Atmospheric Dust Pollution of the Cracow Agglomeration in the Light of Empirical Research

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Abstract

The paper presents the problem of dust pollution in the atmosphere of a typical urban agglomeration. The influence of natural and anthropogenic factors on airborne dust concentration is described. The results of air pollution tests with PM2.5 and PM10 particulate matter at five measurement points in the Cracow agglomeration are presented. The use of statistical methods has shown the relationship between airborne dust concentration and the season of the year. The highest levels of PM2,5 and PM10 dusts are recorded during the autumn and winter months. During the heating season, the municipal and household sector is mainly responsible for dust emissions. Measures to reduce emissions of air pollution from industrial sources and transportation are proposed.

Keywords: *dust, air pollution, monitoring*

Introduction

Air pollution is a growing national and global issue. The pollutants emitted into the atmosphere include dust, i.e. a mixture of suspended solids which form a dispersed phase. Aerosol particles refer to dust particles smaller than 50 µm. Dust can be classified using a number of criteria. Due to particle sizes, the following are identified: total suspended particulates TSP, fine particulate matter with particle diameter less than 10 µm PM10 and very fine particulate matter with particle diameter less than 2.5 µm PM2.5 [1].

Emission of particulates from combustion of solid fuels in central heating boilers makes Cracow one of the most polluted cities in Poland. The city is surrounded by communes where the main source of heating is domestic furnaces. Another reason for the high dust concentration is communication. The high traffic volume on narrow roads without ventilation causes exhaust emissions. Dense urban core and high-rise buildings on the suburbs also hinder the ventilation of the city. The accumulation of pollution in the Cracow agglomeration is influenced by the natural morphology of the area. Cracow is located in the Vistula valley, and the hills surrounding the city block the movement of masses of air, which makes the ventilation conditions extremely poor.

Influence of weather conditions on dust concentration in the air

The dust concentration in the air depends on the interaction of two factors: the emission of pollutants and weather conditions. Emissions are the factor that determines the occurrence of dusts in the atmosphere, while the concentration of dusts depends on weather conditions determining the transport of harmful compounds in the atmosphere [2, 3]. Atmospheric factors may affect the diversity of pollutant concentrations in the air by controlling emissions (e.g. influence of temperature on the length and intensity of the heating season, the intensity of traffic) and by influencing their distribution [4, 5]. Important meteorological parameters are the direction and speed of the wind in the lowest layer of the atmosphere. They determine the movement of air masses from neighbouring areas. The highest dust concentrations are found in the ground level of the atmosphere. During windless weather, pollutants accumulate at the place of their origin. For most substances, the higher the wind speed, the lower the concentration in the air due to the dilution of pollutants. Ventilation is particularly important during the heating season, when increased emissions from fuel combustion in domestic furnaces and motor vehicles result in dust accumulation in the city centre. The disruption of ventilation conditions specific to highly urbanised areas is a major problem, as dense number of urban buildings block natural ventilation corridors, resulting in the accumulation of dust [6–9].

An important weather factor in the Krakow agglomeration is the rain, especially rainfall. Sometimes the temperature distribution is reversed (thermal inversion phenomenon leading to accumulation of dust substances in the troposphere). It occurs during frosty and cloudless nights, which leads to a much lower temperature at the ground surface than in higher air layers. Harmful substances are retained and accumulated in the atmosphere as a result of air sedimentation.

Methods for measuring particulate matter in the air

PM2.5 and PM10 particulate matter are measured as part of the State Environmental Monitoring. The Inspection of Environmental Protection shall use two complementary methods to test the particulate matter content of air:

– the gravimetric (reference) method, considered worldwide to be the most precise;

Tab. 1. Permissible levels for particulate pollutants present in the air [11]
Tab. 1. Poziomy dopuszczalne dla zanieczyszczeń pyłowych obecnych w powietrzu [11]

Name of substance	Averaging period	Permissible level in the air in 2020 [μg/m³]	Permissible annual frequency of exceeding the level
particulate matter PM 2.5	Calendar year	20	-
particulate matter PM10	24 hours	50	35 times
	Calendar year	40	-

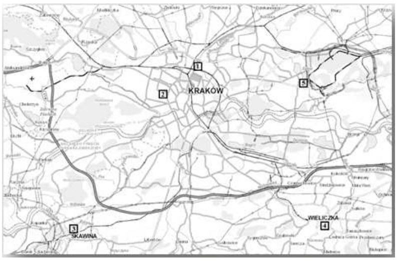

Fig. 1. The location of the test stations [13]: 1. 29 Avenue Listopada, 2. AGH University of Science and Technology, 3. Nowa Huta, 4. Skawina, 5. Wieliczka
Rys. 1. Lokalizacja stanowisk badawczych [13]: 1. aleja 29 Listopada, 2. Akademia Górniczo-Hutnicza, 3. Nowa Huta, 4. Skawina, 5. Wieliczka

– the automatic method, equivalent to the reference method.

The gravimetric method involves the use of aerosol samplers to which air is sucked in. Every 14 days, 14 disposable filters are placed in the sampler, which are changed automatically every 24 hours. Each of these filters is weighted before and after the measurement. The differences between the initial and final masses, related to the volume of air in the device, illustrate the particulate concentrations expressed in micrograms per cubic metre (μg/m³). The gravimetric method shows great accuracy. The only disadvantage of this method is that it takes about weeks to obtain results. At present, in Poland, measurements are performed with this method on 70 PM2.5 and 180 PM10 particle matter monitoring stations.

The automatic meters indicate the dust concentration in real-time so that the measurement results are displayed at the websites of the Inspection of Environmental Protection (Chief Inspectorate of Environmental Protection (GIOŚ) and Voivodeship Inspectorate for Environmental Protection (WIOŚ)). The data is updated on an hourly basis and translated into 24-hour average values for comparison with the permissible level. Measurements using the automatic method are carried out in Poland on 45 PM2.5 and 135 PM10 particle matter monitoring stations.

Particulate matter concentration standards

The permissible level, or air quality standard [10], is the concentration of a substance that can be reached in a given period of time and should not be exceeded after that time.

The information level is the level of the substance in the air above which there is a risk to human health from brief exposure to pollutants of vulnerable population groups. The information level for PM2.5 is 150 μg/m³, the averaging period is 24 hours, the information level for PM10 is 100 μg/m³, the averaging period is 24 hours [11]. The alarm level is the concentration of a substance in the air which, if exceeded in the short term, could cause a hazard to human health [12].

Research section

Methodology and research procedures

The research aimed to determine the concentration of particulate matter in selected strategic points of the urban agglomeration and to indicate whether there are relationships between the season of the year and the concentration of PM2.5 and PM10 in the air. The research was carried out at five measurement points in the Cracow agglomeration:

- 29 Avenue Listopada (one of the most important communication routes in Kraków),
- AGH University of Science and Technology (proximity of the thoroughfare),
- Nowa Huta, T. Ptaszyckiego street (proximity of industrial plants),
- Skawina (a commune included in the agglomeration),
- Wieliczka (a commune included in the agglomeration).

Figure 1 shows the location of the test stations.

The research was carried out in one month of each season: September 2019, November 2019, February 2020 and April 2020. They were performed for 15 days each month, twice a day: in the morning and in the evening. To measure the level of PM2,5 and PM10 particulate matter, a dust measurement device WP 6130 was used, additionally equipped with air temperature and humidity detectors.

Test results and discussion

Table 2 shows the minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on 29 Avenue Listopada.

At the measurement point located on 29 Avenue Listopada (Table 2), the highest PM2.5 level, amounting to 113 μg/m³, occurred on 28 November at 8:40 pm. The lowest value of PM2.5, equal to 1 μg/m³, occurred on 10 September and 14 September in the morning. The highest level of PM10 was also recorded on this station on 28 November at 8:40 pm: it amounted to 120 μg/m³. The lowest level of PM10 of 2 μg/m³ occurred on 10 September and 14 September.

Tab. 2. The minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on 29 Avenue Listopada
Tab. 2. Minimalne i maksymalne zmierzone wartości stężeń PM2,5 i PM10 z punktu pomiarowego przy alei 29 Listopada

	maximum measured concentration values of PM2.5 [μg/m³]	**minimum measured concentration values of PM2.5 [μg/m³]**	**maximum measured concentration values of PM10 [μg/m³]**	**minimum measured concentration values of PM10 [μg/m³]**
29 Avenue Listopada	113 (28 XI 2019)	1 (10 IX i 14 IX 2019)	120 (28 XI 2019)	2 (10 IX i 14 IX 2019)

Tab. 3. The minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on AGH
Tab. 3. Minimalne i maksymalne zmierzone wartości stężeń PM2,5 i PM10 z punktu pomiarowego przy Akademii Górniczo-Hutniczej

	maximum measured concentration values of PM2.5 [μg/m³]	**minimum measured concentration values of PM2.5 [μg/m³]**	**maximum measured concentration values of PM10 [μg/m³]**	**minimum measured concentration values of PM10 [μg/m³]**
AGH University of Science and Technology	127 (28 XI 2019)	2 (14 IX 2019)	139 (28 XI 2019)	3 (14 IX 2019)

Tab. 4. The minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on Skawina
Tab. 4. Minimalne i maksymalne zmierzone wartości stężeń PM2,5 i PM10 z punktu pomiarowego Skawina

	maximum measured concentration values of PM2.5 [μg/m³]	**minimum measured concentration values of PM2.5 [μg/m³]**	**maximum measured concentration values of PM10 [μg/m³]**	**minimum measured concentration values of PM10 [μg/m³]**
Skawina	117 (15 II 2020)	6 (9 IX 2019)	120 (15 II 2020)	8 (9 IX 2019)

Tab. 5. The minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on Wieliczka
Tab. 5. Minimalne i maksymalne zmierzone wartości stężeń PM2,5 i PM10 z punktu pomiarowego Wieliczka

	maximum measured concentration values of PM2.5 [μg/m³]	**minimum measured concentration values of PM2.5 [μg/m³]**	**maximum measured concentration values of PM10 [μg/m³]**	**minimum measured concentration values of PM10 [μg/m³]**
Wieliczka	111 (15 II 2020)	2 (9 IX i 10 IX 2019)	127 (27 XI 2019)	3 (10 IX 2019)

Tab. 6. The minimum and maximum measured concentration values of PM2.5 and PM10 from the measurement point on Nowa Huta
Tab. 6. Minimalne i maksymalne zmierzone wartości stężeń PM2,5 i PM10 z punktu pomiarowego Nowa Huta

	maximum measured concentration values of PM2.5 [μg/m³]	**minimum measured concentration values of PM2.5 [μg/m³]**	**maximum measured concentration values of PM10 [μg/m³]**	**minimum measured concentration values of PM10 [μg/m³]**
Nowa Huta	128 (28 XI 2019)	3 (2 IX i 14 IX 2019)	142 (28 XI 2019)	5 (6 IX 2019)

At the measurement point located on AGH University of Science and Technology (Table 3), the highest PM2.5 level, amounting to 127 μg/m³, occurred on 28 November at 9:00 pm. The lowest value of PM2.5, equal to 2 μg/m³, occurred on 14 September at 11:16. The highest level of PM10 was also recorded on this station on 28 November at 9:00 pm: it amounted to 139 μg/m³. The lowest level of PM10 of 3 μg/m³ occurred on 14 September.

At the measurement point located on Skawina (Table 4), the highest PM2.5 level, amounting to 117 μg/m³, occurred on 15 February at 10.21 pm. The lowest value of PM2.5, equal to 6 μg/m³, occurred on 9 September at 6:10 pm. The highest level of PM10 was also recorded on this station on 15 February at 9:51 pm: it amounted to 120 μg/m³. The lowest level of PM10 of 8 μg/m³ occurred on 9 September at 6:10 pm.

At the measurement point located on Wieliczka (Table 5), the highest PM2.5 level, amounting to 111 μg/m³, occurred on 15 February at 11.27 pm. The lowest value of PM2.5, equal to 2 μg/m³, occurred on 9 September and on 10 September. The highest level of PM10 was also recorded on this station on 27 November at 7:04 pm: it amounted to 127 μg/m³. The lowest level of PM10 of 3 μg/m³ occurred on 10 September at 1:42 pm.

At the measurement point located on Nowa Huta (Table 6), the highest PM2.5 level, amounting to 128 μg/m³, occurred on 22 November at 10:40 pm. The lowest value of PM2.5, equal to 3 μg/m³, occurred on 2 September and on 14 September. The highest level of PM10 was also recorded on this station on 28 November at 10:40: it amounted to 42 μg/m³. The lowest level of PM10 of 5 μg/m3 occurred on 6 September at 10:28 am.

The analysis of the test results shows that the highest concentrations of PM2.5 and PM10 occurred in the autumn month at AGH and Nowa Huta and in the winter month in

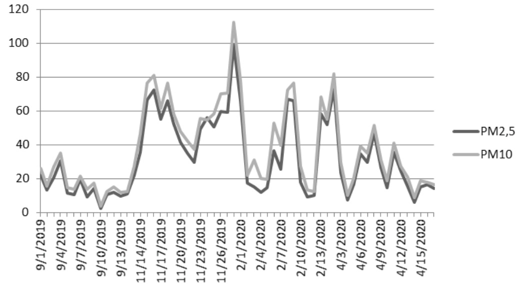

Fig. 2. The daily average concentration of particulate matter: PM2,5 and PM10. The measurement point on 29 Avenue Listopada (in μg/m³)
Rys. 2. Średnie dobowe stężenie pyłu zawieszonego: PM2,5 i PM10. Punkt pomiarowy: aleja 29 Listopada (w μg/m³)

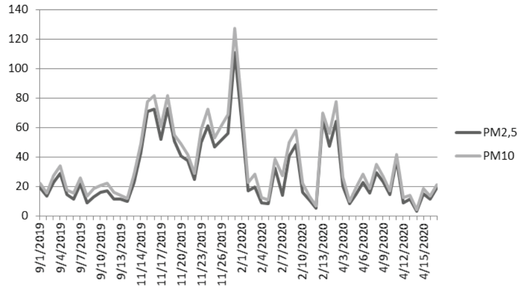

Fig. 3. The daily average concentration of particulate matter: PM2,5 and PM10. The measurement point on AGH (in μg/m³)
Rys. 3. Średnie dobowe stężenie pyłu zawieszonego: PM2,5 i PM10. Punkt pomiarowy: AGH (w μg/m³)

Skawina and Wieliczka. The heating season, which begins in the autumn, is a major contributor to dust emissions. The lowest dust concentrations occurred in the summer month when the air temperature does not require heating of buildings.

In order to determine the number of days on which the daily permissible, information and alarm level has been exceeded, the daily average concentration of particulate matter has been calculated (Figures 2-6).

The lowest concentrations of dust in the air occurred in September and April. The PM10 permissible level was exceeded 11 times in November, 7 times in February and one time in April. The information level was exceeded once in November. The alarm level has not been exceeded. The permissible level for PM2.5 was exceeded 34 times. The information level was not exceeded.

The PM10 permissible level was exceeded 11 times in November and 5 times in February. The information level was exceeded once in November. The alarm level has not been exceeded. The permissible level for PM2.5 was exceeded 30 times. The information level was not exceeded.

The PM10 permissible level was exceeded 5 times in November and 3 times in February. The information level was exceeded once in November. The alarm level has not been exceeded. The permissible level for PM2.5 was exceeded 38 times. The information level was not exceeded.

The PM10 permissible level was exceeded 9 times in November, 3 times in February and one time in April. The information level was exceeded once in November. The alarm level has not been exceeded. The permissible level for PM2.5 was exceeded 39 times. The information level was not exceeded.

The PM10 permissible level was exceeded 10 times in November, 2 times in February and one time in April. The information level was exceeded once in November. The alarm level has not been exceeded. The permissible level for PM2.5 was exceeded 34 times. The information level was not exceeded.

The statistical analysis

For the statistical analysis of the PM2.5 and PM10 measurements, a non-parametric chi-square test was used to investigate the relationship between the variables [14]. The χ2 test consists of comparing the observed values with the theoretical values. The major differences between them means that there is a correlation between the parameters tested. The correlation between the level of particulate matter concentration in the air and the time of year at each test station was studied. The dust level was classified as low for the particulates <30 μg/m3, as average for the values in the range 30–60 μg/m³ and as high for the values above 60 μg/m³.

According to the measurement data from 29 Avenue Listopada station, the test results are as follows: $\chi^2_{PM2,5} = 80,6$, $\chi^2_{PM10} = 59,1$. For the six degrees of freedom, the critical value for the significance level α = 0.05 shall be: $\chi^2_{teor.} = 12,6$ (Figure 7).

A comparison of the calculated value for PM2.5 and PM10: 80.6>12.6; 9.1>12,6, allowed for the rejection of the hypothesis that there is no correlation between the season and the level of dust: $\chi^2_{PM2,5} > \chi^2_{teor.}$ $\chi^2_{PM10} > \chi^2_{teor.}$. The probability of making the type I error is p = 0.000 (p < α). The hypothesis that there is no difference between the variables must be rejected. At a significance level of α= 0.05 it is assumed that there is a statistical relationship between the season and the dust concentration in the air. It was found that the concentrations of particulate matter in autumn and winter are statistically significantly higher than those in the summer. The calculated test value for each measurement point (AGH University of Science and Technology, Skawina, Wieliczka, Nowa Huta) is greater than the critical value, there-

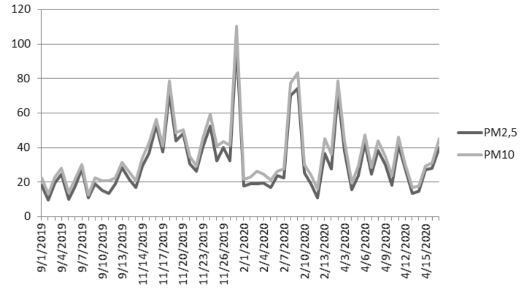

Fig. 4. The daily average concentration of particulate matter: PM2,5 and PM10. The measurement point on Skawina (in μg/m³)
Rys. 4. Średnie dobowe stężenie pyłu zawieszonego: PM2,5 i PM10. Punkt pomiarowy: Skawina (w μg/m³)

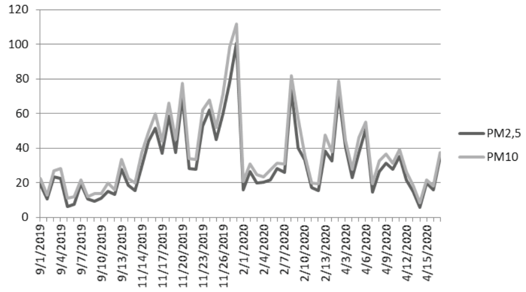

Fig. 5. The daily average concentration of particulate matter: PM2,5 and PM10. The measurement point on Wieliczka (in μg/m³)
Rys. 5. Średnie dobowe stężenie pyłu zawieszonego: PM2,5 i PM10. Punkt pomiarowy: Wieliczka (w μg/m³)

fore the hypothesis of no correlation between variables was rejected.

The analysis of the test results shows that the highest concentrations of particulate matter occurred in the autumn and winter months at each measuring point and the lowest in summer. The highest particulate concentration was recorded on 28 November 2019 in Nowa Huta in ulica Tadeusz Ptaszycki. The concentration of PM2.5 was 128 μg/m³ and PM10 amounted to 142 μg/m³. The lowest value of particulate matter was recorded on 10 September 2019 and 14 September 2019 on 29 Avenue Listopada. The concentration of PM2.5 was 1 μg/m³ and PM10 amounted to 3 μg/m³. After conducting a statistical test and comparing the observed values with the theoretical values, it was found that there are close correlations between the dust concentration in the air and the season of the year.

The research part also includes calculation of the daily average concentration of particulate matter by means of an arithmetic mean of the two measurements per day in order to determine the number of days when the 24-hour average permissible, information and alert levels were exceeded. At each of the stations, the permissible level for PM10 and PM2.5 has been exceeded several times, and the alarm level for PM10 has not been exceeded at any of them.

Discussion and summary

The heating season responsible for dust emissions begins in autumn and winter due to low air temperatures. Single-family and multi-apartment residential buildings lack high chimneys, which results in the emission of pollutants at low heights. As a result, instead of diluting in the atmosphere, local concentrations of pollution in the air increase. One of the main sources of air pollution are individual households and local boiler houses. Coal fired furnaces are characterized by low efficiency and significant dust emissions. In order to reduce the emission of harmful pollution into the atmosphere, it is necessary to modernize the heating system. Attention should be paid to the type and quality of fuel: coal-fired boilers should be replaced by gas, oil or electric ones. Pellet-fired boilers also provide a good solution [15]. However, the aforementioned measures are very expensive, and numerous people cannot afford them. Increasing public awareness and influencing the change of habits regarding the use of fuels in furnaces is extremely important. Financial support is needed for the municipal and household sector (e.g. subsidies for the replacement of furnaces), as well as the imposition of severe penalties for household waste incineration (plastic bottles, tyres, old furniture).

Motor vehicles are to a great extent responsible for particulate emissions [16, 17]. They emit exhaust fumes and wear road surfaces, tyres and brake pads. To reduce traffic, it is worth encouraging city residents to use public transport by introducing cheaper tickets or free journeys. Separate lanes for public transport constitute a useful solution. Another possibility is the development of the cycling infrastructure and investment in bike rentals.

In the industrial sector, the best available technologies should be identified in order to reduce dust emissions [18, 19]. Air protection should be implemented by taking measures to reduce dust emissions at source or by capturing them. One of the solutions allowing for the minimisation of particulate emissions is the air-tightening of processes consisting in the use of covers and seals on technological equipment. In order to reduce emissions, industrial plants should also deploy efficient electrostatic precipitators and chimney filters. The construction of insulating green belts around industrial plants will allow for a partial reduction in the dust dispersion [20].

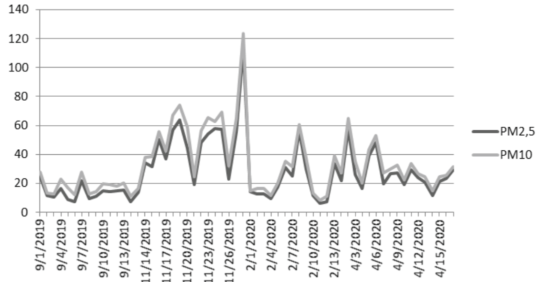

Fig. 6. The daily average concentration of particulate matter: PM2,5 and PM10. The measurement point on Nowa Huta (in μg/m³)
Rys. 6. Średnie dobowe stężenie pyłu zawieszonego: PM2,5 i PM10. Punkt pomiarowy: Nowa Huta (w μg/m³)

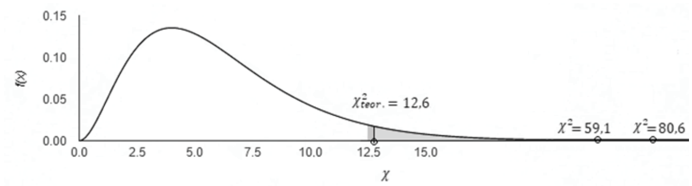

Fig. 7. Chi-square test for PM2,5 i PM10. The measurement point on 29 Avenue Listopada
Rys. 7. Test Chi-kwadrat dla PM2,5 i PM10. Punkt pomiarowy: aleja 29 Listopada

Poland has the highest level of dust in the atmosphere among European countries. Both ordinary citizens and public officials should be aware of the scale of the problem. The impact of polluted air affects all of us, so minimising emissions should become our joint responsibility.

Author Contributions

Karolina Skotnicka (K.S.) did the data collection and result analysis. Wiktoria Sobczyk (W.S.) conceived, designed the search, wrote the paper and result analysis. Both authors have read and approved the final manuscript.

Conflict of interest statement

The authors declare no conflict of interest.

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Literatura – References

1. Janka, R. (2013). Zanieczyszczenia pyłowe i gazowe, Wyd. Naukowe PWN. Warszawa.
2. Juda-Rezler, K. and Toczko, B. (eds.) (2016). Pyły drobne w atmosferze. Biblioteka Monitoringu Środowiska, Warszawa.
3. Kleczkowska, B. and Kleczkowski, P. (2013). Ochrona środowiska z analizą jakości powietrza w Krakowie. Wyd. AGH, Kraków.
4. System prognozowania rozprzestrzeniania zanieczyszczeń powietrza. Forecasting of air pollution propagation system. Available online: http://smog.imgw.pl/content/weather, (accessed on 2 October 2020) (in Polish).
5. Adamiec, E., Dajda, J., Gruszecka-Kosowska A., Helios-Rrybicka, E. Kisiel-Dorohinicki, M., Klimek, R., Pałka, D. and Wąs, J. (2019). Using medium-cost sensors to estimate air quality in remote locations. Case study of Niedzica, southern Poland. Atmosphere, vol. 10, iss. 7, 393, 1-13.
6. Oleniacz, R., Bogacki, M., Szulecka, A. and Rzeszutek, M. (2016). Wpływ prędkości i kierunku wiatru na jakość powietrza w Krakowie" Rzeszów-KrakówV Międzynarodowa Konferencja Naukowo-Techniczna INFRAEKO „Nowoczesne miasta. Infrastruktura i środowisko". 263-276. Available online: http://works.bepress.com/robert_oleniacz/139/ (accessed on 3 October 2020) (in Polish).
7. Sobczyk, W. (edit.) (2014). Wybrane zagadnienia ochrony i inżynierii środowiska. Wydawnictwo AGH, Kraków.
8. Adamiec, E. and Jarosz-Krzemińska, E. (2019). Human health risk assessment associated with contaminants in the finest fraction of sidewalk dust collected in proximity to trafficked roads. Scientific Reports, vol. 9, 16364, 1-11.
9. The influence of the circulation of the atmosphere on meteorological and atmospheric phenomena. Available online: https://us.edu.pl/wplyw-cyrkulacji-atmosfery-na-zjawiska-meteorologiczne-i-atmosferyczne (12 I 2020) (accessed on 20 September) (in Polish).
10. Normy jakości powietrza określone pod kątem rocznej oceny jakości powietrza. Available online: https://powietrze.gios.gov.pl/pjp/content/annual_assessment_air_quality_info, (accessed on 1 October 2020) (in Polish).
11. Regulation of the Minister of the Environment Concerning the Levels of Certain Substances in the Air of 8 October 2019. Item 1931. Dziennik Ustaw 2019. Warszawa, Poland.
12. Informacje o normach jakości powietrza pod kątem poziomów alertowych. Available online: http://powietrze.gios.gov.pl/pjp/content/annual_assessment_air_exposure_alarms_level_info, (accessed on 15 September 2020) (in Polish).
13. www.mapy.geoportal.gov.pl (accessed on 2 October 2020) (in Polish).
14. Sobczyk, W. (2002). Metody statystyczne w badaniach świadomości ekologicznej młodzieży. Skrypt uczelniany do zajęć z przedmiotu: matematyczne opracowanie wyników badań. Agencja Wydawniczo- Konsultingowa Geo, Kraków.
15. Sadlok R. (red.) (2014). Przeciwdziałanie niskiej emisji na terenach zwartej zabudowy mieszkalnej:, Stowarzyszenie na rzecz efektywności energetycznej i rozwoju odnawialnych źródeł energii „Helios", Bochnia.
16. Bogacki, M., Oleniacz, R., Rzeszutek, M., Bździuch, P., Szulecka, A. and Gorzelnik, T. (2020). Assessing the impact of road traffic reorganization on air quality: a street canyon case study. Atmosphere, vol. 11, 7, 695, 1–23.
17. Borowski, G. and Malec, A. (2016). Zagrożenia pyłowe oraz monitoring powietrza atmosferycznego. Ecological Engineering, vol. 50, 161-170.
18. Szulecka, A., Oleniacz, R. and Rzeszutek, M. (2017). Functionality of openair package in air pollution assessment and modeling - a case study of Krakow. Environmental Protection and Natural Resources, vol. 28, 2, 22–27.
19. Generowicz, A. and Korzeniowska-Rejmer, E. (2012). Wpływ warunków meteorologicznych i terenowych na rozprzestrzenianie zanieczyszczeń ze składowisk komunalnych w powietrzu atmosferycznym. Środowisko, vol. 109, 1-Ś, 113-127.
20. Stefanicka, M. (2013). Techniczne metody ograniczania zapylenia w zakładach kruszyw i ocena ich skuteczności. Mining Science, vol. 20, 71-85.

Zanieczyszczenia pyłowe atmosfery aglomeracji krakowskiej w świetle badań empirycznych
Artykuł prezentuje problem zanieczyszczenia pyłowego atmosfery typowej aglomeracji miejskiej. Opisano wpływ czynników naturalnych i antropogenicznych na stężenie pyłów w powietrzu. Przedstawiono wyniki badań zapylenia powietrza cząstkami PM2,5 i PM10 w pięciu punktach pomiarowych aglomeracji krakowskiej. Przy zastosowaniu metod statystycznych wykazano zależność między stężeniem pyłu w powietrzu a porą roku. Największe stężenia pyłów PM2,5 i PM10 obserwuje się w miesiącach jesiennych i zimowych. W sezonie grzewczym za emisję pyłów odpowiedzialny jest głównie sektor komunalno-bytowy. Zaproponowano sposoby ograniczenia emisji zanieczyszczeń atmosfery ze źródeł przemysłowych i transportu.

Słowa kluczowe: *pyły, zanieczyszczenie powietrza, monitoring*