COMPARATIVE STUDY ON AIR QUALITY IN EUROPEAN METROPOLISES

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Abstract. *The atmosphere is a layer of gas that surrounds our planet. The sublayer in the immediate vicinity of the earth's surface, the troposphere, is in a continuous dynamic. Its composition is constantly changing, and substances from anthropogenic activities such as industry, agriculture, car traffic, urbanization, etc., many of which are not found naturally in the atmosphere composition, accelerate this process and can form by reaction pollutants that are dangerous to human health and the environment in general. In addition, in urbanized areas temperatures are higher, and heat usually acts as a catalyst that triggers, facilitates, or accelerates chemical reactions. In this paper, the authors were interested to study the air condition in five cities, with a similar population, from different countries in Europe. Each of the five cities studied, namely Bucharest, Vienna, Hamburg, Warsaw, and Barcelona (with a population between 1.7 and 2 million inhabitants), managed to create areas of influence around them, called metropolitan areas, through which cities manage to develop and urbanize the surroundings, thus reaching a number of inhabitants between 2.3 and 5.7 million spread over large areas of land, from 1800 to 26000 km*^{2}*. Urban agglomerations are very sensitive to pollution, because people can be affected by air pollutants that easily spread various diseases or viruses; therefore the aim of the work is to determine the main pollution sources of these metropolises and to evaluate the air quality applying the global pollution index method.*

Keywords*: air quality index, pollution sources, Europe, metropolis*

INTRODUCTION

Atmospheric pollution has negative effects on the environment and human health. A significant proportion of the population of Europe lives in areas, especially cities, where standard limits regarding air quality are exceeded sometimes, situations that can induce major health risks.

The greenhouse effect, a phenomenon of global environmental degradation, is caused by gases of natural or anthropic origin, such as carbon dioxide, methane, nitrogen protoxide, water vapor, hydrofluorocarbes (HFC), perfluorocarbes (PFC), etc. The greenhouse gases capture the heat of the earth into the atmosphere and lead to the increase of global average temperatures. Thus, the climatic changes appear: the melting of glaciers and ice caps, the increase of the global sea water level, the appearance of extreme meteorological phenomena, deaths due to the high heat, the increase of the degree of infectious diseases, etc. (LAZAR ET DUMITRESCU, 2006; MANISALIDIS ET AL., 2020).

The effects of air pollution on the environment are visible for a long time and are materialized in the degradation of animal, forest, and agricultural heritage, ecosystems degradation, damages caused to metal structures, monuments, and different materials, reducing visibility. For example, tropospheric ozone (O_3) leads to atrophy of some tree species, sulfur dioxide (SO_2) determines acidification of precipitation, with direct negative effects on vegetation, soil, metals, and construction materials and indirect effects on humans, nitrogen oxides (NO , NO_2) contributes to the acidication of rain and favors the accumulation of nitrates at the ground level that can cause alteration of the environmental ecological balance, can cause waters eutrophication, deterioration of fabrics, discoloration of paints, and metal degradation, etc. (DEP, 2017).

The effects of air pollution on human health are manifested by numerous forms: it affects respiratory, circulatory, and olfactory systems, can cause pulmonary dysfunctions, respiratory diseases, acute bronchitis and asthma, can cause irritations, specific intoxication, nausea, vomiting, headache, breathing, coughing, disturbing sleep, stomach, appetite, irritation of eyes, nose, and neck, and can sometimes cause the death of people suffering from heart and respiratory disorders. (ADAMKIEWICZ ET AL., 2022; WEST ET AL., 2023; MANISALIDIS ET AL., 2020).

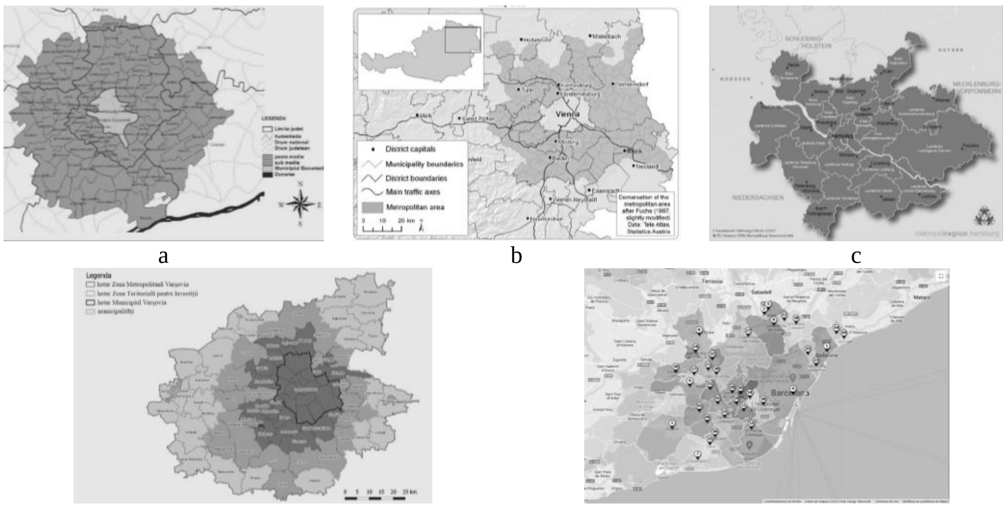
The effects of air pollution on human beings are an important motivation that justifies its control. The respiratory system is the main way of entering the air pollutants into the organisms and, unfortunately, most people cannot choose the atmosphere they breathe.

The population in urban areas includes a wide spectrum of demographic characteristics in terms of age, sex, and health. The following sensitive subpopulations can be identified in this group: very young children, whose circulatory and respiratory system is not sufficiently matured; the elderly whose respiratory and circulatory system work defective; people with pre-existing diseases such as asthma, enfheme, and heart disease. These subpopulations have different reactions to exposure to air pollutants, compared to the usual population.

For these reasons it is extremely important to find solutions to prevent and reduce the level of pollution as much as possible, especially in urban agglomerations and maintain air quality within permissible limits.

MATERIAL AND METHODS

Bucharest (Romania), Vienna (Austria), Hamburg (Germany), Warsaw (Poland), and Barcelona (Spain) are developed European cities, which as a result of the growing population and continuous expansion have managed to become real metropolises (Figure 1 and Table 1) in which many pollutants are emitted in the air by cars, small and large companies, the power plants, individual heating systems, agriculture, etc. The air quality in these areas is monitored to ensure that the health of the citizens is not affected by the numerous pollutants in the air.



a b c

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Figure 1. Maps of cities and corresponding metropolitan areas; a. Bucharest; b. Vienna; c. Hamburg; d. Warsaw; e. Barcelona

Although the five European cities have a relatively similar number of inhabitants and as high strategic importance, obvious differences can be observed with the territorial administrative area and the density of the population at the city level, respectively metropolitan area (MA).

Table 1.

Demographic data (UN, 2024; ***, 2024a-e)

No.	City	City population [pers.]	City surface [km^2]	Population density/city [pers./km^2]	MA population [pers.]	MA surface [km^2]	Population density/MA [pers./km^2]
1	Bucharest	1767520	226	7820.9	2304408	1811	1272.5
2	Vienna	1990490	415	4796.4	2890577	7552	382.8
3	Hamburg	1787280	755	2367.3	5425628	26000	208.7
4	Warsaw	1799000	517	3479.7	3269510	6100	536
5	Barcelona	1702814	101	16859.5	5687000	4268	1332.5

Regarding the main characteristics of the environment and climate, a brief description of them was made in Figure 2.

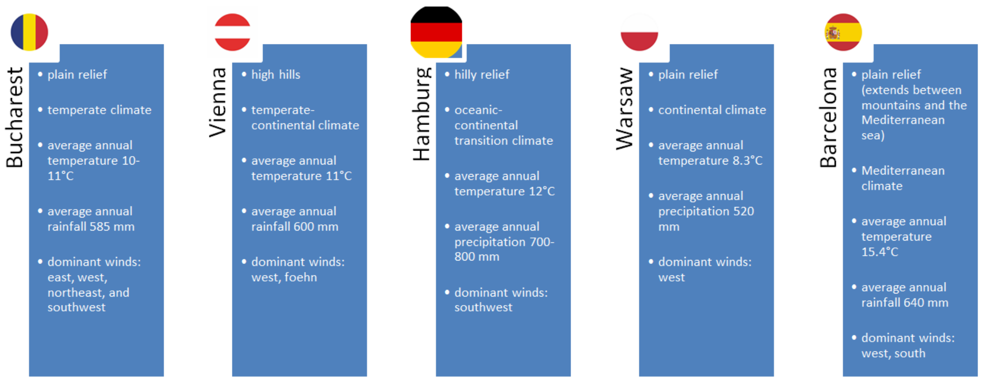

Figure 2. Main environmental and climatic characteristics of the studied areas

Following the analysis of the metropolitan areas, the main sources of air pollution were identified (Figure 3). The main pollutants resulting from the identified sources are dust, fine powders, nitrogen oxides, sulfur oxides, carbon dioxide, carbon monoxide, methane, nitrogen protoxide, volatile organic compounds, etc. Although the pollution resulting from the anthropic activities is significant, nor is the pollution determined by the natural sources, processes, and phenomena, such as volcanoes, oceans, organic decompositions, forest fires, and electric discharges, that emit nitrogen oxides, sulfur dioxide, ash, and other pollutants. Also, the cross-border sources, the pollutants who are transported by the air masses on hundreds or even thousands of kilometers, are not to be neglected. (BICA, 2000; LAZĂR ET DUMITRESCU, 2006; APOSTU AND FAUR, 2022).

Figure 3. Main pollution sources identified in the studied metropolises

The pollutants produced by these sources are transported by air on long distances. During this time, pollutants are chemically transformed or attached to dust and powders or rain drops. Eventually they reach a modified form in humans or plants, animals, buildings, water, soil, etc.

The air quality monitoring is carried out through the monitoring stations located in the critical points in the studied areas in a well-established monitoring network.

Air pollution is beyond the human capacity of a man to be controlled. A concentrated action is required from the decision makers at local, regional, national, and international level. That is why legislative laws and regulations on environmental protection and climatic changes have been developed and limits at European level have been imposed, and the Member States of the European Union are obliged to respect them.

Compared to the European Union, the World Health Organization (WHO) establishes stricter criteria regarding the quality of the air so that in this paper the authors referred to the limit values imposed by WHO (Table 2) according to the new guide on the air quality for individual parameters of air quality (Who, 2021).

Table 2.

Limit values for different air pollutants (WHO, 2021)

Polutant	Mediation period	Limit value
Particulate matter $PM_{2,5}$	1 year	5 µg/m^3
	24 hours	15 µg/m^3
Particulate matter PM_{10}	1 year	15 µg/m^3
	24 hours	45 µg/m^3
Ozone, O_3	peak time*	60 µg/m^3
	Maximum daily average of 8 hours	100 µg/m^3
Nitrogen dioxide, NO_2	1 year	10 µg/m^3
	24 hours	25 µg/m^3
Sulfur dioxide, SO_2	24 hours	40 µg/m^3
Carbon monoxid, CO	24 hours	4 mg/m^3

** - Maximum daily average of the 8-hour average O_3 concentration in the six consecutive months with the highest six-month average O_3 concentration.*

The researchers point out that these values should not be considered safe, because there is no level that pollutants cease to cause damage to the human body and ecosystems.

RESULTS AND DISCUSSIONS

Data collection

Taking into account the pollutants most harmful to health and the environment, the monitoring of the following pollutants was carried out: particulate matter ($PM_{2.5}$ and PM_{10}), carbon monoxide (CO), ozone (O_3), nitrogen dioxide (NO_2), sulfur dioxide (SO_2). In addition, the following parameters were monitored: air temperature, air humidity, pressure, and wind.

The actual monitoring was carried out during 30 days, between May 7 and June 6, current year. This consisted in collecting and centralizing the daily values of the pollutants and calculating the average values for the analysis period (Table 3).

Table 3.

Average values of monitored parameters

No.	City/MA	Monitored parameters									
		$PM_{2,5}$ [μg/m^3]	PM_{10} [μg/m^3]	CO [μg/m^3]	O_3 [μg/m^3]	NO_2 [μg/m^3]	SO_2 [μg/m^3]	T [°C]	H [%]	P [mbar]	W [km/h]
1.	Bucharest	13	20	180	53	27	5	24	65	1012	5,5
2.	Vienna	4	12	200	72	12	2	20	85	1017	13
3.	Hamburg	7	26	175	70	17	3,1	16	71	1022	13
4.	Warsaw	7	19	550	60	42	3,3	19	65	1017	11,1
5.	Barcelona	18	25	220	52	28	1,8	22	80	1013	7,4

T – temperature, H – humidity, P – pressure, W - wind

Data collection was carried out, for all five metropolises analyzed from the web source https://waqi.info/#/c/5.535/7.074/2.7z (EPA, n.d.). The site is a free platform of transparent air quality information for more than 130 countries, covering more than 2000 major cities in the world, in real time through more than 250 thousands monitoring stations.

Evaluation of pollution level

The evaluation of the pollution level was carried out by the method of the global pollution index (I_{PG}). The method allows the assessment of the state of the environment or an environmental component based on a ratio between the ideal state (S_i) and the current/real state (S_r) given by the quality indicators considered for the environment/environmental component analyzed (in our case, for air).

For the assessment of the state of the environment, marks are given from 10 (representing the ideal state, when the environmental factors are not affected by human activities) to 1 (representing the worst state, when the environmental factors are strongly affected by human activities). The method is graphical, the two states being represented graphically by polygons. Their surfaces are determined and the ratio of the two surfaces/states is calculated (the ideal state, S_i, related to the real state, S_r) (LAZAR ET DUMITRESCU, 2006; LAZAR ET FAUR, 2011).

The air pollution index (I_p) was evaluated with the Formula 1 (LAZAR ET FAUR, 2011), using the values of the monitored parameters and the limits imposed by the WHO.

$$I_p = V_o/V_l, \quad (1)$$

where:

I_p – pollution index for a certain environmental component (air, water, soil, etc.);

V_o – average values of the monitored parameters;

V_l – limit values for the monitored parameters.

Knowing the value of the pollution index, a credit score (CS) is given for each monitored parameter according to Table 4 (Table 5). The global air pollution index was calculated, being represented graphically for all 5 metropolises in Figure 4.

Table 4.

Credit rating scale depending on the pollution index value

Credit score (CS)	Pollution index value, I_p
10	0
9	0.0 – 0.25
8	0.25 – 0.5
7	0.5 – 1
6	1 – 2
5	2 – 4
4	4 – 8
3	8 – 12
2	12 – 20
1	> 20

Table 5.

The centralization of the calculated values

City/AM		Parameters						I_{PG}
		$PM_{2,5}$ [µg/m^3]	PM_{10} [µg/m^3]	CO [µg/m^3]	O_3 [µg/m^3]	NO_2 [µg/m^3]	SO_2 [µg/m^3]	
	V_l	15	45	4000	100	25	40	
Bucharest	V_o	13	20	180	53	27	5	1.64
	I_p	0.86	0.44	0.045	0.43	1.08	0.13	
	CS	7	8	9	8	6	9	
Vienna	V_o	4	12	200	72	12	2	1.50
	I_p	0.26	0.26	0.05	0.72	0.48	0.05	
	CS	8	8	9	7	8	9	
Hamburg	V_o	7	26	175	70	17	3.1	1.64
	I_p	0.46	0.57	0.044	0.7	0.68	0.08	
	CS	8	7	9	7	7	9	
Warsaw	V_o	7	19	550	60	42	3.3	1.63
	I_p	0.46	0.42	0.138	0.6	1.68	0.08	
	CS	8	8	9	7	6	9	
Barcelona	V_o	18	25	220	52	28	1.8	1.89
	I_p	1.2	0.55	0.055	0.52	1.12	0.05	
	CS	6	7	9	7	6	9	

Depending on the value obtained for the global air pollution index, we can admit that the air in all five metropolises is subject to anthropogenic activity within acceptable limits (I_{PG} = 1 – 2).

The results indicate that special attention is needed in the case of Barcelona, as the I_{PG} value of the air approaches the upper limit of the classification interval and may create discomfort for life forms. One of the causes for the high I_{PG} value could be represented by the high population density.

Vienna stands out with the lowest pollution index, and Barcelona with the highest, while Bucharest, Hamburg, and Warsaw have approximately the same level of pollution, a median value compared to the other 2 areas.

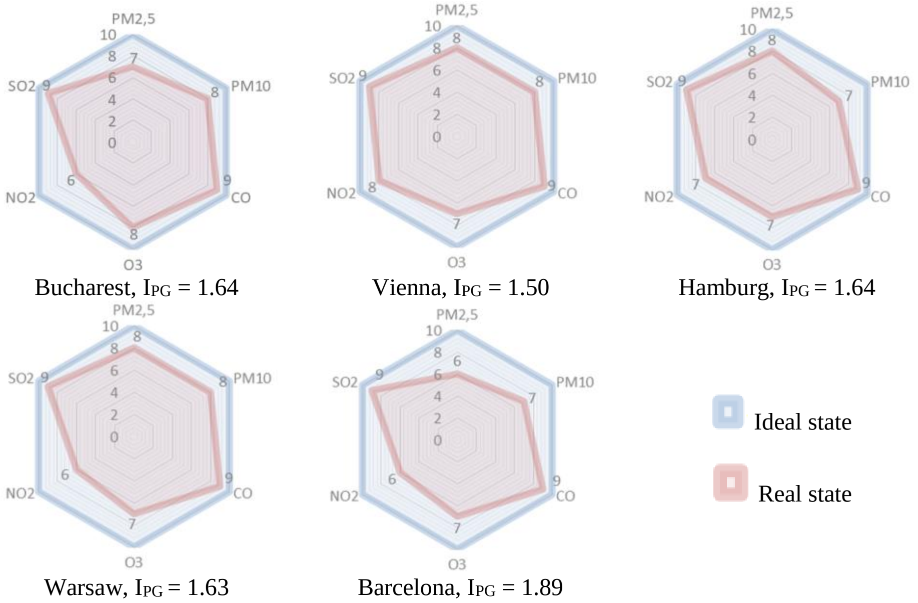

Figure 4. Determination of the global pollution index (graphical method)

Measures to reduce air pollution

We all have the obligation to contribute to the protection of the environment and to ensure, for us and for the next generations, a better quality of air, but also of the environment in general. Here are some of the measures that prevent air pollution:

- Using public transport;
- Saving;
- Reuse and recycling of materials;
- Use of green energy;
- Modernization of facilities or closure of non-performing ones;
- Using the best techniques available in each type of industry.

CONCLUSIONS

The purpose of this paper is to identify the current air quality in large cities/metropolitan areas and draw attention to this existing problem that has negative effects on the environment and human health.

During 30 days, air quality data was collected from the Bucharest, Vienna, Hamburg, Warsaw, and Barcelona metropolises. The following parameters were taken into account: $PM_{2.5}$ and PM_{10}, CO, O_3, NO_2, SO_2, but also air temperature, humidity, pressure, and wind.

The results of the research indicate that the air in all five metropolises is subject to human activity within the permissible limits, but in the case of Barcelona we are approaching the situation where air pollution can create discomfort for life forms.

Maintaining good air quality is a priority for every country, but also for the European Union. Countries are forced to implement the European Union Directives and to this end they regularly make changes to their air quality legislation. For this purpose, air quality monitoring stations are located in the cities, which provide transparent information in real time on various IT platforms.

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