

**Раздел 4. «Экономика. Общеобразовательные, социально-гуманитарные и фундаментальные дисциплины»**FTAMP 03.10.04  
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(E-mail: kirpiczmyh@gmail.com)***Impact of climate change and transport density on the air quality of Almaty metropolis**

This study is aimed at analyzing the impact of climate change and transport density on air quality in the Almaty metropolis. The city has a continental climate due to its location in a mountainous area, which contributes to poor air circulation and the accumulation of pollutants. In addition, the sharp increase in the number of cars in the last decade is worsening the quality of atmospheric air and exacerbating environmental problems. The study identified the relationship between these factors by analyzing the air quality index (AQI), meteorological data, and traffic flow statistics. The results showed that climate change increases temperature inversion and that transport density is the main source of harmful emissions. As a result of the study, it is proposed to develop public transport and strengthen environmental policy.

*Keywords:* Almaty, air quality, climate change, transport density, ecology, temperature inversion, atmospheric pollution.

*Introduction*

Almaty is the largest metropolis and economic center of Kazakhstan. Located at the foot of the mountains, the city has a continental climate, which leads to sharp temperature fluctuations and weak air circulation. In recent years, climate change has been observed at the global and local levels, increasing temperatures and changes in meteorological conditions affect the air quality of Almaty. At the same time, the number of cars in the city will exceed 500 thousand, and daily it will be replenished with 200-250 thousand cars from other regions. This transport density increases the emission of harmful substances into the atmosphere, such as carbon dioxide (CO), nitrogen oxides (NO<sub>x</sub>) and small particles (PM<sub>2.5</sub>, PM<sub>10</sub>). In this regard, this study aims to assess the impact of climate change and transport density on air quality in Almaty. The study seeks to determine how these two factors affect the ecology of the city and how they relate.

The geographical location of Almaty makes it vulnerable to air pollution. Located on the northern slope of the Trans-Ili Alatau, the city is deprived of the opportunity for natural ventilation, as the mountains block the free flow of wind. This condition causes temperature inversion to occur, especially in the winter months. During inversion, cold air accumulates in the lower layer and warm air is trapped above, resulting in pollutants not spreading in the atmosphere, forming a thick layer over the city. Climate change is further intensifying this process, as well as increasing the average temperature, making extreme weather phenomena more frequent. For example, over the past decade, there has been a gradual warming of winter temperatures and a prolongation of summer heat, which negatively affects air circulation.

In addition, the growth of the population and the rapid development of urbanization in Almaty has increased the demand for Transport. Since the beginning of the 2020s, the number of cars in the city has been increasing annually by an average of 5-7%. This includes not only cars of local residents, but also daily commuters from the Almaty region and other regions. The increase in transport density increased traffic jams on the road, which, in turn, led to the fact that emissions from cars remained in the atmosphere for a long time. Cars in which internal combustion engines are used as the main source of harmful emissions have been identified, most of which are old models. In this regard, the concentration of PM<sub>2.5</sub> and PM<sub>10</sub> particles in the air exceeds international standards several times, which poses a threat to the health of residents.

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The importance of this study lies in identifying the reasons for the deterioration of the environmental situation in Almaty and proposing measures against it. Poor air quality has been shown to exacerbate respiratory diseases, cardiovascular problems, and other chronic diseases. Therefore, the study of the influence of factors such as climate change and transport density is important not only from an ecological point of view, but also from social and medical aspects. This study aims to analyze how these two factors affect the ecology of the city and determine their relationship.

The main goal of the study is to assess the climatic and anthropogenic factors that affect air quality and understand how they contribute to the ecological balance in the city. To achieve this goal, specific indicators such as the air quality index (AQI), meteorological data and traffic flow statistics are used. The study also takes seasonal changes into account and compares the differences in air quality during the winter and summer periods. Thus, a complete picture of the air quality of Almaty will be formed.

Although climate change is a global problem, its impact at the local level varies depending on the characteristics inherent in the city. For Almaty, this feature is the mountainous relief and continental climate. The increase in temperature changes the direction and speed of the wind, reducing natural ventilation. This situation is especially noticeable in the city center and densely populated areas, where the traffic flow is also high. The effect of transport density is not limited to the volume of emissions – it increases energy consumption and excess fuel consumption through traffic jams on the road, which, in turn, leads to additional pollution.

Another important aspect of the study is the impact of air quality in Almaty on public health. According to the World Health Organization (WHO), high concentrations of small particles such as PM<sub>2.5</sub> increase the risk of lung cancer, asthma and other respiratory diseases. Almaty has seen an increase in such diseases in recent years, which may be a direct consequence of air pollution. Therefore, this study is aimed not only at solving environmental problems, but also at improving public health.

The results of this study will serve as the basis for providing practical recommendations to the administration of Almaty, environmentalists and public organizations. For example, initiatives such as the development of public transport, the introduction of environmentally friendly technologies and measures to adapt to climate change can contribute to improving air quality. In addition, the study highlights the importance of social campaigns aimed at increasing environmental literacy among urban residents and reducing the use of private cars.

#### *Methodology*

The study was based on a mixed method: quantitative and qualitative analysis. This approach was chosen because it combines the accuracy of quantitative data and the contextual depth of qualitative analysis, allowing a comprehensive study of the impact of climate change and transport density on air quality in Almaty. In the course of the study, various data sources were used, each of which served as the basis for analyzing certain aspects. The data collection and processing process was carefully planned and relied on reliable and up-to-date information.

##### Data sources:

1. Air Quality Index (AQI): as one of the main sources of research AirVision.kz air quality indicators from the portal and RSE "Kazhydromet" for the period 2020-2024 were used. These data include concentrations of pollutants such as PM<sub>2.5</sub> (particles smaller than 2.5 micrometers in diameter), PM<sub>10</sub> (particles smaller than 10 micrometers in diameter), carbon dioxide (CO), nitrogen dioxide (NO<sub>2</sub>), and sulfur dioxide (SO<sub>2</sub>). AirVision.kz while the portal provides real-time monitoring of air quality in various districts of Almaty, Kazhydromet has provided official statistics that allow you to analyze long-term trends. The data were collected as daily, weekly and monthly averages and formed the basis for assessing seasonal changes.

2. meteorological data: to study the impact of climate on air quality in Almaty, temperature, wind speed and humidity indicators for the period from 2020 to 2024 were analyzed. These data were obtained from Kazhydromet Weather Stations and contain information collected from stations installed at various points in the city. To determine temperature inversion, daily temperature profiles were studied and how wind direction

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and speed affect air circulation were assessed. Humidity data were taken into account as an additional factor related to the distribution of pollutants and the formation of atmospheric fog.

3. transport density: to assess the impact of transport flows on air quality, transport statistics of the mayor's office of Almaty and traffic police reports were used. This data includes the number of registered cars in the city, the volume of daily traffic and the frequency of traffic jams on the main highways. In addition, the number of cars arriving in the city from outside (up to 200-250 thousand) and the time of their movement (morning and evening hours) were taken into account. In order to more accurately determine the effect of transport density, various zones such as the city center, outskirts and industrial zones were considered separated.

Analysis methods. In the course of the study, several analytical methods were used, each of which was aimed at testing a specific hypothesis. Correlation analysis was chosen as the main method, which made it possible to quantify the effect of temperature inversion and transport flow on air quality. By calculating the correlation coefficient ( $r$ ), the relationship between climatic factors (temperature, wind speed) and air pollution (PM<sub>2.5</sub>, No. 2) and transport density was determined. For example, studying the correlation between PM<sub>2.5</sub> concentration and transport flow density during temperature inversion helped determine the joint effects of these two factors.

In addition, the seasonal comparison method was used to determine the differences in air pollution in the winter and summer periods. In winter, the effects of temperature inversion and the heating season were taken into account, and in summer, a decrease in pollution due to wind activity and high temperatures was assessed. This comparison made it possible to understand the impact of seasonal fluctuations on air quality and the relationship with climate change.

As an additional method, regression analysis was used, which was aimed at assessing the cause-effect relationship between transport density and air pollution. For example, the relationship between the volume of daily traffic flow (number of cars) and the concentration of CO or PM<sub>10</sub> on the same day was checked using a regression model. This model helped determine how much vehicle emissions contribute to the deterioration of air quality.

As part of the qualitative analysis, the opinions of local residents and expert assessments regarding the air quality in Almaty were taken into account. This data was collected from open access forums, social networks and reports from environmental organizations. Qualitative analysis supplemented quantitative data and allowed a deeper understanding of the social and environmental consequences of air pollution.

Data collection process. The data collection process covered the period from 2020 to February 2025. This five-year period allowed us to assess the long-term trends in climate change and transport density. Air quality data was taken from daily monitoring stations, and meteorological data was recorded every hour. Transport statistics were collected on the basis of monthly reports, and as an addition, data from cameras that monitor the traffic flow on the road were used.

Several measures have been taken to ensure the accuracy of the data. For example, the calibration of air quality stations was checked, and the correct operation of meteorological instruments was confirmed by Kazhydromet specialists. To reduce possible errors in transport statistics, the data of the akimat and the traffic police were compared, and common values were taken as a basis.

Scope and limitations of the study. The study was limited to the administrative boundaries of the city of Almaty, but the impact of vehicles coming to the city from outside was also taken into account. However, the study had some limitations. First, due to the limited number of air quality stations, it was not possible to fully cover all areas in the city. Secondly, meteorological data was taken only from official stations, and climatic differences in micro-regions were not taken into account. Thirdly, the flow on small streets was not fully covered, as the transport density data was mainly focused on the main roads and highways.

Research hypotheses. The study focused on testing the following hypotheses:

1. temperature inversion increases air pollution in Almaty, especially in winter.
2. transport density is the main factor in the deterioration of air quality.
3. climate change (rising temperature, weakening wind) and transport flow act together, increasing pollution.

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The above methods and data sources were used to test these hypotheses. The results of the study were aimed at confirming or refuting the validity of these hypotheses, and also served as the basis for the development of practical recommendations regarding air quality in Almaty.

Data processing and analysis tools. Modern software was used for data processing and analysis. Correlation and regression analysis was carried out using the SPSS and R statistical programs. Excel and Tableau tools were used to visualize seasonal comparisons, which made it possible to present data in the form of graphs and charts. Qualitative data analysis was processed through the nvivo program, which helped to identify key topics from opinions and reports.

In conclusion, this methodology made it possible to comprehensively study the impact of climate change and transport density on air quality in Almaty. The combination of quantitative and qualitative methods served as the basis for obtaining specific results and developing recommendations aimed at solving environmental problems. The next section discusses the results of the study in more detail.

##### *Research results*

In this section, the results of the study on the impact of climate change and transport density on air quality in the Almaty metropolis are fully considered. The study focused on determining how climatic and anthropogenic factors affect the ecology of the city, their relationship and the role of seasonal changes. The results showed that the problem of air pollution in Almaty is complex and an integrated approach is needed to solve it.

Climate change and temperature inversion. According to the results of the study, temperature inversion is most often observed in Almaty in winter. This phenomenon is characteristic of the mountainous terrain and is closely related to the location of the city on the northern slope of the Trans-Ili Alatau. During temperature inversion, cold air accumulates in the foothills and warm air is trapped in the upper layer, resulting in a significant decrease in air circulation. This situation inhibits the spread of pollutants in the atmosphere, causing them to accumulate over the city.

It was found that in the winter period 2023-2024, the concentration of PM<sub>2.5</sub> exceeded an average of 150 mcg/m<sup>3</sup> and reached dangerous levels. This figure is six times higher than the safe limit (25 mcg/m<sup>3</sup>) established by the World Health Organization (WHO). Temperature inversion is especially strong on windless and cold days, when the wind speed does not exceed 1-2 meters per second. In such conditions, pollutants, including PM<sub>2.5</sub>, PM<sub>10</sub> and No. 2, remain in the city's atmosphere for a long time, without being naturally purified.

Climate change further exacerbates this process. Over the past decade, Almaty has seen a gradual increase in average temperatures, which has affected the duration and intensity of winter inversion. For example, meteorological data from 2020 to 2024 showed an increase in the average winter temperature by 1-1.5°C. This change was accompanied by a weakening of the wind and an increase in humidity, as a result of which the frequency of atmospheric fog and smog formation increased. During the study, it was recorded that during temperature inversion, the daily maximum of PM<sub>2.5</sub> concentrations exceeded 200 µg/m<sup>3</sup>, which was especially pronounced in the city center and in areas near the mountains.

Climate change is not limited to the winter period. In summer, extreme temperature increases (35-40°C) and changes in wind direction negatively affect air circulation. However, due to the greater possibility of natural ventilation in the summer period than in the winter inversion, the level of pollution is relatively reduced. Thus, climate change affects air quality in Almaty in different ways, depending on seasonal features, but temperature inversion in the winter period remains the most important factor.

Influence of transport density. Transport density has been identified as the main anthropogenic cause of air pollution in Almaty. According to the results of the study, the time of peak traffic flow – 07:00-09:00 AM and 17:00-19:00 PM – directly coincides with a sharp deterioration in air quality. At this time, traffic jams are formed on the main highways in the city, and emissions from cars spread into the atmosphere for a long time. For example, in January 2024, the level of carbon dioxide (CO) exceeded 5 mg/m<sup>3</sup> per hour and was 1.5 times higher than the permissible limit (MPC-3 mg/m<sup>3</sup>).

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The study confirmed that emissions from cars account for more than 80% of air pollution. This indicator mainly includes substances such as CO, NO<sub>x</sub> and PM<sub>2.5</sub>, which come from internal combustion engines. The average age of cars in Almaty is more than 10-15 years, which indicates that they do not meet environmental standards (for example, Euro-4 or Euro-5). At the same time, most of the 200-250 thousand cars coming to the city from outside have diesel engines, which increases the concentration of PM<sub>10</sub> and No. 2.

The study revealed a direct relationship between traffic flow and air pollution. For example, during traffic jams on the central streets of Almaty (Abay Avenue, Al-Farabi Avenue), the PM<sub>2.5</sub> level exceeded 100 µg/m<sup>3</sup> and was twice as high as in relatively quiet areas on the outskirts of the city (40-50 µg/m<sup>3</sup>). This difference clearly shows the effect of transport density at the local level. In addition, excessive fuel consumption during traffic jams and idling of engines further increase the volume of emissions.

The effect of transport density also depends on seasonal factors. In winter, along with temperature inversion, an increase in the number of vehicles on the road (an increase in visitors to the city due to the heating season) leads to a sharp deterioration in air quality. Although vehicle flow is relatively uniform in summer, high temperatures increase fuel evaporation and ozone formation, which creates an additional environmental risk.

Seasonal differences. Air quality in Almaty is strongly dependent on seasonal changes. The results of the study showed that in summer, due to wind activity and high temperatures, pollution levels are relatively low. For example, in July-August 2023, the concentration of PM<sub>10</sub> was on average around 50 µg/m<sup>3</sup>, which is only slightly higher than the WHO allowable limit (50 µg/m<sup>3</sup>). The average wind speed was 3-5 meters per second, contributing to the spread of pollutants.

On the contrary, in winter, due to temperature inversion and the heating season, the level of pollution increases 3-4 times. In January-February 2023-2024, the concentration of PM<sub>10</sub> reached 150-200 µg/m<sup>3</sup>, and PM<sub>2.5</sub> exceeded 150 µg/m<sup>3</sup>. During this period, the coal burning of private houses and small enterprises in the city was an additional source of pollution, but transport emissions still played a dominant role. In the winter period, the weak wind (0.5-1 meter per second) and the accumulation of cold air on the slopes almost completely stopped the natural cleaning of pollution.

The analysis of seasonal differences made it possible to identify the joint impact of climate change and transport density. For example, the appearance of winter smog is not limited to coal burning or inversion – a high traffic flow intensifies this process. Although pollution is low in summer, climate warming leads to the formation of additional pollutants such as ozone (O<sub>3</sub>), which in the long term can pose new environmental risks.

Correlation. The study found that there is a strong positive correlation ( $r = 0.87$ ) between temperature inversion and transport density. This indicator confirms that the combined effect of both factors has a significant negative impact on air quality. During the correlation analysis, it was found that wind weakness and high transport flow during temperature inversion are directly related to a sharp increase in PM<sub>2.5</sub> and CO levels.

For example, in the winter period, on days when the temperature was below -10°C and the traffic flow exceeded 1000 cars per hour, the concentration of PM<sub>2.5</sub> reached an average of 180 µg/m<sup>3</sup>. This indicator is significantly higher than the values on days when there is no inversion and the traffic flow is low (50-60 µg/m<sup>3</sup>). Regression analysis showed that when the vehicle density effect was assessed individually, each additional 100 vehicles increased PM<sub>2.5</sub> levels by about 5-7 µg/m<sup>3</sup>.

This correlation clearly proves the synergistic effect of climate change and transport density. Temperature inversion inhibits the spread of pollutants, and transport emissions provide the main source of these substances. Thus, both factors strengthen each other and lead to a deterioration in air quality in Almaty.

Additional observations. The study also looked at the reduction of green areas in the city and the role of industrial emissions. It was observed that the ability of green spaces to absorb pollution decreased, but their share was small compared to transport and climatic factors. Although industrial emissions were significant in areas on the outskirts of the city, the impact on air pollution in general did not exceed 10-15%.

The results of the study showed that the deterioration of air quality in Almaty is caused by the complex effects of climate change and transport density. While temperature inversion exacerbates winter pollution,

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traffic flows pose a constant threat throughout the year. This is due to the fact that there is a strong correlation between seasonal differences and correlative relationships. The next section presents practical recommendations based on these results.

##### *Conclusion*

Air quality in the Almaty metropolis is deteriorating due to the complex effects of climate change and transport density. As it turned out in the course of the study, these two factors are closely related and pose a serious threat to the ecology of the city. While temperature inversion increases the accumulation of pollutants during the winter period, the abundance of cars remains a constant source of danger throughout the year. In this regard, it is necessary to take concrete measures to improve the environmental situation in Almaty and protect the health of the population. Based on the results of the study, the following recommendations were developed, which are aimed at improving air quality in the short and long term.

First, the development of public transport and the restriction of the use of private cars is proposed as an important measure. Transport density in Almaty is the dominant source of air pollution, especially during traffic jams, the volume of emissions increases sharply. Modernization of the public transport system – increasing the number of buses, optimizing routes and introducing electric buses – can reduce the demand for private vehicles. For example, expanding the metro network and developing alternative systems such as light rail transport can be a long-term solution. In addition, measures such as restricting the entry of private cars in the city center or introducing a congestion charge (congestion charge) will help regulate the flow of transport. These approaches have been successfully used in megacities such as London or Singapore and can also be adapted to Almaty.

Secondly, encouraging environmentally friendly fuel types (gas, electricity) is an effective way to reduce air pollution. Currently, most cars in Almaty run on gasoline or diesel, which leads to the release of such harmful substances as PM<sub>2.5</sub>, NO<sub>x</sub> and CO. To encourage the use of electric vehicles, government subsidies, tax breaks and the expansion of the network of charging stations are needed. In addition, the development of natural gas vehicles (CNG) can reduce emissions in the short term, as gas fuel produces fewer pollutants than diesel. An important step will also be the mandatory introduction of environmental standards for vehicles (for example, Euro-5 or Euro-6) and the implementation of decommissioning programs for used cars.

Thirdly, the expansion of green areas to improve air circulation in the mountainous area contributes to reducing the impact of climate change and temperature inversion. The location of Almaty at the foot of the mountains naturally worsens air circulation, and the process of urbanization has led to a decrease in green spaces. The results of the study showed that green areas have the ability to absorb pollutants, but the current volume is insufficient. Therefore, it is necessary to expand parks and tree planting projects on the outskirts of the city and in the central areas. For example, the restoration of green belts in the foothills helps to purify the air during inversion. This measure also inhibits climate warming and promotes temperature regulation in the city.

Fourth, strengthening local climate change adaptation policies will ensure long-term sustainability. Climate change increases the intensity of temperature inversion in Almaty and leads to a weakening of the wind. Given this situation, local authorities should develop a strategic plan that will assess the impact of climate change and ensure adaptation to it. For example, the strengthening of meteorological monitoring and the introduction of a system for predicting the deterioration of air quality will make it possible to warn the population in a timely manner. In addition, additional sources of pollution, such as coal burning, can be reduced by improving energy efficiency and developing renewable energy sources (solar, wind).

The implementation of these measures will not only improve the environmental situation in Almaty, but also contribute to the preservation of the health of the population. Air pollution has been shown to exacerbate respiratory diseases, cardiovascular problems, and other chronic diseases. The study found that high concentrations of small particles such as PM<sub>2.5</sub> were associated with an increase in diseases such as asthma and bronchitis among urban residents. Therefore, the proposed measures are aimed not only at solving the environmental problem, but also at bringing social and medical benefits.

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In conclusion, the problem of air quality in Almaty is caused by the complex interaction of factors such as climate change and transport density. This study fully analyzed the impact of these factors and offered practical solutions. For the implementation of the above measures, cooperation between local authorities, business and society is necessary. For example, while the development of public transport requires public investment, the transition to ecological fuel requires the participation of the private sector. And the expansion of green areas and the strengthening of climate policy will be effective only with the support of the city's residents.

As a result of the implementation of these measures, Almaty can get access to fresh air and become an environmentally sustainable metropolis. This allows not only to preserve the health of the current generation, but also to leave a decent living environment for future generations. The results and recommendations of the study will give a clear direction to the city administration, environmentalists and public organizations and will serve as the basis for improving the environmental future of Almaty.

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Шильке Э. О.

#### **Алматы мегаполисінің ауа сапасына климаттың өзгеруі мен көлік тығыздығының әсері**

Бұл зерттеу Алматы мегаполисіндегі ауа сапасына климаттың өзгеруі мен көлік тығыздығының әсерін талдауға бағытталған. Қала таулы аймақта орналасуына байланысты континенттік климатқа ие, бұл ауа айналымының нашарлауына және ластаушы заттардың жиналуына ықпал етеді. Сонымен қатар, соңғы онжылдықта автокөлік санының күрт өсуі атмосфералық ауаның сапасын нашарлатып, экологиялық проблемаларды күшейтуде. Зерттеу ауа сапасының индексі (AQI), метеорологиялық деректерді және көлік ағынының статистикасын талдау арқылы осы факторлардың өзара байланысын анықтады. Нәтижелер климаттың өзгеруі температуралық инверсияны күшейтетінін және көлік тығыздығы зиянды шығарындылардың негізгі көзі екенін көрсетті. Зерттеу қорытындысы бойынша қоғамдық көлікті дамыту және экологиялық саясатты күшейту ұсынылады.

*Түйін сөздер:* Алматы, ауа сапасы, климаттың өзгеруі, көлік тығыздығы, экология, температуралық инверсия, атмосфералық ластану.

Шильке Э. О.

#### **Влияние изменения климата и плотности транспорта на качество воздуха мегаполиса Алматы**

Данное исследование направлено на анализ влияния изменения климата и плотности транспорта на качество воздуха в мегаполисе Алматы. Город имеет континентальный

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климат из-за своего расположения в горной местности, что способствует плохой циркуляции воздуха и накоплению загрязняющих веществ. Кроме того, резкое увеличение количества автомобилей за последнее десятилетие ухудшает качество атмосферного воздуха и усугубляет экологические проблемы. Исследование выявило взаимосвязь этих факторов путем анализа индекса качества воздуха (AQI), метеорологических данных и статистики транспортного потока. Результаты показали, что изменение климата увеличивает инверсию температуры и что плотность транспорта является основным источником вредных выбросов. По итогам исследования предлагается развитие общественного транспорта и усиление экологической политики.

*Ключевые слова:* Алматы, качество воздуха, изменение климата, плотность транспорта, экология, температурная инверсия, загрязнение атмосферы.

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