

Scientific article

MAJOR SOURCES OF FINE PARTICULATE AIR POLLUTION IN FOOTHILL MEGACITY: THE CASE OF ALMATY

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KEY WORDS

foothill basins,
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ABSTRACT

This study analyzes air pollution by fine particulate matter (PM_{2.5}) in Almaty, the largest megacity of Kazakhstan. The city is located in a basin formed by the spurs of the Zailiyskiy Alatau range. Due to its geographical features, it is highly exposed to pollution by anthropogenic fine particulate matter. The main sources of air pollution include transport, industrial enterprises, and heating systems. The objectives of this study are to identify the dominant source of pollution, to assess spatial heterogeneity between central and foothill districts, and to evaluate the effectiveness of household air purifiers in improving indoor air quality. Urban vehicular traffic exhibits a periodic temporal pattern, with daily minima at night and weekly minima on weekends. This dynamic behavior enables a quantitative assessment of its contribution to the overall PM_{2.5} concentration in the urban atmosphere. The results suggest that heat generation systems are likely to be the dominant contributor to PM_{2.5} pollution during the autumn–winter period. In addition, observations indicate that high pollution levels in foothill areas occur approximately 30% less frequently than in central districts. The use of household air purification systems may reduce indoor particulate matter concentrations severalfold under the observed conditions.

1. INTRODUCTION

Cities located in foothill basins face a number of unique environmental challenges associated with their geographical setting. Among these is air pollution, where limited air circulation leads to the accumulation of pollutants such as vehicular and industrial emissions in the atmosphere, resulting in elevated pollution levels [1].

The problem is exacerbated by temperature inversion, a phenomenon in which cold air is trapped near the surface while warmer air remains above. This inversion creates a “cap” that prevents the dispersion of pollutants, leading to smog accumulation and deterioration of air quality. During winter periods, temperature inversion can result in very low temperatures in lowland areas, increasing the demand for heating and further aggravating air quality due to higher emissions from heating systems.

According to the World Health Organization (WHO), air pollution causes approximately 7 million deaths annually (one in eight deaths worldwide) due to exposure to fine particulate matter. The associated health outcomes include ischemic heart disease (40%), stroke (40%), chronic obstructive pulmonary disease (COPD) (11%), lung cancer (6%), and acute lower respiratory infections in children (3%) [2]. Indoor air pollution is particularly harmful due to prolonged exposure to elevated concentrations of fine particulate matter and other airborne pollutants. The most dangerous pollutants are fine particles with a diameter of less than 10

micrometers (PM₁₀), especially those smaller than 2.5 micrometers (PM_{2.5}), as they can penetrate deep into the lungs and enter the bloodstream [3].

Residents of several large cities located in foothill basins suffer from significant air pollution [4]:

Lahore (Pakistan), situated in the foothills of the Himalayas, experiences severe pollution due to intense vehicular traffic and industrial emissions;

Krasnoyarsk (Russia), located in a basin between the Sayan Mountains and the Yenisei Ridge, faces pollution primarily from metallurgical and chemical industries;

Santiago (Chile), located near the Andes, is affected by vehicle emissions and industrial activities;

Ulaanbaatar (Mongolia), situated in a mountain-surrounded basin, experiences severe winter pollution primarily due to coal-fired power plants and residential heating [5];

Bishkek (Kyrgyzstan), located in the foothills of the Tien Shan, faces pollution from transport, industry, and coal-based heating systems [6,7], with the problem being most acute during the cold season;

Dushanbe (Tajikistan), located near the Pamir Mountains, is affected by dust, transport emissions, industrial activity, residential heating, and waste burning [8];

Salt Lake City (USA) experiences severe air pollution associated with temperature inversions and emissions from transportation and residential heating [9].

According to retrospective data reported in [10], eight out of fourteen cities in Kazakhstan were classified as having a “high” level of air pollution in 2019. The leading city in terms of air pollution indicators is Almaty—one of the largest cities in Central Asia and the largest city in Kazakhstan [11]. The Almaty region accounts for 20.8% of the national GDP. As of the end of 2024, the city’s population exceeded 2.28 million people. Almaty is located in the foothills of the Zailiyskiy Alatau range. Recent studies have identified several Central Asian cities, including Almaty, as emerging regional hotspots of particulate air pollution, highlighting the broader environmental significance of PM_{2.5} pollution in the region [12]

Several factors contribute to air pollution in Almaty. These include anthropogenic factors related to human activities (heat and power generation, transport, and industrial enterprises). Recent studies have also explored advanced data-driven approaches for PM_{2.5} prediction in Almaty, further emphasizing the importance of identifying major pollution sources and understanding their temporal variability [13]

Natural factors also play a significant role, including air mass transport processes such as mountain-valley circulation, which facilitates atmospheric cleansing, and temperature inversion in the surface layer, which inhibits pollutant dispersion.

Although the major sources of pollution in the city are generally known, identifying the most influential ones is essential for informed decision-making aimed at improving living conditions in the urban agglomeration. The case of Almaty provides an opportunity to analyze key pollution sources typical for megacities located in foothill basins.

Based on a dataset collected during 2024 and early 2025, this study addresses the following objectives:

- to identify the dominant source of air pollution in the city;
- to assess differences in pollution levels between central and foothill districts;
- to evaluate the effectiveness of household air purification systems in reducing indoor exposure to fine particulate matter.

The paper is structured as follows:

Section 2 describes the data collection process and the methodological approach used to identify dominant pollution sources;

Section 3 presents the results;

Section 4 discusses the findings;

the Conclusion outlines the limitations of the study and directions for future research.

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2. MATERIALS AND METHODS

The main sources of air pollution considered in this study can be conditionally divided into stationary sources, whose emissions do not depend on weekdays or weekends, and non-stationary sources, whose emissions vary significantly depending on the day of the week:

1) Conditionally stationary sources:

- a) combined heat and power plants (CHPs), some of which operate on coal;
- b) households using solid fuels for heating during the winter period.

2) Conditionally non-stationary sources:

- a) transport, whose intensity varies depending on the time of day and day of the week;
- b) industrial enterprises, which often reduce their activity during weekends and holidays.

Considering the seasonal operation of CHPs and residential heating systems, as well as the weekly variability of traffic intensity, it is possible to assess the contribution of these sources to particulate matter concentrations in the city. It is assumed that emissions from industrial enterprises remain relatively stable throughout the year, with reductions during holidays and weekends. Traffic load on urban roads decreases significantly during weekends and holidays. In contrast, heating systems operate continuously regardless of the time of day or day of the week, with heat output depending on ambient air temperature.

To analyze the main causes of air pollution in Almaty, the following steps were performed:

a dataset on air pollution was collected using Atmotube Pro sensors at two locations in Almaty;

a synchronized dataset on urban traffic was compiled;

a dataset on average monthly temperatures for 2024 was incorporated;

the dates of activation and deactivation of CHPs in the city were identified;

average monthly pollution levels were calculated for the selected locations;

correlation analysis was performed between traffic intensity and average monthly PM_{2.5} concentration (amPM_{2.5}), between CHP operational capacity and amPM_{2.5}, and between average monthly temperature and amPM_{2.5}.

2.1 Data Collection

Data collection was carried out from January 2024 to February 2025. The locations of the data collection points are shown in Figure 1.

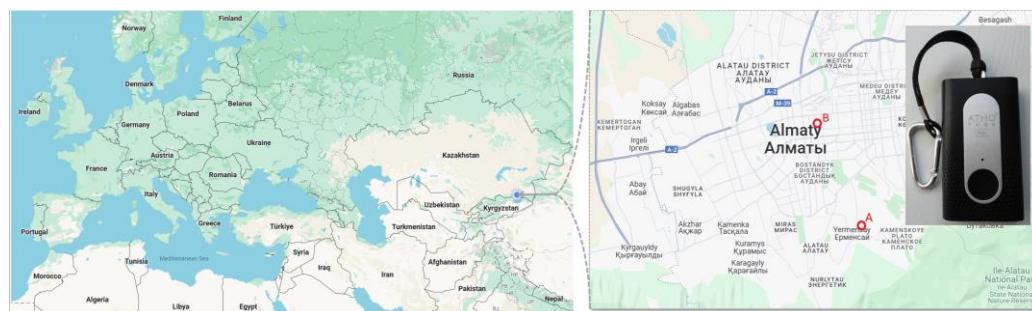


Figure 1. Data collection points in Almaty. The locations are marked with red circles (A -43.188695, 76.930872, B - 3.261284, 76.929322) . On the right, the portable air quality monitoring device Atmotube Pro is shown

The two monitoring locations were selected to represent contrasting urban settings: location A corresponds to a more central, densely built-up area affected by intensive traffic and urban emissions, whereas location B represents a foothill residential area with different dispersion conditions and lower traffic pressure. The approximate geographic coordinates of the monitoring points were added to Figure 1 and its caption. The choice of these locations was

intended to compare central and foothill parts of Almaty rather than to provide full city-wide spatial coverage.

Atmotube Pro is a portable air quality monitor based on optical particle sensing for PM1, PM2.5, and PM10 and an integrated sensor for VOCs and basic meteorological parameters (atmospheric pressure, humidity, and air temperature). The use of low-cost air quality sensors has become increasingly common in urban air pollution studies, although appropriate consideration of calibration and measurement uncertainty remains important [14].

Before measurement campaigns, the devices were operated according to the manufacturer's recommendations. The study focused on relative temporal and spatial differences rather than on regulatory-grade absolute concentration assessment. Therefore, possible sensor uncertainty, humidity effects, and device-to-device variability were considered as limitations of the study.

Measurements were recorded five times during the daytime at approximately 09:00, 12:00, 15:00, 18:00, and 21:00. As a result, a dataset was formed for each monitoring location; an example is presented in Table 1.

Table 1

Sample fragment of the dataset collected at location B

year	month	day	time	AQS	PM1	PM2.5	PM10	VOCs
2024	1	6						
2024	1	7	9	0	105	115	110	1.65
2024	1	7	18	0	154	169	176	0.83
2024	1	7	21	0	127	140	148	2.2
2024	1	8	9	56	9	10	12	1.25
2024	1	8	12	47	17	20	23	1.8
2024	1	8	18	55	39	44	46	0.57
2024	1	8	21	66	25	27	29	0.6
2024	1	9	9	65	15	17	19	0.66
...	...	...	...	...	...	...	...	...
2025	2	27	9	79	15	17	19	0.07
2025	2	27	21	68	26	30	32	0.09
2025	2	28	9	72	22	26	29	0.2

In total, the dataset contains 836 records for location B and approximately 2000 records for location A. Since data collection was performed manually, the dataset for location A contains missing values. In particular, measurements at location A were not conducted from mid-July through August.

Average monthly air temperature values were obtained from the website <http://www.pogodaiklimat.ru/history/36870.htm> (Table 2).

Table 2

Average monthly air temperature in Almaty from January 2024 to February 2025

Month	Average monthly air temperatures in Almaty
January	-1.2
February	-3.9
March	5.6

April	12.8
May	17.6
June	24.5
July	25.1
August	25.6
September	15.9
October	11.8
November	5
December	-3.3
January	-2.6
February	-1.5

The portal <https://yandex.kz/> was used as a source of meteorological data (wind speed and direction, humidity, and temperature) and traffic data. Due to technical constraints, traffic data were collected from May 2024 to February 2025. Traffic data were recorded at the same three-hour intervals as the air pollution measurements.

Additionally, the dates of switching off and switching on central heating in Almaty for 2024 and 2025 were taken into account. Central heating began to be turned off on April 15, 2024 [15], and was gradually resumed starting from October 7 [16].

To assess the effectiveness of indoor air purification systems, additional measurements of indoor air pollution levels were conducted in premises equipped with compact household air purifiers.

2.2 Quantitative Assessment of the Relationship Between Sources and Pollution Levels

To identify statistically significant relationships between pollution sources and PM2.5 concentrations, the linear correlation coefficient (Pearson correlation coefficient [17]) was used. The Pearson correlation coefficient between variables h and y , each consisting of n observations, is calculated as follows:

$$Rp(y, h) = \frac{\sum_{i=1}^n (h_i - \bar{h})(y_i - \bar{y})}{\sum_{i=1}^n (y_i - \bar{y})^2 \sum_{i=1}^n (h_i - \bar{h})^2}$$

where $y^{(i)}$ and $h^{(i)}$ are the observed values of variables y and h , $\bar{y}$ and $\bar{h}$ are their mean values:

$$\bar{h} = \frac{1}{n} \sum_{i=1}^n h_i, \quad \bar{y} = \frac{1}{n} \sum_{i=1}^n y_i$$

A value of $Rp = 1$ indicates a perfect positive linear relationship;

$Rp = -1$ indicates a perfect negative linear relationship;

$Rp = 0$ indicates no linear relationship.

Pearson correlation was used as an exploratory measure of linear association and was not interpreted as direct evidence of causality. To avoid overinterpretation, the results were considered together with the temporal structure of emission sources, seasonal heating operation, weekday–weekend traffic differences, and meteorological context. Statistical significance of the correlation coefficients was assessed using the corresponding p-values.

3. RESULTS

3.1 Monthly Average Concentrations of Particulate Matter

The datasets collected between January 2024 and February 2025 made it possible to calculate monthly average concentrations of particulate matter (Tables 3 and 4).

Table 3*Monthly average concentrations of fine particulate matter at location A*

Month	Number of measurements	PM1	PM2.5	PM10
January	148	38.27	44.62	48.68
February	153	39.88	44.53	46.98
March	118	22.88	26.08	28.39
April	161	11.58	13.57	14.82
May	145	9.59	11.44	12.61
June	114	6.12	7.97	9.43
July	28	4.5	5.99	6.93
September	88	9.81	11.8	13.03
October	126	14.51	17.03	21.91
November	134	24	27.69	30.07
December	114	33.16	38.95	44.21
January	111	29.15	33.82	36.73
February	89	55.59	63.31	67.95

Note: Data collection at location A was not conducted from mid-July through August.

Table 4*Monthly average concentrations of fine particulate matter at location B*

Month	PM1	PM2.5	PM10
January	50.19	57.65	62.55
February	56.29	63.62	67.97
March	35.88	41.02	44.25
April	14.27	16.73	18.06
May	10.32	12.49	13.88
June	7.32	9.25	10.65
July	7.61	9.56	10.88
August	7.49	9.39	10.65
September	11.06	13.31	14.69
October	18.72	21.96	23.94
November	33.68	39.84	44.7
December	60.99	68.65	73.18
January	51.52	59.22	64.58
February	59.56	68.31	74.22

Figure 2 shows the variation in PM2.5 concentrations in the two studied areas of the city.

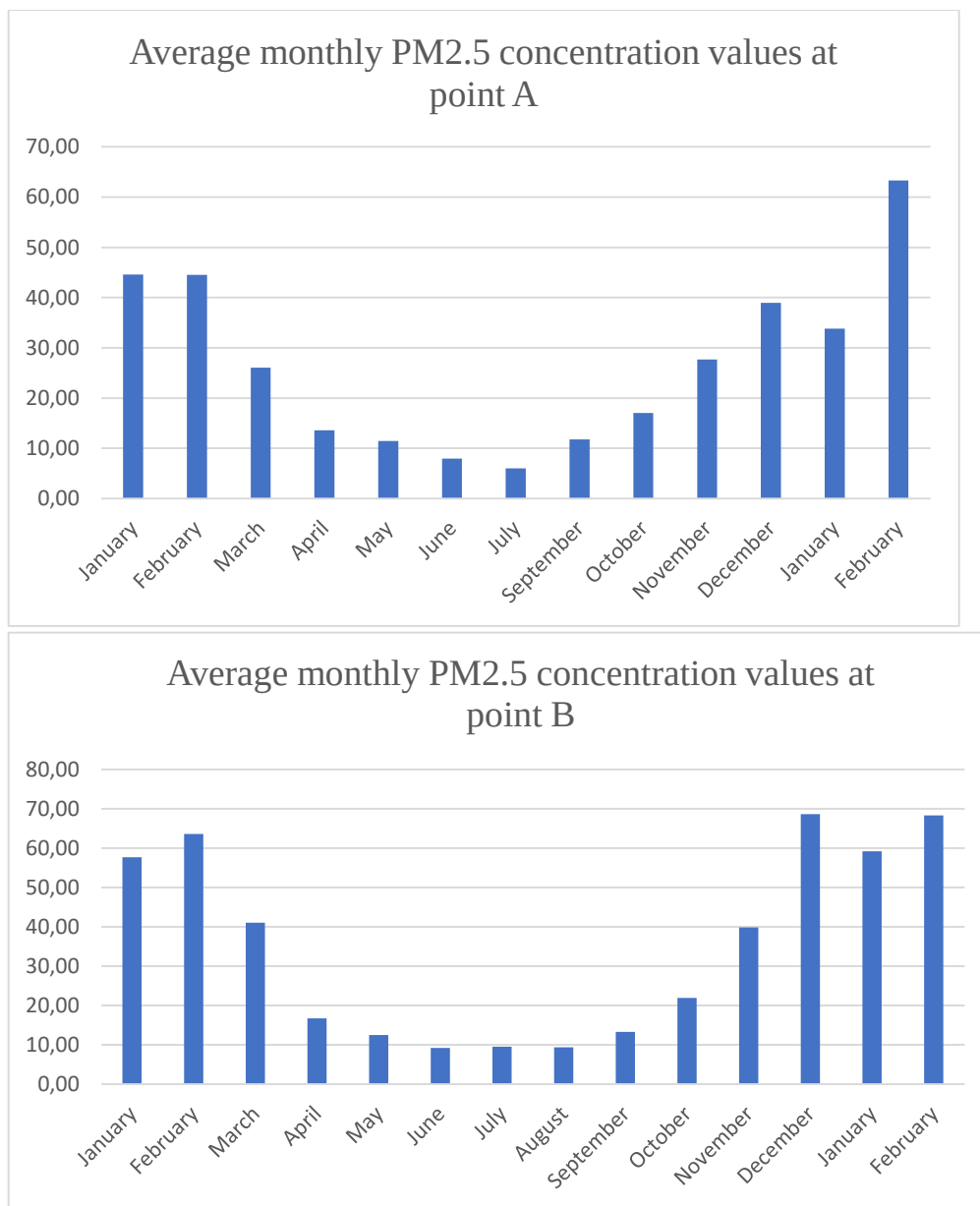


Figure 2. Monthly average PM2.5 concentrations

To assess the influence of stationary pollution sources, monthly average concentrations of particulate matter were calculated separately for weekdays and weekends (Figure 3)

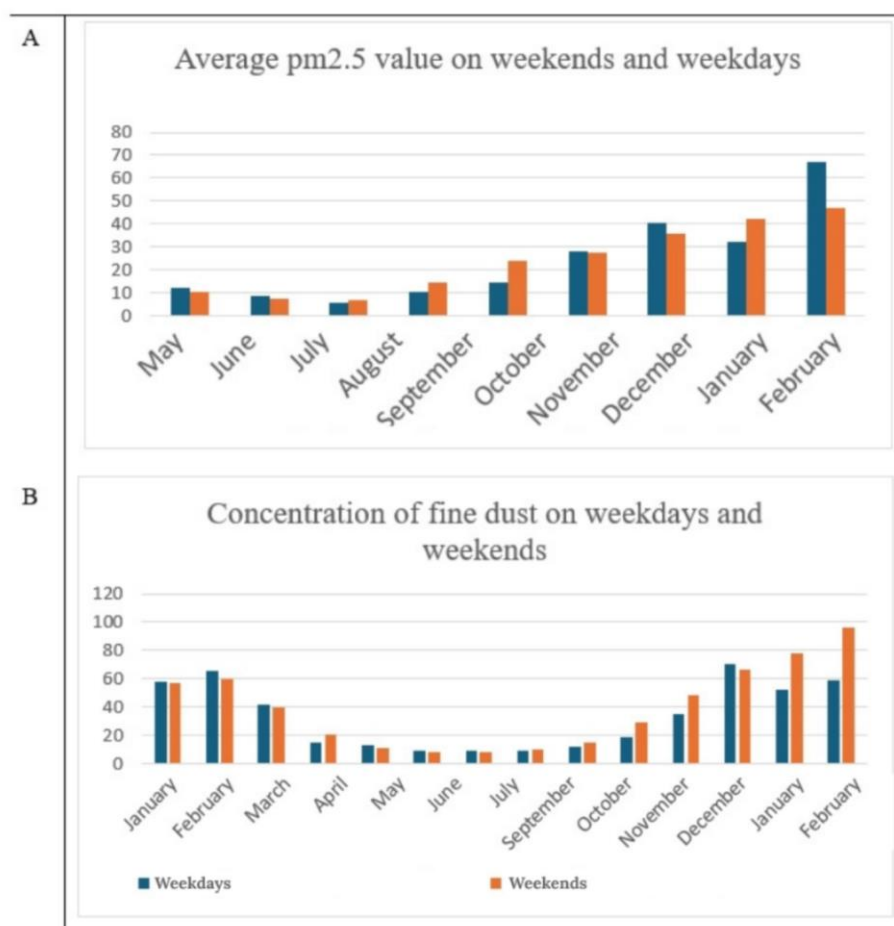


Figure 3. Average pm2.5 value on weekends and weekdays

It should be noted that the correlation between PM2.5, PM1, and PM10 concentrations exceeds 0.99. Therefore, all subsequent analyses performed for PM2.5 are also applicable to PM1 and PM10.

3.2 Traffic Levels and Fine Particulate Matter Concentrations on Weekdays and Weekends

Urban traffic levels were recorded starting from May 2024. Table 5 presents the monthly average values of traffic intensity and fine particulate matter concentrations in the urban atmosphere for weekdays and weekends.

Table 5

Monthly average concentrations of particulate matter and traffic levels in the city on weekdays and weekends

Month	PM2.5_B on weekdays	PM2.5_B on weekends	PM2.5_A on weekdays	PM2.5_A on weekends	traffic on week-days	traffic on week-ends
May	12.91667	11.59565	12.13	10.17	4.4	2.54
June	9.45	8.845	8.22	7.84	3.66	2.32
July	9.15641	8.182353	5.46	7	4.15	1.73
September	12.67647	14.96154	10.26	14.5	5.38	2.46
October	18.76111	29.64667	14.45	24.59	5.41	2.8
November	35.49259	48.21429	27.87	27.31	5.6	3.34
December	70.50476	66.48889	39.34	37.92	6.03	3.6
January	51.85429	77.64286	32.02	42	4.38	2.77
February	58.95833	96.375	66.84	47.21	5.4	2.65

For visualization purposes, the average monthly traffic levels for weekdays and weekends are illustrated in Figure 4. Over the observation period, the average traffic level was 5.05 units on weekdays and 2.79 units on weekends.

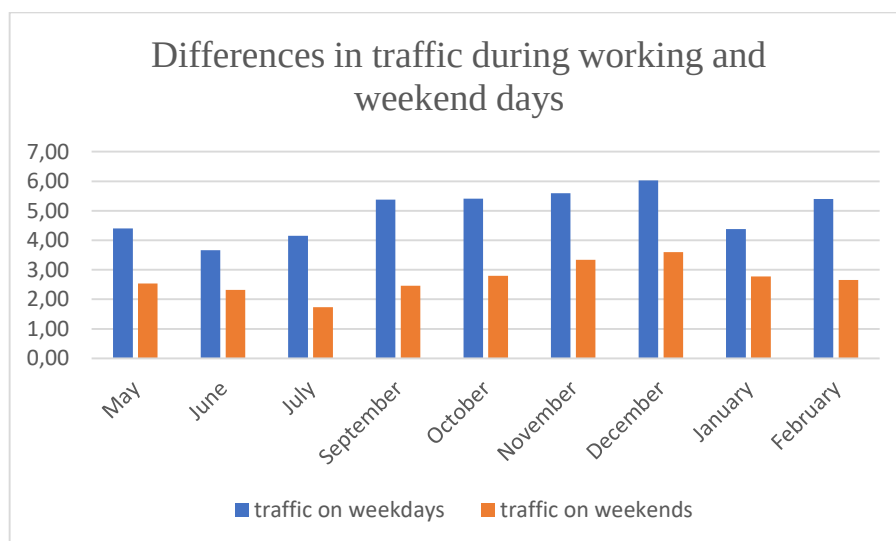


Figure 4. Differences in traffic levels between weekdays and weekends

It should be noted that traffic levels are influenced by weather conditions. During the autumn–winter period, precipitation such as rain and snowfall leads to reduced vehicle speeds, while the number of vehicles remains approximately the same, resulting in traffic congestion.

Since traffic levels differ by nearly a factor of two between weekdays and weekends, it is reasonable to assess how air pollution levels vary accordingly. A significant difference in pollution levels between these periods would indicate a substantial contribution of vehicular traffic to pollution in the near-surface atmospheric layer of the city.

3.3 Correlation Analysis Between Pollution Sources and Particulate Matter Concentrations

The data presented above make it possible to estimate the correlation between particulate matter concentrations and the processes and factors influencing air pollution (Table 6).

Table 6

Correlation coefficients between monthly average PM_{2.5} concentrations and influencing factors

Factors	A/ p-values	B/ p-values
operation of heating systems	0.84889/ $p < 10^{-6}$	0.934362/ $p < 10^{-6}$
air temperature	-0.89336/ $p < 10^{-6}$	-0.95835/ $p < 10^{-6}$
traffic intensity and industrial activity	0.593284/ $p < 10^{-6}$	0.680287/ $p < 10^{-6}$

The correlation analysis shows relationships between PM_{2.5} concentrations and the following factors:

- operation of heating systems;
- air temperature;
- traffic intensity and industrial activity.

All reported Pearson correlation coefficients were statistically significant ($p < 10^{-6}$). However, these results indicate statistical associations and should not be interpreted as evidence of causal relationships.

Although the primary focus of this study is the identification of major PM_{2.5} sources in Almaty, the assessment of household air purifiers was included as an applied component aimed at evaluating a practical measure for reducing personal exposure during periods of elevated

outdoor pollution. The average particulate matter concentrations measured indoors, compared to outdoor air, are presented in Table 7.

Table 7

Average particulate matter concentrations measured outdoors and indoors in premises equipped with air purifiers

Measurement location	Outdoor air	Indoor air
A	42.61	14.56
B	34.03	20.48

Note. The higher annual average outdoor pollution level at location A is due to the fact that the number of measurements during the summer period at this location is approximately half of that at location B.

4. DISCUSSION

The sources of air pollution in Almaty can be conditionally divided, based on their temporal dynamics, into two types: relatively stationary sources (combined heat and power plants (CHPs) operating in base load mode, as well as CHPs and residential heating systems during the heating season) and non-stationary or periodic sources (vehicular traffic and industrial enterprises with predictable reductions in activity during nighttime and weekends).

This complex system of anthropogenic emissions interacts with meteorological factors, which themselves exhibit complex dynamics. These include both regular regional wind patterns, such as mountain–valley circulation, and episodic processes such as cyclones and Arctic air intrusions. As a result, the quantitative level of air pollution recorded by sensors cannot be approximated by simple relationships with clear physical interpretations of the contribution of individual sources. A significant quasi-random component associated with weather variability is present.

Meteorological conditions may substantially modify the observed PM_{2.5} concentrations. Low wind speeds and stable atmospheric stratification reduce horizontal and vertical dispersion and favor pollutant accumulation, whereas stronger winds and mountain–valley circulation can enhance ventilation of the urban basin. High relative humidity may also affect particulate matter measurements and promote particle growth, while precipitation episodes usually contribute to particle removal from the near-surface atmosphere. In winter, the combined effect of increased heating demand, frequent temperature inversions, and weak dispersion conditions can lead to prolonged accumulation of fine particles. Therefore, the observed seasonal increase in PM_{2.5} should be interpreted as the result of both emission intensity and meteorological conditions that regulate accumulation and dilution.

Nevertheless, identifying the dominant sources of pollution is crucial for the development of effective air quality management strategies. In this study, the periodic nature of urban traffic is used as an indirect indicator to identify dominant pollution sources. It can be observed that CHPs and residential heating systems operate continuously during the heating season regardless of the day of the week, whereas traffic levels on weekends average only about 56% of weekday levels.

However, as shown in the presented results, pollution levels do not decrease proportionally on weekends. In some months, pollution levels are even higher on weekends than on weekdays. This suggests that the primary contributors to air pollution in Almaty during the winter period are CHPs and residential heating systems.

This assumption is supported by correlation analysis between pollution levels and CHP operation, as well as between particulate matter concentrations and ambient air temperature. The strong correlation between pollution indicators and air temperature directly indicates the influence of heat generation systems on urban air quality. Modern CHP control systems maintain a constant steam temperature in district heating networks, which leads to increased fuel consumption during colder periods and reduced consumption as ambient temperature rises. The

empirically derived correlation between CHP operational parameters and pollution levels is statistically significant.

In contrast, the relatively low correlation between traffic intensity and particulate matter concentrations indicates that vehicular traffic contributes significantly less to particulate pollution, particularly during the heating season. This is further supported by the absence of a pronounced weekly pattern in pollution levels. Only during the summer period is a slight difference observed between weekday and weekend pollution levels; however, the available data are insufficient for statistically robust conclusions.

Overall, the collected data and performed analyses lead to the following conclusions.

The average concentration of particulate matter indoors, in premises equipped with air purification systems, is significantly lower than outdoors.

The primary source of fine particulate air pollution is heat generation systems.

This conclusion is consistent with findings reported in [8], which state that “in most urban areas of Central and Eastern Europe, the Western Balkans, and Central Asia, seasonal peaks in air pollution are caused by residential heating during winter.” However, the results obtained in this study differ from commonly cited sources that identify transport as the main contributor to urban air pollution [18]. According to our analysis, this is not the case.

A reduction in environmental impact can be achieved by transitioning heating systems to natural gas or, preferably, to electricity generated from environmentally friendly sources (renewable energy or nuclear power). Additional reductions in emissions could be achieved by limiting other combustion-related activities, such as waste burning and open-fire cooking. Although the contribution of these sources is difficult to quantify, improving urban environmental practices could further enhance air quality once heating systems transition to cleaner energy sources.

Vehicular traffic contributes relatively little to particulate air pollution in the city. The contribution of transport and industrial enterprises is several times lower than that of heating systems and becomes noticeable mainly during the spring and summer periods, when overall particulate pollution levels decrease significantly.

4. CONCLUSION

In analyzing the characteristics of pollution sources in the urban atmosphere, the authors aimed to identify the group of sources that make the greatest contribution to air pollution. The key methodological approach was the classification of sources into relatively stationary (with emissions independent of the day of the week) and non-stationary or periodic (with emissions varying significantly depending on the day of the week).

This approach made it possible, based on a relatively limited dataset obtained from two sensors, to conclude that the primary source of air pollution in the megacity of Almaty is heat generation systems, both within the city and in suburban areas, particularly those relying on solid fuel combustion. In combination with the city's geographical features, this leads to high concentrations of fine particulate matter. During winter months, pollution levels of this type often exceed permissible limits severalfold.

Reducing emissions through the transition to gas-based or electric heating systems could significantly decrease particulate concentrations in Almaty's air. It should also be noted that indoor air purification systems can provide substantial protection and reduce health risks during the transition period while urban CHPs are being modernized.

As for transport, its contribution, as well as that of industrial enterprises, is relatively small and becomes noticeable mainly during the summer period.

This study is subject to several limitations:

the analysis is based on data from only two sensors;

the dataset covers a period of just over one year;

the available data are insufficient to draw statistically significant conclusions regarding the impact of traffic during the summer period;

meteorological parameters, such as wind speed and direction, were considered only as part of aggregated statistics, although they may play a significant role in predictive modeling.

Future research involving a larger network of sensors will help to overcome these limitations. In addition, further work will focus on developing methods for forecasting air pollution with high temporal and spatial resolution.

DATA AVAILABILITY

This study uses both the authors' own data, obtained during field measurements conducted in Almaty from 2024 to early 2025, and published materials from Kazakhstani and international researchers relevant to the study of atmospheric air pollution by fine particulate matter. Additionally, the study incorporates generalized data on weather conditions, heating system operation, and traffic load, obtained from open information sources and analytical reports. Additional data may be provided by the authors upon reasonable request.

AUTHOR CONTRIBUTIONS

Conceptualization – RM; methodology – YK; writing and editing – LG; investigation – RM, AS, YK.

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ТАУ ЕТЕГІНДЕ ОРНАЛАСҚАН МЕГАПОЛИСТЕГІ ҰСАҚ ДИСПЕРСТІ БӨЛШЕКТЕРМЕН АУАНЫҢ ЛАСТАНУЫНЫҢ НЕГІЗГІ КӨЗДЕРІ: АЛМАТЫ ҚАЛАСЫ МЫСАЛЫНДА

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ТҮЙІН СӨЗДЕР

тау бөктеріндегі қазаншұңқырлар, ауаның ластануы, Ұсақ дисперсті бөлшектер, Пирсон корреляциясы

АБСТРАКТ

Осы жұмыста Қазақстанның ең ірі мегаполисі — Алматы қаласының атмосфералық ауасының ұсақ дисперсті бөлшектермен (PM_{2.5}) ластануы талданады. Қала Іле Алатауы жотасының сілемдерінен құралған қазаншұңқырда орналасқан. Географиялық ерекшеліктеріне байланысты ол антропогендік шығу тегті ұсақ дисперсті бөлшектермен жоғары деңгейде ластануға ұшырайды.

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Ауаның негізгі ластаушы көздері — көлік, өнеркәсіп кәсіпорындары және жылу жүйелері. Зерттеудің мақсаттары: ластанудың басым көзін анықтау, қаланың орталық және тау бөктеріндегі аудандары арасындағы кеңістіктік айырмашылықтарды бағалау, сондай-ақ тұрмыстық ауа тазартқыштардың үй ішіндегі ауа сапасын жақсарту тиімділігін анықтау. Қалалық автокөлік қозғалысы уақыт бойынша периодтық сипатқа ие: тәуліктік минимумдар түнгі уақытта, ал апталық минимумдар демалыс күндері байқалады. Бұл динамика аталған көздің қалалық атмосферадағы PM_{2.5} концентрациясына қосатын үлесін сандық тұрғыдан бағалауға мүмкіндік береді. Зерттеу нәтижелері күз-қыс кезеңінде жылу энергиясын өндіру жүйелері PM_{2.5} ластануының басым көзі болуы мүмкін екенін көрсетеді. Сонымен қатар, бақылаулар тау бөктеріндегі аудандарда жоғары ластану деңгейлерінің қаланың орталық бөлігімен салыстырғанда шамамен 30%-ға сирек тіркелетінін көрсетеді. Бақыланған жағдайларда тұрмыстық ауа тазарту жүйелерін қолдану үй-жайлардағы ұсақ дисперсті бөлшектердің концентрациясын бірнеше есе төмендетуі мүмкін.

ОСНОВНЫЕ ИСТОЧНИКИ ЗАГРЯЗНЕНИЯ ВОЗДУХА МЕЛКОДИСПЕРСНЫМИ ПЫЛЕВЫМИ ЧАСТИЦАМИ В ПРЕДГОРНОМ МЕГАПОЛИСЕ НА ПРИМЕРЕ АЛМАТЫ

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КЛЮЧЕВЫЕ СЛОВА

предгорные котловины,
загрязнение воздуха,
мелкодисперсные пылевые
частицы,
корреляция Пирсона.

АБСТРАКТ

В настоящей работе анализируется загрязненность мелкодисперсными частицами воздушной среды Алматы, крупнейшего мегаполиса Казахстана. Город находится в котловине из отрогов хребта Заилийский Алатау. В силу географических особенностей он подвергается большому загрязнению мелкодисперсными пылевыми частицами антропогенного происхождения. Источниками загрязнения воздуха являются транспорт, предприятия и системы отопления. В настоящей работе ставится задача выявления наиболее масштабного загрязнителя, оценки неравномерности загрязнения между центральными и предгорными районами и способности бытовых очистителей воздуха улучшать качество воздуха в помещениях. Городской автомобильный трафик представляет собой периодическую временную функцию с суточными минимумами в ночное время и недельными минимумами в выходные дни. Такая динамическая особенность в интенсивности этого источника загрязнения воздуха позволяет количественно оценивать его значимость в общем уровне концентрации пылевых частиц PM_{2.5} городского воздушного бассейна. Полученные результаты позволяют предположить, что в осенне-зимний период системы теплоснабжения могут являться основным источником загрязнения воздуха PM_{2.5}. Кроме того, наблюдения показывают, что в предгорных районах высокие уровни загрязнения фиксируются примерно на 30% реже, чем в центральной части города. В условиях проведенных наблюдений применение бытовых систем очистки воздуха может снижать концентрацию мелкодисперсных частиц в жилых помещениях в несколько раз.

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