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THE ASSESSMENT OF RESPIRATORY DISEASES IN AMBULATORY CARE ATTRIBUTABLE TO AIR QUALITY IN THE UPPER SILESIAN AGGLOMERATION

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Highlights

- Exposure to sulfur dioxide (SO_2) contribute to the increased incidence of respiratory diseases.
- Health situation in the districts of the Silesian Voivodeship varies greatly.
- Local county governments should monitor indicators of respiratory diseases.

Abstract

Objectives: Air pollution remains a critical public health threat in modern societies, with sulfur dioxide (SO_2) driving significant respiratory risks. This study investigated the relationship between criteria air pollutants (particulate matter 2.5 [$PM_{2.5}$], particulate matter 10 [PM_{10}], SO_2, nitrogen oxides [NO_x], Pb, and benzene) and the prevalence of selected respiratory diseases in the Upper Silesian agglomeration over a 5-year period. **Material and Methods:** Outpatient admission data for targeted conditions – including acute pharyngitis, acute tonsillitis, acute laryngotracheitis, pneumonia, bronchitis, and asthma – were obtained from the National Health Fund (Narodowy Fundusz Zdrowia – NFZ) based on the corresponding International Classification of Diseases (ICD) codes (J02, J03, J04, J13, J39, J40, J46). Spearman's and Kendall's correlation coefficients were used to evaluate the associations between average daily concentrations of air pollutants across approx. 50 regional monitoring stations and NFZ-reported disease incidence rates. Although the Upper Silesian Voivodeship is divided into 8 regions, the analysis revealed striking geographic variations. **Results:** A very strong correlation emerged between SO_2 levels and increased respiratory disease incidence in regions 7 and 8 ($\tau = 0.99$, $\rho = 0.9$), alongside a strong correlation in regions 1 and 4 ($\rho = 0.78$). **Conclusions:** These findings highlight the under-examined health impacts of low-level SO_2 and underscore the need for further investigations into the underlying drivers of these regional health disparities. Int J Occup Med Environ Health. 2026;39(5):493–502

Key words:
respiratory diseases, environmental health, air quality, air pollutants, environmental policy, SO_2 exposure

INTRODUCTION

Air pollution remains a critical threat to global public health. Among the primary criteria pollutants – including fine and coarse particulate matter ($PM_{2.5}$, PM_{10}), nitrogen oxides (NO_x), ozone (O_3), benzene, and Pb – sulfur dioxide (SO_2) represents a pervasive exposure risk in both developing and developed countries [1–6]. Characterized as a colorless gas, atmospheric SO_2 originates primarily from anthropogenic activities rather than natural sulfur cycles, barring episodic volcanic eruptions [7]. Its principal sources

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include the smelting of metal ores and the combustion of sulfur-containing fossil fuels within industrial facilities and coal-fired power stations [8]. During combustion, a fraction of this sulfur is converted to sulfur trioxide (SO_3), which is also generated in the atmosphere via the photooxidation of SO_2 by hydroxyl radicals [9]. This SO_3 acts as a crucial precursor to sulfuric acid (H_2SO_4) production and subsequent acid rain formation [10]. Beyond localized environmental degradation, the industrial sulfur cycle significantly influences global climate dynamics; oxidation products such as H_2SO_4 and methanesulfonic acid (MSA) form secondary particles that scatter solar radiation and act as cloud condensation nuclei [11,12]. Biologically, elevated SO_2 concentrations compromise human health by damaging the respiratory epithelium – specifically within the nasal passages, throat, and lungs – and inducing airway narrowing [2,7].

To investigate these impacts, this study focuses on the Silesian Voivodeship, a region covering 12 334 km^2 (approx. 3.9% of Poland's total area) and home to roughly 4.3 million residents. Intensive mineral resource exploitation, dense industrialization, and high population density render the Silesian Voivodeship one of the most anthropogenically modified territories in Poland [13]. Local climatic conditions are highly transitional, shaped by competing western oceanic and eastern continental air masses. The region experiences a mean annual temperature of 7–8°C, low-velocity westerly winds, and elevated annual precipitation driven by its predominantly mountainous terrain. These regional weather patterns overlap with heavy industrial emissions, creating microclimates within urban centers that exhibit distinct, concentrated pollution profiles compared to their rural surroundings [13].

Health effects

At the molecular level, SO_2 triggers neutrophilic inflammation and acute epithelial damage, thereby exacerbating allergic airway inflammation and subepithelial fibrosis [14]. Sulfur dioxide exposure also elevates specific pro-inflammatory cytokines [15], with rodent models demonstrating mechanisms of both acute lung injury and systemic somatic damage [16]. In humans, SO_2 compromises airway physiology in both healthy individuals and patients with underlying pulmonary diseases by increasing airway resistance during respiration [17]. Short-term exposure acutely impairs the respiratory system, inducing dyspnea; consequently, asthmatic populations, especially children, exhibit heightened sensitivity to fluctuations in ambient SO_2 levels [8].

Beyond respiratory pathology, atmospheric SO_2 adversely impacts the cardiovascular and nervous systems, and has been linked to metabolic dysregulation, including type 2 diabetes [18]. Epidemiological data demonstrate that short-term exposure to ambient SO_2 and $PM_{2.5}$ significantly correlates with increased hospitalization rates for hypertensive cardiovascular disease (CVD) [2] and ischemic stroke [3]. Furthermore, prolonged exposure is increasingly associated with renal pathology; for instance, 7.9% of chronic kidney disease cases in the UK in 2021 were attributed to ambient SO_2 exposure [4].

Standards for SO_2

Atmospheric SO_2 concentrations are strictly monitored against internal health guidelines and regional regulatory limits. The WHO defines specific health-protective thresholds [19]:

– 24-hour mean: 20 μg/m^3,
– 10-minute mean: 500 μg/m^3.

In contrast to these advisory guidelines, regional legally binding air quality standards permit higher thresholds with specific annual allowances for exceedances. The permissible limit for the 24-hour average concentration is established at 125 μg/m^3 (not to be exceeded >3 times/calendar year), while the 1-hour average limit is set at 350 μg/m^3 (permitted up to 24 times/year). Furthermore, the public alert threshold (alarm value) for acute exposure is triggered when the 1-hour average concentration reaches 500 μg/m^3 [1,19].

Objective

This study aimed to investigate the relationship between average daily concentrations of criteria air pollutants ($PM_{2.5}$, PM_{10}, SO_2, NO_x, O_3, benzene, and Pb) and the incidence of selected respiratory diseases in the Upper Silesian agglomeration. Utilizing a 5-year dataset (2012–2017), associations were evaluated based on outpatient admission records from local ambulatory healthcare facilities to track regional disease patterns.

MATERIAL AND METHODS

To assess regional air quality, daily mean concentrations of criteria pollutants – $PM_{2.5}$, PM_{10}, SO_2, NO_x, Pb, and benzene – were obtained from the Voivodeship Inspectorate for Environmental Protection (Wojewódzki Inspektorat Ochrony Środowiska), operating under the National Environmental Monitoring (Państwowy Monitoring Środowiska) framework. Data spanned a 5-year period (2012–2017) across 57 monitoring stations distributed throughout the Upper Silesia agglomeration, the Rybnik-Jastrzębie agglomeration, Bielsko-Biała, Częstochowa, and the broader Silesian zone (air quality zones PL2401–PL2405, as designated by the Polish Chief Inspectorate for Environmental Protection [Główny Inspektorat Ochrony Środowiska]).

Healthcare data regarding targeted respiratory conditions were sourced from the Silesian Voivodeship branch of the National Health Fund (Narodowy Fundusz Zdrowia – NFZ). Admissions were tracked according to corresponding International Classification of Diseases (ICD-10) codes, specifically encompassing J02–J04, J36, J39, J40, J43, and J46. To protect privacy and standardize the dataset, healthcare records were aggregated to county-wide averages.

Rather than utilizing absolute outpatient admission counts, data were converted into standardized incidence rates to ensure comparative reliability. Incidence was calculated per 10 000 population, representing the ratio of registered patients with the targeted conditions to the total population at risk within the studied timeframe.

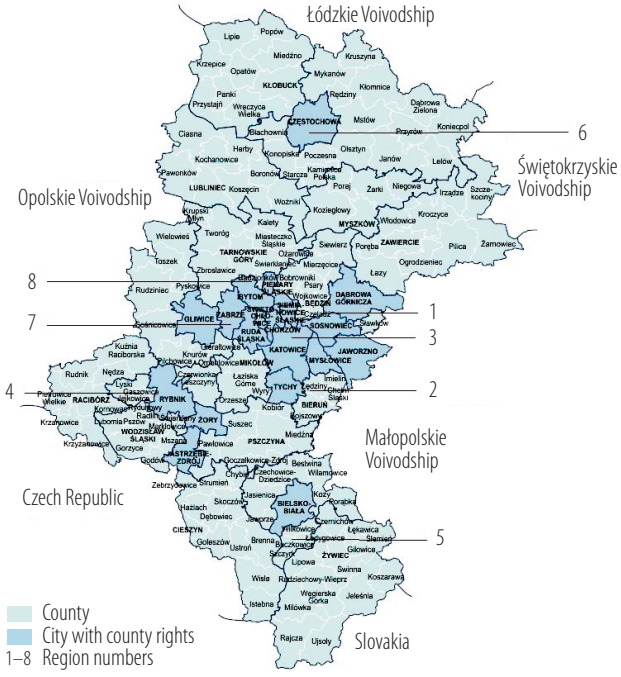


Figure 1. Regions based on the administrative boundaries of the Silesian Voivodeship, Poland

Although the raw dataset encompassed 25 distinct cities, local variations were consolidated by grouping the data into 8 distinct regions based on the administrative and geographical boundaries of the Silesian Voivodeship (Figure 1 and Table 1).

Regional characteristics of the Silesian Voivodeship

The 8 regions of the Silesian Voivodeship exhibit distinct demographic, industrial, and environmental profiles:

– central metropolitan zone (regions 1, 3, 7, and 8) – this industrial core, comprising major urban centers such as Katowice, Chorzów, and Świętochłowice (region 3); Zabrze, Gliwice, and Ruda Śląska (region 7); Bytom, Tarnowskie Góry, and Piekary Śląskie (region 8); and Będzin, Dąbrowa Górnicza, and Sosnowiec (region 1), exhibits the highest population density in Poland, frequently >2500 residents/km² [1]. This extreme population concentration, coupled with intensive industrial activity, heavy vehicular traffic, and dense municipal/do-

Table 1. Cities and counties of Upper Silesia, Poland, grouped into 8 region for research purposes (period 2012–2017)

Region No.	County
1	Będzin county, Dąbrowa Górnicza (city with county rights), Sosnowiec (city with county rights)
2	Bieruńsko-Lędziński county, Tychy (city with county rights), Mikołowski county, Jaworzno (city with county rights)
3	Chorzów (city with county rights), Katowice (city with county rights), Mysłowice (city with county rights), Siemianowice Śląskie (city with county rights), Świętochłowice (city with county rights)
4	Rybnik (city with county rights), Rybnicki county, Żory (city with county rights), Wodzisławski county, Raciborski county
5	Bielsko-Biała (city with county rights), Cieszyn county, Pszczyna county, Żywiec county, Bielsko-Biała (city with county rights)
6	Zawierciański county, Częstochowa (city with county rights), Częstochowski county, Kłobucki county, Lubliniecki county, Myszkowski county
7	Zabrze (city with county rights), Gliwice (city with county rights), Ruda Śląska (city with county rights), Gliwice (city with county rights)
8	Tarnowskie Góry (city with county rights), Piekary Śląskie (city with county rights), Bytom (city with county rights)

mestic emissions, drives persistently elevated ambient air pollution [2];
- northern zone (region 6) – characterized by the lowest population density in the voivodeship [1], this area maintains statistically superior air quality relative to the central metropolitan core [2];
- southern transitional zone (region 5) – this region presents sharp environmental contrasts. Localized urban centers like Bielsko-Biała suffer from chronic smog, whereas the surrounding expansive rural sectors feature significantly lower pollutant levels [2];
- municipal emission-dominated zone (region 4) – despite having a lower overall population density, this region experiences high air pollution levels driven by a dense concentration of low-emission residential heating sources [2];
- industrial-suburban interface (region 2) – this territory features substantial population density, with localized air quality degradation primarily driven by domestic, municipal, and suburban commercial emissions [2,3].

Clinical classification of analyzed respiratory pathologies

The respiratory health outcomes evaluated alongside these regional environmental profiles were tracked via specific International Classification of Diseases (ICD-10) designations:
- J02 – acute pharyngitis,
- J03 – acute tonsillitis,
- J04 – acute laryngotracheitis,
- J13 – pneumonia due to *Streptococcus pneumoniae*,
- J36 – peritonsillar abscess,
- J39 – other diseases of the upper respiratory tract,
- J40 – bronchitis, not specified as acute or chronic,
- J43 – emphysema,
- J46 – status asthmaticus/acute severe asthma.

Statistical analyses

Statistical analyses were performed using non-parametric methods, as the distribution of the dataset violated normality assumptions required for parametric testing. Specifically, Spearman's and Kendall's correlation coefficients were applied to evaluate associations between average daily pollutant concentrations and standardized respiratory disease rates. The choice of non-parametric correlation coefficients was strictly determined by the sample sizes of the analyzed sub-groups and the statistical properties of both measures. Spearman's rank correlation coefficient (ρ) was selected as the primary measure for subgroups with a sample size ≥5. The Spearman's ρ closely

aligns with the Pearson linear correlation coefficient, ensuring a consistent presentation of the results. In cases where the sample size was extremely limited (N = 4), Kendall's tau (τ) was applied. Although this coefficient has a more constrained interpretative range compared to standard linear coefficients, the methodological literature treats it as a more accurate, robust, and less biased estimator when working with very small samples. Therefore, this hybrid approach (differentiating between N ≥ 5 and N = 4) allowed for an optimal compromise between the interpretative utility of the data and the methodological constraints imposed by a small sample size.

RESULTS

Correlation analysis by region

Statistical analysis revealed distinct, geographically variable associations between ambient SO_2 concentrations and outpatient admissions for the evaluated respiratory pathologies:

- region 8 – a near-perfect, very strong positive correlation was observed between SO_2 levels and a broad spectrum of conditions, including acute pharyngitis, acute tonsillitis (Figure 2a), acute laryngotracheitis, pneumonia (Figure 2b), other upper respiratory tract diseases, bronchitis not specified as acute or chronic (Figure 2c) and acute severe asthma (Figure 2d) ($\tau = 0.99$);.
- region 7 – similarly, a very strong positive correlation emerged between SO_2 levels and acute tonsillitis (Figure 3a), acute laryngotracheitis, pneumonia (Figure 3b), peritonsillar abscess , bronchitis not specified as acute or chronic (Figure 3c), and acute severe asthma (Figure 3d) ($\tau = 0.99$);
- region 1 – a very strong positive correlation was detected between SO_2 exposure and chronic or lower airway conditions, specifically bronchitis not specified as acute or chronic (Figure 4a), emphysema, and acute severe asthma (Figure 4b) ($\rho = 0.90$);
- region 4 – a strong positive correlation was found between ambient SO_2 and acute tonsillitis ($\rho = 0.78$).

Detailed correlation statistics for the other 5 regions (2–6) were intentionally omitted from the manuscript, as data gaps in the annual mean values of SO_2 obtained for this study reduced the number of complete data pairs. Presenting Spearman's ρ and Kendall's τ coefficients under such severely limited sample sizes could yield artificially low or unreliable correlation estimates, posing a substantial risk of drawing erroneous conclusions about the underlying relationships.

In contrast to these localized findings, no statistically significant correlations were found between the remaining criteria pollutants ($PM_{2.5}$, PM_{10}, NO_x, O_3, benzene, and Pb) and the prevalence of any selected respiratory diseases across the investigated zones.

Exposure profiles and dose-response trends

Ambient air quality data indicated that chronic, widespread exceedances of the recommended $PM_{2.5}$ and PM_{10} health guidelines occurred continuously throughout the 2012–2017 study period. Conversely, SO_2 concentrations consistently met regulatory standards. However, SO_2 was the singular air pollutant systematically linked to fluctuations in regional respiratory disease prevalence rates. Furthermore, the dose-response curves established across regions 1, 7, and 8 exhibited a linear, non-threshold trajectory, demonstrating that variations in low-concentration SO_2 exposure closely mirror variations in healthcare admissions.

DISCUSSION

Comparative analysis and global context

The robust statistical correlations identified in this study align with a growing body of international literature emphasizing the health risks of sulfur dioxide (SO_2), an under-examined criteria pollutant. The authors' findings of a strong-to-very-strong association between am-

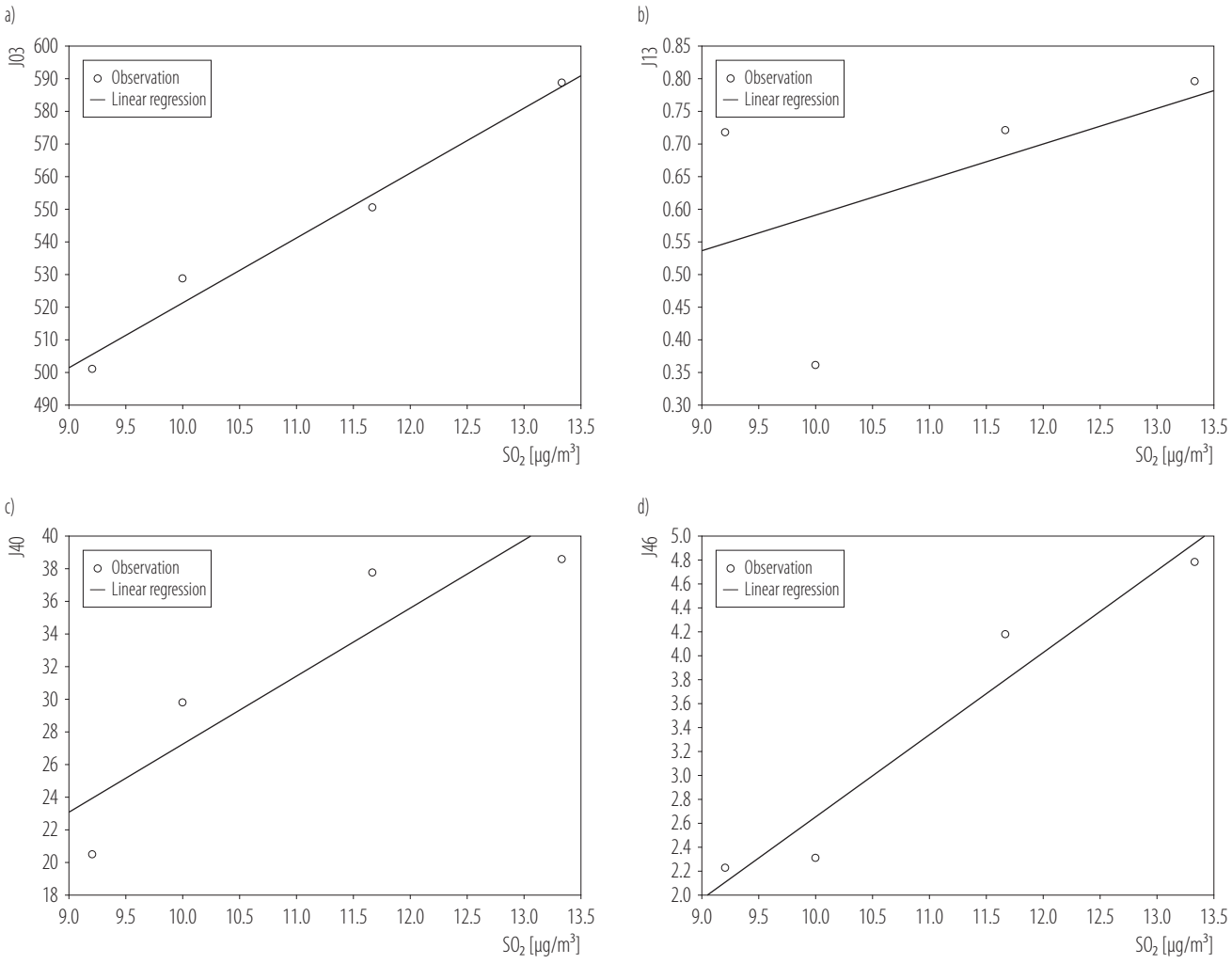


Figure 2. A dependence scatter plot representing 2 variables, SO_2 and the incidence rate of selected respiratory diseases, in region 8 of the Silesian Voivodship, for the years 2012–2017: a) acute tonsillitis (J03), b) pneumonia due to *Streptococcus pneumoniae* (J13), c) bronchitis, not specified as acute or chronic (J40), and d) status asthmaticus/acute severe asthma (J46)

bient SO_2 and respiratory outpatient admissions mirror epidemiological data from Ganzhou, China (2017–2019). There, each 10 µg/m^3 increase in short-term SO_2 exposure was associated with an approx. 3% increase in daily respiratory hospitalizations, a correlation that remained stable even when controlling for co-pollutants [6]. Similarly, a multi-city study across 11 municipalities in Shanxi Province, China, reported that a 10 µg/m^3 rise in SO_2 concentrations corresponded to a 0.6% increase in respiratory admissions and an associated cumulative increase of 4.5 hospitalization days [23]. In Ahvaz, Iran (2011–2013), researchers observed elevated respiratory admission rates driven by ambient SO_2 levels that, consistent with the Silesian Voivodeship dataset, remained safely below established public alert thresholds [24]. Furthermore, a comprehensive systematic review and meta-analysis confirmed that short-term outdoor SO_2 exposure (spanning 1 h to 7 days) significantly elevates both all-cause and respiratory mortality, corroborating the authors' observation that SO_2 exerts adverse health impacts even at low-concentration exposures without clear thresholds [25].

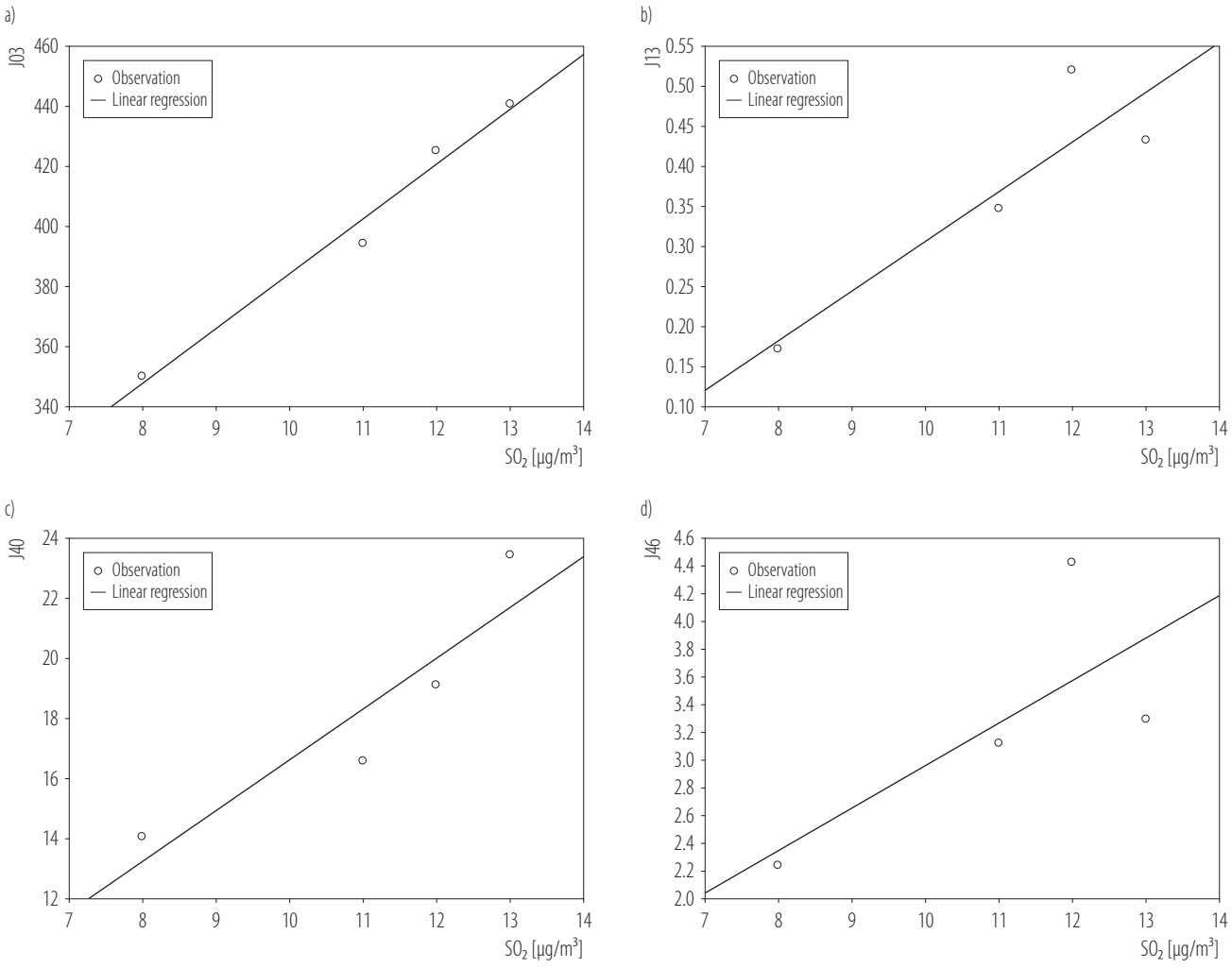


Figure 3. A dependence scatter plot representing 2 variables, SO_2 and the incidence rate of selected respiratory diseases, in region 7 of the Silesian Voivodship, for the years 2012–2017: a) acute tonsillitis (J03), b) pneumonia due to *Streptococcus pneumoniae* (J13), c) bronchitis, not specified as acute or chronic (J40), and d) status asthmaticus/acute severe asthma (J46)

While SO_2 exhibited the singular significant correlation with respiratory morbidity in this study, its real-world health impacts frequently overlap with other ambient air pollutants [18]. Meta-analyses evaluating multi-pollutant interactions (SO_2, NO_x, O_3, and CO) have consistently demonstrated positive associations with chronic obstructive pulmonary disease (COPD) and CVD [26–28]. Additionally, concurrent exposure to elevated SO_2 alongside $PM_{2.5}$ and PM_{10} has been linked to systemic health outcomes, including measurable declines in cognitive function [29].

Regional disparities and public health policy implications

Paradoxically, despite SO_2 concentrations remaining uniform across all 8 analyzed regions and consistently falling within WHO guidelines, striking regional disparities in respiratory disease incidence were observed. This phenomenon indicates that low-level SO_2 exposure may interact synergistically with unmeasured localized confounding factors – such as socioeconomic status, workplace exposures, or varied domestic fuel-burning habits – which warrants urgent, in-depth investigation.

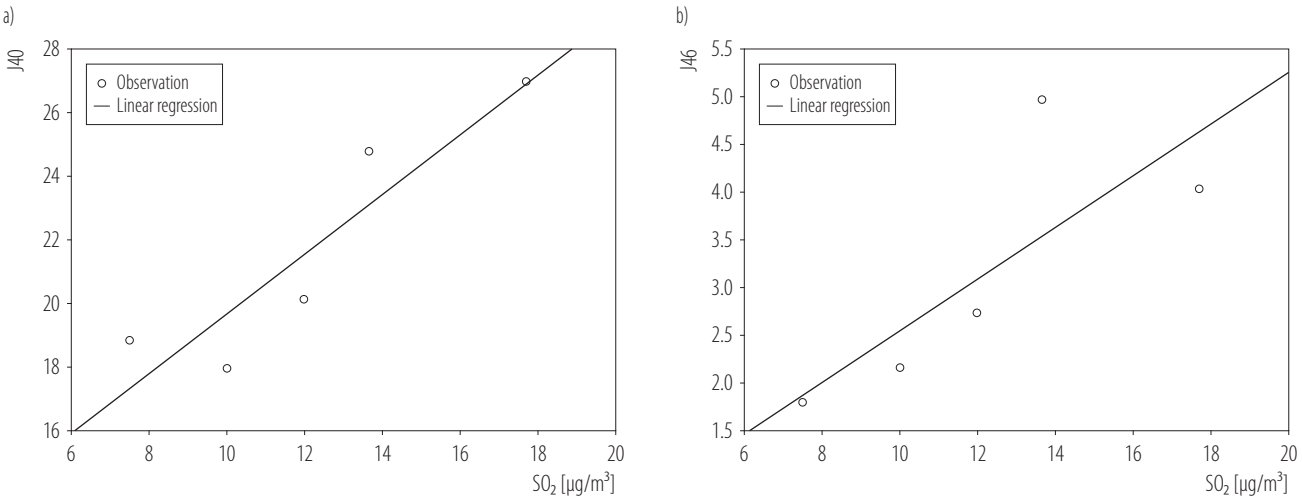


Figure 4. A dependence scatter plot representing 2 variables, SO_2 and the incidence rate of selected respiratory diseases, in region 1 of the Silesian Voivodship, for the years 2012–2017: a) bronchitis, not specified as acute or chronic (J40) and b) status asthmaticus/acute severe asthma (J46)

These data provide an empirical foundation for policy discussions regarding the potential tightening of international ambient SO_2 safety standards.

CONCLUSIONS

This study provides critical empirical data for regional public health officials and policymakers by revealing substantial geographic variations in respiratory disease patterns across the Silesian Voivodeship. Ambient SO_2 exposure demonstrated significant, strong to very strong positive correlations with increased outpatient healthcare admissions for targeted respiratory pathologies in 4 analyzed regions. While these localized associations warrant deeper investigation, they underscore an immediate need for regional municipal authorities to actively track respiratory health indicators and implement targeted, area-specific environmental health interventions.

Limitations

Several limitations should be considered when interpreting these findings. First, due to the ecological and observational design of this study, the identified statistical correlations cannot be interpreted as direct cause-and-effect relationships; establishing physiological causation controlled biochemical and clinical trials. Second, although the authors evaluated a comprehensive suite of criteria air pollutants, multi-pollutant interactions or collinearity, where the health impacts of certain compounds overlap or mask one another, cannot be entirely ruled out. Third, because this analysis relied on aggregated regional healthcare databases rather than a community-based cohort, the results are highly specific to the industrialized microclimates of the Silesian Voivodeship and may not be directly generalizable to regions with different environmental or demographic profiles. Fourth, the authors' models did not adjust for potential confounders, such as meteorological fluctuations (e.g., ambient temperature and relative humidity) or localized socioeconomic and occupational factors, which to independently influence respiratory disease prevalence. Finally, the study's historical timeframe (2012–2017) must be considered. Since 2017, numerous public health and environmental remediation programs have been actively deployed across Silesian Voivodeship. Consequently, while the study data provide a valuable baseline for longitudinal trend analysis, caution must be exercised when extrapolating these historical correlation strengths to the region's current, highly mitigated air quality profile.

AUTHOR CONTRIBUTIONS

Research concept: Joanna Kobza

Research methodology: Joanna Kobza

Collecting material: Joanna Kobza

Statistical analysis: Lechosław Dul

Interpretation of results: Mariusz Geremek

References: Mariusz Geremek

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