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Article

Assessment of Atmospheric Air Quality in the Region of Central Kazakhstan and Astana

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Abstract: One of the main issues of environmental protection is the quality of atmospheric air. These problems are especially acute in industrialized regions, where the level of anthropogenic impact is increasing; in Kazakhstan, Central Kazakhstan belongs to such regions. The purpose of this study is to study the relationship between diseases of the population and air pollutants from industrial sources. The research methodology was the use of ArcGIS tools and the construction of a correlation between two parameters: pollution and morbidity in the region. Analysis of mortality rates of the population by main classes of causes of death for 2017–2020 in the regional context in the Republic of Kazakhstan revealed that the mortality rate in 2020 increased by 20.2%. When analyzing the causes of death of the population, diseases associated with the negative impact of the environment were selected. It was noted that, in general, in the Republic of Kazakhstan from 2017 to 2020, there was a downward trend, but in the Karaganda region, in 2020, it increased by 8.7%. In Astana, this indicator also tended to decrease, but as a result, a very strong correlation was found between the incidence of malignant neoplasms in Astana and nitrogen dioxide pollution (Pearson index 0.95).

Keywords: air environmental protection; air quality assessment; air pollutants; pollution index statistics; health threat

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1. Introduction

Air pollution is pollution of the internal or external environment by any chemical, physical, or biological material and alteration of the natural properties of the atmosphere. Air pollution is caused by natural factors such as volcanic eruptions, wildfires, or excessive evaporation, as well as increased traffic, especially caused by anthropogenic activity, such as urban fuels or industrialization. Each year, countries keep statistics on deaths caused by different types of direct air pollution or caused by diseases due to these types of pollution [1].

The study by the Turkish authors analyzes the impact of a country's geographic region and population density on mortality due to air pollution. The dataset for Turkey and twenty-six countries covers information such as population density, levels of different types of pollution, the number of deaths caused by each type of pollution, and their relation to the current population for the period from 1990 to 2017. In data analysis, air pollution types were studied one by one, and an attempt was made to identify similarities between countries. As a result of this analysis, it was shown that there are similarities between Turkey and other neighboring countries in the deaths observed due to different types of air pollution [2].

The World Health Organization attributed more than four million premature deaths to atmospheric air pollution in 2016. Numerous epidemiological studies show that acute respiratory tract infections and exacerbations of pre-existing chronic respiratory diseases can be the result of exposure to atmospheric (outdoor) air pollution. Nevertheless, the atmosphere contains both chemical and microbial pollutants (bioaerosols), the impact of which on human health remains unclear [3].

Particulate matter pollution in urban areas is a major health problem. Trees in cities can remove small particles from the atmosphere and therefore improve air quality and human health. Some authors describe the impact of trees on PM 2.5 particle concentrations and human health and modeled this interaction for 10 US cities [4]. According to their research, the total number of PM 2.5 particles removed annually by trees ranged from 4.7 tons in Syracuse to 64.5 tons in Atlanta. The presence of trees reduced the number of particles in the cities, which led to a decrease in mortality levels in these regions. The decline in mortality was typically around 1/year per city, but as high as 7.6/year in New York. The average annual percentage of air quality improvement ranged from 0.05% in San Francisco to 0.24% in Atlanta [4]. Therefore, this shows that the impact of urban trees on air quality can lead to improving the health of people in cities.

As previously observed, atmospheric air pollution is caused by various natural and anthropogenic activities. Growing air pollution has a variety of adverse effects on the health of people and other living beings. However, during the rainy season, there is a significant decrease in the concentration of air pollutants. Recently, a number of studies have been carried out to understand the mechanism of removal of air pollutants by rain. These studies have shown that rain removes many air pollutants from the environment [5]. This shows that the climatic features of the regions also matter when considering the relationship between public health and the environment.

Emissions from anthropogenic activities are known to have detrimental effects on human health and ecosystems, and therefore a significant amount of time, effort, and money has been spent developing legislation to minimize their impact. Studies have used the modern combined HadGEM2-ES chemistry–climate model with advanced tropospheric chemistry to estimate the impact of changes in emissions from anthropogenic activities on the load and effect of air pollutants over the past three decades. This HadGEM2-ES model demonstrated that more than 500,000 early deaths per year are reduced due to a significant reduction in sulfate aerosol and up to 8000 early deaths per year are reduced because of improved ozone and nitrogen dioxide pollution as a result of the air pollution legislation. These results highlight the importance of legislation in reducing air pollution-related deaths in these parts of the world and underline the good reasons for developing regions to follow it [6].

In the research studies of Russian scientists, based on known approaches to risk assessment, estimates of the number of attributable deaths from air pollution in Russian cities were obtained. This assessment evaluates the impact of air pollution on public health. The estimates presented in this paper provide important information about the possible scale of the consequences for the health of the Russian population due to atmospheric pollution [7].

Air pollution is one of the 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 are 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 (NO_2), and particulate matter (PM 10 and PM 2.5) 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) [8].

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 nitrogen dioxide (NO_2) is associated with an accelerated decline in static lung volume and diffusive capacity in the elderly. Air pollution associated with nitrogen dioxide (NO_2) may be a risk factor for restrictive lung diseases [9].

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 such region 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 [10]. 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 [11].

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 that 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, the spread of pollutants, and their impact on the environment and human health.

Hypothesis. *Show the relationship between air pollution and mortality in areas with high levels of pollutants.*

To assess the quality of atmospheric air, it is necessary to take into account both environmental and social indicators. In this paper, among the environmental indicators, we will consider the API (atmospheric pollution index), indicators of the highest concentration, and PM (suspended matter), sulfur dioxide (SO_2), carbon dioxide (CO_2), and nitrogen dioxide (NO_2) levels; among social indicators, we will show the level of mortality by main classes of death causes by region over the past 5 years (from 2017 to 2021).

2. Materials and Methods

2.1. Study Area

Central Kazakhstan is an economic and geographical region of the Republic of Kazakhstan. The population is 1,385,533. After the administrative/territorial reform of 1997, it included the enlarged Karaganda region with the center in the city of Karaganda. Until 1997, the disbanded Dzhezkazgan region belonged to Central Kazakhstan. However, in 2022, in the western part of the region, by the decree of Kassym-Jomart Tokayev, the Ulytau region was formed, with the center in Zhezkazgan, since then, Central Kazakhstan has been represented by two regions. The economy of Central Kazakhstan is traditionally based on ferrous and non-ferrous metallurgy, mechanical engineering, and animal husbandry. The landscapes of the region in the north are represented by dry Kazakh small hills, and in the south—steppes and semi-deserts, abutting the northern shore of Lake Balkhash. The river network is poor and low in water.

Figure 1 shows the object of study—the territory of Central Kazakhstan. Central Kazakhstan occupies the space of steppe and semi-desert zones within two large orographic and geomorphological units: the Turgai plateau in the west and the Kazakh small hills in the center and in the east. The physical and geographical differentiation of the territory of Central Kazakhstan is determined by the intersection of the latitudinal zonal boundaries with the meridional geological and geomorphological boundary separating the Turgai Plateau and the Kazakh small hills.

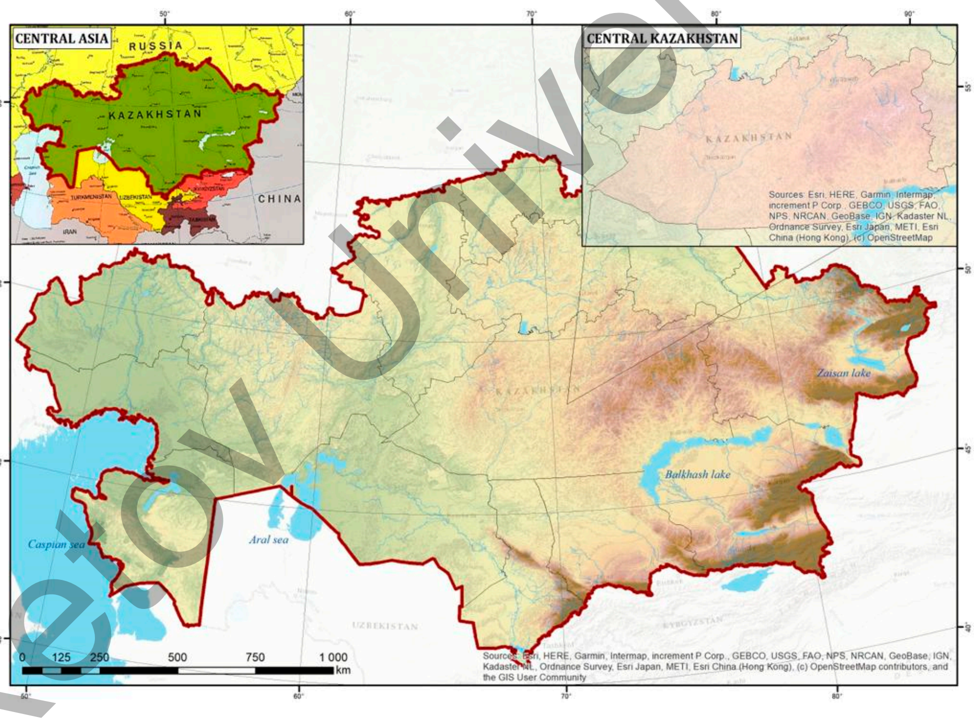

Figure 1. Territory of Central Kazakhstan. (Main map is Kazakhstan geophysical map. On the left side of the map: Kazakhstan location (green color) in the Central Asia. Central Kazakhstan (light red color) is on the right top of the map.)

The economy of Central Kazakhstan is traditionally based on ferrous and non-ferrous metallurgy, mechanical engineering, and livestock farming. The landscapes of the region in the north are represented by the dry Kazakh small hills, and in the south—steppes and semi-deserts, abutting the northern shore of Lake Balkhash. As a megapolis, which is located closer to Central Kazakhstan, the capital of Kazakhstan, Astana, which is geographically located in the northern part of Kazakhstan, was also taken as the object of study.

2.2. Research Methods

The technical route for the overall study is described in Figure 2. The successive stages of the study are shown. Initially, the area for the study was chosen as the most vulnerable area to pollutants based on the industrial agglomeration in the area. Then, statistical materials are collected and the relationship between pollutants and mortality is shown.

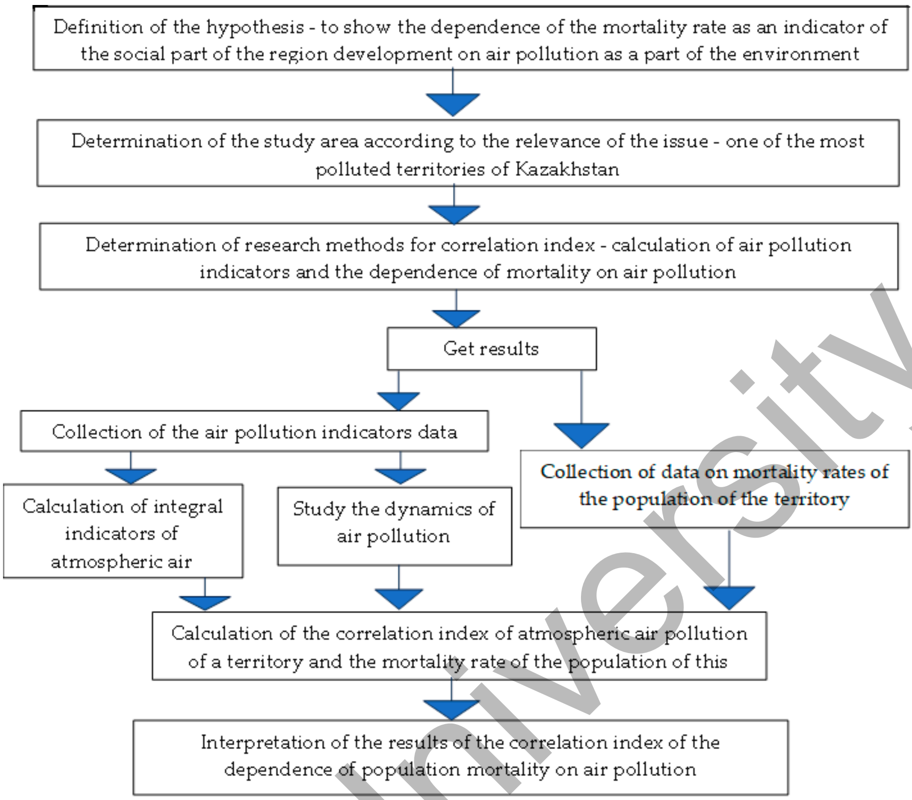

Figure 2. Technical route for the study.

2.2.1. Methods of Statistical Analysis

In the process of studying the atmospheric air quality at the regional level, various methods were used, including the mapping method, mathematical methods of data analysis, and the correlation method. The statistical process flowchart given below in Figure 3 describes what steps were taken to statistically analyze and interpret the data.

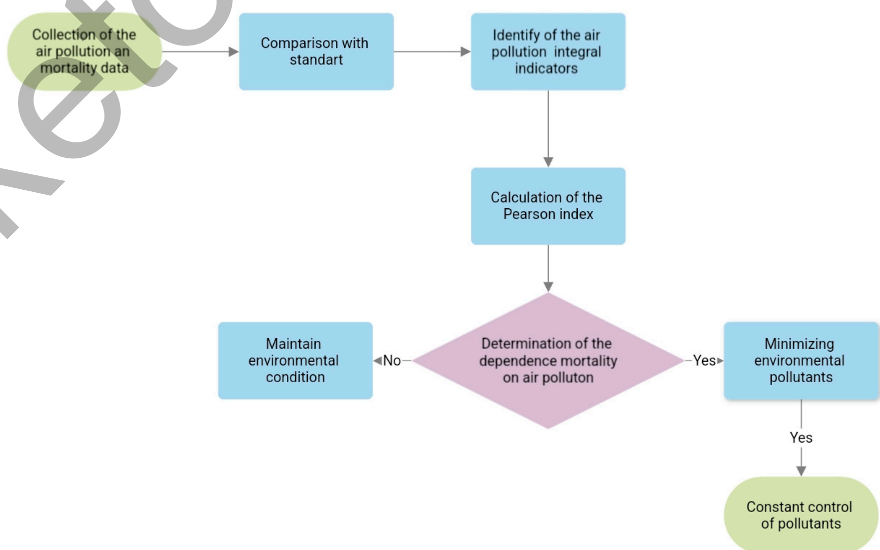

Figure 3. Statistical process flowchart.

Statistical Observation and Grouping Methods

For further research, the atmospheric pollution index (API) and the greatest repeatability (GR) indicators were calculated.

The atmospheric pollution index (API) is an indicator that determines the level of air pollution and its effect on human health. To calculate the API, average daily concentrations of substances are used, which makes it possible to determine the effects of long-term exposure to impurities.

The API is calculated by the following formula:

$$APIi = \sum(q_{av}/MPC_d)Ci$$

where i—pollutants; Ci is a constant taking values of 1.7, 1.3, 1.0, and 0.9 for the corresponding hazard classes of substances 1, 2, 3, and 4 and taking into account the degree of harmfulness of the i-th pollutants to the harmfulness of SO_2; q_{av} is the arithmetic mean of the average daily concentrations measured during the year; and MPC_d—the value of the maximum permissible average daily concentration of a harmful substance [12].

To assess the level of pollution for a month, two indicators are used: SI (standard index), the highest measured concentration of an impurity, divided by MPC_{daily} and GR—the greatest repeatability of exceeding the MPC by single impurity concentrations (expressed in %).

To assess the quality of air pollution per day, the SI indicator is used. The level of air pollution is assessed in 4 categories according to SI and NP values [13].

When studying the dynamics of pollutant emissions into the atmosphere throughout Kazakhstan, statistical observation and grouping methods were used via selection. For environmental criteria, the indicators chosen were the atmospheric pollution index (API), which is a complex index of atmospheric pollution that takes into account several pollutants, and the greatest repeatability (GR), which is the greatest repeatability (%) of exceeding the maximum permissible concentration (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 and standard index (SI)—the highest measured one-time concentration of a pollutant in the atmospheric air normalized to MPC at the observation point. It is determined from observational data at the post for one impurity or at all posts of the territory under consideration for all impurities for a month or a year and characterizes the degree of short-term pollution (Table 1).

Table 1. Assessment of the atmospheric pollution degree *.

Degree		API	SI	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

* The table was composed by the author based on the data [14].

There are 2 types of maximum permissible concentrations (MPCs): one-time (or single) and daily average. Our studies used the average daily MPC.

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 particulate matter 2.5 (PM 2.5) dust in the atmospheric air and the presence of pollutants, sulfur dioxide (SO_2), carbon dioxide (CO_2), and nitrogen dioxide (NO_2) in the studied regions. This analysis was made using the method of statistical observation, sampling (выборка), 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 (SO_2), nitrogen dioxide (NO_2), and carbon dioxide (CO_2), and the level of maximum permissible concentration (MPC). The analysis of contamination with certain substances was performed by comparing the ratio of the MPC level with the indicators of contamination (Table 2).

Table 2. Hygienic standards of the Republic of Kazakhstan for atmospheric air pollutants for determining API *.

Name of Impurities	**Indicators**		**Hazard Class**
	Maximum Single Permissible Concentration (mg/m³)	**Maximum Permissible Average Daily (mg/m³)**	
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

* On approval of Hygienic Standards for Atmospheric Air in Urban and Rural Settlements. Order of the Minister of Health of the Republic of Kazakhstan dated 2 August 2022. P DSM-70. Registered with the Ministry of Justice of the Republic of Kazakhstan on 3 August 2022 No. 29011.

Further, when analyzing the data, the standard deviation for the regions for 2017–2021 was calculated, and the 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 analog 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 considered.

Linear correlation analysis allows for establishing direct connections between variables based on their absolute values. The formula for calculating the correlation coefficient is constructed in such a way that if the relationship between characteristics is linear, the Pearson coefficient accurately establishes the closeness of this relationship. Therefore, it is also called the Pearson linear correlation coefficient. In general, the formula for calculating the correlation coefficient is

$$r_{xy} = \Sigma(x_i - \overline{x}) * (y_i - \overline{y}) / \Sigma(x_i - \overline{x})^2 * (y_i - \overline{y})^2$$

where x_i—the values taken by the variable X, y_i—values taken by the variable Y, $\overline{x}$—average of X, $\overline{y}$—average of Y.

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 performed, and a correlation matrix was compiled with the identification of the Pearson coefficient in Microsoft Excel.

2.2.2. 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.

During the creation of the map, the ArcGIS version 10.4 program was used. ArcGIS is a complete system that allows you to collect, organize, manage, analyze, exchange, and distribute geographical information. As a world leader among platforms for building and using geographic information systems (GIS), ArcGIS is used by people around the world to apply geographical knowledge in the practical field of public administration, business, science, education, and the media.

A small part of the software functionality was used in this work, but the tools used made it possible to create the necessary material in more detail and correctly.

This study used geographic information system technology to build the map. The geographic information system allows a researcher to determine the total volume of environmental problems, see the complete picture of the situation, anticipate potential risks, and consider them in detail [15,16]. The sequence of the performed procedures and operations is shown in Figure 4.

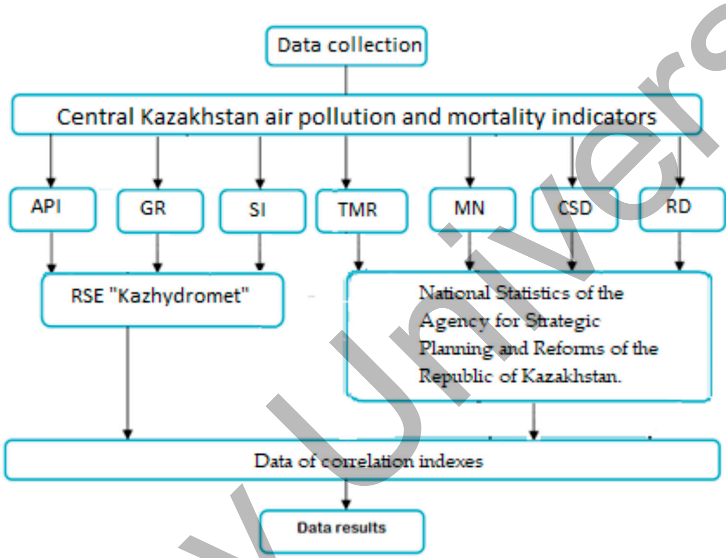

Figure 4. Scheme of the process for creating a map and the correlation dependence of morbidity on atmospheric pollution. API—atmospheric pollution index, GR—the greatest repeatability, SI—standard index, TMR—total mortality rate, CSD—circulatory system diseases, MN—malignant neoplasms, RD—respiratory diseases.

3. Results

3.1. Analysis of Atmospheric Air Pollution in Central Kazakhstan

To begin with, we will analyze the emissions of pollutants into the atmosphere throughout Kazakhstan (Figures 4 and 5).

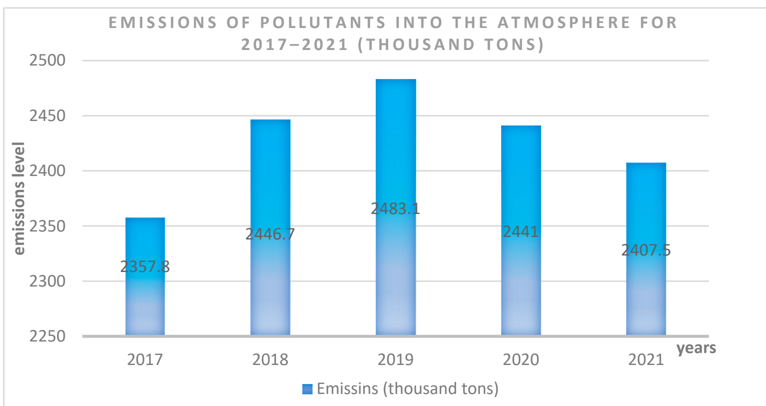

Figure 5. Emissions of pollutants into the atmosphere in the Republic of Kazakhstan from 2017 to 2021. The figure was composed by the author based on the data [17].

Figure 6 shows 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 (Figure 6), 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). The transportation and warehousing sector caused the emission of 114.4 thousand tons of pollutants into the atmosphere [17].

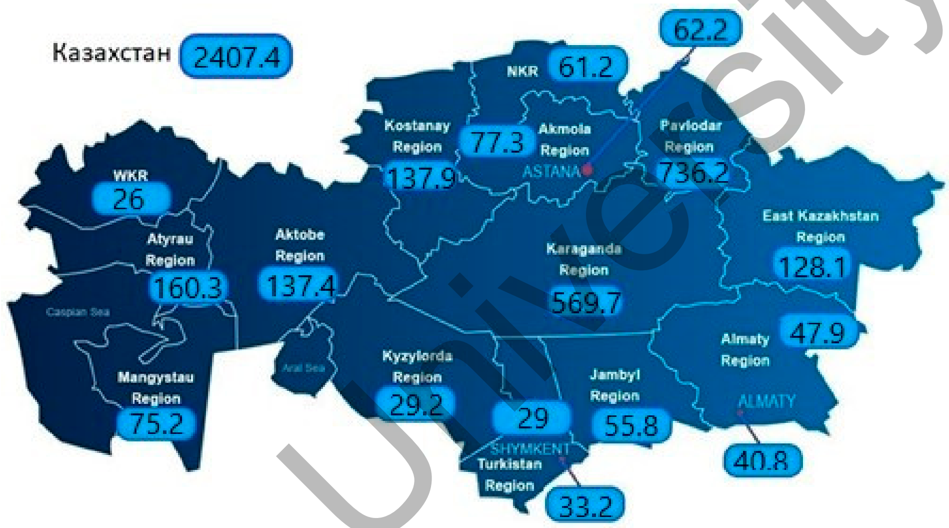

Figure 6. Emission of pollutants (million tons) into the air in the regional breakdown for 2021. Red circle in the map: Astana city is a capital of Kazakhstan. The figure was composed by the author based on the data [17].

Analysis of this data of API and GR indicators for the Central Kazakhstan regions (Karaganda, Zhezkazgan) and Astana city over the past 5 years (Figures 7–9) showed that these cities belong to regions with a very high level of atmospheric pollution.

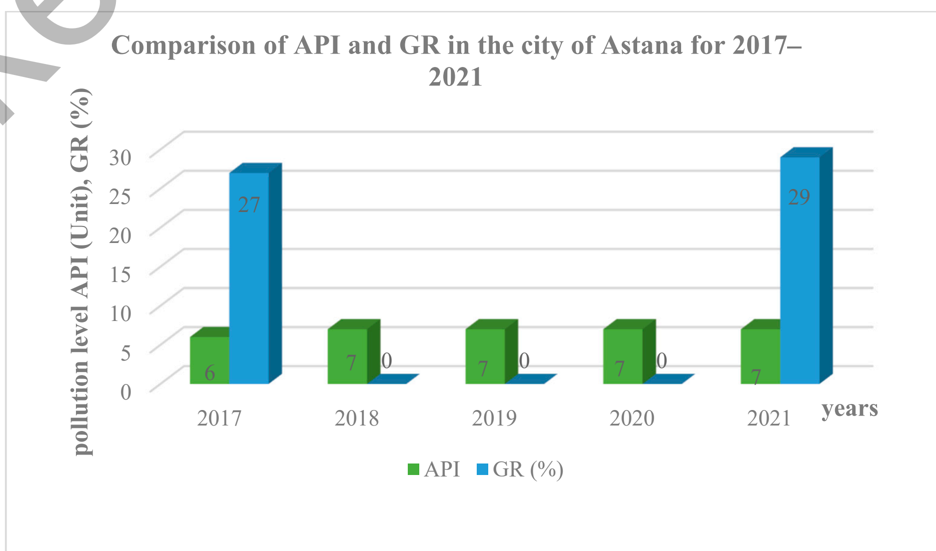

Figure 7. Indicators of API (unit) and GR (%) for the city of Astana for 2017–2021.

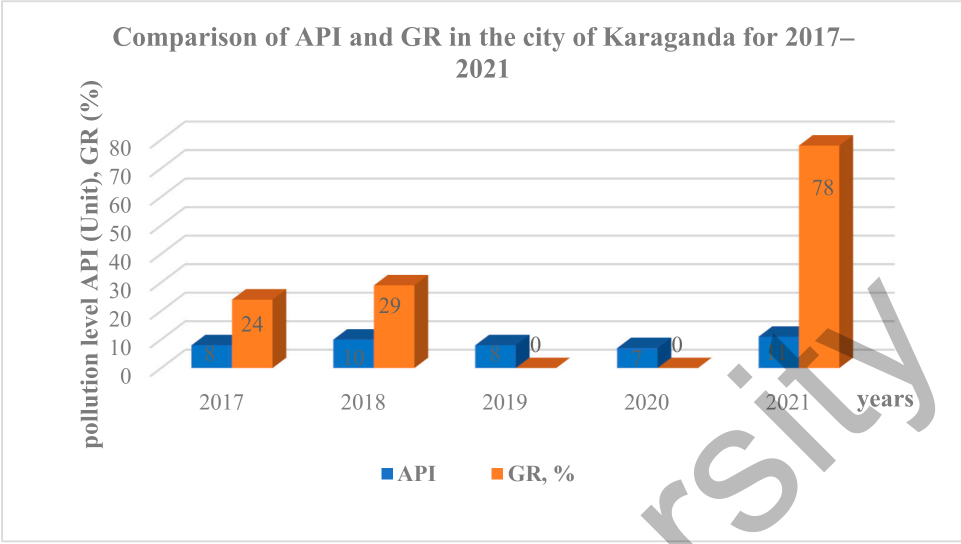

Figure 8. Indicators of API (unit) and GR (%) for the city of Karaganda for 2017–2021.

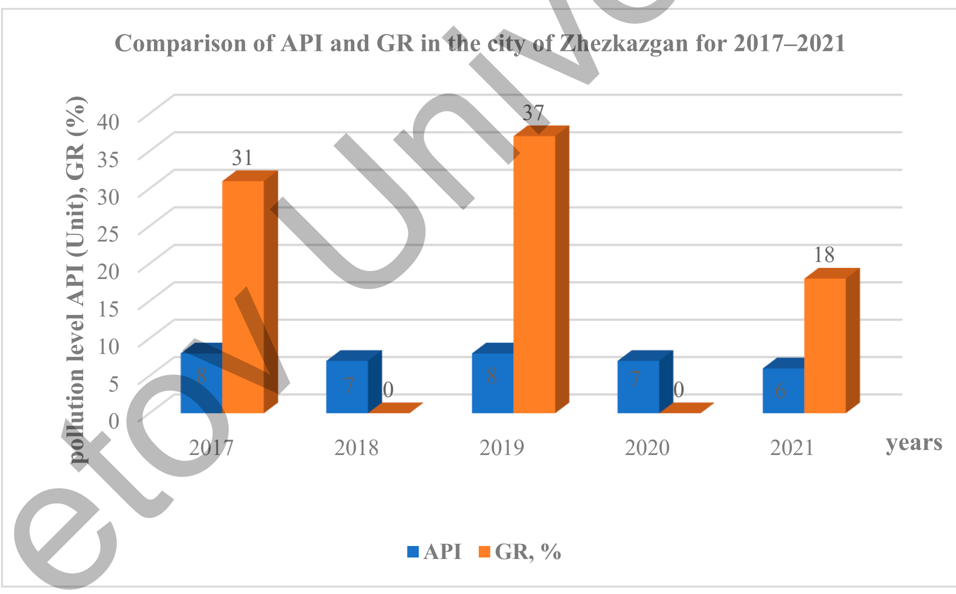

Figure 9. Indicators of API (unit) and GR (%) for the city of Zhezkazgan for 2017–2021.

According to Figure 7 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 of other regions of Central Kazakhstan showed the deterioration of the atmospheric air.

Figure 8 shows that the environmental situation in Karaganda is even worse than in the capital of the republic. Here, API and GR indicators tended 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 (Figure 7).

Figure 9 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 (a 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 sulfur dioxide (SO_2), carbon dioxide (CO_2), and nitrogen dioxide (NO_2) 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.

Regions	Indicators	API (Unit)	2017	2018	2019	2020	2021	MPC Average Daily (mg/m^3)
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

The table was composed by the author based on the data [12].

From the data of Table 3, as well as according to the maximum permissible concentrations (MPCs) 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, at 0.7 mg/m^3; in 2020, this figure was 3.17 mg/m^3, 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 (SO_2) in the atmospheric air in 2017 amounted to 0.931 mg/m^3, which is 1.9 times above the MPC; in 2018–2021 this indicator also exceeded the maximum permissible concentration level. For nitrogen dioxide (NO_2) and carbon dioxide (CO_2) in Astana for 2017–2021, there was also an excess of the MPC level by several times: in 2017, the nitrogen dioxide (NO_2) indicator was 1.74 mg/m^3, which is 8.7 times higher than the MPC, and the CO_2 indicator exceeded the MPC level by 9 times and amounted to 45.19 mg/m^3.

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/m^3, and 3.284 mg/m^3 in 2021, which is 15.92 and 20.526 times higher than the MPC mg/m^3, respectively. As for the indicator of sulfur dioxide (SO_2) in Karaganda, the highest level was registered in 2020, which exceeded the MPC by 6.5 times and amounted to 3.26 mg/m^3. An analysis of the level of nitrogen dioxide (NO_2) in this region showed that the highest indicator was also in 2020, which amounted to 1.09 mg/m^3 (5.5 times higher than the MPC level), and the indicator of carbon monoxide (CO_2) for 2017 and 2020 exceeded the MPC level by 14.5 and 7.2 times and amounted to 72 mg/m^3 and 36.09 mg/m^3, respectively.

In Zhezkazgan, the highest PM 2.5 was registered in 2017. It amounted to 1.0 mg/m^3, which exceeded the MPC by 6.2 times. For other indicators, the analysis determined the highest levels of pollution for sulfur dioxide (SO_2) in 2018, which amounted to 4.13 mg/m^3

(8.62 times higher than the MPC), and for nitrogen dioxide (NO_2) in 2017–2020, which was 57 mg/m^3 (2.9 times higher than the MPC); for carbon monoxide (CO_2), the highest rate was in 2017–2020 mg/m^3, 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 (Figure 10).

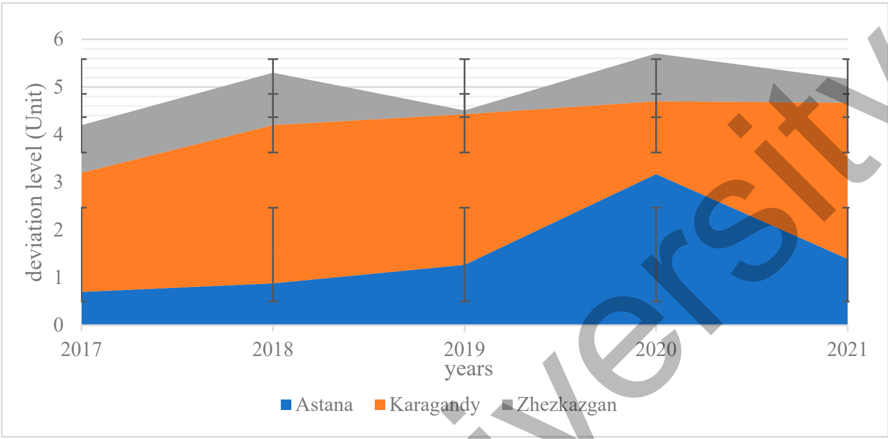

Figure 10. Dynamics of the PM 2.5 level and standard deviation by region for 2017–2021.

Figure 10 shows that the dynamics of the PM 2.5 indicator in Astana for 2017–2021 ranged from 0.7 mg/m^3 to 3.17 mg/m^3, and the standard deviation was 0.984. In Karaganda, the dynamics ranged from 1.52 mg/m^3 to 3.32 mg/m^3, and the standard deviation was 0.762, and in Zhezkazgan, this PM 2.5 indicator ranged from 0.08 to 1.1 mg/m^3 with a standard deviation of 0.435.

3.2. Mortality Rates of the Population in Central Kazakhstan

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

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**	**The Percentage Increase in 2020 Relative to 2017**
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%

The table was composed by the author based on the statistical data according to the Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan (https://stat.gov.kz/ru/, accessed on 1 August 2023).

Table 4 provides an 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 was declining; however, in the Karaganda region, this indicator was 957.34 in 2017, and it increased by 8.7% in 2020, amounting to 94.67. In Astana, this indicator also tended to decrease. 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 tended to increase, were 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 tended 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.

3.3. Dependence of Mortality Rates from the Atmospheric Air Pollution in Central Kazakhstan

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	SO_2	NO_2	CO_2	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 neoplasms	-	−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

The table was composed by the author.

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.

4. Discussion

Our results show that air pollution in Central Kazakhstan and its associated health effects, depending on the source and location of emissions, corresponds to the extractive industry in the region.

There is also another issue, which is the impact of climate change on air pollution, being discussed in the context of Northern Europe. In this region, projected future air quality levels are determined not only by the consequences of climate change affecting regional and local air pollution, but also by climate factors and events that change hemispheric background pollution levels. In the article by Doherty, RM (Doherty, Ruth M.); O'Connor, FM, the impact of air pollution in Northern Europe related to projections of greenhouse gas emissions and emissions of major pollutants and precursors on the future state of the air is examined. There are studies that also link this exposure to air pollution to future changes in air pollution-related mortality and morbidity in Europe [18]. The peculiarities of the climatic state of Central Kazakhstan on the distribution of industrial emissions in this region also influenced our studies.

Changes in the concentrations of both primary (PM 10, CO, NO_x) and secondary (ozone) pollutants in the atmosphere over the Moscow and Kirov regions, Kyiv, and Crimea in the abnormally hot summer of 2011 are presented and analyzed. The concentrations of ozone, PM 10, CO, and NO_x in the atmosphere over the Moscow region from the end of July to the end of August 2010 almost continuously exceeded the maximum permissible concentration (MPC). The region was in the zone of a strong plume of forest and peat fires. The maximum single concentrations of ozone, exceeding its MPC by two to three times, were accompanied by high concentrations of combustion products: the concentrations of PM 10 and CO also exceeded their MPC by three to seven times. The maximum levels of atmospheric air pollution were observed under meteorological conditions unfavorable for the dispersion of pollution, primarily with a small vertical temperature gradient in the lower boundary layer of the atmosphere. The number of additional deaths due to exceeding the maximum allowable concentrations of PM 10 and ozone in the atmosphere over Moscow was estimated. With weather conditions close to those in Moscow, air quality remained mostly satisfactory in the Kirov region, Kyiv, and Crimea, which were almost unaffected by the fires [19].

Air pollution generally refers to the phenomenon when certain substances, which enter the atmosphere as a result of human activities or natural processes, reach a certain concentration that is sustained long enough to become a threat to human comfort, health, or the environment. If air quality deteriorates, people will breathe poisonous gases. The respiratory system is the first to come into contact with poisonous gases, which can provoke the occurrence of respiratory diseases. In this paper, the authors conducted research on the prevention of respiratory diseases in schools under the background of air pollution based on PM 10 analysis. Univariate linear regression and Pearson's correlation were used to analyze the effect of air pollution on the incidence of respiratory symptoms in students. The results show that air pollutants have adverse effects on the respiratory health of students [20].

The current of the Earth's atmosphere not only largely determines its temperature regime, but also strongly affects the concentration of aerosols. Therefore, the study of methods for assessing the synthetic impact of temperature and aerosol pollution on human health is an important topic. Abnormal temperatures were responsible for much of the mortality burden. Cold temperatures accounted for a significantly higher burden of mortality than warm temperatures. Synthetic effects of mortality from temperature and PM 2.5 varied depending on the stability of the atmosphere. A stable atmosphere creates the strongest synthetic effects of temperature and PM 2.5, while a normal atmosphere provides comparatively favorable conditions for human health. The results of the research indicated that the synthetic health effects of temperature and PM 2.5 induced by airflow need to be considered in the further framing of public health policies and air pollution control strategies, especially in the context of climate change [21].

In many regions of the world, climate change is associated with increased temperature extremes, which can have serious consequences for mortality and morbidity. In this research, we studied the impact of extreme weather conditions on hospitalization in Cyprus inland and coastal areas using synoptic weather classifications (air mass types). In addition, the effect of particulate matter (PM 10) air pollution on disease incidence is being studied. The results show that two types of air masses, namely (a) warm, rainy days with high levels of water vapor in the atmosphere and (b) cold, overcast days with high levels of precipitation, were associated with increased hospital morbidity. This applies to both cardiovascular and respiratory diseases for all age groups, but especially for older people over 65 years of age. Particulate air pollution has also been associated with an increase in morbidity in Cyprus, where the effect was more pronounced for cardiovascular disease [22].

Unplanned urbanization, industrial development, and a huge increase in car traffic led to an exponential increase in pollution. Air pollutants such as nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), particulate matter (PM 2.5 and PM 10), volatile organic compounds (VOCs), ozone (O^{-3}), and heavy metals are found in high concentrations in the atmosphere. Particulate matter with a diameter of 10 µm or less (PM 10) is known to have adverse effects on human health and the environment. Particulate pollution is known to have many environmental consequences, from poor visibility to more severe effects such as acid rain, which contaminates soil and water. The detection of heavy metals in atmospheric air is an important area for environmental researchers due to their toxicity to humans. Some heavy metals (hexavalent chromium (Cr), arsenic (As), cadmium (Cd), and nickel (Ni)) are listed as carcinogens. In addition, heavy metals in the atmosphere can accumulate in various plants and animals and enter the human body through the food chain. Heavy metals have a toxic effect when they are involved in biochemical reactions in living organisms. This study reports on the main sources of particulate matter and heavy metals in the atmosphere, their impact, and sustainable environmental management [23].

Air pollution occurs when any harmful gas, dust, or smoke enters the atmosphere and negatively affects the lives of people, animals, and plants. Moreover, air pollution is found all around us in the air we breathe and in the water we drink, and it can be both natural and man-made.

In this article, we will discuss, analyze, and present our observations and possible solutions regarding various types of air pollution. For example, internal and external, their impact on the environment, health, economy, and ecosystem development. We also considered indoor air pollution and its presence in the environment, workplaces, and homes, where their symptoms were seen to manifest as fatigue, irritation of the eyes and nose, and the most common disease, asthma. We concluded that time of exposure to indoor air pollution has a significant effect on the development of the disease, with respiratory disease, heart problems, and cancer being the most common health problems with long-term exposure. During this work, 14 sources of indoor air pollution were summarized and fully analyzed. With regard to air pollution, most of the implemented scientific studies have classified it as the "great killer of our age", with the presence of more than one substance in the inhaled air above natural limits, and it has been recognized that the main causes of air pollution are agricultural activities, mining, exhaust gases of factories and industries, and combustion of fossil fuels.

For both emission sources (indoor and outdoor), short-term exposure is associated with transient respiratory diseases and high hospital rates, while long-term exposure leads to chronic asthma, lung failure, cardiovascular diseases, and cardiovascular mortality.

An increasing relationship has also been found between mortality/morbidity and air pollution concentrations. Another important issue discussed in this paper is the impact of air pollution on the economy of society and the impact on its sustainable development [24].

Epidemiological data on the relationship between exposure to air pollution and cancer are reviewed. The well-documented differences in lung cancer rates between urban and rural areas and the discovery of known carcinogens in the atmosphere have given rise to the hypothesis that long-term exposure to polluted air may influence the risk of lung cancer. However, the problems inherent to adequate assessment of the effect of interest have led to significant difficulties in assessing this effect. Regularly measured air pollutants generally do not include identified carcinogens, and air pollution measurements are usually made using stationary monitors, making it difficult to assess individual exposure, especially long-term ones. The nature of exposure and associated measurement problems have made environmental comparisons a natural approach to studying the effect of air pollution on lung cancer risk. Descriptive/environmental studies undertaken after 1950 often had problems with inadequate mixing control (контроль смешивания), but generally provided evidence consistent with the hypothesis that urban and industrial air pollution may influence lung cancer risk. The results of several case–control and cohort studies are described in this review with a focus on the used exposure metric. These studies, which control for important potential confounding factors, suggest that urban air pollution may be a risk factor for lung cancer, with an estimated relative risk of up to about 1.5 in most settings [25].

Due to urbanization around the world, anthropogenic dust (AD) emissions have been increasing in recent decades because of intensive urban construction and the use of off-road vehicles. Its impact on urban air pollution on a global scale is still unclear. Based on observations, we found that the high urban optical thickness of AD is often accompanied by a strong optical thickness (сильная оптическая толщина) of dust-free aerosol in the planetary boundary layer (PBL), and both values are even comparable. To investigate the causes, an inventory of AD emissions limited by search data from satellites is implemented in a global climate model. The results show that AD-induced surface radiative cooling down to $-15.9 +/- 4.0$ W m^{-2} in the regions leads to a decrease in the height of the PBL, which worsens non-dust pollution. An estimated total global premature death from asthma is 0.8 million deaths per year and is more severe in densely populated regions [26].

Our results show a strong connection between the 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). 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 PM 2.5 dust particles 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.

5. Conclusions

In Kazakhstan, the main causes of air pollution are transport and warehousing. Analyses of data on indicators of the atmospheric pollution index for the Central Kazakhstan regions (Karaganda, Zhezkazgan) and Astana city over the past 5 years prove that these cities have 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 (a region with a high level of pollution).

In Astana, social indicators of development showed the dependence of morbidity on environmental pollution and 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 tended to increase.

As studies have shown on the relationship between air pollution and population mortality, there is a very strong relationship between the total mortality rate from PM 2.5 particles and mortality from respiratory diseases from PM2.5 particles. There is also a dependence of mortality from carcinogenic diseases on nitrogen dioxide pollution. Carbon dioxide also affects mortality, as our study shows. All this could be a prerequisite for developing a strategy to minimize emissions into the atmosphere.

Preventing disease and death from pollution will require tightening 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.

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