International Journal of Design & Nature and Ecodynamics
Vol. 21, No. 5, May, 2026, pp. 1461-1466
Journal homepage: http://iieta.org/journals/ijdne

Monitoring of PM_{10} and $PM_{2.5}$ Air Quality in Skopje, North Macedonia (2023–2024)

Rushan Ceka[1], Ornela Çuçi[2], Iliriana Demaj[1*], Abidin Zenku[3], Flutra Spahiju[3]

[1] Department of Emergency Management, Business College, Pristina 10000, Kosovo
[2] Department of Biosciences and Engineering, Faculty of Economics, Technology and Innovation, Western Balkan University, Tirana 1001, Albania
[3] Department of Engineering for the Protection of the Working and Living Environment, Mother Teresa University, Skopje 1000, Republic of North Macedonia

Corresponding Author Email: iliriana.demaj@hotmail.com

https://doi.org/10.18280/ijdne.210522

Received: 11 March 2026
Revised: 20 May 2026
Accepted: 27 May 2026
Available online: 31 May 2026

Keywords:
air, pollution, quality, environment, measurements

ABSTRACT

Air pollution is one of the most serious global environmental problems. It negatively affects not only ecosystems and the quality of the living environment but also has direct consequences on human health. In this way, air pollution poses a double threat, damaging nature and endangering the well-being of the population, making its treatment one of the most important priorities for environmental protection and public health. Air pollution is mainly caused by various human activities, such as transport, industry, agriculture, fossil fuel combustion, as well as pollution from waste and many other activities. One of the main problems of air pollution is the high concentrations of PM_{10} and $PM_{2.5}$ particulate matter. These particles pose a significant challenge, particularly for developing countries, including the Republic of North Macedonia. This study addresses air pollution in the city of Skopje during the period 2023–2024, with a particular focus on the concentrations of PM_{10} and $PM_{2.5}$ particles. During the research for this paper, through the results obtained from the Lisice station in the city of Skopje for the two-year period 2023–2024, from the analyses performed, it was found that the concentrations of PM_{10} and $PM_{2.5}$ particles have often exceeded the permitted limits. Regarding PM_{10} particles, in 2023, a total of 91 exceedances of the permitted threshold were recorded, while in 2024, 99 exceedances were recorded. $PM_{2.5}$ particles have also recorded exceedances for six months in 2023 and 2024. These exceedances show that air pollution in Skopje continues to be a serious environmental and health problem, which requires stricter and more efficient measures to reduce pollution, improve air quality, and protect the health of city residents.

1. INTRODUCTION

Air pollution in the world today is considered one of the biggest environmental problems and has the greatest impact on global health [1-4]. Despite the application of numerous government regulations, air pollution around the globe continues to increase, causing numerous effects on human health, which is thought to cause 7 million premature deaths per year [5].

Air pollution is thought to be a major driver of non-communicable diseases, including lung cancer, stroke, heart disease, and various breathing problems [6-9]. Therefore, given these concerns, addressing air pollution problems requires the application of policies on energy, waste management, and transportation [10-12].

In the Western Balkan countries, specifically in North Macedonia, air quality in urban areas is degraded and characterized by very high levels of pollution, especially $PM_{2.5}$ and PM_{10} particles. This pollution is thought to be a consequence of rapid urbanization, outdated industrial infrastructure, materials used for heat, and a lack of green spaces [13-15].

Skopje, the capital of North Macedonia, according to literature and various reports from the European Environment Agency (EEA), is considered one of the cities with high pollution, especially from the highest concentrations of fine particles $PM_{2.5}$ and PM_{10}, and from emissions from housing that act as a major contributor to poor air quality [16, 17].

During the winter months, the permitted values of these particles are constantly exceeded, where this alarming situation is reported to come from the specific topography of the city of Skopje, which is positioned in a valley, and the city of Skopje is also affected by the metrological phenomenon of thermal inversion, therefore, this phenomenon blocks pollutants in the very low atmosphere, making it impossible for them to disperse at higher altitudes [14].

This study aimed to assess air pollution levels and temporal trends of $PM_{2.5}$ and PM_{10} pollution in the city of Skopje during the period 2023-2024.

This timeframe was chosen because it includes the most recent data from continuous air quality monitoring in the city.

The Lisice monitoring station, which was selected due to its location in an urban area affected by traffic pollution, urban activities, and seasonal heating, was used.

This study provides the most recent data and a more comprehensive overview of local-level $PM_{2.5}$ and PM_{10} concentrations for Skopje and the Western Balkans region, compared to other reports and studies.

2. MATERIALS AND METHODS

The data used in this research consists of secondary data obtained from the Lisice monitoring station. The data were collected by the Ministry of Environment and Spatial Planning of North Macedonia, specifically through the Macedonian Environmental Information Center and the Air Quality Monitoring Unit. The data are monitored 24 hours a day.

Measurements of air pollution particles $PM_{2.5}$ and PM_{10} are carried out by applying reference and automatic monitoring methods. The gravimetric method (EN12341) is more accurate and is applied only as a reference method for official verification. This method is applied for calibration and validation of all automatic monitoring stations.

GRIMM Aerosol Technik GmbH's Calibration Tower Model 7.850 is used to calibrate the automated PM_{10} and $PM_{2.5}$ analysers. The official monitoring authority in charge of Skopje's air quality monitoring network performs data validation and quality control procedures.

Another method is the automatic method with beta analyzers (β-attenuation - BAM). It is one of the most used devices for continuous measurement of PM_{10} and $PM_{2.5}$, where most of the stations in the city of Skopje (Rektorat, Centar, Lisice, Gazi Baba, Karposh) use BAM analyzers for 24-hour measurement.

This study covers the period from 2023 to 2024.

The data set has an hourly temporal resolution. Missing data were considered as "missing values" and excluded from the analysis. Daily averages were determined from 24-hour measured readings, while monthly averages were derived from the corresponding daily values, from which monthly averages were derived.

Days exceeded were identified based on the limit values set out in Directive 2008/50/EC, and the laws of the Republic of North Macedonia.

Table 1. Permitted values according to EU Directive 2008/50/EC [18] and the values of the Air Pollution Law (No. 151/21 and 3/25) [19]

Pollutant	Limit/Standard Value for 24-hour According to the Directive 2008/50 EC	Additional Information	Limit Values/Standards for Years According to Directive 2008/50 EC	Limit/Standard Value for 24-hour According to the Air Pollution Law (No. 151/21 and 3/25)	Limit Values/Standards for Years According to Air Pollution Law (No. 151/21 and 3/25)
PM_{10}	50 μg/m³	should not be passed more than 35 times in a calendar year	40 μg/m³	50 μg/m³	35 μg/m³
$PM_{2.5}$	Not specified	--	25 μg/m³		25 μg/m³

Note: Directive 2008/50/EC does not specify a 24-hour limit value for $PM_{2.5}$, only annual limit/target values are provided.

Statistical processing of data and processing of figures were done using Microsoft Excel and Pastel 5.

The data of this study were based on data received and analyzed from the monitoring station "Lisice," coordinates: Longitude 21°28′12″ and Latitude 41°58′42, and Altitude 235 m.

The Lisice monitoring station is a combined urban location affected by residential zones, city traffic, and seasonal heating emissions. The environment around is marked by urban activities and population exposure common in the urban area of Skopje.

Therefore, the results of this research aim to reflect particulate pollution levels at the chosen urban monitoring location instead of the whole city of Skopje.

For each of the two study years' monitored months, daily average concentrations were computed. Additionally, using daily mean concentrations, the number of days that exceeded the relevant limit values was determined and tallied.

The evaluation was conducted in compliance with the limit values specified in the applicable EU Air Quality Directives and the Republic of North Macedonia's Air Quality Law (Table 1).

The Wilcoxon signed-rank test was used to compare the monthly mean PM_{10} and $PM_{2.5}$ concentrations between 2023 and 2024. The comparatively limited sample size (n = 12 months) and possible deviations from normalcy led to the selection of this non-parametric test.

3. RESULTS

From the results presented through graphs from the "Lisice" monitoring station, for air pollution in the city of Skopje, for the period January-December 2023-2024, of the PM_{10} and $PM_{2.5}$ parameters, we will discuss this research paper for the 2-year period. We have conducted the analyses and processing of the results, referring to the Law on Ambient Air Quality, Parliament of Macedonia, 2015; the Official Gazette of the Republic of North Macedonia, No:4/13 for $PM_{2.5}$ and the Official Gazette of the Republic of North Macedonia, No. 50.05, for PM_{10}, in full compliance with Directive 2008/50/EC, always for μg/m³.

The results of the average values show that PM_{10} particles showed the highest values during the months of December, January, and February for the years 2023 and 2024. The results also showed high values exceeded during these months of the years 2023 and 2024 (Figure 1 and Table 2).

The minimum value of PM_{10} particles for the year 2023 was recorded during the month of May (22.9 μg/m³), while the maximum was in the month of December (131.7 μg/m³), and the average values for the year 2023 were (47.06 ± 33.91 μg/m³). While for the year 2024, the minimum values were recorded in the months of May and June (35 μg/m³), while the maximum was in the month of January (96.3 μg/m³), and the average value for the year 2024 was (46.47 ± 26.24 μg/m³) (Table 2).

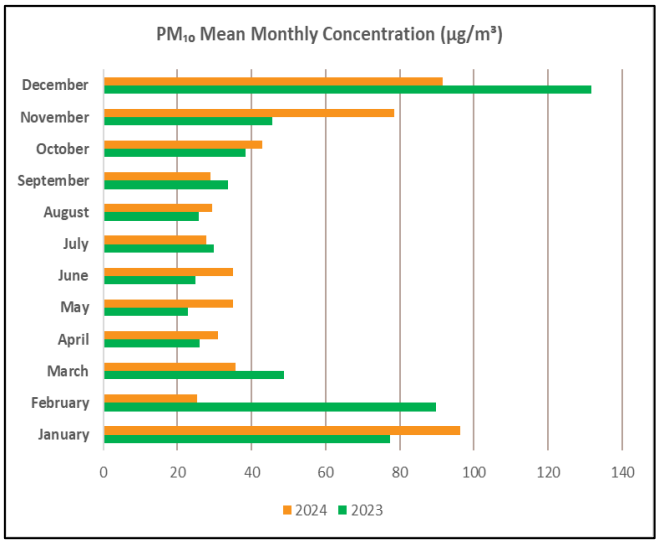

Figure 1. PM_{10} mean monthly concentration (µg/m³) 2023-2024

Table 2. Summary statistics of PM_{10} and $PM_{2.5}$ concentrations (2023–2024) and Wilcoxon signed-rank test results

Month	Mean PM_{10} Concentration (µg/m³)		Mean $PM_{2.5}$ Concentration (µg/m³)	
	Year 2023	Year 2024	Year 2023	Year 2024
January	77.4	96.3	**77.4**	**96.4**
February	89.7	25.4	**57.8**	**57.2**
March	48.8	35.7	**29.4**	**23.3**
April	26.1	30.9	**16.7**	**15.3**
May	22.9	35	**12.2**	**12.2**
June	24.9	35	**9.5**	**14.8**
July	29.9	27.8	**7.6**	**13.9**
August	25.8	29.4	**10.7**	**14.7**
September	33.7	29	**12.7**	**29**
October	38.5	43	**27**	**27**
November	45.7	78.6	**27.3**	**57.8**
December	131.7	91.6	**66.9**	**58**
Mean ± Standard Deviation (SD)	47.06 ± 33.91	46.47 ± 26.24	29.6 ± 24.2	34.96 ± 26.4
Wilcoxon Signed-Rank test	W = 36.0, p-value 0.85		W = 15.0, p-value 0.203	

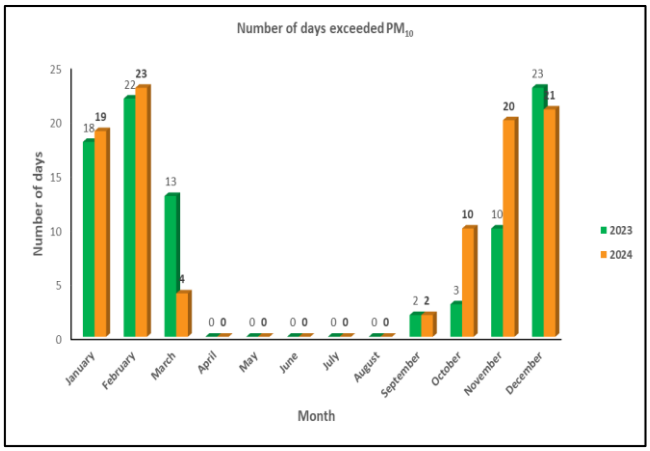

Figure 2. Number of days with PM_{10} exceedances during 2023 and 2024

During this year 2023, there were a total of 91 days of exceedances above the threshold of the allowed values, while during this year 2024, there were a total of 99 days of exceedances above the allowed values (Figure 2 and Table 3).

$PM_{2.5}$ particle results show that in 2023 the highest maximum values were recorded in January (77.4 µg/m³) and December (66.9 µg/m³) indicating high seasonal pollution during winter, similar high results recorded in maximum values were also reported in 2024 January (96.7 µg/m³) where a high increase was also in November (57.8 µg/m³), the minimum values were recorded during the spring-summer months (May-August) being also associated with favorable atmospheric conditions and better dispersion of pollutants (Table 2 and Figure 3).

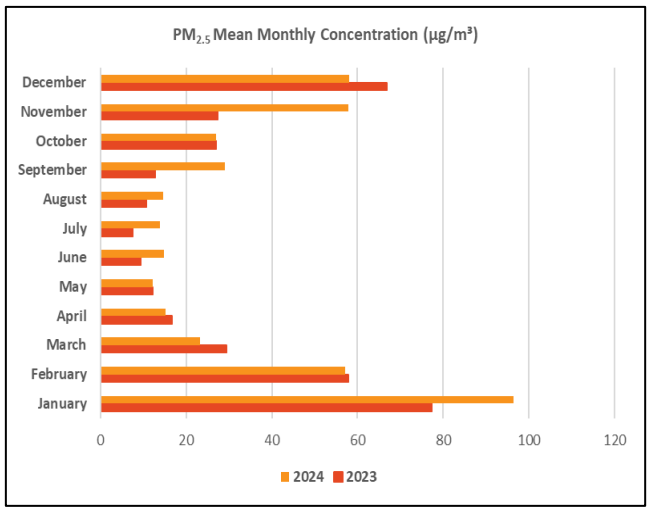

Figure 3. Monthly mean $PM_{2.5}$ concentrations (µg/m³) in 2023–2024

The average value for 2023 was 29.6 ± 24.2 µg/m³, while in 2024 it was 34.96 ± 26.4 µg/m³, indicating a higher deterioration of pollution in 2024 (Table 2). The high standard deviation values in both years indicate large seasonal variability in $PM_{2.5}$ particle concentrations.

Table 3. Number of days exceeded by PM_{10} and $PM_{2.5}$ particles during 2023 and 2024

Month	PM_{10} Exceeding the Number of Days per Month		$PM_{2.5}$ Exceeding the Number of Days per Month	
	2023	2024	2023	2024
January	18	19	28	20
February	22	23	26	26
March	13	4	21	13
April	0	0	3	0
May	0	0	0	0
June	0	0	0	1
July	0	0	0	0
August	0	0	0	0
September	2	2	0	1
October	3	10	0	26
November	10	20	15	26
December	23	21	24	26
Total number of days exceeded	91	99	117	139

In 2023, there were exceedances over the allowed threshold in the months of January, December, February, March, April,

and November (Figure 4).

Also, in 2024, there were exceedances of the allowed threshold for a full 8 months, starting from the months of January, December, November, February, March, June, September, and October (Figure 4).

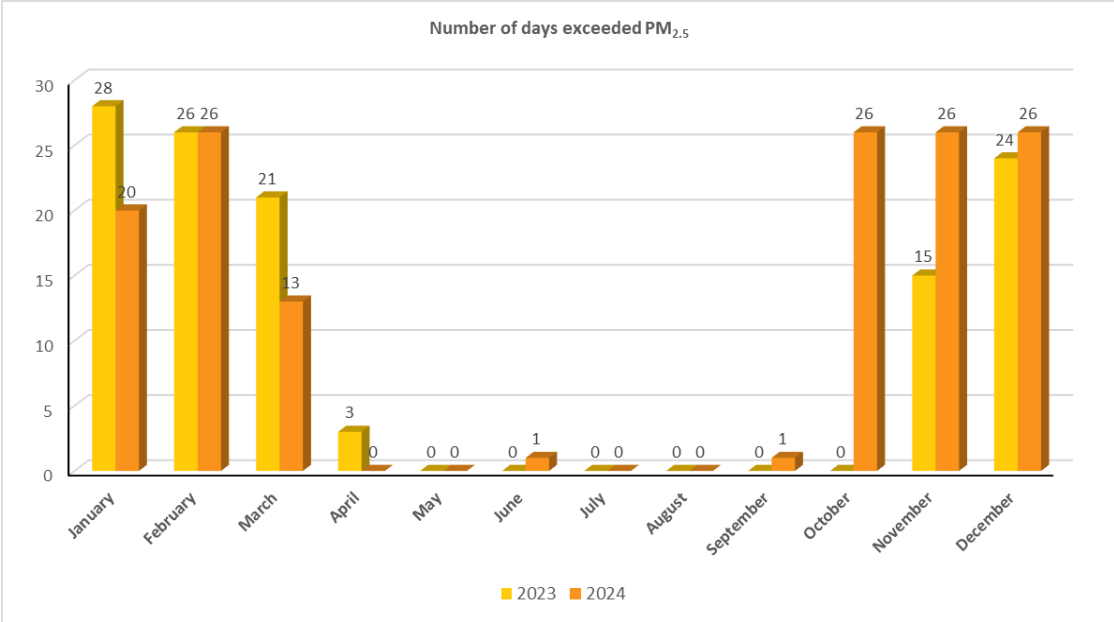

Figure 4. Number of days with $PM_{2.5}$ exceedances during 2023 and 2024

Also, during the comparison of these two years, it was observed that in the months of April, May, June, July, and August, in both years, there were no exceedances above the permitted threshold (Figure 4). With this, we can conclude that climatic conditions play a key role in air pollution in general.

The results of the Wilcoxon test showed no statistically significant changes between the monthly average concentrations of PM_{10} between 2023 and 2024 ($W = 36.0$, $p = 0.85$), similar results were also presented by the monthly concentrations of $PM_{2.5}$ ($W = 15.0$, $p = 0.203$), showing no statistically significant changes between 2023 and 2024.

4. DISCUSSION

From the analysis of the data analyzed for monitoring the concentration of air particles $PM_{2.5}$ and PM_{10} for the years 2023 and 2024 in the city of Skopje, on many days of the year, we have allowed exceedances compared to research [18] and the air quality law No:4/13 [19].

The results showed different seasonal variations, where during the winter months of December, January, and February, there were higher values of pollution from these particles, while during the months of April-August, there were lower values of pollution from PM_{10} and $PM_{2.5}$ particles.

Similar results are reported in previous research in Skopje [20]. Research [20] reports that the biggest polluters during winter are houses and apartments that are traditionally heated with wood and coal, releasing large amounts of particles, and industries that use coal fuel are also known as the main polluters.

For PM_{10} particles, the number of exceedances increased from 91 days in 2023 to 99 days in 2024, an increase that we believe presents a continuing challenge for air quality. The highest levels of exceedances were recorded in December and February on 2 days; this is related to traffic demands from residential and commercial services, atmospheric conditions, and pollution from traffic and industry.

This is in accordance with studies of various cities in the Pristina region [21], Tirana [22], Serbian [23], where during winter the highest values of PM_{10} particles were shown due to the heating of homes and unfavorable meteorological conditions [24, 25].

While for $PM_{2.5}$ particles, we had more exceedances, recording exceedance values in six months of the year for the two years studied, reaching the maximum value (96.4 µg/m³) for January 2024, and (77.4 µg/m³) for January 2023.

These high values of $PM_{2.5}$ particles are also reported in various global studies, which are thought to be a consequence of low temperatures and weak winds, especially during the winter season [26-30].

$PM_{2.5}$ particles have been reported to pose a very serious risk to human health, not only causing premature cardiovascular and cerebrovascular diseases, but also inducing endothelial dysfunction and oxidative stress, which negatively affect human health [31-33].

While during the summer months $PM_{2.5}$ particles showed minimal values (7.6–16.7 µg/m³) for 2023 and (12.2–15.3 µg/m³) for 2024, these results indicate that climatic factors, including temperature, wind, and precipitation, are factors that influence the distribution of these particles.

The results of this research showed that $PM_{2.5}$ particles increased compared to 2023. This is due to the fact that temperatures during the winter of 2024 were lower, which led to an increase in the demand for heating fuel.

Many studies report that Balkan cities experience very severe pollution during the winter, which is mainly driven by the heating of residential buildings using coal and wood for heating, where the values of this pollution are three times higher than in the summer and exceed the values allowed according to WHO guidelines [23, 34-36].

These findings highlight the necessity of applying strategies for controlling Skopje's air quality, especially in winter when exposure to particulate matter poses the greatest health risk.

Regulation and stricter inspection controls of industrial emissions, improved traffic control, and the application of new technologies for cleaner heating.

The significant seasonal variation also means that the prediction and mitigation of pollution events should take into account meteorological circumstances.

This study does not include direct measurements of metrological parameters, including wind speed, temperature, precipitation, humidity, and thermal inversion data. Discussions regarding climatic and topographic factors are based on previous research conducted in the city of Skopje. We recommend that future studies combine measurements of PM_{10} and $PM_{2.5}$ particles with meteorological parameters.

In conclusion to this discussion, we recommend that there be continuous monitoring and effective intervention in the creation of new regulations and strategies for monitoring air quality in Skopje, and we also recommend that the number of monitoring stations in this city and other cities in North Macedonia be increased.

5. CONCLUSION

From the data of this research, we conclude that the particles for PM_{10} and $PM_{2.5}$ at the "Lisice" station in the city of Skopje during the period of 2023 and 2024, air pollution has been continuously above the permitted limits in both years, with the largest number of exceedances in 2024.

From the results, we conclude that PM_{10} has had a greater number of exceedances over the permitted values during several days, while $PM_{2.5}$ has had more exceedances during the winter months.

These seasonal variations may be associated with climatic conditions and increased heating activities during colder periods.

In addition to possible climatic factors, air pollution in Skopje may also be associated with factors such as geographical location, traffic pollution, industrial pollution, and urban impacts, especially pollution from fuels used for heating during the coldest months of the year. However, these factors should be considered as possible explanations rather than direct findings of this study.

To better identify the primary causes of air pollution in Skopje, future research should integrate PM data with meteorological characteristics like wind speed, temperature, rainfall, and thermal inversion events, as well as emission inventories.

We recommended that the relevant authorities implement focused strategies to lower PM_{10} and $PM_{2.5}$ air pollution. To make these acts more noticeable and successful, they should be arranged into long-term initiatives.

Comprehensive inspections, industrial controls of air pollution-causing operations, air risk monitoring, and public notification during high-risk periods are some of the measures.

Reducing emissions at the source, subsidizing health-related technologies (like solar energy and energy-efficient systems), offering treatments to improve home insulation to lower fuel consumption, and increasing lighting in high-rise buildings in densely populated areas should be the main short-term initiatives.

REFERENCES

[1] Manisalidis, I., Stavropoulou, E., Stavropoulos, A., Bezirtzoglou, E. (2020). Environmental and health impacts of air pollution: A review. Frontiers in Public Health, 8: 14. https://doi.org/10.3389/fpubh.2020.00014

[2] Behera, D.K., Viswanathan, P.K., Mishra, S. (2024). Effects of air pollution on global health: Evidence from the global burden of disease study in the BRICS countries. International Archives of Occupational and Environmental Health, 97(8): 813-832. https://doi.org/10.1007/s00420-024-02087-7

[3] Chen, F., Zhang, W., Mfarrej, M.F.B., Saleem, M.H., Khan, K.A., Ma, J., Raposo, A., Han, H. (2024). Breathing in danger: Understanding the multifaceted impact of air pollution on health impacts. Ecotoxicology and Environmental Safety, 280: 116532. https://doi.org/10.1016/j.ecoenv.2024.116532

[4] Adjei, F.A., Afriyie, A. (2025). Air pollution as a global health risk: Emerging evidence, interventions and policy insights. World Journal of Advanced Research and Reviews, 27(1): 1925-1940. https://doi.org/10.30574/wjarr.2025.27.1.2716

[5] Monoson, A., Schott, E., Ard, K., Kilburg-Basnyat, B., Tighe, R.M., Pannu, S., Gowdy, K.M. (2023). Air pollution and respiratory infections: The past, present, and future. Toxicological Sciences, 192(1): 3-14. https://doi.org/10.1093/toxsci/kfad003

[6] Schraufnagel, D.E., Balmes, J.R., Cowl, C.T., De Matteis, S., et al. (2019). Air pollution and noncommunicable diseases: A review by the forum of international respiratory societies' environmental committee, part 2: Air pollution and organ systems. Chest, 155(2): 417-426. https://doi.org/10.1016/j.chest.2018.10.041

[7] Al-Kindi, S.G., Brook, R.D., Biswal, S., Rajagopalan, S. (2020). Environmental determinants of cardiovascular disease: Lessons learned from air pollution. Nature Reviews Cardiology, 17(10): 656-672. https://doi.org/10.1038/s41569-020-0371-2

[8] Howse, E., Crane, M., Hanigan, I., Gunn, L., Crosland, P., Ding, D., Hensher, M., Rychetnik, L. (2021). Air pollution and the noncommunicable disease prevention agenda: opportunities for public health and environmental science. Environmental Research Letters, 16(6): 065002. https://doi.org/10.1088/1748-9326/abfba0

[9] Wang, S., Lai, H. (2025). The global burden, trends and cross-region inequities of non-communicable diseases attributed to ambient particulate matter pollution. Frontiers in Public Health, 13: 1682574. https://doi.org/10.3389/fpubh.2025.1682574

[10] Jonidi Jafari, A., Charkhloo, E., Pasalari, H. (2021). Urban air pollution control policies and strategies: A systematic review. Journal of Environmental Health Science and Engineering, 19(2): 1911-1940. https://doi.org/10.1007/s40201-021-00744-4

[11] Awewomom, J., Dzeble, F., Takyi, Y.D., Ashie, W.B., Ettey, E.N.Y.O., Afua, P.E., Sackey, L.N.A., Opoku, F., Akoto, O. (2024). Addressing global environmental pollution using environmental control techniques: A focus on environmental policy and preventive environmental management. Discover Environment, 2(1): 8. https://doi.org/10.1007/s44274-024-00033-5

[12] Şanlıtürk, D. (2025). The causal link between air pollution and respiratory diseases: Evidence from granger causality test. Thoracic Research and Practice,

26(6): 314-322. https://doi.org/10.4274/ThoracResPract.2025.2025-3-4
[13] Belis, C.A., Pisoni, E., Degraeuwe, B., Peduzzi, E., Thunis, P., Monforti-Ferrario, F., Guizzardi, D. (2019). Urban pollution in the Danube and Western Balkans regions: The impact of major PM2.5 sources. Environment International, 133: 105158. https://doi.org/10.1016/j.envint.2019.105158
[14] Manevska, E., Dimitrovska, O., Radevski, I., Gorin, S., Kuzmanoski, A., Markoski, B. (2025). Meteorological parameters versus PM10: Statistical analysis of the City of Skopje, Republic of North Macedonia using multiple linear regression. Polish Journal of Environmental Studies. https://doi.org/10.15244/pjoes/204196
[15] Nuredini, A., Ghaffarpasand, O., Bousiotis, D., Pope, F.D. (2026). Air pollution in the shadow of global crises: Lessons from a small city in the Western Balkans. Environmental Science: Atmospheres, 6(3): 418-434. https://doi.org/10.1039/D5EA00116A
[16] Andonova, E., Garcia, E.H., García González, M.C. (2023). Air quality, health and the city: The case of Skopje. Seminario Internacional de Investigación en Urbanismo. https://doi.org/10.5821/siiu.12768
[17] Health impacts of air pollution. European Environment Agency. https://www.eea.europa.eu/en/europe-environment-2025/countries/north-macedonia/health-impacts-of-air-pollution.
[18] Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe. https://eur-lex.europa.eu/eli/dir/2008/50/oj/eng.
[19] Law on ambient air quality. Official Gazette of the Republic of Macedonia. https://climate-laws.org/document/law-on-ambient-air-quality_fd2e.
[20] Vasiljevikj-Shikaleska, A., Spirova, S. (2023). Air pollution in Skopje: Practice and awareness in the scope of household heating. International Journal of Economics, Management and Tourism, 3(1): 65-78. https://doi.org/10.46763/IJEMT2331065vsh
[21] Bytyqi, V., Agaj, T., Ibrahimi, B., Qevani, S., Hoxha, B. (2026). Influence of meteorological parameters on particulate matter concentrations in Prishtina, Kosovo. Journal of Ecological Engineering, 27(4): 80-94. https://doi.org/10.12911/22998993/214727
[22] Hysenaj, M., Duraj, S. (2021). Spatiotemporal variations of particulate matter in Tirana. Journal of Ecological Engineering, 22(11): 209-214. https://doi.org/10.12911/22998993/143286
[23] Stanojević, G., Malinović-Milićević, S., Brđanin, E., Milanović, M., Radovanović, M.M., Popović, T. (2024). Impact of domestic heating on air pollution—Extreme pollution events in Serbia. Sustainability, 16(18): 7920. https://doi.org/10.3390/su16187920
[24] Dragomir, M.C.B., Munteniță, C., Simionescu, A.G., Zeca, D.E., Kramar, I., Marynenko, N. (2019). Seasonal and spatial variation of PM10 in an urban area from Romania. Journal of Vasyl Stefanyk Precarpathian National University, 6(3-4): 7-14. https://doi.org/10.15330/jpnu.6.3-4.7-14
[25] Girotti, C., Kowalski, L.F., Silva, T., Correia, E., Shimomura, A.R.P., Kurokawa, F.A., Lopes, A. (2025). Air pollution Dynamics: The role of meteorological factors in PM10 concentration patterns across urban areas. City and Environment Interactions, 25: 100184. https://doi.org/10.1016/j.cacint.2024.100184
[26] Silcox, G.D., Kelly, K.E., Crosman, E.T., Whiteman, C.D., Allen, B.L. (2012). Wintertime PM2.5 concentrations during persistent, multi-day cold-air pools in a mountain valley. Atmospheric Environment, 46: 17-24. https://doi.org/10.1016/j.atmosenv.2011.10.041
[27] Southerland, V.A., Brauer, M., Mohegh, A., Hammer, M.S., Van Donkelaar, A., Martin, R.V., Apte, J.S., Anenberg, S.C. (2022). Global urban temporal trends in fine particulate matter (PM2·5) and attributable health burdens: Estimates from global datasets. The Lancet Planetary Health, 6(2): e139-e146. https://doi.org/10.1016/S2542-5196(21)00350-8
[28] Martinez-Soto, A., Jentsch, M.F., Martinez-Gallegos, V., Duchêne, J., Zipf, A. (2025). Influence of meteorological variables on PM2. 5 concentrations in cities heated with solid fuels: A case study from Temuco, Chile. Atmospheric Environment: X, 29:100401. https://doi.org/10.1016/j.aeaoa.2025.100401
[29] Liu, Z., Wang, H., Shen, X., Peng, Y., Shi, Y., Che, H., Wang, G. (2019). Contribution of meteorological conditions to the variation in winter PM2.5 concentrations from 2013 to 2019 in Middle-Eastern China. Atmosphere, 10(10): 563. https://doi.org/10.3390/atmos10100563
[30] Wang, J., Han, J., Li, T., Wu, T., Fang, C. (2023). Impact analysis of meteorological variables on PM2.5 pollution in the most polluted cities in China. Heliyon, 9(7): e17609. https://doi.org/10.1016/j.heliyon.2023.e17609
[31] Zhang, B., Jiao, L., Xu, G., Zhao, S., Tang, X., Zhou, Y., Gong, C. (2018). Influences of wind and precipitation on different-sized particulate matter concentrations ($PM_{2.5}$, PM_{10}, $PM_{2.5–10}$). Meteorology and Atmospheric Physics, 130(3): 383-392. https://doi.org/10.1007/s00703-017-0526-9
[32] Sangkham, S., Phairuang, W., Sherchan, S.P., Pansakun, N., Munkong, N., Sarndhong, K., Islam, A., Sakunkoo, P. (2024). An update on adverse health effects from exposure to PM2.5. Environmental Advances, 18: 100603. https://doi.org/10.1016/j.envadv.2024.100603
[33] Thangavel, P., Park, D., Lee, Y.C. (2022). Recent insights into particulate matter (PM2.5)-mediated toxicity in humans: An overview. International Journal of Environmental Research and Public Health, 19(12): 7511. https://doi.org/10.3390/ijerph19127511
[34] Rajšić, S.F., Tasić, M.D., Novaković, V.T., Tomašević, M.N. (2004). First assessment of the PM10 and PM2.5 particulate level in the ambient air of Belgrade city. Environmental Science and Pollution Research, 11(3): 158-164. https://doi.org/10.1007/BF02979670
[35] Ceka, R., Shala, S., Srbinovski, M., Bislimi, K., Fetoshi, O., Salihu, F., Ismaili, M. (2018). Monitoring of air quality in Hani Elezit during of year 2016. International Journal of Agriculture and Environmental Research, 4(1): 231-237.
[36] Dimitrova, R., Georgiev, S., Dzhambov, A.M., Ivanov, V., Panev, T., Georgieva, T. (2026). Study of the relationship between urban microclimate, air pollution, and human health in the three biggest cities in Bulgaria. Urban Science, 10(2): 69. https://doi.org/10.3390/urbansci10020069