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Economic and Ecological Analysis of the Relationship Between PM2.5 and PM10 Levels and Industrial and Transport Factors in the Cities of Sumgayit and Almaty

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Abstract. *Air pollution caused by fine and coarse particulate matter is a major environmental and public health issue in rapidly growing cities. This study offers an economic and ecological analysis of PM2.5 and PM10-related air pollution in Sumgayit, Azerbaijan, and Almaty, Kazakhstan. The research combines air quality data with photographic field observations to evaluate the link between particulate matter levels and key urban pollution factors. These factors include industrial activity, traffic congestion, construction processes, fog, smog, and the spatial characteristics of the urban environment. For Almaty, daily PM2.5 and PM10 concentration data from 2020 to 2025 came from AQICN/AirKaz monitoring data. In Sumgayit, PM2.5 data were sourced from the National Hydrometeorological Service under the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. PM10 values were estimated using a PM2.5/PM10 ratio method. Furthermore, photographic field observation data from both cities served as visual and contextual evidence to understand the potential contributions of transport, industrial activities, construction, and weather factors to particulate matter pollution. The study demonstrates that combining measured air quality data, estimated indicators, and field-based visual documentation can create a practical framework for comparing urban air pollution. The findings aim to aid environmental monitoring, urban planning, and discussions about green economy policies in both cities.*

Keywords: *Air pollution, particulate matter, Sumgayit, Almaty, industrial emissions, environmental monitoring*

Introduction

Air pollution is one of the most serious challenges facing urban health, economic productivity, and city development. Among various air pollutants, particulate matter is particularly significant due to its direct impact on respiratory and cardiovascular health. It is closely linked to transportation, industrial activity, construction, fuel burning, and urban weather patterns. PM2.5 refers to fine particles with a diameter of 2.5 micrometers or smaller, while PM10 includes inhalable particles with a diameter of 10 micrometers or smaller. Because of their smaller size, PM2.5 particles can penetrate deeper into the respiratory system, while PM10 is often related to road dust, construction, soil resuspension, and other larger particle sources (WHO, 2021).

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In rapidly growing industrial cities, PM2.5 and PM10 levels are influenced not only by direct emissions but also by the city's layout, weather conditions, traffic volume, industrial areas, and the presence of green spaces. Emissions from transport, brake and tire wear, road dust, industrial combustion, construction activity and stagnant atmospheric conditions are commonly reported as contributors to particulate matter pollution in urban areas (WHO, 2021; OECD, 2020). Road dust resuspension is especially relevant for PM10 because it depends on road surface conditions, traffic intensity, vehicle fleet characteristics and meteorological conditions (CasottiRienda& Alves, 2021).

Sumgayit and Almaty serve as two relevant urban examples for comparing particulate matter pollution. Sumgayit, one of Azerbaijan’s main industrial cities, faces air quality challenges due to industrial activity, urban transport, construction, and the broader impact of its industrial history. In contrast, Almaty, one of Kazakhstan’s largest cities, is often discussed in relation to traffic congestion, emissions from heating, nearby industrial areas, and poor atmospheric dispersion conditions. Its basin-like geography and episodes of temperature inversion may lead to the buildup of pollutants in the lower atmosphere, especially during cold weather (Almaty Air Initiative, 2024; WHO, 2021).

From an economic and ecological standpoint, particulate matter pollution is not just an environmental issue; it is also a development concern. High levels of PM2.5 and PM10 can raise health risks, lower worker productivity, generate extra healthcare costs, and diminish urban life quality. Air pollution also creates measurable economic costs through disease burden, premature mortality, welfare losses and additional pressure on public health systems (WHO Regional Office for Europe & OECD, 2015). The presence of industrial, transportation, and construction sources highlights the need for cleaner production methods, sustainable transport, dust management, environmental monitoring, and better urban planning. In this context, PM2.5 and PM10 levels are key indicators for assessing urban development sustainability. This study aims to examine the link between PM2.5 and PM10 levels and factors related to industry, transport, construction, and the urban environment in Sumgayit, Azerbaijan, and Almaty, Kazakhstan. The research relies on four supporting datasets: photographic observations from Almaty, photographic observations from Sumgayit, daily PM2.5 and PM10 concentration data for Almaty for 2020-2025, and PM2.5 with estimated PM10 data for Sumgayit from the National Hydrometeorological Service of Azerbaijan. The photographic data serve as visual and contextual evidence, while the numerical data enable trend analysis, annual and monthly comparisons, and interpretations of particulate matter patterns (Arifzade, 2026a; Arifzade, 2026b; Mammadov, 2026; Abbasova&Məmmədov, 2026).

The main contribution of this study is its combined methodological approach. Rather than relying solely on numerical air quality data, the paper connects PM2.5 and PM10 information with visual field observations related to traffic congestion, construction, industrial environments, fog, smog, and urban characteristics. This allows for interpreting particulate matter pollution not just as a number but as a visible issue linked to urban environments. Such an approach may be beneficial for environmental monitoring, urban policies focused on a green economy, and comparative studies of air pollution in post-Soviet and industrial urban areas.

Materials and methods

This study uses a mixed-data approach to compare PM2.5 and PM10-related urban air pollution factors in Sumgayit, Azerbaijan, and Almaty, Kazakhstan. The method combines numerical air quality datasets with photographic field observations. The numerical datasets help analyze particulate matter levels. The photographs support the interpretation of possible pollution sources, such as industrial activity, trafficcongestion, construction processes, fog or smog conditions, and visible urban environmental factors.

The study focuses on two urban areas: Sumgayit in Azerbaijan and Almaty in Kazakhstan. Sumgayit, an industrial city near the Caspian Sea, has a history of industrial production, urban expansion, and environmental pressure from transport. Almaty is a large urban center in Kazakhstan, located near the foothills of the Trans-Ili Alatau mountains. Here, air quality may be affected by traffic density, emissions from heating, industrial surroundings, topography, and weather conditions.

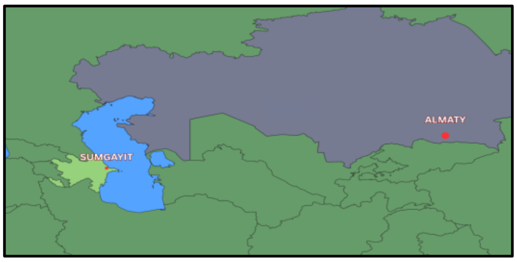

Figure 1

Location and general urban context of Sumgayit and Almaty

This study used four datasets. The first dataset includes photographic field observations related to PM2.5 and PM10 urban pollution factors in Almaty. It contains visual materials on fog, smog, construction activity, industrial surroundings, and traffic congestion (Arifzade, 2026a). The second dataset includes photographic field observations for Sumgayit, covering similar categories such as fog, smog, construction activity, industrial surroundings, and traffic congestion (Mammadov, 2026).

The third dataset contains daily PM2.5 and PM10 concentration data for Almaty from 2020 to 2025. These data are based on AQICN/AirKaz monitoring records and include daily minimum, maximum, median, quartiles, standard deviation, and observation count values (Arifzade, 2026b). The fourth dataset contains PM2.5 indicators for Sumgayit based on the National Hydrometeorological Service under the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. Since direct PM10 measurements were not available in this dataset, PM10 values were estimated using a PM2.5/PM10 ratio-based approach (Abbasova&Məmmədov, 2026).

Table 1

Main datasets used in the study

No.	Dataset	City	Data type	Period	Main purpose
1	*Photographic field observation dataset for Almaty*	*Almaty*	*Visual/field observation*	*2025–2026*	*Identification of visible pollution-related urban factors*
2	*Photographic field observation dataset for Sumgayit*	*Sumgayit*	*Visual/field observation*	*2019–2026*	*Identification of visible pollution-related urban factors*
3	*Daily PM2.5 and PM10 dataset for Almaty*	*Almaty*	*Numerical air quality data*	*2020–2025*	*Trend, annual, and monthly analysis*
4	*PM2.5 and estimated PM10 dataset for Sumgayit*	*Sumgayit*	*Numerical and estimated data*	*Based on available official data*	*Comparative interpretation of PM2.5 and estimated PM10*

The main air quality indicators used in this study are PM2.5 and PM10. PM2.5 refers to fine particulate matter with a diameter of 2.5 micrometers or smaller. PM10 refers to inhalable particulate matter with a diameter of 10 micrometers or smaller. PM2.5 is usually linked to combustion processes, traffic emissions, industrial fuel use, and the formation of secondary aerosols. PM10 can include both fine and coarse particles generated by road dust, construction activity, soil resuspension, industrial dust, and mechanical processes.

For Almaty, the daily median values of PM2.5 and PM10 were chosen as the main indicators for analysis. The median was preferred because it is less affected by extreme values than the maximum value. It offers a more stable view of daily particulate matter levels. Annual and monthly summaries helped to identify trends over time.

In Sumgayit, the available PM2.5 values served as the main official indicator. PM10 values were not regarded as directly measured data. Instead, they were estimated using the PM2.5/PM10 ratio method. This method assumes that PM2.5 makes up about 65 to 70 percent of PM10 under urban air pollution conditions. The estimated PM10 values were calculated using the following formulas:

$$PM10_{estimate}\ 1 = PM2.5\ /\ 0.70$$
$$PM10_{estimate}\ 2 = PM2.5\ /\ 0.65$$

This means that PM10 is presented as an estimated range rather than a single direct measurement. Therefore, the Sumgayit PM10 values should be interpreted only as approximate indicators for comparative research purposes.

Table 2
PM10 estimation approach used for Sumgayit

Indicator	**Formula**	**Interpretation**
Lower PM10 estimate	*PM2.5 / 0.70*	*Assumes PM2.5 forms 70% of PM10*
Upper PM10 estimate	*PM2.5 / 0.65*	*Assumes PM2.5 forms 65% of PM10*
Final PM10 value	*Estimated interval*	*Not a direct instrumental measurement*

Photographic field observation supported the documentation of visible sources and environmental conditions related to particulate matter pollution. The photographs fell into four main categories: fog or smog, construction activity, industrial surroundings, and traffic congestion. Each photograph included metadata such as category, date, location or coordinates, source, and a brief explanation of its relevance to PM2.5 and PM10 pollution. The PM2.5/PM10 ratio approach is used in air pollution studies to understand the relationship between fine and coarse particulate matter. Previous urban studies have reported PM2.5/PM10 ratios near this range under certain local conditions (Drăgoi et al,2025).

The photographic materials did not serve as direct measurements of pollution concentration. Instead, they provided context to understand the urban and environmental factors behind PM2.5 and PM10 patterns. For instance, traffic congestion was seen as a possible source of PM2.5 through exhaust emissions and of PM10 through dust resuspension, brake wear, and tire wear. Recent studies also show that non-exhaust traffic emissions, including brake and tyre wear particles, are important components of traffic-related particulate matter in urban environments (Beddows et al., 2023). Construction activity was mainly linked to PM10 due to dust generation and exposed soil surfaces. Construction dust has been widely discussed as an important source of particulate exposure, particularly where demolition, excavation, material storage and exposed surfaces are not effectively controlled (Wang et al., 2023). Industrial surroundings were viewed as potential sources of both fine and coarse particulate matter, depending on fuel type, production process, and emission control conditions.

Figure 2
Examples of photographic field observations from Almaty.
a) fog conditions; b) industrial surroundings; c) construction activity; d) traffic congestion

Figure 3
Examples of photographic field observations from Sumgayit.
a) fog conditions; b) industrial surroundings; c) construction activity; d) traffic congestion

The Almaty PM2.5 and PM10 datasets were processed using daily median values. The date variable was broken down into year and month components to calculate annual and monthly patterns. Annual summaries compared changes over time, while monthly summaries helped identify seasonal differences.
For Sumgayit, the available PM2.5 values were organized in a table, and estimated PM10 intervals were calculated using the 0.65 to 0.70 ratio method. These values were then analyzed alongside photographic field observations to connect particulate matter indicators to potential industrial, transport, construction, and urban environmental factors.
The analysis includes three main stages:
1. Organizing numerical and photographic datasets
2. Calculating annual and monthly PM2.5 and PM10 indicators
3. Interpreting air pollution patterns in relation to industrial, transport, construction, and urban environmental factors

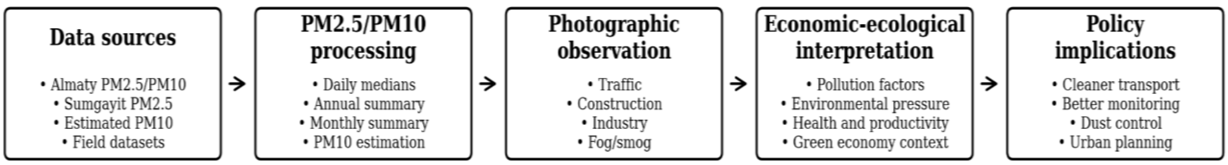

Figure 4
Methodological framework of the study

Results and discussion

The Almaty dataset offers daily PM2.5 and PM10 concentration data from 2020 to 2025. For the analysis, daily median values served as the main indicator because the median is less influenced by short-term extremes than the daily maximum. The annual summary reveals that both PM2.5 and PM10 levels changed significantly during the study period.

Table 3

Annual PM2.5 and PM10 indicators in Almaty based on daily median values, 2020–2025

Year	Available days	Average daily median PM2.5, µg/m³	Average daily median PM10, µg/m³	Median of daily PM10 medians, µg/m³
2020	*232*	*36.7*	*58.51*	*18.27*
2021	*326*	*44.67*	*72.24*	*28.73*
2022	*280*	*38.09*	*60.3*	*22.13*
2023	*285*	*41.02*	*64.5*	*26.4*
2024	*143*	*101.37*	*148.1*	*63.5*
2025	*359*	*43.76*	*54.99*	*24.92*

The results show that particulate matter levels in Almaty remained significant throughout the study period. The annual average daily median values for PM2.5 ranged from 36.70 µg/m³ in 2020 to 44.67 µg/m³ in 2021. For PM10, the range was from 58.51 µg/m³ in 2020 to 72.24 µg/m³ in 2021. In 2022 and 2023, the values stayed within a similar range. This indicates that particulate matter pollution was not just a one-year issue but a persistent problem for urban air quality. In 2024, annual averages for both PM2.5 and PM10 are much higher. However, this year also shows extremely high individual values and fewer available days compared to previous years. Therefore, the 2024 data should be interpreted with caution. It might indicate real pollution spikes, issues with the sensors, temporary extreme events, or problems with data quality. As such, the 2024 value can help identify a potential abnormal pollution period, but it should not be viewed as a straightforward long-term trend without further validation.

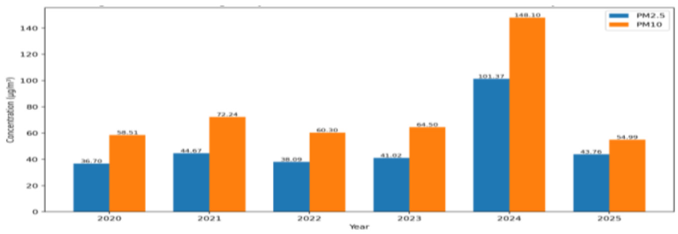

Figure 5

Annual average daily median PM2.5 and PM10 concentrations in Almaty, 2020–2025.

Source: Prepared by the authors based on Arifzade (2026b)

Monthly summaries show that PM2.5 and PM10 levels in Almaty were usually higher in the cold months and lower in the warmer ones. This pattern may be connected to emissions from heating, less atmospheric mixing, stagnant air, and temperature inversions. The winter months, particularly December, January, and February, had more buildup of particulate matter than the spring and summer months.

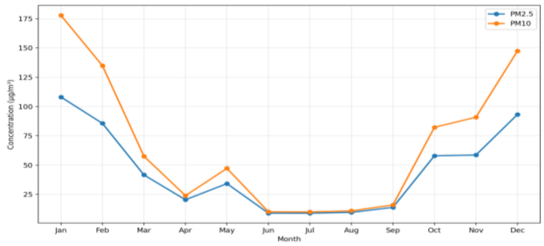

Figure 6

Monthly variation of PM2.5 and PM10 concentrations in Almaty, 2020–2025

For Sumgayit, official PM2.5 data came from the National Hydrometeorological Service under the Ministry of Ecology and Natural Resources of the Republic of Azerbaijan. Since direct PM10 values were not in the same dataset, we estimated PM10 using the PM2.5/PM10 ratio approach. These values should be seen as approximate indicators, not as direct PM10 measurements.

Table 4

PM2.5 and estimated PM10 values for Sumgayit

Year	City	Official PM2.5, µg/m³	Estimated PM10 minimum, µg/m³	Estimated PM10 maximum, µg/m³
2021	*Sumgayit*	*22*	*31.4*	*33.8*
2022	*Sumgayit*	*21*	*30*	*32.3*
2023	*Sumgayit*	*23*	*32.9*	*35.4*

The results show that PM2.5 values in Sumgayit remained fairly stable from 2021 to 2023. Estimated PM10 values also fluctuated within a small range. This indicates that particulate matter pollution in Sumgayit should be viewed alongside industrial activity, transport traffic, construction work, and local urban dust sources.

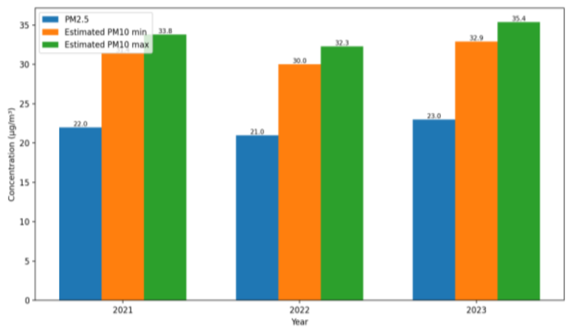

Figure 7

PM2.5 and estimated PM10 values in Sumgayit, 2021–2023

The photographic field observation datasets help interpret the numerical results by showing visible urban factors related to particulate matter pollution in Almaty and Sumgayit. The examples in Figures 2 and 3 include fog, smog, industrial areas, construction activity, and traffic jams. These factors can increase PM2.5 through combustion, transport, and industrial emissions, and PM10 through road dust, construction dust, tire and brake wear, and resuspended particles.

In Almaty, higher levels of particulate matter, especially in cold months, may relate to traffic density, heating-season emissions, industrial areas, and poor atmospheric conditions. In Sumgayit, stable PM2.5 values and estimated PM10 intervals should connect with the city's industrial profile, construction activity, transport flow, and local dust sources. While photographic materials do not directly measure air pollution, they provide useful context for understanding possible sources behind the observed and estimated indicators. From an economic and ecological viewpoint, PM2.5 and PM10 pollution pressures affect urban air quality, public health, worker productivity, healthcare expenses, and city management.

Therefore, cleaner transport, better industrial monitoring, control of construction dust, regular road cleaning, and green urban planning are key policy directions for both cities. Overall, combining numerical datasets with photographic field observations links particulate matter indicators to real urban processes and supports a clearer understanding of air pollution in the context of sustainable urban development.

Conclusion

This study examined the factors related to PM2.5 and PM10 air pollution in Sumgayit and Almaty. It used numerical datasets and photographic field observations. The results indicate that Almaty experiences more seasonal changes, with higher levels of particulate matter in the colder months. In contrast, Sumgayit shows relatively stable PM2.5 levels and estimated PM10 ranges. Key contributors in both cities include industrial activity, traffic congestion, construction dust, fog and smog conditions, and various urban environmental factors.

The study shows that combining air quality data with visual field evidence gives a solid basis for understanding urban air pollution. Cleaner transport, better industrial monitoring, dust control, and green urban planning are suggested as important policies to reduce particulate matter pollution and promote sustainable urban development.

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