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ENVIRONMENTAL POLLUTION IN THE CITY OF BUCHAREST

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Abstract: The work covers air quality monitoring tools in Bucharest, major industrial facilities impacting pollution and the city's eight air quality monitoring stations. Data on pollutant emissions from Bucharest's thermal power plants (SO_2, NO_x and dust) are presented.
Finally, the paper graphically presents the annual average concentrations of NO_2, SO_2, PM10 and O_3 at the monitoring stations and examines pollution peaks and daily limit exceedances from 2017 to 2022.

Keywords: *multiple pollution, pollution monitoring, pollution in the city of Bucharest*

INTRODUCTION

The IPCC report [1] highlights that urban environments will be the most affected by atmospheric pollution, with the urban population expected to double by 2030 [2]. The negative consequences of urban population growth over time will impact both the environment (increased extreme events such as severe floods, extreme heat waves, desertification, the disappearance of small alpine glaciers and the loss of biodiversity) and human health (increased incidence of digestive and cardiac diseases due to hunger and even death).

Key factors with significant environmental impacts that are closely associated with urbanization include: deforestation, erosion and drainage caused by land use; excessive consumption of natural resources; urban waste production; air pollution; reduction of green spaces and the increase in road and air traffic.

The United Nations Environment Programme (UNEP) reports that cities cover only 2 % of the Earth's surface but are responsible for over 75 % of global natural resource consumption [3]. A significant challenge for large cities is pollution resulting from both internal road traffic and industrial activities on their peripheries [4], with increasingly concerning consequences for human health.

To highlight the influence of air pollution on living organisms, two indicators are used: *mortality*, referring to the reduction in life expectancy caused by air pollution, and *morbidity*, which is correlated with the frequency of disease occurrence.

The association between short-term increases in air pollution from all major air pollutants (NO_2, NO, O_3, SO_2 and particulate matter) and mortality associated with cardiovascular and respiratory diseases has been confirmed. The duration of exposure to pollutants is an important factor to consider when choosing critical values for pollution indicators.

In some studies, the polluting factors and methods for reducing their effects have been highlighted [5 – 9], while in others, the focus has been on pollutants such as NO_2, SO_2, and PM10 [10]. From a practical perspective, it is important to highlight the pollution level caused by each pollutant and the cumulative effect of multiple pollutants by calculating a pollution index [11 – 14].

This paper examines: - the influence of air pollution on the environment and living organisms; - the air quality in the city of Bucharest, as a consequence of the deterioration of air quality due to multiple pollution.

MATERIAL AND METHODS

Air quality monitoring instruments

The instruments used to evaluate and monitor the environment analyze the atmospheric composition, allowing for an assessment of air quality. In Bucharest, the instruments used in monitoring stations to evaluate and monitor the environment include [15]: - CO Analyzer – Thermo 48i Model; - NO_x Analyzer – Thermo 42i Model; - SO_2 Analyzer – Thermo 43i Model; - O_3 Analyzer – Thermo 49i Model; - BTEX Analyzer – AMA GC5000 Model; - PM10/PM2.5 Analyzer – Thermo TEOM 1405-DF Model; - Gravimetric Sampler PM10/PM2.5 – LIFETEK 100-SELECT 16; - Weather Sensors (thermo-hygrometer, pressure sensor, solar radiation sensor, pluviometer, wind vane, wind speed sensor ("Robinson's anemometer")); - Secured Interface for data validation. These instruments are illustrated in Figure 1.

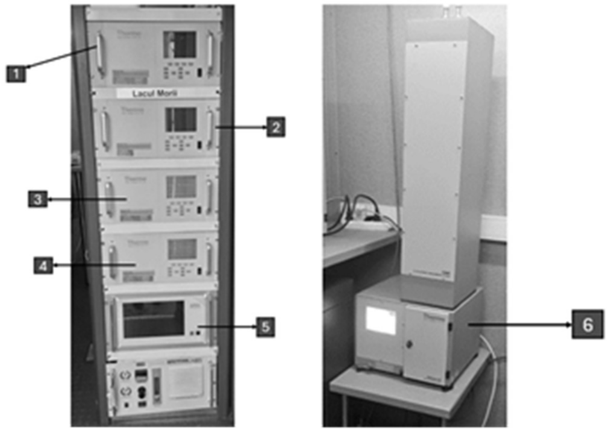

Figure 1. *Analyzers in the monitoring station: 1. CO Analyzer – Thermo 48i Model; 2. NO-NO$_2$-NO$_x$ Chemiluminescence Analyzer – Thermo 42i Model; 3. SO$_2$ Analyzer – Thermo 43i Model; 4. O$_3$ Analyzer – Thermo 49i Model; 5. BTEX Analyzer – AMA GC5000 Model; 6. Particulate matter Analyzer – Thermo TEOM 1405-DF Model*

CO Analyzer – Thermo 48i Model (1, Figure 1) operates on the principle of Gas Filter Correlation (GFC), which depends on carbon monoxide (CO) in the gas sample absorbing infrared radiation at a specific wavelength [16]. This analyzer measures CO concentration in the air, expressed in parts per million (ppm) or milligrams per cubic meter ($mg \cdot m^{-3}$).
NO-NO$_2$-NO$_x$ Chemiluminescence Analyzer – Thermo 42i Model (2, Figure 1) is used to measure nitrogen oxide (NO) concentration in a given environment. It works based on the interaction between NO and ozone (O_3), producing a specific luminescence whose intensity is directly proportional to the concentration of nitrogen oxide [17].
SO$_2$ Analyzer – Thermo 43i Model (3, Figure 1) functions on the principle of ultraviolet (UV) light absorption by SO_2 molecules, which become excited at a specific wavelength. The sample is passed through a hydrocarbon separator, which removes hydrocarbons from the sample by forcing them through the wall of the tube [18].
O$_3$ Analyzer – Thermo 49i Model (4, Figure 1) operates by absorbing UV light at a specific wavelength by ozone molecules. The sample is introduced into the device via the sampling panel and then divided into two gas streams [19].
BTEX Analyzer – AMA GC5000 Model (5, Figure 1) specializes in measuring concentrations of specific chemical compounds in the air, particularly aromatic hydrocarbons such as BTEX, styrene, trimethylbenzene and ethyltoluene [20].
Particulate matter Analyzer – Thermo TEOM 1405-DF Model (6, Figure 1) is used for real-time measurement of the mass concentration of suspended particulates. TEOM instruments use only filters to measure real-time particulate mass in the air stream through an inertial mass transducer. The mass weighing principle of the Tapered Element Oscillating Microbalance (TEOM) is based on the relationship between mass change and a specific parameter, in this case, frequency [21].

Gravimetric Sampler PM10/PM2.5 – LIFETEK 100-SELECT 16 is used to determine PM10/PM2.5 particles in the surrounding air. The method for determining atmospheric dust concentration is based on gravimetric measurement. This involves extracting a specific volume of gas using a pump over a specified period, measuring the volume of the extracted gas and then weighing the collected dust.
Data recorded by these instruments are stored on a server, and access to these data is available through a secured interface.

Air quality monitoring stations in the city of Bucharest

Based on the dominant emission sources, air quality monitoring stations are classified into: - *traffic stations* – located near a main road; - *background stations* – located in areas where pollution levels are representative of the average exposure of residents or vegetation. These are further classified according to building density or distribution as follows: *urban background stations* – built-up area; *suburban background stations* – mostly built-up area; rural background stations – other areas; - *industrial stations* – located near an industrial area or source.
In the Bucharest-Ilfov area, continuous measurements of major pollutants are carried out through 8 monitoring stations [22 – 24]:

- one **regional background station** in Balotești – station code **B8** – coverage area from 200 to 500 km;
- one **suburban background station** in Măgurele – station code **B7** – coverage area from 1 to 5 km;
- one **urban background station** at Lake Morii – station code **B1** – coverage area from 1 to 5 km;
- two **traffic stations** at Sos. Mihai Bravu – station code **B3** and at Cercul Militar Național – station code **B6** – coverage area from 10 to 100 m;
- three **industrial stations** in Drumul Taberei – station code **B5**, in Titan – station code **B2** and in Berceni – station code **B4** – coverage area from 100 m to 1 km.

Since in 2016 all monitoring equipment at the monitoring stations was replaced and valid information from previous years was insufficient, the period chosen for analysis was 2017 - 2022.
To obtain an overview of the emissions of major atmospheric pollutants, such as NO_2, SO_2, PM10 and O_3 in Bucharest, data for the period 2017 - 2022 were collected from two distinct sources. Data regarding emissions from thermoelectric power plants in Bucharest, available on the European Commission website [25], were analyzed, as well as data provided by the monitoring stations in the Bucharest-Ilfov area [26].

RESULTS AND DISCUSSION

Air quality analysis in the city of Bucharest

In the urban area, pollutants primarily originate from urban sources (road traffic, residential heating, construction activities etc.) and industrial sources, mainly from thermal and electric power generation.

To analyze whether emissions from the energy sector influence the data recorded by monitoring stations, Figure 2 shows the thermoelectric power plants in Bucharest listed in the E-PRTR (European Pollutant Release and Transfer Register) and the locations of the monitoring stations are indicated in Figure 3.
This arrangement provides an overview of the relationship between industrial activities and environmental monitoring results in the city of Bucharest.

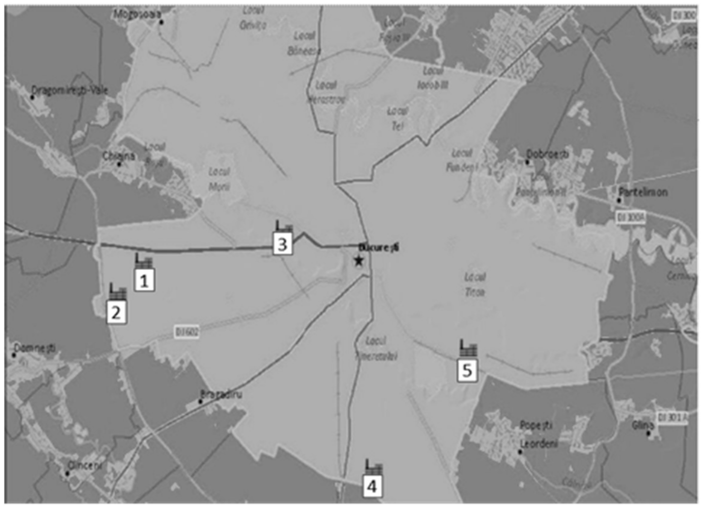

Figure 2. *The placement of industrial facilities registered in the E-PRTR in 2022 in the city of Bucharest [27]: 1. SC Vest Energo SA; 2. SC Electrocentrale București SA - CET Vest; 3. SC Electrocentrale București SA - CET Grozăvești; 4. SC Electrocentrale București SA - CET Sud; 5. SC Electrocentrale București SA - CET Progresu*

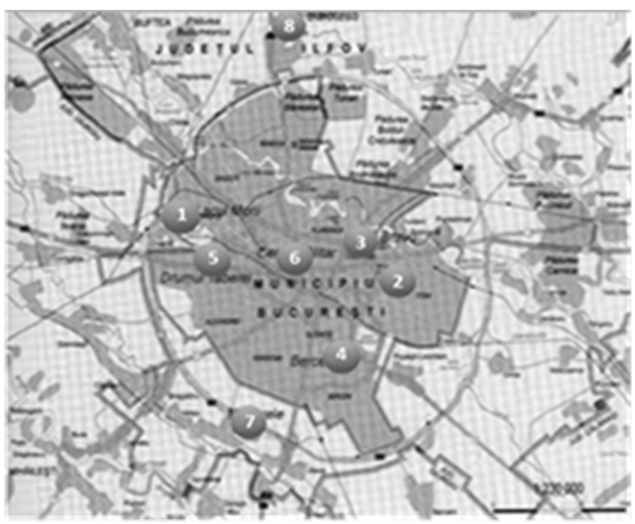

Figure 3. *The placement of monitoring stations [23, 24] in the Bucharest-Ilfov area: 1. B1 - Lacul Morii (urban); 2. B2 – Titan (industrial); 3. B3 – Mihai Bravu (traffic); 4. B4 – Berceni (industrial); 5. B5 – Drumul Taberei (industrial); 6. B6 - Cercul Militar Național (traffic); 7. B7 – Măgurele (suburban); 8. B8 – Balotești (regional)*

Figure 2 illustrates five industrial installations with a significant environmental impact that exceeded the threshold values for air pollutant emissions, out of a total of 27 installations inventoried in Bucharest in 2022.
Regarding industrial emissions in Bucharest, the main sources of NO_x, SO_2 and dust are thermal power plants (Table 1). These plants use both natural gas and fuel oil as fuel.

Table 1. *Emission quantities of the industrial installations in the energy sector recorded in the E-PRTR in Bucharest in 2022 [22, 25]*

No.	**Industrial facility**	**Activity listed in Annex 1 of Law no. 278/2013 on Industrial Emissions**	**Activity specified in the E-PRTR Regulation**	**Pollutant**	**Quantity of emissions [t·year^{-1}]**	**Emission threshold [t·year^{-1}]**	**Exceedance [t·year^{-1}]**
1.	SC Vest Eenergo SA, Sector 6	1.1. Combustion of fuels in installations with a total rated thermal input of 50 MW or more	1.c. Thermal power stations and other combustion installations with a heat input of 50 MW	NO_x	109	100	9
2.	SC Electrocentrale București SA - CET Vest, Sector 6			CO_2	$341\cdot10^3$	$100\cdot10^3$	$241\cdot10^3$
				NO_x	357	100	257
3.	SC Electrocentrale București SA - CET Grozavesti, Sector 6			CO_2	$248\cdot10^3$	$100\cdot10^3$	$148\cdot10^3$
4.	SC Electrocentrale București SA - CET Sud, Sector 3			CO_2	$712\cdot10^3$	$100\cdot10^3$	$612\cdot10^3$
				NO_x	353	100	253
5.	SC Electrocentrale București SA - CET Progresu, Sector 4			CO_2	$312\cdot10^3$	$100\cdot10^3$	$212\cdot10^3$
				NO_x	158	100	58

Figure 4 graphically illustrates the quantities of NO_x, SO_2 and dust emissions, expressed in tons per year, generated by six thermal power plants in Bucharest [26].

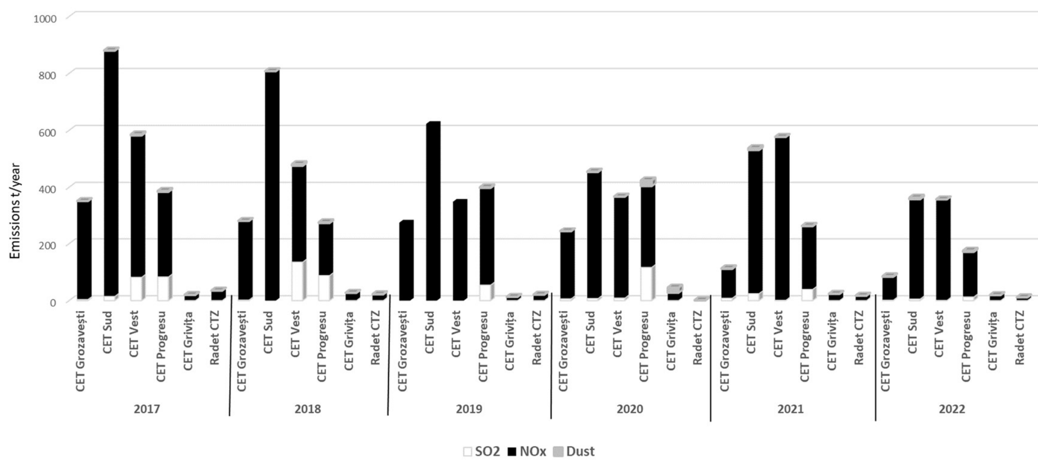

Figure 4. *The quantity of SO_2, NO_x and dust emissions from thermal power plants in Bucharest, in tons per year, during the period 2017 - 2022*

It can be observed that thermoelectric power plants operating exclusively on natural gas (CET Grivița and Radet CTZ) generate lower pollutant emissions compared to other plants that, although primarily using natural gas, operate occasionally on fuel oil. The emission data is summarized in Table 2.

Table 2. *Emission quantities from thermal power plants in Bucharest, for the years 2017 - 2022, expressed in tons per year*

Pollutant	Year	CET Grozăvești	CET Sud	CET Vest	CET Progresu	CET Grivița	Radet CTZ
SO_2	2017	3.806	14.8	81.86	83.371	0.114	0.128
	2018	2.108	0	135.561	88.176	0.154	0.197
	2019	0	0	0	54.625	0.078	0.182
	2020	6.29	7.24	8.85	116.68	0.15	0.163
	2021	8.273	24.665	1.302	39.459	0.133	0.152
	2022	1.533	5.399	0.686	12.866	0.107	0.1022
NO_x	2017	347.671	864.94	500.1	300.639	19.796	34.83
	2018	279.672	807.747	339.794	186.09	26.85	21.849
	2019	275.575	622.38	349.002	343.144	12.92	20.452
	2020	237.52	446	357.98	287.284	27.518	18
	2021	103.265	506	575.567	223.907	23.36	16.837
	2022	82.105	352.44	356.712	158.321	19.147	11.3263
Dust	2017	0.184	0.72	3.94	3.35	0.36	0.51
	2018	0.12	0.001	5.921	3.038	0.489	0.624
	2019	0	0	0	2.253	0.237	0.584
	2020	1.4	1.55	0.49	20.21	0.476	1
	2021	2.168	6.606	0.162	1.164	0.424	0.481
	2022	2.201	5.605	0.112	4.431	0.349	0.3237

A decreasing trend in emissions for all pollutants has been observed in recent years. Annual fluctuations in emissions may reflect changes in technology, variations in energy demand, or compliance measures with environmental regulations.

The evolution of the annual average concentrations of NO_2, SO_2, PM10 and ozone (O_3) in Bucharest is presented in Figures 5 – 8, based on data recorded at stations B1-B8, for the period 2017 - 2022 [23, 24, 28].
From the analysis of Figure 5, the highest concentrations of the pollutant NO_2 were recorded at traffic-type stations. This finding suggests that NO_2 pollution is largely generated by road traffic. The lowest values were recorded at the regional-type station B8.

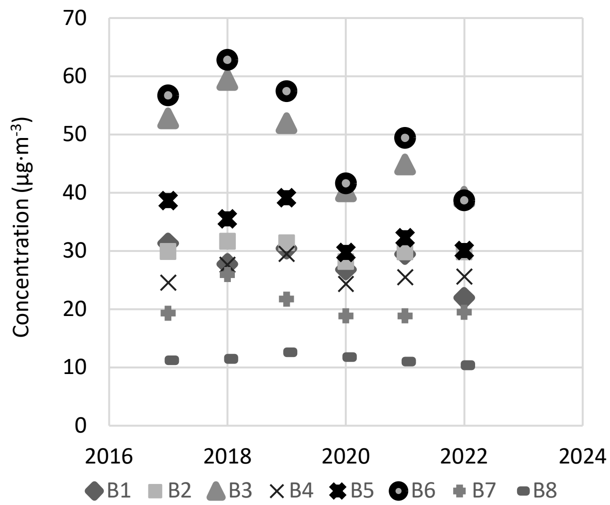

Figure 5. *The evolution of the annual average concentrations of NO_2, in $\mu g \cdot m^{-3}$, measured by the monitoring stations in Bucharest from 2017 to 2022*

The concentrations of SO_2 remained relatively constant during the analyzed period, with no significant long-term increases or decreases. There are minor variations between the monitoring stations, but most stations recorded similar concentrations over the years. For SO_2, the annual average is slightly higher at industrial-type stations (Figure 6).

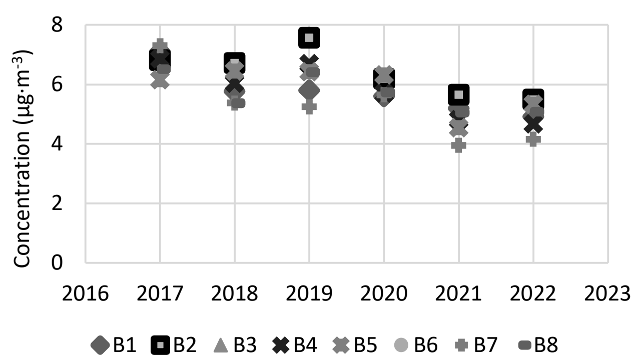

Figure 6. *The evolution of the annual average concentrations of SO_2, in $\mu g \cdot m^{-3}$, measured at the monitoring stations in Bucharest from 2017 to 2022*

In Figure 7, it can be observed that the variation in annual average concentrations for the pollutant PM10 was relatively uniformly distributed across all monitoring stations over the six years, with a significantly lower value in 2017 at the suburban background station and higher values at the traffic-type station B3, compared to the other stations.

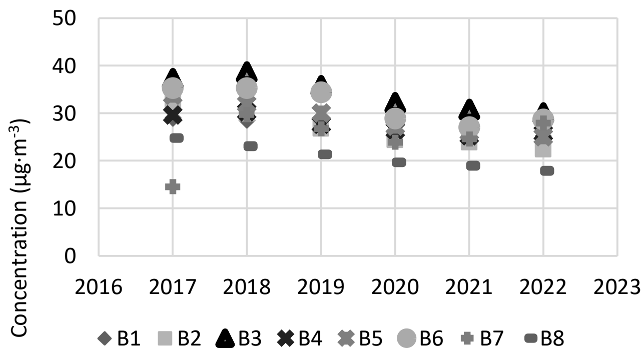

Figure 7. *The evolution of the annual average concentrations of PM10, in µg·m^{-3}, measured at the monitoring stations in Bucharest from 2017 to 2022*

Ozone, being a secondary pollutant, depends on the emissions of precursor pollutants and climatic conditions. Ozone concentrations are measured at only four of the eight monitoring stations. The annual average concentrations of ozone show variations over the years at each location. Higher ozone concentrations are observed at stations located in suburban and regional areas (Figure 8).

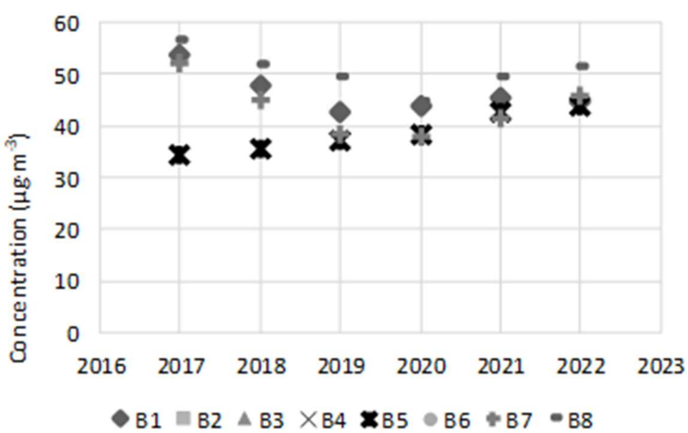

Figure 8. *The evolution of the annual average concentrations of ozone, in µg·m^{-3}, measured at the monitoring stations in Bucharest from 2017 to 2022*

Pollution peak. A pollution peak defines the situation or moment when there is an excessive amount of one or more air pollutants present, which may present risks to the environment or human health. These peaks signify exceedances of daily or hourly limit values. The causes of exceedances may include meteorological conditions (such as atmospheric calm; lack of wind or light winds) that create conditions favorable for the accumulation of pollutants to levels that affect human health, as well as thermal inversions that keep pollutants near the ground. Other causes could be heavy road traffic, the burning of fossil fuels during winter, or the incineration of waste that releases harmful chemicals into the atmosphere.

Based on measurements taken at monitoring stations in Bucharest [23, 24, 28], represented in Figure 9, violations of air quality standards for human health protection were observed for three pollutants (PM10, ozone (O_3) and NO_2). Most exceedances occurred at traffic-type stations for the pollutant PM10, indicating the significant contribution of road traffic to particulate matter pollution and the need for implementing preventive and control measures. For instance, in 2021, at the B1 Lacul Morii monitoring station, the maximum recorded value for PM2.5 was approximately 5.66 times the limit value, for NO_2 it was approximately 3.82 times, and for ozone, it was 1.15 times.

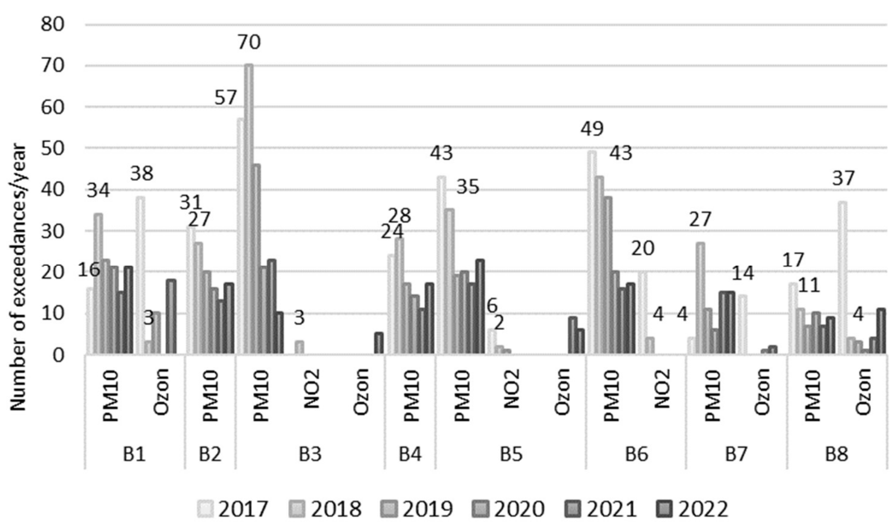

Figure 9. *The number of exceedances of daily and hourly limit values recorded at monitoring stations in Bucharest from 2017 to 2022, for the pollutants ozone (O_3), NO_2 and PM10 [23, 24]*

These pollution peaks can have negative effects on human health, particularly for those with preexisting respiratory and cardiovascular conditions. On the other hand, long-term exposure to relatively low doses of pollutants [29] can also pose health risks.

CONCLUSIONS

The paper analyzes the issue of multiple urban pollution effects and their impact on the environment and living organisms. - tools for monitoring air quality; - significant industrial installations regarding pollution in Bucharest; - the evolution of annual average concentrations of pollutants NO_2, SO_2, PM10 and ozone in Bucharest from 2017 to 2022.

From the analysis of the presented data, the following conclusions can be drawn: - although measures have been implemented to reduce emissions, the industry continues to have a significant impact on air quality; - there is a need to intensify modernization measures for installations, implement technologies for reducing nitrogen oxides ($DeNO_x$) and sulfur oxides ($DeSO_x$) from flue gases, as well as technologies for dust removal and promote the use of low-sulfur fuels; - in 3 out of the 6 years analyzed, the average annual concentrations recorded at traffic-type stations exceeded the NO_2 limit value by almost 50 % or more. However, the legislation does not specify the extent to which the limit value for this pollutant can be exceeded, representing a significant gap for all monitored atmospheric pollutants; - the highest number of exceedances of limit values recorded at all analyzed stations occurred for the pollutant PM10, followed by exceedances for ozone. Both pollutants are specific to road traffic, indicating the significant impact of road traffic on the environment and human health. For example, the traffic station B3 recorded 70 exceedances of the PM10 limit concentrations.

Given these observations, it should also be considered that the risk of exposure to atmospheric chemical pollutants is just one of many environmental factors that can affect public health and the surrounding environment in Bucharest. In addition to monitored chemical pollutants, attention should be given to other types of pollution, such as *noise* and *electromagnetic radiation*. This involves the effective monitoring and management of various types of pollutants, not just chemical pollutants, to ensure public health and overall environmental protection.

It is necessary to assess the combined effect of multiple pollution by calculating the value of the pollution indicator. For this purpose, it is recommended to resort to calculating the specific energy participation of pollutants in each practical case [30 – 34].

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