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The Influence of Restaurant Zones on Local Air Quality: Evidence from Novi Sad

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Abstract: This research examines how restaurant activity might influence local air quality in the urban area of Novi Sad. The study was designed to assess air pollution levels in proximity to restaurant clusters, with a focus on the impact of these establishments during critical times of the day. Air pollution data were gathered at four central sites near these clusters during two daily periods: midday (12:00 PM) and evening (7:00 PM). The results reveal that nitrogen dioxide (NO_2) levels were significantly higher in areas with dense restaurant activity during the evening hours. This highlights the relationship between increased human activity, cooking emissions, and delivery traffic associated with restaurants. In contrast, green spaces and pedestrian-friendly zones consistently maintain lower pollution levels, suggesting that urban design and planning can mitigate some of the adverse effects of air pollution. Furthermore, a comparative analysis of weekday and weekend measurements, alongside an evaluation of a 24-hour city-wide air quality trend, indicates that pollutant levels tend to rise during peak restaurant hours, especially in the evening. These findings highlight the significance of acknowledging that restaurants can impact localized air quality changes, particularly during peak operational periods. Although the research is based on limited data, it emphasizes the pressing need to consider the environmental impact of hospitality venues in urban planning and sustainability efforts, promoting a healthier urban environment for all residents.

Keywords: Air quality, restaurants, Novi Sad, PM2.5, PM10, NO_2, O_3

1. Introduction

An international environmental issue that directly impacts the quality of life for city residents is air pollution (Thomas, 2017)

In addition to harming physical health, it negatively affects social interactions, outdoor activities, and mood, collectively diminishing the city's vitality. For city residents, dining out is a significant social activity (Gao et al., 2020). Chronic exposure to air pollution, especially PM2.5 and NO2, is linked to higher incidence of cardiovascular disorders such ischemic heart disease, heart attacks, and strokes as well as respiratory conditions like lung cancer, asthma, and chronic obstructive pulmonary disease (Hilly et al., 2024).

This highlights the need to address further the factors that influence the quality of air in areas frequently used for dining out.

First it is important to state the adverse health effects of PM10 and PM2.5 and the associated health risks that are highlighted by Chang et al. (2021) and (Shah et al., 2020), who emphasize the connection between cooking and exposure to these types of air pollutants. Compared to places far from charcoal grill restaurants, it was discovered that the outdoor air near these establishments was more polluted with VOCs like BTEX and n-alkanes. As a result, nearby households and pedestrians may be exposed to high concentrations of pollutants and the secondary by-products they produce (Kim & Lee, 2012). The findings of a study by Sofuoglu et al. (2015) demonstrated that using deep-frying margarine in small-scale businesses could result in significantly higher amounts of particulate matter exposure during deep-frying.

While burning natural gas resulted in an increase in the

concentration of CO2, burning charcoal resulted in a significant increase in the CO level. Additionally, the dining area's air quality was determined to be the worst at the restaurant with the worst ventilation, and this was greatly impacted by the kitchen ventilation's operational state (Zhao et al., 2020). Lyu et al. (2022) emphasize that different type of food causes different amount of air pollutants. While Lee et al. (2001) already in 2001 noted that the way food is prepared influence the air quality. It indicates that both several factors should be taken into account when addressing this topic and that the influence of the restaurants is acknowledged in studies for some time now.

The general public is unaware that culinary operations kitchens can generate hazardous substances. It appears that restaurant owners often overlook the importance of occupational health in kitchens, as they fail to comprehend the impact of heat on food and the creation of hazardous compounds that can harm the environment (Durban, 2022). Cooking methods (such as frying versus wet cooking), pan size (smaller pans are better), oil type (the best type depends on smoking temperature), cooking temperature, food type and additives, heating source surface area (smaller burners are better), ventilation, and cooking temperature all affect the type and abundance of PM and ultrafine particles produced by both electric and gas cooking (Nassikas et al., 2024).

Globally, cooking uses a significant amount of energy, particularly in developing nations. Natural gas, charcoal, wood, kerosene, electricity, liquefied petroleum gas, biogas, and biomass are among the fuels that are typically used for cooking. As a result, the cooking procedures release significant amounts of hazardous air pollutants and greenhouse gases every day, explain ElSharkawy and Ibrahim (2022).

Durban (2022) further explain that cooking produces biomass smoke, which contains particulate matter (PM), carbon monoxide (CO), nitrogen dioxide (NO_2), formaldehyde, and various hazardous organic compounds, including benzene and other polycyclic aromatic hydrocarbons (PAHs). Especially in the winter, NO_2 concentrations were much greater when cooking than when cleaning (for example, frying versus handwashing and running the dishwasher by nearly 60%) (Keller et al., 2024)

Zhang et al. (2025) are stating that cooking activities have a significant negative impact that is frequently neglected, especially in specific contexts such as in commercial buildings. Cooking fumes have been a major source of concern for several years, particularly in densely populated cities where restaurants are often situated in close proximity to sensitive structures and residential areas. Restaurants emit pollutants as a result of heating and cooking operations that use a variety of fuels and cook a variety of food types. Cooking materials, cooking methods, and even cooking fuel have a significant impact on the quantity of pollutants released from those sources (ElSharkawy & Ibrahim, 2022).

Further it is important to emphasize that due to the rapid growth of the restaurant industry, cooking fume emissions have gotten worse. Restaurant emissions significantly contribute to outdoor air pollution levels, in addition to endangering the health of patrons and employees (ElSharkawy & Ibrahim, 2022). All these aspects demonstrate the need to put this topic into the focus of research and to analyze the impact on the air quality in the area full of restaurants.

Gao et al. (2020) adds that pollutant emissions from restaurant chimneys significantly and directly impact the ambient air outside, especially during the grilling process, which releases pollutants at a much higher rate than other cooking methods used in restaurants. The external atmosphere can change in response to any modifications, whether favourable or unfavourable, in the internal cooking methods or combustion efficiency of restaurants.

It is essential to acknowledge that restaurant-related activities have a detrimental impact on the environment, particularly in terms of air quality. The degree of these adverse effects and their implications for health underscore the need to examine the impact of this research on air quality in outdoor areas near restaurants. Furthermore, it is crucial to tailor the research to the local context. Consequently, the research is focused on four areas in Novi Sad, city in Serbia, where popular and busy restaurants are situated. The aim of the paper is to explore potential impact of restaurant presence and related urban activity on local air quality in Novi Sad. To achieve this, the following methods are employed.

2. Materials and Methods

This research aims to assess the level of air pollution in areas surrounding restaurants in Novi Sad, focusing on whether the presence and activity of restaurants might influence local air quality. The research is based on the expected influences of cooking emissions, increased foot and vehicle traffic, and other restaurant-related factors that may contribute to changes in pollution levels in urban microenvironments, due to the impact of frying and grilling on the emission of PM2.5 and NO2. Additionally, the presence of delivery vehicles, waste management activities, and increased human density can further contribute to localized air pollution. This suggests that it is crucial to focus more closely on areas with numerous restaurants in relation to air pollution.

Air quality data were collected on June 20th, 2025 (Friday), and June 22nd, 2025 (Sunday), using the AirCare mobile application, which provides real-time pollution measurements from public sensors. The app reports concentration of pollutants, including PM2.5, PM10, O3 (ozone), NO2 (nitrogen dioxide), CO (carbon monoxide), and the overall AQI (Air Quality Index).

By measuring pollution levels at selected locations near the restaurant, research aims to conclude if restaurant-related activity (such as cooking, increased traffic, and pedestrian density) contributes to changes in air pollutant concentrations. The research also compares weekdays and weekends to assess whether differences in daily activity patterns affect pollution levels. Additionally, broader 24-hour air quality trends are analyzed to contextualize localized

findings.

2.1. Data collection

Data were recorded manually from the AirCare app, to ensure consistency, all readings were taken during stable weather conditions-clear skies, mild temperatures, and little wind, which may have contributed to lower pollution levels

Measurements were taken at two time intervals: 12:00 PM (before lunch period)

7:00 PM (lunch –diner period)

Four locations across Novi Sad were selected based on their proximity to restaurants that are frequently visited. The names of individual restaurants are not recorded, but all sites are known to host multiple restaurants with moderate to high activity. The location varied in terms of their environmental setting, including:

A park-adjusted area

A pedestrian commercial street

A mixed-use urban street

A traffic-heavy area with high restaurant density.

Figure 1 shows the wider area around the location of measurement.

Additionally, data from the last 24 hours were analyzed to observe any changes in the trends of air pollution in the analyzed locations (Figure 2).

To explore potential differences between workdays and weekends, measurements are collected on a workday (Friday) and on Sunday at a similar time (midday, around 12PM).

2.2. Data analysis

Data collected on air quality in selected locations is organized and presented in a table, allowing for easy comparison and analysis of the results. Descriptive analysis is used to observe trends in pollutant levels. Air Quality Index values were interpreted using standardized U.S. AQI categories (e.g., good) with color coding applied to differentiate pollution levels. Special attention is given to variations in NO2, and particulate matter, as these pollutants are most closely linked to combustion sources and urban activity, including restaurant operation and traffic density.

The analysis focused on identifying environmental patterns and potential localized pollution hotspots in areas with a high concentration of restaurants. This approach enabled the identification of possible links between environmental characteristics, human activities, and air pollution, even within relatively short geographical distances.

3. Results

This section should provide a concise and precise description of the experimental results, their interpretation, and the experimental conclusions that can be drawn.

3.1. Analysis of air quality and pollution levels

Air quality measurements were collected at four selected locations in Novi Sad, Serbia, during midday to assess baseline pollution levels near dining areas. In all of these sites, there are restaurants and dining areas that were focus of this

research. Restaurants observed are located in the regions of Danube Park, Futoška Street, Jevrejska Street, and Zmaj Jovina pedestrian zone.

At the Danube Park area, the Air Quality Index (AQI) measures 49, indicating good air quality. Particulate matter concentrations are very low, with PM2.5 at 7 μg/m³. Ozone levels are higher (104 ppb), which is consistent with sunlight exposure in open areas. Carbon monoxide (CO) and nitrogen dioxide (NO_2) levels are minimal at 0.2 ppm and 2 ppb, respectively.

In the urban street zones of Futoška Street and Jevrejska Street, AQI values were similar at 43. Both locations recorded comparable PM2.5 (6 μg/m3) and PM10 (8-9 μg/m3) levels to other places. Notably, NO2 concentrations at these sites were elevanted to 13 ppb.

The Zmaj Jovina Pedestrian street zone showed an AQI of 45 with particulate matter concentrations comparable to other locations (PM2.5 at 7 μg/m3, PM10 at 8 μg/m3). Nitrogen dioxide levels were considerably lower at 1 ppb, reflecting the reduced traffiic in the area.

The generally good air quality results may also reflect the favorable weather conditions on the day of the measurement, including clear skies and stable temperatures.

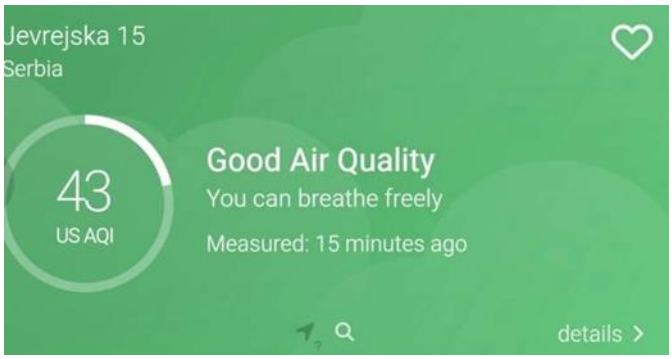

Figure 1: Air Quality 12 PM- Jevrejska street Friday.

Table 1: Air Quality Measurements Near Dining Areas in Novi Sad 12 PM.

Location	AQI	PM2.5	PM10	O3	CO	NO2	Color Code
Danube Park	49	7	8	104	0.2	2	
Futoška Street	43	6	8	94	0.2	13	
Jevrejska Street	43	6	9	94	0.2	13	
Zmaj Jovina Pedestrian Street	45	7	9	95	0.2	1	

To assess potential changes in air quality during peak restaurant hours, additional measurements were taken at 7:00 PM at the same areas. The evening data revealed increased nitrogen dioxide levels in areas with more intense traffic and

restaurant-related activity, suggesting a potential link between environmental conditions and human behavior patterns during dinner hours.

At the Danube Park, the air quality remained stable, with all values nearly identical to the midday measurements. The AQI remained at 49, and pollutant concentrations remained low, confirming that this location, surrounded by greenery and away from major streets, was less affected by urban activity.

In contrast, Futoška Street showed a notable increase in nitrogen dioxide, from 13 ppb at 12:00 PM to 26 ppb at 7:00 PM. PM2.5 and PM10 slightly decreased. This may reflect higher traffic volumes during the evening rush, along with intensified restaurant operations.

Jevrejska street experienced the most significant spike, with NO2 rising from 13 ppb at midday to 41 ppb in the evening. This location, characterized by its dense restaurant presence and vehicle access, is likely to accumulate emissions from both cooking activities in restaurants and increased motor traffic during dinner hours.

Meanwhile, Zmaj Jovina, a pedestrian zone, continued to demonstrate minimal pollution levels. Both AQI and individual pollutant concentrations remained consistent, with NO2 at just 3 ppb, reinforcing the positive environmental impact.

These evening results underscore the environment sesitivity of restaurant in conext of air pollution and importance of monitoring pollution exposure during periods of high commercial activity.

Table 2: Air Quality Measurements Near Dining Areas in Novi Sad 7 PM.

Location	AQI	PM 2.5 µg/m³	PM10 µg/m³	O3 µg/m³	CO mg/m³	NO2 µg/m³	Color Code
Danube Park	49	7	8	104	0.2	3	
Futoška Street	46	5	7	98	0.2	26	
Jevrejska Street	46	6	10	103	0.2	41	
Zmaj Jovina Pedestrian Street	49	7	8	1041	0.2	3	

To explore whether air pollution levels differ between weekdays and weekends, additional data were collected on a Sunday during the midday, using the same locations and methodology. The results, shown in Table 3, revealed a noticabe shift in overall air quality compaed to the weekdays. While resutls from Friday fell entirely within „Good"(AQI<50) category, all Sunday values were eleavnted into the „Moderate" (AQI 57-62) range. Interestingly, this increase occured despite relatevely low NO2 levels, suggesting that the chnage was not primarly driven by traffic emissions.

On weekends, restaurants often experience peak hours during luch hours which may lead to emissions that accumulate in surrounding areas, especially when the urban flow is llimited.

Table 3: Air Quality Measurements Near Dining Areas in Novi Sad 12 PM (Sunday).

Location	AQI	PM 2.5 µg/m³	PM10 µg/m³	O3 µg/m³	CO mg/m³	NO2 µg/m³	Color Code
Danube Park	57	5	5	111	0.2	1	
Futoška Street	62	5	4	114	0.2	9	
Jevrejska Street	62	6	4	114	0.2	9	
Zmaj Jovina Pedestrian Street	57	5	5	111	0.2	1	

3.2. 24-hour air quality changes

The area shown in Figure 1 is also reviewed to determine if changes occur within a 24-hour time frame. For all locations in this area, results were similar as presented in Figure 2 for June 20, 2025.

Pollution levels were moderate from 6 PM to 6 AM, then improved to "Good" from approximately 8 AM to 6 PM. This pattern aligns with the daily restaurant rhythm, suggesting that evening periods may contribute to higher pollution levels.

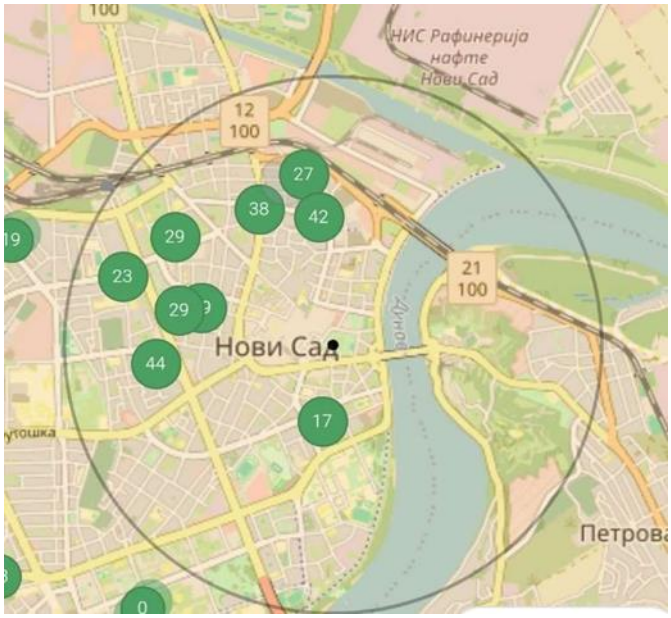

Figure 2. Covered areas.

Figure 3. Air Quality 7 PM- Jevrejska street Sunday.

Figure 4. 24-hours overview.

4. Conclusion

This paper explores the relationship between restaurant activity and local air quality in Novi Sad. Through real-time air quality measurements collected during the midday and evening hours, significant variations are identified in pollutant levels, particularly nitrogen dioxide (NO2) in areas located near restaurant clusters.

While pedestrian-friendly areas (Danube Park and Zmaj Jovina) maintained low pollution levels, streets with heavier restaurant density (Jevrejska and Futoška) showed worse air quality, especially during evening hours.

Further analysis showed that high air pollution is associated with peak restaurant hours. Several factors can be associated with it – cooking emissions, delivery traffic and reduced atmospheric circulation.

Although this research is based on limited data and localized measurements, the findings suggest that restaurant zones may contribute to an increase in pollution.

These findings suggest that restaurants not only react to surrounding environmental conditions but may also play a role in shaping urban air quality over different periods.

These results can be explained in the following way: restaurants often operate at full capacity during evening hours. It includes increased use of grills, ovens, and fryers, which may release fine particles and gases into the surrounding air via ventilation systems. Higher human density in restaurant areas can influence micro-level air circulation and impact air quality. It additionally leads to more traffic in these areas.

Findings made by observing measurements collected for this research, show that more attention is needed to be directed towards the influence that restaurants have and it is important to investigate more the influence that restaurants have on air quality as this is the first step towards finding mechanisms for reducing negative impact and improve air quality in these areas.

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Uticaj restoranskih zona na kvalitet vazduha u urbanim sredinama: primer Novog Sada

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Apstrakt: Ovo istraživanje ispituje kako bi aktivnost restorana mogla uticati na lokalni kvalitet vazduha u urbanom području Novog Sada. Studija je osmišljena da proceni nivoe zagađenja vazduha u blizini klastera restorana, sa fokusom na uticaj ovih objekata tokom kritičnih perioda dana. Podaci o zagađenju vazduha prikupljeni su na četiri centralne lokacije u blizini ovih klastera tokom dva dnevna perioda: podne (12:00 časova) i veče (19:00 časova). Rezultati pokazuju da su nivoi azot-dioksida (NO_2) bili značajno viši u područjima sa gustom aktivnošću restorana tokom večernjih sati. Ovo ističe vezu između povećane ljudske aktivnosti, emisija gasova iz kuvanja i saobraćaja dostave povezanog sa restoranima. Nasuprot tome, zelene površine i pešačke zone konstantno održavaju niže nivoe zagađenja, što sugeriše da urbani dizajn i planiranje mogu ublažiti neke od negativnih efekata zagađenja vazduha. Štaviše, uporedna analiza merenja radnim danima i vikendom, zajedno sa procenom 24-časovnog trenda kvaliteta vazduha u celom gradu, ukazuje da nivoi zagađivača imaju tendenciju rasta tokom špica restorana, posebno uveče. Ovi nalazi ističu značaj priznavanja da restorani mogu uticati na lokalizovane promene kvaliteta vazduha, posebno tokom špica rada. Iako je istraživanje zasnovano na ograničenim podacima, ono naglašava hitnu potrebu da se u urbanističkom planiranju i naporima za održivost uzme u obzir uticaj ugostiteljskih objekata na životnu sredinu, promovišući zdravije urbano okruženje za sve stanovnike.

Ključne reči: Kvalitet vazduha, restorani, Novi Sad, PM2.5, PM10, NO_2, O_3.