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Multidimensional Analysis of Air Pollution Measurements Concentration with PM10 and PM2.5 on the Campus of the Bialystok University of Technology

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ABSTRACT

The interdependence between air quality, human health and the state of the environment has prompted the development of research on causes, control and improvement of existing pollutants in the air. This paper addresses the problem of air pollution by PM2.5 and PM10 in particulate matter. There was draws attention to solutions to protect air against existing PM2.5 and PM10. Measurements of PM2.5 and PM10 concentrations in selected twenty control points on the campus of the Białystok University of Technology were discussed and analysed. On the basis of the obtained results, an assessment of the air quality in the area in question was performed. Slight hourly fluctuations in the concentration of particulate matter in the air were observed, higher in the morning and evening hours. On 15 March and 16 March, daily exceedances of the permissible PM10 and PM2.5 concentrations were recorded at both the Białystok University of Technology campus and the air quality monitoring stations in Białystok. Comparing the influence of meteorological conditions on PM10 and PM2.5 concentrations, faint correlations were found for temperature and wind speed. As temperature increased, particulate matter concentrations decreased. Low wind velocities corresponded with exceedances of the permissible daily concentrations of PM10 and PM2.5 in the air.

Keywords: air protection, particulate matter, PM2.5, PM10, air monitoring

INTRODUCTION

The state of the natural environment has a key impact on people's well-being, while human activities significantly affect the natural environment. Progressive natural changes in climate - as well as those as a result of human activities and their negative effects - are contributing to the development of research into the exact cause of, and possibilities for improving, each of the emerging problems. Today, one of the main disciplines focusing the world's attention due to the scale of occurrence and impact is particulate air pollution [1, 2]. This pollution is defined as the introduction into the atmosphere of substances that are harmful to people and other living organisms and reduce the quality of the natural environment [3]. In spite of the technologies used to purify flue gases, it is often possible to observe places with strongly exceeded permissible particulate matter concentrations, even without the use of measuring devices, where the phenomenon called smog occurs. This is caused by particulate matter and gases emitted through emitters located at heights of up to 40 m. With the accompanying temperature inversion, low-level emissions cause air pollutants to be trapped and accumulate close to the ground surface [4].

Numerous studies of airborne concentrations of pollutants including PM2.5 and PM10 [5-8] have shown that there are different types of smog. Two main types of smog have been characterised: photochemical smog - occurring in summer when temperatures oscillate between 25-30°C and the lack of wind traps the effects of fuel combustion in transport near the ground. The second type, which has been documented many times, is acidic smog (London smog) [5]. This pollution accurs in the autumn and winter season, when the heating of houses with often poor-quality fuel is predominant. As a result of temperature inversions, the cold air, which is heavier with all the exhaust fumes, is trapped near the ground surface [5-9]. Polish smog, which unlike acidic and photochemical smog occurs during different meteorological conditions, is increasingly distinguished. According to Czerwińska and Wielgosiński (2020), it can a bit similar to London smog only due to the time of year and the occurrence of smog episodes in Poland. However, it differs from the Polish one mainly in its chemical composition [5-6]. The London type is predominantly sulphur dioxide, whereas in Poland there are not as many exceedances of the permissible level of sulphur dioxide as there are particulate matter [4,6, 10]. Polish smog is dominated by carbon monoxide and particulate matter such as PM2.5 and PM10. Based on the observations, it was noted that the majority of recorded exceedances of particulate matter concentrations involved sunny weather, higher atmospheric pressure, negative temperatures, and incoming frosty air from the east. In contrast, it was less common to have smog with London-type characteristics, where mainly windless weather, high atmospheric humidity and positive winter temperatures predominate [10].

Among the various pollutants in the ambient air, particulate matter has the greatest impact on human health. Analyzing particle sizes, it has been noted that the smaller the particles, the more harmful to human health particulate matter increases. PM2.5, particles smaller than a human hair, penetrates deep into the lungs and blood through the inhalation route, causing respiratory and cardiovascular diseases, reproductive and central nervous system dysfunctions and cancer [10]. Air pollution increases the risk of death by up to 26% per year accounting for 3.5 million deaths worldwide. Each 10 $\mu g/m^3$ increase in concentration with long-term exposure to particulate matter results in an average 14% increase in lung cancer mortality and 9% more deaths from cardiovascular disease, demonstrating the magnitude of the impact of air pollution on living organisms [1, 11, 13-16].

In addition, thanks to a growing awareness of the health impacts of the surrounding air, solutions to reduce emissions and maximize protection from emitted particles are constantly being improved. More and more countries around the world, as well as individual industrial units, adopt an environmentally friendly policy by implementing emission control measurements and reporting them to the public. They also use air purification equipment that is tailored to the size and type of particles emitted, in line with good practice. These are primarily industrial plant equipment operating on the principle of centrifugal force, such as cyclones and dust collectors. Combustion processes are also used, e.g. in vehicle catalytic converters, which remove the resulting harmful products of fuel combustion. In homes and public facilities, filtration processes are most commonly used to eliminate PM2.5 and PM10 from the air. This involves the use of several filters in air purifiers that trap particles of a certain size, unpleasant odours, heavy metals and bacteria on the surface [17-18]. A number of effective solutions are being used in transport, urban planning, energy and industry to reduce PM2.5 and PM10 air pollution. Some of them include, among others, in industry the implementation of clean technologies reducing emissions from industrial stacks and improving municipal and agricultural waste management. In transport, priority is given to fast urban transportation, pedestrian and cycling networks in cities, as well as intercity rail services for freight and passengers [18]. Taking into account the beneficial impact of the natural environment on the elimination of air pollutants, an increase in the afforestation of urban areas and the use of clean energy such as solar, wind or hydroelectric power are promoted [19-20].

In view of the major impact of PM2.5 and PM10 on human health and their circulation in the environment, the control of concentrations of particulate matter is developing rapidly through continuous and periodic measurements at numerous control points countrywide. In Poland, these measurements are carried out by the State Monitoring of the Environment (PMŚ), which makes the collected data available to the public so that the air quality in a given area can be monitored on an ongoing basis. On the basis of the obtained results, in addition to public information on current air quality, multi-annual analyses of changes in PM2.5 and PM10 concentrations are prepared, as well as an assessment of their causes, effects and a forecast for the following years.

The aim of the conducted research was to analyse and assess the air quality on the Bialystok University of Technology campus. The study of PM2.5 and PM10 concentrations was carried out at twenty control points, with measurements taken at 10:00, 12:00, 14:00, 16:00 and 18:00 at each point in order to determine changes in the concentration of particulate matter on a daily basis. The study was conducted over the period March-May 2022. On the basis of the compilation of the obtained results, an analysis of changes in PM2.5 and PM10 concentrations during the entire study period was also carried out, and attempts were made to assess the influence of the meteorological conditions prevailing at a given time on the obtained data. In addition, a comparison was made between the received results and the recorded concentrations from the Provincial Institute for Environmental Protection (WIOŚ) stations, which belong to the PMŚ.

MATERIALS AND METHODS

The study of PM2.5 and PM10 concentrations was conducted in the area of the Bialystok University of Technology campus. The university is located in the centre of the city of Białystok, which is the capital of the Podlaskie Voivodeship. The research was carried out in an area of approximately 286,000 m^2 [23]. The main buildings on the campus include four faculties: Civil Engineering and Environmental Sciences, Computer Science, Electrical Engineering and Mechanical Engineering. On the other side of the campus are the student dormitories and bus stops. The location's proximity to busy roads may result in higher pollution's levels due to linear emissions. All campus buildings are heated from the municipal district heating network. The Central heating Plant (CHP) is obliged to provide the required levels of emissions to air, and thus the lack of individual heating sources on the campus. This limits particulate matter emissions from the facilities of the Bialystok University of Technology [24]. As the study is conducted outdoors, it is important to take into account the meteorological conditions in place and assess their impact on the formation of PM2.5 and PM10 concentrations. In Poland, wind directions are not the same at each season of the year. In summer, winds from the east and south-east predominate, in autumn they change to the east and south-east, while in winter, winds from the south-west predominate. In spring, during the surveys carried out, the wind directions are distributed quite proportionally. Sometimes the wind direction can have a significant effect on the distribution of particulate matter concentrations in a given area due to windblown pollution from linear emissions near roads. Alternatively, pollution can be retained at low wind speeds in areas where home heating with inefficient boilers or the use of poor quality fuel is prevalent [25-27].

Measurements of PM2.5 and PM10 concentrations were conducted on the Bialystok University of Technology campus (Fig. 1) during the first half of spring 2022 – 15 March, 16 March, 17 March and 18 March, 5 April, 6 April, 8 April, 12 April, 13 April, 14 April, 15 April, 26 April, 27 April, 28 April, 29 April, and 3 May, 4 May, 5 May and 6 May. On each test day, measurements were taken five times outdoors at each measuring and control point, at 10:00, 12:00, 14:00, 16:00 and 18:00.

Twenty measurement and control points were selected, which differ in, among other things:
- purpose,
- location in relation to urban roads of different intensity and internal campus roads,
- location in relation to car parks and bus stops.

On each measuring day, tests were carried out with a DT-96 meter at a height of 150 cm. The device has two channels measuring particles up to 2.5 microns and 10 microns. Thus, PM2.5 and PM10 concentration results were obtained simultaneously during a single measurement.

Surrounding all the measurement and control points, the campus has a network of roads with car parks allowing easy access on foot as well as by vehicle to any facility in the area. The buildings of the faculties of the Bialystok University of Technology defined by points No. 1, 2, 3, 4, 5 and the Library – no. 6 are located in the southern part of the campus. On the northern side they are surrounded by pavements and greenery, while on the southern side there is a large car park and a test track – point #9, which can be reached from Świerkowa Street, along which there is a communal forest. Measurement and control point

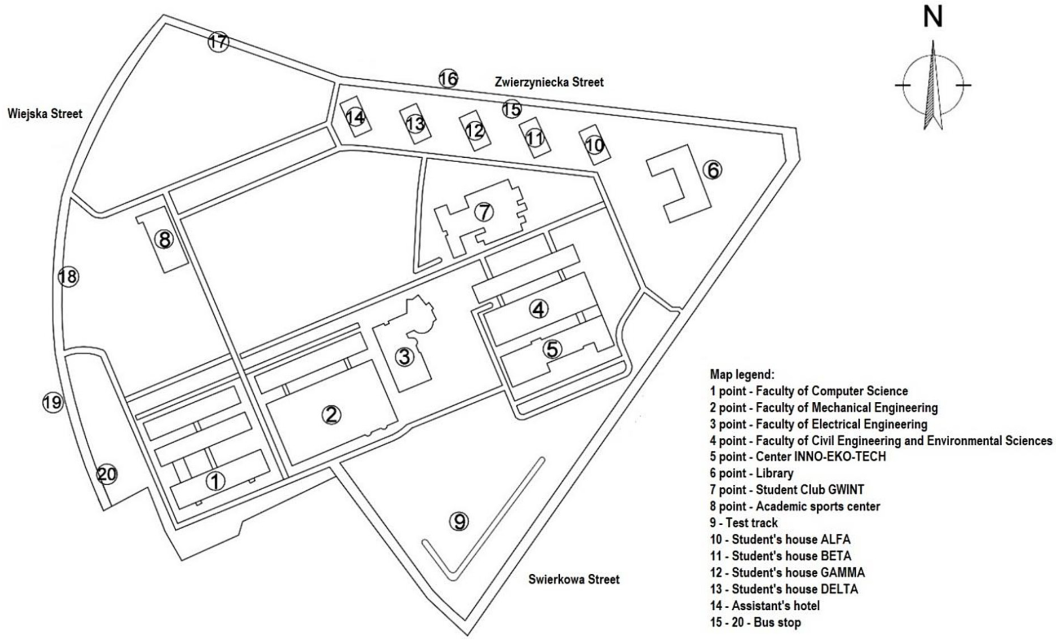

Figure 1. BUT Campus map and control points

#7 – the Student Club and point #8 which is the Academic Sports Centre are located in the centre of the campus area next to the main green area. Measurement and control points No. 10, 11, 12, 13 and 14, being the Academic Houses and the Assistant Hotel, are located at the border of the campus with Zwierzyniecka Street with heavy traffic. Measurement points No. 15, 16, 17, 18, 19 and 20 are bus stops located at the campus boundary on Zwierzyniecka Street and Wiejska Street. Both streets, with high traffic volumes, surround the University site on two sides.

RESULTS AND DISCUSSION

The resulting daily average PM2.5 and PM10 concentrations from all measurement points on the BUT campus were compared with the daily averages on those days from the WIOŚ measurement stations. In order to assess the influence of roads in the neighborhood of the measurement sites on the levels of PM2.5 and PM10 concentrations, the daily average concentrations of particulate matter recorded at the two air quality monitoring stations in Białystok were considered and presented in Table 1. Because the background around the stations is similar to the study area, most of the data was taken from the PdBialAlPils station located in the city centre at Aleja Józefa Piłsudskiego, which is one of the most busy streets in Białystok. The selected measuring station was put into operation in 2022, while the measurements started in the last week of March. Therefore, in the case of comparing test days in that month, data were obtained from the PdBialWarsza station on Warszawska Street. Measurements are carried out automatically on a continuous basis, collecting information on hourly and daily average concentrations of the tested particulates.

Analyzing the collected data, it can be noted that the highest daily concentrations were recorded on 15 March for both PM2.5 – amounting to 62.8 $\mu g/m^3$ and 60.4 $\mu g/m^3$ for PM10. This also exceeded the daily allowable concentrations for PM2.5 of 25 $\mu g/m^3$ and for PM10 of 50 $\mu g/m^3$. In total, exceedances of daily PM2.5 concentrations were recorded five times on 15 March, 16 March, 18 March, 13 April and 14 April. PM10 concentrations exceeding the daily standard occurred twice – on 15 March and 18 March. The lowest concentration levels were recorded on 8 April amounting to 5.4 µg/m3 for PM2.5 and 7.1 µg/m3 for PM10. Summarizing the comparison presented in Figure 2, it was found that the daily average concentrations of both PM2.5 and PM10 on all measurement days do not exceed the daily average results obtained from the station of the Provincial Inspectorate of Environmental Protection in Białystok.

Figure 3 shows the pattern of changes in the average PM10 concentration at all measurement and control points during each hour of measurements. After the first measurement

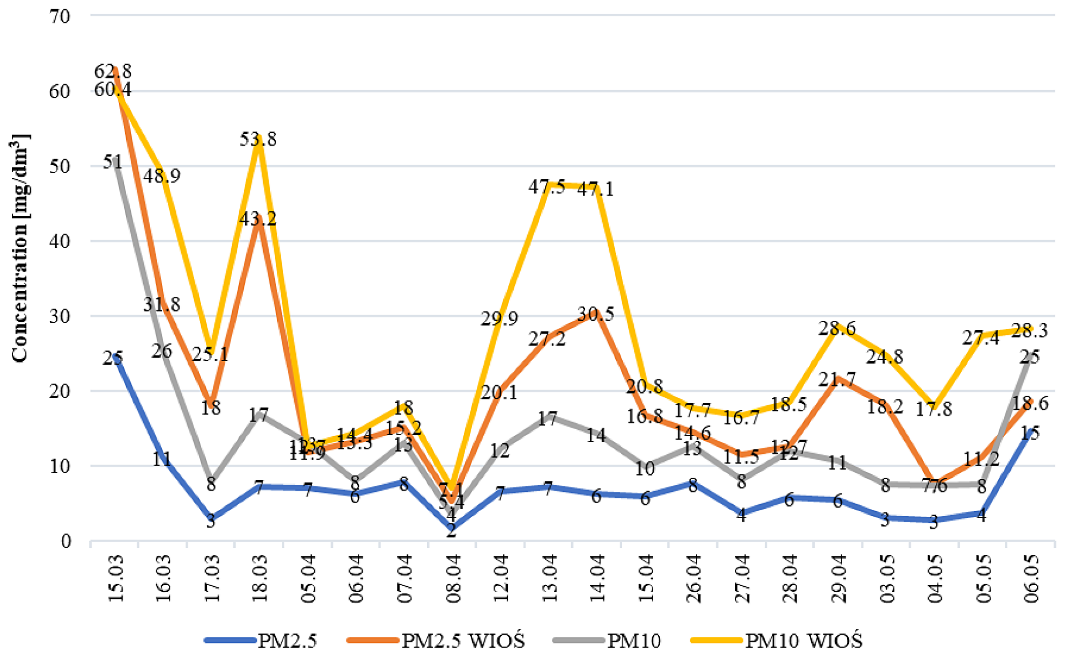

Figure 2. Comparison of daily average measurements of PM2.5 and PM10 with results collected from stations PbBialWarsza and PbBialAlPils

at 10:00 a.m., the average PM10 concentrations at a significant part of the points started to decrease gradually. This may be mainly due to the decreasing intensity of traffic after the morning hours, as well as ongoing classes at the University. At some of the measurement points, at the 16:00 there was observed slight increase in concentration relative to 14:00. At point #10, the highest concentration of 36 μg/m^3 was obtained. This may have been due to renewed increased traffic on city roads as well as on the BUT campus. This time is mostly the end of the working day, as well as a significant part of classes at the University. A further slight increase in PM10 concentrations was noted over the next two hours. Elevated PM10 concentrations throughout the entire survey day relative to most measurement points were noted at bus stops – point #16 and #18. This may be due to the continuous movement of vehicles, which, when stopping and restarting, emit more pollutants than vehicles in motion.

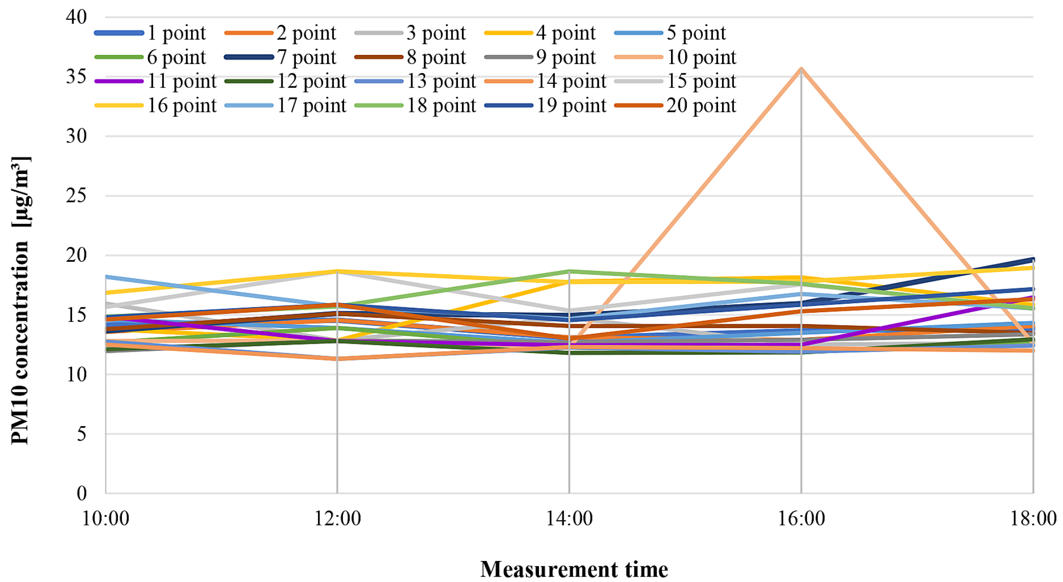

Figure 3. Average daily variations in PM10 concentration over the study period

Similar relationships were found for the changes in PM2.5 concentrations throughout the entire study period. Figure 4 shows the changes in the average PM2.5 concentrations at each time point of the study for all measurement and control points.

Initial PM2.5 concentrations also gradually began to decrease, reaching their lowest value at 14:00 of 5 µg/m³ at three measurement and control points. Measurements at 16:00 showed an increase in PM2.5 concentrations. By 18:00, a further increase in particle concentrations was recorded. The highest PM2.5 concentrations of 11 µg/m³ were recorded at 10:00 at the measurement point #17, at 16:00 for #10 and at 18:00 point #7. Taking into account daily PM2.5 and PM10 concentrations as well as day-to-day variations in road traffic, it is worth noting that fluctuations in particulate matter concentrations may be caused by changing vehicle traffic on urban roads with dense bus routes as well as on internal roads of the Białystok University of Technology campus. It has been observed that after the morning traffic rush, there is a decrease in vehicular activity, which reflects a decrease in PM2.5 concentrations at a significant part of the measurement and control points and a renewed increase in the afternoon [28].

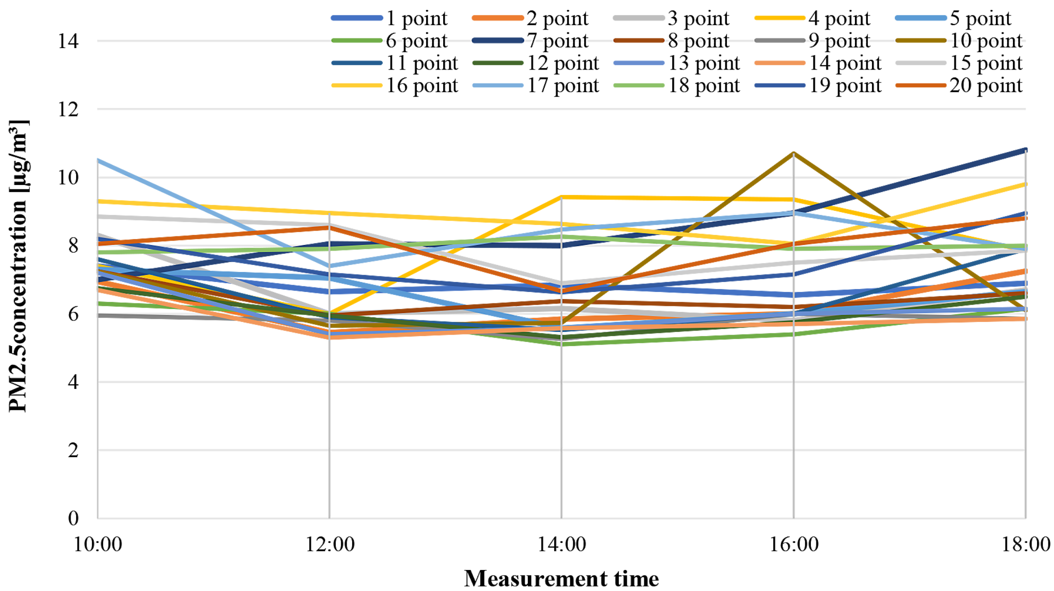

Figure 4. Average daily variations in PM2.5 concentrations over the study period

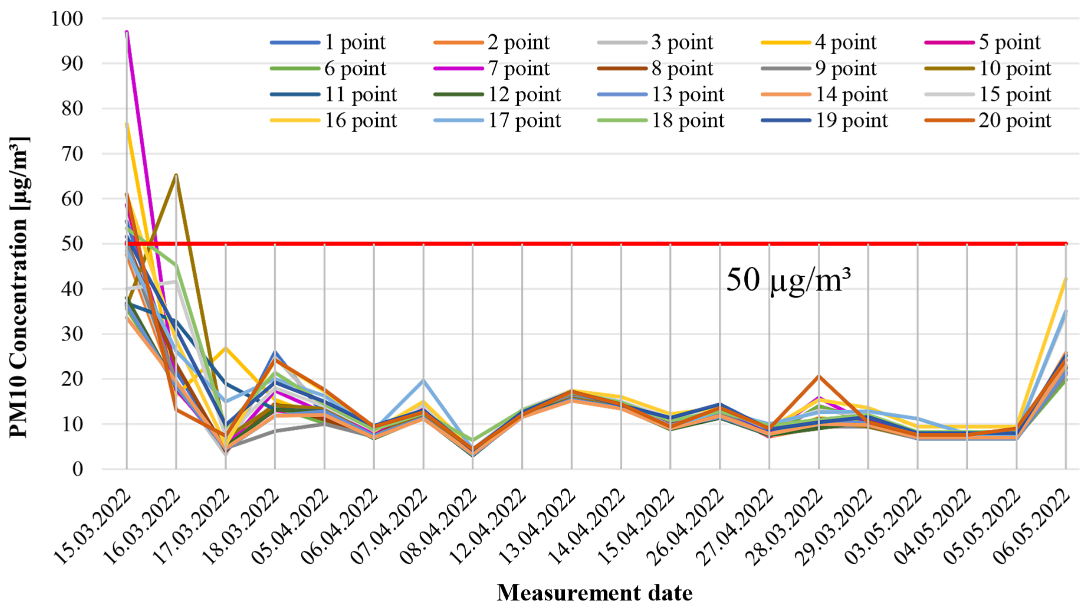

Figure 5. Average daily distribution of PM10 concentrations during the study period

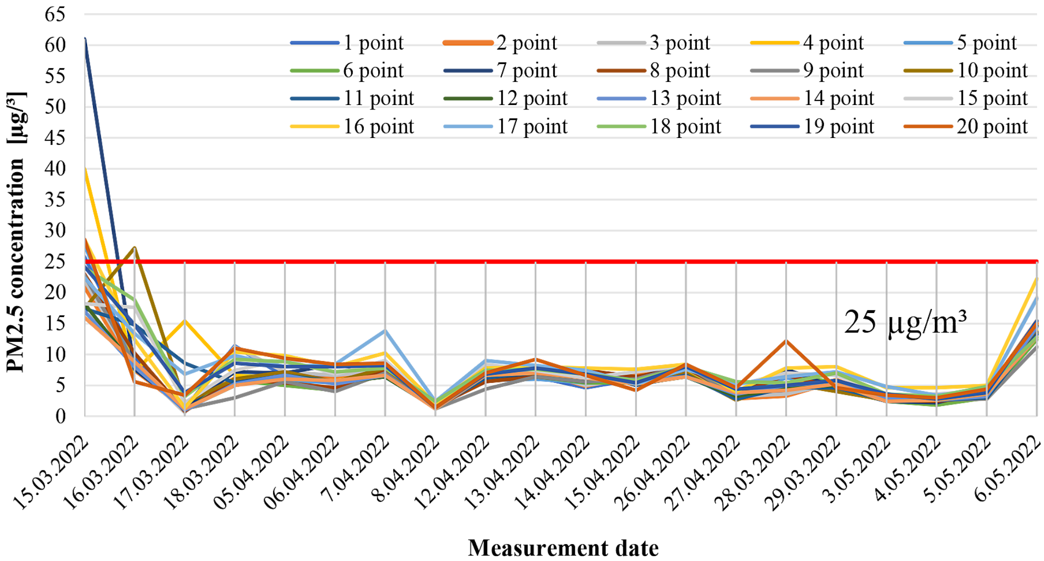

Figure 6. Average daily spread of PM2.5 concentrations over the study period

In addition, the changes in PM10 and PM2.5 concentrations over all measurement days are presented on the basis of the obtained results (Figures 5 and 6). To illustrate the whole study period, all received measurements during each study day were extracted and daily average concentrations were calculated for all measurement points. Figure 5 illustrates the distribution of PM10 during the investigation season in relation to the PM10 daily legally limited level of 50 µg/m^3. During the first two measurement days on 15 March and 16 March, the average concentration on campus exceeded the limit value of 50 µg/m^3. The highest concentration on 15 March was 97 µg/m^3 at #7 control point, while on 16 March it was 65 µg/m^3 at #10. In the following days, a decrease in daily PM10 concentrations began to be recorded, reaching the lowest on 8 April – 3 µg/m^3 at fourteen measuring points.

Figure 6 shows the changes in the average PM2.5 concentration over all measurement days at each study point. As with PM10, there were exceedances of the PM2.5 permissible concentration level of 25 µg/m^3 at the beginning of the study period, on 15 March and 16 March 2022. The highest concentration was 61 µg/m^3 on 15 March. On 8 April, the lowest PM2.5 concentrations ranging from 1 µg/m^3 to 2 µg/m^3 occurred at all measurement and control points.

In both Figure 5 and Figure 6, a similar distribution of particulate matter concentration changes during the investigation days can be observed. In the beginning there were noticeable rises in PM10 and PM2.5 concentrations above the permissible norms, while in the middle of the surveys the concentrations remained at the lowest levels with single episodes of increase of particulate matter in the air, but not exceeding the permissible norm.

In order to establish the relationship of meteorological conditions on particulate matter concentrations, data from the National Meteorological Institute's available on the website "Meteoblue" were used. The air temperature, relative humidity and wind speed throughout the study period were taken into account. Using the meteorological information, interrelationships between the weather factors analysed and PM2.5 and PM10 concentrations were calculated using the Pearson correlation coefficient. The correlations define the interaction between the two studied factors in the range from -1 to 1. The closer the result is to zero, the weaker the interdependencies are [28]. Table 1 shows the resulting Pearson correlation coefficient for PM2.5 and PM10.

Analysing the relationship between daily PM2.5 and PM10 and temperature, a negative correlation of -0.25 for PM10 and -0.20 for PM2.5 can be observed. During the survey period, daily temperatures increased, while average daily

Table 1. Correlation coefficient between PM2.5 and PM10 and meteorological elements

Parameter	PM10	PM2.5
Temperature	- 0.25	- 0.20
Humidity	- 0.07	- 0.06
Wind speed	- 0.30	- 0.21

concentrations of both PM2.5 and PM10 started to decrease. The initial high above-normal concentrations of PM2.5 and PM10 may have been caused by temperatures close to freezing, which resulted in the reheating of buildings during the colder period, giving rise to an increase in emitted particles from chimneys. After 8 April, there was an increase in the average daily temperature, thus reflecting the maintenance of lower PM2.5 and PM10 concentrations. Rawicki's (2016) study confirms the influence of air temperature in forming the variability of the imission of suspended particulates. He conducted statistical analyses on the basis of collected data from the winter period in the area of selected six Polish cities. These analyses confirmed the statistically significant role of temperature in shaping PM10 concentrations in the air [29].

Considering the relative humidity during the study period and the daily average concentrations of PM2.5 and PM10, the obtained correlation coefficient indicates that there is no significant relationship between the two factors studied. Humidity fluctuated more than temperature, although it was noted that, in general, as the temperature decreased or remained lower, humidity also started to decrease. It can be assumed that humidity is often interdependent on temperature, which also translates to a negligible extent into the influence of changes in particle concentration in ambient air.

The wind speed in March, during the first days of the investigations, remained at a low level of 10-13 km/h. It corresponds with the obtained highest concentrations of PM10 and PM2.5 at the moments of exceeding the daily permissible level of particulate matter in the atmospheric air. With the beginning of April 2022, the wind speed increased to 30–38 km/h, while the measured concentrations of particulate matter started to decrease. The obtained correlation coefficient indicates a similar relationship of the effect of wind speed on particles concentrations as for temperature. For PM10, the correlation was -0.30, while for PM2.5 it was -0.21. This may be due to the retention of pollutants in a given area during windless weather, e.g. single-family housing estates fueled by inefficient installations, areas of large industrial plants or linear emissions along roads. During higher wind speeds, particulate matter is blown away. Similar conclusions were reached by Wierzbińska and Szczepaniak (2021), who conducted research on the influence of meteorological conditions on particulate matter immission in the city of Żywiec. They proved that one of the main factors influencing air quality, in particular, is wind, which can significantly affect air quality. They found that particulate matter emissions are directly dependent on wind direction and strength. Studies conducted by this research group found that low wind speeds corresponded with increases in particulate matter concentrations in the air [13].

CONCLUSIONS

The study attempts to analyse PM2.5 and PM10 particulate matter pollution on the Bialystok University of Technology campus. The study showed that the main factor influencing the concentration of particles emitted from various sources is the year season and the associated changing atmospheric conditions. In the daytime distribution of PM2.5 and PM10 concentrations, a significant influence on local air pollution was exerted by linear emissions from streets around the campus, car parks and bus stops, where the highest particulate emissions are produced by motor vehicles stopping and starting. However, it is the weather conditions of the day that affect the retention or dispersion of pollutants.

During the hourly readings, the highest concentrations at most of the measurement and control points occurred at times 10:00 and 16:00 and 18:00 amounting to a maximum of 11 $\mu g/m^3$ for PM2.5. The highest PM10 concentration of 36 $\mu g/m^3$ was recorded at 16:00 for the #10 measurement and control point. After the morning traffic peak, the levels of PM2.5 and PM10 decreased between 12:00 and 14:00. No significant fluctuations in particulate matter concentrations were recorded during the measurement hours in the study area. It can be concluded that the traffic intensity around the measurement and control points does not have a strong influence on the daily variations of pollutant concentrations in the air. However, taking into account the occurring road emissions, it should be taken into account their overall influence on higher concentrations of pollutants in the air than in areas with lower street density and traffic intensity.

Summarising the obtained correlation coefficient between meteorological conditions and particulates in the air, it was found that temperature and wind speed had the greatest influence among the analysed weather factors on both PM2.5 and

PM10. As the temperature increased, a decrease in PM2.5 and PM10 concentrations was recorded, while at low wind speeds, particulate concentrations exceeded the permissible levels in the air.

During the first two experiments' days on 15 March and 16 March, the measured average PM10 concentrations on campus exceeded the limit value of 50 μg/m^3. The highest concentration on 15 March was 97 μg/m^3 at the #7 measuring point, while on 16 March it was 65 μg/m^3 at the #10 point. In the following days, a decrease in daily PM10 concentrations began to be recorded, reaching the lowest on 8 April - 3 μg/m^3 at fourteen measuring points. A similar pattern of concentration changes occurred in the case of PM2.5. The highest concentration of particulate matter was 61 μg/m^3 on 15 March, thus exceeding the daily permissible concentration of 25 μg/m^3.

Data obtained at the air monitoring stations in Bialystok were also compared. As in the study area, the monitoring stations showed exceedances of PM10 and PM2.5 concentrations on 15 March and 16 as well. At the Warszawska Street station, on 15 March, the exceeded PM2.5 level was 60.4 μg m^3 and 62.8 μg/m^3 for PM10, while on 16 March the PM2.5 concentration reached 31.8 μg/m^3, and for PM10 it was 48.9 μg/m^3 – just close to the daily permissible level. In conclusion, it was observed that the daily average concentrations of both PM2.5 and PM10 on all measurement days did not exceed the daily average results obtained from the station of the Provincial Inspectorate for Environmental Protection in Białystok. Conducted tests of PM2.5 and PM10 concentrations show that the best air quality on the Białystok University of Technology campus occurs during higher air temperatures, which may be related to the end of heating season where buildings located nearby the University are heated with poor-quality fuel. The dispersion of pollutants by wind can also be observed. The heating of buildings on the campus by CHP network also significantly reduces the overall concentration of particulate matter, without generating additional sources of emissions to the air.

Using all forms of atmospheric air protection, from the implementation of monitoring, forecasting and early warning systems for airborne particles, to the development of emission-free techniques, it is possible to achieve increasingly better air quality results by minimising air emissions and mitigating their effects. To this end, a network of automatic measuring devices could be implemented on the Bialystok University of Technology campus, monitoring current levels of PM2.5 and PM10 particulate matter concentrations and reporting exceedances. Sending information from the measurement sensors could trigger the operation of air purifiers that could be used in the University's buildings.

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