Content of air pollutants in Kraljevo

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Abstract: Air pollution remains a critical public health and environmental challenge, contributing to morbidity and mortality through cardiovascular, respiratory, neurological, and developmental pathways. Global exposure to ambient sulfur dioxide, particles with aerodynamic diameters equal to or less than 2.5 and 10 µm, nitrogen oxides, ozone, carbon monoxide and volatile organic compounds continues to exceed World Health Organization guidelines for over 99% of the world's population. Therefore, this study deals with the analysis of concentrations of airborne pollutants in the city of Kraljevo over a period of one heating season. Particularly, in this paper we will focus on the influence of seasonal residential heating and combustion-related emissions on air pollution while analysing the seasonal and monthly variations in pollutant levels and comparing observed concentrations against WHO standards. These findings reinforce the causal role of fine particulate matter and NO_2 pollution in health deterioration and highlight the need for stringent air quality standards and targeted mitigation, especially during the winter months.

Keywords: Air pollution, environmental protection

1. Introduction

Air pollution is a significant environmental and public health challenge in urban areas worldwide. Exposure to airborne pollutants such as particulate matter (PM2.5 and PM10), nitrogen oxides (NO, NO_2, NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), and ozone (O_3) has been linked to respiratory and cardiovascular diseases, premature mortality, and decreased quality of life. [2,6] The World Health Organization (WHO) identifies air pollution as one of the leading environmental risk factors contributing to global disease burden, particularly in regions with rapid urbanization and industrial development.

The city of Kraljevo, located in central Serbia, represents a mid-sized urban center with a unique mix of industrial activity, residential heating, and vehicular traffic — all potential sources of air pollution.

This study aims to provide a comprehensive analysis of air quality in Kraljevo over a period of one heating season (October 2024–April 2025), with specific objectives to: quantify ambient concentrations of key air pollutants (SO_2, NO, NO_2, NO_x, CO, O_3, PM2.5, and PM10), analyse seasonal and monthly variations in pollutant levels, compare observed concentrations against WHO standards.

In the Republic of Serbia, the results of the Census 2022 showed that 64.2% of apartments used wood for heating, 17.3% of apartments were heated predominantly by electricity, and 12.6% of apartments used gas fuel for heating. Other energy sources (coal, heavy fuel oil, wind energy, solar and geothermal energy) are far less represented and together they make up 3.8% of dwellings. [7]

2. Methodology

The measuring devices and equipment which were used to sample sulfur dioxide are PROEKOS AT-801x and ASV 4G 8R. They are air sampling machines with digital readings of start time, elapsed time, current and total airflow during the day. The measurement of sulfur dioxide concentration is carried out on the basis of ultraviolet fluorescence using the reference accredited method SRPS EN 14212. For sampling suspended particles of less than 10 microns (PM10) and suspended particles (PM2.5), a sequential ambient air sampler model SEQ 47/50 Sven Leckel (Germany) was used. Reference methods SRPS EN 14341 for PM10, and SRPS EN 14907 for PM2.5 were applied for measuring their concentrations. Moreover, the measurement of the concentration of nitrogen dioxide is carried out on the basis of chemiluminescence using the reference accredited method SRPS EN 14211. Infrared spectroscopy is used to measure the concentration of carbon monoxide using the reference accredited method SRPS EN 14626, while the measurement of ozone concentration is performed by ultraviolet photometry in accordance with the reference accredited method SRPS EN 14625.

3. Results and Discussion

3.1 Overall Pollution Levels (Heating Season 2024–2025)

Air quality measurements in Kraljevo during the heating season (October 2024 – April 2025) indicate elevated levels of several pollutants, particularly particulate matter. Table 1 summarizes the mean and maximum values of key pollutants compared to World Health Organization (WHO) guidelines. [1,5]

Table 1. Average and maximum concentrations of major pollutants

Pollutant	Mean μg/m³	Max μg/m³	WHO limit*

			µg/m³
SO_2	7.46	97.7	40 (24h)
PM10	63.7	361	45 (24h)
PM2.5	51.6	313	15 (24h)
NO_2	16.0	96.8	25 (24h)
NO_X	41.0	501	-
CO	0.86	4.18	4 (24h)
O_3	22.5	85.0	100 (8h)

* WHO Air Quality Guidelines (2021)

As shown in Table 1, the analysis of air pollutant concentrations indicates that particulate matter poses the greatest concern in the monitored area. The mean concentrations of PM10 (63.7 µg/m³) and PM2.5 (51.6 µg/m³) both significantly exceeded the WHO 24-hour guideline limits of 45 µg/m³ and 15 µg/m³, respectively, with maximum values reaching hazardous levels of 361 µg/m³ and 313 µg/m³. [3] Although the mean concentrations of SO_2 (7.46 µg/m³), NO_2 (16.0 µg/m³), and CO (0.86 µg/m³) remained below their respective WHO thresholds, occasional peaks—for SO_2 (97.7 µg/m³), NO_2 (96.8 µg/m³), and CO (4.18 µg/m³)—surpassed the recommended limits, suggesting episodic pollution events likely related to local emissions. O_3 levels remained within safe bounds throughout the period, with a maximum of 85.0 µg/m³, below the WHO 8-hour limit of 100 µg/m³. Although WHO guidelines do not specify a limit for NO_x, the recorded maximum of 501 µg/m³ indicates substantial pollution likely linked to seasonal residential heating. [4]

3.2 Monthly Variation

Table 2. Monthly average concentrations of key air pollutants (Heating Season 2024-2025)

Month	SO_2 µg/m³	PM10 µg/m³	PM2.5 µg/m³	NO_2 µg/m³	NO_X µg/m³	CO µg/m³	O_3 µg/m³
Oct 2024	5.8	60.6	40.7	17.2	44.62	0.76	28.3
Nov 2024	6.4	73.2	60.5	18.3	56.11	1.16	17.1
Dec 2024	6.6	62.4	55.2	15.0	49.19	1.11	13.8
Jan 2025	7.1	83.6	74.3	17.1	47.14	0.95	13.6
Feb 2025	9.5	64.3	54.5	14.9	29.00	0.86	28.8
Mar 2025	8.4	50.4	32.6	15.8	30.40	0.54	30.6
Apr 2025	7.9	35.5	25.8	12.6	22.47	0.51	33.6

Monthly variations in air pollutant concentrations from October 2024 to April 2025 revealed distinct seasonal trends. Sulphur dioxide (SO_2) levels increased from 5.8 µg/m³ in October to a peak of 9.5 µg/m³ in February, remaining well below the WHO 24-hour guideline of 40 µg/m³. Particulate matter concentrations were significantly elevated during the winter months, with maximum values recorded in January 2025 for both PM_{10} (83.6 µg/m³) and $PM_{2.5}$ (74.3 µg/m³), far exceeding the WHO recommended limits of 45 µg/m³ and 15 µg/m³, respectively. [1,3,6] Nitrogen dioxide (NO_2) and nitrogen oxides (NO_x) also followed this pattern, with higher concentrations observed from October through January, indicating increased emissions from heating. Carbon monoxide (CO) concentrations peaked in November (1.16 μg/m^3) and decreased steadily towards April, remaining within WHO guideline values. In contrast, ozone (O_3) concentrations were lowest in winter and increased toward spring, reaching a maximum of 33.6 μg/m^3 in April, consistent with enhanced photochemical activity under higher solar radiation. [4] The above-mentioned findings highlight the influence of seasonal factors, particularly during the heating season, on ambient air quality in the study area.

4. Conclusions

As previously mentioned, we can conclude that air quality in the city of Kraljevo is significantly compromised during the colder months, with particulate matter levels frequently and substantially exceeding WHO air quality guidelines. The dominant contributor to elevated pollution levels appears to be residential heating, especially the use of solid fuels such as wood and coal. Given the health risks associated with sustained exposure to fine particulates and NO_2, especially among sensitive populations, there is an urgent need for mitigation strategies. These may include stricter regulation of heating sources, subsidising for cleaner technologies, promotion of energy efficiency, and improved public communication during high-risk pollution episodes. The results of this study underscore the importance of continuous monitoring, data transparency, and integrated air quality management to protect public health and promote sustainable urban development in Kraljevo.

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