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Case Study of Pollution with Particulate Matter in Selected Locations of Polish Cities

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Abstract: Despite the introduction of increasingly restrictive regulations, the air quality in Poland is still considered one of the worst in Europe. Two cities (Wroclaw and Cracow) were selected for this study, so they represent a pair of Polish cities with poor air quality, and at the same time are academic cities, popular with tourists. The article focuses on the emission of particulate matter, which is one of the most dangerous components of air pollution. The focus was on particles less than 10 µm in diameter which are most often neglected at measuring stations. We have identified the sources of particulate emissions in selected locations in Wroclaw and Cracow, and then measured particles in terms of their mass and number distribution. It was noted that the PM_{10} emission values obtained as a result of the measurements were different from the value specified by the Inspectorate of the Environmental Protection in Poland.

Keywords: urban air quality; $PM_{2.5}$; PM_{10}; particle emission sources

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1. Introduction

The monitoring and evaluation of ambient air quality is the first important step in controlling air pollution. Monitoring pollutant concentrations in air is pivotal to properly manage air quality [1,2]. Air pollution can be defined as a phenomenon harmful to the ecological system and the normal conditions of human existence and development when some substances in the atmosphere exceed a certain concentration [3]. Air pollution comes from a wide variety of sources, which discharge of harmful substances into the atmosphere, causing adverse effects to humans and the environment. They can be natural or anthropogenic [4]. One of harmful pollutants are particulate matters. Fine particulate matters of aerodynamic diameter lower than 2.5 µm ($PM_{2.5}$) are considered to be one of the most important environmental factors contributing to the global human disease burden [5]. As half of the world's population (55%) lives in urban areas, the environmental degradation produced by cities threatens the health and quality of life of a fair share of the world's population [6]. Many articles focus on explaining the connections between pollutants and their toxicological effects on the environment [7]. Outdoor air pollution led to an estimated 4.2 million premature deaths worldwide and half a million in the European Union (EU) in 2016 [8,9]. Exposure to ambient $PM_{2.5}$ particulate matter has been found to be associated with different negative health endpoints, from minor respiratory symptoms to premature mortality. This worldwide burden of disease includes 7–10 million premature deaths, mostly in developing countries [10]. Acute lower respiratory infections (ALRI), including pneumonia and bronchiolitis of bacterial and viral origin, are the largest single cause of mortality among young children worldwide and thus account for a significant burden of disease worldwide [11]. Outdoor air pollution has been associated with increased symptoms and increased ALRI mortality.

Toxicologic evidence suggests that exposure to particulate air pollution can cause pulmonary inflammation and affect host defenses against infection [12]. The World Health Organization (WHO) estimated, that in 2016, 91% of the world population was living in places where the WHO air quality guidelines levels were not met. According to WHO, about 440,000 people die every year due to air pollution in Europe. In Poland only, which is at the forefront of European countries with the most polluted air, it is about 44,000 people a year [8]. Based on the specificity of formation and the influence of particles on the human body it can be stated that one of the basic issues in assessing air quality is the concentration of particles. Particulate matter is a term generally used to describe a type of air pollutant consisting of a complex of various mixtures of suspended particles that vary in size, composition and place of formation [13]. The main sources of this type of pollution are factories, power plants, incinerators, motor vehicles and many others. The basic division of particles is based on their aerodynamic diameter, which allows for the determination of two main groups: $PM_{2.5}$ and PM_{10}, i.e., particulate matter with diameters smaller than 2.5 μm and 10 μm, respectively [14].

Air quality monitoring is carried out in Poland by the Environmental Protection Inspectorate. On the basis of the reports and their analyses, it was concluded that the air in Poland is one of the most polluted in Europe. In 2018, the WHO published a list [15] of the 50 most polluted cities in Europe. Unfortunately, Poland is at the top of this list. In terms of $PM_{2.5}$ as many as 36 of those cities are located in Poland. One of them is Cracow, which is the subject of this article's analysis. As mentioned, the assessment of air quality in Poland is carried out by the Inspectorate of Environmental Protection. Measurement stations and measurement methods are established in accordance with the relevant Regulations of the Environment Ministry.

On problem is the insufficient number of measuring stations in Poland and the fact that only a small part of them measures $PM_{2.5}$ particles and none of them measures particles up to 1 micrometer in diameter (e.g., in the city of Poznan there are five measuring stations, and only three of them allow the measurement of both PM_{10} and $PM_{2.5}$). The ambient air pollution is particularly noticeable in urban agglomerations, but unfortunately it is not limited to them. The deterioration of air quality is already observable in much smaller towns and even villages. In the case of the developing countries, the problem is more serious due to overpopulation and uncontrolled urbanization along with the development of industrialization [16]. The author of [17] pointed out that in Poland the particularly negative impact on air quality is related to households and transport. The transport sector is being developed in the direction of electromobility, however, Polish roads are still dominated by vehicles equipped with conventional engines. Recent scientific studies [18–20], carried out in Poland, analyse the impact of particulate emissions from both road and air transport. The authors of [19] have made an analysis to classify the vehicles and also to identify the advantages of the latest developments in conventional, hybrid and electric vehicles.

The aim of the article was the assessment of particulate air pollution in two selected cities in Poland. Firstly, the particle emission sources were identified in selected locations in two Polish cities (Wroclaw and Cracow), and then measurement of particles in terms of their mass distribution and numbers was performed.

2. Materials and Methods

2.1. Research Object

The choice of Wroclaw and Cracow as the study object was mainly based on their excessive emissions of air pollutants, but not only that. Cracow was chosen because it is the most polluted city in Poland, which is mainly influenced by its geographical location. The unfavorable location of the city in the Vistula valley, surrounded (on three sides) by terrain elevations, means the polluted air hangs over the city instead of being removed. In addition, the buildings of air corridors, which so far allowed to remove some pollutants from the city and introduce fresh air into it, and low emissions significantly affect the pollution distribution of this city. Wroclaw, on the other hand, due to its characteristic dense buildings (mainly old tenement houses and estates of old single-family houses), also struggles with high air pollution, especially in the autumn and winter period. In this case, the first step (identification of sources) is understood as the determination of all factors that create the possibility of an increase in the concentration of particles in the air. The distribution of emission sources should be adopted according to the modeling needs. For this reason, the emission can be divided into:

- point (emission from single sources, most often from high chimneys),
- household (emission from many different sources, e.g., from inhabited areas),
- transport (emissions from means of transport, mainly roads).

The research area was chosen based on data from documents such as the National Air Quality Program or Annual Air Quality Assessments for the Poland Voivodeships, performed by the Inspectorate of Environmental Protection in Poland. Based on the analysis of the maps prepared in those documents, the areas of increased emission were indicated, and its source was identified. The maps contained in the above-mentioned documents concern the distribution of the average annual concentration of PM_{10} in Wroclaw and Cracow [21,22]. In Wroclaw, the highest average annual concentration of PM_{10} occurs in the south of the agglomeration and in the eastern part of the city. In case of Cracow, the highest average annual concentration is found in the central part of the agglomeration. The air quality is worst in the following districts: Kazimierz, Old Town, Prądnik Biały, Prądnik Czerwony.

The second step concerns air quality measurements. Air quality measurements were taken in two popular tourist and academic cities in Poland—Wroclaw and Cracow—respectively. Both cities are known to their poor air quality. In 2018, Cracow appeared in 8th place on the list of European cities with the worst air quality. The poor air quality in Cracow is mainly due to the city's location. According to [23], the inflow of air from the surrounding areas results in a deterioration of the air quality in Cracow. Unfortunately, the city is surrounded by communities where low-quality coal stoves are still the dominant method of heating houses [23]. Measurement locations were selected in the first step and they represent each type of air pollution source.

Measurements were carried out in the following locations of Wroclaw:

- Przemkowska Street (point sources),
- Slezna Street (transportation sources),
- Ustronie Street (household sources).

Measurements were carried out in the following locations of Cracow:

- Ujastek Street (point sources),
- Debnicki Bridge (transportation sources),
- Zapolskiej Street (household sources).

It is worth noting that the locations of the measurement points do not coincide with those used by Environmental Protection Inspectorate. Measurement points have been selected to reflect the real problems of residents suffering from poor air quality. The measurements took place in two sessions: morning and afternoon. Each measurement lasted 30 min. During this time the measuring device collected 186 samples (one sample/10 s). With those 12 measurements (six in Wroclaw and six in Cracow) a total of 2232 samples were collected. Measurements were taken in early autumn, when the heating season was slowly beginning. The ambient temperature was in the 14–20 °C range. The weather conditions during the measurements were not the same. Rainfall accompanied all morning measurements only in Wroclaw. Moreover, it intensified with each subsequent measurement.

2.2. Measuring Equipment

The study used an outdoor environmental air quality monitoring device in selected cities (Wroclaw and Cracow). The number and mass distribution, and immissions of particulate matter were used as criteria for urban air quality. A TSI Optical Particle Sizer (OPS) 3330 was used to measure the number and mass of particulate matter (PM) in

Wroclaw and Cracow. At this point, it is important to emphasize the difference between emissions and immissions. Emission is the mass of substances released directly into the environment, both from natural and anthropogenic sources. The amount of these substances is determined in units of weight over time, e.g., g/h, kg/year. Immission, also called concentration of pollutants, is the amount of a dust or gas pollutants in a given volume of air unit. Immission (the object of our interest) is determined in units of weight of the substance per unit volume, e.g., μ/m^3, g/m^3 [24].

The analyzer used in our research enables the measurement of particles in the range from 0.3 to 10 µm for concentrations from 0 to $3000/cm^3$. TSI's 3330 Optical Particle Sizer (OPS) is a lightweight, portable device that provides fast and accurate measurement of particle concentration and size distribution using single particle counting technology. Sixteen measurement channels were used during the tests [25]. The quality of the measurement is ensured by the manufacturer's calibration standards.

3. Results

3.1. Analysis of Particle Number (PN) Distribution in Wroclaw and Cracow

The obtained results were analysed in terms of the type of air pollution immission source. They were divided into transportation, household, and point sources of immission. The analysis has shown that for all measurements performed (irrespective of the source of immission), particulate matter occurred in the whole measurement range, i.e., 0.34–10.00 µm (Table 1). The highest results (irrespective of immission source) were obtained during morning measurement in Wroclaw. The graphs show the results obtained during two measurements (a morning one and an afternoon one) from each type of immission source. Figure 1 shows the characteristics of the particles number concentration as a function of their size (dN/dlogDp).

Table 1. Detailed results of PN distribution in Wroclaw and Cracow.

Pollutant	Point-Source		Transportation Source		Household Source	
	Wroclaw	Cracow	Wroclaw	Cracow	Wroclaw	Cracow
range of the diameter of the largest particles number [µm]	0.3–0.5	0.3–1	0.3–0.5	0.3–1	0.3–0.5	0.3–1
share of particles with a diameter smaller than 1 µm	<99%	<96%	<99%	<98%	<99%	<98%

A more detailed description is provided in Figure 2 which is showing the percentage share of each particle diameter in the test in each type of immission source. The green color indicates the shares up to 5%, yellow the range between 5% and 50%, and red above 50%. Additionally, the range of the diameter of the largest particles number, and the share of particles with a diameter smaller than 1 µm, are shown in Table 1.

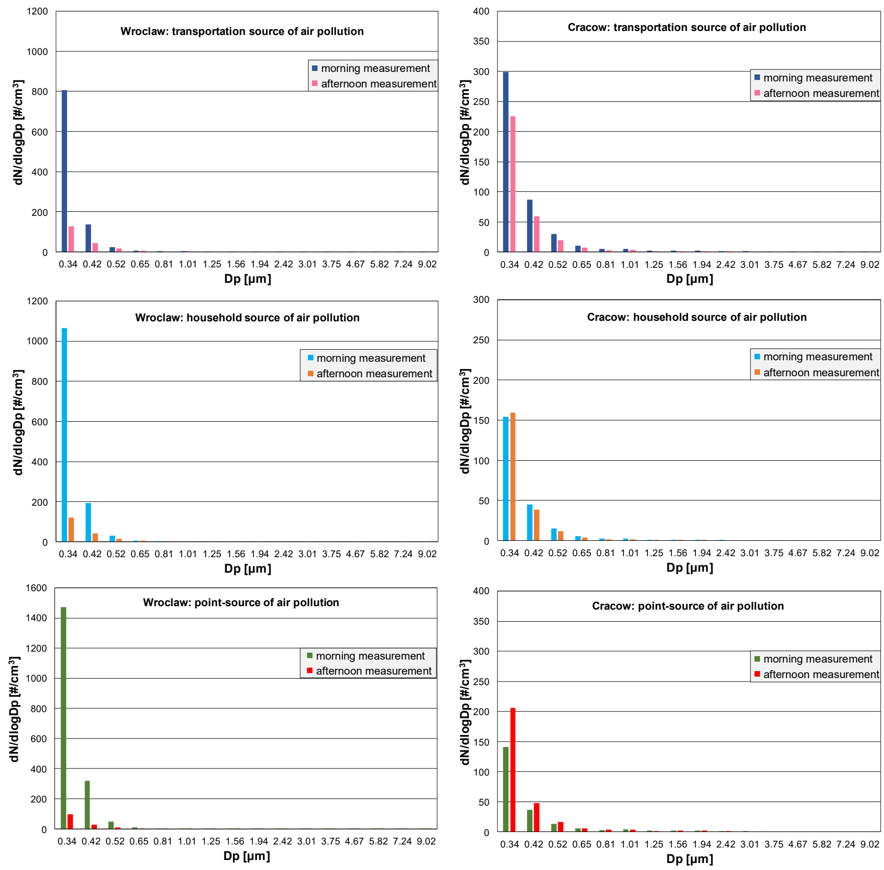


Figure 1. Particle number (PN) distributions in Wroclaw and Cracow.

	Wroclaw						Cracow					
	morning measurement			afternoon measurement			morning measurement			afternoon measurement		
Diameter	transportation	household	point	transportation	household	point	transportation	household	point	transportation	household	point
0.34	81.60%	81.55%	79.14%	46.79%	63.48%	89.99%	67.03%	67.09%	65.82%	63.29%	72.16%	77.13%
0.42	13.87%	14.83%	7.37%	12.84%	21.98%	31.52%	19.46%	19.42%	16.92%	14.74%	17.58%	20.35%
0.52	2.50%	2.36%	1.33%	4.52%	7.83%	11.60%	6.70%	6.46%	6.23%	4.90%	5.18%	6.60%
0.65	0.65%	0.51%	0.35%	1.68%	2.57%	4.11%	2.27%	2.35%	2.63%	1.87%	1.79%	2.37%
0.81	0.32%	0.22%	0.17%	0.92%	1.28%	1.56%	1.11%	1.15%	1.35%	1.04%	0.80%	1.06%
1.01	0.29%	0.17%	0.15%	0.77%	0.94%	2.04%	1.13%	1.03%	1.90%	1.12%	0.73%	1.25%
1.25	0.13%	0.07%	0.07%	0.34%	0.37%	0.68%	0.44%	0.42%	0.88%	0.49%	0.30%	0.52%
1.56	0.15%	0.07%	0.08%	0.40%	0.42%	0.66%	0.43%	0.45%	0.95%	0.53%	0.31%	0.52%
1.94	0.16%	0.08%	0.08%	0.41%	0.44%	0.76%	0.44%	0.44%	1.02%	0.55%	0.32%	0.51%
2.42	0.11%	0.05%	0.06%	0.22%	0.24%	0.44%	0.32%	0.34%	0.75%	0.39%	0.24%	0.36%
3.01	0.07%	0.03%	0.03%	0.13%	0.13%	0.23%	0.21%	0.24%	0.49%	0.25%	0.16%	0.22%
3.75	0.05%	0.02%	0.03%	0.09%	0.10%	0.16%	0.17%	0.19%	0.37%	0.20%	0.13%	0.17%
4.67	0.04%	0.01%	0.02%	0.07%	0.07%	0.14%	0.12%	0.15%	0.26%	0.14%	0.10%	0.13%
5.82	0.03%	0.01%	0.02%	0.07%	0.06%	0.11%	0.08%	0.10%	0.20%	0.12%	0.08%	0.09%
7.24	0.02%	0.01%	0.01%	0.06%	0.05%	0.09%	0.06%	0.10%	0.14%	0.09%	0.07%	0.06%
9.02	0.02%	0.01%	0.01%	0.05%	0.04%	0.07%	0.04%	0.08%	0.11%	0.07%	0.05%	0.05%

Figure 2. Percentage of particles number by their size in tests (all sectors).

3.2. Analysis of Particulate Mass (PM) Distribution in Wroclaw and Cracow

The next stage of the analysis was particulate mass (PM) distribution in Wroclaw and Cracow. Figure 3 presents mass distribution of particulate matter in measurement points in the Wroclaw and Cracow areas. The results obtained are presented in the form of characteristics of the particles mass concentration as a function of their diameter (dM/dlogDp). This analysis showed that particulate matter occurred throughout the whole measurement range, i.e., 0.34–10.00 µm.

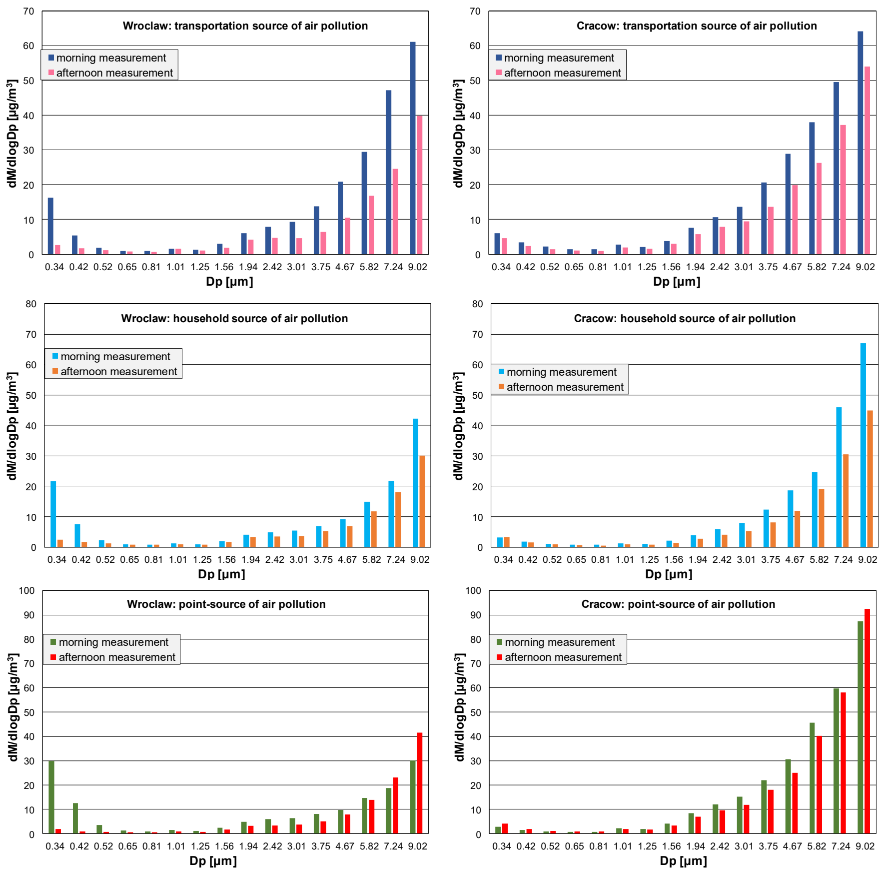


Figure 3. Particulate mass (PM) distribution in Wroclaw and Cracow.

A more detailed description is provided in Figure 4 which shows the share percentage of each particle diameter in the test in each type of immission source. The green color indicates the shares up to 5%, yellow the range between 5% and 50%. Additionally, the range of the diameter of the largest particles number, and the share of particles with a diameter smaller than 1 µm are shown in Table 2.

	Wroclaw						Cracow					
	morning measurement			afternoon measurement			morning measurement			afternoon measurement		
Diameter	transporatation	household	point	transporatation	household	point	transporatation	household	point	transporatation	household	point
0.34	7.20%	14.74%	19.67%	2.09%	2.67%	1.76%	2.36%	1.58%	0.97%	2.39%	2.38%	1.50%
0.42	2.36%	5.17%	8.23%	1.41%	1.78%	0.93%	1.32%	0.88%	0.48%	1.22%	1.12%	0.67%
0.52	0.82%	1.59%	2.37%	1.00%	1.22%	0.63%	0.88%	0.56%	0.34%	0.76%	0.63%	0.43%
0.65	0.41%	0.66%	0.85%	0.69%	0.77%	0.45%	0.57%	0.40%	0.28%	0.53%	0.42%	0.32%
0.81	0.40%	0.56%	0.64%	0.50%	0.75%	0.48%	0.54%	0.38%	0.27%	0.45%	0.36%	0.34%
1.01	0.69%	0.82%	1.04%	1.26%	1.06%	0.77%	1.06%	0.64%	0.74%	1.03%	0.64%	0.71%
1.25	0.59%	0.64%	0.72%	0.81%	0.80%	0.67%	0.81%	0.51%	0.66%	0.83%	0.51%	0.59%
1.56	1.32%	1.31%	1.62%	1.53%	1.75%	1.50%	1.51%	1.05%	1.38%	1.61%	1.00%	1.24%
1.94	2.64%	2.75%	3.19%	3.40%	3.58%	2.95%	2.98%	1.98%	2.86%	3.03%	2.03%	2.52%
2.42	3.49%	3.26%	3.95%	3.83%	3.69%	3.11%	4.15%	2.96%	4.06%	4.15%	2.94%	3.42%
3.01	4.14%	3.67%	4.25%	3.75%	3.97%	3.42%	5.34%	4.01%	5.12%	4.94%	3.83%	4.26%
3.75	6.07%	4.76%	5.25%	5.26%	5.62%	4.67%	8.05%	6.22%	7.43%	7.16%	5.95%	6.49%
4.67	9.21%	6.29%	6.41%	8.53%	7.55%	7.15%	11.29%	9.41%	10.35%	10.41%	8.77%	8.98%
5.82	12.98%	10.14%	9.68%	13.66%	12.66%	12.65%	14.83%	12.44%	15.41%	13.78%	14.00%	14.47%
7.24	20.76%	14.88%	12.39%	19.92%	19.62%	21.00%	19.31%	23.16%	20.15%	19.45%	22.38%	20.86%
9.02	26.94%	28.76%	19.74%	32.36%	32.49%	37.88%	25.01%	33.81%	29.50%	28.26%	33.04%	33.20%

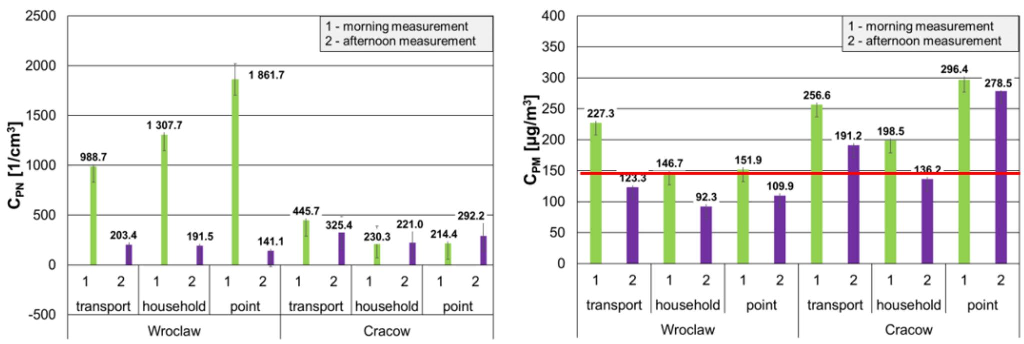
Figure 4. Percentage of particulate matter by their size in tests (all sectors).

Table 2. Detailed results of PM distribution in Wroclaw and Cracow.

Pollutant	Point-Source		Transportation Source		Household Source	
	Wroclaw	Cracow	Wroclaw	Cracow	Wroclaw	Cracow
range of the diameter of the largest particulate matter [µm]	0.3–0.5 1.5–10	2–10	0.3–0.4 2–10	2–10	0.3–0.4 2–10	2–10
share of particulate matter with a diameter smaller than 1 µm	<19%	<4%	<10%	<7%	<16%	<5%

3.3. Total Average Number and Mass Concentrations of Particulate Matter in Wroclaw and Cracow

The final stage of the analysis of the results of the studies carried out in Wroclaw and Cracow consisted in creating the characteristics presenting the total average concentration of particulate matter in terms of number and mass with a division into air pollution sources. The results obtained are shown in Figure 5a,b.



(**a**) (**b**)

Figure 5. Total average concentration of particle number (**a**) and particulate mass (**b**) in each city (in red line marked alarm level for PM_{10} emission settled by Inspectorate of Environmental Protection).

Figure 5a presents an analysis of the total average number concentration (CPN) of particulate matter obtained during air quality measurements in Wroclaw and Cracow. Data were divided according to the type of source of measured immission (transport, household and point). The results obtained for individual sources were as follows:

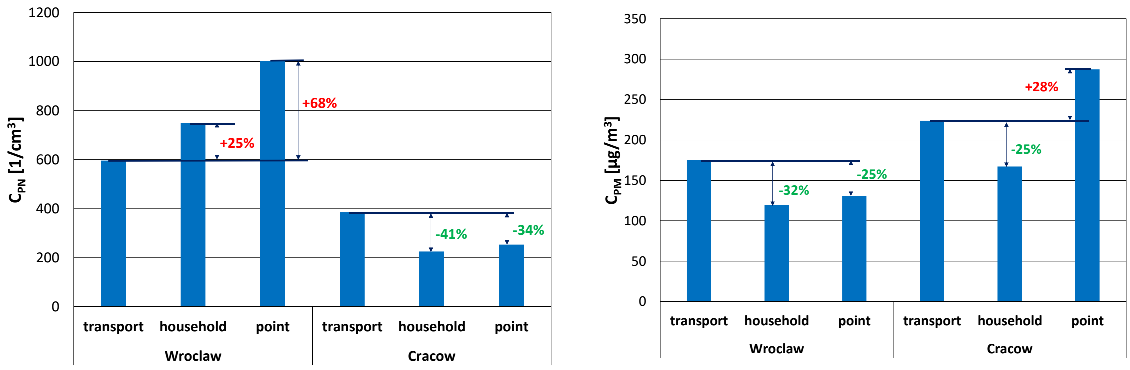
- point immission sources 1000 cm^{-3} (in Wroclaw), 253 cm^{-3} (in Cracow),
- household immission sources 750 cm^{-3} (in Wroclaw), 226 cm^{-3} (in Cracow),
- transportation immission sources 596 cm^{-3} (Wroclaw), 386 cm^{-3} (Cracow).

Figure 5b presents an analysis of the total average mass concentration (C_{PM}) of particulate matter obtained during air quality measurements in Wroclaw and Cracow. Data were divided according to the type of source of measured immission (point, household and transport). The results obtained for individual sources were as follows:

- point immission sources 131 $\mu g/m^3$ (in Wroclaw), 287 $\mu g/m^3$ (in Cracow),
- household immission sources 120 $\mu g/m^3$ (in Wroclaw), 167 $\mu g/m^3$ (in Cracow),
- transportation immission sources 175 $\mu g/m^3$ (Wroclaw), 224 $\mu g/m^3$ (Cracow).

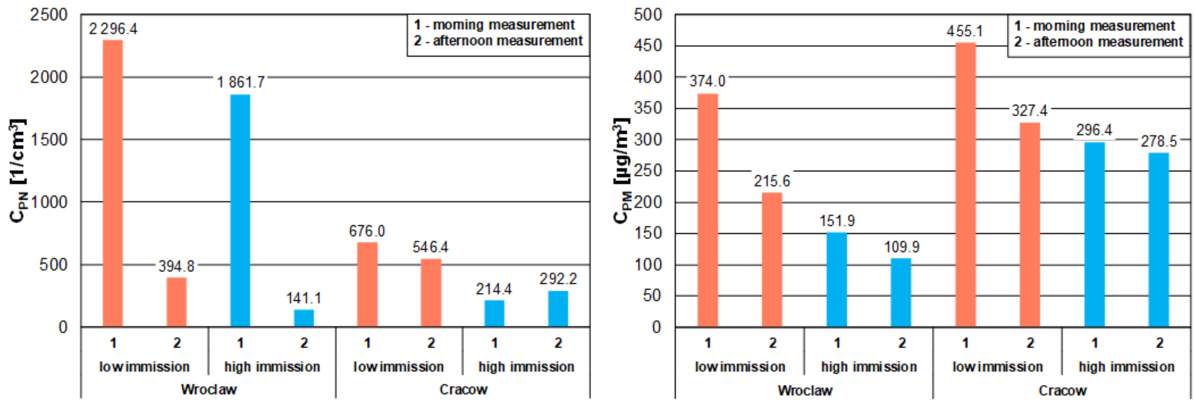
Figure 5b presents a total average mass concentration of particulate matter obtained during measurements at 1 September 2020 in Wroclaw and 3 September 2020 in Cracow. Equipment, which was used to measurements has range to 10.00 µm. This mean that prepared graph shows concentration of particulate matter to 10.00 µm (PM_{10}). The red line in Figure 5b indicates the limit above which the smog alarm is announced.

In order to compare, the results of measurements taken on the same day by the measuring station of the Environmental Protection Inspectorate were checked. The differences between the results from the Environmental Protection Inspectorate and those obtained during the research result from the location of the research stations. The measurements carried out by the authors were focused on points with increased emissions. Therefore, the measurements showed a large exceedance of PM_{10} standards and indicate the regionalization of the city's pollution. During the measurements hours, the PM_{10} results obtained by the Inspectorate of Environmental Protection did not exceed 40 μg/m^3 for Wroclaw and 50 μg/m^3 for Cracow. The data was obtained from the measurement data bank of the Environmental Protection Inspectorate for the selected station located in the vicinity of the measurement points identified in the research. Figure 6a,b show the averaged results of the performed measurements. The value of the immission obtained from transport was set as the baseline. Thanks to this, the percentage differences obtained in other sectors were determined. The obtained results were also presented in terms of low and high (point) imission. Low imission is the sum of the values obtained for the transport and household sectors (Figure 7a,b).



(**a**) (**b**)

Figure 6. Total average concentration of particles distribution in terms of: (**a**) number, (**b**) mass.



(**a**) (**b**)

Figure 7. Low and high particle emission results in terms of: (**a**) number, (**b**) mass.

4. Discussion

The area of interest during testing was particles up to 10.00 μm in aerodynamic diameter. At each of the measurement points, both morning and afternoon particulate matter occurred over the entire measurement range. Due to the number distribution, small diameter particles (up to 0.3 μm) predominated during the tests. The largest number of particles was in the size range up to 1 μm. In the case of Wroclaw, there was a significant difference between the number of particles obtained during the morning measurement compared to the afternoon one. The weather conditions were considered the cause. Rainfall accompanied all morning measurements in Wroclaw. Moreover, it intensified with each subsequent measurement. A relation between the degree of rainfall intensity and the accompanying wind with increased PM immission was noticed. During the rainfall, a very large number of solid particles were observed, in terms of mass and number. The authors of the study [26,27] mention the influence of humidity on air quality. In effect, that morning rain was effective in reducing the particulate immission, i.e., cleaning the air. In Cracow, on the other hand, the values obtained during the morning and afternoon measurements were similar.

The predominant share of particles with a diameter smaller than 1 μm (almost 100%) was observed during the measurements. This means that it is these smallest particles that are most abundant in the air. This effect is visible in both the Wroclaw and Cracow agglomerations. It is worth noting that the point-source measurement is also nearby a highway as well as a nearby railway station where the emissions from the train and diesel engine locomotive are present not only household exhaust emissions. Wind and wind turbulences which mix the particulate matter around the city and country also exist. The conducted assessment of pollution with particles pays particular attention to the share of the smallest particle size (up to 1 micrometer) in the total emissions. It is these particles that are not filtered by the human body and go directly into the respiratory system.

In terms of mass distribution, particles with a diameter greater than 1.5 μm represented the largest shares in the mass of particles. According to the obtained mass distributions of particulate matter within Wroclaw and Cracow agglomerations, the particles with a larger diameter, i.e., about 5 μm, have the greatest impact on the particulate matter immissions. The share of particulate matter with a diameter smaller than 1 μm is significantly decreased compared to the numerical distribution. This means that both in Cracow and Wroclaw (from the perspective of mass distribution of particulate matter) particles with larger diameters dominate.

The results in Figure 7 show that the transport sector is not at all the largest source of the measured particulate pollution immission in all cases. Due to the number of particles, it would be better to take a closer look at transport in Cracow. The obtained data show that the imission from households and the point imission are about 40% lower. On the other hand, in Wroclaw the biggest problem (during the research) was the point imissions. Due to the mass of particles, transport is the main source of air pollution with particles. It follows from the results obtained by us that the main source of PM pollution is low emission (surface and transport). Industrial chimneys, responsible mainly for point emission, are high, therefore the pollution is dispersed over a much larger area, far beyond the city limits.

Figure 5 presents the results of the particulate matters up to 10 μm. According to the legislation, these are PM_{10}. The results obtained during the measurements were compared with the data from official sources of Environmental Protection Inspectorate. As expected, the obtained results not only significantly exceeded the values presented by the Environmental Protection Inspectorate, but also the daily PM_{10} standards (in some cases, even by twice). This means that despite meeting the legal requirements, it would be worth considering a more precise location of the measuring stations.

The results obtained indicate that it is necessary to improve measurement methods, especially for the smallest particles, smaller than $PM_{2.5}$. As mentioned in the Introduction the number of measuring stations, not only in Wroclaw and Cracow but also across Poland, is insufficient. This also applies to the measurement of particles smaller than 2.5 μm. Our measurements were not made in accordance with the guidelines of Environmental Protection Inspectorate, however indicated that it is necessary to extend the measurements performed by the smallest particles. The assessment thus carried out highlights the shortcomings of air quality monitoring stations measuring these smallest particles. Perhaps the application of the method [28], but extended by the measurement of particulate matter, would help in determining better measuring station locations. The choice of the location of the measurement points in our research was not accidental. Similarly to [6], we were guided not only by the data from official reports, but also by taking into account subjective factors that are not taken into account in the analyses of the Environmental Protection Inspectorate. Unfortunately, both of these cities struggle with the problem of poor air quality and nuisance smog. It is related not only to the location of both cities, but also to the habits of the inhabitants. Coal stoves are still used as the main source of heating in many homes. Fortunately, the situation is improving year by year. City authorities introduce new restrictions and activate programs aimed at achieving clean air such as replacement of stoves, development of bicycle infrastructure, restrictions on vehicle entry to city centers. This applies both to subsidies encouraging residents to use green energy, and to changing the city's infrastructure.

5. Conclusions

Nowadays, air pollution is considered to be one of the biggest problems affecting society worldwide [29–32]. Specific attention is paid to one component of pollution, i.e., excessive particulate emissions. This is a crucial contaminant since it contains other pollutants adsorbed on particle surfaces, such as heavy metals. Unfortunately, Poland is at the top of the European countries with the worst air quality. Particle immission tests were carried out in two Polish cities (Wroclaw and Cracow). A total of 12 tests were carried out during the measurements (two for each type of immission source). Each measurement location represented one type of emission: transport, household and point. The conducted research shows that it is the low immission, i.e., from transport and households, that is the largest source of air pollution in the locations selected by us. The results obtained during the measurements clearly indicate that the data are not consistent with those presented by the Environmental Protection Inspectorate. The data analyzed in this article is much larger, and additionally significantly exceeds the daily PM_{10} standard. Despite the fact that the Environmental Protection Inspectorate's measuring stations are arranged in accordance with legal requirements, they are still insufficiently precise. There are still places, popular on the map of Wroclaw and Cracow, where excessive PM_{10} emissions occur, despite satisfactory data from official sources.

Moreover, the measurements performed by the Inspectorate of Environmental Protection are not sufficient. It should be necessary to expand research to include monitoring of particulate matter PM_1 and even smaller ones. The next step should be to perform further, more detailed research. On that basis, it will be possible to propose a new method for selecting the location of measurement points, especially in those places where excessive particulate emissions are a problem. Obviously, this will not directly improve air quality, but it will certainly enable better monitoring. This will enable local improvements to be made, which in the long run will have a positive impact on air quality throughout the city. Additionally, in order to reduce the level of pollution in the studied cities, it is suggested to develop social programs aimed at actively acting against air pollution. In addition, the city authorities in their environmental protection programs should focus on replacing furnaces, changing road infrastructure, expanding bicycle paths, or introducing various benefits for people using electric motor vehicles.

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