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Seasonal Variability Analysis of PM10 Pollution in 2020-2023 in Selected Health Resorts

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Abstract: Air pollution with PM10 particulate matter is a serious problem not only in cities but also in health resorts, particularly during the heating season. Air pollution has serious health consequences. Long-term exposure to suspended particulate matter can increase the risk of upper respiratory tract and cardiovascular diseases. This study aims to analyze the seasonal variability of PM10 pollution between 2020 and 2023 in health resorts in southern Poland. Health resorts such as Rabka-Zdrój (a mountain health resort), Rymanów-Zdrój (a foothill health resort), Iwonicz-Zdrój, and Solec-Zdrój (a lowland health resort) became the subject of study. Despite the lack of exceedances of the alarm level, a significant local abundance of permissible daily standards was observed in the analyzed health resorts. It might have an impact on the ecological and health safety of residents. In February and March, during the analyzed period, the highest levels of PM10 dust concentrations were recorded.

Keywords: atmospheric pollution, air quality, health resorts, environmental pollution, PM10

1. Introduction

The natural environment is currently exposed to numerous environmental pollutants. One of them is air pollution, which is one of the world's most significant ecological problems (Kochanek et al. 2025). Pollutants in water, soil, and the atmosphere directly affect human health, ecosystems, and the prevailing climate (Ciuła et al. 2025, Basta & Ciuła 2024, Wiewiórska et al. 2023). In 2019, after the coronavirus (COVID-19) pandemic, interest in this topic increased (Myung & Joung 2024), as air pollution with dust is considered the main cause of diseases and premature deaths worldwide. Additionally, dust emission is the second-largest natural factor contributing to atmospheric PM pollution, estimated at approximately 2 billion tons per year (Stafoggia et al. 2016). Airborne particulate matter penetrates the respiratory tract and adversely affects the human body, e.g., the heart and respiratory system. Bioaerosols, in turn, are particles that act as a medium for the spread of airborne pathogens (Myung & Joung 2024). In most studies, two types of suspended dusts may be distinguished: PM2.5 and PM10. Due to its properties, PM10 posed a particular threat (Lelieveld et al. 2015), as it consisted of solid particles with a diameter smaller than 10 micrometers, able to penetrate the respiratory system, causing serious lung and heart diseases, and also affecting the daily quality of life (Beck-Speier et al. 2012, Brauer et al. 2012, Goix et al. 2014, Goldberg 2011, Saleh et al. 2019). The focus may be on PM2.5 particulate matter (diameter less than 2.5 μm), which can penetrate the lungs, and PM1.0 particulate matter (diameter less than 1.0 μm), which can enter the bloodstream through the alveoli. Exposure to PM1.0 particulate matter is often considered a cause of death due to stroke, and long-term inhalation may increase the risk of neurological disorders (Saju et al. 2023). The formation of harmful suspended dust was primarily a result of human activity. The PM10 produced came not only from natural sources, such as volcanoes, soil dust, and others. It was created as a result of anthropogenic activities (traffic, heating, energy production, and others) and as a secondary product, condensed from the gas phase (ammonium nitrate and ammonium sulfate, etc.) (Bołzan & Michalak 2024, Ciuła et al. 2018, Gaska et al. 2019). As a result, the chemical composition, size distribution, or reactivity of PM differ significantly depending on the location and season, causing substantial changes in the health impact due to these parameters (Mircea et al. 2020, Belis et al. 2020, Jain et al. 2020). Research conducted by Weber et al. (2021) demonstrated that reactive oxygen species (ROS) were transported or induced by particulate matter (PM), resulting in oxidative stress that, in turn, led to adverse health effects, including respiratory and cardiovascular diseases. However, research by Domínguez-Rodríguez et al. showed,

in the context of desert dust, that exposure to PM dust caused a 2% increase in the risk of cardiovascular mortality for every 10 $\mu g \cdot m^{-3}$ of PM10 dust measured (Domínguez-Rodríguez et al. 2021). Another disease that suspended dust contributes to was pulmonary embolism, which ranked third among fatal, acute cardiovascular diseases after myocardial infarction and stroke (Douma et al. 2010, Zhai et al. 2021). Pulmonary embolism was primarily caused by a blockage of the pulmonary artery or its branches (Li et al. 2022). The incidence of pulmonary embolism globally ranges from 0.39‰ to 1.15‰ (Hulle et al. 2017, Sonne-Holm et al. 2022), with a 25% mortality rate if left untreated. Previous studies showed links between short-term exposure to PM2.5 (particles with an aerodynamic diameter of ≤ 2.5 μm) and PM10 (particles with an aerodynamic diameter of ≤ 10 μm) and an increased incidence of pulmonary embolism (Di Blasi et al. 2022, Gwon et al. 2022, Li et al. 2022). However, since PM consisted of a complex mixture of different compounds from various sources, its health effects could vary significantly (Du et al. 2022). Studies have shown that the intensification of sandstorms and climate change has led to an increase in the amount of PM dust emitted into the environment worldwide (Achilleos et al. 2020, Maki et al. 2022, Wu et al. 2021, Zhang et al. 2023). Research also highlights the impact of PM dust on increased cardiovascular mortality and the number of hospital admissions (Renzi et al. 2018, Zhang et al. 2024). This article is focused on the analysis of PM10 concentrated dust in selected health resorts located in southern Poland: Rabka Zdrój (mountain health resort) (Flaga-Maryańczyk & Baran-Gurgul 2022), Rymanów Zdrój (submontane health resort) (Gmyrek-Gołąb 2019), Iwonicz Zdrój (Gmyrek-Gołąb 2019), and Solec Zdrój (lowland health resort) (Kiniorska & Brambert 2018) in the years 2019-2023. The analysis aims to determine the extent to which PM10 concentrations vary by season, as well as identify potential factors that have influenced these changes. The results enabled the assessment of air quality in health resorts and the identification of periods of increased health risk for residents and visitors.

2. Research Method

The article analyzed the concentrations of PM10 suspended dust based on data from GiOS (GIOŚ, 2025), in the years 2020-2023. The data includes the average daily concentration of suspended PM10 dust in the analyzed locations. The detailed characteristics of the analysis measurement stations are presented in Table 1. Average daily values were analyzed seasonally.

Table 1. Analyzed measurement stations, location, and type

Location	Type	Number of measurement days in 2020-2023
Rabka Zdrój, Orkana Street	Reference station + automatic + manual (weighing)	1,443.0
Solec Zdrój, 1 Maja 10 Street	Automatic station	1,424.0
Iwonicz Zdrój, Rąba Street	Automatic station	1,444.0
Rymanów Zdrój, Parkowa Street 5	Automatic station	1,434.0

Source: own study based on https://powietrze.gios.gov.pl

The location of measurement stations has been determined in accordance with the Regulation of the Minister of the Environment of September 13, 2012. Every five years, the Voivodeship Inspectorate for Environmental Protection conducts a five-year assessment. Its purpose, inter alia, is to verify whether the number and location of measurement stations are adequate for reliable annual air quality assessments (GIOŚ, location, 2025).

Rabka Zdrój is a village located in the Lesser Poland Voivodeship, in the Nowy Targ poviat, where PM concentrations are frequent and in high quantities. However, recent studies have shown a downward trend in this area (Flaga-Maryańczyk & Baran-Gurgul 2022). The following diseases are treated in Rabka Zdrój: respiratory conditions (including bronchial asthma and allergies); circulatory system diseases (including hypertension and cardiovascular ones); skin diseases; and diabetes. Rymanów Zdrój is a village located in the Subcarpathian Voivodeship, in the Krosno poviat. Rymanów Zdrój primarily treats diseases of the respiratory system, circulatory system, orthopedic and traumatic conditions, rheumatic disorders, as well as kidney and urinary tract problems. Iwonicz Zdrój is a village located in the Subcarpathian Voivodeship, in the Krosno poviat. The main areas of treatment include: orthopedic and traumatic problems, nervous system diseases, rheumatic conditions, digestive system diseases, upper respiratory tract diseases, osteoporosis, obesity, and skin problems. Solec Zdrój is a village in Poland located in the Świętokrzyskie Voivodeship, in the Busko poviat, specializing in the treatment of rheumatic diseases, locomotor system, skin, as well as circulatory and respiratory condition.

Research shows that air pollution, among other things, has had a significant impact on people's well-being and quality of life. While analysing and evaluating research results, it is essential to take the following factors into account: winds, traffic, seasons, ambient temperature, and air humidity, which affect the level of pollution (Metryka-Telka & Kowalik 2022, Wierzbińska et al. 2023). The main source of PM particulate matter was exhaust fumes, but also emissions from brakes, tires, road wear, and re-suspension of dust, which became the essence of unregulated PM in many locations (Marcazzan et al. 2001). It is also important to monitor pollution from processing sites, as they emit various air pollutants, including particulate matter (PM), which significantly affect local air quality and human health. (Ramadan et al. 2025, Basta & Szewczyk 2024, Przydatek & Basta 2020, Ciuła et al. 2024). Research conducted by Grange et al. (2021) showed that PM concentrations increased with the traffic gradient from rural to urban areas. While analyzing the given areas, it must also be taken into account that the dependence of the occurrence of exceedances of PM particle concentration indicators depends, among other factors, on classifying the area into a specific category based on air quality, temperature, and humidity (Zender-Świercz et al. 2024). The said exceedances most often occurred in large urban agglomerations where public transport and heavy traffic were present. The phenomenon is largely related to the combustion of liquid fuels (Pasela et al. 2017, Cembrzyńska et al. 2012).

3. Data Analysis

The analyzed area of PM10 covered the village of Rabka-Zdrój, a picturesque health resort in the Nowy Targ poviat, which, despite its health status, has been struggling with the problem of air quality for years. In the past, Rabka Zdrój was one of the leaders in Poland in terms of air pollution, particularly with suspended PM10 dust. In 2017, as many as 66 days with exceeding the daily PM10 standard were recorded, and the annual average concentration was 36 $\mu g \cdot m^{-3}$, which constituted 90% of the EU standard. In response to this problem, the authorities of Rabka-Zdrój implemented several measures to improve air quality. A local anti-smog resolution, which prohibits the use of non-class central heating boilers and class 3 and 4 boilers, was introduced. Additionally, an air quality monitoring station was installed, the results of which were available in real time on the commune's website. In 2024, the annual average PM10 concentration was 20 $\mu g \cdot m^{-3}$, and the number of days with exceeding the daily standard dropped to 19.

Using data (GIOŚ, 2025), the average annual PM10 concentrations in the years 2020-2023 are compiled below by means of Excel. It should be noted that PM10 concentration measurements in atmospheric air were taken in the years when the COVID-19 pandemic prevailed, i.e., in 2020-2022. The factors that particularly influenced this situation comprised: lower car traffic intensity caused by a drop in emissions of exhaust fumes and dust from tires, brakes, and road surfaces. The partial or complete suspension of work in industrial plants and construction sites reduced the emission of industrial pollutants, while remote work and travel restrictions resulted in a decrease in emissions related to personal and public transportation. Additionally, in 2020-2022, there were periodically favorable meteorological conditions (more rainfall, better air circulation), which favored the dispersion of pollutants. In some regions (especially urban ones), the reduction in social activity reduced the demand for heating public spaces, which may have contributed to a decrease in emissions from coal stoves and boilers. Thanks to local programs, including stove replacement as well as anti-smog resolutions, ecological awareness increased. The COVID-19 pandemic had a noticeable impact on improving air quality in Poland, primarily due to a reduction in emissions from transportation and industry. However, after lifting the restrictions in 2022, PM10 concentrations in many cities returned to pre-pandemic levels, which indicated the need to continue efforts to improve air quality.

Having analyzed data from GIOS, it was observed that in 2020, the average annual PM10 concentration was approximately 26.16 $\mu g \cdot m^{-3}$. The PM10 concentration was 27.31 $\mu g \cdot m^{-3}$. After the stabilization of the pandemic situation, in 2022 and 2023, the PM10 concentration was recorded at 23.33 $\mu g \cdot m^{-3}$and 19.27 $\mu g \cdot m^{-3}$, respectively, as shown in Figure 1.

The factors contributing to the decrease in PM10 suspended dust concentration in 2022-2023 include the "Clean Air" program, which is widespread in Poland, and local anti-smog resolutions, which also had a significant impact on the growing number of replaced heating sources in households. Social awareness increased, and more people showed interest in air quality and the reduction of emissions, for example, by opting for public transport over cars. In the analyzed years, there were more days with atmospheric precipitation than in previous years, which favours air circulation and natural air purification. To analyse the distribution of PM10 pollution in the atmospheric air in more detail, each month of a given year in Rabka Zdrój was examined. The results are presented in Figure 2 and Table 2. The data in the table were presented in the unit: $\mu g \cdot m^{-3}$.

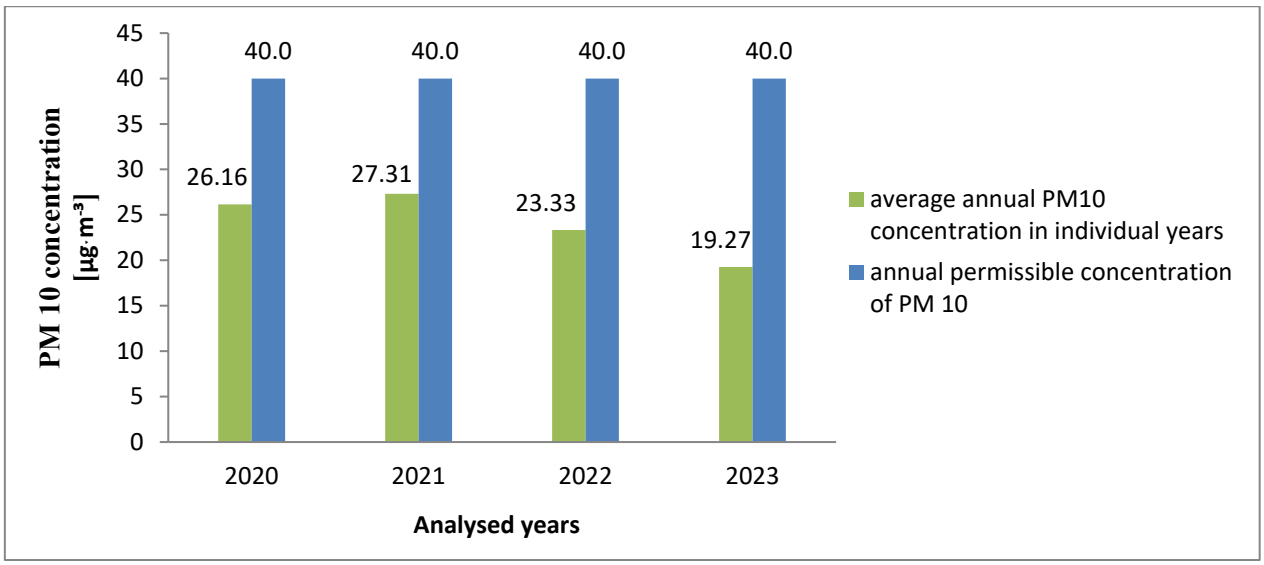

Fig. 1. Average annual PM10 suspended dust concentration, years 2020-2023, Rabka Zdrój
Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

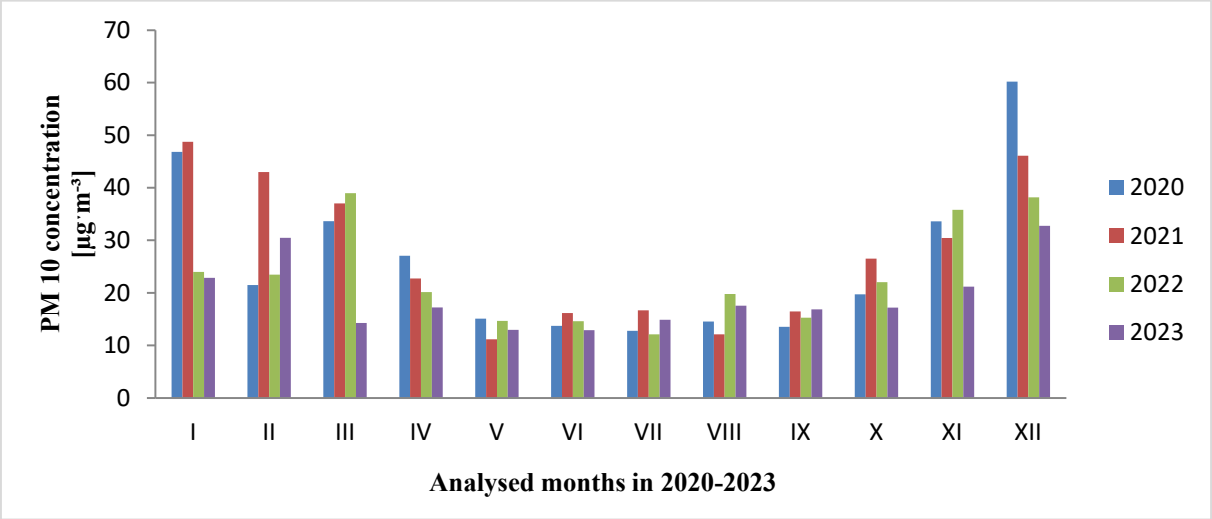

Fig. 2. Annual distribution of PM10 suspended dust concentration, years 2020-2023, Rabka Zdrój
Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

In 2020, in Rabka Zdrój, the PM10 concentration was found to range from 46.83 µg·m^{-3} to as much as 60.21 µg·m^{-3}. In 2021, an increase in PM10 was noted month-to-month, and on an annual basis, a slight decrease from 48.75 µg·m^{-3} in January to 46.10 µg·m^{-3} in December was noted. In 2022, a 50% drop in PM10 content occurred (48.75 µg·m^{-3} in January 2021, 24.0 µg·m^{-3} in January 2022). Over the entire year, from January to December, the PM10 content increased by approximately 14.16 µg·m^{-3} (January 24.0 µg·m^{-3}, December 38.16 µg·m^{-3}). The year 2023 was characterized by the lowest PM10 content in the air in January (22.85 µg·m^{-3}), while the highest concentration was recorded in December (32.74 µg·m^{-3}). Having analyzed the data, the standard deviation was also taken into account. It was a decreasing trend in the analyzed period, and it ranged from 13.50 µg·m^{-3} in 2023 to 20.90 µg·m^{-3} in 2020, indicating a scatter of data around 7.4 µg·m^{-3}.

Table 2. PM10 concentration value for the town of Rabka Zdrój, annual distribution in $\mu g \cdot m^{-3}$

Year	Month												Standard deviation
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2020	46.83	21.48	33.62	27.05	15.08	13.73	12.78	14.55	13.55	19.73	33.62	60.21	20.90
2021	48.75	42.99	37.02	22.73	11.16	16.16	16.66	12.10	16.45	26.52	30.45	46.10	20.26
2022	24.00	23.47	38.98	20.15	14.67	14.59	12.11	19.78	15.27	22.05	35.81	38.16	15.53
2023	22.85	30.48	14.26	17.23	12.95	12.90	14.88	17.57	16.85	17.18	21.17	32.74	13.50

Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

Considering the months with high PM10 concentration indicators, the daily distribution of the measured parameter was analyzed. The results are presented in Figures 3 and 4 and in Tables 3 and 4. The data in the table were presented in the unit: $\mu g \cdot m^{-3}$.

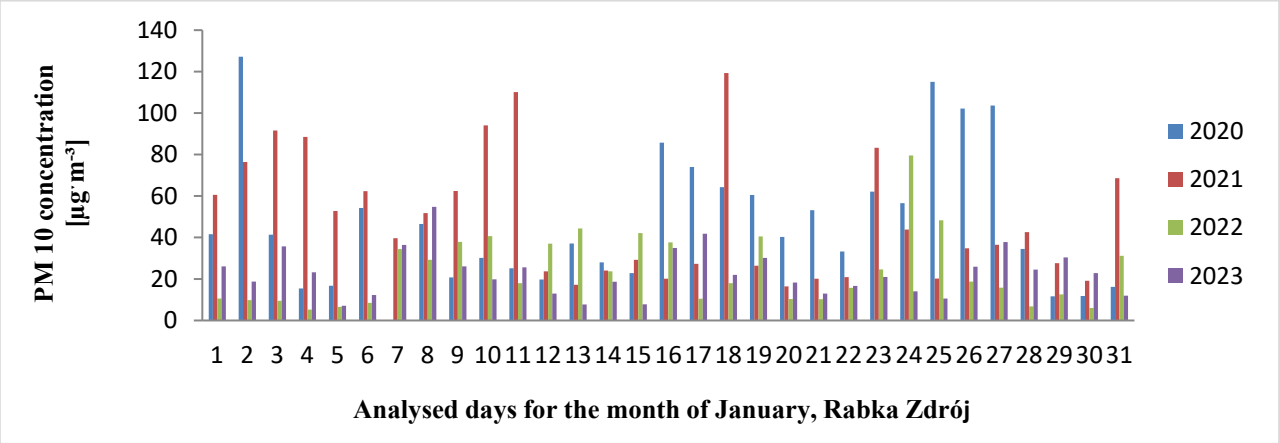

Fig. 3. Monthly distribution of PM10 suspended dust concentration, January, Rabka Zdrój
Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

In 2020, the average PM10 concentration in Rabka Zdrój was elevated, which was typical for the winter heating season. Moderate exceedances of the standards were observed. They were mainly caused by seasonal combustion of solid fuels in households and atmospheric conditions favouring the accumulation of pollutants. The highest recorded PM10 content was 127.1 $\mu g \cdot m^{-3}$on the second day of January, and the lowest PM10 content was recorded in this month on the 29th (11.6 $\mu g \cdot m^{-3}$). In 2021, in Rabka Zdrój, concentrations increased in January compared to the previous year. It was the time of partial lockdowns and people spending more time at home, which might in have resulted in increased use of heating stoves and boilers. Additionally, meteorological conditions could make it difficult to disperse pollutants. The highest daily PM10 concentration value was recorded on January 11 (110.1 $\mu g \cdot m^{-3}$), and the lowest on January 20 (16.41 $\mu g \cdot m^{-3}$). In 2022, in Rabka Zdrój, a clear decrease in PM10 concentrations was noted compared to 2021, which may be the result of improved air quality thanks to the introduced anti-smog programs and the replacement of obsolete heat sources. However, winter concentrations still remained higher than the permissible standards. The highest value was recorded on January 24 (79.28 $\mu g \cdot m^{-3}$), and the lowest on January 4 (5.25 $\mu g \cdot m^{-3}$). In 2023, in Rabka Zdrój, the lowest PM10 concentrations were recorded in January of the entire analysed period. It was a positive signal, proving the effectiveness of pro-ecological activities in the region, better fuel quality, and more favourable atmospheric conditions. However, there were still periods when daily standards were exceeded, indicating a need for further work to improve air quality. The highest value was recorded on January 8 (54.79 $\mu g \cdot m^{-3}$and the lowest on January 5 (7.05 $\mu g \cdot m^{-3}$).

January was a month with high PM10 concentrations in Rabka Zdrój due to the heating season and weather conditions conducive to the accumulation of pollutants. The COVID-19 pandemic influenced the increase in PM10 concentrations in 2021 due to increased use of home heating. Stove replacement programs and improved fuel quality began to yield results, becoming visible from 2022. Despite the declines, there were still exceedances of the standards, which meant that it was necessary to continue environmental actions and educate residents.

Table 3. PM10 concentration value for the town of Rabka Zdrój, individual days, January. Month, Year in $\mu g \cdot m^{-3}$

Month	Year			
January	2020	2021	2022	2023
1	41.60	60.58	10.55	26.07
2	127.14	76.36	9.78	18.76
3	41.33	91.62	9.44	35.74
4	15.43	88.52	5.25	23.19
5	16.74	52.75	6.54	7.05
6	54.26	62.33	8.49	12.24
7	-*	39.62	34.39	36.39
8	46.54	51.75	29.22	54.79
9	20.78	62.44	37.89	26.08
10	30.15	94.04	40.64	19.8
11	25.17	110.13	17.94	25.61
12	19.73	23.66	37.05	12.97
13	37.12	17.23	44.34	7.67
14	28.03	24.03	23.68	18.63
15	22.86	29.23	42.13	7.76
16	85.70	20.16	37.61	34.95
17	73.97	27.32	10.47	41.8
18	64.30	119.33	17.94	21.99
19	60.49	26.34	40.53	30.15
20	40.24	16.41	10.36	18.29
21	53.17	20.15	10.27	12.95
22	33.21	20.93	15.76	16.65
23	62.13	83.22	24.63	20.98
24	56.59	43.79	79.58	14.04
25	115.06	20.22	48.31	10.53
26	102.13	34.81	18.72	25.9
27	103.61	36.50	15.81	37.78
28	34.48	42.55	6.81	24.5
29	11.60	27.61	12.57	30.36
30	11.82	19.14	6.03	22.86
31	16.21	68.60	31.17	11.97

* No data available

Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

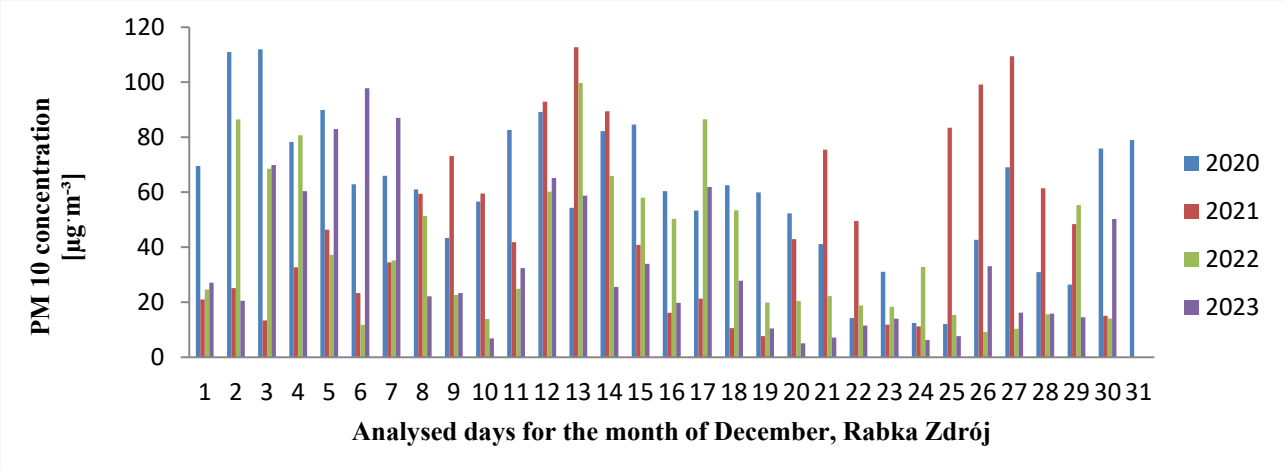

Fig. 4. Monthly distribution of PM10 suspended dust concentration, December, Rabka Zdrój
Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

December 2020 in Rabka Zdrój was characterized by a relatively high PM10 content in atmospheric air, mainly due to the heating season and favourable atmospheric conditions (inversions, windless days). The highest value was recorded on January 3 (111.9 µg·m^{-3}), and the lowest on January 12 (12.42 µg·m^{-3}). In 2021, an increase in the PM10 concentration was noted in December, often exceeding the standard of 40 µg·m^{-3}, caused by a return to more intensive social and economic activity. The use of solid fuels in homes increased (more people heating their homes), as did car traffic. The highest value was recorded on January 13 (112.6 µg·m^{-3}), and the lowest on January 3 (13.32 µg·m^{-3}). In December 2022, in many places in Poland and mountainous regions, such as Rabka-Zdrój, a decrease in PM10 concentrations to an average of about 30-35 µg·m^{-3}was noted. This was likely the result of the introduced anti-smog programs, the replacement of outdated stoves, and more favourable meteorological conditions. The highest value was recorded on January 2 and 17 (above 86 µg·m^{-3}), and the lowest on January 26 (9.13 µg·m^{-3}). In 2023, a further decrease in the average PM10 concentration was noted. The highest value was recorded on January 6 (97.79 µg·m^{-3}), and the lowest on January 20 (5.01 µg·m^{-3}).

Table 4. PM10 concentration value for the town of Rabka Zdrój, individual days, December in µg·m^{-3}

Month	Year			
December	2020	2021	2022	2023
1	69.49	20.97	24.59	27.10
2	110.93	25.08	86.45	20.53
3	111.93	13.32	68.52	69.87
4	78.27	32.70	80.66	60.38
5	89.89	46.36	37.23	82.98
6	62.86	23.33	11.71	97.79
7	65.94	34.48	35.15	87.06
8	61.02	59.40	51.35	22.12
9	43.37	73.10	22.60	23.30
10	56.61	59.51	13.88	6.81
11	82.62	41.79	24.86	32.36
12	89.16	92.90	60.20	65.15
13	54.35	112.68	99.73	58.73
14	82.19	89.40	65.83	25.50
15	84.57	40.84	57.98	33.97
16	60.40	16.16	50.33	19.78
17	53.28	21.26	86.48	61.87
18	62.50	10.58	53.41	27.80

Table 4. cont.

Month	Year			
December	2020	2021	2022	2023
19	59.93	7.65	19.89	10.42
20	52.26	42.91	20.42	5.01
21	41.13	75.43	22.19	7.13
22	14.23	49.51	18.83	11.47
23	31.06	11.82	18.29	14.01
24	12.42	11.20	32.81	6.26
25	12.06	83.41	15.34	7.64
26	42.71	99.16	9.13	33.10
27	69.05	109.42	10.33	16.19
28	30.95	61.4	15.56	15.86
29	26.41	48.36	55.30	14.52
30	75.85	15.05	14.06	50.27
31	78.96	-	-	-

Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

December was a month with high PM10 concentrations during the year, which was mainly the result of the intensive heating season and unfavourable weather conditions. However, in the years 2020-2023, a positive trend of decreasing concentrations had been observed, especially since 2022, which resulted from growing effectiveness of anti-smog and ecological activities in the Rabka-Zdrój region. The analysis of PM10 pollution distribution for the health resort in Rymanów was also conducted; the results are presented in Figure 5 and Table 5. The average monthly values were calculated for each of the analyzed years. The data in the table were presented in the unit: µg · m ³.

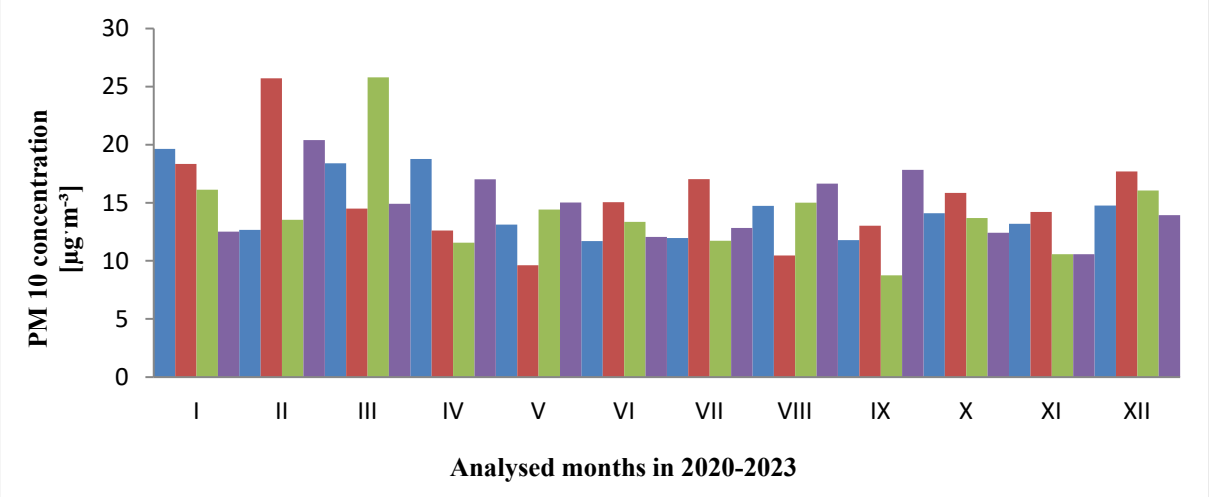

Fig. 5. Annual distribution of PM10 suspended dust concentration, years 2020-2023, Rymanów
Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

The pollution values in 2020 remained at a constant level, ranging from 11.71 µg·m^{-3} to 19.64 µg·m^{-3}over the12 months. The highest concentrations were recorded in January and April (19.64 and 18.77 µg·m^{-3}), and the lowest in June, July, and September (11.71, 11.96, and 11.78 µg·m^{-3}). The standard deviation was also calculated. It alternately increased and decreased in analyzed years, from 7.31 in 2020 to the highest value of 8.65 in 2021indicating a scatter of data around 0.5 to 1 µg·m^{-3}.

Table 5. PM10 concentration value for the town of Rymanów, individual months 2020-2023 in $\mu g \cdot m^{-3}$

Year	Month												Standard deviation
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2020	19.64	12.67	18.39	18.77	13.12	11.71	11.96	14.73	11.78	14.10	13.18	14.76	7.31
2021	18.34	25.72	14.50	12.61	9.61	15.04	17.03	10.46	13.02	15.85	14.21	17.70	8.65
2022	16.12	13.53	25.79	11.56	14.41	13.36	11.72	15.01	8.75	13.68	10.57	16.05	7.99
2023	12.51	20.39	14.91	17.01	15.02	12.06	12.83	16.64	17.83	12.42	10.57	13.93	8.10

Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

In 2021, the values of PM10 suspended particulate concentration increased. Among the 12 months, the highest values were reached for the months of January (18.34 $\mu g \cdot m^{-3}$), February (25.72 $\mu g \cdot m^{-3}$), and December (17.70 $\mu g \cdot m^{-3}$). The lowest PM10 concentration values were recorded in May (9.61 $\mu g \cdot m^{-3}$). In 2022, PM10 concentration values decreased in a greater number of months, compared to month after month. The highest value was recorded in March (25.79 $\mu g \cdot m^{-3}$), and the lowest in September (8.75 $\mu g \cdot m^{-3}$). In 2023, these values in Rymanów did not fall below 10.57 $\mu g \cdot m^{-3}$ in November and did not exceed 20.39 $\mu g \cdot m^{-3}$ in February. Comparing the years from 2020 to 2023, in the vast majority of the months analyzed, a downward correlation of PM10 concentration in the atmospheric air was observed. In February and March, single peaks were visible in 2021 and 2022. The highest PM10 concentration was observed in March 2022 (25.79 $\mu g \cdot m^{-3}$), which was higher than the PM10 dust concentration in February 2021 (25.72 $\mu g \cdot m^{-3}$). The analysis was presented in Figure 6 and Table 6. The data in the table were presented in the unit: $\mu g \cdot m^{-3}$.

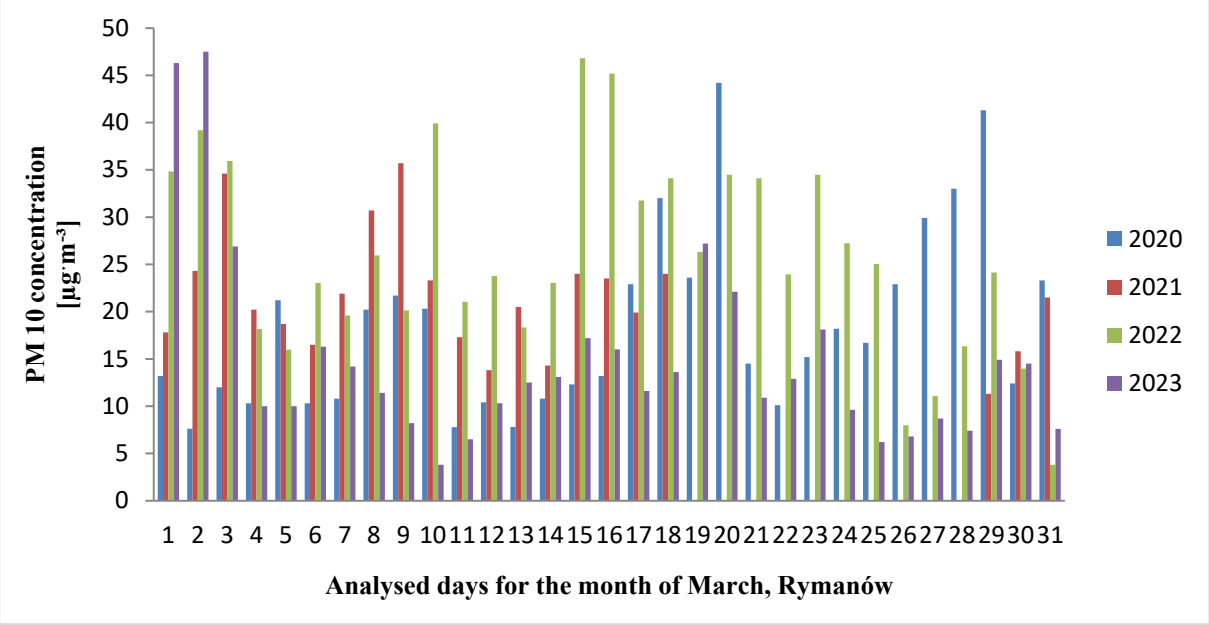

Fig. 6. Monthly distribution of PM10 suspended dust concentration, March, Rymanów
Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

High PM10 concentration values during the month were recorded in 2020 on March 20 and 29 (44.2 $\mu g \cdot m^{-3}$ and 41.3 $\mu g \cdot m^{-3}$). In 2021, no exceedances of the permissible PM10 suspended dust concentration values (50 $\mu g \cdot m^{-3}$) were observed, but it should also be noted that there were measurement gaps on March 19-28. In 2022, on March 15 and 16, values above 40 $\mu g \cdot m^{-3}$ were visible (46.8 $\mu g \cdot m^{-3}$ and 45.1 $\mu g \cdot m^{-3}$, respectively). In 2023, on March 1 and 2, high concentrations of 46.3 $\mu g \cdot m^{-3}$ and 47.5 $\mu g \cdot m^{-3}$, respectively, were recorded. The exceedances of the permissible standard for PM10 suspended dust concentration were visible, probably due to the characteristics of the analyzed month at the turn of winter and spring, and thus the fluctuation of temperature levels at the end of the heating season.

Table 6. PM10 concentration value for Rymanów, individual days, March in $\mu g \cdot m^{-3}$

Month	Year			
March	2020	2021	2022	2023
1	13.20	17.80	34.84	46.3
2	7.61	24.30	39.19	47.5
3	12.00	34.60	35.93	26.9
4	10.30	20.20	18.15	10.0
5	21.20	18.70	15.97	10.0
6	10.30	16.50	23.04	16.3
7	10.80	21.90	19.60	14.2
8	20.20	30.70	25.95	11.4
9	21.70	35.70	20.14	8.20
10	20.30	23.30	39.91	3.80
11	7.78	17.30	21.04	6.50
12	10.4	13.80	23.77	10.3
13	7.80	20.50	18.33	12.5
14	10.80	14.30	23.04	13.1
15	12.30	24.00	46.81	17.2
16	13.20	23.50	45.18	16.0
17	22.90	19.90	31.75	11.6
18	32.00	24.00	34.11	13.6
19	23.60	-	26.31	27.2
20	44.20	-	34.48	22.1
21	14.50	-	34.11	10.9
22	10.10	-	23.95	12.9
23	15.20	-	34.48	18.1
24	18.20	-	27.23	9.60
25	16.70	-	25.04	6.20
26	22.90	-	7.98	6.80
27	29.90	-	11.07	8.70
28	33.00	-*	16.33	7.40
29	41.30	11.30	24.13	14.9
30	12.40	15.80	13.97	14.5
31	23.30	21.50	3.80	7.60

* No data available

Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

The next health resort that was subjected to the analysis of PM10 suspended particulate matter concentration was Iwonicz Zdrój. Figure 7 and Table 7 show the annual analysis of average concentrations in January to December in the years 2020-2023. The data in the table were presented in the unit: $\mu g \cdot m^{-3}$.

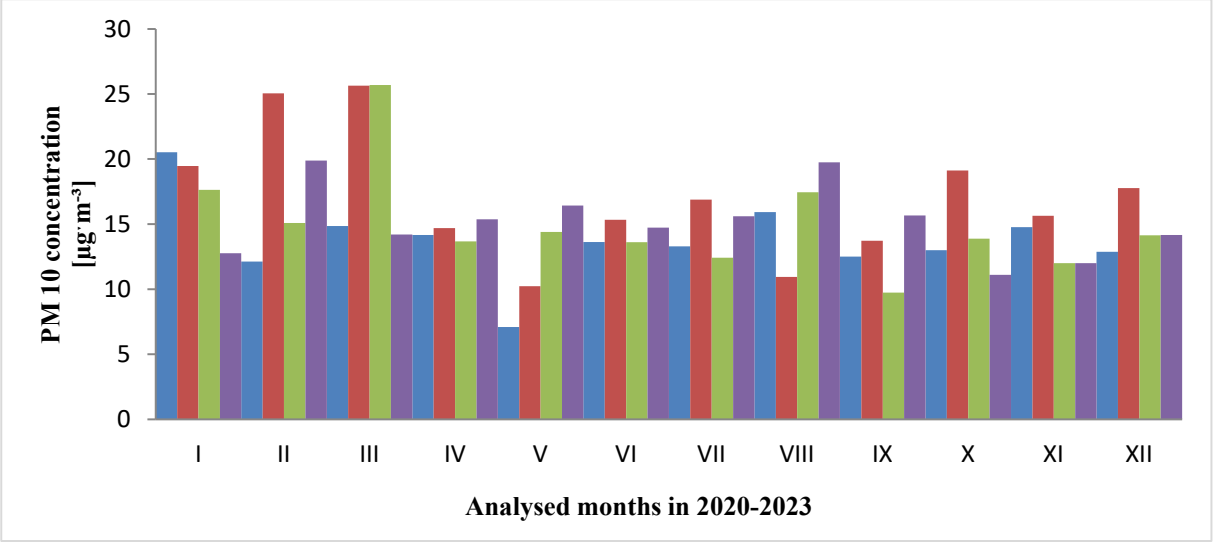

Fig. 7. Annual distribution of PM10 suspended particulate concentration, years 2020-2023, Iwonicz Zdrój
Source: own study based onhttps://powietrze.gios.gov.pl/pjp/archives

In 2020, the highest PM10 suspended particulate concentration was recorded in January (20.52 µg·m^{-3}), and the lowest in May (7.09 µg·m^{-3}). In 2021, contrarily, there were two months: February (25.04 µg·m^{-3}) and March (25.64 µg·m^{-3}), with the lowest concentrations in May and August (10.22 µg·m^{-3} and 10.95 µg·m^{-3}, respectively). In 2022, similarly to 2021, the highest concentration was recorded in March and amounted to 25.68 µg·m^{-3}, and the lowest was in September (9 µg·m^{-3}). In 2023, the values dropped slightly, and the highest PM10 suspended particulate concentration was recorded in February (19.88 µg·m^{-3}), and the lowest in October(11.10 µg·m^{-3}).The standard deviation was also calculated, which in analyzed years alternately ranged from 5.53 in 2020 to the highest value of 8.77 in 2021, indicating a scatter of data around 3.20 µg·m^{-3}.

Table 7. PM10 concentration value for Iwonicz Zdrój, individual months 2020-2023 in µg·m^{-3}

Year	Month												Standard deviation
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2020	20.52	12.13	14.85	14.17	7.09	13.63	13.29	15.92	12.50	12.99	14.77	12.88	5.53
2021	19.46	25.04	25.64	14.70	10.22	15.33	16.88	10.95	13.72	19.11	15.64	17.76	8.77
2022	17.63	15.09	25.68	13.67	14.39	13.61	12.42	17.45	9.74	13.88	12.00	14.14	7.47
2023	12.76	19.88	14.20	15.37	16.43	14.73	15.60	19.74	15.67	11.10	12.00	14.16	7.39

Source: own study based onhttps://powietrze.gios.gov.pl/pjp/archives

Due to the recurring high average monthly PM10 concentrations, the month of March was subjected to a special analysis, as it belonged to the transitional period between winter and spring, characterized by large temperature fluctuations and the activity of the heating season. The analysis was shown in Figure 8 and Table 8. The data in the table were presented in the unit: µg·m^{-3}.

In 2020, the highest value was 35.8 µg·m^{-3} on March 19. In 2021, the highest values of permissible PM10 suspended particulate concentration occurred on March 2 and 24 (44.5 µg·m^{-3}and 46.3 µg·m^{-3}, respectively). In 2022, values above 40 µg·m^{-3}were recorded on March 1, 14, 15, and 21 (40.82 µg·m^{-3}, 49.53 µg·m^{-3}, 42.27 µg·m^{-3}, and 44.99 µg·m^{-3}, respectively). On March 1, 2023, 42.8 µg·m^{-3} was recorded. High PM10 suspended particulate concentration values, similar to Rymanów, were probably due to the characteristics of the analyzed month, at the turn of winter and spring, and thus were subjected to temperature fluctuations and the heating season.

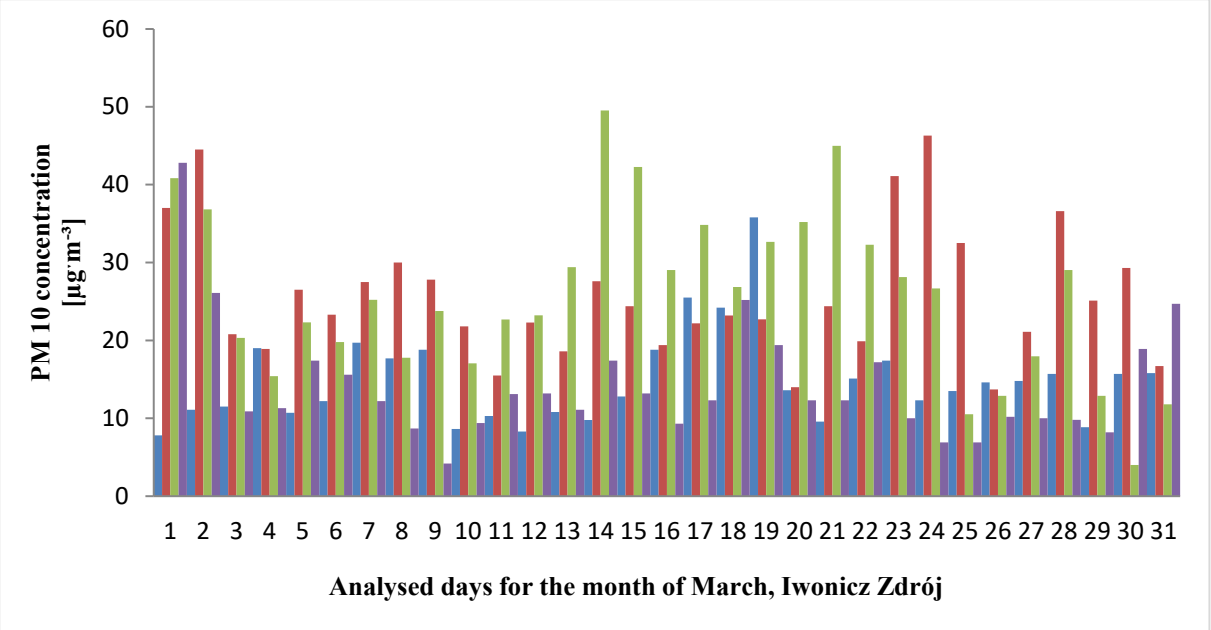

Fig. 8. Monthly distribution of PM10 suspended particulate concentration, March, Iwonicz Zdrój
Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

Table 8. PM10 concentration value for Iwonicz Zdrój, individual days, March in µg·m^{-3}

Month	Year			
March	2020	2021	2022	2023
1	7.80	37.00	40.82	42.80
2	11.10	44.50	36.83	26.10
3	11.50	20.80	20.32	10.90
4	19.00	18.90	15.42	11.30
5	10.70	26.50	22.31	17.40
6	12.20	23.30	19.78	15.60
7	19.70	27.50	25.22	12.20
8	17.70	30.00	17.78	8.70
9	18.80	27.80	23.77	4.20
10	8.64	21.80	17.05	9.40
11	10.30	15.50	22.68	13.10
12	8.30	22.30	23.22	13.20
13	10.80	18.60	29.41	11.10
14	9.78	27.60	49.53	17.40
15	12.80	24.40	42.27	13.20
16	18.80	19.40	29.03	9.30
17	25.50	22.20	34.83	12.30
18	24.20	23.20	26.85	25.20
19	35.80	22.70	32.66	19.40
20	13.60	14.00	35.20	12.30
21	9.57	24.40	44.99	12.30
22	15.10	19.90	32.29	17.20
23	17.40	41.10	28.12	10.00
24	12.30	46.30	26.67	6.90
25	13.50	32.50	10.52	6.90

Table 8. cont.

Month	Year			
March	2020	2021	2022	2023
26	14.60	13.70	12.89	10.20
27	14.80	21.10	17.96	10.00
28	15.70	36.60	29.03	9.80
29	8.85	25.10	12.88	8.20
30	15.70	29.30	4.00	18.90
31	15.80	16.70	11.80	24.70

Source: own study based on – https://powietrze.gios.gov.pl/pjp/archives

In Iwonicz-Zdrój, the highest average monthly PM10 concentrations were observed in the winter-spring months, primarily in February and March. The highest daily PM10 concentration values occurred in March but did not exceed the permissible daily standard of 50 $\mu g \cdot m^{-3}$, except for one day in 2022 (March 14 – 49.53 $\mu g \cdot m^{-3}$). The observed values related to the intensification of local heating at the end of the winter season and the variable meteorological conditions characteristic of March (e.g., temperature inversions, lack of wind, drops in night-time temperatures). Despite the relatively low level of exceedances, the visible seasonality and single episodes of high PM10 values indicated the need for further air quality monitoring in this town.

The next health resort village that was subjected to the analysis of PM10 suspended particulate matter concentration is Solec Zdrój. Figure 9 and Table 9 show the annual analysis of average concentrations in January to December in the years 2020-2023. The data in the table were presented in the unit: $\mu g \cdot m^{-3}$.

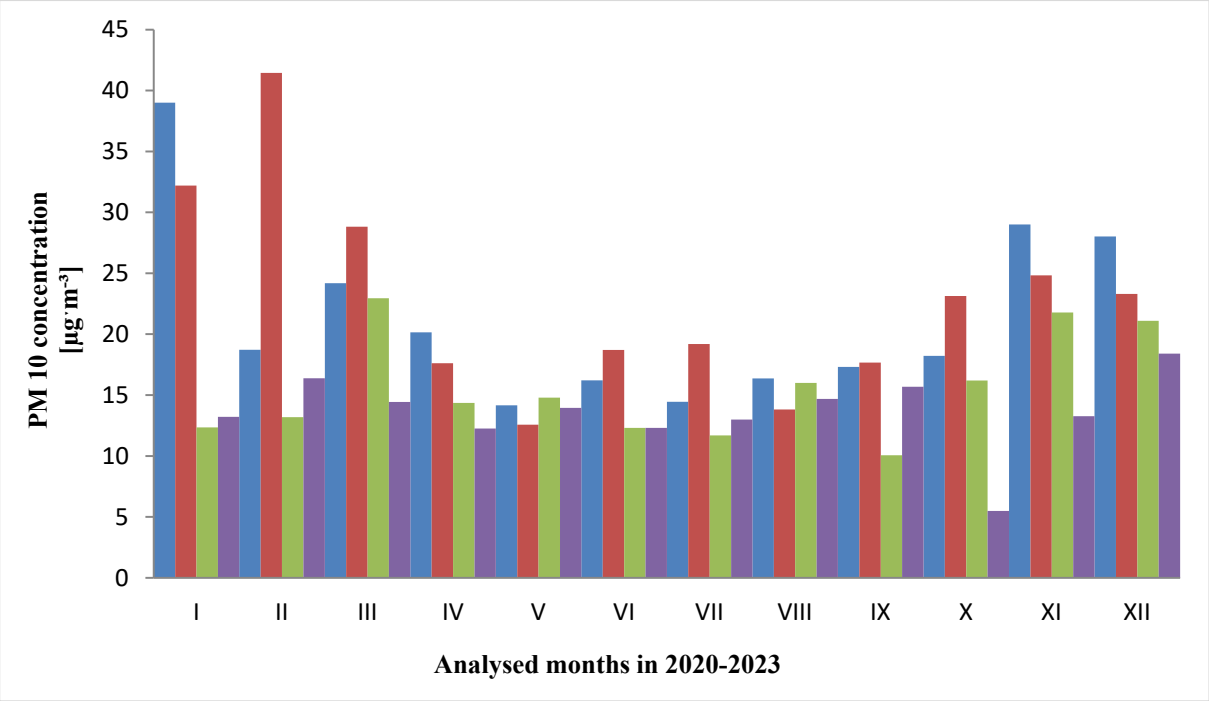

Fig. 9. Annual distribution of PM10 suspended particulate concentration, years 2020-2023, Solec Zdrój
Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

In 2020, the highest PM10 suspended particulate concentration was recorded in January (39.59 $\mu g \cdot m^{-3}$), and the lowest in May (14.16 $\mu g \cdot m^{-3}$). In 2021, it was the month of February (40.81 $\mu g \cdot m^{-3}$), with the lowest PM10 concentration in May and August (12.49 $\mu g \cdot m^{-3}$and 13.85 $\mu g \cdot m^{-3}$, respectively). In 2022, similarly to 2021, the highest concentration was recorded in March and amounted to 25.68 $\mu g \cdot m^{-3}$, but also in November 22.02 $\mu g \cdot m^{-3}$and December 20.32 $\mu g \cdot m^{-3}$, and the lowest was in September (9.91 $\mu g \cdot m^{-3}$). In 2023, these values dropped slightly, and the highest PM10 suspended particulate concentration was recorded in February (17.48 $\mu g \cdot m^{-3}$) and December (17.84 $\mu g \cdot m^{-3}$), and the lowest in October 5.47 $\mu g \cdot m^{-3}$. The standard deviation was also calculated. It alternately increased and decreased in analyzed years, from 6.68 in 2023 to the highest value of 13.32 in 2021indicating a scatter of data around 5.5 $\mu g \cdot m^{-3}$.

Table 9. PM10 concentration value for Solec Zdrój, individual months 2020-2023 in μg·m^{-3}

Year	Month												Standard deviation
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
2020	39.01	18.72	24.18	20.15	14.16	16.21	14.44	16.37	17.31	18.22	29.00	28.02	12.11
2021	32.21	41.45	28.82	17.62	12.56	18.70	19.20	13.82	17.67	23.14	24.83	23.31	13.32
2022	12.35	13.19	22.94	14.35	14.79	12.31	11.69	16.00	10.05	16.19	21.78	21.09	7.75
2023	13.21	16.38	14.43	12.25	13.95	12.30	12.98	14.68	15.69	5.49	13.27	18.40	6.68

Source: own study based onhttps://powietrze.gios.gov.pl/pjp/archives

Due to the observed seasonality of pollution, probably caused by seeking alternative sources of heating such as burning solid fuels resulting from rising electricity prices (Kirešová et al. 2022), the month of February was subjected to a special analysis, which in many years showed the highest average monthly PM10 values. The analysis was shown in Figure 10 and Table 10. The data in the table were presented in the unit: μg·m^{-3}.

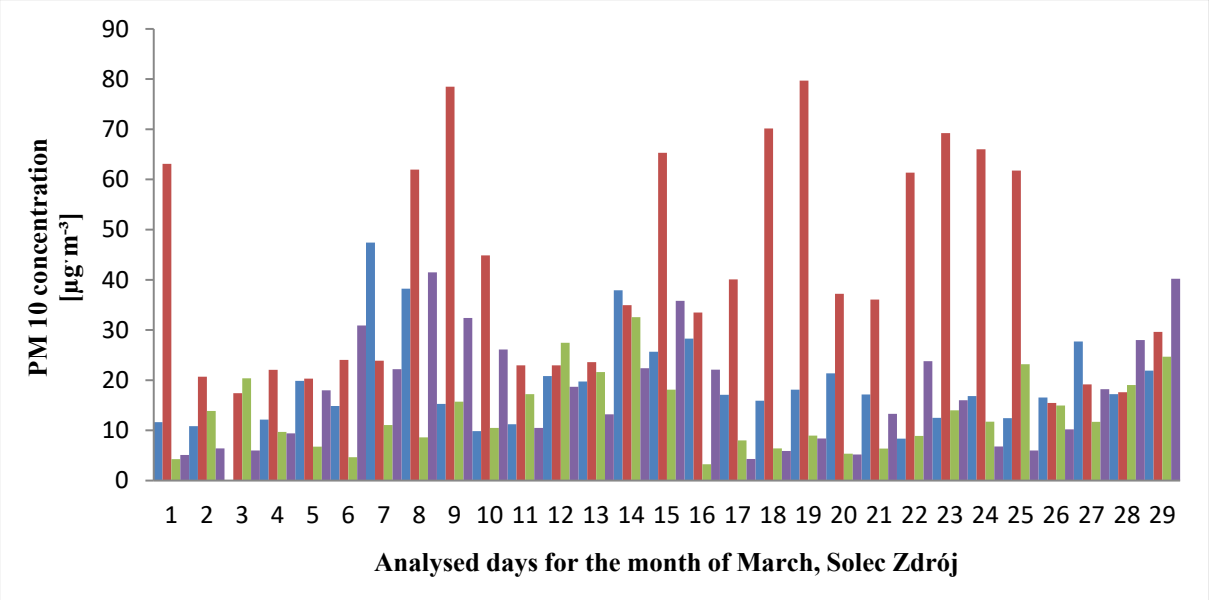

Fig. 10. Monthly distribution of PM10 suspended particulate concentration, February, Solec Zdrój
Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

In 2020, in Solec Zdrój, the highest PM10 value was 47.4 μg·m^{-3}on February 7, and the lowest was 8.35 μg·m^{-3} on February 22. In 2021, the highest values of permissible PM10 suspended particulate concentration over 24 hours (50 μg·m^{-3}) occurred on February 1 (63.1 μg·m^{-3}), 8 (61.9 μg·m^{-3}), 9 (78.4 μg·m^{-3}), 15 (65.3 μg·m^{-3}), 18 (70.1 μg·m^{-3}), 19 (79.6 μg·m^{-3}), 22 (61.3 μg·m^{-3}), 23 (69.2 μg·m^{-3}), 24 (66.0 μg·m^{-3}), and 25 (61.7 μg·m^{-3}), and the lowest on February 26 (15.4 μg·m^{-3}). In 2022, the highest PM10 concentration values were recorded on February 14 (32.5 μg·m^{-3}), and the lowest on February 1 (4.26 μg·m^{-3}), 16 (3.24 μg·m^{-3}), and 20 (5.34 μg·m^{-3}). In 2023, the highest value recorded in February was 41.5 μg·m^{-3}on February 8 and 40.2 μg·m^{-3} on February 29, and the lowest was on February 1 (5.1 μg·m^{-3}) and 20 (5.2 μg·m^{-3}).

Table10. PM10 concentration value for Solec Zdrój, individual days, February in μg·m^{-3}

Month	Year			
February	2020	2021	2022	2023
1	11.65	63.11	4.26	5.10
2	10.83	20.68	13.86	6.40
3	-	17.40	20.37	6.00
4	12.16	22.08	9.69	9.40
5	19.85	20.33	6.77	18.00

Table10. cont.

Month	Year			
February	2020	2021	2022	2023
6	14.85	24.04	4.67	30.90
7	47.43	23.87	11.05	22.20
8	38.22	61.96	8.62	41.50
9	15.28	78.49	15.71	32.40
10	9.85	44.86	10.48	26.10
11	11.22	22.95	17.23	10.50
12	20.81	22.97	27.44	18.70
13	19.74	23.61	21.63	13.20
14	37.93	34.95	32.57	22.40
15	25.67	65.31	18.11	35.80
16	28.27	33.48	3.25	22.10
17	17.09	40.08	8.01	4.30
18	15.92	70.15	6.40	5.90
19	18.12	79.68	8.97	8.40
20	21.36	37.21	5.35	5.20
21	17.16	36.08	6.38	13.30
22	8.36	61.36	8.89	23.80
23	12.48	69.22	13.99	16.00
24	16.82	66.01	11.74	6.80
25	12.43	61.76	23.19	6.00
26	16.56	15.47	14.97	10.20
27	27.72	19.18	11.69	18.20
28	17.22	17.60	19.05	28.00
29	21.90	29.62	24.67	40.20

Source: own study based onhttps://powietrze.gios.gov.pl/pjp/archives

In Solec-Zdrój, the highest average monthly PM10 concentrations occurred mainly in the winter months – January, February, and March. The year 2021 was particularly unfavourable in terms of air quality, with 10 days exceeding the daily PM10 concentration standard. A downward trend in maximum concentration values was observed in subsequent years, suggesting an improvement in air quality in this town. Nevertheless, episodes of high concentrations still occurred during the winter period, indicating the need for continuous monitoring and possible remedial actions during the heating season.

4. Trends and Correlations

During the analyzed four-year period, a noticeable downward trend in PM10 concentrations was observed, particularly after 2021. The highest monthly concentration of the entire period was in March 2022 – 25.79 $\mu g \cdot m^{-3}$. Significant increases ("spikes") in concentrations occurred in February (2021) and March (2022 and 2023). Rymanów, like other analyzed health resorts, experienced the highest PM10 concentrations in the winter-spring period, mainly in February and March. The highest values did not exceed the permissible daily standard of 50 $\mu g \cdot m^{-3}$, but several days were close to this limit, indicating a potential risk of exceedance in the future. High concentrations may result from typical transitional conditions between winter and spring, such as the intensification of local emission sources (heating), variable weather conditions, and temperature inversions. The downward trend in PM10 concentrations in 2022-2023 was probably the result of improving local air quality, but it still justified the need for further monitoring. The decrease in concentrations from 2021 to 2023 could be attributed to the implementation of the nationwide "Clean Air" program, local anti-smog resolutions, and an increase in social awareness of environmental protection. More and more people were reducing emissions – e.g., by choosing public transport instead of a car. Additionally, a greater number of days with precipitation in the analyzed years favoured natural circulation and air purification.

January was a month particularly exposed to high PM10 concentrations due to the heating season and meteorological conditions (e.g., temperature inversions, lack of wind). December, like January, was characterized by elevated PM10 concentrations, mainly due to home heating and unfavourable atmospheric conditions. In summary, January, February, March, and December were the months with the highest PM10 concentrations – due to the heating season and unfavourable weather conditions. The year 2021 was a transitional period – the COVID-19 pandemic led to increased use of home furnaces. A visible improvement in air quality occurred in 2022 and 2023, confirming the effectiveness of anti-smog actions, the replacement of heat sources, and changes in residents' behavior. Despite the general decrease, daily exceedances of permissible standards still occurred, indicating the need for further monitoring, education, and actions to reduce emissions.

5. Results and Discussion

Based on the Regulation of the Minister of Climate and Environment of December 11, 2020, on assessing the levels of substances in the air, the limit values for the permissible concentrations of PM10 suspended dust were adopted, which in Poland, in accordance with European Union regulations, is 40 $\mu g \cdot m^{-3}$ (Dz. U. 2020, poz. 2279). It was the average value calculated based on measurements taken over the course of a calendar year. Additionally, the standard allows the daily PM10 concentration to exceed 50 $\mu g \cdot m^{-3}$ for a maximum of 35 days a year. The WHO proposes stricter limits: the annual average for PM10 should be approximately 15-20 $\mu g \cdot m^{-3}$, and the daily average should be approximately 45-50 $\mu g \cdot m^{-3}$. EU regulations allow for lowering the standards from 2030 onwards, including stricter annual and daily average PM10 values (WHO Global Air Quality Guidelines 2021).

Tables 11-14 present the number of exceedances of permissible PM10 suspended particulate concentrations in the air in a seasonal breakdown for individual health resorts. The most exceedances were recorded in the winter season in 2020 in Rabka Zdrój and in 2021 in other towns. Definitely, the most exceedances were recorded in Rabka-Zdrój in the winter season of 2020. Throughout the year, the number of days with exceedances of permissible values was 45, which significantly exceeds the permissible number of 35 days per year. The air pollution index in this resorts in the analysed four-year period was as follows: in 2020 – 12.3% of days with exceedances, in 2021 – 11.0%, in 2022 – 7.7%, and in 2023 – 5.8%. For comparison, the permissible share of days with exceedances of PM10 concentrations is 9.6% annually (i.e., 35 days per year).

Table 11. Number of days on which the PM10 concentration was above the detection limit in Rabka Zdrój

Place: Rabka Zdrój				
Month	Year			
	2020	2021	2022	2023
January	1	8	2	7
February	12	13	1	1
March	6	5	7	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	4	3	6	4
December	22	11	12	9
Total number of days with PM10 exceedances	45	40	28	21

Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

In turn, in Solec Zdrój, the number of days with the largest exceedance of permissible values was 18 (2021). In the four-year research period, the air pollution index was as follows: in 2020, 4.4% of days with non-compliance with permissible standards were recorded, 4.9% in 2021, and 0% in 2022 and 2023.

Table 12. Number of days on which the PM10 concentration was above the detection limit in Solec Zdrój

Place: Solec Zdrój				
Miesiąc	Year			
	2020	2021	2022	2023
January	9	2	0	0
February	0	10	0	0
March	1	3	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	3	1	0	0
December	3	2	0	0
Total number of days with PM10 exceedances	16	18	0	0

Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

In the case of Iwonicz Zdrój, the number of days with the largest exceedance of permissible values was 1 day in 2021 and 2023. In the four-year research period, the air pollution index was as follows: in 2020 and 2022, no days with non-compliance with permissible standards were recorded, while in 2021 and 2023, 0.30% of days with non-compliance with permissible standards were recorded.

Table 13. Number of days on which the PM10 concentration was above the detection limit in Iwonicz Zdrój

Place: Iwonicz Zdrój				
Month	Year			
	2020	2021	2022	2023
January	0	0	0	0
February	0	1	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	0	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	0	0	0	1
Total number of days with PM10 exceedances	0	1	0	1

Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

In Rymanów, the number of days with the largest exceedance of permissible values was 6 days (2021). In the four-year research period, the air pollution index was as follows: in 2020, 0.6% of days with non-compliance with permissible standards were recorded, 1.6% in 2021, 0% in 2022, and 0.3% in 2023.

Table 14. Number of days on which the PM10 concentration was above the detection limit in Rymanów

Place: Rymanów				
Month	Year			
	2020	2021	2022	2023
January	1	1	0	0
February	0	3	0	0
March	0	0	0	0
April	0	0	0	0
May	0	0	0	0
June	0	0	0	0
July	0	2	0	0
August	0	0	0	0
September	0	0	0	0
October	0	0	0	0
November	0	0	0	0
December	1	0	0	1
Total number of days with PM10 exceedances	2	6	0	1

Source: own study based on https://powietrze.gios.gov.pl/pjp/archives

None of the analysed resorts had PM10 concentrations of 200 $\mu g \cdot m^{-3}$ recorded, which was the threshold value for informing the public about the risk of an alert level. The state of atmospheric suspended particulate matter pollution in the health resorts suggested the need for further research to assess the potential health risk to the population, especially in the submontane town of Rabka Zdrój.

In the years 2020-2023, the average annual concentrations of PM10 particulate matter in southern Polish health resorts, such as Rabka-Zdrój, Rymanów-Zdrój, Iwonicz-Zdrój, and Solec-Zdrój, remained below the permissible standards, indicating good air quality in these locations. In 2020-2023, the highest average annual concentration of PM10 particulate matter in Poland was recorded in Nowa Ruda (Lower Silesia Province), in which it amounted to 84 $\mu g \cdot m^{-3}$ in 2022. This concentration places Poland in 11th place among the 37 countries cooperating with the European Environment Agency (EEA) in terms of the highest average annual PM10 concentrations. This may indicate the need to take measures to improve air quality, such as modernizing heating systems or reducing emissions from transport (GIOŚ, 2025).

6. Conclusions

The results of the conducted research formed the basis for the following conclusions:

- The analyzed data confirmed the so-called seasonality of pollution.
- The highest PM10 air pollution levels were recorded in Rabka-Zdrój, particularly during the winter season. In the other health resorts, the number of exceedances was significantly lower, and in many cases, it did not occur at all.
- In the summer months, the average PM10 concentrations were relatively stable and low, and such large fluctuations in PM10 levels as those observed in the autumn-winter period were not present. This was likely due to various, more favorable atmospheric conditions – better dispersion of pollutants or higher ambient temperatures, which limited the need for household heating during the spring-summer periods.
- Summer brought a significant improvement in air quality, which resulted from better ventilation conditions and lower exhaust emissions.
- Despite the lack of exceedances of the alert level, significant local exceedances of permissible standards were found, which could have affected the ecological and health safety of residents.
- Further research is necessary, especially in the submontane region of Rabka-Zdrój, to assess the potential health risks to the population.
- The effect of measures aimed at improving air quality has been-noticeable (2023 was the cleanest year among the analyzed periods).

Particular attention should be paid to the fact that, despite growing public awareness of air quality, residents' knowledge of PM10 emission sources and methods for reducing them remains insufficient. Further systematic educational activities aimed at residents are recommended. Their objective is not only to inform about the sources of PM10 emissions, but also, and above all, to raise awareness of the health consequences of inhaling polluted air, i.e., respiratory and circulatory system diseases, or an increased risk of premature death. Education ought to be an integral part of promoting specific, positive attitudes, as well as solutions such as replacing outdated heating sources, reducing waste incineration, choosing public transportation, and regular property cleaning to reduce dust levels. Engaging local communities through information campaigns, meetings with experts, civic initiatives, and educational activities in schools plays a key role in adapting them to different age groups.

References

Achilleos, S., Mouzourides, P., Kalivitis, N., Katra, I., Kloog, I., Kouis, P., Middleton, N., Mihalopoulos, N., Neophytou, M., Panayiotou, A., Papatheodorou, S., Savvides, C., Tymvios, F., Vasiliadou, E., Yiallouros, P., & Koutrakis, P. (2020). Spatio-temporal variability of desert dust storms in Eastern Mediterranean (Crete, Cyprus, Israel) between 2006 and 2017 using a uniform methodology. *Sci. Total Environ.*, *714*, 136693. https://doi.org/10.1016/j.scitotenv.2020.136693

Basta, E., & Ciuła, J. (2024). Study of the Quality of Surface Waters in the Sącz Agglomeration. *Journal of Ecological Engineering*, *25*(12), 223-243. https://doi.org/10.12911/22998993/194095

Basta, E., & Szewczyk, P. (2024). The Use of Methane from Landfill Gas to Generate Energy and its Management at the Plant as a Way to Reduce Climate Change. *Rocznika Ochrona Środowiska*, *26*, 236-250. https://doi.org/10.54740/ros.2024.024

Beck-Speier, I., Karg, E., Behrendt, H., Stoeger, T., & Alessandrini, F. (2012). Ultrafine Particles Affect the Balance of Endogenous Pro- and Anti-Inflammatory Lipid Mediators in the Lung: In-Vitro and in-Vivo Studies. *Part. Fibre-Toxicol.*, *9*(27). https://doi.org/10.1186/1743-8977-9-27

Belis, C. A., Favez, O., Mircea, M., Diapouli, E., Manousakas, M.-I., Vratolis, S., Gilardoni, S., Paglione, M., Decesari, S., Mocnik, G., Mooibroek, D., Salvador, P., Takahama, S., Vecchi, R., & Paatero, P. (2029). *European Commission, and Joint Research Centre: European Guide on Air Pollution Source Apportionment with Receptor Models: Revised Version 2019*. Publication Office of the European Union, Luxembourg, 2019. Retrieved from: https://www.researchgate.net/profile/Stergios-Vratolis-2/publication/336134844_jrc117306_jrc117306_rm_guide2019_revision_pubsy_revised_by_ipo_cb_clean_1/links/5d91ca8f299bf10cff1a1fae/jrc117306-jrc117306-rm-guide2019-revision-pubsy-revised-by-ipo-cb-clean-1.pdf

Bołzan, M., & Michalak, J. (2024). Air Quality Matters: assessment of air quality in typical public places. *Przegląd elektrotechniczny*, *100*(1). ISSN 0033-2097. https://doi.org/10.15199/48.2024.01.29

Brauer, M., Amann, M., Burnett, R. T., Cohen, A., Dentener, F., Ezzati, M., Henderson, S. B., Krzyzanowski, M., Martin, R. V., Van Dingenen, R., van Donkelaar, A., & Thurston, G. D. (2011). Exposure Assessment for Estimation of the Global Burden of Disease Attributable to Outdoor Air Pollution. *Environ. Sci. Technol.*, *46*(2), 652-660. https://doi.org/10.1021/es2025752

Cembrzyńska, J., Krakowiak, E., & Brewczyński, P. Z. (2012). Particulate pollution of PM10 and PM2.5 due to strong anthropopressure in Sosnowiec city. *Environmental Medicine*, *15*(4), 31-38. Retrieved from: https://www.researchgate.net/publication/312159475_Particulate_pollution_of_PM10_and_PM25_due_to_strong_anthropopressure_in_Sosnowiec_city

Ciuła, J., Gaska, K., Generowicz, A., & Hajduga, G. (2018). Energy from landfill gas as an example of circular economy. *E3S Web of Conferences*, *30*, 03002. https://doi.org/10.1051/e3sconf/20183003002

Ciuła, J., Generowicz, A., Wiewiórska, I., Gaska, K., Gronba-Chyła, A., Golonka, M., & Makara, A. (2024). Environmental aspect of waste to energy installation: quality of waste generated by technology. *Clean Technologies and Environmental Policy*, *26*(9), 1-16. https://doi.org/10.1007/s10098-024-02788-0

Ciuła, J., Wiewiórska, I., Potok, H., & Babiarz, A. (2025). Recycling of Sewage Sludge in Poland – Environmental Aspects and Risks Related to Its Management in a Circular Economy. *Rocznik Ochrona Środowiska*, *27*, 320-340. https://doi.org/10.54740/ros.2025.026

Di Blasi, C., Renzi, M., Michelozzi, P., de' Donato, F., Scortichini, M., Davoli, M., Forastiere, F., Mannucci, P. M., & Stafoggia, M. (2022). Association between air temperature, air pollution and hospital admissions for pulmonary embolism and venous thrombosis in Italy. *Eur. J. Intern. Med.*, *96*, 74-80. https://doi.org/10.1016/j.ejim.2021.09.019

Domínguez-Rodríguez, A., Báez-Ferrer, N., Abreu-González, P., Rodríguez, S., Diaz, R., Avanzas, P., & Hernández-Vaquero, D. (2021).Impact of Desert Dust Events on the Cardiovascular Disease: A Systematic Review and Meta-Analysis. *J. Clin. Med., 10*(4), 727. https://doi.org/10.3390/jcm10040727

Douma, R. A., Kamphuisen, P. W., & Büller, H. R. (2010). Acute pulmonary embolism. Part 1: epidemiology and diagnosis. *Nat. Rev. Cardiol.*, *7*, 585-596. https://doi.org/10.1038/nrcardio.2010.106

Dz. U. 2020, poz. 2279. Regulation of The Minister of climate and environment of December 11, 2020, on assessing substance levels in the air. Retrieved from: https://www.infor.pl/akt-prawny/DZU.2020.262.0002279%2Crozporzadzenie-ministra-klimatu-i-srodowiska-w-sprawie-dokonywania-oceny-poziomow-substancji-wpowietrzu.html?utm.comhttps://powietrze.gios.gov.pl/pjp/content/annual_assessment_air_acceptable_level

Flaga-Maryańczyk, A., & Baran- Gurgul, K. (2022). The Impact of Local Anti-Smog Resolution in Cracow (Poland) on the Concentrations of PM10 and BaP Based on the Results of Measurements of the State Environmental Monitoring. *Energies*, *15*(1), 56. https://doi.org/10.3390/en15010056

Gaska, K., Generowicz, A., Lobur, M., Jaworski, N., Ciuła, J., & Vovk, M. (2019). Advanced algorithmic model for poly-optimization of biomass fuel production from separate combustible fractions of municipal wastes as a progress in improving energy efficiency of waste utilization. *E3S Web of Conferences*, *122*, 01004. https://doi.org/10.1051/e3sconf/201912201004

GIOŚ, 2025. Retrieved from: https://powietrze.gios.gov.pl/pjp/archives

GIOŚ, location, 2025. Retrieved from: https://powietrze.gios.gov.pl/pjp/content/show/1000919

Gmyrek-Gołąb, K. (2019). *The cultural potential of the statutory Carpathian health resorts*. Retrieved from: https://d1wqtxts1xzle7.cloudfront.net (in Polish)

Goix, S., Lévêque, T., Xiong, T.-T., Schreck, E., Baeza-Squiban, A., Geret, F., Uzu, G., Austruy, A., & Dumat, C. (2014). Environmental and Health Impacts of Fine and Ultrafine Metallic Particles: Assessment of Threat Scores. *Environ. Res.*, *133*, 185-194. https://doi.org/10.1016/j.envres.2014.05.015

Goldberg, M. (2011). A Systematic Review of the Relation Between Long-Term Exposure to Ambient Air Pollution and Chronic Diseases, *Rev. Environ. Health*, *23*, 243-298. https://doi.org/10.1515/REVEH.2008.23.4.243

Grange, S. T., Fischer, Zellweger, C., Alastuey, A., Querol, X., Jaffrezo J-L., Weber, S., Uzu, G., & Hueglin, Ch. (2021). Switzerland's PM10 and PM2.5 environmental increments show the importance of non-exhaust emissions. *Atmospheric environment: X*, *12*, 100145. https://doi.org/10.1016/j.aeaoa.2021.100145

Gwon, J. G., Lee, S. A., Park, K.-Y., Oh, S. U., Kim, J. S., & Seo, H.-M. (20220. Long-term exposure to air pollution and incidence of venous thromboembolism in the general population: a population-based retrospective cohort study. *J. Clin. Med.*, *11*, 3517. https://doi.org/10.3390/jcm11123517

Hulle, T., Cheung, W. Y., Kooij, S., Beenen, L. F. M., van Bemmel, T., van Es, J., Faber, L. M., Hazelaar, G. M., Heringhaus, C., Hofstee, H., Hovens, M. M. C., Kaasjager, K. A. H., van Klink, R. C. J., Kruip, M. J. H. A., Loeffen, R. F., Mairuhu, A. T. A., Middeldorp, S., Nijkeuter, M., van der Pol, L. M., Schol-Gelok, S., ten Wolde, M., Klok, F. A., Huisman, M. V., Fogteloo, A. J., Kroft, L. J. M., Brekelmans, M. P., Vermaire, R. M. J., Bastiaansen-Bergsma, H., Biedermann, J. S., Klijn, A., van der Voort, S., Lieveld, A. W. E., de Jong, P. Y., Schaar, C. G., & del Sol, A. I. (2017). Simplified diagnostic management of suspected pulmonary embolism (the YEARS study): a prospective, multicentre, cohort study. *Lancet*, *390*, 289-297. https://doi.org/10.1016/S0140-6736(17)30885-1

Jain, S., Sharma, S. K., Vijayan, N., & Mandal, T. K. (2020). Seasonal Characteristics of Aerosols (PM2.5 and PM10) and Their Source Apportionment Using PMF: A Four Year Study over Delhi. India, *Environ. Pollut.*, *262*, 114337. https://doi.org/10.1016/j.envpol.2020.114337

Kiniorska, I. & Brambert, P. (2018). Innowacyjność i oferta uzdrowiska w Solcu-Zdroju. Retrieved from: https://journals.pan.pl/Content/110411/PDF/10_Kiniorska.pdf (in Polish)

Kirešová, S., Guzan, M., & Rusyn, V. (2022). *Particulate Matter PM2.5 and PM10 and Its Impact on Air Quality in Urban and Rural Areas*. Retrieved from: https://www.researchgate.net/publication/366593174_Particulate_Matter_PM25_and_PM10_and_Its_Impact_on_Air_Quality_in_Urban_and_Rural_Areas

Kochanek, A., Grąz, K., Potok, H., Gronba-Chyła, A., Kwaśny, J., Wiewiórska, I., Ciuła, J., Basta, E., & Łapiński, J. (2025). Micro- and Nanoplastics in the Environment: Current State of Research, Sources of Origin, Health Risks, and Regulations—A Comprehensive Review. *Toxics*, *13*(7), 564. https://doi.org/10.3390/toxics13070564

Lelieveld, J., Evans, J. S., Fnais, M., Giannadaki, D., & Pozzer, A. (2015). The Contribution of Outdoor Air Pollution Sources to Premature Mortality on a Global Scale. *Nature*, *525*, 367-371. https://doi.org/10.1038/nature15371

Li, Z., Zhang, Y., Yuan, Y., Yan, J., Mei, Y., Liu, X., Xu, Q., & Shi, J. (2022). Association between exposure to air pollutants and the risk of hospitalization for pulmonary embolism in Beijing, China: a case-crossover design using a distributed lag nonlinear model. *Environ. Res.*, *204*, 112321. https://doi.org/10.1016/j.envres.2021.112321

Maki, T., Tanaka, T. Y., Koshiro, T., Shimizu, A., Sekiyama, T. T., Kajino, M., Kurosaki, Y., Okuro, T., & Oshima, N. (2022). Changes in dust emissions in the Gobi desert due to global warming using MRI-ESM2.0. *Sola*, *18*, 218-224. https://doi.org/10.2151/sola.2022-035

Marcazzan, G. M., Vaccaro, S., Valli, G., & Vecchi, R. (2001). Characterisation of PM10 and PM2.5 particulate matter in the ambient air of Milan (Italy). *Atmospheric Environment*, *35*, 4639-4650. https://doi.org/10.1016/S1352-2310(01)00124-8

Metryka-Telka, M., & Kowalik, R. (2022). Analysis of air quality assessment in Kielce in relation to the Covid-19 pandemic. *Structure and Environment*, *14*(1), 24-32. https://doi.org/10.30540/sae-2022-004

Mircea, M., Calori, G., Pirovano, G., & Belis, C. A. (2020). European Guide on Air Pollution Source Apportionment for Particulate Matter with Source Oriented Models and Their Combined Use with Receptor Models, Tech. Rep. EUR 30052 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-10698-2. JRC119067. https://doi.org/10.2760/470628

Myung, H., & Joung, Y.S. (2024). Contribution of Particulates to Airborne Disease Transmission and Severity: A Review, *EnvironSciTechnol. 23*, *58*(16), 6846-6867. https://doi.org/10.1021/acs.est.3c08835

Pasela, R., Milik, J., Budzińska, K., Szejniuk, B. (2017). Analiza wyników pomiarów stężeń zanieczyszczenia powietrza pyłem PM10 i PM2,5 na stacji pomiarowej plac Poznański w Bydgoszczy. *Ecological Engineering*, *18*(1), 240-246. https://doi.org/10.12912/23920629/68307 (in Polish)

Przydatek, G., & Basta, E. (2020). Systemic Efficiency Assessment of Municipal Solid Waste Management in the Suburban Municipality. *E3S Web of Conferences*, *154*(2), 03001. https://doi.org/10.1051/e3sconf/202015403001

Ramadan, B. S., Budihardjo, M. A., Syafrudin, H S Huboyo1, & S A Sari (2025). Analysis of particulatematter (PM10 and PM2.5) emissions from Jatibarang landfill: implications for air quality and health. *Earth and Environmental Science 1477*, 012033. https://doi.org/10.1088/1755-1315/1477/1/012033

Renzi, M., Forastiere, F., Calzolari, R., Cernigliaro, A., Madonia, G., Michelozzi, P., Davoli, M., Scondotto, S., & Stafoggia, M. (2018). Short-term effects of desert and non-desert PM10 on mortality in Sicily, Italy, *Environ. Int.*, *120*, 472-479. https://doi.org/10.1016/j.envint.2018.08.016

Saju, J. A., Bari, Q. H., Mohiuddin, K. A. B. M., & Strezov, V. (2023). Measurement of ambient particulate matter (PM1.0, PM2.5 and PM10) in Khulna City of Bangladesh and their implications for human health. *Environ Syst Res*, *12*(42). https://doi.org/10.1186/s40068-023-00327-2

Saleh, Y., Antherieu, S., Dusautoir, R., Y. Alleman, L., Sotty, J., De Sousa, C., Platel, A., Perdrix, E., Riffault, V., Fronval, I., Nesslany, F., Canivet, L., Garçon, G., & Lo-Guidice, J.-M. (2019). Exposure to Atmospheric Ultrafine Particles Induces Severe Lung Inflammatory Response and Tissue Remodeling in Mice. *Int. J. Environ. Res. Pu.*, *16*, 1210, https://doi.org/10.3390/ijerph16071210

Sonne-Holm, E., Kjærgaard, J., Bang, L. E., Fosbøl, E., Carlsen, J., & Winther-Jensen, M. (2022). Pulmonary embolism: Age specific temporal trends in incidence and mortality in Denmark 1999-2018. *Thromb. Res.*, *210*, 12-19. https://doi.org/10.1016/j.thromres.2021.12.011

Stafoggia, M., Zauli-Sajani, S., Pey, J., Samoli, E., Alessandrini, E., Basagaña, X., Cernigliaro, A., Chiusolo, M., Demaria, M., Díaz, J., Faustini, A., K. Katsouyanni, A.G. Kelessis, C. Linares, S. Marchesi, S. Medina, P. Pandolfi, N. Pérez, X. Querol, G. Randi, A. Ranzi, A. Tobias, & F. Forastiere, (2016). Desert Dust Outbreaks in Southern Europe: Contribution to Daily PM10 Concentrations and Short-Term Associations with Mortality and Hospital Admissions. *Environ Health Perspect*, *124*(4), 413-419. https://doi.org/10.1289/ehp.1409164

Weber, S., Uzu, G., Favez, O. et al. (2021). Source apportionment of atmospheric PM10 oxidative potential: synthesis of 15 year-round urban datasets in France. *ACP*, *21*, 11353-11378. https://doi.org/10.5194/acp-21-11353-2021

WHO Global Air Quality Guidelines 2021. Retrieved from: https://iris.who.int/bitstream/handle/10665/345329/9789240034228-eng.pdf?sequence=1

Wierzbińska, M., Kozak, J., & Zając, E. (2023). Variability of PM10 particulate matter concentrations in the area of Krościenko nad Dunajcem in the years 2018-2022. *Polish Journal of Materials and Environmental Engineering*, *5*(25), 14-22. https://doi.org/10.53052/pjmee.2023.5.02

Wiewiórska, I., Lobur, M., Vovk, M., Makara, A., & Kowalski, Z. (2023). Analysis of the impact of changes in surface water quality on the dynamics of treatment processes in drinking water treatment technological systems. *Desalination and Water Treatment*, *315*, 1-12. https://doi.org/10.5004/dwt.2023.30053

Wu, Y., Wen, B., Li, S., & Guo, Y. (2021). Sand and dust storms in Asia: a call for global cooperation on climate change. *Lancet Planet. Health*, *5*, 329-330. https://doi.org/10.1016/S2542-5196(21)00082-6

Zender-Świercz, E., Galiszewska, B., Telejko, M., & Starzomska, M. (2024). The effect of temperature and humidity of air on the concentration of particulate matter – PM2.5 and PM10. *Atmospheric Research*, *312*(15), 107733. https://doi.org/10.1016/j.atmosres.2024.107733

Zhai, Z., Wang, D., Lei, J., Yang, Y., Xu, X., Ji, Y., Yi, Q., Chen, H., Hu, X., Liu, Z., Mao, Y., Zhang, J., Shi, J., Zhang, Z.u., Wu, S., Gao, Q., Tao, X., Xie, W., Wan, J., Zhang, Y., Zhang, S., Zhen, K., Zhang, Z., Fang, B., & Wang, C. (2021). Trends in risk stratification, in-hospital management and mortality of patients with acute pulmonary embolism: an analysis from the China pUlmonary thromboembolism REgistry Study (CURES). Eur. *Respir. J.*, *58*. https://doi.org/10.1183/13993003.02963-2020

Zhang, C., Yan, M., Du, H., Ban, J., Chen, C., Liu, Y., & Li, T. (2023). Mortality risks from a spectrum of causes associated with sand and dust storms in China. *Nat. Commun.*, *14*, 6867. https://doi.org/10.1038/s41467-023-42530-w

Zhang, C., Zhao, D., Liu, F., Yang, J., Ban, J., Du, B., Du, P., Lu, K., Ma, R., Liu, Y., Sun, Q., Chen, S., & Li, T. (2024). Dust particulate matter increases pulmonary embolism onset: A nationwide time-stratified case-crossover study in China. *Environment International*, *186*, 108586. https://doi.org/10.1016/j.envint.2024.108586