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The impact of Polish smog on public regional health – baseline results of the EP-PARTICLES study

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ABSTRACT

The EP-PARTICLES study was created to assess the impact of air pollution on the health and mortality of the population of Eastern Poland. The biggest cities of the region are Lublin, Białystok, Olsztyn, Rzeszow, and Kielce, whose inhabitants constitute less than 25% of the total population of the analyzed region. The vast majority of air pollution studies to date have been conducted in heavily polluted areas, where patients are exposed to moderate to extreme concentrations of pollutants. The composition of the pollution itself is also not without significance, as it differs significantly from the types of smog we are familiar with. The type of air pollution known as Polish smog is rich in compounds such as $PM_{2.5}$, PM_{10}, and polycyclic aromatic hydrocarbons (benzo(a)pyrene) from low emissions associated with household heating with solid fuels (coal, wood, and often also waste) and imposes detrimental effects on the health and life of the population, in particular in the context of cardiovascular effects. In this publication, we aimed to present the baseline results of the EP-PARTICLES investigators' research up to this point and propose steps aimed at changing the state of air quality and reducing existing exposure. Fields covered so far include atrial fibrillation, acute coronary syndromes, ischemic stroke, heart failure, renal function, and cardiovascular mortality.

KEY WORDS: stroke, air pollution, atrial fibrillation, acute coronary syndrome, renal function.

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INTRODUCTION

The EP-PARTICLES study was created to assess the impact of air pollution on the health and mortality of the population of Eastern Poland. The biggest cities of the region are Lublin, Białystok, Olsztyn, Rzeszow, and Kielce, whose inhabitants constitute less than 25% of the total population of the analyzed region. The area was chosen not coincidentally, starting with Podlaskie Voivodeship, known as the 'green lungs of Poland', and then spreading across the entire eastern part of the country. It is an area characterized by unique natural features, large forest areas, lack of factories and relatively low industrialization. Moreover, this region is widely known as the one with the lowest per capita income in the European Union, and therefore is characterized by low socioeconomic status. In the cold season, the residents' suboptimal heating choices are posing a major anthropogenic threat to air quality in the form of low emissions. Both the poor heating choices and the specific geographic location of Eastern Europe, especially at times of frosty Russian weather conditions characterized by high pressure, cold air, and sunshine, favor the phenomenon known as Polish smog. The air pollution, rich in compounds such as $PM_{2.5}$, PM_{10}, and polycyclic aromatic hydrocarbons (benzo(a)pyrene) from low emissions associated with household heating with solid fuels (coal, wood, and often also waste), imposes detrimental effects on the health and life of the population, in particular in the context of cardiovascular effects.

Overall, characteristics of the cities contribute to moderately increased levels of air pollution; however, due to the high percentage of solid fuels, these pollutants are characterized by a large percentage of suspended dust, especially of small diameter, and benzo(a)pyrene, which as extant literature describes, prove to be harmful to the health and life of the inhabitants.

The vast majority of air pollution studies to date have been conducted in heavily polluted areas, where people are exposed to moderate to extreme concentrations of pollutants [1, 2]. Looking at the analysis near Poland, a study performed in the region of the former Soviet republics revealed that air-pollution-related cardiovascular disease was responsible for an estimated 178,000 (UI: 112,000-251,000) premature deaths and for the loss of 4,010,000 (UI: 2,518,000-5,611,000) productive years of life (DALYs) in 2019 [3]. The composition of the pollution itself is also not without significance, as it differs significantly from the types of smog we are familiar with – London smog, rich in sulfur compounds, and Los Angeles smog, where nitrogen oxides predominate [4].

Long before this project was developed, Podlaskie Voivodeship caught our interest in terms of the impact of air pollution on mortality. We studied gender differences in the impact of smog on mortality, distinguishing cardiovascular mortality in the years 2008-2017. We observed that an increase of SO_2 concentration by 1 μg/m³ (relative risk [RR] = 1.07, 95% confidence interval (CI): 1.02-1.12; $p = 0.005$) and a 10°C decrease of temperature (RR = 1.03, 95% CI: 1.01-1.05; $p = 0.005$) was related to an increase in the number of daily deaths. No gender differences in the impact of air pollution on mortality were observed. In the analysis of the subgroup of cardiovascular deaths, the main pollutant that was found to have an effect on daily mortality was $PM_{2.5}$; the RR for a 10 μg/m³ increase of $PM_{2.5}$ was 1.07 (95% CI: 1.02-1.12; $p = 0.01$), and this effect was noted only in the male population [5].

The results have led us to acknowledge the need to deepen both the research scope and the studied area. We also posed questions of whether the recommendations concerning acceptable concentrations of air pollutants should be stricter, or whether is there even a safe concentration of SO_2 in the air at all. Since the publication of this study, World Health Organization (WHO) standards for air quality have become more rigorous for each of the pollutants [6].

The primary objectives of the project are to analyze the short- and long-term impact of air pollution on hospital admissions for acute coronary syndromes (ACS), atrial fibrillation (AF), ischemic stroke, and cardiovascular mortality. In addition, the impact of Polish smog on kidney function will also be investigated. Worth mentioning is also the fact that thanks to internationally recognized specialists, especially in the field of renal function and AF, we will be able to present a modern and comprehensive approach to the scientific method in the subject of not only air pollution and frequency of hospitalizations and mortality but also knowledge on the pathophysiology of renal dysfunction and induction of AF. With respect to AF we will work together with Prof. Gregory Y. H. Lip, whose research led to the creation of the CHA_2DS_2-VASc and HAS-BLED scores. As for the impact of air pollution on renal function, the experts contributing to the project are Prof. Vladimir Tesar and Prof. Goce A. Spasovski.

In this publication, we aimed to present the baseline results of our project up to this point and propose steps aimed at changing the state of air quality and reducing existing exposure.

DATA COLLECTION, METHODOLOGY, AND STATISTICAL APPROACH OF THE EP-PARTICLES STUDY

Data on hospitalization and cause-specific mortality were obtained from the National Health Fund and Central Statistical Office, respectively. Information on weather conditions was collected from the Institute of Meteorology and Water Management. Data on air pollutant concentrations are obtained in stages. In the first step, data on daily pollutant concentrations are collected from all local stations of the Voivodeship Inspectorate of Environmental Protection. Due to the underdeveloped network of air quality monitoring stations, we will use our novel air pollution modeling method created in cooperation with the Institute of Environmental Protection and the National Research Institute. Based on a patient's zip code, the model can determine patients' exposure based on current air pollutant concentrations from available stations and their flow based on winds, atmospheric pressure, sunshine, or humidity. The association between the short-term effect of air pollution and the occurrence of hospitalization, emergency room visit, and deaths will be estimated and expressed as odds ratios (OR) with 95% CI using a combination of conditional logistic regression (CLR) and distributed linear and non-linear lag models (DLNM) up to 7 days [7, 8]. The case-crossover (CCO) design is a recognized method to assess exposure to air pollution and mortality and morbidity. We are going to use CCO combined with DLNM models [9]. The threshold of statistical significance for all statistical analyses was a p-value < 0.05.

ATRIAL FIBRILLATION MORBIDITY

Our particular interest is to investigate whether air quality and pollution structure affect the short-term number of emergency room and hospital admissions for AF. Research on the impact of pollution on AF has not yet been conducted in Eastern Poland. However, air pollution is increasingly recognized as a contributor to cardiovascular disease risk, including cardiac arrhythmias [10]. A few studies have previously suggested a triggering effect of exposure to air pollution on acute exacerbation of AF [11-13].

Our first analysis focused on three cities of Eastern Poland – Kielce, Lublin, and Rzeszów – in the years 2016-

2020. During the analyzed period, 18,140 emergency hospitalizations for AF were recorded. The worst air quality was observed in Lublin (59% of days with exceeded WHO standards for particulate matter [PM]). In Rzeszow, an increase in $PM_{2.5}$ concentrations of 10 μg/m³ (OR = 1.04, 95% CI: 1.01-1.08; p = 0.02) and PM_{10} (OR = 1.03, 95% CI: 1.01-1.07; p = 0.02) resulted in an increase in emergency hospitalizations for AF. This effect was more pronounced in the population > 65 years of age and during the heating season ($p < 0.001$). The main air pollutant affecting an increase in emergency hospitalizations for AF in Lublin was NO_2 (OR for an increase of 10 μg/m³ = 1.05, 95% CI: 1.02-1.07, $p < 0.001$). A similar effect was observed in the population of Kielce residents (OR = 1.09, 95% CI: 1.001-1.018; p = 0.048).

This analysis revealed that changes in air pollution levels may increase the risk of sudden AF episodes, especially in the elderly. We associate the more pronounced health effects noted during the heating season with the particular toxic effects of Polish smog. These results have so far been presented at the Preventive Cardiology 2022 conference of the Polish Cardiac Society and are yet to be published. The upcoming analysis will focus on residents of the entire region of Eastern Poland.

ACUTE CORONARY SYNDROMES MORBIDITY

The impact of pollution on the incidence of ACS had been explored by us prior to the EP-PARTICLES study but was initially limited to the city of Bialystok. Two studies have been designed, one showing the overall population and the other focusing on a group particularly vulnerable to pollutants – elderly patients.

In the first one, a total of 2,645 patients with ACS, residing in the city of Bialystok, who were hospitalized between 2009 and 2017 were qualified for the analysis [14]. The number of patients admitted for ST-segment elevation myocardial infarction (STEMI), non-ST-segment elevation myocardial infarction (NSTEMI), and unstable angina (UA) was 791, 999, and 855, respectively. The daily concentration norm for $PM_{2.5}$ recommended by the WHO was exceeded on 24.58% of the days. The significant increase in the number of ACS hospitalizations was associated with an interquartile-range increase in NO_2 concentration, with an odds ratio of 1.08 (95% CI: 1.02-1.15, p = 0.01), 1.09 (95% CI: 1.01-1.18, p = 0.03), and 1.11 (95% CI: 1.00-1.22, p = 0.048) for patients with ACS, NSTEMI, and UA, respectively.

The study showed that the effects of air pollution and weather conditions on the number of ACS hospitalizations are also observed in cities with moderately polluted or good air quality. NO_2 was identified as the main air pollutant affecting the incidence of ACS.

The second study included 1618 elderly inhabitants of Białystok in Poland with a mean age of 75 years [15]. Elevated PM_{10} levels were associated with a higher number of hospitalizations for ACS on the day of exposure (mean [SD], 0.61 [0.78] vs. 0.44 [0.69]; $p < 0.001$), and this effect persisted in the subsequent days (1.07 [1.07] vs. 0.88 [1.00]; p = 0.02). An increase of PM_{10} concentrations by 10 μg/m³ was associated with an increase in the number of hospitalizations due to unstable angina, and significant effects were observed even after 6 days (rate ratio, 1.16; 95% CI: 1.03-1.32; p = 0.02).

In summary, we observed that increased exposure to air pollution, in particular, elevated PM_{10} levels, is associated with a higher incidence of ACS both on the day of exposure and over the following days in the elderly population.

In further analysis, we decided to compare the differences in the impact of smog on the ACS in two cities, Bialystok as a non-industrial city and Katowice as an industrial city [16]. We observed differences in the analyzed air pollutant concentrations. In Katowice, the daily concentration norm for $PM_{2.5}$ and PM_{10} was exceeded in 45.2% and 27.6%, respectively, which is noticeably higher than in non-industrial Białystok. The main results showed that the risk of air pollution-related ACS was higher in the industrial than the non-industrial area. The effect of NO_2 on the incidence of NSTEMI was observed in both areas. In the industrial area, the effect of PMs and SO_2 on NSTEMI and STEMI was also observed. A clinical effect was more delayed in time in patients with NSTEMI, especially after exposure to PM_{10}. Chronic exposure to air pollution may underlie the differences in the short-term effect between particulate air pollution impact on the incidence of STEMI.

The findings are consistent with most of the previous studies performed in Poland. Buszman *et al.* found that most of the analyzed air pollutants had an impact on STEMI incidence on the day of exposure, whereas NSTEMI admissions were observed the following day after the exposure [17]. None of the weather conditions were associated with increased admission rates for ACS. Konduracka *et al.* analyzed the influence of PM and NO_2 on the number of hospitalizations due to ACS in Kraków [18]. The main finding of this study is in line with our analyses, suggesting that in all age groups, exposure to $PM_{2.5}$ is associated with an increase in the number of hospitalizations due to myocardial infarction on the day of the exposure. Interestingly, the effect of PM_{10} was observed only with a simultaneous decrease of 1°C in the mean daily temperature. Januszek *et al.* performed an analysis focusing on the differences in the influence of PM_{10} in polluted and non-polluted cities. The authors of the study found that although air pollution had an impact on the increase in angioplasties due to ACS, the effect was more pronounced in non-polluted cities [19]. These results differ from our comparison of industrial and non-industrial areas, suggesting that the composition of PM and the average concentration of PMs may influence the short-term results.

RENAL FUNCTION

The impact of air pollution on kidney function for a long time was not in the spotlight of researchers. Our study "Exposure to air pollution and renal function" might have changed that as it was one of the first in Europe that focused on the medium- and short-term impact of air pollution on renal function [20]. As noted in this paper, many studies reported geographic variation in the burden of chronic kidney disease (CKD). Differences were noted even after adjusting for diabetes mellitus, arterial hypertension, and obesity, which are considered to be major contributors to renal function worsening. This fact suggests that variation in the burden of CKD is likely due to factors other than these traditional risk factors [21]. One of them is air pollution, which was confirmed in our analysis.

CKD was diagnosed approximately in every fourth patient. The odds of CKD increased with an increase in the annual concentration of $PM_{2.5}$ (OR for interquartile range (IQR) increase = 1.07; 95% CI: 1.01-1.15, $p = 0.037$) and NO_2 (OR for IQR increase = 1.05; 95% CI: 1.01-1.10, $p = 0.047$). The IQR increase in weekly $PM_{2.5}$ concentration was associated with a 2% reduction in expected eGFR (β = 0.02, 95% CI: −0.03 to −0.01).

This led us to the following conclusions: Short-term exposure to elevated air pollution levels was associated with a decrease in the estimated glomerular filtration rate (eGFR). The main pollutants affecting the kidneys were PMs and SO_2. In the medium-term, an increase in the annual concentration of $PM_{2.5}$ and NO_2 resulted in an increased number of patients with CKD.

ISCHEMIC STROKE MORBIDITY

According to the latest WHO report, the number of deaths due to stroke has increased and in 2019 it was responsible for over 6 million deaths [22]. The association between air pollution and ischemic stroke incidence has been well established. However, most of the studies performed so far have been conducted in highly polluted areas and there is still a lack of research in regions with low and moderate levels of air pollution.

In the EP-PARTICLES study, the aim was to investigate temporal variations of ischemic stroke incidence in the 'capital of the green lungs of Poland' – Bialystok – and its link with short-term exposure to air pollution [23]. In 11 years, from 2010 to 2020, we recorded 4838 cases of ischemic stroke with a daily mean of 1.3 cases. In Figure 1 we present the results as the OR and 95% CI associated with a 10 ug/m^3 increase in exposure to analyzed air pollutants. Moreover, the negative effect of air pollution was more noticeable in the cold season. When analyzing sex-specific differences, only women were vulnerable to smog.

The major findings were that smog influences the incidence of ischemic strokes, with the greatest effect in the cold season. The highest and the lowest frequencies of stroke incidence occurred at the beginning of the week and at weekends, respectively. The main pollutants affecting the number of hospitalizations were PMs as well as NO_2 and CO. A short-term effect of air pollution was noted even up to 3 days after exposure.

HEART FAILURE MORBIDITY

As Marc Lalonde suggested, the greatest determinants of human health are lifestyle and the environment [24]. Increasing life expectancy has contributed to making heart failure (HF) more common. Over 1.2 million people suffer from this condition in Poland [25].

Therefore, we performed an analysis of whether environmental and socioeconomic factors affect hospitalization rates due to HF [26]. To our knowledge, this is the first nation-wide study which focuses on the impact of socioeconomic and environmental factors on HF. We analyzed 1,618,734 HF-related hospitalizations in the years 2012-2019 in Poland. The data on HF-related hospitalization were obtained from the National Institute of Public Health — National Institute of Hygiene in Poland and aggregated to 380 counties (NUTS4) level as the 3-year means. Information on air pollutant concentrations and socioeconomic variables was obtained from the Chief Inspectorate for Environmental Protection and the Central Statistical Office, respectively. In our analysis, we used panel regression methods and the generalized least squares method. In Figure 2 we present medical, socioeconomic, and environmental factors and their effect on hospitalizations due to HF.

The results revealed that HF-related hospitalizations have been on the rise in the last decade (years 2012 to 2019) [26]. This trend was most noticeable in regions with low socioeconomic development and poor medical facilities. Moreover, exposure to particulate matter affected hospitalization rates. The study indicates that health policy measures including environmental and socioeconomic instruments may result in positive health outcomes.

CARDIOVASCULAR DISEASE MORTALITY

Following WHO reports, over 18 million people die annually due to cardiovascular diseases (CVD) in the world [22]. Furthermore, 50 thousand premature deaths can be attributed to the detrimental influence of air pollution in Poland [27].

We conducted 3 studies evaluating the link between exposure to air pollution and mortality due to CVD. The first study was conducted in 2 transit cities in north-eastern Poland – Lomza and Suwalki – in the years 2008-2017 and investigated CVD-related and pulmonary-related mortality [28]. It is worth noting that inhabitants of these 2 cities were particularly exposed to traffic-related air pollution due to the lack of ring roads during the analyzed period. In the second study, we analyzed mortality due to CVD in 3 cities of north-eastern Poland (Bialystok, Lomza, Suwalki) in the years 2008-

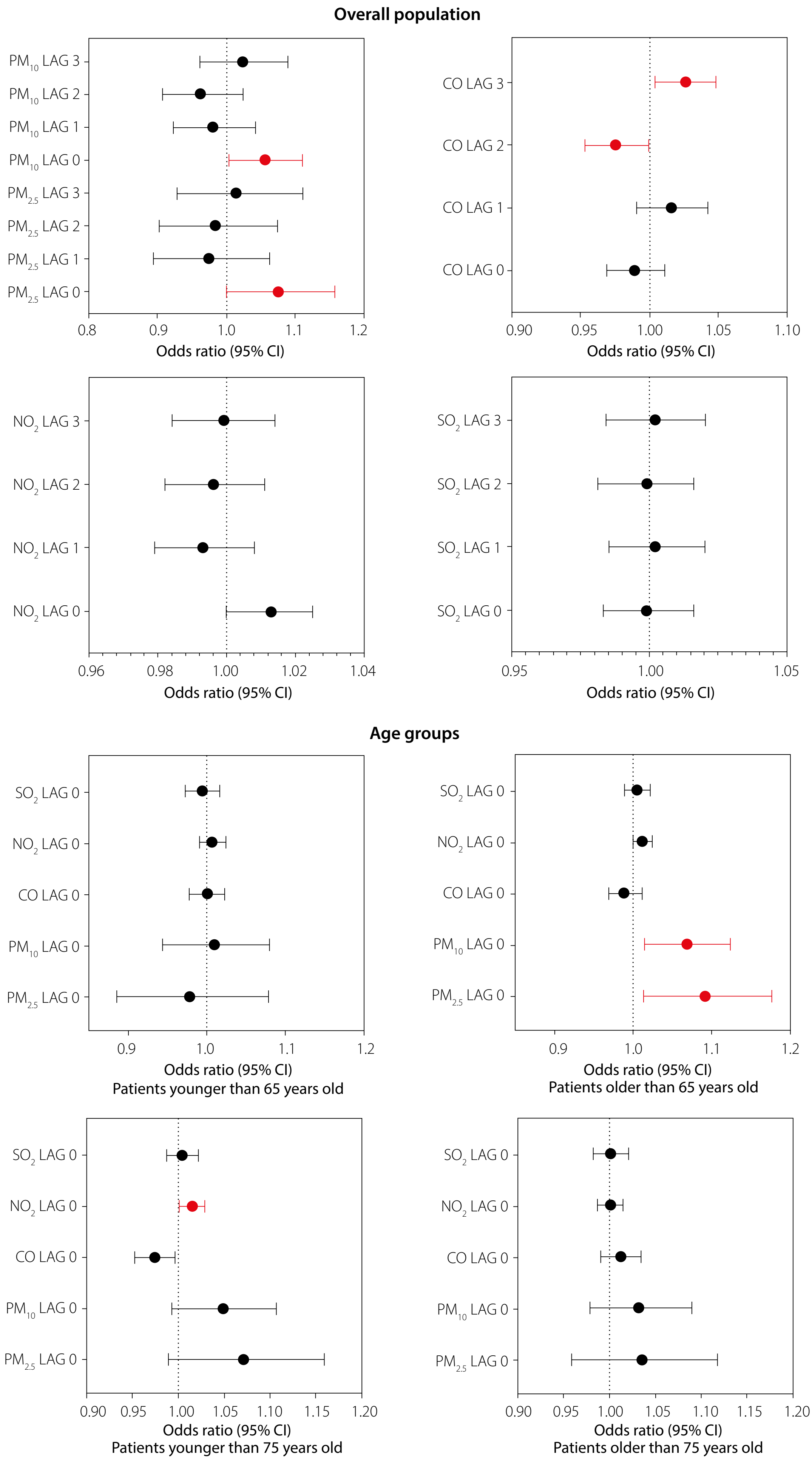

FIGURE 1. Short-term influence of exposure to air pollution on ischemic stroke incidence

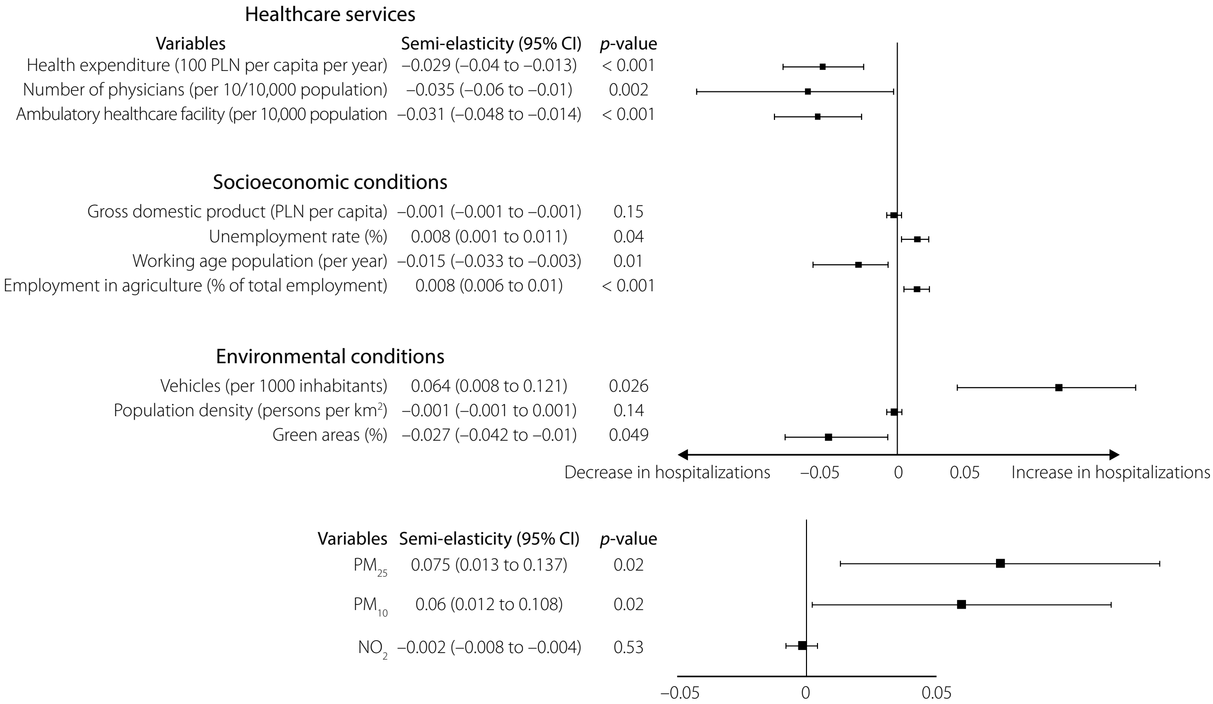

FIGURE 2. Influence of medical factors, socioeconomic and environmental conditions on hospitalization rates due to heart failure

2017 [29]. Even though this area is often described as the 'green lungs of Poland', we proved that it is not free of air pollution. In the last study, we decided to analyze the short-term influence of Polish smog on CVD-related and case-specific mortality due to ACS and ischemic stroke in 5 voivodeship capitals in Eastern Poland – Bialystok, Kielce, Lublin, Olsztyn, and Rzeszow – in the years 2016-2020 [30].

The conclusions drawn from all of the 3 aforementioned studies are similar. The short-term impact of particulate matter on CVD-related mortality is also observed in moderately polluted areas. Additionally, NO_2 significantly affected mortality due to CVD. The detrimental influence of air pollution was most noticeable in the cold season. We also found age- and sex-specific differences. Females and elderly people were the groups most vulnerable to Polish smog [30].

SUMMARY

To our knowledge, the studies we have designed and carried out are the first of their type in Poland. They prove that the negative effects of Polish smog affect not only large agglomerations but also small towns and villages. The results will help expand the current knowledge on air pollution and should serve as a basis for recommendations for prevention and policies at the local and global levels, particularly targeting risk groups such as the elderly and patients with comorbidities.

As researchers, we recommend a thorough analysis of our findings, collaborative research endeavors, and continuous dissemination of knowledge regarding air pollution. It is crucial to comprehend that the adverse health impacts resulting from smog in Poland are occurring at the moment and pose a threat to both present and future generations. Unless prompt action is taken, the situation is likely to deteriorate significantly.

In our assessment, it is imperative for researchers and environmental activists to undertake further endeavors in several key areas. Foremost among these is the enhancement of knowledge on established air quality standards and the adverse consequences associated with inhalation of polluted air. Insufficient awareness among the majority of our nation's populace regarding smog-related matters can be attributed to the dearth of information on available measures for individual protection and mitigation of the detrimental effects of air pollution. This issue is further compounded by a lack of individual efforts to curtail harmful emissions, a factor that holds particular significance in the context of low-emission reduction initiatives. Communities should proactively pursue measures aimed at safeguarding public health from the impacts of Polish smog. These measures may include the development of monitoring and early warning systems, the provision of resources to protect vulnerable populations, and the implementation of educational programs.

Moreover, in our opinion, air quality issues, in addition to individual actions, should not only be solved at the local and national levels but should be European-wide. The lack of effective solutions at the EU level results in major health inequalities between countries and does not allow for the effective implementation of prevention methods. Finally, it is crucial to acknowledge that in the endeavor to combat smog, due attention should also be given to other forms and sources of pollution, including but not limited to noise, light, soil and water contamination, and most notably, the impact of climate change, which act synergistically and mutually exacerbate the detrimental effects induced by individual pollutants.

Despite the growing body of knowledge in this field, still some issues need to be investigated. The results of the present study suggest that socioeconomic factors may play a crucial role in the spatiotemporal trends and the outcomes in the group of patients with HF. However, the relationship between socioeconomic inequality and air quality in Poland is not well understood yet. Although the influence of short-term exposure on human health was brought into the spotlight by our research, the influence of long-term exposure remains unknown. Hopefully, further research will bring answers to these questions.

FUTURE PERSPECTIVES OF EP-PARTICLES STUDY

Development of our research will include a comparison of the toxic effects of Polish smog with other types of smog on a pan-European scale, including London smog and photochemical smog. The analysis will therefore cover air pollution in various European countries, taking into account local specifics and the impact on residents. Our basic research is expected to lead to the implementation of an innovative model for the prevention of air quality-related diseases, based on the original "PM-years" index. In order to counteract the negative effects of smog on a pan-European scale, we plan to undertake international cooperation in the form of strengthening collaboration between European countries in the exchange of knowledge, technology, and best practices related to the reduction of air pollution. In addition, we intend to investigate how air pollution reduction affects the decrease in mortality and morbidity from the studied medical conditions. Based on a concentration-response curve, we will assess the positive health effects on premature morbidity and mortality associated with a 10 $\mu g/m^3$ reduction in air pollution. The change in prevalence will be estimated as a baseline morbidity and mortality rate with imputed percentage changes in morbidity risk associated with a 10 $\mu g/m^3$ increase in air pollution.

DISCLOSURE

The authors report no conflict of interest.

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AUTHORS' CONTRIBUTIONS

AK, MŚ, ŁK prepared research concept and design. AK, MŚ collected data and wrote the article. EJD, ŁK critically revised the article. All authors approved the final version of publication.