PEOPLE OR WEATHER

WHAT IMPROVES AIR QUALITY?

ANALYSES WITH THE APPLICATION OF THE MODEL NORMALIZING CONCENTRATION OF AIR POLLUTANTS WITH THE APPLICATION OF METEOROLOGICAL DATA

PILOT STUDY

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1 » INTRODUCTION

When one side says: *We have an improvement in air quality, and the other one responds: Yes, but it is only because winter was mild and people did not smoke much in their boilers*, the question arises: **who is right?** To answer this question, the authors of the present study decided to look at the impact of meteorological factors on air quality variations observed in recent years. Using an advanced statistical model (random forest model[1]), it has been determined what the contribution of weather conditions is, and what that of human actions is, in the improvement of air quality. Hourly databases were used for the analyses – concentrations of PM10 from the GIOŚ[2] and meteorological data from the IMGW[3]. Locations which had the longest complete measurements series from year 2008 to 2019 were selected, this refers both in terms of PM10 concentration range and in weather parameters. Data, presenting the reduction of PM10 concentrations between 2010 and 2019 are shown in Table 1, with division into results:

- taking into account only human actions, after eliminating the impact of meteorological factors (column c);
- actual measurements taking into account both weather factors and human actions (column d).

The most substantial reduction, resulting from measures undertaken to decrease the amount of emissions (after elimination of the impact of meteorological factors), was achieved for two stations in Kraków: 22.9 $\mu g/m^3$ and 22.6 $\mu g/m^3$. In turn the worst results were obtained in case of two stations in Gdańsk and one in Warsaw, where human activity contributed to the increase of concentrations.

TABLE 1.

CUMULATIVE RESULTS FROM ANALYZED LOCATIONS, A REDUCTION OF THE AVERAGE ANNUAL PM10 CONCENTRATION IN 2019 AS COMPARED TO 2010

MEASUREMENT STATION	STATION TYPE, SURROUNDINGS	WEATHER--INDEPENDENT REDUCTION PEOPLE'S ACTIONS [μg/m³]	REDUCTION ACC. ACTUAL MEASUREMENTS WEATHER DEPENDENT [μg/m³]
a	b	c	d
Kraków Krasińskiego Ave	roadside, main street	22.9	29.5
Kraków Bulwarowa St	industrial, multi-family buildings	22.6	32.4
Zakopane Sienkiewicza St	urban background, city centre, park	13.4	21.3
Katowice Kossutha St*	urban background, multi-family buildings	8.8	17.7
Warszawa Niepodległości Ave	roadside, main street	5.6	15.1
Gdańsk Kaczeńce St	urban background, single-family buildings, allotment gardens	4.7	6.5
Bielsko-Biała Kossak-Szczuckiej St**	urban background, multi-family buildings, allotment gardens	3.4	14.9
Szczecin Andrzejewskiego St	urban background, multi-family buildings	2.4	8.6
Gdańsk Powstańców Warszawskich St	urban background, single- and multi-family buildings	–1.0	4.1
Warszawa Wokalna St*	urban background, multi-family buildings	–3.3	–0.5
Gdańsk Wyzwolenia St	urban background, multi-family buildings	–5.1	–0.9

*2010 compared to 2018
**2012 compared to 2019

2 » CONCLUSIONS

Of all the analyzed locations, **the most significant improvement in air quality resulting from human activities was recorded in Kraków**. The PM10 concentration at both analyzed stations subject to assessment, irrespective of weather, decreased by 23 µg/m³ between 2010 and 2019.

This distinct decrease in pollution constitutes **strong evidence of effectiveness of the scheme for elimination of burning solid fuels in household boilers in the Małopolska Region capital city and the Anti-Smog Resolution, in force in the region, introducing a number of restrictions and obligations**. In particular, the obligation to replace non-class furnaces has yielded positive effects also in other locations, such as Zakopane for instance, where the pollution reduction independent of meteorological factors has amounted to 13 µg/m³. Such result may be attributed to the activities of residents and local governments as well as to the large share (40%) of heat production from an emission-free energy source (geothermal energy).

Unfortunately, there are also cities in Poland, where no improvement has been recorded, or even a deterioration in air quality has been noted, if the positive impact of meteorological conditions is disregarded. **In the years 2016-2019, 18.4 thousand boilers were eliminated in Kraków and only 1.7 thousand[4] in Warsaw**. The ambitious Anti-Smog Resolution for Kraków, banning the use of solid fuels, has contributed to a significant improvement in air quality. In Warsaw, at Wokalna St (Ursynów district), **human activity has caused an increase in concentration by 3.3 µg/m³. In Gdańsk**, in the Nowy Port district, at the station in Wyzwolenia St, an increase of 5.1 µg/m³ has been recorded. This is probably due to the high **intensity of activity in the sea port**, which generates pollution and this instance may be referred to as an example of a negative impact of industry.

The findings of this study show clearly that effective actions can contribute, regardless of weather, to improving air quality. Given the actions that led to the best result in this analysis, namely the elimination of solid fuels boilers in Kraków, efforts at the rate of boilers replacement throughout the country should be stepped up.

3 » METHODOLOGY AND DATA SOURCES

The analysis was performed using a publicly available *rmweater* model, which is used to normalize concentrations with meteorological factors, **that is to divide the measurements results into weather-dependent and independent of weather**. The model which uses the random forest method can be downloaded as R program package. The method used is based on "machine-based learning", an area of artificial intelligence that builds the appropriate, best-fitting model based on the relationships found in the data. The analysis used two sets of data for the years 2008 to 2019:

- one-hour concentrations of PM10,
- meteorological data – one-hour weather parameters.

3.1 › AIR POLLUTANTS CONCENTRATIONS DATA

The source of information on air quality used in the analyzes was the databank of the Central Inspectorate of Environmental Protection[5]. The study used information on the one-hour concentrations of particulate matter PM10 from the period 2008-2019. The final year was 2019, as it is the last verified year (at the time of the analyses). Data set on concentrations obtained thereby included 105 912 records for 254 stations. The criterion for the completeness of the measurements series was then adopted at the minimum level of 85% so as to use the data for further calculations. Following this preliminary qualitative analysis, 54 measurement stations were selected for further study, whose number was reduced due to the lack of meteorological data, among others.

3.2 › METEOROLOGICAL DATA

The meteorological data were derived from the synoptic stations of the Institute of Meteorology and Water Management PIB[6]. The synoptic database contains one-hour values of the meteorological parameters necessary for the analysis (as required by the applied model). The database contains 107 categories, of which the following are selected:

- air temperature [°C],
- atmospheric pressure [hPa],
- height of cloud base [m],
- relative humidity [%],
- direction of wind [°],
- wind velocity [m/s],
- wind gusts [m/s].

The decision to choose these parameters was dictated by an analysis of scientific studies, in which the random forest model was used. The synoptic database possesses a limited number of stations (only 67), which prevents analysis for all locations and cities. As a result, 13 cities have been selected for the next stage, meaning that data from a single weather station in some cities have been used for many stations measuring concentrations of air pollutants.

3.3 METHODOLOGY

Nineteen locations across Poland were obtained which met the criteria for completeness of air pollution and meteorological measurements within city area. Qualitative analyses were performed and 11 locations were eventually selected for modeling. Locations for which there were significant seasonal data gaps were abandoned. In addition to the hourly concentrations of PM10 and weather parameters, the model uses:

- day of the year (1-366),
- hours (1-24),
- day of the week (1-7).

The model used in the analysis works on the principle of "learning" how the selected parameters affect the concentrations of air pollutants. Putting it very roughly, the script answers the question – if the temperature is -10°C, wind 2 m/s and it is 10:00 on the second day of January, etc. what is the concentration of PM10? The model compares the result with the actual measurements and "learns" until the result from the model best describes the measured concentrations. What is more, the advantage of this model is the separate calculation of indicators for each weather parameter, such as temperature for example. That is, the determination of what the concentration would be if the temperature was -10°C, or what the concentration would be if the wind speed was 1 m/s. Owing to this, it projects what PM10 concentrations are likely to occur during given weather conditions. Assuming that "average weather" is every day at every hour, the impact of meteorology on air quality is excluded. This very process is the normalization of concentrations with meteorological data. **Analyzing the long-term measurements period, we have answered the question: People or weather – what improves air quality? The model shows how much PM10 concentrations have fallen due to people's actions, entirely independent of the weather.**

The result of the analysis presented in Table 1 is a reduction of the average annual particulate matter concentration expressed in $\mu g/m^3$ in 2019 as compared to 2010 for each of the 11 stations analyzed, owing to human activity, irrespective of weather.

4 » FINDINGS

For more in-depth presentation purposes, two road traffic stations were selected: located in Warsaw at Niepodległości Ave and in Kraków at Krasińskiego Ave. Two factors were taken into account when selecting the stations: they both are of the same type and are located in the largest Polish cities. At both stations, measurements results indicate a decrease in PM10 concentrations during the analyzed period, of however, different levels: for Warsaw it was 15.1 μg/m³ and for Kraków 29.5 μg/m³ between year 2010 and 2019. The application of the random forest model indicated that after eliminating the influence of weather conditions (warmer and more windy winters), the reduction of concentrations is at 5.6 μg/m³ for Warsaw and 22.9 μg/m³ for Kraków respectively (Table 2 and Table 3).

TABLE 2.

AVERAGE ANNUAL CONCENTRATION OF PM10 FOR KRAKÓW – KRASIŃSKIEGO AVE: MODEL RESULTS AND ACTUAL MEASUREMENT OF CONCENTRATIONS AT THE GIOŚ STATION

YEAR	MODEL [μg/m³]	MEASUREMENTS [μg/m³]
2008	80.6	80.8
2009	78.8	78.6
2010	79.1	79.0
2011	73.5	76.6
2012	69.6	65.8
2013	66.2	59.7
2014	65.4	63.9
2015	66.8	67.8
2016	62.4	56.7
2017	58.1	55.3
2018	57.0	56.6
2019	56.2	49.5
	People's actions	Total (weather conditions and people's actions)
The difference in concentrations between 2010 and 2019	**22.9**	**29.5**

TABLE 3.

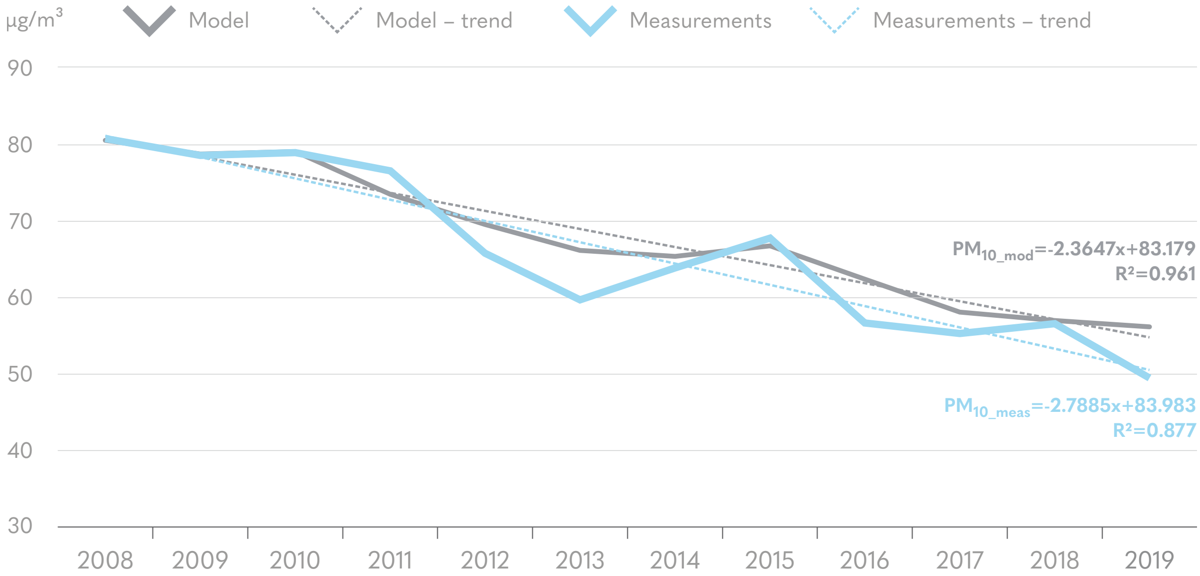
AVERAGE ANNUAL CONCENTRATION OF PM10 FOR WARSAW – NIEPODLEGŁOŚCI AVE: MODEL RESULTS AND ACTUAL MEASUREMENT OF CONCENTRATIONS AT THE GIOŚ STATION

YEAR	MODEL [µg/m³]	MEASUREMENTS [µg/m³]
2008	52.6	41.4
2009	49.4	50.4
2010	48.4	52.4
2011	46.5	49.1
2012	41.8	38.6
2013	40.3	39.7
2014	41.6	41.7
2015	42.7	41.1
2016	43.5	41.6
2017	43.9	42.1
2018	47.3	42.9
2019	42.9	37.3
	People's actions	Total (weather conditions and people's actions)
The difference in concentrations between 2010 and 2019	**5.6**	**15.1**

The following figures (Figure 1 and Figure 2) show the calculated and measurement average annual concentrations of PM10. There is also a trend line for model and measurements results, which is to determine the rate of change in concentrations during the investigated period. The trend analysis for Kraków indicates a steady decrease trend of PM10 concentration for both the actual data (average decrease of 2.79 µg/m³ per year, R^2=0.8771), and for the data derived from the model after the removal of the impact of changing meteorological parameters (average decrease of 2.36 µg/m³ annually, R^2=0.9603).

FIGURE 1.

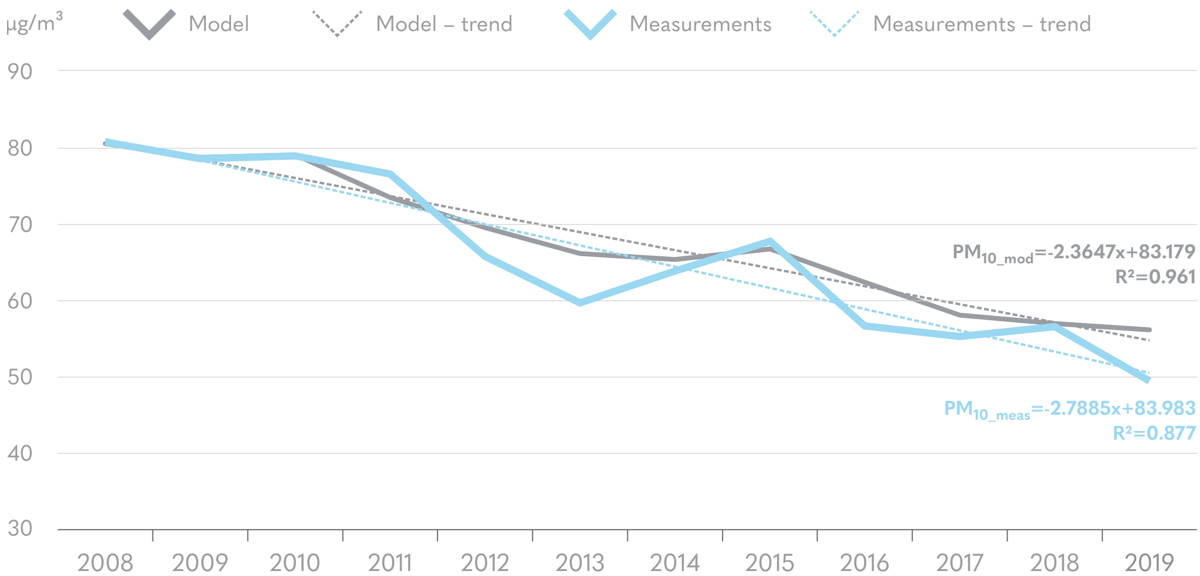
TREND FOR THE MEASUREMENT AND MODEL OF ANNUAL AVERAGE CONCENTRATIONS OF PM10 FOR KRAKÓW – KRASIŃSKIEGO AVE



In Warsaw, the trend line for both the measurements (R^2=0.5132) and the corrected values (R^2=0.4753) is a rather unsatisfactory representation, which does not make it possible to state whether the trend is clearly downward.

FIGURE 2.

TREND FOR THE MEASUREMENT AND MODEL OF ANNUAL AVERAGE CONCENTRATIONS OF PM10 FOR WARSAW – NIEPODLEGŁOŚCI AVE



The following set of graphs (Figure 3 and Figure 4) describes how the various components of the model (meteorology, days per year, time), affect the concentrations of pollutants which are calculated by the algorithm. Each meteorological factor affects PM10 concentrations differently. When viewing the graphs, note that each of them has a different scale for the Y-axis, i.e. the PM10 concentration values. This is directly related to the influence of a given weather parameter on the model result (concentrations value).

The factors that most affect air quality include air temperature (air_temp) and wind speed (ws). A drop in temperature below 5ºC entails an increase in the concentration of particulate matter. This is mainly due to an increase in the amount of emissions originating from the so-called low-stack emissions (burning of fuels for heating purposes), as the temperature decreases. In addition, the freezing weather in Poland is linked to the anticyclone (high pressure) weather, which is associated with deterioration of dispersion conditions (lower wind speed and temperature inversions). At very low temperatures (-20°C) concentrations are present at the level of 150 µg/m^3 in Kraków and over 60 µg/m^3 in Warsaw. Above 5ºC, the effect of thermal effects is almost unnoticeable. The second significant meteorological factor affecting the concentration of pollutants is the wind speed determining dispersion conditions. This relationship is of exponential character, and a significant increase in concentration is noted as the speed falls below 3 m/s. Indirect effects must be taken into account when assessing the effect of atmospheric pressure (atmospheric_pressure). Cyclonic systems (low pressure) are linked to weather with high wind speed and rain/snowfall, frequent exchanges of air masses, which contribute to good air quality. The high-pressure systems are characterized by a smaller pressure gradient and therefore lower wind speed as well as by the occurrence of temperature inversions, which is conducive to accumulating pollutants in the near proximity of emission sources.

Some of these interdependencies are similar for all locations. In general, the influence of meteorological factors in most of the cases analyzed will be similar. For example, concentration of particulate matter at -10°C at each location will be on average higher than at +10°C, although it will vary at each location. Similar results were obtained for days of week (week day), where weekdays showed more polluted air than weekends. However, for some variables there will be significant differences between the respective locations. This is true for time-related components among others (next day of the year – day_julian or time of day – hour). Different time emission profiles related to the activity of inhabitants in a given area will affect their diversified participation in the shaping of air quality. As an example, the volume of motor traffic may be presented (congestion may occur in specific hours or traffic may be distributed evenly throughout the day) or the dominant heating method (where there are more individual heating sources, the effect of the heating season on the pollutant concentrations in winter will be significant). In Warsaw, concentrations of PM10 are increased fairly evenly from 10 o'clock to the end of the day, while in Kraków the morning commuter peak (around 9 a.m.) and the evening rise (after 8 p.m.) are more obvious. The parameter that varies the locations significantly is the wind direction (wd). The wind blowing from the north has a direction defined as 0° (360°), while the wind blowing from the east has a direction defined as 90°, etc. In Kraków, the highest concentrations occur for the situation with the wind blowing from the north-east, and in Warsaw from the south.

FIGURE 3.

GRAPHS OF PARTIAL DEPENDENCE OF MODEL PARAMETERS WITH ONE-HOUR CONCENTRATIONS OF PM10 FOR KRAKÓW – KRASIŃSKIEGO AVE

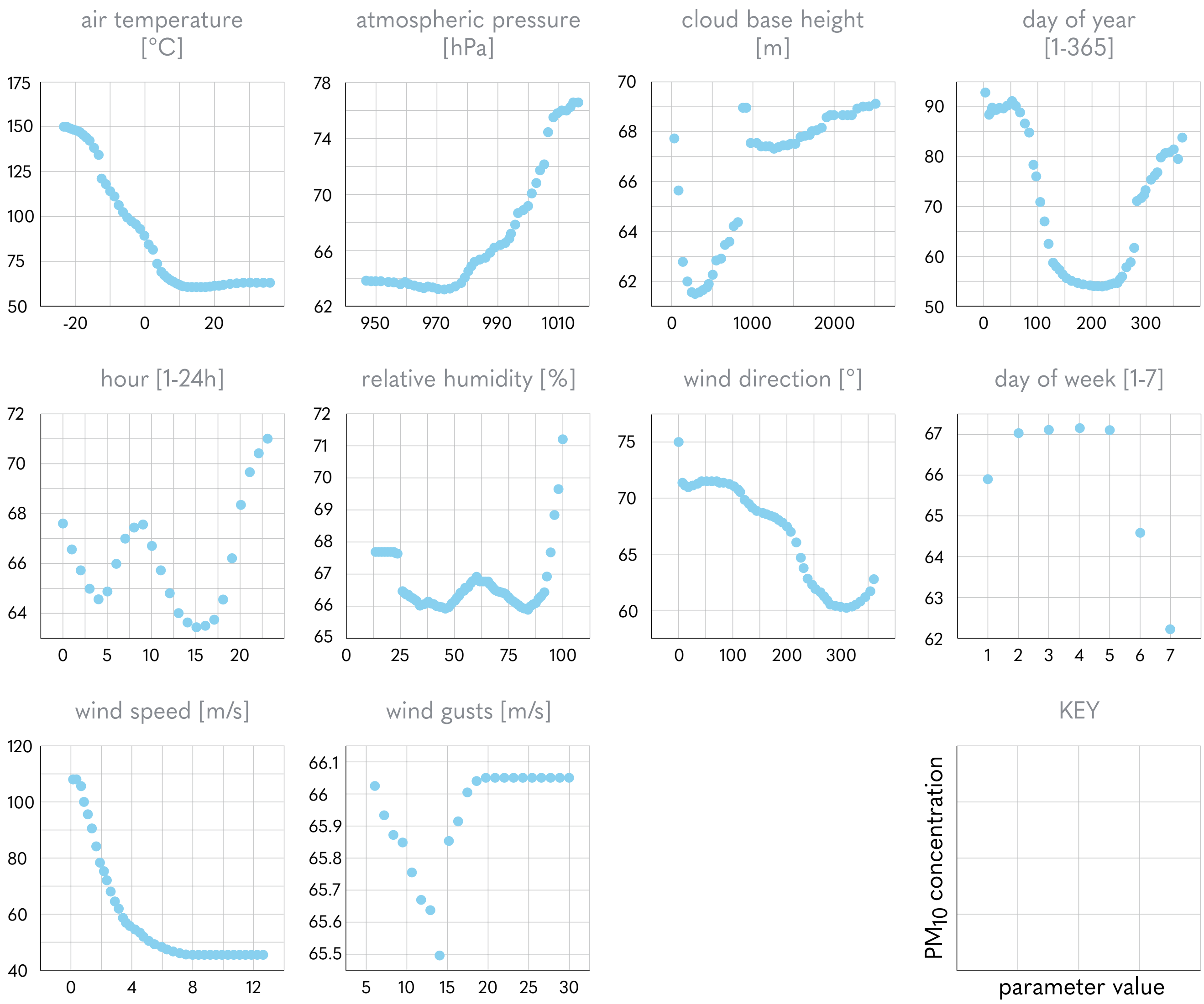
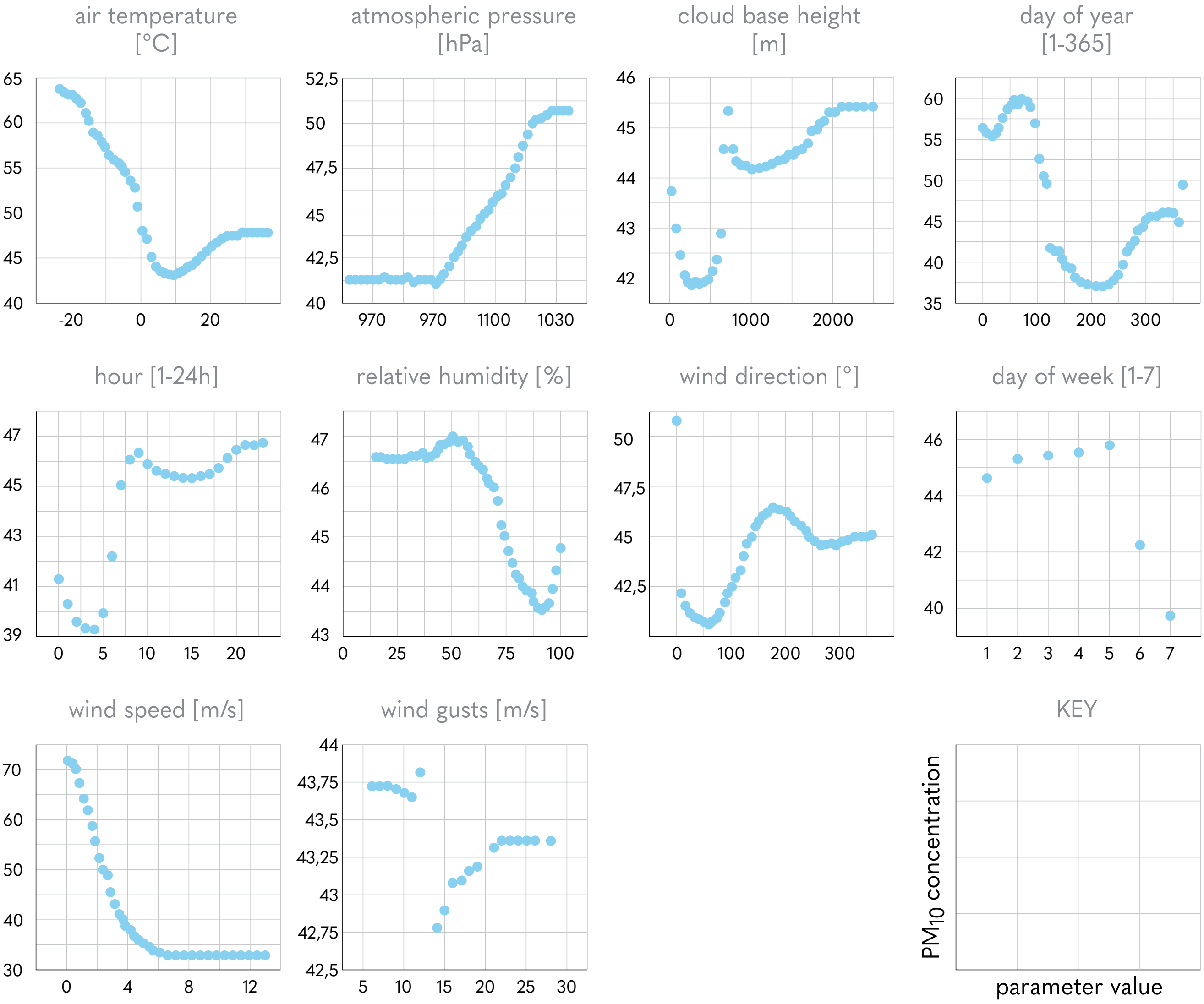


FIGURE 4.

GRAPHS OF PARTIAL DEPENDENCE OF MODEL PARAMETERS WITH ONE-HOUR CONCENTRATIONS OF PM10 FOR WARSAW – NIEPODLEGŁOŚCI AVE



The analysis of the direct relationship between particulate matter concentrations and meteorological parameters for selected years (examples of results for data from Krakow shown in Figures 5 and 6) also confirms the results obtained from the random forest model. With the same meteorological values, lower dust concentrations are recorded in subsequent years. This confirms that the amounts of pollutants entering the atmosphere has been decreasing in recent years.

FIGURE 5.

AVERAGE CONCENTRATIONS OF PM10 DEPENDING ON THE WIND SPEED FOR 2008, 2013 AND 2019 AT THE STATION IN KRAKÓW – KRASIŃSKIEGO AVE

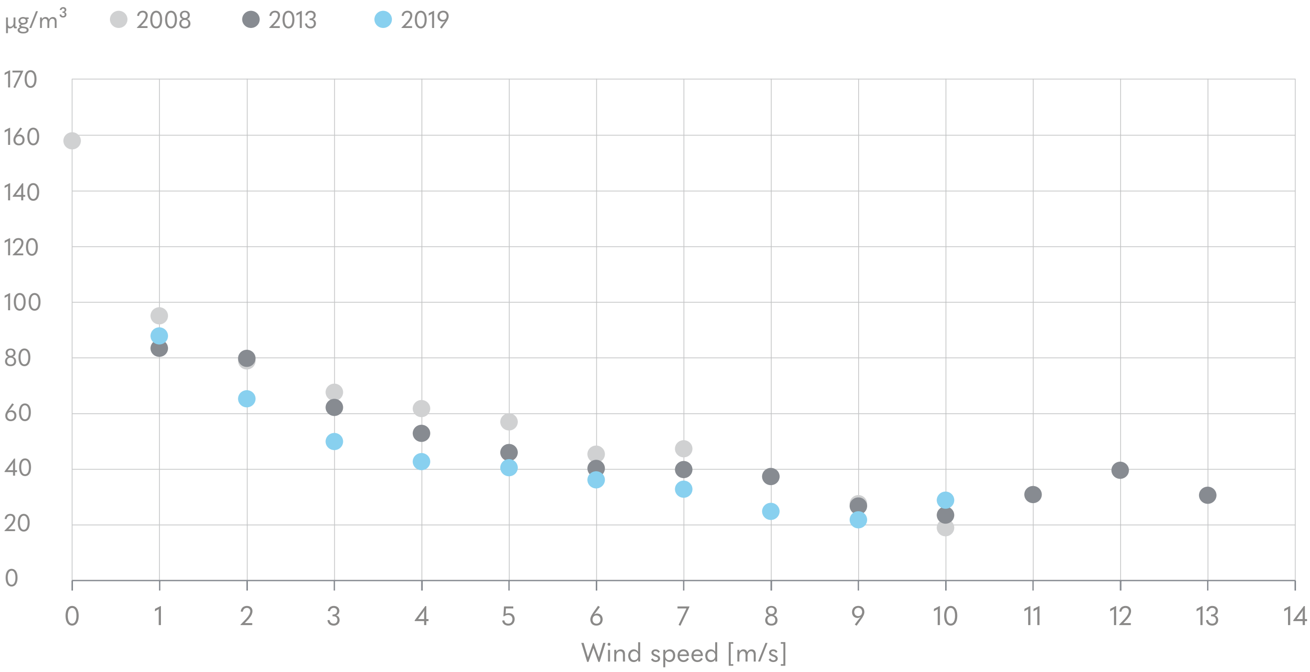
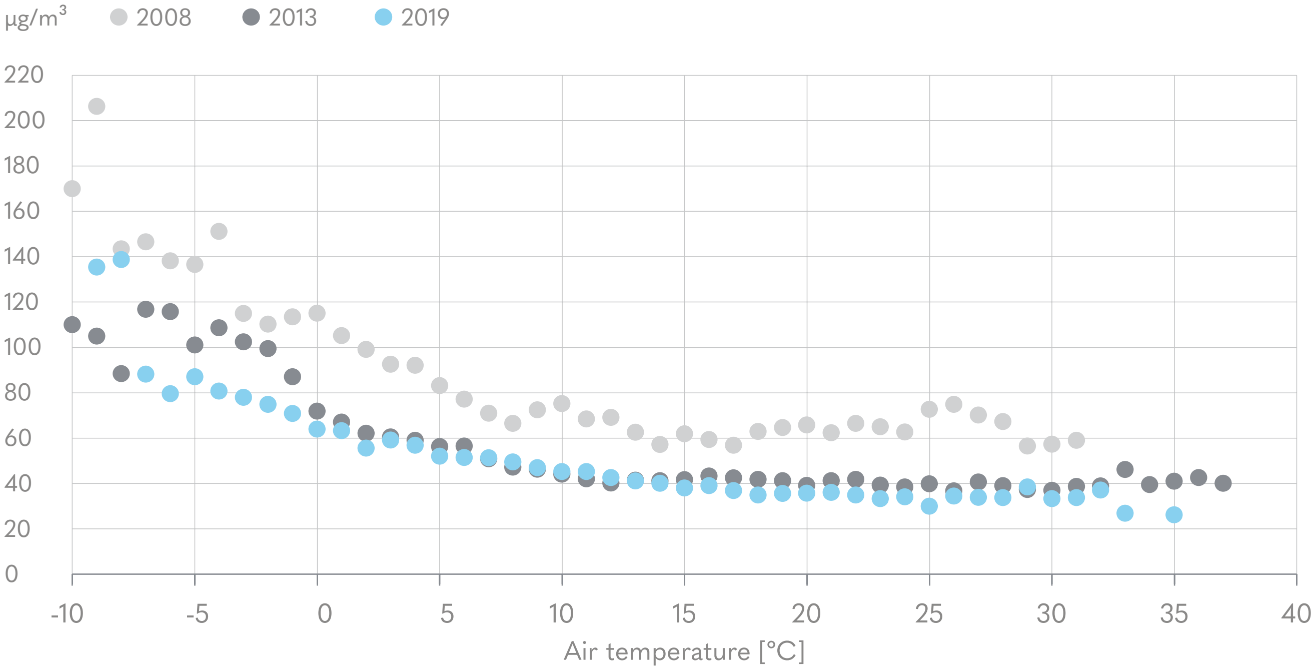


FIGURE 6.

AVERAGE CONCENTRATIONS OF PM10 DEPENDING ON THE AIR TEMPERATURE FOR 2008, 2013 AND 2019 AT THE STATION IN KRAKÓW – KRASIŃSKIEGO AVE



SOURCES:

1 Model: https://github.com/skgrange/rmweather. Examples of model author's calculations: Grange, S. K., Carllaw, D. C., Lewis, A. C., Boletta, E., and Hueglin, C. (2018). Random forest meteorological normalization models for Swiss PM10 trend analysis. Atmospheric Chemistry and Physics 18.9, pp. 6223--6239. [access: 22.01.2021]

2 Central Inspectorate of Environmental Protection — http://powietrze.gios.gov.pl/pjp/archives [available 22.01.2021]

3 Institute of Meteorology and Water Economy: //dane.imgw.pl/data/dane_pomiarowo_obserwacyjne/dane_meteorologiczne/terminowe/synop/ [access: 22.01.2021]

4 https://krakowskialarmsmogowy.pl/2020/12/29/kryzys-w-wymianie-kopciuchow-raport-polskiego-alarmusmogowego/; https://www.polskialarmsmogowy.pl/polski-alarm-smogowy/aktualnosci/szczegoly,likwidacjakopciuchow-stoi-w-miejscu---pas-podsumowujeprogramy-wymiany-kotlow,1403.html [access: 10.03.2021r.]

5 Measurements databank for GIOŚ: http://powietrze.gios.gov.pl/pjp/archives

6 IMGW-PIB public data: https://danepubliczne.imgw.pl/

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