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The concentration level of PM10 in southern Poland (Katowice, Kraków, and Rzeszów) during the year 2018

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Original article

Abstract

Human health and food quality are greatly affected by the state of the ambient air. In the European Union, Poland is considered as a country that has the most polluted air. The level of PM10 concentration exceeds the EU limit value in almost all the areas of Poland, but higher concentrations are registered in the southern regions, which are considered as the coal heartlands. Katowice, Kraków, and Rzeszów are three big cities in the southern part of Poland and are surrounded by coal mining industries. High PM10 concentrations are usually registered in these three cities, especially in the winter period. In 2018, the peak PM10 daily concentration occurred in the three cities at the same period (04/03/2018 in Rzeszów, 05/03/2018 in Kraków, and 05/03/2018 in Katowice). The aim was to identify the effect of each of the 8 coal mines that exist in Poland on the level PM10 concentration for the first week and March where the highest daily PM10 concentration for the year 2018 was registered. Using HYSPLIT Frequency analysis, the results showed that 100% of the particles coming from Bełchatów, Bolesław Śmiały, Halemba, Jas-Mos, Pniówek and Marcel Coal Mines hit Katowice region, and 10% from Bogdanka. While for Kraków, it was affected by 100% of the particles that are originated from Bolesław Śmiały, Pniówek, Halemba, and Jas-Mos Coal Mines and 10% Bogdanka, Bełchatów, and Marcel Coal Mines. Moreover, Rzeszów was the least affected city by the coal mines, 10% of the particles coming from Bogdanka, Bełchatów, Jas-Mos and Marcel, Halemba, and Pniówek Coal Mines attributed to high PM10 concentration during the first week of March 2018. Katowice and Kraków are more affected by the coal mines industry, Particulate Matter particles originating from the coal mines sites contribute to the high level of PM10 concentration.

Keywords

- PM10
- Coal Mines
- HYSPLIT trajectory frequency analysis
- Katowice
- Kraków
- Rzeszów

Authors contributions

A – Conceptualization
B – Methodology
C – Formal analysis
D – Software
E – Investigation
F – Data duration
G – Visualization
H – Writing – original draft preperation
I – Writing, reviewing & editing

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Conflict of interest

None declared.

Introduction

Particulate Matter (PM) continues to be a health and environmental threat in many countries due to the high concentration levels. Particulate Matter (PM) is one of the most dangerous air pollutants that is composed of complex mixtures of small particles and liquid droplets [1]. This form of pollution is primarily caused by factories, power plants, incinerators, motor vehicles, and a variety of other sources. The primary classification of particles is based on their aerodynamic diameter, which allows for the identification of two major groups: PM2.5 and PM10, i.e., particulate matter with sizes less than 2.5 um and larger than 10 um, respectively [2].

Based on the reports of the European Environment Agency (EEA), Poland registers concentrations that exceed the European Union limit values, especially for PM10 and PM2.5. In the list of the 50 most polluted cities in Europe in terms of PM2.5 published by the World Health Organization (WHO) in 2018, out of 50 cities, 36 were located in Poland (Figure 1) [3], and among those cities are Krakow and Katowice, and those cities were the subject of many research studies [2–4, 6]. Moreover, in the 2020 EEA report, the premature deaths attributable to PM2.5 in Poland were 46300 deaths, which was the third top number after Germany and Italy [7]. Besides, many types of research dealt with the high mortality rate and the characteristics of the PM particles in many regions of Poland [8–13].

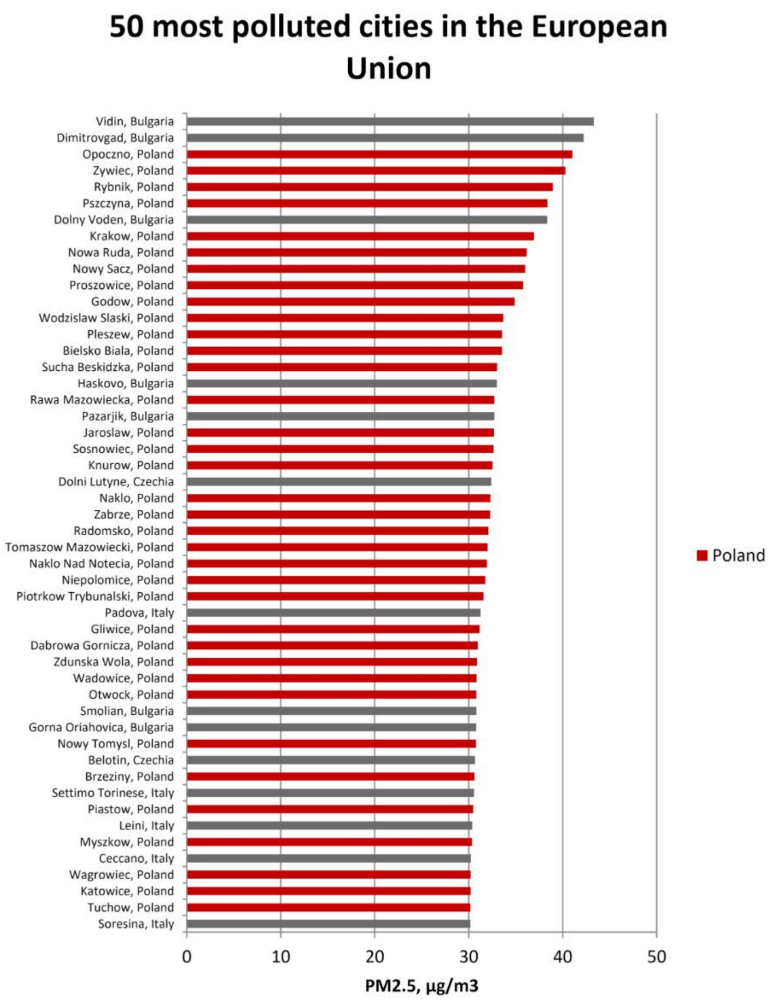


Figure 1. 50 most polluted cities in the European Union in 2018 [3]

One of the primary sources of PM particles in Poland is the coal mine industry. The country is dependent on coal to power homes and the economy, since it is the second-largest country in Europe after Germany in coal mining, and 70% of the electricity is generated from hard coal and lignite [14], and electricity production especially from coal and lignite have dangerous environmental effects [15, 16].

The PM10 concentrations statistics and maps concerning the daily limit value that is published every year in the European Air Quality reports, always show high PM10 concentrations registered in most of the parts of Poland. The map of the 90.4 percentile of PM10 daily concentrations in 2018 (Figure 2) represents the general situation of the high PM10 daily concentration that Poland suffers from. The map shows that the PM10 concentrations that were registered daily were higher than the European Standard daily limit value of 50 μg/m³ [7].

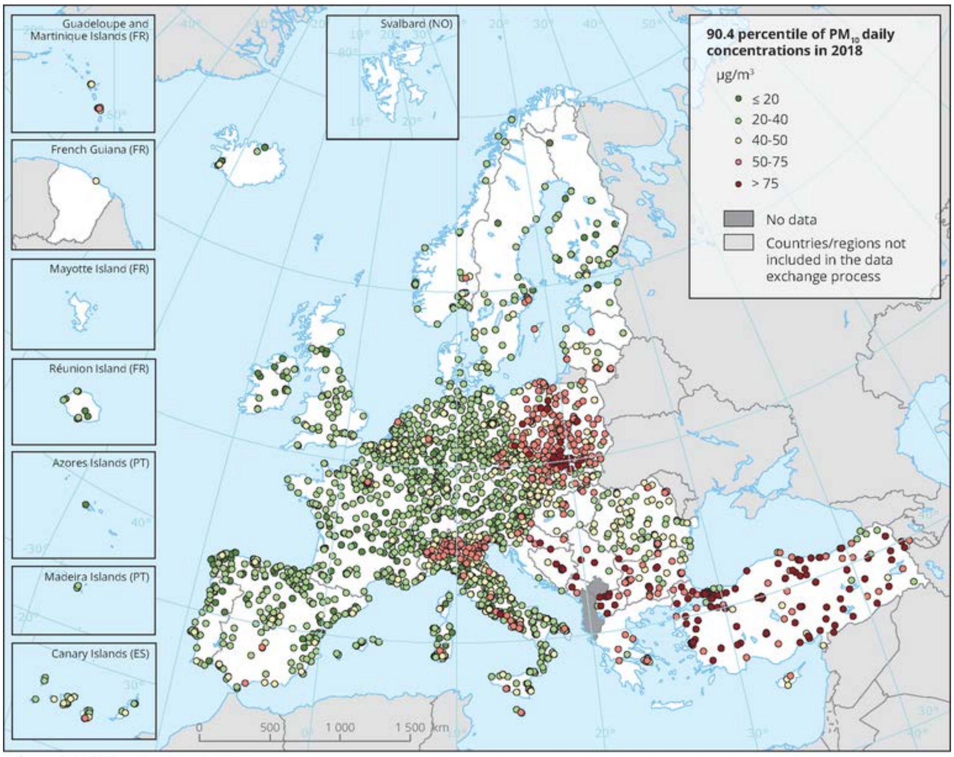
Moreover, concentrations of more than 75 μg/m³ can be seen in the Southern parts of Poland. Also, Poland has the problem of not having enough air quality measuring stations, particularly those measuring PM10 and PM2.5 [2], and that is one of the reasons that many researchers worked on using the Low-cost sensors to fill the gaps in the needed data [17–21].

The focus of this study is to determine the impact of each of Poland's eight coal mines on the level of PM10 concentration during the first week and month of March when the highest daily PM10 concentration for the year 2018 was recorded in the three cities of Kraków and Katowice and Rzeszów.

Materials and methods

Area of the study

The southern parts of Poland register higher PM10 concentrations than the other parts of Poland. The three cities Katowice, Rzeszów, and Kraków are the cities chosen for this study since they are three big main cities in the southern region of Poland.



Reference data: ©ESRI | ©EuroGeographics

Figure 2. Map of 90.4 percentile of PM10 daily concentrations in 2018 [7]

Figure 3. The geographical position of Kraków, Katowice, Rzeszów air quality stations, and the 8 coal mine sites

Figure 3 illustrates the geographical position of the three cities of the study, with also the geographical position of the 8 coal mine sites that exist in Poland.

PM10 daily average concentration in 2018

The data of the PM10 concentrations were retrieved from the website of the CHIEF INSPECTORATE FOR ENVIRONMENTAL PROTECTION, responsible for the air quality measurements and monitoring of the air quality stations in Poland (http://www.powietrze.gios.gov.pl/).

The winter is the period where the PM10 concentration is at its peak. In 2018, maximum concentration of daily average PM10 in Rzeszów, Kraków and Katowice were registered in the 4th, 5th and 6th of March respectively, with PM10 average daily of 151.8 μg/m^3, 174.8 μg/m^3, and 223.6 μg/m^3 in the Rzeszów-Nowe Miasto, Katowice ul. Kossutha 6, and Kraków, Aleja Krasińskiego air quality stations respectively (Figure 4).

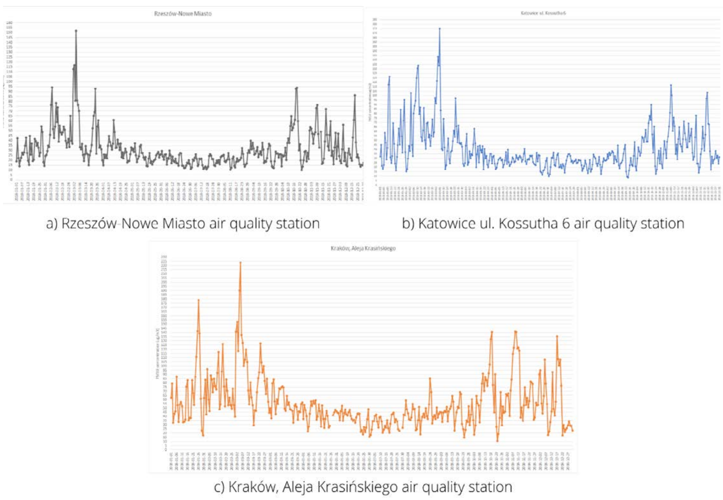


Figure 4. 2018 daily average concentration PM10 in Rzeszów, Katowice, and Kraków air quality stations

HYSPLIT trajectory frequency analysis

The Air Resources Laboratory (ARL) of the National Oceanic and Atmospheric Administration (NOAA) of the United States created the Hybrid Single-Particle Lagrangian Integrated Trajectory Model (HYSPLIT) [22]. The model is a hybrid of the Lagrangian and Eulerian approaches. HYSPLIT model is commonly used to create air mass forward and backward trajectories from known starting points. The HYSPLIT model is frequently driven by meteorological data from the Global Data Assimilation System (GDAS), which is utilized by the Global Forecast System (GFS) model to place observations into a gridded model space for initiating or initializing weather forecasts with observational data. GDAS data has traditionally had a horizontal resolution of 1°(GDAS1), corresponding to 100 km and 23 vertical layers [23], which is the meteorological data used in this research.

The trajectory frequency analysis is a method contained in HYSPLIT model that counts the number of trajectories that intersect with each grid point of the domain selected. The trajectory frequency will begin a trajectory from a single position and height for the period specified by the user, then add the number of times the trajectories pass over each grid cell on a user-defined grid. The model normalizes the results by either the total number of trajectories (counted only once) or the total number of endpoints passing through a grid cell [24].

A simulation was done for the period between the 1st and the 8th of March 2018 for each of the 8 coal mine sites to discover the percentage of the particles that originated from those Coal mine sites that intersect with the three cities selected for the study (Rzeszów, Katowice, and Kraków). Trajectory frequency analysis of 168H of the forward trajectory of PM10 particles was done for the 8 coal mine sites in the period mentioned above.

Results and discussion

The results of the trajectory frequency analysis show that Katowice is the most affected city by the coal mine sites followed by Kraków and Rzeszów.

As the frequency analysis counts the percentage of the particle trajectories that intersect with each domain, Figures 5 and 6 illustrate the frequency analysis results of the 8 coal mine sites and show that Katowice receives 100% of the particles emitted from Bechatów, Bolesław Śmiały, Halemba, Jas-Mos, Pniówek, and Marcel Coal Mines, and 10% from Bogdanka. Kraków, on the other hand, was impacted by 100% of the particles that originate from the Bolesław Śmiały, Pniówek, Halemba, and Jas-Mos Coal Mines and 10% from the Bogdanka, Bechatów, and Marcel Coal Mines. Besides, Rzeszów was the slightest influenced city by the coal mines, 10% of the particles coming from Bogdanka, Bełchatów, Jas-Mos and Marcel, Halemba, and Pniówek Coal Mines credited to PM10 concentration amid the primary week of March 2018.

Many coals mine sites have almost the same dispersion shape as Bolesław Śmiały, Halemba, Jas-Mos, Marcel, and Pniówek sites, and that is because those coal mine sites are close to each other geographically.

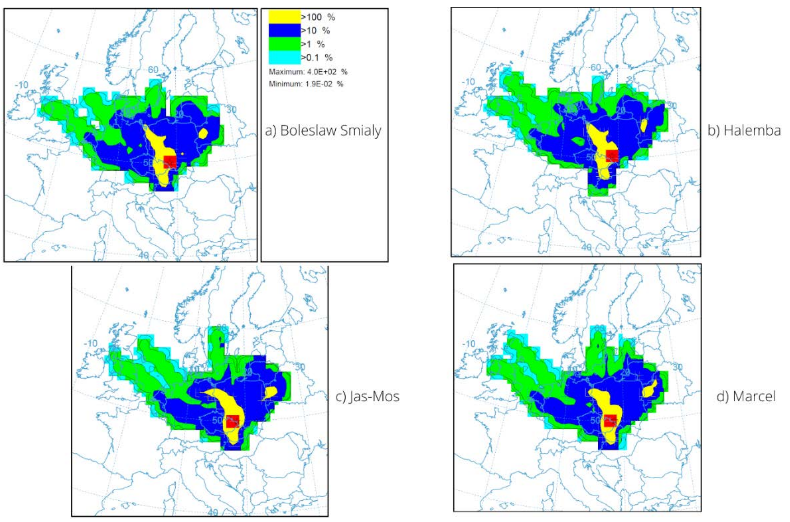


Figure 5. Trajectory frequency analysis of 168H of forward trajectory of PM10 particles from different coal mine sites

The star indicates the coal mine site in each picture; a) Bolesław Śmiały Coal Mine, b) Halemba Coal Mine, c) Jas-Mos Coal Mine and d) Marcel Coal Mine

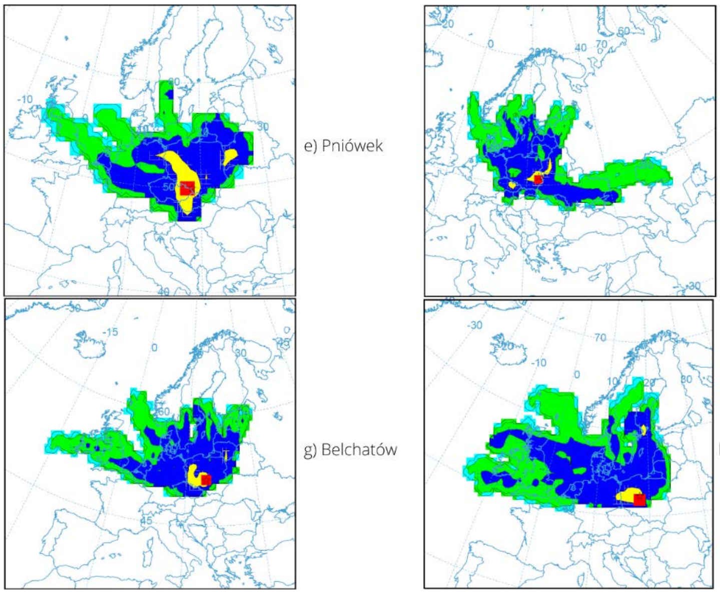


Figure 6. Trajectory frequency analysis of 168H of forward trajectory of PM10 particles from different coal mine sites

The Star indicate the coal mine site in each picture; a) Pniówek Coal Mine, b) Bogdanka Coal Mine, c) Bełchatów Coal Mine and d) Konin Coal Mine

Konin Coal mine site is the only site that didn't have any influence over the PM10 concentration during the 8 days of March 2018. Most of the particles emitted from that site affect the middle and the northern parts of Poland.

Seven out of eight coal mine sites contributed to the high PM10 concentration during the first 8 days of March 2018. While Katowice is the most affected city by the coal mine site due to its close geographical position, Krakow registered a higher PM10 concentration than the other two cities. The meteorological conditions also helped in the peak PM10 concentration, with low temperature, wind speed, boundary layer, and temperature inversion occurrence.

During the winter months, the recommended 24-hour PM2.5 and PM10 levels are consistently surpassed. According to [6], Kraków has a considerable PM enrichment with heavy metals, and PM10 and PM2.5 have the greatest values of non-carcinogenic risk. In addition, many other studies highlighted the problem of PM10 episodes in wintertime in Katowice, Kraków, and Rzeszów [11, 15] founding that the main source of PM particles are household heating systems, and coal burning. However, the coal mine industries remain as a source participating in the increasing of PM concentration levels throughout the year and not only in wintertime.

Even though Poland has made great progress in lowering the emission of gas and dust compounds, and dedusting and desulphurization of exhaust gases are used in coal mine industrial sites, it remains, and is expected to remain, among the EU countries with the highest emission rate [26]. Moreover, the results showed that a big percentage of the particles affects the PM concentration level and that is clearly seen in the measurements of the PM10 concentration, especially in the Upper Silesia Coal Region, where hard coal has been constantly mined for around 160 years. Additionally, besides the bad impact on air quality, the coal mine activities can have negative irreversible effects on the environment, such as terrain deformation, increasing the concentration of the mineral contamination in the soil like Zinc (Zn), Copper (Cu), Lead (Pb) and Cadmium (Cd), and abnormalities in hydrological systems [27].

Conclusions

The High PM concentration continues to be a big problem in many countries especially during wintertime, where the meteorological conditions are favourable for the PM particles to stay in the atmosphere for a longer time and to be trapped near the ground surface due to temperature inversions. In this study, coal mine sites participated in the high PM10 concentration registered in the three chosen cities for this study during the 8 first days of March 2018. However, the coal mine industry is not the only source of PM particles. The use of coal and wood in domestic furnaces and boilers is also considered a major source of PM particles. Thus, coal production and consumption will continue to help in the occurrence of high PM concentration, unless major decisions will be made to decrease those effects and to protect the public health of humans and the environment.

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