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Street-level of air pollution in the city of Novi Sad, Serbia

Ulični nivo zagađenja vazduha u gradu Novom Sadu, Srbija

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Abstract: The research determined variations in the concentrations of sulfur dioxide and nitrogen dioxide in the air of the city of Novi Sad, with the accompanying environmental parameters of temperature, humidity, and noise level. As a result, the findings from this study were based on data from the monitoring of aeropollutant levels on the City Traffic Line. Sulfur dioxide and nitrogen dioxide concentrations were detected using lowcost monitors at bus stops over the course of one working week and at two time intervals. The results showed a wide range of concentrations for nitrogen dioxide (from 22.8 μg/m^3 to 34.5 μg/m^3) and sulfur dioxide (from 0 to 170 μg/m^3), all values falling within the permitted limits.The findings will help to establish a strategy for addressing air pollution and lowering SO_2 and NO_2 emissions in urban areas, highlighting the potential importance of developing urban solutions for residential areas with planned bus stops.

Keywords: Urban traffic, Public tramsportation, Air pollution, Sulfur dioxide, Nitrogen dioxide, City of Novi Sad.

Sažetak: Istraživanjem su utvrđene varijacije u koncentracijama sumpor-dioksida i azot-dioksida u vazduhu grada Novog Sada, sa pratećim parametrima životne sredine temperature, vlažnosti i nivoa buke. Kao rezultat toga, nalazi iz ove studije zasnovani su na podacima iz monitoringa nivoa aerozagađujućih materija na gradskoj saobraćajnoj liniji. Koncentracije sumpor-dioksida i azot-dioksida su detektovane korišćenjem niskobudžetnih monitora na autobuskim stajalištima tokom jedne radne nedelje iu dva vremenska intervala. Rezultati su pokazali širok raspon koncentracija azot-dioksida (od 22,8 μg/m3 do 34,5 μg/m^3) i sumpor-dioksida (od 0 do 170 μg/m^3), a sve vrednosti su u dozvoljenim granicama. Nalazi će pomoći u uspostavljanju strategije za rešavanje problema zagađenja vazduha i smanjenja emisije SO_2 i NO_2 u urbanim sredinama, naglašavajući potencijalni značaj razvoja urbanih rešenja za stambena područja sa planiranim autobuskim stajalištima.

Ključne reči: Gradski saobraćaj, Javni prevoz, Zagađenje vazduha, Sumpor-dioksid, Azot-dioksid, Grad Novi Sad.

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INTRODUCTION

According to the EPA report on urban pollution indicators, three areas in cities with high levels of nitrogen dioxide that approached or exceeded the limit values prescribed by the EU stand out (UTRAP Group, 2021). They are: certain streets in the city center; highway; entrance and exit from the city. The first area of the dense urban body with a concentrated quantity of traffic is significant for our analysis. The city and suburbs that were formed based on Novi Sad's designated city zones serve as the study's spatial limits.

According to Articles 69 and 70 of the Law on Environmental Protection, the Republic, the Autonomous Province, and the Local Self-Government Unit must continuously monitor the environment within the bounds of their legal authority. Continuous control and monitoring of the state of the environment is carried out by measuring, testing and evaluating indicators of the state and pollution of the environment, which includes air quality (Law of Environmental Protection, 2004-2018).

Existing urban zones are merged and determined according to the following criteria:

- the spatial arrangement of city facilities, especially with regard to the industrial zone,
- the location of the main city road and transit road,
- the characteristics of existing traffic zones.

After defining the urban zones, the focus was on the evaluation of city traffic emissions in Novi Sad on the longest line, Line 13, which connects the university camp and other parts of the city.

Based on the EPA report (UTRAP Group, 2021), it was concluded that the examination and identification of potential data gaps related to air quality management around the main traffic infrastructure nodes could be included in ongoing air quality improvement programs in all major cities in Serbia.

The case of Novi Sad, as the second largest city in Serbia, was taken earlier (Veličković et al., 2014) to assess the potential impacts of selected restrictive measures on air pollution from traffic. Veličković et al. published one of the first studies on the impact of freight traffic on air pollution in cities in the Balkan region (Veličković et al., 2014). In doing so, it was determined that the analysis of individual gas emissions reveals the expected overall positive effects of renewing the vehicle fleet in most cases. However, the total amount of the same emissions hardly increases, so this specific measure is not enough to achieve the envisaged goals of the EU strategy concerning sustainable urban transport. Also, some negative impacts of restrictive measures on gas emissions were recorded and discussed. The observed complex impact of restrictive measures on urban traffic air pollution indicates that urban traffic planning and modeling requires a comprehensive database, clear goals and higher priority of environmental criteria in traffic planning (Fabregat et al., 2022; Óvári et al., 2023).

Fundamental to addressing urban traffic-related air pollution is a better understanding of how air quality and urban traffic currently intersect. This association includes (UTRAP Group, 2021):

- An overview of the impact on public health related to air pollution in general, and especially to pollution caused by transport;
- The legislative and regulatory frameworks for monitoring air pollution and complying with regulations;
- Review of work on air quality in the region of Novi Sad.

The potential of poor air quality to cause adverse effects on health and other environmental factors is well documented, and, according to the European Environment Agency (EEA, 2021), "the extent of policy action taken in Europe to specifically address air pollution related to transport has increased in recent years, reflecting the important contribution of transport to reducing air quality" (EEA, 2021).

Air pollution as a whole is responsible for the occurrence of some diseases: cancer, asthma, cardiovascular diseases, diabetes, obesity, and dementia, and poor air quality has been identified by the WHO (WHO, 2021) as an "urgent global health situation".

In the case of urban transport, the air pollutant most directly associated with traffic in high-density urban areas is nitrogen dioxide (NO_2). Nitrogen dioxide exists in the environment as a gas and is formed by a reaction between ozone, other radicals and nitrogen monoxide (NO), which is emitted during the combustion process. Sources of nitrogen monoxide include fossil fuel combustion in SUS-engines (internal combustion engine - SUS engine) and stationary combustion sources, such as industry and home heating (European Commision - Directorate-General XI, 1997; WHO, 2000a). As nitrogen monoxide is a precursor to the creation of other pollutants, aeropollutants such as ground-level ozone (O_3) and secondary particles of size 2.5µm (PM2.5), vehicles also contribute to the total levels of these pollutants in the ambient air. Motor vehicles directly emit PM2.5, and the wear and tear of brakes and tires also contributes to the appearance of PM10 (particles with a diameter of 10 µm) in the air. Medical studies have shown a link between higher nitrogen monoxide concentrations and short-and long-term respiratory and lung effects, as well as a potential link between nitrogen monoxide and increased susceptibility to bacterial and viral infections (WHO, 2000b).

Air pollution is characterized by the easy transport of polluting components over a wide area. The consequences of air pollution are reflected in: impairment of air quality; reduction of visibility; interaction with climatic conditions; endangerment of material goods; endangerment of all forms of life; biological danger; pathogenic effects.

Large amounts of incompletely burned hydrocarbons from motor vehicles are found in the atmosphere of cities. The present pollutants with ozone and atomic oxygen, as strong oxidants, enter into chemical reactions and are formed: hydrogen peroxide, free radicals, aldehydes, and substances that react with nitrogen dioxide to create peroxyacetyl nitrates (PAN), secondary pollutants. Secondary pollutants with primary pollutants form photochemical smog (EPA, 2000). The main causes of photochemical smog are the release of sulfur dioxide into the atmosphere and the reaction of automobile exhaust gases in the presence of light.

Combustion of coal and some products of the petrochemical industry, which contain a significant number of sulfur compounds, are the main sources of sulfur dioxide. A particle in polluted air catalyzes the oxidation of sulfur dioxide into sulfur trioxide. The conversion of sulfur dioxide into sulfur trioxide is done predominantly by photochemical oxidation. When a molecule of sulfur dioxide (SO_2*) is excited by absorbing a quantum of light, it undergoes oxidation more easily. Sulfur trioxide formed by oxidation dissolves in water droplets that are dispersed in the air, forming sulfuric acid, and reaches the ground again in the form of acid rain (Rajs et al., 2012). The most important effects of sulfur dioxide air pollution include an increase in the risk of cardiopulmonary disease, myocardial infarction, chronic obstructive pulmonary disease, respiratory disease, and death (Wu et al., 2022). The continuous increase of industrial sulfur dioxide emissions increases (treshold of 8μg/m^3) the share of the population with chronic diseases, of which respiratory diseases make up a significant share (He, 2008).

Air quality management, as a unique monitoring system, is defined by the Air Protection Act (Air Protection Law, 2009, 2013, 2021). The existing air quality control program on the territory of the City of Novi Sad includes fixed measurements of the level of pollutants in the local network of measuring stations and measuring points at locations for continuous fixed and indicative measurements. Air quality monitoring in urban areas is usually carried out in the traditional way of installing monitoring stations at fixed locations. Due to high construction and maintenance costs, fixed monitoring stations are rarely deployed, even in high-income countries, not to mention in low- and middle-income countries (Qin et al., 2022). Also, the distribution of polluting substances in the air can vary dramatically over short distances (less than 1 km) in an urban environment (Qin et al., 2022). The reasons for this are the unevenly distributed large number of emission sources, such as emissions from cars, as well as the extremely complex process of dispersion of polluting substances in the air in the urban environment. As a result, air quality measurements obtained from traditional fixed air quality monitoring stations can only provide average levels over a larger area. The city has therefore been entrusted with forming a local network for air quality monitoring and, if necessary, defining additional measuring points using mobile measuring devices to control air quality parameters.

The subject of these investigations are measurements of air pollution levels at additional measuring points in the city in order to more realistically assess the impact of pollution on the environment. These are bus stops for public city transportation in residential areas. This kind of problem is the reason for monitoring changes in the concentration of sulfur dioxide and nitrogen dioxide as the main pollutants in the urban environment in Novi Sad at city bus stops and in locations with the highest population density and traffic frequency. The method described in this paper determines the time period of transportation during the day, the location of city bus stops, and the concentration of exhaust gases in the form of sulfur dioxide and nitrogen dioxide in order to comprehend the impact of urban transport in Novi Sad. A city transportation company's line that links a larger portion of the city with the university district was looked into. In the spring of 2018, when there was the most weather variation and the most traffic, exhaust gas concentrations were examined for two different time periods. The results demonstrate when and where the amount of exhaust gases is at its highest, information that is critical for enhancing safety and having an impact on the environment.

The results confirmed a large variation in the concentrations of these pollutants depending on the humidity and temperature as meteorological parameters, and noise as a physical parameter of environmental pollution, expressed especially in cities.

1. MATERIALS AND METHODS

Concentration data of harmful gases, nitrogen dioxide and sulfur dioxide, were collected from each bus stop (eleven stops) on Line 13 of the Public City Transport Company of Novi Sad, simultaneously with meteorological parameters and noise levels relevant for this research. Line 13 was chosen as a representative urban transport route in Novi Sad. This line connects the university camp with various parts of the city and passes through busy streets, boulevards, and small streets, and it can be said that it connects the entire city, which contributes to better transportation of students and other citizens to their desired destinations. Given that route 13 is in different parts of the city, the frequency of traffic is also different, as is the pollution by gases such as nitrogen dioxide and sulfur dioxide.

Table 1 - Average values of sulfur dioxide and nitrogen dioxide concentration and climate parameters and noise level on Line 13 public transportation in Novi Sad

		Sulfur dioxide					**Nitrogen dioxide**				
B. stop	**Parameter**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 5**
S1	**C(μg/m³)**	50.0	50.0	45.0	20.0	24.0	59.6	23.2	45.6	23.2	28.9
	t(ºC)	22.6	28.3	27.6	30.6	28.0	23.6	22.1	29.3	22.1	27.4
	H(%)	37.0	35.0	32.5	33.5	39.0	47.5	51.0	31.0	51.0	34.5
	L(dB)	84.1	82.3	83.7	77.9	65.2	75.7	76.3	72.8	76.4	74.4
S2	**C(μg/m³)**	44.0	44.0	27.0	14.0	30.0	39.2	29.1	26.7	29.1	26.6
	t(ºC)	24.0	26.0	25.2	31.0	31.4	23.5	22.3	29.2	22.3	27.2
	H(%)	37.0	38.0	35.0	34.0	31.5	46.5	49.5	32.0	49.5	35.0
	L(dB)	84.4	83.7	83.3	81.5	82.5	83.3	76.9	82.3	76.9	80.2
S3	**C(μg/m³)**	42.0	42.0	5.0	19.0	24.0	36.5	36.5	24.8	31.5	23.5
	t(ºC)	25.4	25.5	25.0	31.3	31.0	23.4	22.6	29.2	22.6	28.3
	H(%)	36.5	38.0	34.5	32.5	33.0	47.0	48.0	32.5	48.0	34.5
	L(dB)	85.3	81.1	83.6	80.3	83.5	86.9	81.3	81.7	81.3	81.9
S4	**C(μg/m³)**	25.0	25.0	8.0	25.0	18.0	33.0	33.2	22.5	28.5	24.4
	t(ºC)	20.5	25.9	26.1	33.4	28.8	23.3	22.9	28.9	22.9	27.7
	H(%)	34.5	37.5	37.3	30.5	33.5	47.0	48.0	33.5	48.0	34.5
	L(dB)	82.6	81.6	82.3	79.7	80.7	83.5	77.8	82.2	80.2	80.0
S5	**C(μg/m³)**	30/0	24.0	5.0	15.0	14.0	33.4	35.0	22.9	35.0	24.1
	t(ºC)	31.7	24.6	26.1	33.6	29.2	22.9	24.2	29.0	24.2	27.8
	H(%)	32.0	38.5	38.0	31.0	33.5	47.5	45.5	33.5	45.5	35.0
	L(dB)	79.5	77.3	81.1	82.9	84.7	78.9	77.8	79.6	77.8	77.2
S6	**C(μg/m³)**	10.0	10.0	3.0	20.0	19.0	33.7	20.1	23.2	20.1	25.1
	t(ºC)	28.7	26.1	26.1	31.7	29.2	22.8	23.8	28.2	23.9	27.8
	H(%)	34.0	38.0	38.0	32.5	33.6	46.5	45.5	34.5	45.5	35.5
	L(dB)	83.6	80.3	81.1	77.9	85.8	82.3	79.8	79.3	79.8	78.6
S7	**C(μg/m³)**	11.0	11.0	42.0	14.0	28.0	34.2	19.4	24.4	19.4	27.2
	t(ºC)	27.7	26.5	26.4	31.6	28.8	22.8	24.6	28.2	24.1	27.8
	H(%)	34.5	37.5	36.5	31.5	34.0	46.5	46.0	33.5	46.0	35.0
	L(dB)	85.5	79.1	80.3	78.6	84.7	89.2	76.0	84.9	76.0	82.7
S8	**C(μg/m³)**	16.0	15.0	14.0	20.0	20.0	31.7	19.2	22.3	19.2	28.3
	t(ºC)	29.1	29.4	29.4	32.2	29.6	23.1	24.6	28.2	24.6	27.1
	H(%)	35.5	37.5	33.0	31.5	36.0	46.5	48.0	35.5	48.0	36.0
	L(dB)	89.0	85.1	84.0	82.4	82.8	81.1	84.8	84.4	84.8	82.7
S9	**C(μg/m³)**	72.0	72.0	17.0	36.0	39.0	36.4	19.5	25.7	19.5	28.5
	t(ºC)	30.2	28.8	28.4	32.6	32.9	23.8	24.9	27.8	25.0	26.1
	H(%)	34.5	36.0	36.0	28.5	33.2	48.5	44.5	38.5	47.5	37.5
	L(dB)	91.1	81.7	81.6	85.7	85.3	85.3	78.9	86.2	78.9	84.6
S10	**C(μg/m³)**	10.0	10.0	20.0	17.0	19.0	34.9	21.6	29.6	21.6	28.3
	t(ºC)	29.6	28.9	27.5	33.2	30.0	24.6	24.5	27.9	24.5	26.2
	H(%)	34.0	36.0	33.5	31.0	31.0	47.0	45.0	37.5	44.5	37.0
	L(dB)	79.6	82.9	85.3	87.9	86.9	87.6	83.5	82.1	83.5	84.6
S11	**C(μg/m³)**	10.0	10.0	15.0	14.0	20.0	34.6	18.7	41.2	18.7	38.2
	t(ºC)	27.4	28.3	26.8	31.0	32.2	25.0	24.5	27.7	24.5	26.2
	H(%)	35.2	38.0	30.5	32.0	32.0	45.5	45.0	37.5	45.0	37.0
	L(dB)	76.7	65.3	82,5	87.9	76.3	79.8	72.5	75.8	72.5	74.6

C - Concentration; t - Temperature; H - Humidity; L - Noise level

Air sampling, i.e., sulfur dioxide and nitrogen dioxide gases, was performed during one working week, in two time intervals: at the beginning of the working day (from 10 a.m. to 1 p.m.) and during the peak traffic volume (from 3 p.m. to 6 p.m.). The steps were taken by the students of fundamental academic studies in April 2018 as part of regular practical exercises at the Department of Ecology, Faculty of Economics and Engineering Management in Novi Sad, University Business Academy in Novi Sad. Such short tests were done as an indication to local authorities that pollution measurements should also be carried out in places where stationary stations for collecting data on air pollution are not planned.

Each time interval included five measurements in the span of two minutes, which was selected during the measurement based on the position of the city bus stop and the assumption of maximum and minimum gas emissions during traffic at all 11 measurement points (S1-S11; S-station or bus stop). The mean daily values for gas concentrations, air temperature and humidity, and noise level are displayed in Table 1.

Concentration levels of sulfur dioxide and nitrogen dioxide were measured with an Aeroqual Series 200 device (Aeroqual Limited, 2010/12., Kiurski et al., 2016). The principle of instrument operation is primarily based on the use of semipermeable sensors sensitive to different individual gases, based on metal oxides that exhibit an electrical change in resistance in the presence of the measured gas. The sensor uses active technology with an internal fan to draw air over the gas-sensitive sensor at a specific flow for its precise detection. The device uses a lithium battery. The minimum, maximum, and average values of the measured gas in ppm or mg/m^3 are read on the device screen.

The detection limit for nitrogen dioxide is 0–1 ppm with a resolution of 0.001 ppm and an accuracy of ± 0.02 ppm, and a detection limit of 0.005 ppm. For sulfur dioxide, the measurement range is from 0–100 ppm with a resolution of 0.1 ppm and an accuracy of ± 0.5 ppm with a detection limit of 0.4 ppm (Aeroqual Limited, 2010/12).

A 5-in-1 digital multi-tester, PeakTech 3690 (Ahrensburg, Germany) (PeakTech 3690, 2016.), was used to measure noise, temperature, and air humidity. The measurement range of air humidity is from 33-99% with a resolution of 1% and an accuracy of +/-3%+5%; the measuring range for temperature is 0-50 ºC with a resolution of 0.1°C and an accuracy of +/-3%+3°C. The instrument measures the noise level in the range of 35-100 dB, with an accuracy of +/-5dB at 94dB.

2. RESULTS AND DISCUSSION

In the past years, manual, indicative measurements of nitrogen dioxide and sulfur dioxide in Novi Sad met the standards prescribed for urban zones in the member states of the European Union (Directive 2008/50/EC, air quality, 2008). The largest number of exceedances during these tests in Novi Sad was recorded at the bus stop in the city center.

The city transport company and the total traffic in the city are singled out as mobile polluters. The variability of air quality in Novi Sad can be observed not only through a relatively small number of data from measurement sites but also through the large influence of the main pollutants, given that Novi Sad is in a plain and has a good wind rose. Also, given that the air quality in an area is greatly influenced by the features of the relief, the direction and speed of the wind are also factors. Thus, low air pressure, absence of wind, high air humidity, fog, and temperature inversion reduce the spread of pollutants in height and distance, keeping them in the ground layers and concentrating them near the source of pollution or in lower parts of the city. It can create “smog” with compounds that are extremely toxic and dangerous to human health. To reduce air pollution in the city in order to protect people's health, ecosystems, and material goods, it is necessary to take a number of measures.

Based on the measured concentrations of sulfur dioxide, a large variation of values was determined during the measurement in 5 working days, considering that the temperature during the month of April varied from 16.9 ºC on the first day of measurement to 33.8 ºC on the last day of measurement. The values of sulfur dioxide concentrations were high, but within prescribed maximal limit value for SO_2 of 350 $\mu g/m^3$ (Rule Book on Limit Values, 1992, 1999, 2006). Particularly high concentrations were measured at measuring points 3 and 9 on the fourth day, which can be seen from the graph of mean values, Figure 1. However, those values are still within the permissible limits.

Noise intensity was also measured within microclimate parameters in general environmental conditions. Noise levels were generally around 65-89 dB (Table 1), which is normal for a city bus in motion but 1.5 times higher than the permitted limit of 60 dB in commercial-residential zones. Street-level noise is one of the primary noise sources in urban areas, according to other studies (Mohareb and Maassarani, 2019; Monazzam et al., 2021). Due to the significance of street-level noise exposure, public health and urban planning should prioritize decreasing environmental sources of excessive street-level noise (McAlexander et al., 2015).

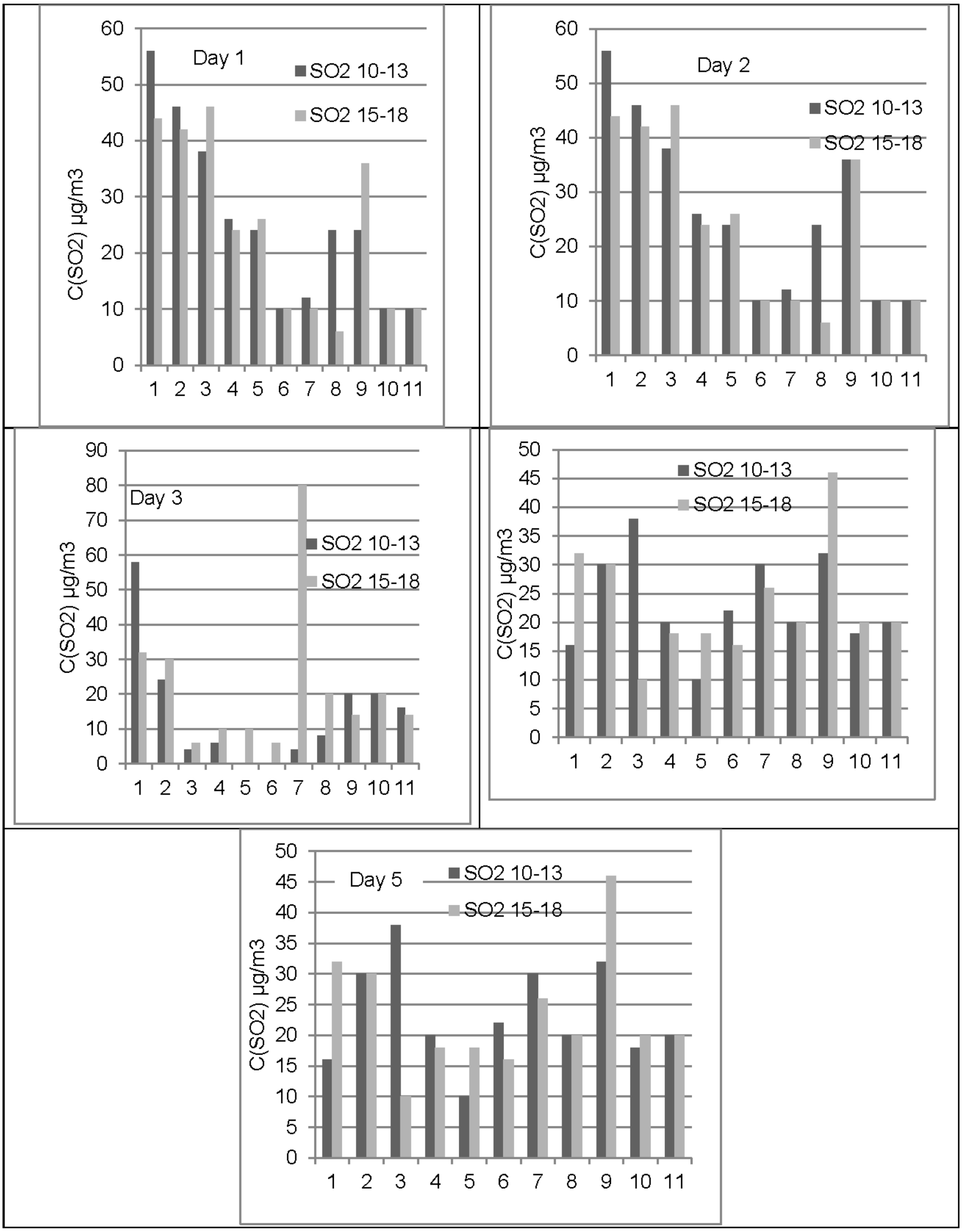

Figure 1 - Over the course of five measurement days, during the hours of 10 a.m. to 1 p.m. and 3 p.m. to 6 p.m., the change in sulfur dioxide (SO_2) concentration at line 13's stops. (Kiurski et al., 2019)

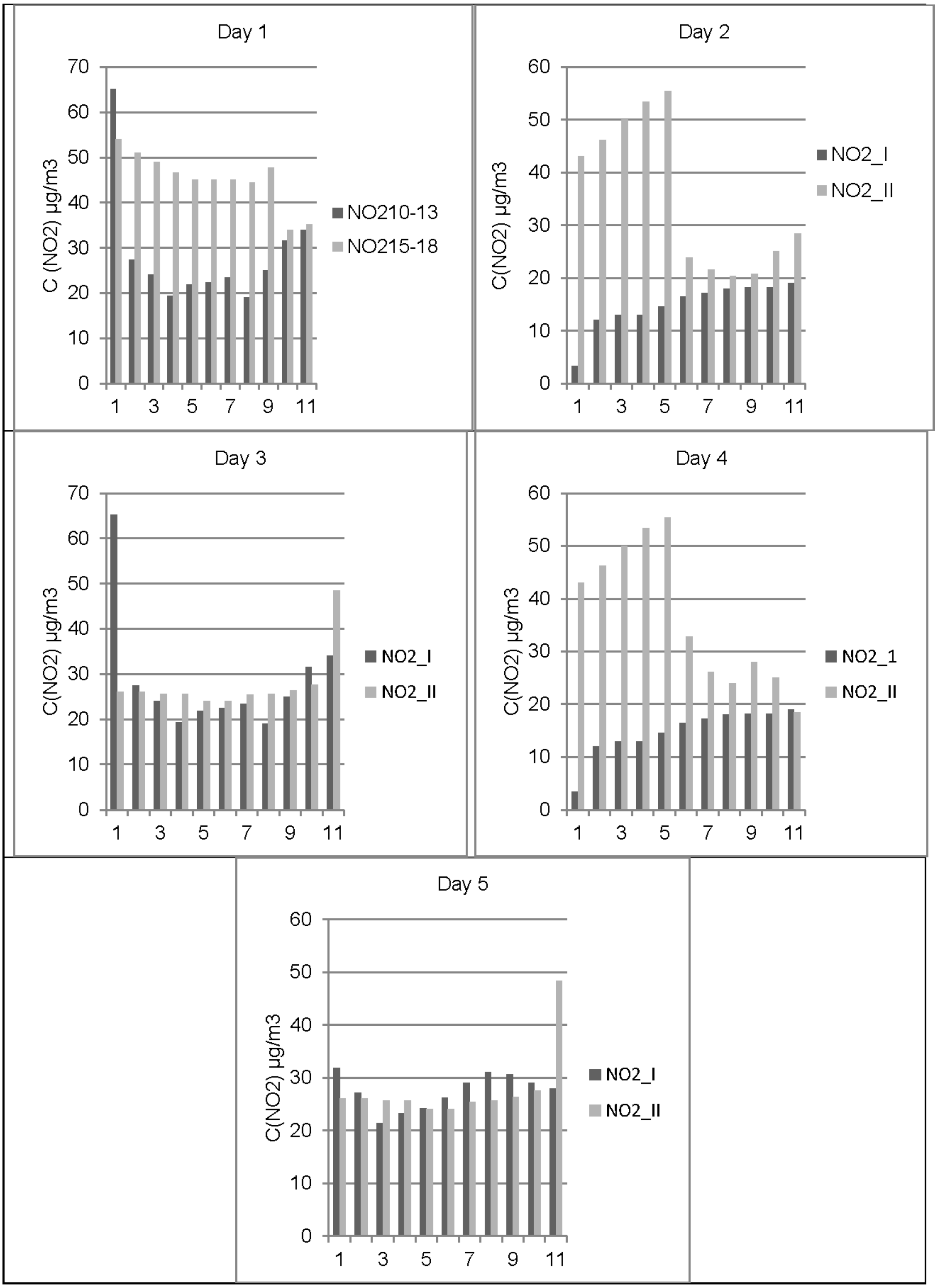

Figure 2 - Over the course of five measurement days, during the hours of 10 a.m. to 1 p.m. and 3 p.m. to 6 p.m., the change in nitrogen dioxide (NO_2) concentration at line 13's stops. (Kiurski et al., 2019)

The results of monitoring the nitrogen dioxide concentration in the air of Novi Sad show that the average value was 22.8 µg/m^3 for the first measurement period in the morning and 34.5 µg/m^3 for the second measurement period (from 3-6 p.m.), which is significantly lower than the prescribed annual average value of 50 µg/m^3, Figure 2. The obtained results show that average concentrations tend to increase slightly during the afternoon hours, from 3-6 p.m. and higher temperature, but they are still lower than both the average annual and high values.

Given that the limit value of nitrogen dioxide was surpassed at measuring points 5 (S5) and 9 (S9) in the busiest section of Novi Sad on the fourth day of measurement, Figure 2, it can be argued that the air in Novi Sad is fairly polluted based on the amounts of pollutants that were measured there.

The highest level of sulfur dioxide was measured at bus stop 9 (S9) on the fourth day of measurement, Figure 1. The concentrations of tested pollutants were within the permitted limits at other measuring points. At all measuring stations, it has been observed that the level of contaminating substances is greater in the morning (when this level is also impacted by weather conditions: humidity and temperature).

Given that sulfur dioxide and nitrogen dioxide are the main indicators of air pollution, it can be assumed that the concentrations of other pollutants, which were not tested, are also moderately elevated. There is a possibility that people's health will be endangered.

As a result, measures such as proper traffic routing in the center, traffic with as few delays as possible, and the relocation of some traffic routes should be implemented. This would significantly reduce pollution on the city's main thoroughfares as well as on frequently used access roads. In urban areas, the concentration of nitrogen oxides (NO_x) is not constant; it varies both during the day and during the week, as like as meteorological parameters. The intensity of traffic in a certain area is directly responsible for increasing the concentration, so the concentration of nitrogen dioxide in the afternoon is higher than the daily minimum. The average annual concentration of nitrogen oxides (NO_x) in cities ranges from 20-90 µg/m^3.

CONCLUSION

Air quality control in city traffic, particularly on Line 13, which connects nearly the entire city and comprises streets of all types, suggests the necessity of figuring out how the polluting elements present are related to one another. The best model for elucidating the source of pollutant emissions and their interaction can be chosen based on the test findings and applied to real systems. Additionally, this might make it difficult for the environmentally aware company JGSP Novi Sad to implement its CSR (corporate social responsibility) initiative of routinely monitoring air pollution on city streets.

The findings can be applied to developing AQI guidelines for the Province of Vojvodina and the Republic of Serbia as well as risk assessments for exposure to sulfur dioxide and nitrogen dioxide emissions in urban areas. The research's findings also served as the foundation for the development of a set of corrective actions as well as planning, architectural, legal, economic, and administrative preventive measures. This is crucial when developing urban planning solutions for residential areas with scheduled bus stops, with an emphasis on better air quality and environmental protection. The research's stated goals were in line with the area of specialization of Novi Sad's City Administration for Environmental Protection.

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