http://dx.doi.org/10.7494/geom.2019.13.2.31

Tomasz Gorzelnik[1], Robert Oleniacz[2]

Suitability Analysis of New Air Quality Monitoring Stations in Krakow as Related to Assessment of Spatial and Temporal Variability of PM10 Concentrations[3]

Abstract: The exceedance of air quality standards in urban agglomerations leads local communities to take actions that aim to improve aerosanitary conditions. For these actions to be efficient, it is essential to regularly collect accurate quantitative data that is able to characterize the degree of ambient air pollution. In order to achieve this objective, air quality monitoring systems are constantly being extended.

In this paper, the usefulness of newly established air quality measuring stations in Krakow was examined. The assessment was carried out using statistical methods on the basis of the spatial and temporal variability of particulate matter (PM_{10}) air concentrations over the period of 2016–2017. In the analysis, meteorological data (wind directions) were applied. The main part of this assessment was a pairwise comparison of the PM_{10} concentrations measured at particular stations. The differences between the average values and the Pearson correlation coefficient were considered. In order to verify the statistical significance of the obtained results, the *t*-Student test was conducted. The greatest absolute differences between the measured values occurred during the autumn-winter period (heating season). Notwithstanding the foregoing, a high variability was also observed among the traffic stations.

Keywords: air pollution, suspended particulate matter, monitoring network optimization, statistical analyses

Received: 19 April 2018; accepted: 15 November 2018

[1] AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Environmental Management and Protection, Krakow, Poland, email: tomaszgo@agh.edu.pl
ORCID ID: https://orcid.org/0000-0002-8695-9639

[2] AGH University of Science and Technology, Faculty of Mining Surveying and Environmental Engineering, Department of Environmental Management and Protection, Krakow, Poland, email: oleniacz@agh.edu.pl
ORCID ID: https://orcid.org/0000-0001-9307-6204

[3] The paper was prepared within the scope of AGH UST statutory research No. 11.11.150.008

1. Introduction

Increased air concentrations of particulate matter have been a serious problem in many Polish cities for many years [1–5]. The particles suspended in ambient air (especially their fine fraction) along with the substances bound to them (e.g., PAHs, PCDDs/PCDFs, and heavy metals) can be harmful to human health [6–12]. Poor air quality is closely related to emissions from many sources (e.g., the household and municipal sector, traffic, and industry). However, the negative impact of these emissions can be intensified by specific topography and meteorological factors [13, 14]. Many studies suggest that particulate matter concentrations and atmospheric conditions are correlated [1, 15, 16]. Wind speed and direction as well as mixing-layer height (thermal inversion) are very important factors that affect air pollutant concentrations [17, 18]. Dense urban housing makes ventilation conditions worse and aggravates pollution in big cities, including Krakow [19, 20]. Differentiations in the shape and use of terrain as well as the location of air emission sources also cause spatial variability in the air pollution status.

Krakow is one of those cities where air quality standards are regularly exceeded [21]. In recent years, there have been single episodes of particularly high PM_{10} air concentrations (values over the alarm rate of 300 $\mu g \cdot m^{-3}$) [22]. These situations take place especially in autumn and winter during the heating season [13, 14, 23]. The poor quality of ambient air carries various activities that are oriented towards the minimization of air pollution. One of these actions was the adoption of a resolution related to limitations of solid fuel usage in Lesser Poland Voivodeship – the so-called anti-smog resolution [24]. The well-functioning monitoring system plays a key role in supporting such actions; it also allows for the verification of the modeled and forecasted results in air quality research [25–27].

The network of automatic air quality monitoring stations in Krakow was created in 1991. The number and locations of the measuring points have changed in previous years. Currently, the number of working automatic monitoring stations measuring PM_{10} concentrations in Krakow is the highest in history (Fig. 1).

In 2016, the air quality monitoring network in Krakow was expanded by creating a second traffic station and two additional urban background stations. One year later, a new industrial station and another urban background station were put to work. Such a rapid development of the air quality monitoring system in Krakow raises the question about the usefulness of the new measuring stations. All of the eight working stations currently in Krakow measure the concentration of PM_{10}. An unconventionally large number of measuring points in the area of one conurbation with a population not exceeding one million inhabitants [28] can provide accurate information about the spatial diversification of PM_{10} air concentrations in the city.

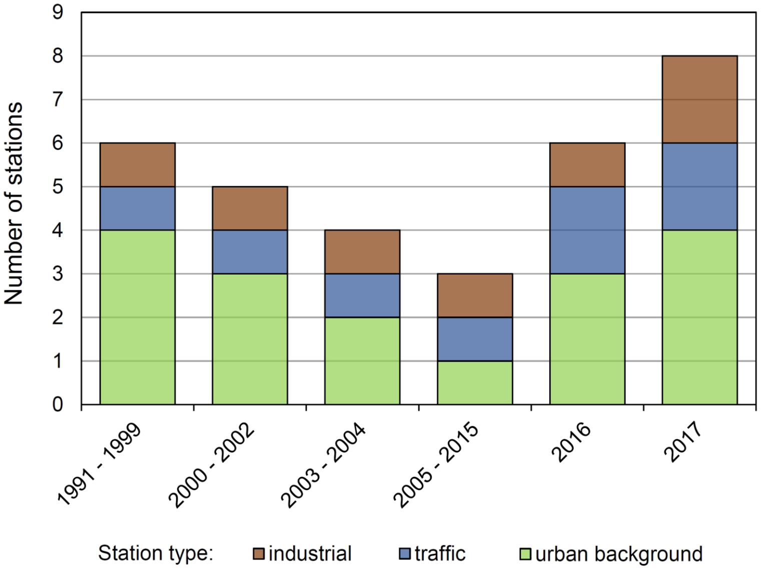

Fig. 1. Number of automatic air quality monitoring stations measuring PM10 concentrations in Krakow (1991–2017)

Source: own work based on information obtained from Voivodeship Inspectorate of Environmental Protection in Krakow

The usefulness of different stations can be characterized by numerical indicators, including the spread of average monthly or the daily PM_{10} concentrations calculated for a chosen pair of stations. Statistical tools (e.g., the correlation coefficient and multiple regression) have been previously used in air quality research [14, 15, 22, 29, 30]. Statistical analyses of PM_{10} concentrations can help prove the usefulness of the new measuring stations by discovering a significant diversity in the collected data.

2. Materials and Methods

The materials include air pollution data originating from PM_{10} concentration measurements conducted at eight automatic air quality monitoring stations in the Krakow agglomeration (Fig. 2). This data is available through the air quality webpage of the Voivodeship Inspectorate of Environmental Protection in Krakow [21]. The measuring methods and equipment applied at different stations are listed in Table 1. In this paper, wind direction data is also considered; this was obtained from a meteorological station located near the center of the city of Krakow in the area of AGH University of Science and Technology (AGH UST) [31].

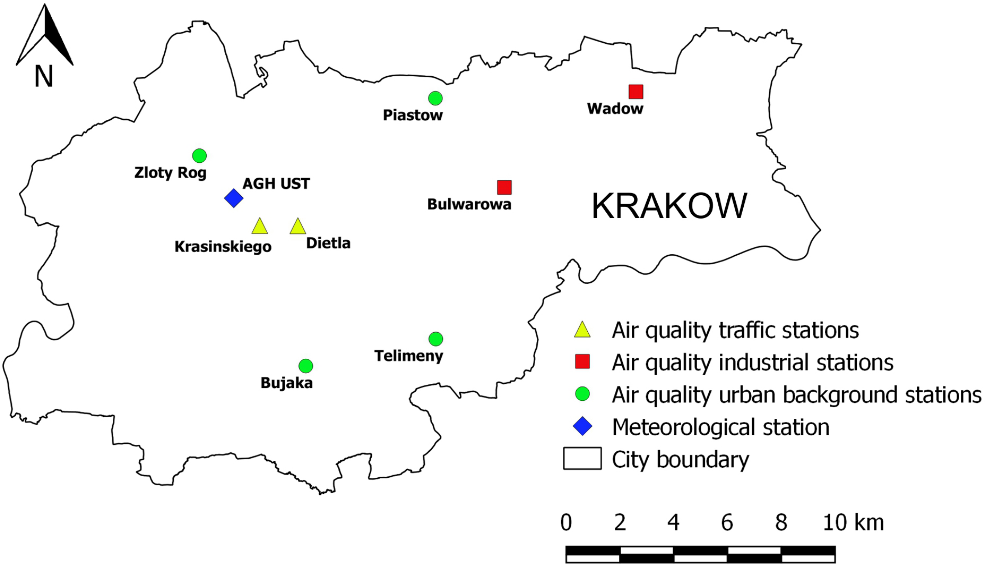

Fig. 2. Location of analyzed air quality monitoring and meteorological stations in Krakow

Source: own work based on [31, 32]

In the analyses, hourly and daily measurement results were considered from the period of January 1, 2016, through December 31, 2017, with reference to the real working time of each station during the analyzed period. In some cases, these values were averaged over month-, half year-, and year-long periods. The summer half year is understood as the period between May and October, and the remaining part of the year (November–April) is treated as the winter half year. The weather parameters cover the same period as the air pollution dataset. In some graphs and tables, abbreviations for the monitoring stations' names were applied (as listed in Table 1).

In order to measure the suitability of the new monitoring stations, the following methods were applied. The measurement results from particular stations were pairwise compared, and the differences between the hourly, daily, monthly, half-yearly, and annually averaged PM_{10} air concentrations from the analyzed stations were calculated. The air quality monitoring stations with the greatest variability of measured values relative to the other stations were recognized as the most useful. In these comparisons, pairs of stations representing the same types (urban background, traffic, or industrial) were considered. The Pearson correlation coefficient was calculated for different pairs of stations. The relationship between the analyzed pairs of daily concentrations was additionally presented on scatter plots. The statistical significance of the calculation results was examined in the *t*-Student test.

Table 1. Characteristics of air quality monitoring system in Krakow and currently used PM10 dust monitors and measuring methods

Monitoring station name (abbreviation)	Station type	Start year	Currently used PM_{10} measuring equipment / method
Krasińskiego (Kras)	traffic	1991	Grimm M 180 dust monitor / light scattering
Bulwarowa (Bulw)	industrial	1997	Bam 1020 dust monitor (Met One Instruments, Inc.) / β-ray attenuation
Bujaka (Buja)	urban background	2010	
Dietla (Diet)	traffic	2016	
Piastów (Pias)	urban background	2016	
Złoty Róg (Zlot)	urban background	2016	
Wadów (Wado)	industrial	2017	
Telimeny (Teli)	urban background	2017	

Source: own work based on information obtained from Voivodeship Inspectorate of Environmental Protection in Krakow

The impact of wind direction on the PM_{10} concentrations was shown on graphs generated in RStudio via the function called "pollutionRose" (openair package [27, 33]).

3. Results

The variability of the PM_{10} air concentrations depends on the types of compared measuring stations and on the season. High variations of concentrations are more common at traffic and industrial stations, but the peak values occurring between November and March were present in the urban background pairs of stations (Figs. 3, 4). The absolute differences between PM_{10} concentrations at each station are higher in autumn and winter, and they decrease in spring and summer. In winter, differences that were even greater than twice as high as in the summer were recorded. For example, the average difference between the Bujaka and Złoty Róg stations was 6 $\mu g \cdot m^{-3}$ for the summer period and 17 $\mu g \cdot m^{-3}$ for winter (Fig. 3). What is more, differences exceeding 20 $\mu g \cdot m^{-3}$ only occurred in January (Figs. 3, 4).

Figures 5 and 6 show the scatter plots obtained for PM_{10} concentrations in selected pairs of the same types of air quality monitoring stations in Krakow, including the new stations created during the period of 2016–2017. The continuous line on Figures 5 and 6 represents data fitting, and the dashed lines represent the double underestimation and overestimation (FAC2). The concentrations measured at urban background stations are typically similar to each other (Fig. 5). The values recorded at the Krasińskiego station are commonly greater than at the second traffic station (Dietla). The Piastów station is usually exposed to the lowest PM_{10} concentrations (Figs. 5, 6).

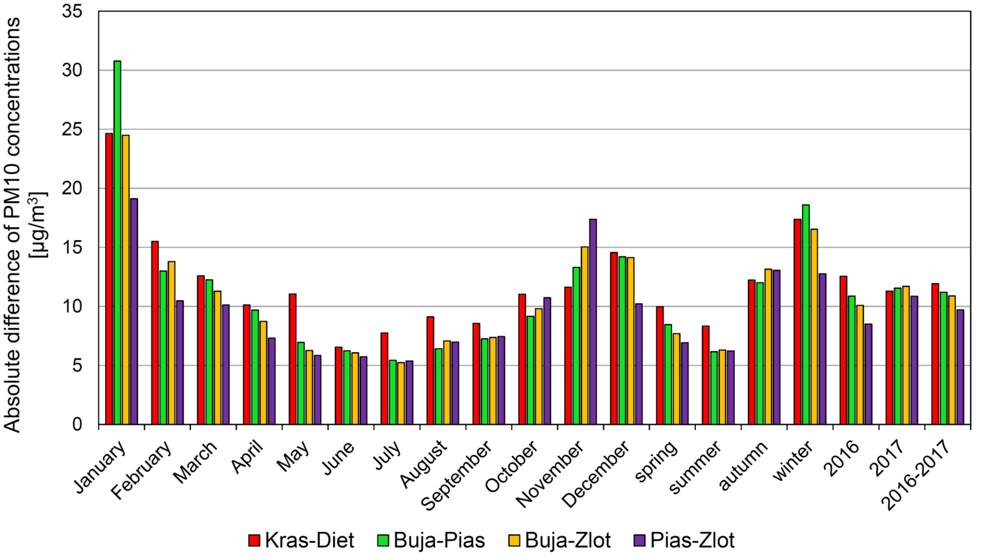

Fig. 3. Absolute differences of PM10 concentrations for each pair of stations measured with one-hour resolution at air quality monitoring stations in Krakow averaged for months, seasons, and years (2016–2017)

Source: own work based on [21]

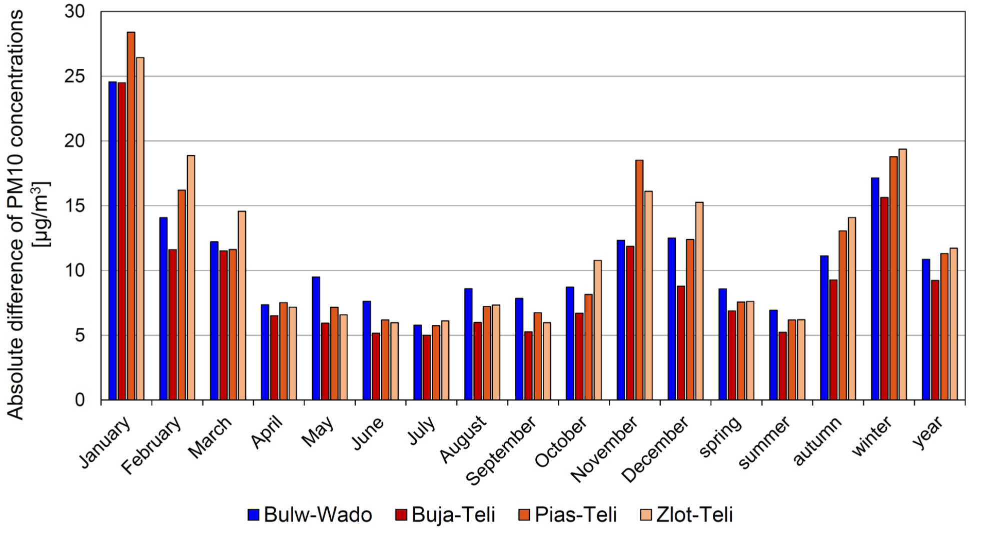

Fig. 4. Absolute differences of PM10 concentrations for each pair of stations measured with one-hour resolution at air quality monitoring stations in Krakow averaged for months, seasons, and years (2017)

Source: own work based on [21]

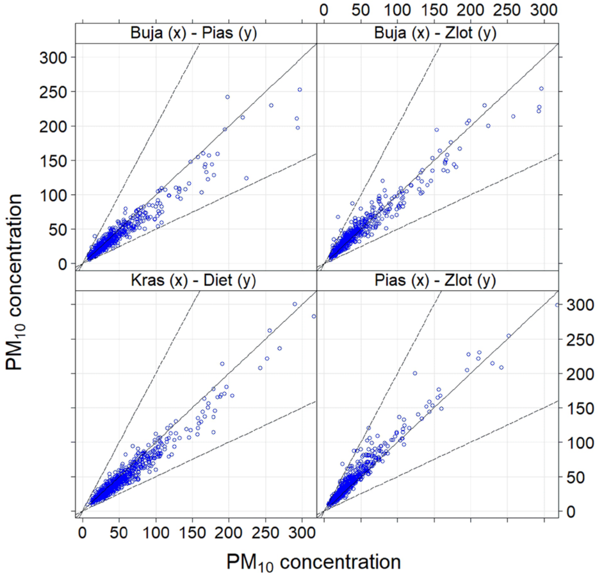

Fig. 5. Scatter plots for PM10 concentrations in selected pairs of air quality monitoring stations in Krakow (24-hour data from 2016–2017) [μg/m^3]

Source: own work based on [21]

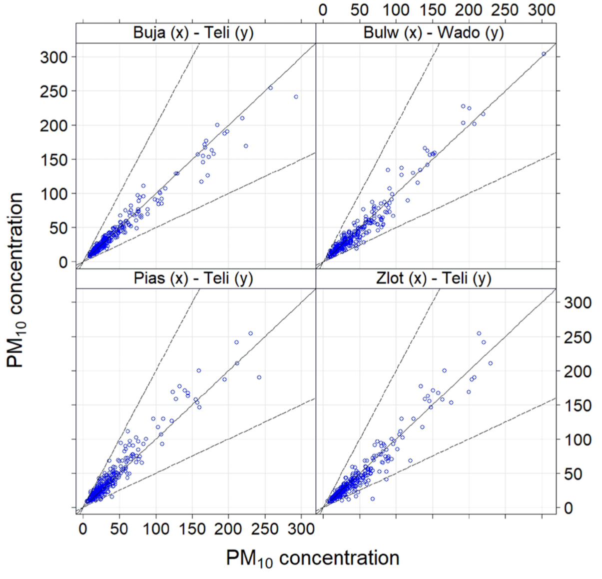

Fig. 6. Scatter plots for PM10 concentrations in selected pairs of air quality monitoring stations in Krakow (24-hour data from 2017) [μg/m^3]

Source: own work based on [21]

An analysis of the Pearson correlation coefficients indicates that the measured PM_{10} concentrations are strongly positively correlated in spite of the considerable absolute differences (Tabs. 2, 3). The linear relationship between PM_{10} concentrations is stronger in the winter half year than in the summer half year. For example, the correlation coefficient calculated for the daily averaged values from the period of 2016–2017 may have varied from 0.965 to 0.977 in the winter period and from 0.896 to 0.927 in summer. The coefficient calculated for 2017 was higher than in 2016 in all pairs except Piastów/Złoty Róg (Tab. 2). The linear correlation between the industrial stations is very similar to the relationship between the urban background stations (Tab. 3).

Table 2. Linear Pearson correlation coefficient calculated for 24-hour dataset from selected pairs of measuring stations (2016–2017)

Period	Kras-Diet	Buja-Pias	Buja-Zlot	Pias-Zlot
January	0.982	0.951	0.975	0.974
February	0.979	0.988	0.983	0.993
March	0.937	0.950	0.912	0.967
April	0.927	0.911	0.937	0.962
May	0.843	0.800	0.839	0.850
June	0.818	0.752	0.782	0.851
July	0.731	0.829	0.867	0.814
August	0.791	0.859	0.874	0.884
September	0.948	0.917	0.944	0.934
October	0.912	0.931	0.943	0.915
November	0.982	0.950	0.918	0.917
December	0.985	0.964	0.938	0.967
Summer half-year	0.896	0.903	0.927	0.908
Winter half-year	0.977	0.965	0.967	0.971
2016	0.960	0.958	0.960	0.980
2017	0.985	0.973	0.975	0.969
2016–2017	0.976	0.968	0.970	0.971

Table 3. Linear Pearson correlation coefficient calculated for 24-hour dataset from selected pairs of measuring stations (2017)

Period	Bulw-Wado	Buja-Teli	Pias-Teli	Zlot-Teli
January	0.986	0.977	0.967	0.972
February	0.989	0.993	0.985	0.973
March	0.959	0.962	0.916	0.893
April	0.912	0.962	0.869	0.895
May	0.517	0.892	0.811	0.830

Table 2. cont.

June	0.745	0.798	0.718	0.846
July	0.857	0.919	0.867	0.739
August	0.789	0.963	0.900	0.939
September	0.943	0.967	0.972	0.972
October	0.960	0.975	0.953	0.961
November	0.956	0.960	0.940	0.877
December	0.924	0.981	0.916	0.851
Summer half-year	0.902	0.945	0.919	0.948
Winter half-year	0.975	0.983	0.969	0.967
Year	0.972	0.985	0.972	0.969

Westerly and southwesterly wind directions were dominant during the analyzed period and were present in the aggregate for more than 50% of the year (Fig. 7). In turn, there were virtually no northerly winds at all. The concentration distribution for different wind directions is similar at each urban background station. High particulate matter concentrations (above 80 μg·m^{-3}) were not observed when easterly and northeasterly winds prevailed.

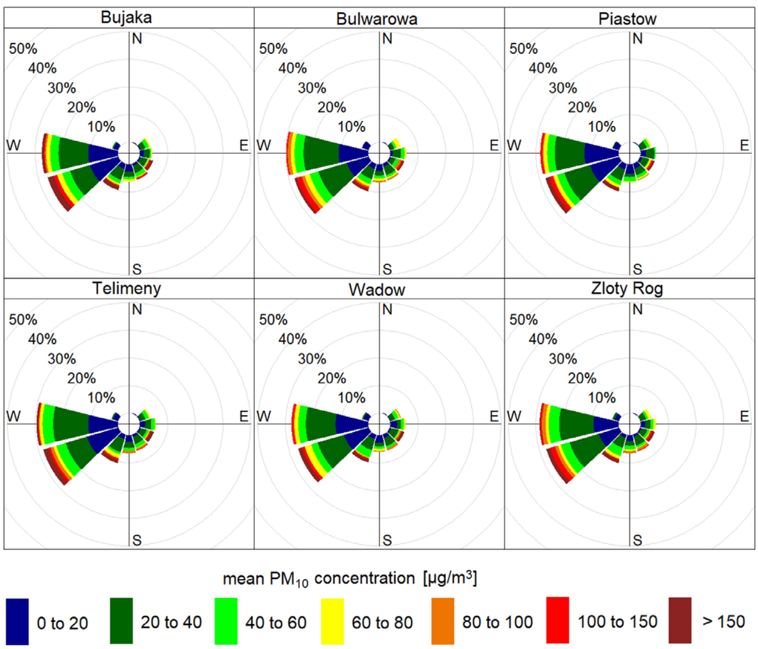

Fig. 7. Pollution rose graphs for urban background and industrial stations in Krakow (2017)

Source: own work based on [21, 31]

The statistical significance analysis revealed that the differences between the mean PM_{10} concentrations from each pair of stations in 2017 were significant at a significance level of $\alpha = 0.05$ (Tab. 4).

Table 4. *t*-Student significance test for dependent samples results performed for one-hour dataset (2017)

Compared stations	Valid data records	*t* statistic	Materiality level (*p*-value)	Statistical significance
Kras–Diet	8661	34.18	0.000	significant
Buja–Pias	8169	21.90	0.000	significant
Buja–Zlot	8083	−7.83	0.000	significant
Buja–Teli	8198	7.08	0.000	significant
Pias–Zlot	8452	−36.18	0.000	significant
Pias–Teli	8564	−18.25	0.000	significant
Zlot–Teli	8519	13.46	0.000	significant
Bulw–Wado	8325	10.78	0.000	significant

4. Discussion

The performed analyses enabled us to assess the suitability of the newly established air quality monitoring stations in Krakow. The main measure of the suitability was the spatial diversity of PM_{10} air concentrations as a parameter recorded by all of the stations in the research area. The inclusion of wind field analyses and their integration with the monitoring data allowed us to take a broader approach to the problem of measuring the stations' usefulness.

In general, it can be noticed that the new stations are particularly useful during the heating season when the variability of PM_{10} concentrations is at its highest (Figs. 3, 4). This refers to all types of stations. The differences between the one-hour PM_{10} concentrations recorded for several pairs of stations are higher in the cold half year than the annual average of these differences. The maximal value of 31 $\mu g \cdot m^{-3}$ (Fig. 3) also appeared in winter.

The major differences between the traffic stations infer the usefulness of the Dietla station. This station recorded distinctly lower values than the Krasińskiego station (Fig. 5). This may be largely determined by the intensity of the nearby road traffic. Due to its location, however, the measuring point at Dietla Street is likely more exposed to the urban background as related to the Krasińskiego station. The diversity of PM_{10} concentrations is similar for both the industrial and traffic station pairs (Figs. 3, 4). What is more, the variability of particulate matter concentrations in the wind direction sectors is comparable for the industrial and urban background stations (Fig. 7).

An analysis of the scatter plots allowed us to notice that most of the points are concentrated close to the solid lines, which indicates a strong correlation between the data (Figs. 5, 6). This relationship was verified through the calculation of the Pearson correlation coefficient (Tabs. 2, 3). In all cases, an increase of particulate matter concentration at one station implies the growth of this value at the second one from a particular pair. During the spring and summer months, there was a weaker correlation than during the remainder of the year. This indicates that some linearity interferences can exist during the summer half year.

The pollution-rise analyses revealed that PM_{10} concentrations can be related to specific meteorological factors (such as wind direction). The occurrence of high concentrations in certain wind sectors may be connected with the pollution inflow from outside the research area (Fig. 7). Considering the above, it is reasonable to maintain the stations in the new locations due to their ability to detect the influence of the above-mentioned inflows.

The t-Student test confirmed the statistical significance of the discovered differences between the average values calculated for particular data series (Tab. 4). This means that the variability of PM_{10} concentrations for selected pairs of all types of stations is not coincidental.

5. Conclusions

The main aims of this paper were to prove the usefulness of the new air quality monitoring stations in Krakow and also demonstrate the scope of this usefulness. The bases of the performed research were statistical analyses involving PM_{10} air concentration data and meteorological parameters.

The results showed that the greatest variability of PM_{10} levels occur during the heating season and in other situations when the absolute values of PM_{10} concentrations are relatively high. What is more, it can be noted that high concentrations are more common under specific weather conditions. This implies that meteorological factors such as wind direction influence the PM_{10} concentrations. Consequently, in strongly urbanized area with dense housing where wind fields and, thus, PM_{10} air concentrations are diversified, broadened the monitoring system seems to be especially useful.

The existence of new air quality monitoring stations can be crucial for a more accurate examination of PM_{10} levels in locations where the fine particles are transported by wind. One of the weaknesses of these analyses is a scarce dataset, which is related to the relatively brief functioning of the measuring points. For a better quality of the statistical assessment of new monitoring station suitability, it is recommended to continue the research over the next few years when the dataset is more abundant than currently.

References

[1] Czernecki B., Półrolniczak M., Kolendowicz L., Marosz M., Kendzierski S., Pilguj N.: *Influence of the atmospheric conditions on PM10 concentrations in Poznań, Poland.* Journal of Atmospheric Chemistry, vol. 74, no. 1, 2017, pp. 115–139.

[2] Juda-Rezler K., Toczko B. (red.): *Pyły drobne w atmosferze: kompendium wiedzy o zanieczyszczeniu powietrza pyłem zawieszonym w Polsce*. Biblioteka Monitoringu Środowiska, Główny Inspektorat Ochrony Środowiska, Warszawa 2016.

[3] Lewandowska A.U., Falkowska L.M.: *High concentration episodes of PM10 in the air over the urbanized coastal zone of the Baltic Sea (Gdynia – Poland).* Atmospheric Research, vol. 120–121, 2013, pp. 55–67.

[4] Ośródka L., Krajny E., Klejnowski K., Rogula-Kozłowska W., Błaszczyk J., Kobus D., Wypych A.: *Indeks jakości powietrza jako miara zanieczyszczenia powietrza w Polsce.* Nauka Przyroda Technologie, t. 5, nr 4, 2011, pp. 1–11.

[5] Sówka I., Fortuna M., Zwoździak A., Rybak J., Skrętowicz M., Kwiecińska K.: *Analiza stężeń pyłów drobnych w wybranych punktach Wrocławia.* [in:] Traczewska T.M. (red.), *Interdyscyplinarne zagadnienia w inżynierii i ochronie środowiska: praca zbiorowa. 2*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2012, pp. 451–457.

[6] Badyda A., Gayer A., Czechowski P.O., Majewski G., Dąbrowiecki P.: *Pulmonary Function and Incidence of Selected Respiratory Diseases Depending on the Exposure to Ambient PM10.* International Journal of Molecular Sciences, vol. 17, no. 11, 2016, pp. 1954–1965.

[7] Cembrzyńska J., Krakowiak E., Brewczyński P.Z.: *Zanieczyszczenie powietrza pyłem zawieszonym PM10 oraz PM2,5 w warunkach silnej antropopresji na przykładzie miasta Sosnowiec.* Medycyna Środowiskowa, t. 15, nr 4, 2012, pp. 31–38.

[8] Gruszecka-Kosowska A.: *Assessment of the Kraków inhabitants' health risk caused by the exposure to inhalation of outdoor air contaminants.* Stochastic Environmental Research and Risk Assessment, vol. 32, issue 2, 2016, pp. 485–499.

[9] Holnicki P., Tainio M., Kałuszko A., Nahorski Z.: *Burden of Mortality and Disease Attributable to Multiple Air Pollutants in Warsaw, Poland.* International Journal of Environmental Research and Public Health, vol. 14, no. 1359, 2017, pp. 1359–1372.

[10] Samek L., Furman L., Mikrut M., Regiel-Futyra A., Macyk W., Stochel G., van Eldik R.: *Chemical composition of submicron and fine particulate matter collected in Krakow, Poland. Consequences for the APARIC project.* Chemosphere, vol. 187, 2017, pp. 430–439.

[11] Talbi A., Kerchich Y., Kerbachi R., Boughedaoui M.: *Assessment of annual air pollution levels with PM1, PM2.5, PM10 and associated heavy metals in Algiers, Algeria.* Environmental Pollution, vol. 232, 2018, pp. 252–263.

[12] West J.J., Cohen A., Dentener F., Brunekreef B., Zhu T., Armstrong B., Bell M.L., Brauer M., Carmichael G., Costa D.L., Dockery D.W., Kleeman M., Krzyzanowski M., Künzli N., Liousse C., Lung S.C., Martin R.V., Pöschl U., Pope C., Roberts J.M., Russell A.G., Wiedinmyer C.: *What We Breathe Impacts Our Health: Improving Understanding of the Link between Air Pollution and Health.* Environmental Science & Technology, vol. 50, no. 10, 2016, pp. 4895–4904.

[13] Oleniacz R., Bogacki M., Rzeszutek M., Kot A.: *Meteorologiczne determinanty jakości powietrza w Krakowie.* [in:] Konieczyński J. (red.), *Ochrona powietrza w teorii i praktyce. T. 2*, Instytut Podstaw Inżynierii Środowiska Polskiej Akademii Nauk, Zabrze 2014, pp. 163–178.

[14] Oleniacz R., Bogacki M., Szulecka A., Rzeszutek M., Mazur M.: *Assessing the impact of wind speed and mixing-layer height on air quality in Krakow (Poland) in the years 2014–2015.* Czasopismo Inżynierii Lądowej, Środowiska i Architektury – Journal of Civil Engineering, Environment and Architecture, z. 33, nr 63 (2/II/16), 2016, pp. 315–342.

[15] Majewski G., Przewoźniczuk W., Kleniewska M., Rozbicka K.: *Analiza zmienności wybranych zanieczyszczeń powietrza w zależności od opadów atmosferycznych w rejonie Ursynowa.* Acta Agrophysica, vol. 13, nr 2, 2009, pp. 419–434.

[16] Žibert J., Pražnikar J.: *Cluster analysis of particulate matter (PM10) and black carbon (BC) concentrations.* Atmospheric Environment, vol. 57, 2012, pp. 1–12.

[17] Czarnecka M., Nidzgorska-Lencewicz J.: *The impact of thermal inversion on the variability of PM10 concentration in winter seasons in Tricity.* Environment Protection Engineering, vol. 43, nr 2, 2017, pp. 157–172.

[18] Majewski G.: *Zanieczyszczenie powietrza pyłem zawieszonym PM10 na Ursynowie i jego związek z warunkami meteorologicznymi.* Przegląd Naukowy Inżynieria i Kształtowanie Środowiska, t. 1, nr 31, 2005, pp. 210–223.

[19] Bajorek-Zydroń K., Wężyk P.: *Atlas pokrycia terenu i przewietrzania Krakowa.* Urząd Miasta Krakowa, Kraków 2016.

[20] Halecki W.: *Parki rzeczne – jako forma ochrony powietrza w Miejskiej Wyspie Ciepła.* Wszechświat, t. 118, nr 4–6, 2017, pp. 133–139.

[21] Wojewódzki Inspektorat Ochrony Środowiska w Krakowie: *System monitoringu jakości powietrza* [Voivodeship Inspectorate of Environmental Protection in Krakow: *Air quality monitoring system*]. [on-line:] http://monitoring.krakow.pios.gov.pl [access: 01.02.2018].

[22] Ćwiek K., Majewski G.: *Wpływ elementów meteorologicznych na kształtowanie się stężeń zanieczyszczeń powietrza na przykładzie Krakowa.* Przegląd Naukowy. Inżynieria i Kształtowanie Środowiska, t. 24, nr 1 (67), 2015, pp. 54–66.

[23] Rawicki K.: *Variability of particulate matter concentrations in Poland in the winter 2012/2013.* Folia Pomeranae Universitatis Technologiae Stetinensis. Agricultura, Alimentaria, Piscaria et Zootechica, t. 31, nr 312, 2014, pp. 143–152.

[24] Projekt LIFE-IP MALOPOLSKA: *Portal Małopolska w Zdrowej Atmosferze – Uchwała antysmogowa* [The LIFE-IP project MALOPOLSKA: *Małopolska in a Healthy Atmosphere Portal – Anti-smog resolution*] [on-line:] https://powietrze.malopolska.pl/antysmogowa/ [access: 01.02.2018].

[25] Gulia S., Shiva Nagendra S. M., Khare M., Khanna I.: *Urban air quality management – A review.* Atmospheric Pollution Research, vol. 6, no. 2, 2015, pp. 286–304.

[26] Szulecka A., Mazur M.: *Application of the Statistical Error and Quantitative Performance Measures in the Evaluation Process of Short-Term Air Quality Forecasts for Krakow (Poland).* Geomatics and Environmental Engineering, vol. 10, no. 3, 2016, pp. 87–99.

[27] Szulecka A., Oleniacz R., Rzeszutek M.: *Functionality of openair package in air pollution assessment and modeling – a case study of Krakow.* Ochrona Środowiska i Zasobów Naturalnych – Environmental Protection and Natural Resources, vol. 28, no. 2(72), 2017, pp. 22–27.

[28] *Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe*. OJ L 152, 11.6.2008.

[29] Chlebowska-Styś A., Sówka I.: *Trendy zmian stężenia pyłów zawieszonych (PM10 i PM2,5) oraz benzo(a)pirenu na przykładzie wybranych miast Wielkopolski.* [in:] Kaźmierczak B., Kotowski A., Piekarska K. (red.), *Interdyscyplinarne zagadnienia w inżynierii i ochronie środowiska: praca zbiorowa. 6,* Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2015, pp. 40–53.

[30] Rozbicka K., Michalak M.: *Charakterystyka stężeń wybranych zanieczyszczeń powietrza na obszarze Warszawy (Poland).* Przegląd Naukowy. Inżynieria i Kształtowanie Środowiska, t. 24, nr 2 (68), 2015, pp. 193–206.

[31] Wydział Fizyki i Informatyki Stosowanej, Akademia Górniczo-Hutnicza im. Stanisława Staszica w Krakowie: *Serwis Meteo* [Faculty of Physics and Applied Computer Science, AGH UST: *Meteorological Service*]. [on-line:] http://meteo.ftj.agh.edu.pl/meteo [access: 01.02.2018].

[32] Główny Inspektorat Ochrony Środowiska: *Portal Jakości Powietrza* [Chief Inspectorate for Environmental Protection: *Air Quality Portal*]. [on-line:] http://powietrze.gios.gov.pl/pjp/archives [access: 01.02.2018].

[33] Carslaw D.C., Ropkins K.: *openair – An R package for air quality data analysis.* Environmental Modelling & Software, vol. 27–28, 2012, pp. 52–61.

Analiza przydatności nowych stacji monitoringu jakości powietrza w Krakowie w ocenie przestrzennego i czasowego zróżnicowania stężeń pyłu zawieszonego PM_{10}

Streszczenie: Przekroczenia norm jakości powietrza w aglomeracjach miejskich skłaniają lokalne społeczności do podejmowania działań mających na celu poprawę warunków aerosanitarnych. Aby wspomniane działania były skuteczne, bardzo istotne jest regularne zbieranie dokładnych danych ilościowych opisujących stopień zanieczyszczenia powietrza atmosferycznego. Utworzony w tym celu system monitoringu jakości powietrza jest stale rozbudowywany.
W niniejszej pracy podjęto się zbadania użyteczności nowo utworzonych stacji pomiarowych w Krakowie. Ocena dokonana została metodami statystycznymi, na podstawie przestrzennego oraz czasowego zróżnicowania stężeń pyłu zawieszonego PM_{10} w latach 2016 i 2017. W analizach posłużono się ponadto danymi o kierunkach wiatru. Istotą oceny było porównanie parami stacji pod względem mierzonych tam stężeń pyłu PM_{10}, różnic ich wartości średnich i wartości współczynnika korelacji liniowej Pearsona. W celu sprawdzenia istotności wyników przeprowadzony został test *t*-Studenta. Największe różnice bezwzględne pomiędzy analizowanymi wynikami zaobserwowane zostały w okresie jesienno-zimowym (sezon grzewczy). Niezależnie od powyższego, duże zróżnicowanie wystąpiło także pomiędzy stacjami typu komunikacyjnego.

Słowa kluczowe: zanieczyszczenie powietrza, pył zawieszony, optymalizacja sieci monitoringu, analizy statystyczne