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THE ASSOCIATION BETWEEN AIR POLLUTIONS AND EMERGENCY HOSPITALIZATIONS DUE TO COPD AND ASTHMA ACROSS 16 POLISH CITIES: POPULATION-BASED STUDY

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Abstract
Objectives: In recent years numerous initiatives aimed at reducing air pollution have been undertaken in Poland. The general objective was to examine the correlation between air pollution measured by the level of particulate matter ≤10 μm in diameter (PM_{10}) and emergency hospitalizations due to chronic obstructive pulmonary disease (COPD) and asthma in 16 Polish cities (capitals of the regions). **Material and Methods:** The authors aimed to diagnose the situation across 16 cities over a 5-year period (2014–2019). Data on the number of hospitalizations was retrieved from the national public insurance system, the National Health Fund. A total number of 22 600 emergency hospitalizations was analyzed (12 000 and 10 600 in 2014 and 2019, respectively). The data on air pollution was accessed via the public register of the Chief Inspectorate for Environmental Protection air quality database. The authors of this article have used the data on PM_{10} daily exposure in each of the 16 cities in 2014 and 2019. Statistical methods included: non-parametric tests, a 2-stage modelling approach for time-series data, and multivariate meta-analysis of the results. **Results:** The results indicated that there was a statistically significant decrease in PM_{10} concentration in 2019 in comparison to 2014 in all cities, mainly in the autumn and winter season. However, the correlation between the improvement in the air quality and a decrease in emergency hospitalizations due to asthma and COPD turned out to not be as strong as expected. The authors observed a strong correlation between PM_{10} concentrations and hospitalizations due to asthma and COPD, but only when air quality norms were significantly above acceptable levels. **Conclusions:** Air pollution measured by PM_{10} concentration might be used as one of the predictors of the asthma and COPD emergency hospitalization risk, yet other factors like respiratory tract infection, health care organizational aspect, patient self-control, compliance and comorbidities should also be taken into consideration. Int J Occup Med Environ Health. 2024;37(1):110–27

Key words:
asthma, COPD, environmental health, PM_{10}, air pollutions, emergency hospitalizations

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INTRODUCTION

Air pollution is recognized as the single biggest environmental threat to human health [1]. The estimates show that 4.2 million premature deaths worldwide in 2016 were caused by exposure to outdoor air pollution [1]. In epidemiological studies, the level of fine particulate matter with a diameter of ≤10 µm (PM_{10}) is often used as an indicator of exposure to air pollution and represents the mass of particles that enters the respiratory tract [2]. The short-term exposure to PM_{10} causes an increase in mortality of approximately 0.5% for each increment of 10 µg/m^3 in daily concentrations [3]. Studies of the acute effects of air pollution also show evidence of increased mortality and morbidity related to the level of these solid particles, even at low to moderate concentrations [4–8].

Poor air quality is particularly dangerous for people suffering from a number of chronic diseases associated with the malfunctioning of the respiratory system [9]. In the case of respiratory diseases, it has been observed that poor air quality is associated with the exacerbation of respiratory symptoms [10,11], primarily for the deterioration of the course and control of bronchial asthma [11,12] and chronic obstructive pulmonary disease (COPD) [11,13] even with the need for emergency hospitalization. It has recently been confirmed that air pollution is also associated with the deterioration of the quality of life of patients with bronchial asthma [14–16].

For many years, some of the major Polish cities had the highest levels of air pollution across all European Union cities [17]. Numerous national and local programs and initiatives have been implemented to improve the air quality. The objective of the study was to examine the association between air pollution measured by the level of PM_{10} and emergency hospitalizations due to COPD and asthma in 16 major Polish cities in 2014 and 2019. The latter allowed the authors to assess whether the improvements in the air quality were associated with lower risks of hospitalizations. Air pollution is one of many factors that influence the course of COPD and asthma diseases. These other factors include: respiratory tract infection, health care organizational aspect, patient self-control, compliance with treatment, smoking, comorbidities [18,19]. The study did not analyze other causes of respiratory disease exacerbations.

Previous studies were focused on analyzing the association between the air pollution and respiratory diseases hospitalization in Poland [20–22] and other countries [10,23,24] as well as globally [13]. The added value of the study relates to both comprehensiveness of the hospitalization data (solely emergency hospitalizations due to COPD and asthma, including patients age and sex data) as well as broader territorial scope (16 cities, which are the capitals of all Polish regions) and time-horizon (comparison of the 2019 to 2014) of the analyses. Selecting only patients with asthma (category J.45 of the International Statistical Classification of Diseases and Related Health Problems, Tenth Revision [ICD-10]) or COPD (J.44) instead of including all group of respiratory diseases (as done in previous studies in Poland [21,22]) allows for a more detailed analysis of the problem. In case of patients with bronchial hyperresponsiveness air pollution may worsen the course of the disease and impact the need for urgent hospitalization [12,13].

MATERIAL AND METHODS

Data sources and preparation

Data on the number of hospitalizations was retrieved from the national public insurance system in Poland, the National Health Fund (NHF). The following criteria were applied:

- only emergency hospitalization (100% data completeness; planned admissions were excluded),
- due to COPD and/or asthma (categories J.44 and J.45 of ICD-10),
- in 16 Polish cities which are capitals of 16 Polish regions (localizations of hospitalizations were reported into the NHF database),
- in the year 2014 and 2019.

For each hospitalization, also collected was the data on: the exact date of admission, patient's age and gender. A total number of 22.6 thousands emergency hospitalizations was analyzed (12.0 thousand and 10.6 thousand in 2014 and 2019 respectively). In Poland, the emergency hospitalizations are covered solely by the public health insurance system, so the study used population-based data sources.

The data on air pollution was accessed via the public register of the Chief Inspectorate for Environmental Protection air quality database [25]. It provides information on the air quality standards per location of each measurement station. The authors have used the data on mean daily concentration of PM_{10} in each of the 16 cities in 2014 and 2019. Within each city the measurements have been chosen from exactly 1 monitoring station, preferably the one for which data were accessible for both years. In the case of really small number of cities for which a few such stations were available the authors have selected that one with the most complete data and/or with the strongest correlation with the mean taken from all stations. The choice of the PM_{10} concentration as the air pollution measure was done both due to the data availability (complete data available for both analyzed years in all 16 cities) as well as previous studies results, where the level of PM_{10} was shown as a good predictor of respiratory diseases exacerbations [14,22].

Statistical methods

Firstly, descriptive statistics by individual cities and 2 years (2014 and 2019) were conducted. Due to skewness of the distribution of both hospitalizations and PM_{10} concentration data, non-parametric tests (Mann-Whitney U test and ANOVA rank) were applied to detect differences in the levels of these variables across years and days of the week. Time-series data was analyzed using a 2 stage approach. In the first step of the modelling framework, the authors applied a differently structured distributed lag non-linear models (DLNMs) to reflect the so called exposure-lag-response associations. This technique allowed to take into account simultaneously both delay in the occurrence of the outcome triggered by the exposition as well as non-linear dependencies. The structure of imputed data which defines the space of lags and the space of exposition was the combination of 2 functions. In all models the lagged effect of PM_{10} up to 7 days was incorporated. The overdispersed Poisson distribution (quasi-Poisson) of daily emergency hospitalizations was assumed and to explore the temporal association between the risk of the outcome and PM_{10} concentration, the generalized linear models (GLM) were applied. Based on the literature [26] and initial data exploration, to avoid biased estimates, all models were adjusted to day of the week. It is crucial, because patients tend to avoid going to hospital over the weekend and may delay visit, postponing it to Monday and Tuesday [27]. Stratified analyses by age (≥65 years and <65 years) and sex were additionally conducted.

Potential nonlinear confounding was verified and the adjustment for seasonality and long-term time-trend was realized by modelling PM_{10} concentration as well as its lags by the polynomial splines. The effect of PM_{10} was specified using the piecewise quadratic functions and lagged effect of PM_{10} was modelled by a natural cubic splines with 4 equally distributed knots. A GLM model was used to smooth the function with respect to time, and natural spline with 10 degrees of freedom per year was incorporated. The PM_{10} emergency hospitalizations from respiratory disease associations cumulated over the lag days for each city were pooled in the second-stage analysis. Region-specific reduced coefficients and variance-covariance matrices were extracted from models set for individual cities and the multivariate meta-analysis was used to summarize results across all localizations. To better reflect the dose-response association the points of highest risk of hospitalizations were calculated (PM_{10} max concentration) and the effect sizes for this value of PM_{10} concentrations were presented. The results were expressed in terms of relative risks with 95% confidence intervals (CI). The extension of Cochran Q-test and I^2 statistic were presented to examine the heterogeneity between cities [26]. To check robustness of the findings the authors repeated all analyses in sex (males and females), year (2014 and 2019) and age (≥65 years and <65 years) strata.

Analysis was conducted using the R Software for Windows (v. 4.0.4, R Foundation for Statistical Computing, Vienna, Austria). A significance level was set at $p < 0.05$ and 2-tailed tests were performed.

RESULTS

Comparing years 2014 to 2019, the total number of hospitalized patients reported to the NHF database with main cause of disease, ICD-10, from groups J.44 and/or J.45 decreased from 1.53 million to 1.46 million (i.e., for about 4.4%), whereas the total number of people living in Poland was similar and only slightly lower (for about 0.25%) in 2019. In the case of emergency hospitalizations, a decreasing trend was also observed, and the total number of emergency hospitalizations in Poland due to COPD and/or asthma decreased from 58.6 thousand in 2014 to 45.4 thousand in 2019 (i.e., for about 22%). Decrease in hospitalizations occurred also in 16 cities taken into account in this study, and a decrease of >11% compared with 2014 was reported (12 000 and 10 600 in 2014 and 2019, respectively).

In both analyzed years, the lowest number of emergency hospitalization due to COPD and asthma per 10 000 population was reported in Łódź (9.2 in 2014 and 8.1 in 2019) and the highest in Opole (29.2 in both 2014 and 2019). The median level of mean daily PM_{10} concentration ranged in 2014 from 19.6 (Q1; Q3 13.2; 30.1) in Gdańsk to 39.6 (Q1; Q3 26.8; 57.7) in Wrocław and from 16.4 (Q1; Q3 12.2; 25.6) in Gdańsk to 27.3 (Q1; Q3 20.2; 41.9) in Kraków in 2019. Table 1 presents summary statistics for hospitalizations and mean daily PM_{10} concentration by 16 selected cities and across years 2014 and 2019. In both years, the majority of hospitalized patients were aged ≥65 years.

In 8 cities beneficial change in air pollution as well as decrease in the number of emergency hospitalizations were observed (both rate of hospitalization and PM_{10} concentration decreased in 2019 year compared with 2014). In 4 cities (Białystok, Gdańsk, Lublin and Opole) the number of hospitalizations in 2014 and 2019 increased slightly even though the improvement of air condition was observed during this period of time. In 3 cases (Kielce, Poznań and Szczecin) the rise in the number of hospitalizations was accompanied by a decline in the air pollution.

In both analyzed years, in the majority of cities, a clear pattern of lower number of hospitalizations during weekends was observed, with simultaneous excess of emergency admissions to the hospital on Mondays and Tuesdays (Table 2, Figure 1).

Analyses conducted separately for 4 seasons showed that there was statistically significant improvement in the air quality in 2019 in comparison to 2014, in the majority of cities, especially during the 3 seasons: summer, fall and winter, in 10, 15 and all 16 cities respectively (Table 3). The improvement in the air quality was accompanied by a statistically significant decrease in the number of hospitalizations in the following number of cities: 6 in summer, 4 in fall and 3 in winter (Table 3). However, in case of some cities and seasons an opposite pattern was observed, where statistically significant decrease in air pollution in 2019 vs. 2014 was accompanied by a statistically significant increase in the number of hospitalizations (e.g., fall in Kielce and Poznań, and winter in Gdańsk) (Table 3, Figure 2 and 3).

The results of the models predicting the risk of COPD and asthma emergency hospitalizations, depending on the mean daily PM_{10} concentration for total population

Table 1. Summary statistics for hospitalization and average daily PM_{10} concentration in 16 Polish cities, 2014 and 2019

Place	Hospitalizations				PM_{10} [µg/m³] (Me (Q1; Q3))
	total		men [n (%)]	age ≥65 years [n (%)]	
	n	n/10 000			
2014					
Białystok	458	15.5	266 (58.1)	269 (58.7)	26.5 (17.7; 38.0)
Gdańsk	1169	25.3	571 (48.8)	705 (60.3)	19.6 (13.2; 30.1)
Katowice	388	12.8	180 (46.4)	219 (56.4)	34.7 (21.1; 53.1)
Kielce	204	10.2	98 (48.0)	89 (43.6)	36.4 (26.4; 54.2)
Kraków	1485	19.5	720 (48.5)	827 (55.7)	35.3 (21.7; 55.6)
Lublin	861	25.1	392 (45.5)	473 (54.9)	29.3 (19.0; 41.9)
Łódź	654	9.2	307 (46.9)	393 (60.1)	26.3 (18.9; 37.5)
Olsztyn	421	24.1	205 (48.7)	266 (63.2)	28.1 (18.2; 38.2)
Opole	351	29.2	179 (51.0)	132 (37.6)	31.8 (20.6; 48.0)
Poznań	724	13.2	386 (53.3)	387 (53.5)	32.2 (18.5; 46.5)
Rzeszów	338	18.4	164 (48.5)	193 (57.1)	26.0 (17.9; 37.6)
Szczecin	531	13.0	255 (48.0)	209 (39.4)	20.0 (13.2; 31.3)
Toruń	505	24.9	232 (45.9)	277 (54.9)	22.3 (14.7; 35.6)
Warsaw	2759	16.0	1294 (46.9)	1584 (57.4)	25.6 (18.1; 37.2)
Wrocław	871	13.8	399 (45.8)	482 (55.3)	39.6 (26.8; 57.7)
Zielona Góra	271	22.8	123 (45.4)	144 (53.1)	22.5 (15.1; 36.6)
total	11 990	16.7	5771 (48.1)	6649 (55.5)	
2019					
Białystok	477	16.0	243 (50.9)	306 (64.2)	19.5 (13.4; 25.7)
Gdańsk	1211	25.9	626 (51.7)	818 (67.5)	16.4 (12.2; 25.6)
Katowice	276	9.4	124 (44.9)	153 (55.4)	25.7 (19.6; 39.3)
Kielce	269	13.8	149 (55.4)	157 (58.4)	26.1 (19.7; 38.2)
Kraków	965	12.5	419 (43.4)	570 (59.1)	27.3 (20.2; 41.9)
Lublin	876	25.8	423 (48.3)	565 (64.5)	22.6 (16.6; 31.4)
Łódź	554	8.1	222 (40.1)	353 (63.7)	22.4 (16.4; 31.5)
Olsztyn	293	17.0	105 (35.8)	215 (73.4)	17.2 (12.0; 24.8)
Opole	375	29.2	176 (46.9)	207 (55.2)	24.2 (17.1; 35.5)
Poznań	856	16.0	396 (46.3)	547 (63.9)	23.1 (15.0; 38.0)
Rzeszów	225	11.5	99 (44.0)	114 (50.7)	18.6 (13.8; 28.1)
Szczecin	589	14.6	290 (49.2)	291 (49.4)	16.4 (12.3; 22.5)
Toruń	331	16.4	165 (49.8)	180 (54.4)	22.4 (16.2; 33.6)
Warsaw	2389	13.4	1095 (45.8)	1482 (62.0)	19.6 (15.2; 27.5)
Wrocław	677	10.6	299 (44.2)	380 (56.1)	22.2 (16.6; 31.3)
Zielona Góra	246	17.5	98 (39.8)	156 (63.4)	17.3 (13.2; 25.1)
total	10 609	14.6	4929 (46.5)	6494 (61.2)	

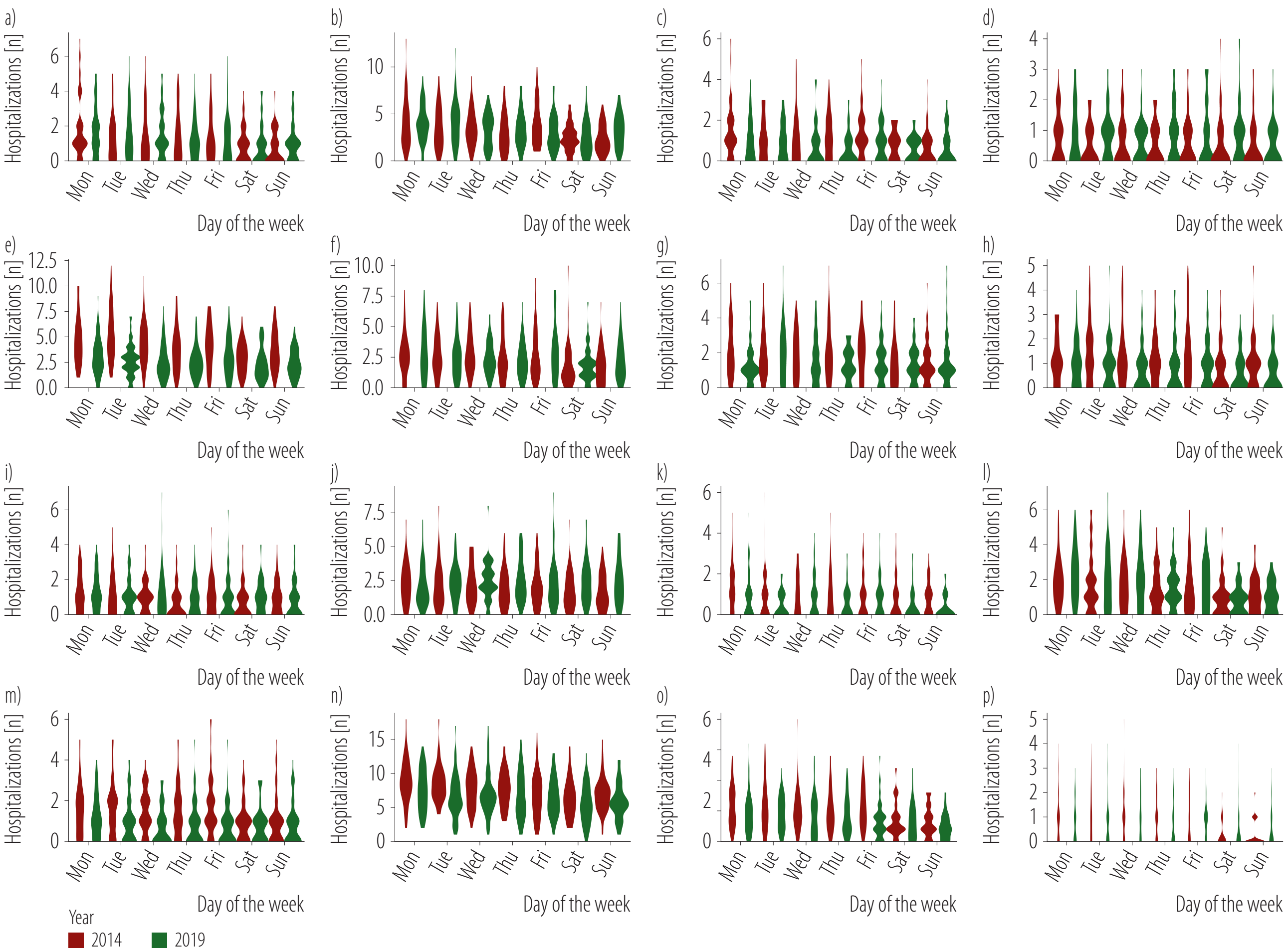
Table 2. Number of daily hospitalizations in 16 Polish cities by day of the week, Poland, 2014 and 2019

City	Hospitalizations [n] (Me (Q1; Q3))					
	2014			2019		
	weekday	weekend	p	weekday	weekend	p
Białystok	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	**<0.001**	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	**0.003**
Gdańsk	3.0 (2.0; 5.0)	2.0 (1.0; 3.0)	**<0.001**	4.0 (2.0; 5.0)	3.0 (1.0; 4.0)	**0.004**
Katowice	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	**<0.001**	1.0 (0.0; 1.0)	0.0 (0.0; 1.0)	0.146
Kielce	0.0 (0.0; 1.0)	0.0 (0.0; 1.0)	0.048	1.0 (0.0; 1.0)	0.0 (0.0; 1.0)	0.319
Kraków	4.0 (3.0; 6.0)	3.0 (2.0; 4.0)	**<0.001**	2.0 (2.0; 4.0)	2.0 (1.0; 3.0)	0.060
Lublin	2.0 (1.0; 4.0)	1.0 (1.0; 3.0)	**<0.001**	2.0 (1.0; 4.0)	2.0 (1.0; 3.0)	**0.014**
Łódź	2.0 (1.0; 3.0)	1.0 (0.0; 2.0)	**<0.001**	1.0 (1.0; 2.0)	1.0 (1.0; 2.0)	0.298
Olsztyn	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	**<0.001**	1.0 (0.0; 1.0)	0.0 (0.0; 1.0)	**0.006**
Opole	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	0.131	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	0.475
Poznań	2.0 (1.0; 3.0)	1.0 (1.0; 3.0)	**0.015**	2.0 (1.0; 3.0)	2.0 (1.0; 3.0)	0.863
Rzeszów	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	**0.038**	0.0 (0.0; 1.0)	0.0 (0.0; 1.0)	**<0.001**
Szczecin	1.0 (1.0; 2.0)	1.0 (0.0; 2.0)	**<0.001**	2.0 (1.0; 3.0)	1.0 (0.0; 1.0)	**<0.001**
Toruń	1.0 (1.0; 2.0)	1.0 (0.0; 1.0)	**<0.001**	1.0 (0.0; 1.0)	1.0 (0.0; 1.0)	0.488
Warsaw	8.0 (6.0; 10.0)	6.5 (5.0; 8.0)	**<0.001**	7.0 (5.0; 9.0)	5.0 (3.8; 7.0)	**<0.001**
Wrocław	2.0 (1.0; 4.0)	1.0 (1.0; 2.0)	**<0.001**	2.0 (1.0; 3.0)	1.0 (0.0; 2.0)	**<0.001**
Zielona Góra	1.0 (0.0; 1.0)	0.0 (0.0; 0.0)	**<0.001**	1.0 (0.0; 1.0)	0.0 (0.0; 1.0)	**<0.001**

P is based on Mann-Whitney U test.
Bolded are statistically significant differences between the groups.

in each of the analyzed cities is presented in Figure 4. In many cities the higher risk of hospitalization for higher concentration of PM_{10} can be observed, however the results are not equivalent for each city. The curves revealed non-linear shapes of the association. In most cities the pattern of increasing risk of hospitalization to some city-specific threshold of PM_{10} was observed. However, for high PM_{10} values, confidence intervals were wide and tails of the curves could be estimated with poor precision (to not darken visualization 95% CIs in graphs specific for each city were nor presented) (Figure 4).

Table 4 and Figure 5a present the result of the pooled meta-analysis for 16 cities for 2014, 2019 years and both joined together. Figure 5b, 5c and 6 present the same analysis for subgroups (females, males, year 2014 and 2019 separately, population <65 years and ≥65 years). Generally, in 2014 year and pooled 2014 and 2019 years statistically significant, non-linear positive association between mean daily PM_{10} concentration and the increased risk of hospitalization was observed. The risk of hospitalization increased up to some threshold levels of the PM_{10} daily mean concentration and stabilized above this threshold (Table 4). For example, for the total population, in 2014, the risk of hospitalization increased by 35% for the PM_{10} concentration level of 45, while for the pooled data 2014 and 2019 the risk of hospitalization increased by 21%



Wider sections of the violin plot represent a higher probability of the given number of hospitalisation; the skinnier sections represent a lower probability.

Figure 1. Number of hospitalizations by day of the week (violin plots) in 16 Polish cities: a) Białystok, b) Gdańsk, c) Katowice, d) Kielce, e) Kraków, f) Lublin, g) Łódź, h) Olsztyn, i) Opole, j) Poznań, k) Rzeszów, l) Szczecin, m) Toruń, n) Warsaw, o) Wrocław, p) Zielona Góra, Poland, 2014 and 2019

for the PM_{10} concentration level of 39. In most models the results for high concentration were insignificant, due to less precise estimations (small number of days with such high mean daily concentration of PM_{10}). In 2019 the pooled effect did not show any association, however high heterogeneity between cities was noticed. The trend of higher hospitalization risk was generally observed in all analyses in 2014 and both years. Yet the significant results were detected only in total population and in subgroup analysis by gender and age only in population of <65 years in restriction to the year 2014 (Table 4).

DISCUSSION

Air pollutions are one of the most important harmful environmental factors affecting respiratory functions. Thus, potentially, the most vulnerable group of patients are patients with BA and COPD.

In worldwide studies it has been confirmed for many years now, that exposure to particulate matter is associated with a greater likelihood of exacerbation of BA and COPD symptoms, as well as a greater number of hospital admissions [28–37].

In Poland, there is not as many studies concerning this matter [20–22] primarily because of difficulties in access-

Table 3. Comparison of daily mean of concentration of particulate matter ≤10 µm in diameter (PM$_{10}$) and number of daily hospitalizations by seasons across 16 Polish cities, 2014 and 2019

Variable	Spring			Summer			Fall			Winter		
	2014	2019	p	2014	2019	p	2014	2019	p	2014	2019	p
Daily mean PM$_{10}$ concentration [µg/m^3] (Me (Q1; Q3))												
Białystok	20.5 (15.3; 29.6)	22.1 (17.4; 29.8)	0.470	22.1 (16.9; 27.6)	15.7 (11.7; 21.1)	**<0.001**	38.6 (29.5; 48.6)	20.7 (15.5; 27.7)	**<0.001**	28.1 (19.2; 45.7)	18.4 (11.9; 26.2)	**<0.001**
Gdańsk	15.2 (10.7; 23.0)	19.0 (13.8; 26.3)	**0.004**	16.3 (11.8; 26.0)	15.1 (12.0; 20.1)	0.229	26.8 (16.5; 36.0)	22.2 (14.4; 35.7)	0.358	22.5 (15.9; 33.7)	13.4 (10.9; 20.6)	**<0.001**
Katowice	30.3 (20.4; 43.4)	27.4 (23.1; 36.1)	0.689	21.7 (16.8; 28.8)	19.6 (17.4; 22.4)	**0.025**	42.3 (34.3; 55.8)	32.9 (21.4; 48.1)	**<0.001**	57.7 (36.8; 76.0)	36.3 (24.1; 57.5)	**<0.001**
Kielce	31.9 (22.8; 43.6)	26.3 (20.1; 36.9)	0.055	27.8 (22.1; 35.6)	23.0 (19.2; 26.3)	**<0.001**	46.0 (34.1; 60.5)	30.8 (22.6; 43.4)	**<0.001**	49.0 (33.7; 69.6)	32.4 (18.6; 51.9)	**<0.001**
Kraków	27.7 (20.1; 39.5)	29.1 (22.3; 40.7)	0.299	22.5 (18.5; 28.2)	21.6 (19.0; 26.4)	0.424	46.7 (36.1; 60.0)	37.1 (23.4; 52.0)	**<0.001**	66.3 (41.2; 104.2)	31.0 (18.2; 58.4)	**<0.001**
Lublin	24.5 (14.9; 30.2)	22.6 (18.1; 30.0)	0.686	22.3 (15.8; 28.0)	18.6 (14.0; 22.9)	**<0.001**	39.4 (30.4; 54.3)	26.4 (18.2; 33.0)	**<0.001**	35.8 (27.5; 57.7)	28.1 (19.5; 43.3)	**0.006**
Łódź	20.9 (14.4; 27.9)	25.0 (19.2; 32.8)	**0.005**	22.4 (16.3; 29.0)	16.8 (14.0; 19.9)	**<0.001**	35.5 (26.2; 42.6)	26.8 (19.4; 33.2)	**<0.001**	35.3 (25.1; 48.9)	28.6 (16.8; 42.1)	**0.007**
Olsztyn	22.8 (16.1; 32.2)	19.6 (14.0; 28.6)	0.056	25.9 (18.0; 35.5)	12.0 (9.6; 17.9)	**<0.001**	32.5 (21.2; 41.9)	20.6 (14.0; 26.5)	**<0.001**	32.7 (20.0; 47.0)	18.9 (12.9; 28.6)	**<0.001**
Opole	27.0 (17.4; 37.9)	25.1 (18.7; 35.9)	0.888	23.4 (17.7; 30.2)	20.7 (17.0; 25.3)	0.132	39.9 (30.8; 55.9)	29.2 (19.7; 45.6)	**<0.001**	44.7 (26.4; 67.8)	26.1 (15.2; 46.3)	**<0.001**
Poznań	23.7 (15.2; 38.2)	23.2 (17.8; 31.2)	0.841	23.5 (16.7; 33.2)	14.6 (12.3; 19.9)	**<0.001**	41.8 (30.7; 53.0)	36.2 (23.3; 48.0)	**0.031**	43.9 (26.0; 55.1)	28.1 (15.6; 50.4)	**0.004**
Rzeszów	22.8 (16.4; 29.6)	19.5 (15.2; 29.3)	0.214	19.4 (15.7; 26.0)	14.7 (12.7; 18.1)	**<0.001**	33.5 (23.3; 43.0)	20.7 (15.2; 28.8)	**<0.001**	31.7 (25.7; 48.4)	26.0 (16.8; 42.2)	**0.023**
Szczecin	16.2 (12.2; 24.5)	17.9 (14.5; 24.3)	**0.016**	15.7 (10.8; 23.5)	13.7 (11.3; 16.9)	0.144	27.3 (16.5; 40.3)	18.2 (11.3; 26.6)	**<0.001**	31.0 (17.1; 46.7)	17.0 (11.9; 25.2)	**<0.001**
Toruń	18.2 (13.3; 25.4)	24.1 (19.5; 31.0)	**<0.001**	18.6 (12.6; 23.2)	19.8 (14.9; 26.7)	0.095	35.7 (20.7; 45.7)	26.8 (19.7; 37.1)	**0.036**	30.7 (20.6; 48.5)	21.1 (13.0; 36.9)	**0.005**
Warsaw	21.2 (15.7; 29.0)	22.2 (17.0; 28.3)	0.781	19.4 (15.6; 25.0)	15.5 (12.2; 17.7)	**<0.001**	36.1 (24.8; 46.2)	22.5 (17.1; 28.3)	**<0.001**	33.4 (25.8; 48.6)	21.4 (14.5; 35.3)	**<0.001**
Wrocław	32.1 (21.3; 44.4)	23.9 (18.9; 33.3)	**<0.001**	30.9 (23.1; 40.8)	18.1 (15.5; 22.4)	**<0.001**	47.5 (36.7; 64.7)	26.0 (17.6; 36.0)	**<0.001**	50.6 (34.0; 75.6)	23.6 (15.2; 40.2)	**<0.001**
Zielona Góra	17.8 (14.5; 26.4)	17.8 (13.3; 26.6)	0.357	16.0 (12.8; 22.7)	15.4 (12.6; 18.2)	0.106	30.3 (20.4; 41.1)	19.5 (14.9; 28.4)	**<0.001**	36.0 (22.7; 52.9)	18.8 (12.5; 27.4)	**<0.001**
Daily hospitalizations [n] (Me [Q1; Q3])												
Białystok	1.0 (0.0; 1.5)	1.0 (0.0; 2.0)	0.076	1.0 (0.0; 2.0)	1.0 (0.0; 2.0)	0.93	1.0 (0.0; 2.0)	1.0 (0.0; 2.0)	0.053	1.0 (0.0; 2.0)	1.0 (0.0; 2.8)	**0.047**
Gdańsk	3.0 (2.0; 4.0)	4.0 (2.0; 5.0)	0.102	2.0 (1.0; 3.0)	2.0 (1.0; 3.8)	0.487	4.0 (2.0; 5.0)	3.0 (2.0; 4.0)	**0.026**	3.0 (2.0; 5.0)	4.0 (2.3; 6.0)	**0.013**
Katowice	1.0 (0.0; 1.0)	0.0 (0.0; 1.0)	**0.025**	1.0 (0.0; 1.0)	0.0 (0.0; 0.8)	**<0.001**	1.0 (0.0; 1.8)	1.0 (0.0; 1.0)	0.18	1.0 (1.0; 2.0)	1.0 (0.0; 2.0)	0.192
Kielce	0.0 (0.0; 1.0)	1.0 (0.0; 1.0)	**0.014**	0.0 (0.0; 1.0)	0.0 (0.0; 1.0)	0.467	0.0 (0.0; 1.0)	1.0 (0.0; 1.0)	**0.04**	0.0 (0.0; 1.0)	1.0 (0.0; 1.8)	0.067
Kraków	4.0 (2.0; 5.0)	2.0 (1.0; 4.0)	**<0.001**	3.0 (2.0; 5.0)	2.0 (1.0; 3.0)	**<0.001**	4.0 (2.0; 5.0)	2.0 (1.0; 3.0)	**<0.001**	5.0 (3.0; 6.0)	3.0 (2.0; 4.8)	**<0.001**
Lublin	2.0 (1.0; 3.0)	2.0 (1.0; 4.0)	0.227	1.0 (1.0; 2.0)	1.0 (1.0; 2.8)	0.719	2.0 (2.0; 4.0)	2.0 (1.0; 3.0)	0.409	3.0 (2.0; 4.0)	3.0 (2.0; 4.0)	0.994
Łódź	2.0 (1.0; 3.0)	1.0 (1.0; 3.0)	0.345	1.0 (1.0; 2.0)	1.0 (0.0; 2.0)	**0.043**	2.0 (1.0; 3.0)	1.0 (1.0; 2.0)	**0.012**	2.0 (1.0; 3.0)	2.0 (1.0; 3.0)	0.769
Olsztyn	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	**0.005**	1.0 (0.0; 1.0)	1.0 (0.0; 1.0)	**0.026**	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	0.061	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	0.053

Variable	Spring 2014	Spring 2019	Spring p	Summer 2014	Summer 2019	Summer p	Fall 2014	Fall 2019	Fall p	Winter 2014	Winter 2019	Winter p
Opole	1.0 (0.0; 1.0)	1.0 (0.0; 2.0)	0.271	1.0 (0.0; 1.0)	1.0 (0.0; 1.0)	0.199	1.0 (0.0; 1.8)	1.0 (0.0; 1.8)	0.684	1.0 (0.0; 2.0)	1.0 (0.3; 2.0)	0.07
Poznań	2.0 (1.0; 3.0)	2.0 (1.0; 3.0)	0.205	1.0 (1.0; 3.0)	1.0 (1.0; 2.0)	0.903	2.0 (1.0; 3.0)	2.0 (2.0; 4.0)	**0.002**	2.0 (1.0; 3.0)	2.0 (1.0; 3.0)	**0.03**
Rzeszów	0.0 (0.0; 1.0)	0.0 (0.0; 1.0)	0.603	0.0 (0.0; 1.0)	0.0 (0.0; 1.0)	**0.003**	1.0 (0.0; 2.0)	0.0 (0.0; 1.0)	**<0.001**	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	0.104
Szczecin	1.0 (1.0; 2.0)	1.0 (1.0; 3.0)	0.389	1.0 (0.0; 2.0)	1.0 (0.0; 2.0)	0.868	1.0 (1.0; 2.0)	2.0 (1.0; 2.0)	0.479	1.0 (0.0; 2.0)	2.0 (1.0; 3.0)	0.052
Toruń	1.0 (0.0; 2.0)	1.0 (0.0; 1.0)	**0.026**	1.0 (0.0; 2.0)	0.0 (0.0; 1.0)	**<0.001**	1.0 (1.0; 2.0)	1.0 (0.0; 2.0)	**0.011**	1.0 (0.0; 2.0)	1.0 (0.0; 1.8)	**0.011**
Warsaw	8.0 (6.0; 9.0)	7.0 (5.0; 9.0)	0.082	6.0 (5.0; 8.0)	5.0 (3.0; 6.0)	**<0.001**	8.0 (6.0; 9.0)	6.0 (5.0; 8.0)	**0.002**	9.0 (7.0; 10.8)	8.0 (6.0; 11.0)	0.553
Wrocław	2.0 (1.0; 3.5)	2.0 (1.0; 3.0)	0.144	2.0 (1.0; 3.0)	1.0 (0.0; 2.0)	**0.005**	2.0 (1.0; 3.0)	2.0 (1.0; 3.0)	0.09	3.0 (2.0; 4.0)	2.0 (1.0; 3.0)	**0.007**
Zielona Góra	1.0 (0.0; 1.0)	1.0 (0.0; 1.0)	0.624	0.0 (0.0; 1.0)	0.0 (0.0; 1.0)	0.187	1.0 (0.0; 1.0)	1.0 (0.0; 1.0)	0.555	1.0 (0.0; 1.0)	1.0 (0.0; 1.0)	0.531

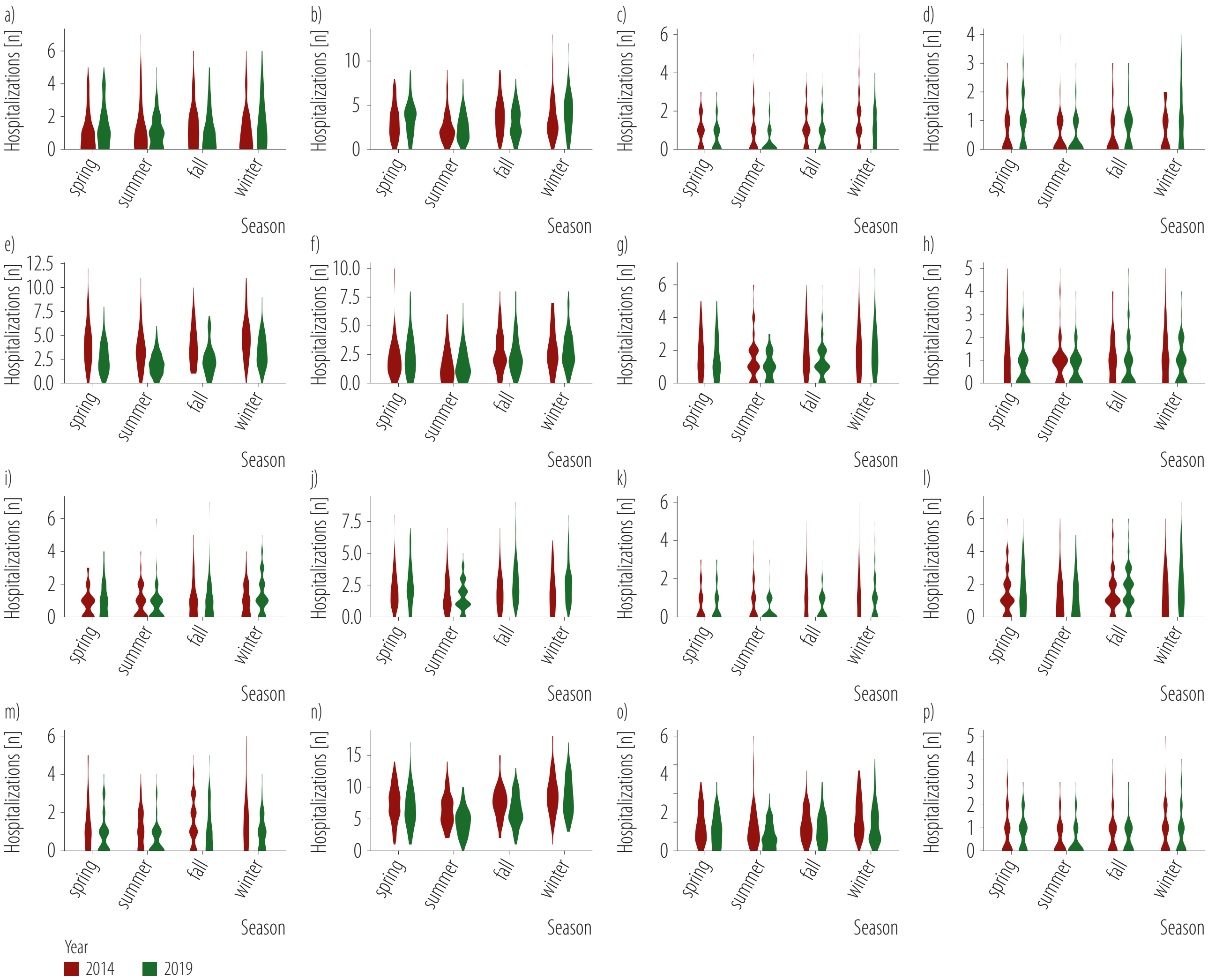
P is based on Mann-Whitney U test.
Bolded are statistically significant differences between the groups.

ing data, incomplete data on air pollution or limited access to information on the causes of hospitalization.

In the course of chronic diseases, such as BA and COPD, the elimination of factors responsible for the deterioration of the process of illness is crucial not only for the patient himself, but also for the healthcare system. Even though, poor air quality is only one of the factors, it is still unquestionably of great importance.

This study provided an overview of the association between air pollution measured by the level of PM_{10} and emergency hospitalizations due to COPD and asthma in 16 Polish cities in 2014 and 2019. The authors have selected years 2014 and 2019 for 2 reasons. One reason was the authors' belief that there was an improvement of air quality in between these 5 years. Secondly, the authors wished to avoid COVID pandemic impacts in their analyses. The authors qualified 16 cities for the analysis, significantly more than in previous studies [20–22]. Although, the authors had planned to research even more, only in those cities there was continuous air quality monitoring.

The analysis conducted by seasons showed a statistically significant decrease in PM_{10} concentration in all cities, mainly in the autumn and winter season. These results are in line with other studies indicating a positive effect of ongoing air quality improvement programs in Poland, focused, *i.a.*, on changes in heating systems [17,38]. For example, in Kraków, the daily average PM_{10} in winter decreased by 50%, in 2019 in comparison to 2014. There was also a statistically significant difference in the hospitalizations ratio between 2014 and 2019: reductions in hospitalizations were recorded, but not in all cities and not for each season (Table 3). The expected translation of the improvement in the air quality into a decrease in emergency hospitalizations due to asthma and COPD did not turn out to be so obvious. For example, there were cities where statistically significant decrease in air pollution in 2019 compared with 2014 was accompanied with

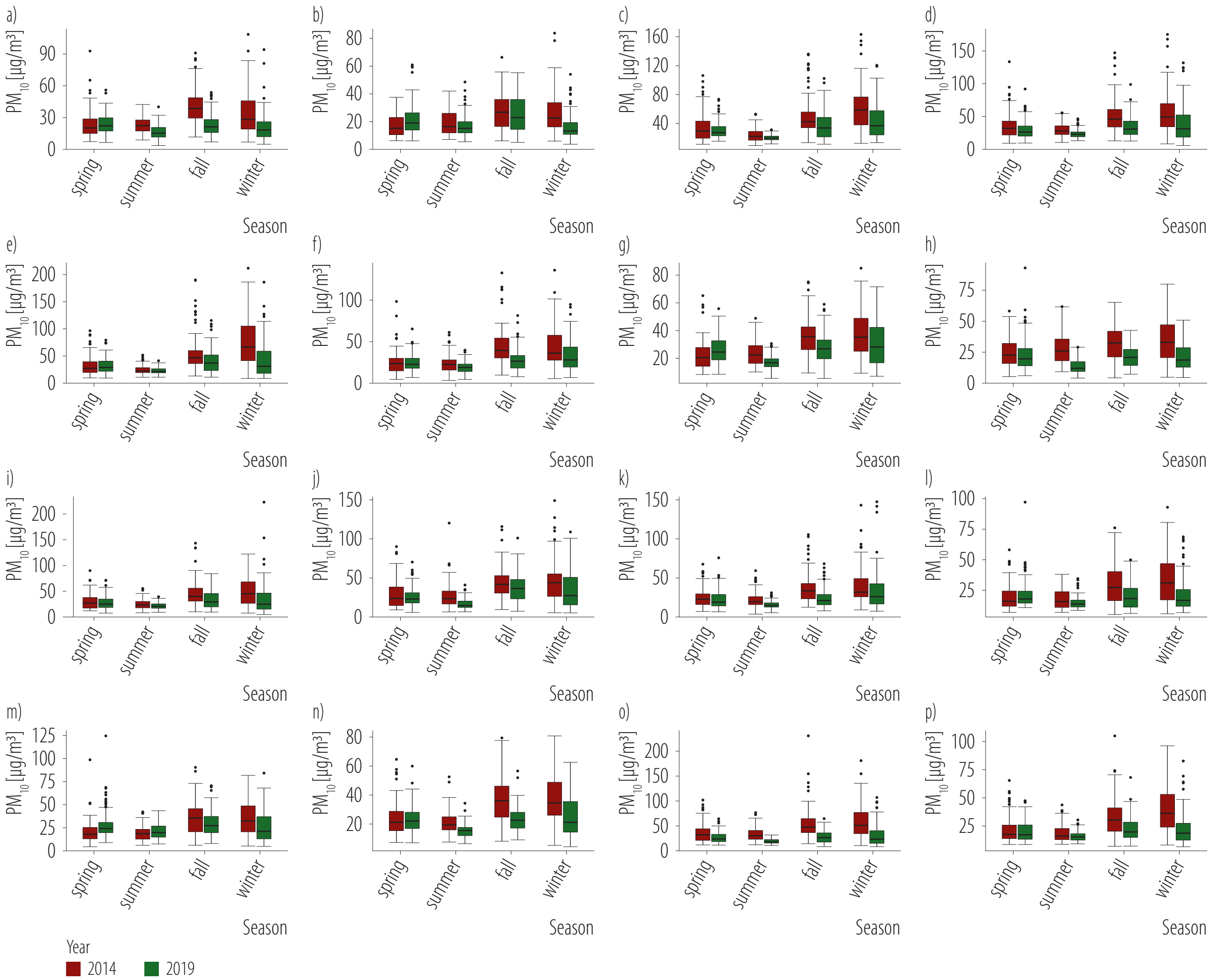


Wider sections of the violin plot represent a higher probability of the given number of hospitalisation; the skinnier sections represent a lower probability.

Figure 2. Number of daily hospitalizations by seasons (violin plots) in 16 Polish cities: a) Białystok, b) Gdańsk, c) Katowice, d) Kielce, e) Kraków, f) Lublin, g) Łódź, h) Olsztyn, i) Opole, j) Poznań, k) Rzeszów, l) Szczecin, m) Toruń, n) Warsaw, o) Wrocław, p) Zielona Góra, Poland, 2014 and 2019

statistically significant increase in the number of hospitalizations (Tables 3).

However, the meta-analysis summarizing data for all cities and predicting the risk of emergency hospitalization depending on the PM$_{10}$ concentration generally showed a consistent positive association. There were statistically significant effects in models with pooled years and in 2014, as well as in some subgroup analyses. The authors have found a statistically significant, non-linear relationship between higher PM$_{10}$ concentration and an increased risk of hospitalization. For example, in 2014 in the case of the whole population, the risk of hospitalization increased by 35% for the daily mean PM$_{10}$ concentration level of 45 μg/m^3 and stabilized above this threshold (Table 2, Figure 1). The fact that the results were statistically significant for the year 2014 and not for 2019 may suggest that PM$_{10}$ concentration might be a predictor of emergency hospitalization only for certain, sufficiently

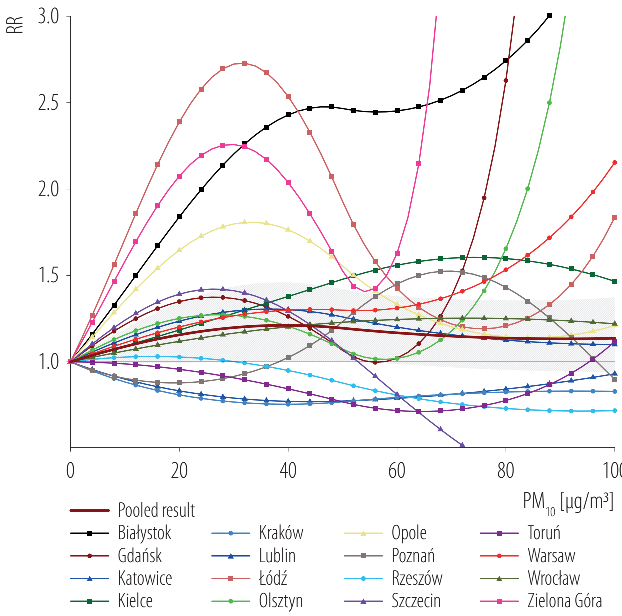


Boxes in the plots refer to quartiles of the distribution, horizontal lines inside plots denotes medians and points denotes outliers.

Figure 3. Mean daily concentration of particulate matter ≤10 µm in diameter (PM_{10}) by season (box plots) in Polish 16 cities: a) Białystok, b) Gdańsk, c) Katowice, d) Kielce, e) Kraków, f) Lublin, g) Łódź, h) Olsztyn, i) Opole, j) Poznań, k) Rzeszów, l) Szczecin, m) Toruń, n) Warsaw, o) Wrocław, p) Zielona Góra, Poland, 2014 and 2019

high pollution levels (for 2019 the PM_{10} threshold for the whole population was 25 µg/m^3). However, another reason might be growing public awareness of the need to monitor and avoid exposure to high levels of pollution [38]. Also, the general changes ongoing in the Polish health system organization within the last couple of years put a lot of emphasis on improving out-patient care and limiting hospital admissions [39]. This could also impact the improvement in asthma and COPD monitoring and disease management processes and limit the need of hospitalizations.

The general, positive relationship between air pollution and respiratory diseases hospitalizations has been shown also in more recent studies [21,22,24,40]. But each study has certain limitations and therefore the topic should continue to be explored. Yet, in the case of the study focusing solely on emergency hospitalizations due to COPD and asthma (instead of all types of hospitalization,



Pooled result is presented as dark red solid thick line and region specific estimates are reflected by dotted and dashed lines with different symbols.

Figure 4. Overall cumulative summary of particulate matter ≤10 µm in diameter (PM_{10}) – hospitalization association for total population of females and males in both years 2014 and 2019 together, Poland

including the non-acute ones and all respiratory diseases) allowed for reducing some of the confounding factors (e.g., including planned surgical admissions for other respiratory diseases) and conducting a more precise analysis. Results of this exploratory study confirm that high air pollution must be taken into account in the group of patients with bronchial hyperresponsiveness: asthma and COPD [12,13,41,42] and that some pre-existing conditions can increase the risk of emergency hospitalizations. Yet, air pollution constitutes one of many factors contributing to COPD and asthma emergency hospitalizations. Other factors, like respiratory tract infection, patients self-control, compliance with treatment, smoking, comorbidities should be also taken into consideration [18,19]. For example, a recent systematic review and meta-analysis by [18] showed that some strategies to support self-management in patients with asthma might reduce the risk of hospitalization and emergency department visit by 89.1% and 84.2%, respectively. Thus, future studies should focus on a broader perspective of the asthma and COPD monitoring and treatment processes (e.g., include also out-patients consultations and pharmaceutical prescriptions patterns).

The study had some limitations. The data from the air pollution measurement stations do not necessarily represent the exact, actual patient exposure to PM_{10}, as patients live at different distances from these stations, similarly as the place of hospitalization does not have to be the exact and nearest of exposure. Secondly, in term of comparing the situation between 2014 and 2019, the ongoing changes in the organization of healthcare system in Poland [43] means that the structure of hospitals (including those with emergency departments) might have changed in some cities, also the admission criteria might differ across time, cities and hospitals. The migration of patients from outskirts to considered cities as well as in opposite direction might have biased the number of hospitalizations in some of 16 studied cities.

There was another limitation in the studies, worth mentioning. The authors have not taken into consideration the potential confounders, such as: smoking, respiratory infections, co-morbidities, medicines, physical effort, allergen exposures, irritants, harmful occupational exposures, stress. This was not possible due to the lack of access to the mentioned data.

The socio-economic costs associated with exposure to polluted air and, in consequence, numerous hospitalizations are significant. Unfortunately, the authors are not able to accurately assess the total losses resulting from them, due to the number of factors that determine the condition of human health.

Being aware of the fact, that the control of chronic diseases depends on so many factors, the authors strongly believe, that the NHF should allow a complete access to the database. Thanks to this action, the next studies could be methodologically more improved.

Table 4. The association chronic obstructive pulmonary disease (COPD) and asthma emergency hospitalizations and mean daily PM_{10} concentration: the result of pooled analysis for 16 Polish cities, overall cumulative effect, meta-analysis of 16 regions, Poland, 2014 and 2019

	Participants									
	total	p	sex				age			
			females	p	males	p	<65 years	p	≥65 years	p
2014 and 2019										
PM_{10} concentration (RR (95% CI))										
0	1 (ref.)		1 (ref.)		1 (ref.)		1 (ref.)		1 (ref.)	
20	1.16 (1.00–1.34)		1.09 (0.90–1.33)		1.22 (0.97–1.53)		1.25 (0.97–1.63)		1.08 (0.89–1.31)	
40	1.21 (1.01–1.46)		1.14 (0.89–1.46)		1.30 (0.98–1.72)		1.34 (0.98–1.84)		1.12 (0.87–1.43)	
60	1.17 (0.99–1.38)		1.13 (0.91–1.41)		1.23 (0.97–1.56)		1.26 (0.98–1.62)		1.11 (0.90–1.38)	
max*	1.21 (1.01–1.46)		1.14 (0.89–1.45)		1.30 (0.98–1.73)		1.34 (0.98–1.84)		1.12 (0.88–1.42)	
I^2 [%]	1	0.697	1	0.864	16	0.181	30	0.030	1	0.470
2014										
PM_{10} concentration (RR (95% CI))										
0	1 (ref.)		1 (ref.)		1 (ref.)		1 (ref.)		1 (ref.)	
20	1.23 (1.02–1.49)		1.25 (0.95–1.64)		1.26 (0.96–1.66)		1.37 (1.01–1.84)		1.14 (0.89–1.46)	
40	1.34 (1.05–1.73)		1.37 (0.96–1.95)		1.39 (0.98–1.98)		1.50 (1.02–2.20)		1.24 (0.89–1.72)	
60	1.32 (1.06–1.66)		1.33 (0.97–1.83)		1.36 (0.98–1.88)		1.36 (0.97–1.91)		1.28 (0.95–1.73)	
max**	1.35 (1.05–1.73)		1.37 (0.96–1.95)		1.40 (0.98–1.99)		1.50 (1.02–2.20)		1.29 (0.96–1.73)	
I^2 [%]	1	0.974	1	0.618	1	0.628	3	0.411	1	0.573
2019										
PM_{10} concentration (RR (95% CI))										
0	1 (ref.)		1 (ref.)		1 (ref.)		1 (ref.)		1 (ref.)	
20	1.07 (0.81–1.42)		0.95 (0.65–1.40)		1.13 (0.77–1.66)		0.95 (0.58–1.56)		1.15 (0.76–1.73)	
40	1.05 (0.77–1.44)		0.89 (0.57–1.41)		1.19 (0.73–1.93)		1.00 (0.56–1.77)		1.07 (0.67–1.71)	
60	0.95 (0.74–1.21)		0.82 (0.58–1.16)		1.17 (0.78–1.78)		1.14 (0.75–1.74)		0.84 (0.61–1.17)	
max***	1.08 (0.79–1.47)		1.00 (1.00–1.00)		1.20 (0.64–2.25)		1.37 (0.74–2.53)		1.15 (0.74–1.78)	
I^2 [%]	28	0.046	1	0.756	22	0.097	17	0.169	26	0.062

I^2 – heterogeneity between cities.
PM_{10} concentration for which maximal risk of hospitalization was observed in total/female/male/<65/≥65 population was equal to * 39/46/39/39/46 in 2014 and 2019 years, ** 45/44/44/38/74 in 2014 year, *** 25/0/n.a./ n.a./23 in 2019 year (n.a. when estimate was increasing without stabilization).

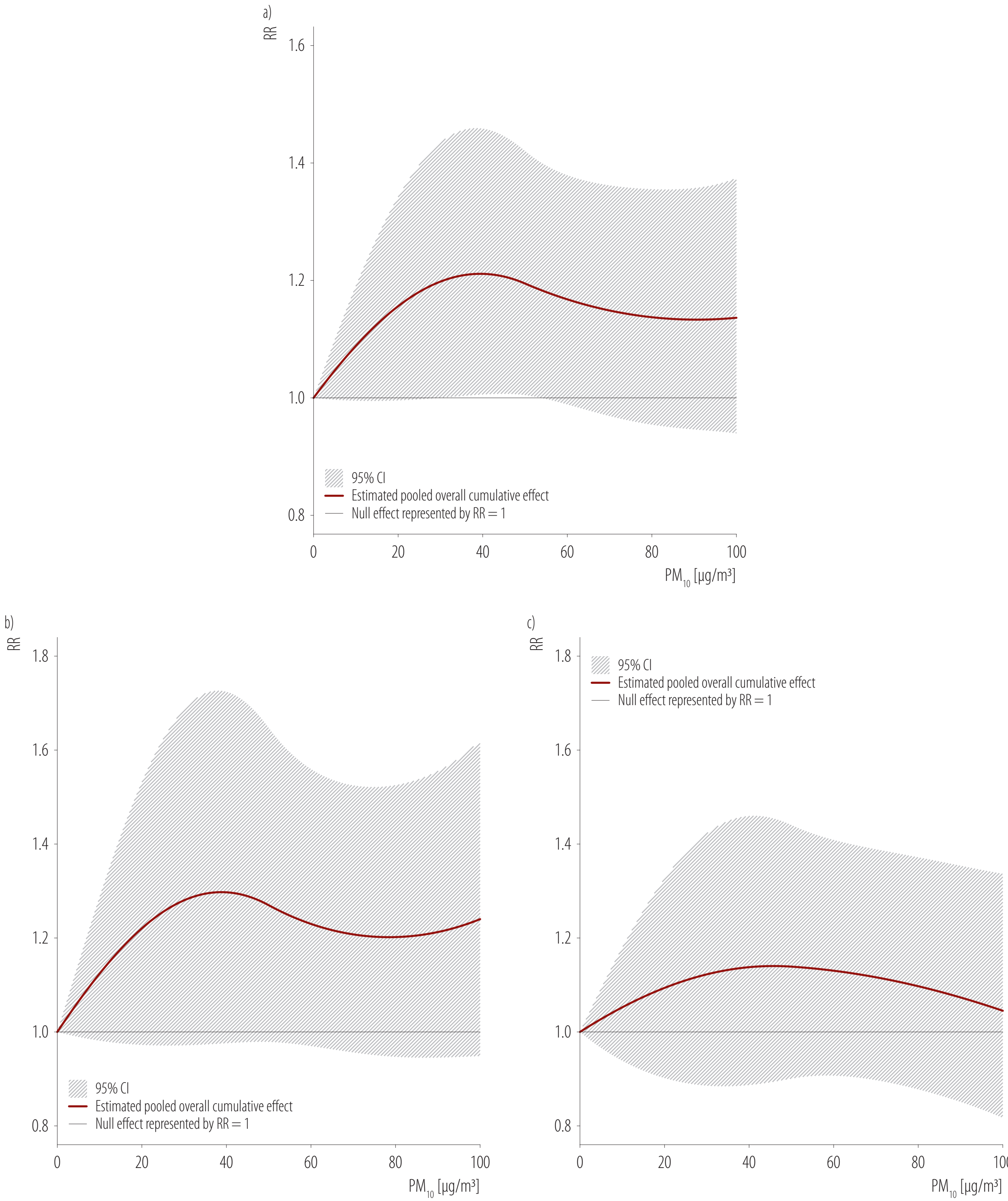


Figure 5. Pooled overall cumulative summary of of particulate matter ≤10 µm in diameter (PM_{10}) – hospitalization association for a) total population and of b) females and c) males – meta-analysis based on individual data from 16 Polish cities, 2014 and 2019

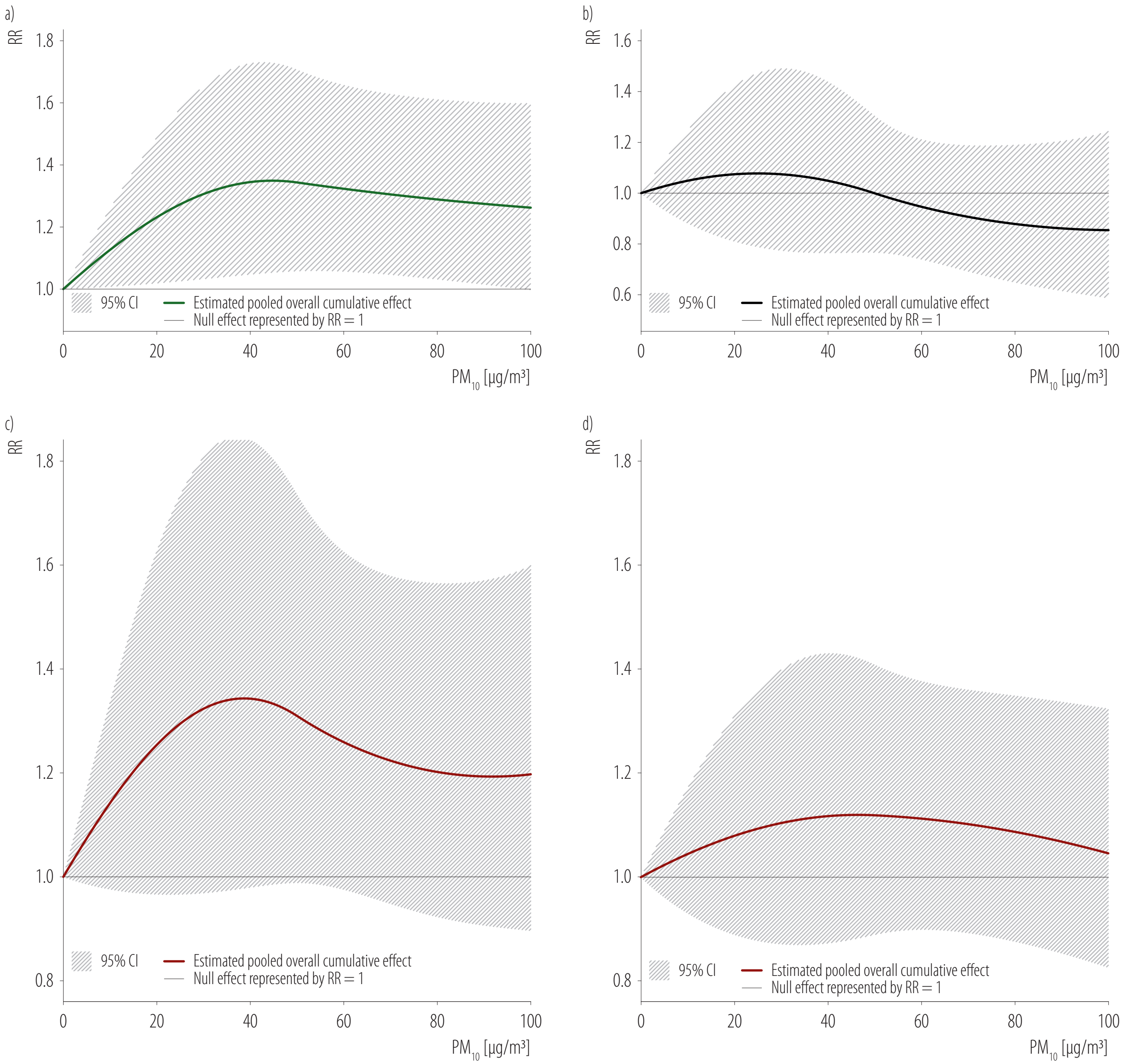


Figure 6. Pooled overall cumulative summary of fine particulate matter ≤10 µm in diameter (PM_{10}) – hospitalization association for a) 2014 and b) 2019 year, c) population <65 years and d) ≥65 years – meta-analysis based on individual data from 16 Polish cities, 2014 and 2019

CONCLUSIONS

The hypothesis that improving air quality will visibly reduce the amount of hospitalization has not been confirmed in all cities. There were cities where although air quality has been improved in 2019 in comparison to 2014, the number of emergency hospitalizations due to COPD and asthma increased. Air pollution measured by PM_{10} concentration might be used as one of the predictors of the asthma and COPD emergency hospitalization risk, yet other factors like respiratory tract infection, health care organizational aspect, patient self-control, compliance and comorbidities should also be taken into consideration.

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