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Impact of heatwaves and meteorological factors on ground-level ozone levels in urban ecosystems of continental and coastal Croatia

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INTRODUCTION

Ground-level ozone is a secondary pollutant and a powerful oxidant formed by photochemical reactions from primary precursors in the presence of solar radiation. Its elevated concentrations directly threaten human health, urban biodiversity, and ecosystems. The aim of this study was to quantify the impact of heatwaves on ground-level ozone levels in urban areas with distinct climatic characteristics: a continental center (Osijek) and a coastal region (Rijeka). The paper analyzes a ten-year series of hourly and daily measurement data (2014–2023) from automatic stations of the State Network for Continuous Air Quality Monitoring, alongside corresponding meteorological parameters (temperature, relative humidity, air pressure, and wind speed).

MATERIALS AND METHODS

Hourly and daily data of ozone concentrations and meteorological parameters collected from the Osijek-1 and Rijeka-2 monitoring stations were analyzed. Data processing and modeling included the analysis of diurnal patterns and seasonal cycles to determine average hourly and annual fluctuations in ozone concentrations. Multiple regression analysis was applied to model the dependence of ozone levels on meteorological parameters by year, while principal component analysis (PCA) was used to reduce dataset dimensionality and identify the main sources of variability. Fourier analysis identified dominant periodic cycles within the observed time series.

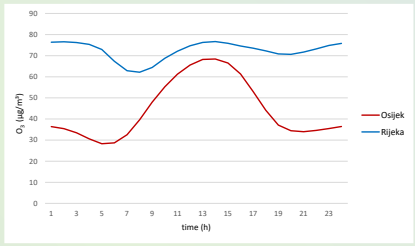


Figure 1. Diurnal cycle of average ozone concentrations in Osijek and Rijeka for the period from 2014 to 2023.

RESULTS AND DISCUSSION

The results confirm that heatwaves, driven by climate change, significantly enhance photochemical ozone production. At both observed locations, a clear diurnal pattern with a peak in the afternoon hours and a marked summer increase in concentrations were recorded, with Osijek displaying a wider range of daily oscillations, while Rijeka records generally higher average and maximum ozone concentrations (Fig. 1). In Osijek, the link between high temperatures and elevated ozone levels is more direct due to the continental climate. Conversely, a more complex dynamics was determined in Rijeka, where coastal air circulation, pressure changes, and regional transport significantly influence the intensity and duration of high pollution episodes (Fig. 2). Statistical modeling showed that years with extreme heatwaves and high air pressure exhibit high coefficients of determination, confirming meteorology as the dominant driver of ozone formation during these periods. The PCA analysis further identified temperature and solar radiation as the primary factors of the first principal component (Fig. 3), while the Fourier transform confirmed a dominant one-year cycle in both environments, directly linking summer periods of high solar radiation to increased photochemical ozone production (Fig. 4).

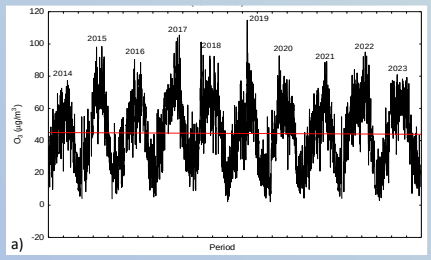


Figure 2. Daily ozone concentration in a) Osijek and b) Rijeka for the period 2014–2023.

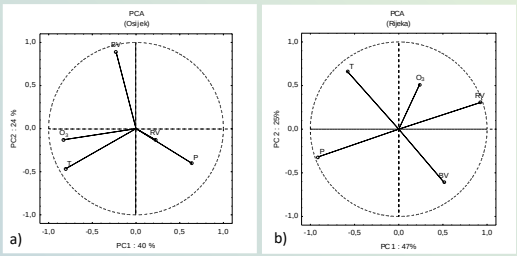


Figure 3. Factor loadings (variables) for the period 2014–2023 in a) Osijek and b) Rijeka.

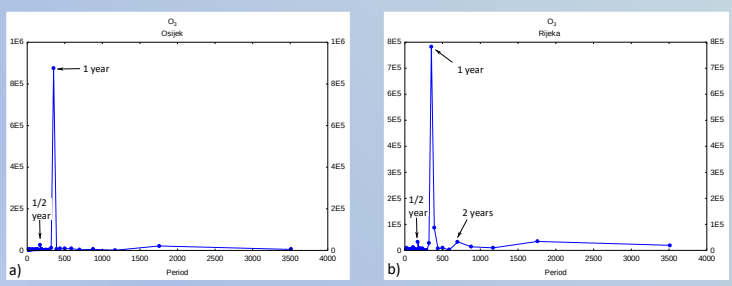


Figure 4. Periodogram for the 2014–2023 period for a) Osijek and b) Rijeka.

CONCLUSION

This study confirms strong seasonal and diurnal patterns of ground-level ozone in Osijek and Rijeka driven by photochemical processes. Heatwaves significantly increase the risk of threshold exceedances, with temperature effects being direct in continental areas, while additionally modified by coastal circulation and air pressure in coastal regions. These findings provide a solid basis for local environmental policies and climate adaptation measures to protect public health and ecosystems.

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