ORIGINAL ARTICLE

Annals of Agricultural and Environmental Medicine 2024, Vol 31, No 1, 13–23
www.aaem.pl

Relationship between concentration of air pollutants and frequency of hospitalisations due to respiratory diseases

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Grzywa-Celińska A, Krusiński A, Dos Santos Szewczyk K, Kurys-Denis E, Milanowski J. Relationship between the concentration of air pollutants and frequency of hospitalisations due to respiratory diseases. Ann Agric Environ Med. 2024;31(1):13–23. doi: 10.26444/aaem/169486

Abstract

Introduction and Objective. Smog, which contains fine dusts, non-metal oxides, metals and organic compounds can have irritating, allergenic and immunomodulatory effects leading to the development of respiratory diseases and their exacerbations. The aim of the study was to search for a relationship between concentrations of air pollutants and the frequency of hospitalizations due to exacerbation of asthma, chronic obstructive pulmonary disease, or abnormalitis in breathing.

Materials and method. Hospital admission data was accessed from the hospital digital in-formation system. From the publicly available database of the Chief Inspectorate for Environmental Protection, data concerning the concentrations of pollutants, such as $PM_{2.5}$ and PM_{10}, sulphur oxide IV (SO_2), nitric oxide IV (NO_2), carbon monoxide II (CO), benzene and ozone (O_3), measured daily with hourly accuracy was used. The results of the average concentrations of air pollutants were compared with the rates of hospitalization in the corresponding time intervals.

Results. A number of statistically significant correlations were shown indicating the role of increased concentrations of each of the tested contaminants in the frequency of hospitalizations. In particular, strongly positive correlations were shown between the frequency of hospitalizations due to COPD and $PM_{2.5}$ and PM_{10}, asthma with benzene and NO_2, and for respiratory disorders in general with benzene, CO and SO_2.

Conclusions. The results indicate that air pollution can be a significant modifiable risk factor for exacerbations of respiratory diseases and therefore its avoidance plays an important role in primary prevention.

Key words
asthma, air pollution, respiratory diseases, COPD

INTRODUCTION

Atmospheric air pollution is an important civilization problem, and at the same time one of the most important modifiable risk factors for respiratory diseases. By reducing exposure to harmful substances contained in the air that is breathed, it is possible to improve the health of individuals and entire populations.

Air pollution – so-called smog – contains combustion products originating primarily from industrial processes, transport (diesel engines) and households. Tropospheric ozone is a special type of pollution which is formed of other substances (mainly hydrocarbons and nitrogen oxides) when exposed to heat and UV radiation. The main components of smog include particulate matter (PM) fractions of sizes up to 10 µm (PM_{10}) and 2.5 µm ($PM_{2.5}$), as well as sulphur oxide IV (SO_2), nitric dioxide IV (NO_2), carbon monoxide II (CO), ozone (O_3) and aromatic hydrocarbons such as benzene.

The pathomechanism of the harmful effect of smog is complex and includes, e.g. induction of inflammation, impairment of cellular immunity, generation of reactive oxygen species, induction of apoptosis and DNA damage. Due to the easy penetration of smog into the bronchial tree, the main toxic effect concerns the lungs, but a number of other diseases related to smog are also known, e.g. cardiovascular diseases, malignancies, endocrinopathies, fertility disorders, or impaired development of foetuses and children [1].

Chronic obstructive pulmonary disease (COPD) is a disease of the lower respiratory tract and pulmonary parenchyma caused by toxic damage mainly by tobacco smoke, as well as other substances, in particular combustion products contained in smog. The basis for the diagnosis of COPD is clinical symptoms and irreversible bronchial obstruction confirmed by spirometry with bronchodilatation test. In the treatment, bronchodilators are primarily used, but the most effective intervention remains the avoidance of harmful substances [2].

Asthma (J45, according to ICD-10) also affects the lower respiratory tract, but its course is dominated by an inflammatory process with eosinophilic infiltration. An inseparable element of asthma is bronchial hyperreactivity. The components of smog intensify this hyperreactivity and

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Received: 04.05.2023; accepted: 11.07.2023; first published: 21.07.2023

inflammation, but the smog particles themselves can also be allergens exacerbating the course of the disease [3].

Abnormalities in breathing are a non-specific term with its own statistical code in the ICD-10 classification (R06) and are one of the most common initial diagnoses in patients presenting to emergency wards [4, 5]. The term 'breathing disorders' is most often associated with shortness of breath, usually having pulmonary or cardiac causes [6].

Very few studies examining the relationship between air pollution and exacerbations of chronic respiratory diseases have been conducted in Poland.

OBJECTIVE

The aim of the study was to check whether there are positive correlations between the level of basic air pollutants and the frequency of hospitalization of patients with respiratory disorders or exacerbations of chronic lung diseases in the Hospital Emergency Department. An additional aim was to check whether the increase in air pollution levels results in a higher incidence of hospitalization for diseases, such as asthma and COPD, or non-specific breathing disorders. Knowledge of the clinical significance of air pollution can be a supporting factor in the discussion of how to prevent the development or exacerbation of lung diseases in a population.

MATERIALS AND METHOD

Among the patients hospitalized between the 1 January 2015 – 31 December 2018 in the Emergency Department of the Independent Public Clinical Hospital No. 4 in Lublin, south-eastern Poland, 2,131 people with a final diagnosis J44 (COPD), J45 (asthma) or R06 (abnormalities of beathing) classification according to the International Classification of Diseases, 10th Revision (ICD-10) were selected. The admission data was accessed from the hospital digital information system. The patients participating in the study provided informed consent, and the study was approved by the Ethics Committee of the Medical University of Lublin (Decision No. KE-0254/41/2023). The research was conducted in accordance with the Helsinki Declaration.

The most important air pollutants in the city of Lublin were considered. From the publicly available database of the Chief Inspectorate for Environmental Protection, data from the years 2015–2018 concerning the concentrations of pollutants, such as $PM_{2.5}$ and PM_{10}, SO_2, NO_2, CO, benzene and O_3 measured daily with hourly accuracy was used in the study. For subsequent years, the results of concentrations were averaged with an accuracy of the month, and for the last analyzed year (2018), additionally, with accuracy to the averages of individual days.

The results of the average concentrations of air pollutants were compared with the rates of hospitalization in the corresponding time intervals.

Statistical analysis. Statistical analysis of the data collected in the Excel sheet was carried out using the Statistica software version 13 (Statsoft Poland). Distribution of the studied variables was checked using the Shapiro-Wilk test, a non-parametric Spearman rank correlation test was used in the assessment of their relationship. The correlations between the individual variables evaluated are graphically represented by scatter plots curves showing the strength and direction of the relationship, with accompanying lines covering 95% confidence intervals (95 % CI).

RESULTS

In 2016, the average concentration of ozone was significantly lower compared to other periods ($p<0.01$). The average SO_2 concentration in 2015 and 2016 were significantly lower than in 2017 and 2018. The average concentrations of $PM_{2.5}$ in 2015 and 2016 were significantly higher compared to 2017 (Tab. 1).

Table 1. Concentrations of air pollution variables in Lublin, Poland (2015–2018)

Variables	Year	Arithmetic mean	Median
Benzene μg/m^3	2015	1.68	1.29
	2016	2.25	2.11
	2017	1.83	1.33
	2018	1.50	1.45
Carbon monoxide mg/m^3	2015	0.35	0.33
	2016	0.37	0.36
	2017	0.40	0.34
	2018	0.36	0.31
Nitric oxide IV (NO_2) μg/m^3	2015	23.36	23.03
	2016	21.74	21.03
	2017	21.75	20.55
	2018	21.63	21.82
Ozone μg/m^3	2015	45.25	43.53
	2016	37.57	36.12
	2017	48.01	52.76
	2018	48.90	51.28
Sulphur oxide IV (SO_2) μg/m^3	2015	3.65	3.39
	2016	3.80	3.72
	2017	5.24	3.88
	2018	5.56	5.05
PM2.5 μg/m^3	2015	28.06	23.94
	2016	26.01	25.18
	2017	21.95	15.90
	2018	24.45	23.79
PM10 μg/m^3	2015	36.44	33.62
	2016	30.92	32.09
	2017	32.61	26.19
	2018	33.67	32.86

In 2018, the highest benzene values occurred from October – March. Similar results applied to CO, NO_2, SO_2, $PM_{2.5}$ and PM_{10}. In the case of ozone, the highest values occurred between April – July. Concentrations of air pollutants showed annual seasonal variability, with an increase in the autumn-winter period. The exception was the level of ozone, which increased during the summer periods.

Results by diagnosis. Of the 2,131 patients in the emergency ward enrolled in the study, 557 had a diagnosis of COPD (26%), 1,433 asthma (67%), and 141 respiratory disorders (7%) (Tab. 2).

Table 2. Frequency of hospitalization due to selected respiratory diseases, 2015–2018

	COPD (J44)	Asthma (J45)	Abnormalities of breathing (R06)	total
2015	151	333	17	501
2016	111	359	17	487
2017	140	400	67	607
2018	155	341	40	536
total	557	1433	141	2131

A few significant positive correlations were shown between air pollutant concentrations and the frequency of hospitalisations for pulmonary reasons (Tab. 3).

There was a moderately strong positive correlation between COPD exacerbations and $PM_{2.5}$ and PM_{10} (2017).

A strong positive correlation of asthma exacerbations with benzene and NO_2 was shown (2016).

For the diagnosis of abnormalities of breathing, a strong positive correlation with benzene, CO and SO_2 and $PM_{2.5}$ (2015) was demonstrated.

In addition, analysis of data from 2018, where concentrations of air pollutants were measured with accuracy to days, showed significant positive correlations of COPD with CO, NO_2, SO_2, $PM_{2.5}$ and PM_{10}, asthma with NO_2, and respiratory disorders with CO, SO_2 and PM_{10} (Tab. 3).

Table 3. Correlation between the concentration of air pollutants and the frequency of hospitalization due to asthma (J45), COPD (J44) and breathing abnormalities (R06)

Pair of variables	N	J44		J45		R06	
		rho	*p*	rho	*p*	rho	*p*
2015-2018 (average values of measurements for individual months)							
Benzene [μg/m³]	48	0.077	0.6047	0.134	0.3630	0.204	0.1641
Carbon monoxide (CO) [mg/m³]	48	0.189	0.1977	0.216	0.1408	0.274	0.0593
Nitric oxide IV (NO_2) [μg/m³]	48	0.207	0.1590	0.172	0.2412	0.010	0.9482
Ozone (O_3) [μg/m³]	48	-0.077	0.6014	-0.226	0.1221	-0.092	0.5349
Sulphur oxide IV (SO_2) [μg/m³]	48	0.296	0.0413	0.015	0.9205	0.309	0.0325*
PM2.5 [μg/m³]	48	0.349	0.0151	0.163	0.2690	0.162	0.2715
PM10 [μg/m³]	48	0.398	0.0051	0.147	0.3188	0.214	0.1436
2015 (average values of measurements for individual months)							
Benzene [μg/m³]	12	-0.320	0.2858	-0.410	0.1642	0.608	0.0275*
Carbon monoxide (CO) [mg/m³]	12	-0.123	0.6883	-0.461	0.1131	0.721	0.0054*
Nitric oxide IV (NO_2) [μg/m³]	12	-0.099	0.7465	-0.380	0.2007	0.330	0.2706
Ozone (O_3) [μg/m³]	12	0.359	0.2282	0.245	0.4201	-0.492	0.0873
Sulphur oxide IV (SO_2) [μg/m³]	12	0.116	0.7058	-0.415	0.1581	0.726	0.0049*
PM2.5 [μg/m³]	12	-0.088	0.7740	-0.311	0.3012	0.635	0.0196*
PM10 [μg/m³]	12	-0.069	0.8226	-0.250	0.4094	0.531	0.0619
2016 (average values of measurements for individual months)							
Benzene [μg/m³]	12	0.333	0.3165	0.621	0.0414*	0.096	0.7791
Carbon monoxide (CO) [mg/m³]	12	0.153	0.6527	0.462	0.1523	0.176	0.6043
Nitric oxide IV (NO_2) [μg/m³]	12	0.333	0.3165	0.703	0.0158*	-0.137	0.6879
Ozone (O_3) [μg/m³]	12	-0.384	0.2442	-0.265	0.4313	-0.183	0.5909
Sulphur oxide IV (SO_2) [μg/m³]	12	0.210	0.5353	0.283	0.3989	0.470	0.1443
PM2.5 [μg/m³]	12	0.279	0.4069	0.384	0.2442	0.315	0.3453
PM10 [μg/m³]	12	0.196	0.5628	0.384	0.2442	0.315	0.3453
2017 (average values of measurements for individual months)							
Benzene [μg/m³]	12	0.541	0.0691	0.271	0.3942	0.011	0.9741
Carbon monoxide (CO) [mg/m³]	12	0.462	0.1304	0.365	0.2434	-0.062	0.8494
Nitric oxide IV (NO_2) [μg/m³]	12	0.376	0.2282	0.524	0.0802	-0.144	0.6561
Ozone (O_3) [μg/m³]	12	-0.411	0.1841	-0.506	0.0930	0.480	0.1144
Sulphur oxide IV (SO_2) [μg/m³]	12	0.499	0.0985	0.196	0.5413	-0.084	0.7951
PM2.5 [μg/m³]	12	0.598	0.0402*	0.346	0.2708	-0.228	0.4767
PM10 [μg/m³]	12	0.587	0.0448*	0.392	0.2073	-0.158	0.6247
2018 (average values of measurements for individual months)							
Benzene [μg/m³]	12	0.289	0.3614	0.541	0.0691	-0.143	0.6578
Carbon monoxide (CO) [mg/m³]	12	0.460	0.1327	0.497	0.0999	-0.069	0.8318
Nitric oxide IV (NO_2) [μg/m³]	12	0.112	0.7287	0.249	0.4349	-0.313	0.3212
Ozone (O_3) [μg/m³]	12	-0.042	0.8968	-0.796	0.0019*	-0.056	0.8619
Sulphur oxide IV (SO_2) [μg/m³]	12	0.539	0.0703	0.179	0.5779	0.151	0.6385
PM2.5 [μg/m³]	12	0.252	0.4291	0.495	0.1020	-0.134	0.6784
PM10 [μg/m³]	12	0.487	0.1084	0.372	0.2338	-0.077	0.8109
2018 (daily measurements)							
Benzene [μg/m³]	365	0.068	0.2021	0.003	0.9543	0.103	0.0518
Carbon monoxide (CO) [mg/m³]	365	0.197	0.0002*	0.036	0.4994	0.158	0.0028*
Nitric oxide IV (NO_2) [μg/m³]	365	0.155	0.0034*	0.149	0.0049*	0.084	0.1124
Ozone (O_3) [μg/m³]	365	-0.081	0.1265	-0.182	0.0006*	-0.084	0.1141
Sulphur oxide IV (SO_2) [μg/m³]	365	0.134	0.0117*	0.028	0.6022	0.138	0.0090*
PM2.5 [μg/m³]	365	0.125	0.0182*	0.039	0.4601	0.027	0.6069
PM10 [μg/m³]	365	0.109	0.0405*	0.032	0.5444	0.130	0.0146*

Rho – Spearman's rank correlation coefficient; J44 – chronic obstructive pulmonary disease (COPD); J45 – asthma; R06 – abnormalities in breathing. Significant correlations are shown in red

Results by years. Correlations between concentrations of air pollutants and selected respiratory diseases in the years 2015–2018 are presented below.

2015–2018 (average measurements for individual months). In 2015–2018, none of the concentrations of air pollutants correlated significantly with the frequency of hospitalisation, neither due to J44 nor J45. However, a significant positive correlation was observed between SO_2 concentration (rho=0.309, p=0.0325) (Fig. 1) and the frequency of hospitalisation due to R06.

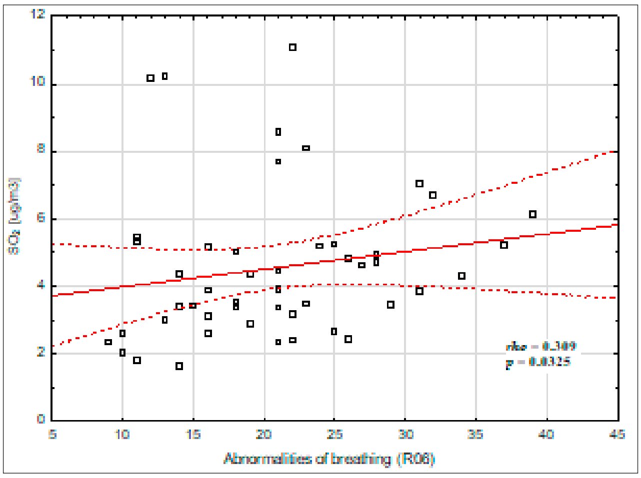

Figure 1. Scatter plot showing the correlation between SO2 concentrations and the rate of hospitalization for R06 in 2015–2018

2015 (average measurements for individual months). In 2015, none of the tested air pollutants correlated significantly with the frequency of hospitalisation, neither due to J44 nor J45. However, a significant, strong, positive correlations were found between benzene concentrations (rho=0.608; p=0.0275) (Fig. 2), CO (rho=0.721; p=0.0054)

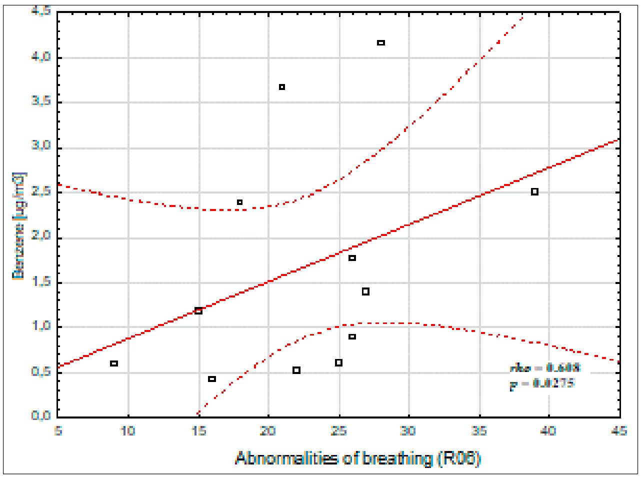

Figure 2. Scatter plot showing the correlation between benzene concentration and the incidence of hospitalization for R06 in 2015

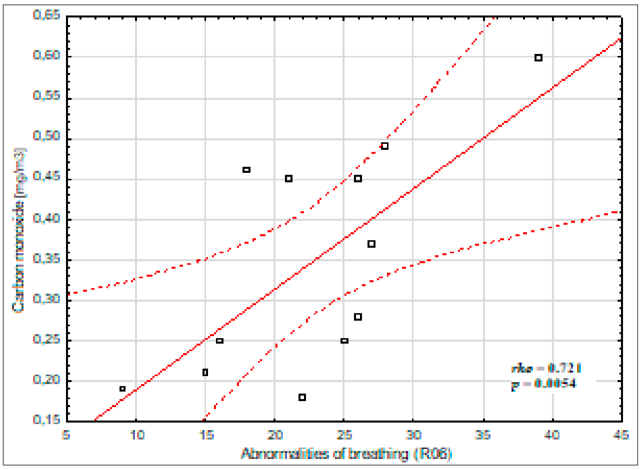

Figure 3. Scatter plot showing the correlation between CO concentration and the incidence of hospitalization for R06 in 2015

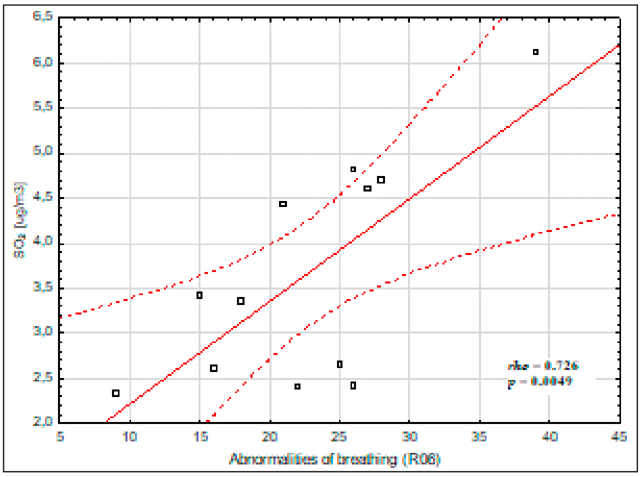

Figure 4. Scatter plot showing the correlation between SO2 levels and the rate of hospitalization for J45 in 2015

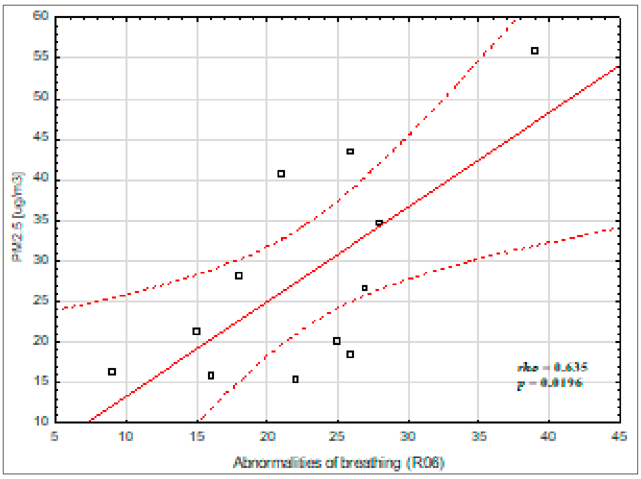

Figure 5. Scatter plot showing the correlation between PM2.5 levels and the rate of hospitalization for R06 in 2015

(Fig. 3), SO_2 (rho=0.726; p=0.0049) (Fig. 4), and $PM_{2.5}$ (rho=0.635; p=0.0196) (Fig. 5), and the frequency of hospitalisation for R06.

2016 (average measurements for individual months.) In 2016, none of the air pollutants studied correlated significantly with the frequency of hospitalisation, neither due to J44 nor R06, but there were significant, strong, positive correlations between benzene concentrations (rho=0.621; p=0.0414) (Fig. 6) and NO_2 (rho=0.703; p=0.0158) (Fig. 7) and the frequency of hospitalisation for J45.

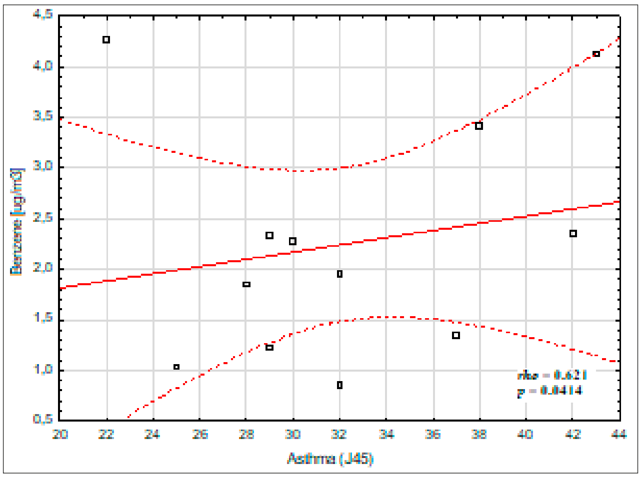

Figure 6. Scatter plot showing the correlation between benzene levels and the incidence of hospitalization for J45 in 2016

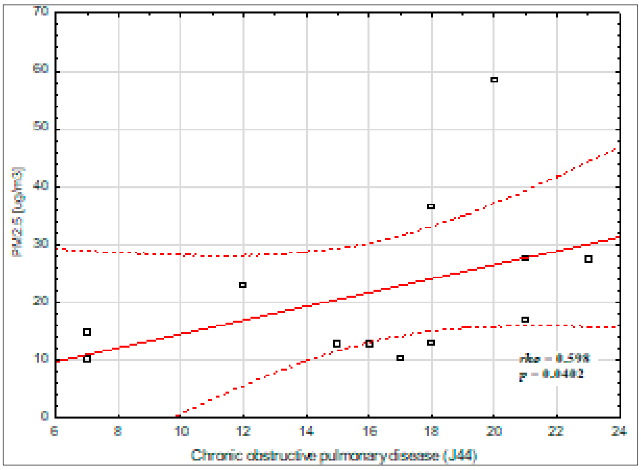

Figure 8. Scatter plot showing the correlation between PM2.5 levels and the incidence of hospitalization for J44 in 2017

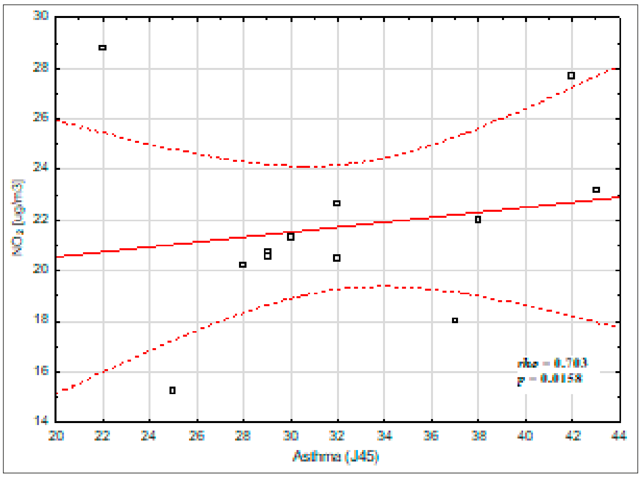

Figure 7. Scatter plot showing the correlation between NO2 levels and the incidence of hospitalization for J45 in 2016

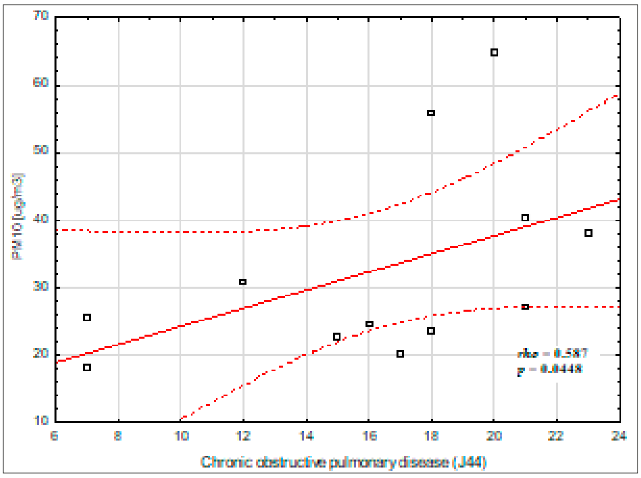

Figure 9. Scatter plot showing the correlation between PM10 levels and the incidence of hospitalization for J44 in 2017

2017 (average measurements for individual months).

In 2017, significant, moderately strong, positive correlations were noted between $PM_{2.5}$ concentrations (rho=0.598; p=0.0402) (Fig. 8) and PM_{10} (rho=0.587; p=0.0448) (Fig. 9) and the frequency of hospitalisation for J44. In 2017, none of the air pollutants studied correlated significantly with the frequency of hospitalisation, neither due to J45 nor to R06.

2018 (average measurements for individual months).

In 2018, none of the air pollutants studied correlated significantly with the frequency of hospitalisation, neither due to J44 nor R06. However, there was a significant, strong, negative correlation between ozone concentration (rho=-0.796; p=0.0019) (Fig. 10) and the frequency of hospitalisation for J45.

2018 (daily measurements).

In 2018, significant positive correlations were recorded between concentrations of CO (rho=0.197: p=0.0002) (Fig. 11), NO_2 (rho=0.155; p=0.0034) (Fig. 12), SO_2 (rho=0.134, p=0.0117) (Fig. 13), $PM_{2.5}$ (rho=0.125: p=0.0182) (Fig. 14) and PM_{10} (rho=0.109; p=0.0405) (Fig. 15) with the frequency of hospitalisation for J44. Also, there was a significant, positive correlation between NO_2 concentration (rho=0.149; p=0.0049) (Fig. 16) and the frequency of hospitalisation for J45. In addition, in the same year, a significant, weak, negative correlation between ozone concentrations (rho=-0.182; p=0.0006) (Fig. 17) and the frequency of hospitalisation for J45 was observed. Besides, the significant, positive correlations between CO concentrations (rho=0.158; p=0.0028) (Fig. 18), SO_2 (rho=0.138; p=0.0090) (Fig. 19),

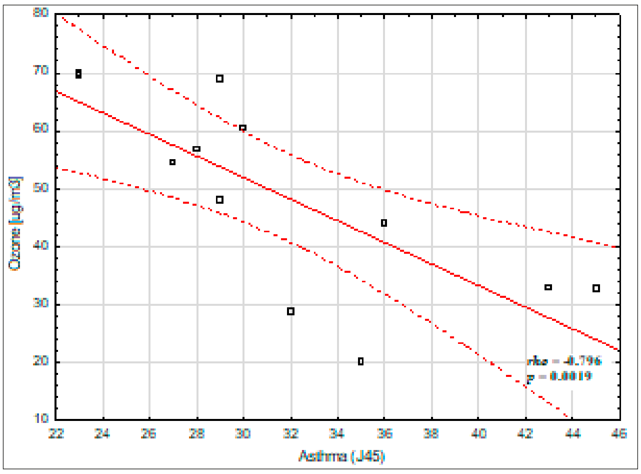

Figure 10. Scatter plot showing the correlation between ozone levels and the incidence of hospitalization for J45 in 2018

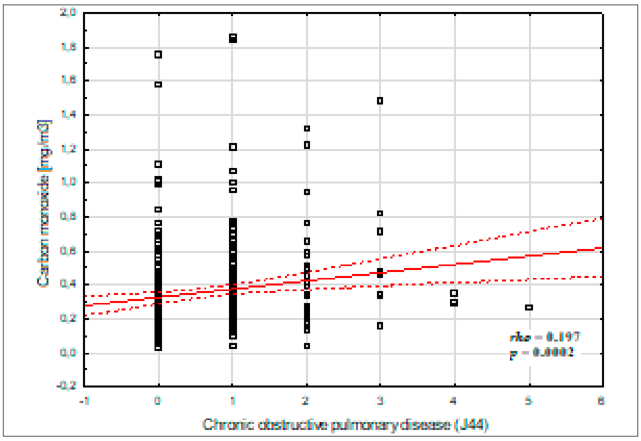

Figure 11. Scatter plot showing the correlation between CO levels and the incidence of hospitalization for J44 in 2018 (daily measurements)

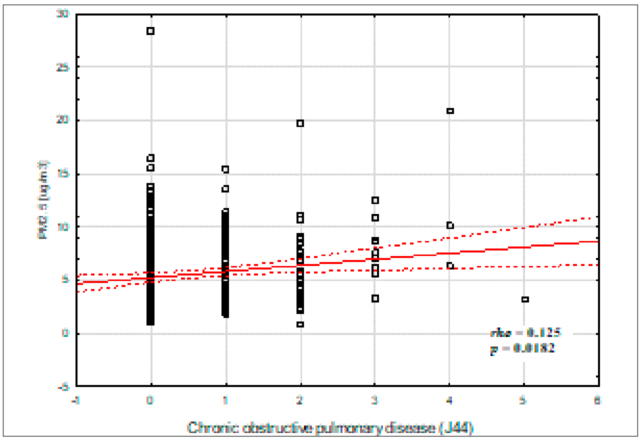

Figure 14. Scatter plot showing the correlation between PM2.5 levels and the incidence of hospitalization for J44 in 2018 (daily measurements).

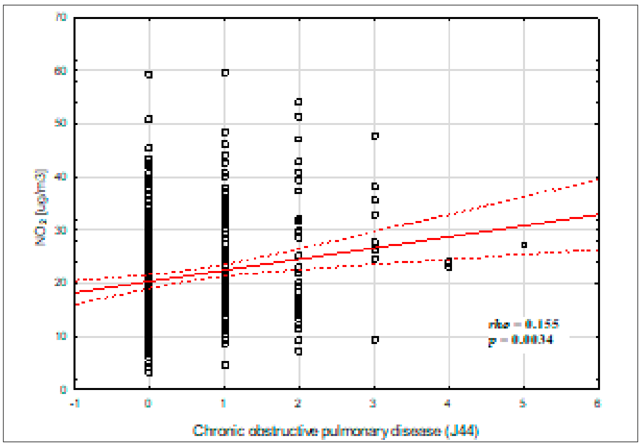

Figure 12. Scatter plot showing the correlation between NO2 levels and the incidence of hospitalization for J44 in 2018 (daily measurements)

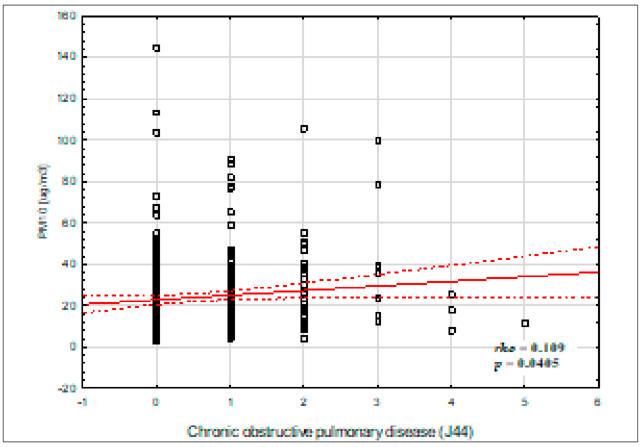

Figure 15. Scatter plot showing the correlation between PM10 levels and the incidence of hospitalization for J44 in 2018 (daily measurements).

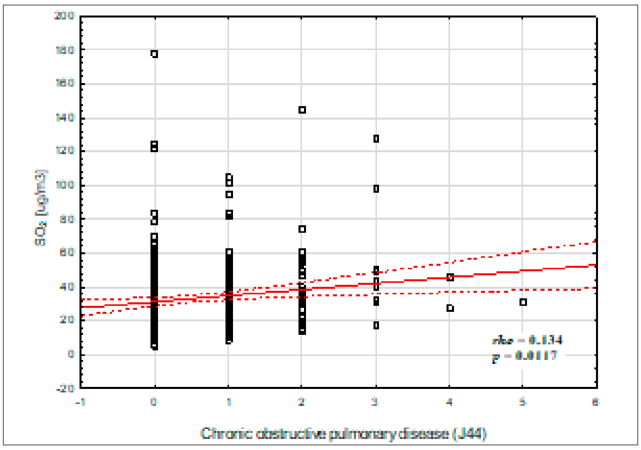

Figure 13. Scatter plot showing the correlation between SO2 levels and the incidence of hospitalization for J44 in 2018 (daily measurements)

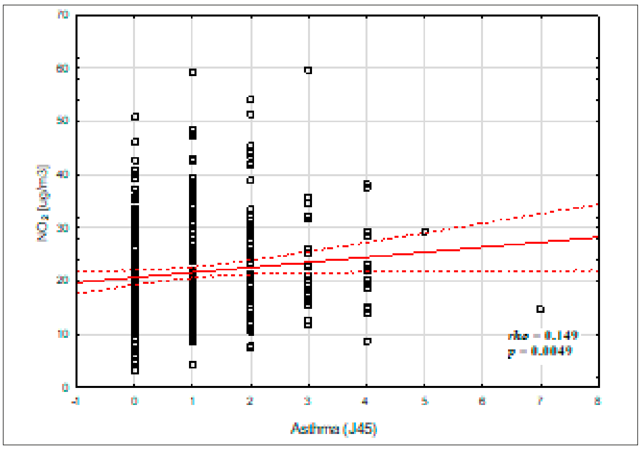

Figure 16. Scatter plot showing the correlation between NO2 levels and the incidence of hospitalization for J45 in 2018 (daily measurements)

PM_{10} (rho=0.130; p=0.0146) (Fig. 20) and the frequency of hospitalisation for R06 were recorded.

DISCUSSION

Respiratory dysfunctions are one of the most frequent reasons for the admission of patients to emergency wards [7] and can take many forms, ranging from exacerbations of chronic diseases to acute conditions, resulting from respiratory infections or many other causes. The study undertook the task of estimating the impact of air pollution on the frequency of hospitalization for respiratory reasons in the emergency ward of the biggest hospital in Lublin, south-eastern Poland.

Air pollution is a mixture of gaseous elements, chemicals and particulate matter that can affect different parts of and the function of the respiratory system in a complex way

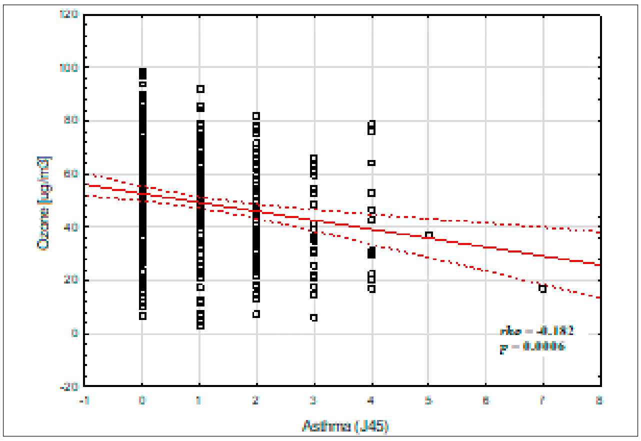

Figure 17. Scatter plot showing the correlation between ozone levels and the incidence of hospitalization for J45 in 2018 (daily measurements)

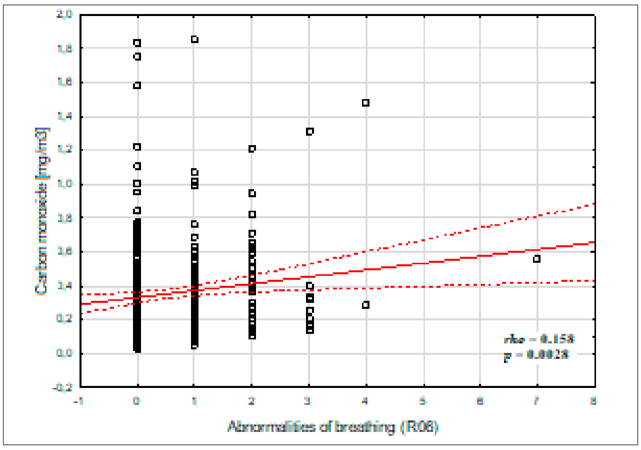

Figure 18. Scatter plot showing the correlation between CO levels and the incidence of hospitalization for R06 in 2018 (daily measurements)

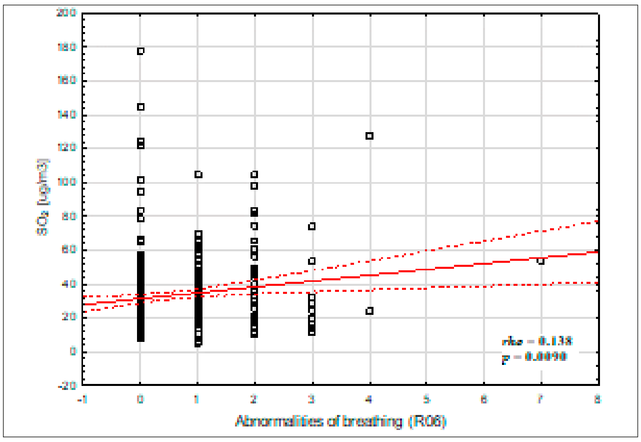

Figure 19. Scatter plot showing the correlation between CO levels and the incidence of hospitalization for J44 in 2018 (daily measurements)

[8]. Therefore, the effects of exposure to benzene, CO, NO_2, ozone, SO_2, $PM_{2.5}$ and PM_{10} were examined.

Acceptable standards for individual respiratory air pollutants are regulated by the World Health Organization (WHO) according to which the concentration of substances in the air breathed must not exceed: 25/d [µg/m³] for NO_2, 40/d [µg/m³] for SO_2, 4/d [mg/m³] for CO, 45/d [µg/m³] for PM_{10}, 15/d [µg/m³] for $PM_{2.5}$, 100/8 h [µg/m³] for ozone [9]. These recommendations, however, do not apply to

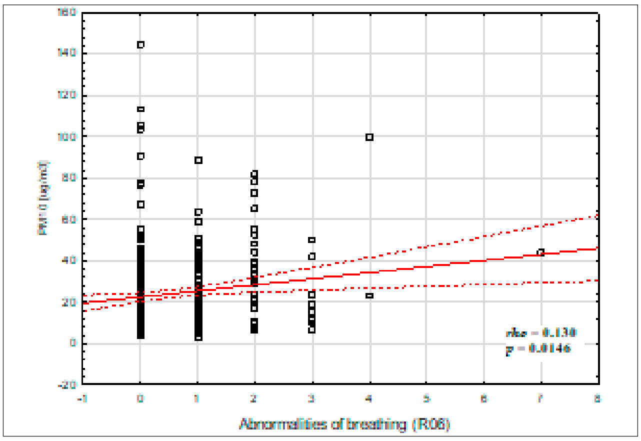

Figure 20. Scatter plot showing the correlation between PM10 levels and the incidence of hospitalization for R06 in 2018 (daily measurements).

concentration of benzene, which is regulated by the Directive of the European Parliament of 21 May 2008, which sets its maximum concentration at the level of 5/year [µg/m³] [10].

Benzene (C6H6). A representative of aromatic hydrocarbons [11]. Its harmful effects result from the stimulation of oxidative stress and genetic and epigenetic mutations. It is known primarily as a carcinogen, but is also associated with various reproductive, immune, nervous, endocrine, cardiovascular and respiratory system diseases [12, 13].

A study conducted between 1995–2000 in Drammen, Norway, showed that among other pollutants, benzene had the strongest association with respiratory hospital admissions for the total study period [14]. Research conducted in Hong Kong which aimed to assess the short-term effects of benzene on emergency COPD hospitalizations, found a positive correlation between the two variables [15]. No such relationships were demonstrated, however, in the current study, although associations found between the frequency of hospitalizations for asthma and exposure to benzene are consistent with the results reported by other studies. A significantly increased risk of asthma development due to exposure to benzene was also shown by Arif and Shah [16]. Another example is the study conducted in six French cities among schoolchildren which showed that asthma was significantly positively associated with benzene, SO_2, PM_{10}, nitrogen oxides NO_x and CO [17].

The relationship between benzene and the higher occurrence of hospitalizations due to asthma found in the current study may probably result from the induction of reactive oxygen species that intensify bronchial hyperreactivity, leading to their obstruction.

Carbon monoxide (CO). Inhalation of CO gas leads to generalized hypoxia by binding to haemoglobin and mitochondrial enzymes, causing inflammation and apoptosis by accumulating in the body [18]. The negative effects of CO on lung function and more frequent hospitalizations for asthma have been described previously [19].

The results obtained in the current study confirm previous observations on the positive correlation between CO concentrations and the frequency of hospitalization due to abnormalities of breathing and COPD [20–22]. In agreement with this study, previous studies have also shown such a positive association [17]. Positive correlations were also noted between respiratory symptoms, i.e. exacerbations, breathlessness, cough and sputum in ex-smokers with COPD and CO [23].

In the current study, no relationship was observe between CO concentration and the frequency of hospitalizations for asthma, although in some studies this relationship was reported. CO exposure was also associated with a higher incidence of pulmonary infections and asthma exacerbations [24]. Moreover, for patients with asthma, a significant inverse relationship was observed between CO level and morning and evening peak expiratory flow (PEF) [25].

Nitrogen dioxide (NO_2). Constituting the second, after $PM_{2.5}$, the most important risk factor for death due to air pollution [26], among nitrogen oxides, NO_2 is the most harmful. It is a source of reactive oxygen species, irritates the respiratory epithelium and leads to metaplasia of goblet cells, increasing the production of mucus [1]. The current study showed a significant correlation between NO_2 concentrations and the frequency of hospitalizations for both asthma and COPD. In previous studies, NO_2 had a positive association with respiratory hospital admissions [20], which was not proved in this research.

The negative impact of NO_2 on the pathophysiology of respiratory diseases has been widely described previously. In the prospective research of Chen et al. [27], a long-term exposure to NO_2 impacted faster decline in total lung capacity, residual volume, ratio of residual volume to total lung capacity, diffusion capacity of the lungs, and the ratio of alveolar volume to total lung capacity in elderly patients. According to a study conducted in Bushehr, Iran, increasing concentrations of NO_2 had a direct and a significant effect on patients with COPD [28], which is consistent with the results of the current study.

The relationship between NO_2 and worsening of COPD is well known [29, 30]. Evangelopoulos et al. [23] in the UK examined 130 ex-smoking COPD patients carrying a personal monitor specifically designed to measure the temperature, NO_2 and other particles (O_3, NO, CO, and PM <2.5 and <10 µm) at 1-min time resolution. The Patients recorded information about respiratory symptoms and measured the PEF. In that study, breathlessness was associated with NO and O_3; cough with NO_2, NO and CO; and sputum production with NO and CO. However, particulate matter was negatively associated with breathlessness, coughing and wheezing. None of the examined pollutants had an impact on sleep disturbance.

The findings of the current study prove the relationship between NO_2 and frequency of hospitalizations for asthma [29]. Similarly, studies carried out in Germany also proved a significant increase in risk for exacerbations of both asthma and COPD owing to NO_2 exposure at levels below European regulatory limit values [31]. Chang et al. [30] found that NO_2 was associated with higher number of daily admissions because of asthma and COPD, which aligns with the current study, and mentions lung infections that were not examined in the current study.

Ozone (O3). In the situation of global warming, tropospheric ozone (trioxygen, O_3) is becoming an increasingly important health hazard [32]. Ozone, as a secondary pollutant, is formed by the chemical transformations of ozone precursors [33], more precisely, by the catalytic reactions of nitrogen oxides with CO, methane, and non-methane volatile organic compounds in the presence of sunlight [34].

It has been proven previously that even in healthy volunteers, exposure to air and 0.5 ppm of ozone (O_3) led to a significant decrease in vital capacity, decrease in tidal volume, increase of airway resistance and respiratory rate [35]. The study by Paulin et al. [36] found that long-term historical ozone exposure was associated with reduced lung function, greater emphysema and air trapping on computed tomography (CT) scan, worse patient-reported outcomes, and increased respiratory exacerbations for individuals with a history of heavy smoking. Ozone exposure triggers inflammation and hyper-responsiveness of the bronchi, causing bronchoconstriction and lung function impairment [37]. Oxidative stress leads to allergic sensitization, morphological changes of the respiratory tract, and impacts host defence. Numerous studies have confirmed the effect of respiratory ozone exposure on the frequency of hospitalization for pulmonary causes.

A study conducted in Guangzhou, China, proved that exposure to O_3 was significantly related to an increase in respiratory hospitalizations in the warm period (May – October) [38]. A systematic review and meta-analysis by Gao et al. [39] indicated the impact of short-term ambient ozone exposure on increased risk of COPD hospitalizations. In the Silesian Province in south-western Poland, a significant increase in the risk of outpatient visits and hospitalizations due to respiratory diseases was observed in response to the increase in ozone concentration [40].

Conversely to the above-mentioned research, the current study did not prove a positive correlation between the frequency of hospitalizations for COPD and R06 in any of the examined time periods. Moreover, it was surprising that there was a significant negative correlation between ozone concentration and the frequency of hospitalization for J45 in 2018. In the same year, a strong positive correlation was observed between the frequency of hospitalizations due to concentrations of J45 and NO_2. To explain this phenomenon, it is necessary to consider the fact that ozone is a secondary pollutant formed most often from nitrogen dioxide in the presence of sunlight. During the current study, ozone concentrations never exceeded the values considered harmful. The study conducted in the Lublin region at three measuring points (one of which was located 13 km from Lublin), ozone concentrations requiring public notification of the risk of an alert level (180 $\mu g \cdot m^{-3}$ one-hour average) were not recorded [33]. It is worth considering that Poland does not belong to countries with a high degree of sunlight, which may explain the weaker formation of ozone from other chemical compounds. This may be also caused by the predominance of winter smog over summer smog observed in Poland. In addition, during the days with high sunlight, residents could spend part of their time in places equipped with air conditioning, which can reduce the concentration of ozone in the air [20].

However, the current study is not the only one that has not demonstrated a significant impact of ozone exposure on the incidence of hospitalizations for respiratory diseases. In the study conducted in China, no significant association was found of O_3 levels with respiratory disease morbidity [41]. The study by Hoffman et al. also did not prove a correlation between ozone concentration and exacerbations of asthma nor COPD [31]. Moreover, Vahedin et al. [20] reported a protective effect of O_3 on respiratory hospitalizations after adjustment for other air pollutants. In the study conducted by Pedersen et al. [42], apart from exposure to sea salt, ozone was the only air pollutant not causing an increased risk of asthma in children. It must therefore be summarised that the data is inconclusive, which indicates the need for more research on this topic.

Sulphur dioxide (SO_2). is one of the most important gaseous factors irritating the respiratory system. SO_2 in the air that is breathed is predominantly derived from the combustion of fossil fuels [41]. Apart from the harmful impact on the lower respiratory tract causing decreased lung function, cough and dyspnoea, it can also cause irritation of the nose, throat, and sinuses [43]. A recent study by Lin et al. [44] describes bronchoconstriction as the stimulatory effect by SO_2 on vagal bronchopulmonary C-fibres in anaesthetised rats.

Results of the current study show a significant positive correlation between SO_2 concentration and the frequency of hospitalizations in the 2015–2018 period due to abnormalities in breathing (R06). Analysis of data from 2015 revealed a strong positive correlation between SO_2 levels and the incidence of hospitalization for J44. Besides, in daily measurements in 2018, a positive correlation was noted between SO_2 concentrations and hospitalizations due to J44 and R06. The strong association of SO_2 with R06 may be due to the imprecision of the term – breathing disorders – can mimic many diseases, among them asthma and COPD.

In the current study the relationship between the frequencies of hospitalizations has not been confirmed for all examined years and for all studied diseases; however, the observations are consistent with the results of Zhou et al. [45], who proved a positive exposure-response relationship between SO_2 concentration and risk of in-patient visits due to respiratory reasons. Similarly, Tomic-Sepric et al. [46] proved that even short-term exposure to SO_2 leads to increased risk of emergency ward visits for allergic respiratory diseases, particularly for asthma with concomitant allergic rhinitis. In the current study, no such relationship was found – the patients were not divided into those with allergic and non-allergic asthma, nor was the diagnosis of allergic rhinitis considered. Although most studies provide evidence of an increase in the incidence of hospitalizations due to exposure to SO_2, in the research of Jin et al. [41] such a significant association was not observed.

Particulate matter $PM_{2.5}$. Due to its small size, $PM_{2.5}$ penetrates well into the lower respiratory tract, carrying hydrocarbons and heavy metals on its surface [1]. In the lungs, it induces apoptosis, inflammatory processes, and the formation of reactive oxygen species, which lead to hyperreactivity of the bronchi and increased sensitivity to allergens. It has been shown that $PM_{2.5}$ can cause asthma exacerbations [47] and lower FEV1/FVC. In addition, by affecting immune mechanisms, $PM_{2.5}$ may exacerbate COPD [48]. An interesting multicentre study from Poland, indicates that exposure to harmful substances, including $PM_{2.5}$, is related to an increased clinical and inflammatory response and extended hospitalization due to COVID-19 in paediatric patients [49].

The relationship between the concentration of $PM_{2.5}$ with increased hospital admissions of patients with COPD and breathing abnormalities has been found in Athens, Greece [50]. This relationship was also proven for COPD by the researchers in Shenyang, China [24]. In the current study, no impact was observed of $PM_{2.5}$ on hospitalizations due to exacerbations of COPD; however, there was a relationship between $PM_{2.5}$ concentrations and the frequency of hospitalization due to abnormalities of breathing. Contrary to those results, however, according to studies carried out in Washington, USA [51], and Iraq [20], exposure to $PM_{2.5}$ did not correspond with an increase in the incidence of hospitalization from respiratory disorders.

Particulate matter PM_{10}. Due to its larger size, PM_{10} has an irritating and allergenic effect mainly at the level of the upper respiratory tract, but its effect on diseases affecting the lower respiratory tract is also known. Studies have shown increased levels of macrophages and lymphocytes in bronchoaveolar lavage fluid (BALF) in patients exposed to PM_{10} [52]. It is worth noting that PM_{10} is also a carrier for other air pollutants.

The current study indicates a relationship between the increase in PM_{10} concentration and the frequency of hospitalizations due to COPD. In a study of Hoffmann et al., the correlation between PM_{10} concentration and exacerbations of asthma and COPD was not found [31], although PM_{10} had a positive association with respiratory hospital admissions [20]. Other studies indicate a link between PM_{10} and asthma exacerbations, and in the USA an increase in hospitalizations for COPD has been shown in association with an elevated concentration of PM_{10} [48, 53]. The results of the current study are consistent with studies indicating a link between PM_{10} and COPD exacerbations.

The mechanisms through which air pollutants can affect the respiratory system are complex. The direct airway irritation can result in the bronchospasm, while oxidative stress promotes inflammation. Inhaled fine particulate matter may additionally carry allergenic or harmful particles, which can enhance this effect [54].

To sum up, it is worth emphasising that in the current study, with the exception of $PM_{2.5}$, none of the tested substances exceeded the standards acceptable by the World Health Organisation (WHO). Despite this, however, many relationships have been detected between even their low concentrations and anincrease in the frequency of hospitalizations related to the severity of chronic lung disease symptoms. This may mean that concentrations considered safe, are still not safe enough.

Limitations of the study. In addition to some interesting observations, the study also has some limitations. The first of these is the possibility of some distortion of the tentative diagnoses that patients receive in the Emergency Department. A group of patients with asthma or COPD exacerbation may have been included in the R06 group, because often patients who do not have their medical documentation with them may report a history of another disease than the one they actually have. The Emergency Department is not the place to confirm a chronic disease. In addition, some patients reporting asthma have COPD. In a similar mechanism, some asthma-reporting patients may have been in the COPD group, and ***vice versa.***

Furthermore, indoor air pollution was not measured. The measurements of air pollutants used in the study originated from a measuring point located in close proximity to Clinical

Hospital No. 4 in Lublin. Although most patients lived within the hospital area, the Emergency Department may also have admitted patients who lived in more distant areas, which may mean that it cannot be arbitrarily assumed that the concentrations of harmful substances in the air were at the same level as at measuring point in the current study. In addition, weather conditions that could have affected the intensity of pollution were not taken into consideration.

The R06 group may also have included patients who had breathing disorders from other non-pulmonary causes, such as heart failure, although it is possible that in such patients the impact of the increase in air pollution may also play a role in exacerbating the disease.

CONCLUSIONS

The results obtained confirm previous observations on the positive correlation between SO_2, benzene, CO, PM_{10} and $PM_{2.5}$ concentrations and the frequency of hospitalization due to abnormalities in breathing. Positive correlations were also noted concerning COPD for all examined substances, with the exception of benzene. The frequency of hospitalizations for asthma correlated with the concentration of benzene and NO_2. It is worth noting that all pollutant levels (except $PM_{2.5}$) did not exceed the upper normal limits suggested by the WHO guidelines of 2021. While the obtained results seem to be important in confirming the association between NO_2 exposure and the hospitalization occurrence, further research is needed to clarify the effect of NO_2 on exacerbation rates of the most common chronic respiratory diseases.

The study adds to the science by reporting associations between air pollutant concentrations and the exacerbations of chronic respiratory diseases leading to hospitalization. The discrepancies between scientific studies on the impact of concentrations of harmful substances in the air that is breathed, indicate the need for further research, preferably based on a similar methodology and taking into account factors that may affect the degree of atmospheric air pollution.

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