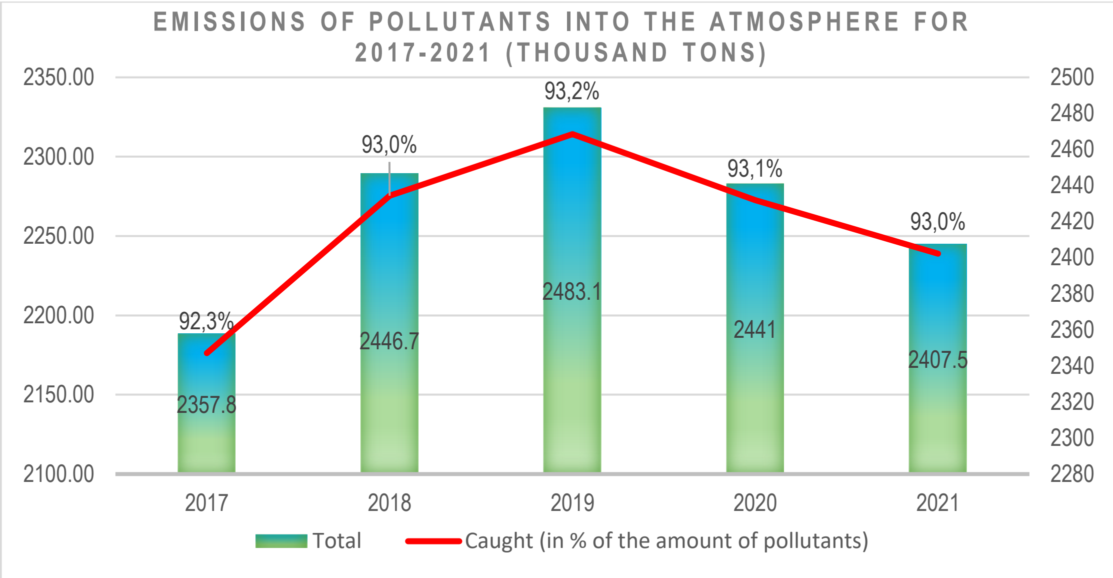
The indicators of the social development of the regions of the Republic of Kazakhstan were also analyzed using the method of statistical analysis, and among the criteria, such indicators as mortality of the population and the main classes of population death causes (malignant neoplasms, diseases of the circulatory system, respiratory diseases) were taken.

When assessing the quality of atmospheric air, it is necessary to take into account not only environmental, but also social indicators, therefore, in order to show the relationship between environmental and social indicators, a correlation analysis was made and a correlation matrix was compiled with the identification of the Pearson coefficient in Microsoft Excel.

3. Research Methodology

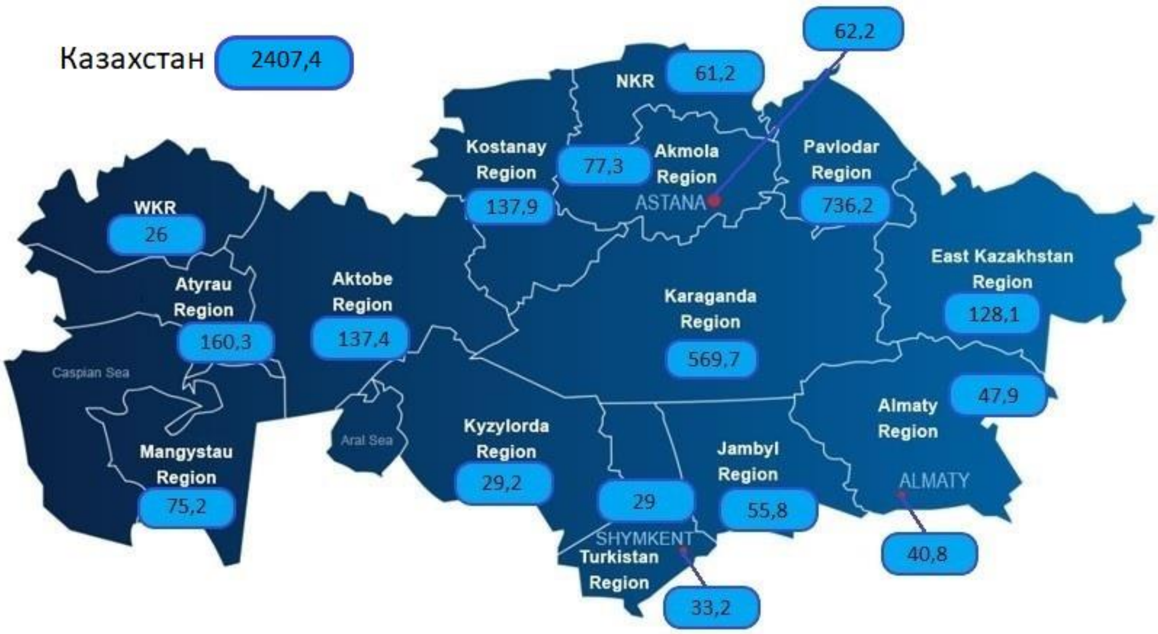
Analysis of atmospheric air pollution in Central Kazakhstan. To begin with, we will analyze the emissions of pollutants into the atmosphere throughout Kazakhstan (Fig. 1,2)

Figure 1. Emissions of pollutants into the atmosphere over the past 5 years in the Republic of Kazakhstan.



Note – The figure was composed by the author based on the data https://www.kazhydromet.kz/ru/ecology/ezhemesyachnyy-informacionnyy-byulleten-o-sostoyanii-okruzhayuschey-sredy

Figure 2. Emission of pollutants into the air in the regional breakdown(разрез) for 2021

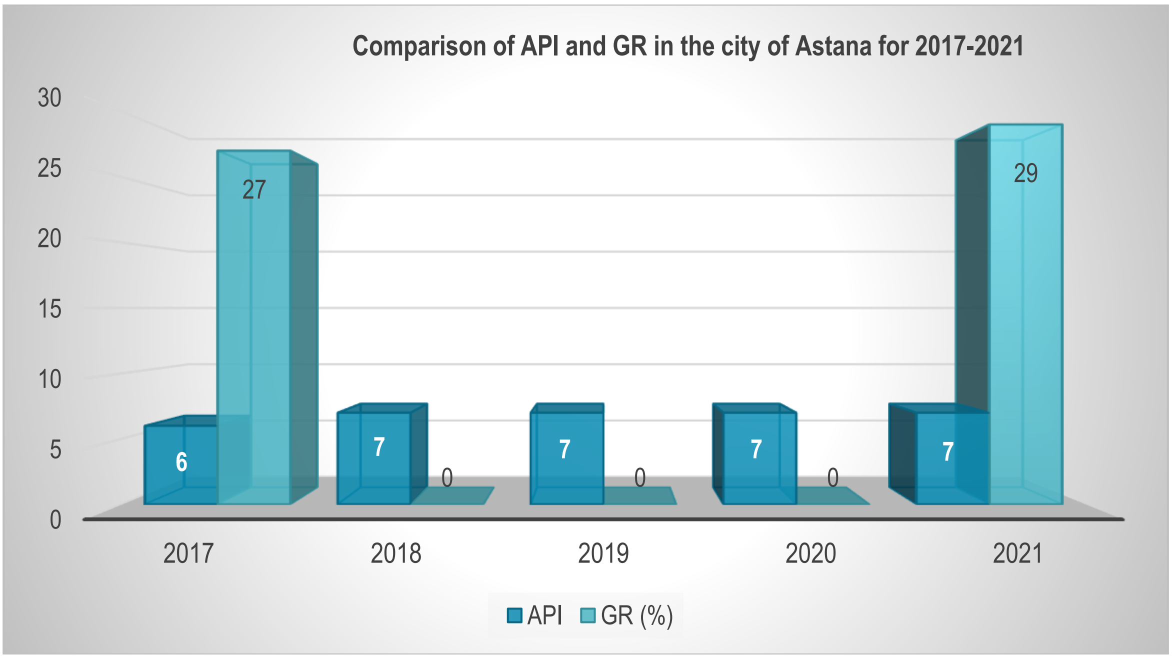


Note - The figure was composed by the author based on the data https://informburo.kz/novosti/v-kakix-regionax-kazaxstana-samyi-zagryaznyonnyi-vozdux

Figures 1 and 2 show that in 2021 the volume of pollutants from all stationary sources amounted to 34.3 million tons, of which 31.9 million tons (93%) were captured and neutralized. And the volume of pollutants emitted into the atmospheric air amounted to 2.4 million tons, which is 2% more than in 2017. From the data in the regional breakdown(разрез), it can be seen that one of the leaders in terms of pollutant emissions is the Central Kazakhstan region. Of the 2.4 million tons of emissions into the atmosphere, 2.1 million tons were generated by the industrial sector. At the same time, most of the emissions are in the heat and power supply segment - 945 thousand tons, followed by the manufacturing industry - 728 thousand tons, as well as mining and quarrying - 357 thousand tons. Sector of transportation and warehousing caused the emission of 114.4 thousand tons of pollutants into the atmosphere (https://informburo.kz/novosti/v-kakix-regionax-kazaxstana-samyi-zagryaznyonnyi-vozdux).

Analysis of data on API indicators for the Central Kazakhstan regions (Astana, Karaganda, Zhezkazgan) over the past 5 years (Fig. 3-5) showed that these regions belong to cities with a very high level of atmospheric pollution air.

Figure 3. Indicators of API and GR for the city of Astana for 2017-2021



According to figure 3 and the assessment of the air pollution degree in Astana for the period from 2017 to 2021, according to the criteria of API and GR, it belongs to the 3rd degree, that is, to a high level of air pollution. The main reason for this is the poor environmental situation in the region, i.e. emissions of pollutants into the atmosphere from numerous vehicles, the private sector, etc.

Analysis with other regions of Central Kazakhstan showed the deterioration of the atmospheric air.

Figure 4. Indicators of API and GR for the city of Karaganda for 2017-2021

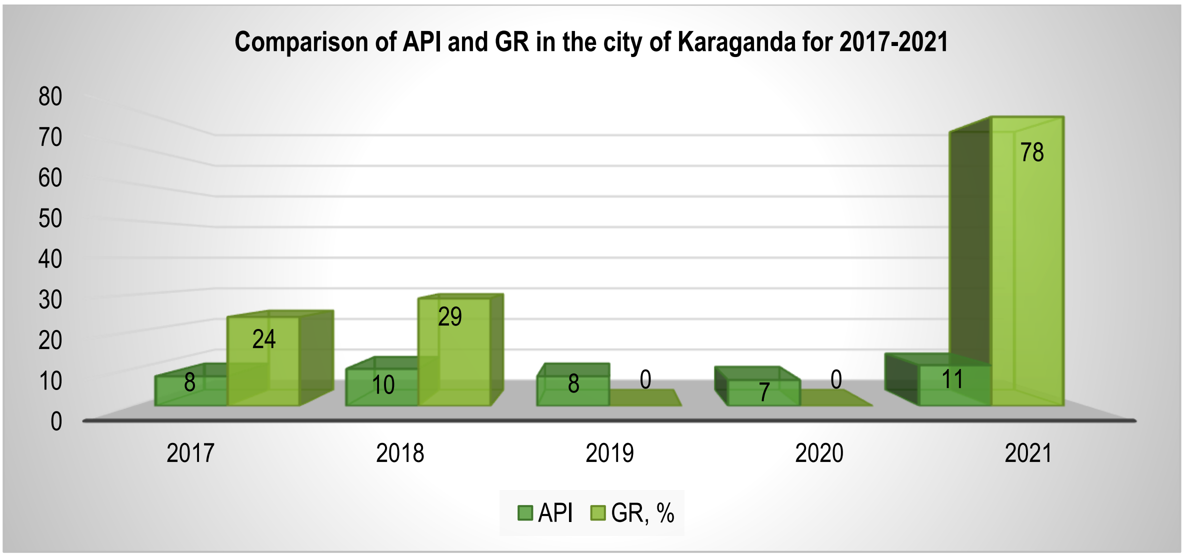


Figure 4 shows that the environmental situation in Karaganda is even worse than in the capital of the republic. Here, API and GR indicators tend to increase from 2017 to 2021. For example, API increased from 8 to 11, which, according to the assessment of air pollution, refers to high (class 3) pollution, and the GR indicator increased 3.25 times from 24 in 2017 to 78 in 2021. The reason for the poor environmental situation was the negative impact of industrial facilities on the environment and inefficient natural resource management policy in the region. The environmental indicators of another industrially developed region of Central Kazakhstan, the city of Zhezkazgan, showed that this city also has air pollution (Fig. 5).

Figure 5. Indicators of API and GR for the city of Zhezkazgan for 2017-2021

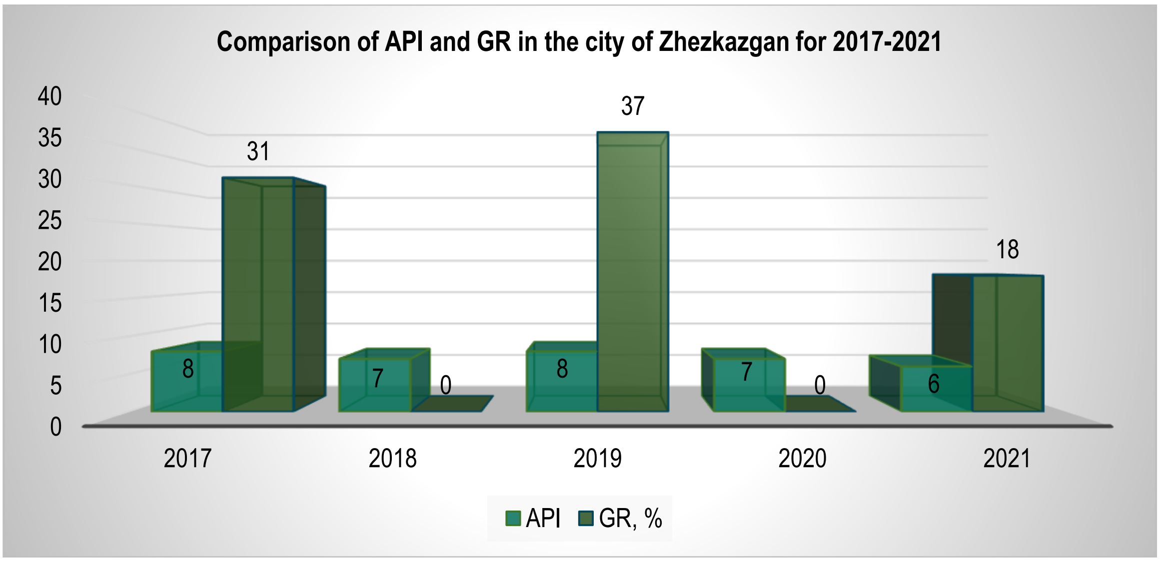


Figure 5 shows the analysis of API and GR indicators of Zhezkazgan for 2017-2021, which shows that the environmental indicators of atmospheric air are at a high level and, according to the assessment of atmospheric pollution, this region can be classified as class 3 in terms of pollution (the region with a high level of pollution). The main cause of environmental problems in this city is also a large industrial load and inefficient environmental protection measures.

One of the important environmental indicators is the level of pollutants in the air. We considered such indicators as PM (2.5) dust and the presence of SO2, CO2, NO2 pollutants in the atmosphere of the mentioned regions for 2017-2021. (Table 3).

Table 3. The content of pollutants in atmospheric air for 2017-2021 in the context of the regions of Central Kazakhstan (mg/m^3)

Regions	Indicators	API	2017	2018	2019	2020	2021	Average value
Astana	PM (2,5)	0,16	0,7	0,88	1,27	3,17	1,394	1,4828
	SO_2	0,5	0,931	1,15	2,0	0,26	2,0	1,2682
	CO_2	5,0	10	12,92	35,03	45,19	30,994	26,8268
	NO_2	0,2	1,74	1,68	1,29	0,19	0,996	1,1792
Karaganda	PM (2,5)	0,16	2,5	3,320	3,163	1,53	3,284	2,7594
	SO_2	0,5	0,466	0,303	0,14	3,26	0,420	0,9178
	CO_2	5,0	72	27,252	19,0	36,09	13,60	33,5884
	NO_2	0,2	0,46	0,304	0,313	1,09	0,375	0,5084
Zhezkazgan	PM (2,5)	0,5	1,0	1,100	0,084	1,0	0,50	0,7368
	SO_2	0,5	2,120	4,310	0,995	2,52	1,12	2,213
	CO_2	5,0	20	13,0	7,7	17,0	10	13,54
	NO_2	0,2	0,57	0,340	0,45	0,53	0,11	0,4

Note – composed by the author according to https://www.kazhydromet.kz/ru/ecology/ezhemesyachnyy-informacionnyy-byulleten-o-sostoyanii-okruzhayuschey-sredy

From the data of Table 1, as well as according to the maximum permissible concentrations (MPC) of pollutants in the air of populated areas, we see that almost all indicators in the studied regions are several times higher than the MPC level, for example, in 2017, indicators of PM (2.5) in Astana exceeded the maximum permissible concentration level by 4.4 times and showed 0.7 mg/m3, and in 2020, this figure was 3.17 mg/m3, which is 19.8 times higher than the MPC. As for the content of other pollutants in the atmospheric air in Astana, we also see indicators that are many times higher than the MPC, for example, the content of sulfur dioxide (SO2) in the atmospheric air in 2017 amounted to 0.931 mg/m3, which is 1.9 times above MPC, in 2018-2021 this indicator also exceeds the maximum permissible concentration level. For nitrogen dioxide (NO2) and carbon monoxide (CO2) in Astana for 2017-2021 there is also an excess of the MPC level by several times: in 2017, the NO2 indicator was 1.74 mg/m3, which is 8.7 times higher than the MPC, and the CO2 indicator exceeded the MPC level by 9 times and amounting to 45.19 mg/m3.

From the data of table 1 for other studied regions, it is also clear that the indicators are several times higher than the MPC, for example, in Karaganda, the PM (2.5) indicator in 2017 was 2.5 mg/m3, and in 2021 3.284 mg/m3, which is 15.92 and 20.526 times higher than the MPC mg/m3, respectively. As for the indicator of sulfur dioxide (SO2) in Karaganda, the highest level was registered in 2020, which exceeded the MPC by 6.5 times and amounted to 3.26 mg/m3. An analysis of the level of nitrogen dioxide (NO2) in this region showed that the highest indicator was also in 2020, which amounted to 1.09 mg/m3 (5.5 times higher than the MPC level), the indicator of carbon monoxide (CO2) for 2017 and 2020 exceeded the MPC level by 14.5 and 7.2 times and amounted to 72 mg/m3 and 36.09 mg/m3, respectively.

In Zhezkazgan, the highest PM (2.5) was registered in 2017. It amounted to 1.0 mg/m3, which exceeded the MPC by 6.2 times. For other indicators, the analysis determined the highest levels of pollution in 2018 for sulfur dioxide (SO2), which amounted to 4.13 mg/m3 (8.62 times higher than the MPC), for nitrogen dioxide (NO2) in 2017 - 0, 57 mg/m3 (2.9 times higher than the MPC), for carbon monoxide (CO2) the highest rate was in 2017 - 20 mg/m3, which was 4 times higher than the MPC level.

Further, for clarity, we will convert the data of the above-mentioned table into a diagram, in particular, the average values of PM (2.5) dust. Using the mapping method, we will continue to analyze the dynamics of the level of PM (2.5) and the standard deviation by region for the analyzed period (Fig. 6).

Figure 6. Dynamics of the PM (2.5) level and standard deviation by region for 2017-2021

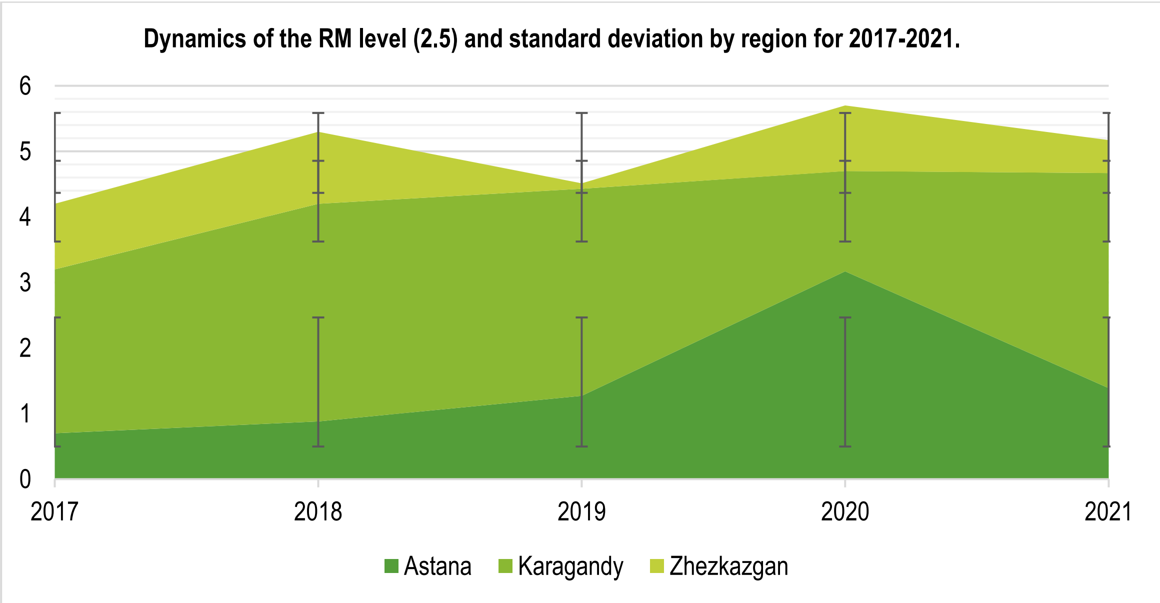


Figure 6 shows that the dynamics of the PM(2.5) indicator in Astana for 2017-2021 ranged from 0.7 mg/m3 to 3.17 mg/m3, and the standard deviation was 0.984. In Karaganda, the dynamics ranged from 1.52 mg / m3 to 3.32 mg / m3, the standard deviation was 0.762, and in Zhezkazgan, this indicator PM (2.5) ranged from 0.08 to 1.1 mg / m3 with a standard deviation of 0.435.

The mortality rates of the population by main classes of death causes for 2017-2021 by region are given in Table 4.

Analysis of population mortality rates by main classes of death causes for 2017-2020 in a regional breakdown. Thus, in the Republic of Kazakhstan, the mortality rate in 2017 was 715.22, and in 2020 it increased by 20.2% and amounted to 860.24. When analyzing the causes of mortality of the population, diseases associated with the negative impact of the environment were selected, thus, having examined the mortality rates from malignant neoplasms, we note that in general in the Republic of Kazakhstan from 2017 to 2020 the trend is declining, yet in the Karaganda region, on the contrary, this indicator in 2017 was 957.34, and in 2020 it increased by 8.7% and amounted to 94.67. In Astana, this indicator also tends to decrease.

Table 4. Mortality rates of the population by main classes of death causes per 100,000 people for 2017-2020 in a regional breakdown

	Total mortality rate				
	2017	*2018*	*2019*	*2020*	*2020 to 2017 in %*
Republic of Kazakhstan	715,22	713,75	719,08	860,24	20,3%
Karaganda region	957,34	968,15	973,65	1124,58	17,5%
Astana	389,56	395,74	391,05	532,18	36,6%
	Malignant neoplasms				
Republic of Kazakhstan	83,90	80,81	79,30	78,66	-6,2%
Karaganda region.	87,07	92,35	89,79	94,67	8,7%
Astana	82,27	86,39	79,20	70,84	-13,9%
	Circulatory system diseases				
Republic of Kazakhstan	174,83	167,28	163,14	193,79	10,8%
Karaganda region.	314,27	321,34	325,47	351,86	12%
Astana	123,10	124,80	115,87	129,19	5%
	Respiratory diseases				
Republic of Kazakhstan	92,22	86,92	87,89	122,88	33,2%
Karaganda region.	101,33	94,02	90,22	98,15	-3,1%
Astana	31,25	30,44	31,07	52,57	68,2%
Note – composed by the authors					

In 2017, the indicator was 82.27, which is 13.9% higher than in 2020 (70.84). The dynamics of mortality from diseases of the circulatory system, which tends to increase, was also taken into consideration. In the Republic of Kazakhstan from 2017 to 2020 indicators increased by 10.8% from 174.8 to 193.7. In the Karaganda region and Astana, this indicator also tends to increase by 12% and 5%, respectively, from 314.27 to 351.86 in the Karaganda region and from 123.10 to 129.19 in Astana.

Assessment of atmospheric air quality and the interrelationship of environmental and social indicators for 2017-2021 on the example of Astana is reflected in table 5.

Table 5. Correlation matrix of ecological and social indicators for the city of Astana for 2017-2021

	GR	API	PM(2,5)	SO2	NO2	CO2	Mortality	Malignant neoplasms	Circulatory system diseases	Respiratory diseases
GR	1									
API	1	1								
PM(2,5)	1	0,445	1							
SO_2	1	0,474	0,004	1						
NO_2	-1	-0,497	-0,974	-0,225	1					
CO_2	1	0,628	0,854	0,389	-0,911	1				
Mortality	-	0,357	0,977	-0,101	-0,958	0,752	1			
Malignant neo-plasms	-	-0,263	-0,931	-0,222	0,952	-0,898	-0,881	1		
Circulatory system diseases	-	0,017	0,571	-0,717	-0,502	0,104	0,727	-0,356	1	
Respiratory diseases	-	0,313	0,977	-0,094	-0,962	0,761	0,998	-0,905	0,705	1

Note – composed by authors

From the tables we see a strong connection between studied indicators. Thus, the interrelationship between environmental and social indicators in the city of Astana is very high. The matrix shows that there is a direct correlation between mortality and atmospheric air pollution with carbon dioxide (the Pearson index is 0.75), and there is also a very large dependence of mortality on pollution with PM 2.5 particles (the Pearson index is 0.97). And further analysis shows a direct correspondence between mortality and respiratory diseases (Pearson's index is 0.98), which may be precisely due to the state of atmospheric air in the city. It is also seen that mortality is correlated with circulatory diseases (Pearson's index is 0.72).

There is a very strong correlation between malignant neoplasm rates in the city of Astana and nitrogen dioxide pollution (Pearson's index is 0.95). When it enters the human body in the form of a gas, the dissolution of nitrogen dioxide occurs inside the lungs, which is why nitrogen dioxide negatively affects the mucous membranes of the respiratory system and causes burns. It has been proven that constant inhalation of contaminated air leads to oncological diseases.

There is also a relation between pollution with dust particles PM 2.5 and respiratory diseases (Pearson's index is 0.97), which can be the influence of pollutants on the health of the population in this nosological group.

Conclusions and Further Research

In Kazakhstan, the main causes of air pollution are transport and warehousing. Analysis of data on indicators of the Atmospheric Pollution Index for the Central Kazakhstan regions (Astana, Karaganda, Zhezkazgan) over the past 5 years prove that these regions are cities with a very high level of air pollution. The main reason for this is the poor environmental situation in the region, in other words, emissions of pollutants into the atmosphere from numerous vehicles, the private sector, etc.

In Zhezkazgan, the environmental indicators of atmospheric air are at a high level and, according to the assessment of atmospheric pollution, this region can be classified as class 3 in terms of pollution (the region with a high level of pollution).

In Astana, social indicators of development showed the dependence of morbidity on environmental pollution, atmospheric air. The dynamics of mortality from diseases of the circulatory system is increasing across Central Kazakhstan and Kazakhstan in general. In the city of Astana, this indicator also tends to increase.

From the matrix of dependence of morbidity and mortality on the state of atmospheric air, it can be seen that there is a direct correspondence between mortality and atmospheric air pollution with carbon dioxide and PM 2.5 particles. There is a correlation between indicators of malignant neoplasms in the city of Astana and nitrogen dioxide pollution. There is also a relationship between contamination with PM 2.5 dust particles and respiratory diseases. Preventing disease and death from pollution will require tightening of the EPA's air quality standards. Robust prevention will require a government-driven transition to renewable energy sources, combined with a phase-out of subsidies and tax credits for fossil fuels. Highly localized information about the health effects of air pollution can catalyze pollution prevention.

Credit Authorship Contribution Statement

The authors contributed equally to this study.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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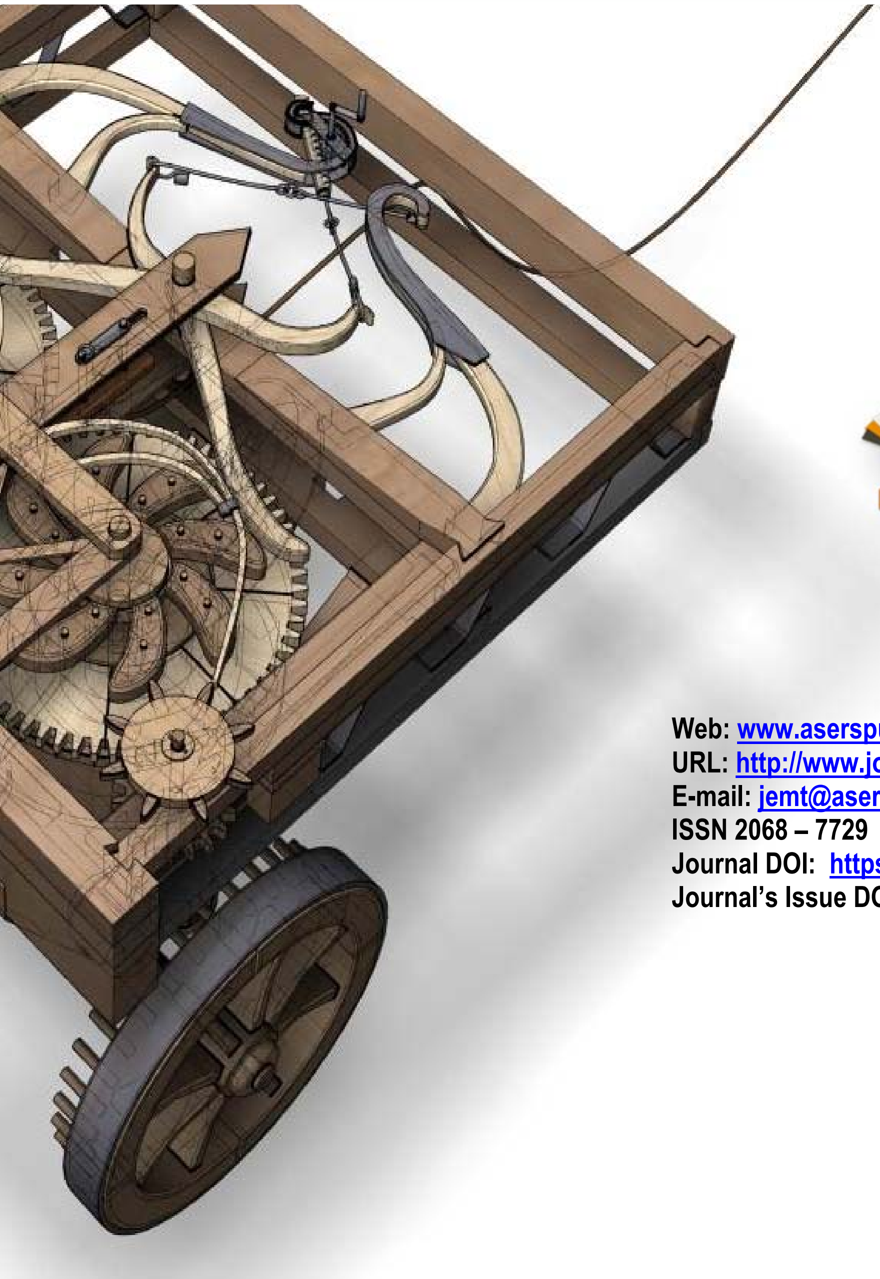

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