

The Impact of Air Pollution on Public Health in Some Regions of Kosovo

Daorson Aliu*, Teuta Kryeziu-Aliu

Primary Centre for Family Medicine, Ferizaj, Kosovo

Abstract

Background: Air pollution is a major environmental and public health concern in Kosovo, particularly in urban areas during the winter season. Fine particulate matter (PM₁₀ and PM_{2.5}) poses significant health risks due to its ability to penetrate deeply into the respiratory system.

Aims: This study aimed to assess the levels, seasonal variation of PM₁₀ and PM_{2.5} concentrations in selected urban areas of Kosovo, and to compare them with international air-quality standards.

Study Design: Three urban regions Prishtina, Peja, and Gjilan were selected based on demographic significance, degree of urbanization, and availability of continuous

monitoring data.

Methods: Daily PM₁₀ and PM_{2.5} measurements for the year 2024 were analysed data from the Kosovo Hydro-Meteorological Institute. Annual and seasonal averages were calculated and compared with World Health Organization (WHO) and European Union (EU) air-quality standards. Pearson correlation analysis was applied to evaluate the relationship between PM₁₀ and PM_{2.5} concentrations.

Results: All studied regions exceeded WHO annual guideline limits for PM₁₀ (15 µg/m³) and PM_{2.5} (5 µg/m³), while remaining within EU permissible limits. Prishtina recorded the highest annual mean concentrations (PM₁₀: 28.3 µg/m³; PM_{2.5}: 18.21 µg/m³). Seasonal analysis showed

that winter pollution levels were more than twice as high as summer values, with particularly elevated levels observed in Gjilan. A very strong positive correlation between PM_{10} and $PM_{2.5}$ and higher level of significance of $p < 0.01$, which suggests common emission sources, including traffic, construction activities, and solid-fuel combustion for heating.

Conclusion: Urban areas in Kosovo experience persistent air pollution that exceeds WHO recommendations, especially during winter. These findings highlight the need for enhanced air-quality monitoring, stricter emission control policies, and targeted public health interventions.

Keywords: Air pollution; Public health; Exposure assessment; Urban environment.

INTRODUCTION

One of the biggest problems for the environment and human health worldwide is air pollution. High levels of pollutants in the atmosphere are a result of increased urbanisation, heavy transportation, industry, and the combustion of fossil fuels (1). Nitrogen dioxide (NO_2) is mostly produced by automobiles, sulphur dioxide (SO_2) is produced by coal and industry, Tropospheric Ozone (O_3) is created by atmospheric chemical processes. Carbon monoxide (CO) with polycyclic aromatic hydrocarbons (2). Pollutants such as black carbon, methane, tropospheric ozone, and aerosols affect the amount of incoming sunlight (3). The worldwide urban population surpassed the rural population in 2008, marking a turning point in the urban-rural demographic balance. By 2050, it is expected to account for more than 70% of the world's population (4,5). The problem of air pollution is complicated. It is a mixture of several gases and particles, volatile organic compounds, ozone, carbon monoxide, sulphur oxide, and nitrogen oxide are examples of air pollution (6,7). Higher energy and water usage (8) declining air quality (9), increased CO emissions (10), and major consequences for human health. PM is dangerous because fine particles penetrate deep into lungs and bloodstream, causing heart/lung disease, cancer, asthma, stroke, and premature death, with no safe exposure level recognized (11). The quality of life in Kosovo has deteriorated due to environmental degradation, industrial pollutants, and a weak waste management system. Many

cities in Kosovo experience inadequate air quality, with concentrations of particulate matter in diameter or smaller ($\text{PM}_{2.5}$) significantly surpassing both national and European Union (EU) standards established by the World Health Organization (12). The current levels of air pollution pose significant risks to Kosovo's population of 1.9 million, resulting in detrimental health effects (13). Exposure to fine $\text{PM}_{2.5}$ poses significant dangers to human health, as these particles can penetrate deep into the lungs and enter the bloodstream, leading to various illnesses and even fatalities. As a consequence, they can lead to serious health issues, including lower respiratory tract infections, cancer affecting the trachea, bronchi, and lungs, ischaemic heart disease (IHD), heart attacks, and chronic obstructive pulmonary disease (COPD) (14). A large proportion of the population in Kosovo is exposed to ambient $\text{PM}_{2.5}$ concentrations exceeding both the European Union (EU) limit value ($25 \mu\text{g}/\text{m}^3$) and the more stringent WHO air quality guideline ($10 \mu\text{g}/\text{m}^3$). Particulate matter (PM) concentrations in Kosovo are considerably higher during winter, primarily due to unfavourable meteorological conditions that restrict atmospheric dispersion, along with increased emissions from solid-fuel combustion for residential and other heating needs (1). Reports that $\text{PM}_{2.5}$ exposure is associated with increased cardiovascular risk, including hypertension, atherosclerosis, arrhythmias, myocardial infarction, reduced lung function, premature death in individuals with heart or lung

disease and mortality (15,16,17). In Kosovo, there is a lack of sufficient scientific data regarding air pollution and its associated health impacts. In this context, the aim of the study was to provide updated information on population exposure to PM_{2.5} and PM₁₀ in selected municipalities in Kosovo.

MATERIALS AND METHODS

Study Area

The study was conducted in selected regions of Kosovo, including urban areas where official air-quality monitoring stations are located (Prishtina, Gjilan and Peja). These regions were chosen based on population density, availability of air-quality data, and reported health concerns.

Description of Regions

Prishtina is located in the north-eastern part of Kosovo, with geographic coordinates 42.66° N, 21.16° E. It lies in a hilly-plain area, with an average elevation of approximately 652 meters above sea level. The climate is continental with Mediterranean influences, featuring cold winters with occasional snowfall and hot, dry summers. The average annual temperatures range between 10–12°C. Winter temperature inversions contribute significantly to the accumulation of air pollutants (KHMI). Rapid urbanization has led to several consequences, including infrastructure expansion, increased air pollution, and the reduction of green spaces in central urban areas. Peja is located in the western part of Kosovo, at the foothills of the Bjeshkët e Nemuna. It is one of the most important geographical, cultural, and

economic centres of the region. Geographical Coordinates: approximately 42.66° N, 20.29° E. Elevation: around 500 meters above sea level in the city centre; higher altitudes extend toward Rugova Canyon. Peja has a continental–mountain climate, characterized by: Cold winters with moderate snowfall, Warm to hot summers, Average annual temperature: roughly 11–12°C. Gjilan is located in the southeaster part of Kosovo, near the borders with North Macedonia and Serbia. It serves as an important regional centre for trade, agriculture, and administration. Geographical Coordinates: approximately 42.46° N, 21.47° E. Elevation: around 460–520 meters above sea level, depending on the part of the city. Gjilan has a continental climate, characterized by Cold winters with occasional snowfall, Hot and dry summers.

Materials / Data Sources

In our study, we did not use exceedance days as the primary indicator. Instead, we analysed daily PM₁₀ and PM_{2.5} pollution includes particles with diameters of 10 micrometres (µm) or smaller, called PM, and extremely fine particles with diameters that are generally 2.5 micrometres (µm) and smaller (18) measurements provided by the Kosovo Hydro-Meteorological Institute (19) and calculated annual and seasonal mean concentrations for each city. Pollution was determined by comparing these mean values with the WHO and EU air quality standards. This data was generated with Complementary Sensor Networks (KHMI).

Methods

The methods used in this study were obtained from the Kosovo Hydro Meteorological Institute (19) and include official air-quality measurements for the year 2024. The analysis was conducted for three selected regions: Prishtina, Peja, and Gjilani, chosen based on their demographic importance, level of urbanization, and availability of continuous monitoring data. To evaluate climatic influences and potential pollution sources, the dataset was divided into two seasons:

Winter (November–March) characterized by increased use of solid fuels for heating, thermal inversions, and generally higher particulate concentrations.

Summer (June–September) characterized by higher temperatures, greater atmospheric mixing, and typically lower PM_{2.5} and PM₁₀ levels.

Annual and seasonal mean concentrations were calculated and compared with World Health Organization (WHO) and European Union (EU) air quality standards.

Statistical Analysis

Exceedances of World Health Organization (WHO) and European Union (EU) air quality standards were determined for the study period. Pearson correlation analysis (PCA) was conducted to assess relationships between PM₁₀ and PM_{2.5} concentrations across the two seasons: Winter (November–March) and Summer (June–September). Additionally, Chi-square (χ^2) tests and one-way ANOVA with least significant difference (LSDp) for 5% and 1% significance

levels were performed using the statistical software MINITAB 18.

RESULTS AND DISCUSSION

Urban air pollution is an environmental concern of many cities throughout the world and now recognized as an important health problem, both nationally and worldwide. The air quality measurements (AQM) for the three municipalities (Prishtina, Peja, and Gjilan) that we investigated were compared to WHO and EU criterion norms. The results highlight important public health issues and show large regional variations in pollution levels. The WHO yearly recommendation of 15 $\mu\text{g}/\text{m}^3$ is exceeded by all three regions, suggesting that coarse particle pollution is a year-round problem. All regions are still inside the 40 $\mu\text{g}/\text{m}^3$ yearly EU limit, though. Prishtina exhibits the highest yearly average (28.3 $\mu\text{g}/\text{m}^3$), suggesting ongoing exposure to higher PM₁₀, perhaps as a result of winter heating, building dust, and heavy traffic. In 2017, 3.5 million premature deaths from respiratory infections, diabetes, cardiovascular disease, lung infections, obstructions, and cancer were caused by transportation-related air pollution (6). The effects of exposure to pollutants in the indoor environment can be acute and chronic and vary from person to person, which can be considered a major public health concern. Some results from Kosovo Agency of Statistics (20,21) reports that the number of cancer cases has significantly increased from 3110 in 2022 to 4165 in 2023. The lower averages in Gjilan (20.92 $\mu\text{g}/\text{m}^3$) and Peja

(19.46 $\mu\text{g}/\text{m}^3$) indicate either better natural ventilation or fewer emission sources. Pollution in Prishtina and Gjilan are significantly greater, probably as a result of severe winter pollution occurrences. Peja exhibits a lower and more stable peak, probably as a result of improved air circulation. Prishtina exhibits high minimum levels, indicating that pollution is present all year round. There are times when the air is noticeably cleaner in Peja and Gjilan. While all municipalities satisfy the EU standard for PM10, none of them meet the WHO standard. Table 1 shows that the Prishtina locality's maximum PM10 values were 43.61 $\mu\text{g}/\text{m}^3$, while the lowest values were 17.04 $\mu\text{g}/\text{m}^3$. The difference between these values was 26.57 $\mu\text{g}/\text{m}^3$, while the differences for PM2.5 were 24.53 $\mu\text{g}/\text{m}^3$, which can be regarded as highly significant differences on high variation and can be considered the area with the highest health risk. Results are presented in Figure 1.

The PM2.5 is the most dangerous pollutant because it penetrates deep into the lungs and

bloodstream. From our results for PM2.5 we evidence different results in three regions. In the region of Prishtina the annual average for PM2.5 was 18.21 $\mu\text{g}/\text{m}^3$ and compared with WHO standards (5 $\mu\text{g}/\text{m}^3$) shows Very high exceedance (3.6 $\times$ above) while with EU standards levels are within the limit (25 $\mu\text{g}/\text{m}^3$). While Locality Peja's extreme values (Max and Min) for PM10 and PM2.5 were 26.93 $\mu\text{g}/\text{m}^3$ and 23.02 $\mu\text{g}/\text{m}^3$, respectively, moderate spread has the best levels but still above WHO. Additionally, the highest values for PM10 and PM2.5 in the region of Gjilan were 33.49 and 31.89 $\mu\text{g}/\text{m}^3$, respectively. This indicates days with exceptionally high pollution levels and is a very high variability characterised on unstable pollution. According to Table 1, there was a very substantial coefficient of correlation on value $r=0.98^{**}$ or $p<0.01$, between Pm10 and Pm2.5 particles. Results are presented in Table 1 and Table 2.

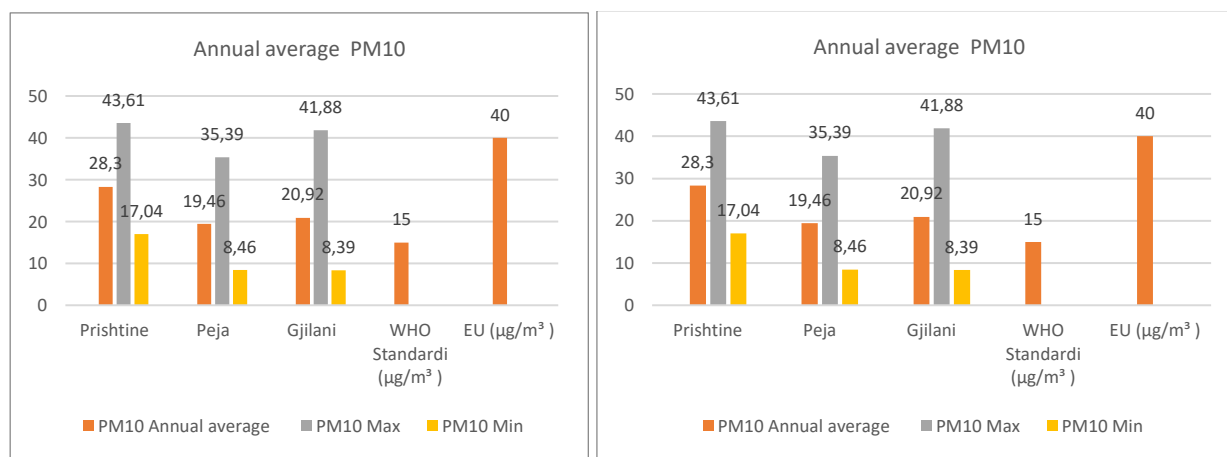


Figure 1. Comparison the annual average pollution with WHO and EU Standards

Table 1. The Annual average of pollution in three regions in Kosovo

Pollution	Locality	Prishtine	Peja	Gjilan	WHO Standard($\mu\text{g}/\text{m}^3$)	EU ($\mu\text{g}/\text{m}^3$)
PM10	annual average	28.3	19.46	20.92	15	40
	Max	43.61	35.39	41.88		
	Min	17.04	8.46	8.39		
PM2.5	annual average	18.21	13.82	16.84	5	25
	Max	34.22	29.66	37.75		
	Min	9.69	6.64	5.86		

Table 2. The mean pollution levels in Prishtina throughout the winter and summer

Prishtina/months	PM10 Winter	PM2.5 Winter	PM10 Summer	PM2.5 Summer
1	43.61	34.22	17.04	9.69
2	35.21	23.74	23.3	11.42
3	26.47	16.83	22.91	12.09
4	35.22	27.25	23.24	12.48
5	37.7	28.8	21.54	12.02
Average	35.64 $\mu\text{g}/\text{m}^3$	26.16 $\mu\text{g}/\text{m}^3$	21.60 $\mu\text{g}/\text{m}^3$	11.54 $\mu\text{g}/\text{m}^3$

Notes: Months for winter seasons are included: 1-January W, 1-May S, 2-February W, 2-June S, 3-March W, 3-July S, 4-November W, 4-August S, 5-December W, 5-September S

Some results on the pollution in Prishtina, reported that 15,141 respiratory visits (11,344 with diagnostic "J", 3797 with diagnosis "U07") and 6440 cardiovascular visits were recorded during the observation period. The temperature varied from -8.6 to 28.3 °C (mean: 10.8 °C) and the particulate matter (PM2.5) concentration ranged from 2.4 to 120.3 $\mu\text{g}/\text{m}^3$ (22). A time trend line with 25 and 23 nodes, respectively, worked well for respiratory and cardiovascular cases. Many studies by different authors (23,24)

related to air pollution suggest that exceeding the standard limits can cause diseases such as negative impact on lung development in children and adolescents. Most studies have suggested negative effects of air pollution on lung function and respiratory symptoms in children. According to Menace of Air Pollution in the 21st Century, pollution is an unwanted alteration in the physical, chemical, or biological properties of soil, water, and air that may have an impact on life or pose a risk to any living thing and it is

determined that respiratory allergies (asthma, rhinitis) are a threat posed by air pollution (25). Children who are exposed to pollution may experience immune system impairment, respiratory disorders, nasopharyngeal carcinoma, and leukaemia (26). The average winter concentration of PM₁₀ is 35.64 µg/m³, while the average summer concentration is 21.16 µg/m³. This shows that PM₁₀ levels in winter are approximately 65% higher than in summer. The winter values range from 26.47 to 43.61 µg/m³, indicating significant variability influenced by weather, heating intensity, and atmospheric conditions. Summer values are much lower and more stable, ranging from 17.04 to 23.30 µg/m³, reflecting better air dispersion and lower emissions. The average winter concentration of PM_{2.5} is 26.16 µg/m³, compared to 11.54 µg/m³ in summer. PM_{2.5} levels in winter are more than double the summer values (approximately 126% higher). Winter values range from 16.83 to 34.22 µg/m³, consistently exceeding WHO recommended limits. Summer values remain low, between 9.69 and 12.48 µg/m³, indicating significantly cleaner air during warmer months. The ratio PM_{2.5}/PM₁₀ from our results is: Winter seasons: $26.16 / 35.64 = 0.73$ which indicates pollution dominated by fine particles and for Summer seasons: $11.54 / 21.60 = 0.53$ which suggests a higher share of coarse dust in summer. According to the Kosovo Environmental Strategy (KES) 2013–2022, the main contributors to air pollution are power plants, industrial facilities (metallurgy, mines,

and cement factories), households, the transport sector, small combustion plants, agricultural activities, and waste burning. The exposure to heat-related health concerns in metropolitan areas and larger urban centres has increased proportionately with the world's growing urban population (27). The PM₁₀ levels in regions of Peja decreased by 56%, from an average of 28.46 µg/m³ in the winter to 12.47 µg/m³ in the summer. In contrast, PM_{2.5} drops by 68% from 22.41 µg/m³ in winter to 7.17 µg/m³ in summer. In Peja, PM_{2.5} also makes up a sizable portion of PM₁₀, however the Winter ratio was: 22.41 divided by 28.46 equals 0.79 shows that fine particles from combustion (wood, coal, transportation, etc.) are the main source of winter pollution. The summer ratio, which is $7.17/12.47 = 0.57$, indicates a little greater contribution from coarse particles (dust resuspension). All winter values are higher than WHO limits, with some exceeding WHO limits by more than twice (PM_{2.5}=29.66 µg/m³, for example). Summer averages are likewise higher than WHO norms. The WHO yearly limit of 5 µg/m³ is still exceeded by only one summer PM_{2.5} point (8.46 µg/m³), which is above the PM_{2.5} summer pattern. This shows that although levels are much lower than in the winter, Peja still does not satisfy WHO standards in the summer. Results are summarized in Table 3.

Results for PM₁₀ and PM_{2.5} measurements for winter (W) and summer (S) in Gjilan are shown in the Table 4.

Table 3. The mean pollution levels in Peja throughout the winter and summer

Peja/months	PM10 Winter(W)	PM2.5 Winter(W)	PM10 Summer (S)	PM2.5 Summer(S)
1	35.39	29.66	11.62	6.64
2	33.42	22.018	14.09	6.87
3	18.91	12.33	17.35	7.1
4	25.27	21.85	10.81	6.78
5	29.29	26.2	8.46	8.46
Average	28.456	22.4116	12.466	7.17

Notes: Months for winter seasons are included: 1-January W, 1-May S, 2-February W, 2-June S, 3-March W, 3-July S, 4-November W, 4-August S, 5-December W, 5-September S

Table 4. The mean pollution levels in Gjilan throughout the winter and summer

Gjilan/months	PM10 Winter(W)	PM2.5 Winter(W)	PM10 Summer (S)	PM2.5 Summer(S)
1	41.81	37.75	8.39	5.86
2	41.88	34.35	11.85	7.1
3	21.66	17.27	12.4	8.37
4	30.6	25.89	12.84	9.37
5	30.04	27.69	11.08	7.7
Average	33.198	28.59	11.312	7.68

Notes: Months for winter seasons are included: 1-January W, 1-May S, 2-February W, 2-June S, 3-March W, 3-July S, 4-November W, 4-August S, 5-December W, 5-September S

The PM10 and PM2.5 pollution levels are much greater in the winter than in the summer. PM10 levels in the winter range from 21.66 to 41.88 $\mu\text{g}/\text{m}^3$. While February had the highest number (41.88 $\mu\text{g}/\text{m}^3$), with January coming in second (41.81 $\mu\text{g}/\text{m}^3$). March had the lowest winter PM10 (21.66 $\mu\text{g}/\text{m}^3$). The WHO's recommended annual threshold of 15 $\mu\text{g}/\text{m}^3$ is exceeded by the average winter PM10 (33.198 $\mu\text{g}/\text{m}^3$), indicating significant pollution. PM2.5 levels in the winter range from 17.27 to 37.75 $\mu\text{g}/\text{m}^3$. The highest winter PM2.5 is at January (37.75 $\mu\text{g}/\text{m}^3$). While

the average winter PM2.5 (28.59 $\mu\text{g}/\text{m}^3$) is nearly 4 times higher than WHO's recommended annual guideline of 5 $\mu\text{g}/\text{m}^3$, and this indicates significant health risk during winter, as PM2.5 penetrates deeply into the lungs. PM10 levels in the summer range from 8.39 to 12.84 $\mu\text{g}/\text{m}^3$, the August month having the highest value (12.84 $\mu\text{g}/\text{m}^3$). The average summer PM10 (11.312 $\mu\text{g}/\text{m}^3$) is significantly lower than winter levels and falls within safe bounds. In contrast, PM2.5 ranges from 5.86 to 9.37 $\mu\text{g}/\text{m}^3$. August month has the highest summer time PM2.5 (9.37 $\mu\text{g}/\text{m}^3$).

The average ($7.68 \mu\text{g}/\text{m}^3$) is far lower than winter levels, yet it is marginally more than the WHO's suggested limit of $5 \mu\text{g}/\text{m}^3$. The PM10 results for winter ($33.198 \mu\text{g}/\text{m}^3$) are almost three times greater than those for summer ($11.312 \mu\text{g}/\text{m}^3$). Additionally, PM2.5 levels in the winter ($28.59 \mu\text{g}/\text{m}^3$) are nearly four times greater than those in the summer ($7.68 \mu\text{g}/\text{m}^3$).

CONCLUSIONS AND RECOMMENDATION

Based on the data available from our results for the three regions, the following main conclusions are; Annual concentrations of PM2.5 and PM10 frequently surpass WHO and EU limits. Pristina among the regions is with a significantly elevated risk of long-term health impacts.

Based on the results for these three locations, we can recommend that:

- Continuous air quality monitoring should be expanded, especially in Prishtina and Gjilan, where variability and maximum pollution concentrations are higher. Specific monitoring programs should be established, especially during the winter season when pollution is highest.
- There is a need to implement strong measures of control emissions during winter seasons since particulate matter concentrations are 60-120% higher, municipalities should implement temporary winter measures, such as restrictions on the use of low-quality fuel, subsidize cleaner heating systems.

- High PM levels throughout the year in Pristina indicate that some of them come from vehicle emissions. The strategies such as improved public transport and reduced vehicle use are recommended, where is possible.

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