



CASE STUDY OF POLLUTION WITH PARTICULATE MATTER IN HATHUA LOCATIONS OF GOPALGANJ DISTRICT

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ABSTRACT

In this present paper we studied about the air quality in Hathua is still considered one of the worst in Gopalganj district of Bihar. Two places (Hathua and Thawe) were selected for this study, so they represent a pair of Gopalganj district with poor air quality, and at the same time are popular cities. 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 Hathua and Thawe, and then measured particles in terms of their mass and number distribution. It was noted that the PM10 emission values obtained as a result of the measurements were different from the value specified by the Inspectorate of the Environmental Protection in Gopalganj district.

Keywords: Particulate matter pollution, Metal pollution, Fine and coarse particles.

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 (PM2.5) 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 PM2.5 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 Gopalganj only, which is at the forefront of Bihar State with the most polluted air, it is about 44,00 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 PM₁₀, i.e., particulate matter with diameters smaller than 2.5 µm and 10 µm, respectively [14]. Air quality monitoring is carried out in Gopalganj by the Environmental Protection Inspectorate. On the basis of the reports and their analyses, it was concluded that the air in Gopalganj is one of the most polluted in Bihar. In 2018, the WHO published a list [15] of the 50 most polluted cities in Bihar. Unfortunately, Gopalganj is at the top of this list. In terms of PM_{2.5} as many as 36 of those cities are located in Bihar. One of them is Thawe, which is the subject of this article's analysis. As mentioned, the assessment of air quality in Gopalganj 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. One problem is the insufficient number of measuring stations in Gopalganj and the fact that only a small part of them measures PM_{2.5} particles and none of them measures particles up to 1 micrometre in diameter (e.g., in the city of Gopalganj there are five measuring stations, and only three of them allow the measurement of both PM₁₀ 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 Gopalganj 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, roads are still dominated by vehicles equipped with conventional engines. Recent scientific studies [18–20], carried out in Gopalganj, 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 Gopalganj. Firstly, the particle emission sources were identified in selected locations in two places (Hathua and Thawe), 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 Hathua and Thawe as the study object was mainly based on their excessive emissions of air pollutants, but not only that. Thawe was chosen because it is the most polluted places in Gopalganj, which is mainly influenced by its geographical location. 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. Hathua, 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 modelling 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 Gopalganj Voivodeships, performed by the Inspectorate of Environmental Protection in Gopalganj. 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 PM10 in Hathua and Thawe [21,22]. In Hathua, the highest average annual concentration of PM10 occurs in the south of the agglomeration and in the eastern part of the city. In case of Thawe, the highest average annual concentration is found in the central part of the agglomeration. The air quality is worst in the following districts: Patna, Siwan, Chapra, and Sitamarhi. The second step concerns air quality measurements. Air quality measurements were taken in two popular tourist and academic cities in Gopalganj—Hathua and Thawe—respectively. Both cities are known to their poor air quality.

In 2018, Thawe appeared in 8th place on the list of Bihar with the worst air quality. The poor air quality in Thawe is mainly due to the Gopalganj location. According to [23], the inflow of air from the surrounding areas results in a deterioration of the air quality in Thawe. Unfortunately, this place 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. 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 measurement took place in two sessions: morning and afternoon. Each measurement lasted 30 min. During this time the measuring device collected several samples (one sample/10 s). With those some measurements (few in Hathua and few in Thawe) a total sample 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 Hathua. Moreover, it intensified with each subsequent measurement.

2.2. Measuring Equipment

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

At this point, it is important to emphasize the difference between emissions and emissions. 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. Emission, also called concentration of pollutants, is the amount of a dust or gas pollutants in a given volume of air unit. Emission (the object of our interest) is determined in units of weight of the substance per unit volume, e.g., μm^3 , g/m³ [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/cm³. 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 Hathua and Thawe

The obtained results were analysed in terms of the type of air pollution emission source. They were divided into transportation, household, and point sources of emission. The analysis has shown that for all measurements performed (irrespective of the source of emission), particulate matter occurred in the whole measurement range, i.e., 0.34–10.00 μm (Table 1). The highest results (irrespective of emission source) were obtained during morning measurement in Hathua. The graphs show the results obtained during two measurements (a morning one and an afternoon one) from each type of emission 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 Hathua and Thawe.

Pollutant	Point Source		Transportation Source		Household Source	
	Hathua	Thawe	Hathua	Thawe	Hathua	Thawe
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 emission source. The green colour 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.



Plate 1. Particle number (PN) taken in Hathua by author.



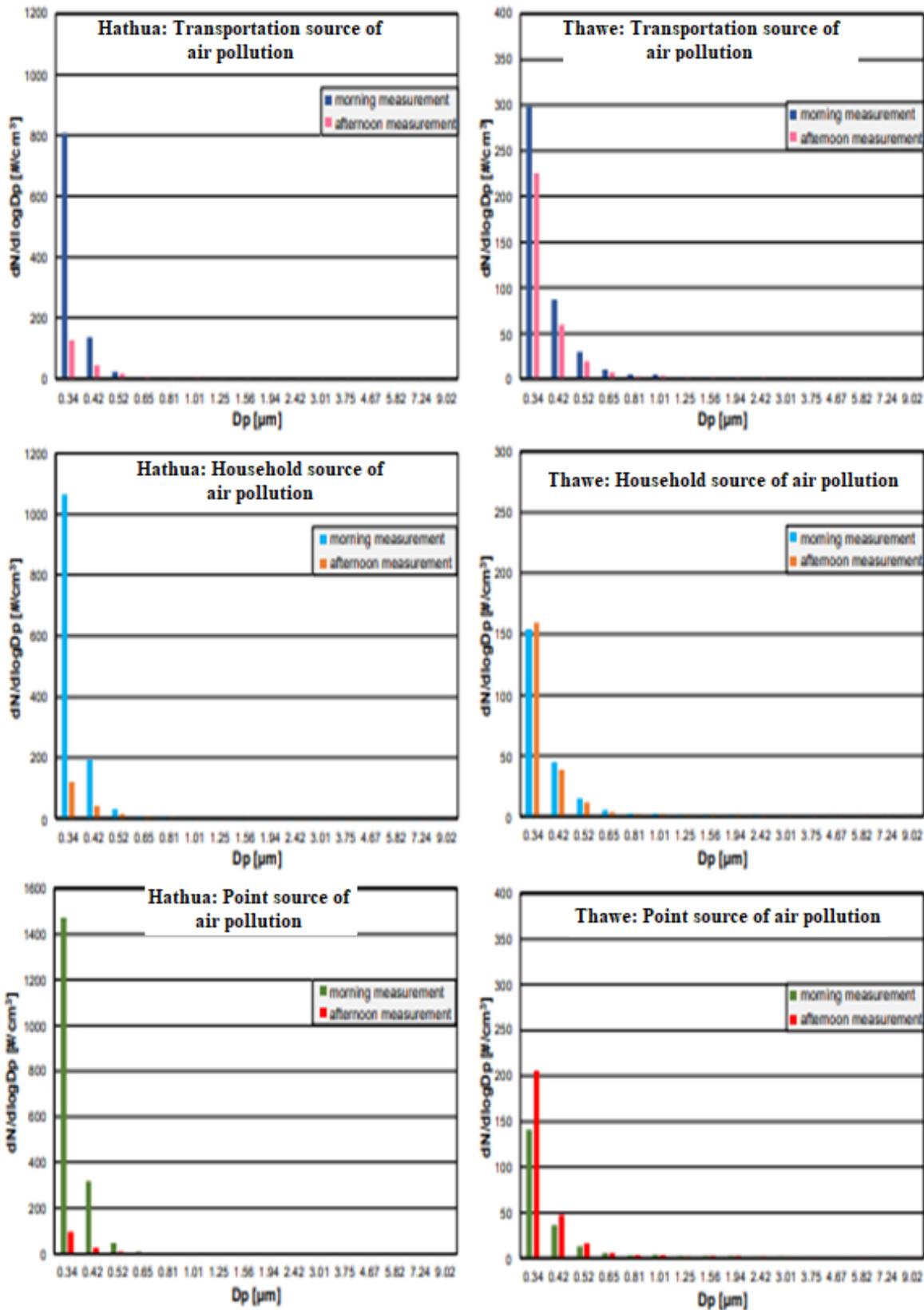


Figure 1. Particle number (PN) distributions in Hathua and Thawe.

Diameter	Hathua						Thawe					
	morning measurement			afternoon measurement			morning measurement			afternoon measurement		
	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. Total Average Number and Mass Concentrations of Particulate Matter in Hathua and Thawe

The final stage of the analysis of the results of the studies carried out in Hathua and Thawe 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 3a, b.

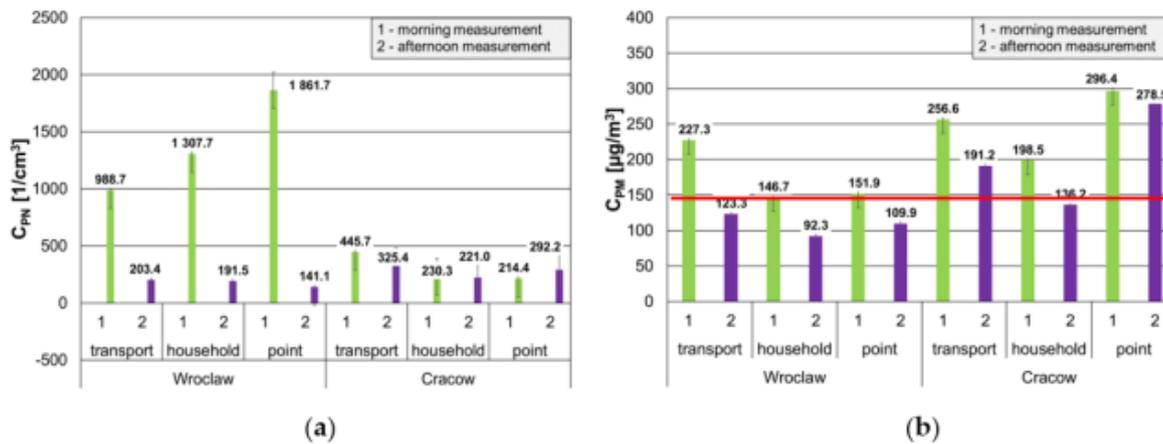


Figure 3. Total average concentration of particle number (a) and particulate mass (b) in each city (in red line marked alarm level for PM10 emission settled by Inspectorate of Environmental Protection).

Figure 3a presents an analysis of the total average number concentration (CPN) of particulate matter obtained during air quality measurements in Hathua and Thawe. Data were divided according to the type of source of measured emission (transport, household and point). The results obtained for individual sources were as follows:

- point emission sources 1000 cm⁻³ (in Hathua), 253 cm⁻³ (in Thawe),
- household emission sources 750 cm⁻³ (in Hathua), 226 cm⁻³ (in Thawe),
- transportation emission sources 596 cm⁻³ (Hathua), 386 cm⁻³ (Thawe).

Figure 3b presents an analysis of the total average mass concentration (CPM) of particulate matter obtained during air quality measurements in Hathua and Thawe. Data were divided according to the type of source of measured emission (point, household and transport). The results obtained for individual sources were as follows:

- point emission sources 131 µg/m³ (in Hathua), 287 µg/m³ (in Thawe),
- household emission sources 120 µg/m³ (in Hathua), 167 µg/m³ (in Thawe),
- transportation emission sources 175 µg/m³ (Hathua), 224 µg/m³ (Thawe).

Figure 3b presents a total average mass concentration of particulate matter obtained during measurements at 1 September 2022 in Hathua and 3 September 2022 in Thawe. 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 (PM10). The red line in Figure 3b 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 PM10 standards and indicate the regionalization of the city's pollution. During the measurements hours, the PM10 results obtained by the Inspectorate of Environmental Protection did not exceed 40 µg/m³ for Hathua and 50 µg/m³ for Thawe. 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 4a,b show the averaged results of the performed measurements. The value of the emission 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) emission. Low emission is the sum of the values obtained for the transport and household sectors (Figure 5a, b). The measurements carried out by the authors were focused on points with increased emissions. Therefore, the measurements showed a large exceedance of PM10 standards and indicate the regionalization of the city's pollution. During the measurements hours, the PM10 results obtained by the Inspectorate of Environmental Protection did not exceed 40 µg/m³ for Hathua and 50 µg/m³ for Thawe. 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 4a, b shows the averaged results of the performed measurements. The value of the emission 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) emission. Low emission is the sum of the values obtained for the transport and household sectors (Figure 5a,b).

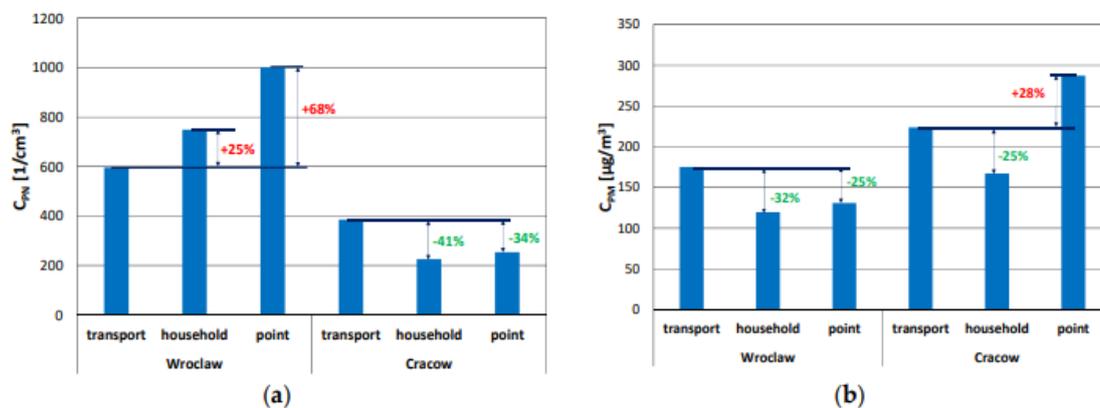


Figure 4. Total average concentration of particles distribution in terms of: (a) number, (b) mass.

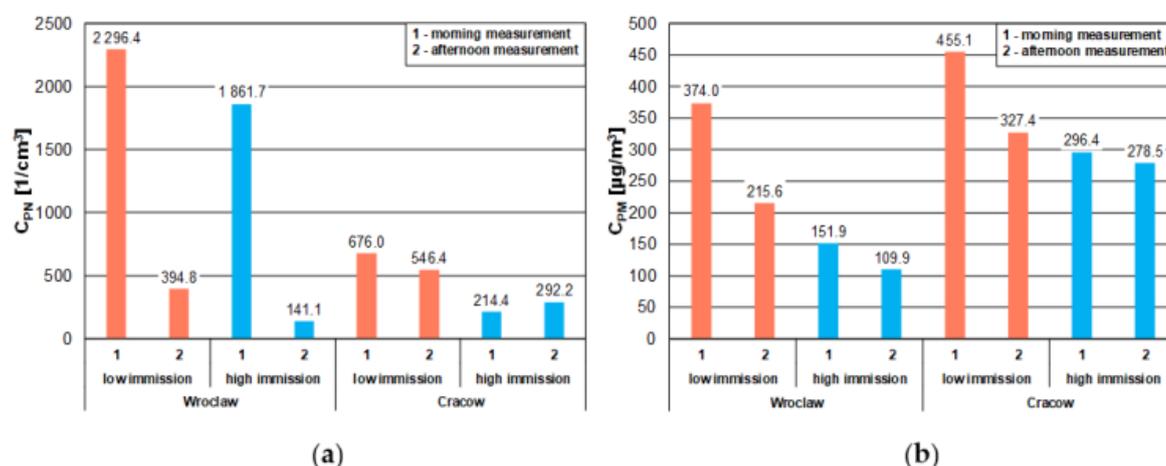


Figure 5. Low and high particle emission results in terms of: (a) number, (b) mass.

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 Hathua, 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 Hathua. Moreover, it intensified with each subsequent measurement. A relation between the degree of rainfall intensity and the accompanying wind with increased PM emission 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 emission, 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 Hathua and Thawe 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 micrometre) 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 Hathua and Thawe agglomerations, the particles with a larger diameter, i.e., about 5 μm , have the greatest impact on the particulate matter emissions. 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 Thawe and Hathua (from the perspective of mass distribution of particulate matter) particles with larger diameters dominate.

The results in Figure 5 show that the transport sector is not at all the largest source of the measured particulate pollution emission in all cases. Due to the number of particles, it would be better to take a closer look at transport in Thawe. The obtained data show that the emission from households and the point emission are about 40% lower. On the other hand, in Hathua the biggest problem (during the research) was the point emissions. 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 PM10.

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 PM10 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 PM2.5. As mentioned in the Introduction the number of measuring stations, not only in Hathua and Thawe but also across Gopalganj, 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 centres. 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, Gopalganj is at the top of the Bihar state with the worst air quality. Particle emission tests were carried out in two Polish cities (Hathua and Thawe). A total of 12 tests were carried out during the measurements (two for each type of emission source). Each measurement location represented one type of emission: transport, household and point. The conducted research shows that it is the low emission, 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 analysed in this article is much larger, and additionally significantly exceeds the daily PM10 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 Hathua and Thawe, where excessive PM10 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 PM1 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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