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Original Research

Non-Dioxin-Like PCBs – the Key Air Pollutant Associated with Lung Cancer in 15 Cities in Silesia

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Abstract

We investigated the relationship between atmospheric pollutants and lung cancer incidence in Silesia. The key aim was to answer the question whether differences in lung cancer incidence across cities in Silesia can be explained in part by differences in air pollution exposure, and which carcinogenic pollutants are the most important risk factors. We used data from the National Health Fund to measure lung cancer incidence in each city. Measurements of PM_{10} and specific pollutants, including B[a]P, Cd, and PCBs, were taken from monitoring stations and a regional study. The linear regression model was used to investigate the relationship between individual pollutants and the incidence rate of lung cancer. Multivariate regression analysis was also carried out to assess the combined effect of pollutants on lung cancer incidence. In the multivariate model, exposure to ndl-PCBs appears to be the most significant predictor of lung cancer incidence (among women) when controlling the mixture of pollutants. The results of our study suggest that while overall pollution levels in Silesia have decreased, substantial disparities remain in pollution exposure and in lung cancer incidence. It is important to note that, for Silesia, the sources of ndl-PCBs tend to be associated with specific domestic or small-scale activities, such as burning plastic waste.

Keywords: PCBs, particular matter, air pollution, lung cancer

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Introduction

Ambient air pollution is an established cause of lung cancer based on evidence from numerous epidemiologic studies dating back to the 1970s [1, 2]. Ambient air pollution can also contain specific chemical agents known to cause cancer, arsenic, cadmium, polychlorinated biphenyls, benzene, beryllium, and polycyclic aromatic hydrocarbons (i.e., benzo[a] pyrene). However, less is known about the role of specific constituents in lung cancer due to air pollution exposure. Recently, more attention has that been paid to inhalation exposure to polychlorinated biphenyls (PCBs – known human carcinogens) in outdoor environments. There is increasing evidence that inhalation of vapor-phase PCBs may be even more important than ingestion [3, 4]. Inhalation is not the only important route of exposure to PCBS, but can result in cancer and other serious diseases [5]. Unfortunately, there is a profound lack of data to support exposure and exposure-response assessment for inhaled PCBs.

A 2016 World Health Organization (WHO) report on air quality in cities around the world reports that 33 of the 50 most polluted cities in Europe (based on average fine particulate matter concentrations – $PM_{2.5}$) are in Poland. Ten of these cities are in the province of Silesia [6], which has a long history of heavy industrial activity, including coal mines and exploration and processing plants for non-ferrous metal ores (although many of these facilities were closed by 1998). In a population of more than 4 000 workers of a lead and cadmium smelter in the UK, a significant increase of lung cancer cases associated with employment duration has been observed [7]. Since that time, overall pollutant emissions have been lower, but in some cities the concentrations of particular contaminants remain above recommended levels. Additionally, more recent inventories have documented numerous sources of emissions for dioxin, furans and PCBs (including 6 coking plants, 13 metallurgic plants, 17 processing plants for electronic waste, 5 medical and veterinary waste incinerators, 3 waste battery processing plants, 2 cement plants, and 2 plants processing waste containing PCBs or pesticides) [8]. Previous studies have documented high levels of carcinogenic air pollutants in Silesia, particularly benzo[a]pyrene, benzene, heavy metals (cadmium, lead), and fine particulate matter [9, 10]. In 2009, the International Agency for Research on Cancer reevaluated the evidences of cadmium carcinogenicity and classified this metal as a sufficient factor for lung cancer development [11].

Lung cancer is the leading cause of cancer mortality among both men and women in Poland. Poland has seen a constant increase in the incidence rate of lung cancer since 1980 – especially among women [12]. But substantial disparities remain in lung cancer incidence and mortality across Poland, which may reflect differences in exposure to air pollution. One previous study estimated (based on existing mortality data and relative risks from US studies) the attributable fraction of lung cancer due to ambient air pollution ($PM_{2.5}$) exposure to range from 20% to over 40% in the 11 largest Polish cities [13]. However, to our knowledge no prior study has looked at exposure to specific pollutants and lung cancer in Poland.

In this study, we investigate the relationship between atmospheric pollutants and lung cancer incidence in 15 cities in Silesia. We used data from the National Health Fund, which provides a complete record of health procedures completed in the population, to measure lung cancer incidence in each city. Measurements of particulate matter (PM_{10}) and specific pollutants including benzo[a]pyrene, cadmium, and PCBs were taken from monitoring stations and a regional study. The key aim here was to answer the question whether differences in lung cancer incidence across cities in Silesia, situated in close proximity, can be explained in part by differences in air pollution exposure and which carcinogenic pollutants are the most important risk factors.

Materials and Methods

The study population consisted of people living in 15 cities in the province of Silesia in Poland: Bielsko-Biała (BB), Bytom (BY), Chorzów (CH), Częstochowa (CZ), Dąbrowa Górnicza (DG), Gliwice (GL), Jaworzno (JA), Katowice (KT), Piekary Śląskie (PS), Ruda Śląska (RS), Rybnik (RY), Sosnowiec (SO), Tychy (TY), Zabrze (ZA), and Żory (ZO). These cities are part of the greater Silesia agglomeration – an extended metropolitan area with a historically high concentration of industry. The total population across these 15 cities in 2014 was 1 932 608. Out of a total of 19 cities in Silesia, 4 smaller cities (with a combined population of 285 959) were excluded because data were not available for all pollutants for the specific time period. Thus, the 15 cities included in the study represent the majority of the urban population in the province.

Potential industrial sources of dioxin, furans and PCBs emissions remain, including: 6 coking plants and 13 metallurgical plants, 17 processing plants of electrical and electronic waste, 5 medical and veterinary waste incinerators, 3 waste battery processing plants, 2 cement plants, 1 utilization plant of wastes containing PCBs, and 1 utilization plant of waste containing pesticides.

Air Pollution Exposure

We analyzed the mean yearly concentrations of particulate matter (PM_{10}), benzo(a)pyrene (BaP) and cadmium in suspended dust using data for the period from 1989 to 2008 in the 15 cities. This data comes from the Provincial Sanitary and Epidemiological Station in Katowice [14], and for the years from 1999 to 2008 from the networks of the measurement stations of the State Environment Monitoring (SEM)

[15] as previously described [10]. We also used data (mean value) from measurements of air contamination by dioxins (PCDDs), furans (PCDFs), dioxin-like polychlorinated biphenyls (dl-PCBs) and non-dioxin like polychlorinated biphenyls (ndl-PCBs) conducted from December 2014 to February 2015 in the same 15 cities. The measurement data of dioxins and PCBs are the results of sampling at one time (mean value of the two-month measurements), which took place in the study of others [13]. It is important to note that in our previous research, samples taken two years earlier at the same points in five cities showed the same order of magnitude of PCB and dioxin concentrations. These samples were taken at the same points where the existing monitoring stations (for PM_{10}, BaP and cadmium) are located. The sample collection and the measurements of analyzed compounds in the samples was previously described [9]. Analysis of the samples was carried out in the certified testing laboratory of E & H Services, a.s. (Czech Republic). The certificate of accreditation No. 4/2016 was issued on the basis of assessing the fulfillment of the accreditation criteria in accordance with CSN EN ISO/IEC 17025:2005.

Lung Cancer Incidence

Data on the incidence of lung cancer was obtained from the National Health Fund (NHF) of Poland for the 15 cities of the province of Silesia for the years 2011-2014. The NHF registry records information on all benefits provided by healthcare entities and forwarded for payment under an agreement with the NHF. Data provided to NHF by health care providers include, among other information, patient ID number, date of birth, sex, place of residence, clinical diagnosis data coded according to the International Statistical Classification of Diseases and Health Problems ICD-10, and date of the treatment service provided [17]. Annual incidence rates were calculated for each city using the number of new lung cancer diagnoses recorded in the NHF registry and the official population for each city recorded in that year, after which an average incidence rate was calculated for each city across the years 2011-2014. Age distribution was similar across the cities, so incidence rates were not standardized for age.

Statistical Analysis

For regression analysis we focused on data from the 15 cities for the period 1999-2008 because data was not available for all cities for the earlier period. Relative cumulative exposure values were calculated for PM_{10}, BaP, and cadmium over the period 1999-2008 by taking the lowest value found across all cities over the study period (set to 1) and converting all other values to multiples of this low value. To derive a cumulative value for each city across all years, the values for each year were summed. Because the PCDD/Fs, dl-PCBs, and ndl-PCBs were measured at two points in time (2014 and 2015), cumulative exposure score was calculated on the base of medium value. Relative exposure values were calculated by taking the lowest measurement for each constituent (set to 1) and converting all other values to multiples of that low value. While data for PM_{10}, BaP and cadmium was available for some cities for the earlier period as well (1989-1998), we did not include this period in the regression analyses as data was not available for all 15 cities.

The collected epidemiological and air pollution data was evaluated for normal distribution by the Shapiro-Wilk test with a confidence level of 95%. First, a linear regression model, using the nonparametric independence R-Spearman test, was used to investigate the relationship between individual pollutants and the incidence rate of lung cancer. Second, a multivariate regression analysis was also carried out to assess the combined effect of pollutants on lung cancer incidence. All analyses were carried out using a threshold of statistical significance set at a value of $p \leq 0.05$. Statistical analysis of the collected material was carried out using Microsoft Office (MS Word, MS Excel, MS Access) and Statistica 12 StatSoft Poland, with the addition of the medical kit.

Results and Discussion

The mean annual lung cancer incidence rate for 2011-2014 varied substantially across the 15 cities included in the study. Lung cancer incidence rates per 100,000 inhabitants ranged in men from 190 in Żory to 357 in Sosnowiec, and in women from 92 in Rybnik to 226 in Sosnowiec. Overall average annual concentration levels of PM_{10}, BaP and cadmium in suspended dust decreased substantially for all 15 cities between 1989 and 2008 – particularly in the first decade 1989-1999. Across all 15 cities, the average annual PM_{10} concentration observed dropped from 154.7 μg/m^3 in 1989 to 63.1 μg/m^3 in 1999, and then to 42.2 μg/m^3 in 2008. In 1989, the average annual PM_{10} concentration observed ranged from 192 μg/m^3 in Chorzów to 125 μg/m^3 in Tychy, while in 2008 it ranged from 68.5 μg/m^3 in Piekary Śląskie to 28 μg/m^3 in Bielsko-Biała. Average annual concentration levels of BaP and cadmium in PM_{10} also dropped from 1989 to 2008, from 54.3 to 29.2 μg/m^3 for BaP and from 24.2 to 4.7 μg/m^3 for cadmium. However, in recent years substantial variation remains across the 15 cities in pollution levels, as with lung cancer incidence (Figs 1-2).

In the univariate analysis of pollution exposure 1999-2008 and lung cancer (Table 1), BaP exposure in men and women ($p = 0.024$ and $p = 0.007$) and ndl-PCBs in women ($p = 0.044$) appear as statistically significantly correlated with lung cancer incidence. The results in this study did not show a significant association between PM_{10} or cadmium and lung cancer incidence.

In the multivariate model (Table 2), including all the measured pollutants, BaP no longer appears to be significant. However, among women, exposure to ndl-PCBs appears to be the only significant predictor of lung cancer incidence when controlling for other pollutants. None of the individual pollutants exhibited a statistically significant correlation with lung cancer incidence in men. Additionally, the overall model is not statistically significant for men. However, when PCBs were removed from the model, a significant effect was seen for cadmium on lung cancer incidence for both men and women.

Average annual pollution levels declined over the period 1998-2008 in all 15 cities. However, substantial variation remains in levels of overall pollution and specific constituents across neighboring cities in the greater Silesian agglomeration. Additionally, there is

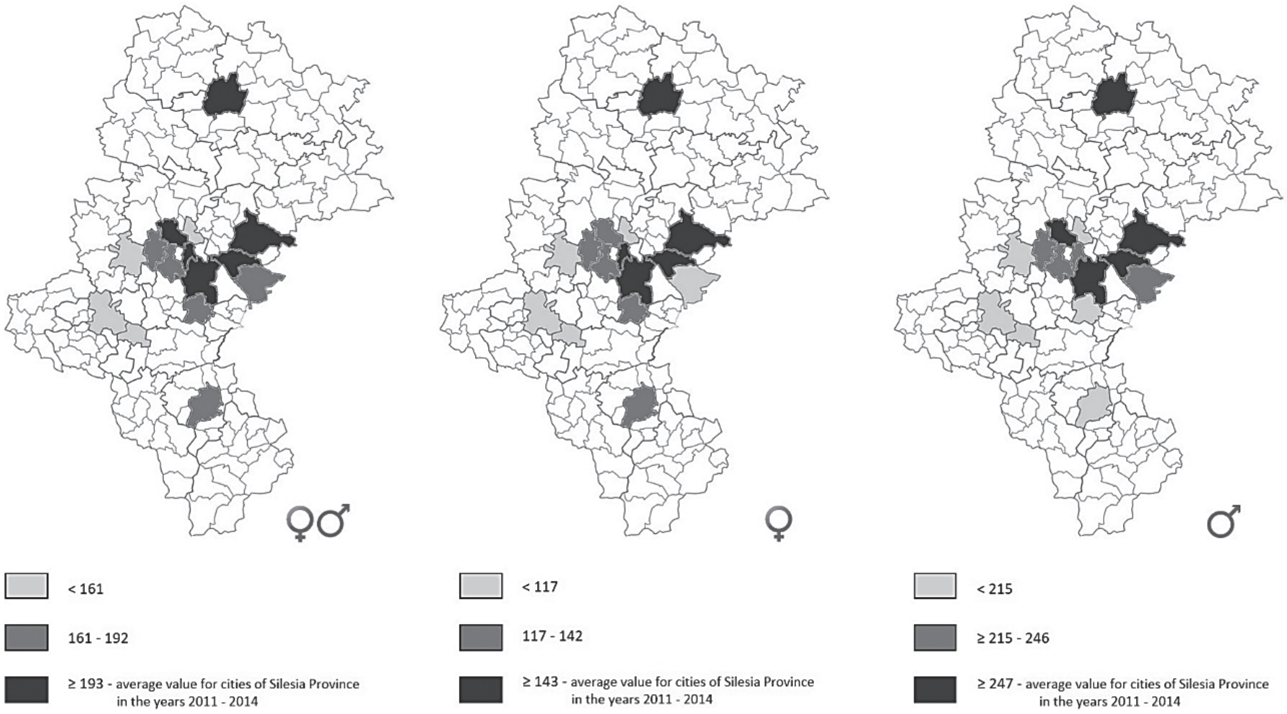


Fig. 1. Incidence rate of lung cancer in the cities of Silesia Province.

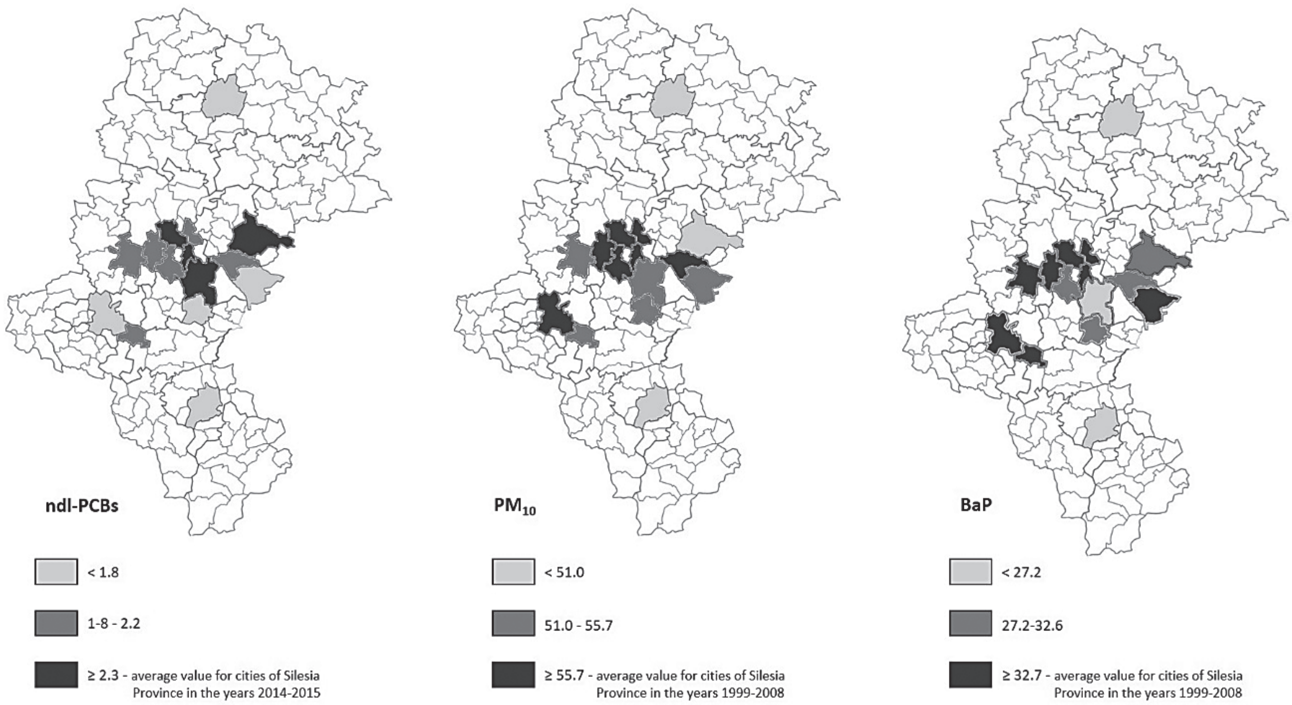


Fig. 2. Ranking of ndl-PCB, PM_{10} and BaP concentrations in cities of Silesia Province.

Table 1. Relationship between long-term exposure to air pollution (1999-2008) and the incidence of lung cancer in the population of women in 2011-2014; linear R-Spearman regression.

Compounds	Men		Women	
	p-value	R	p-value	R
PM_{10}	0.585	-0.154	0.328	-0.271
B(a)P in PM_{10}	0.024	-0.579	0.007	-0.664
Cd in PM_{10}	0.143	0.396	0.196	0.354
PCDD/Fs*	0.930	0.025	0.594	0.150
dl-PCBs*	0.219	0.337	0.233	0.328
ndl-PCBs*	0.098	0.443	0.044	0.525

*on the basis of indicatory data

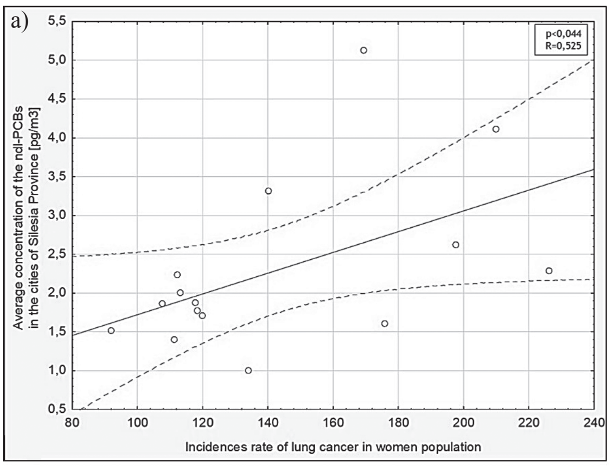
notable variation in annual lung cancer incidence across the cities included in the study, with incidence more than two times greater in the top-ranked cities versus the lowest. In the multivariate regression, the strongest effect was seen for ndl-PCBs and lung cancer incidence in women. Additionally, when PCBs were removed from the multivariate model, a significant effect was seen for cadmium in men and women. PCBs may be one of the major reasons for continued growth of lung cancer, despite the continuing decline in the number of smokers in recent years.

It is interesting to note the difference in the observed association with ndl-PCB exposure in men and women. In Fig. 3, which plots lung cancer incidence against ndl-PCBs exposure, a similar trend can be seen in both men and women, but the association is only statistically significant among women. We hypothesize that this difference may be due to higher exposure to other sources of pollutants among men, particularly cigarette smoking and occupational exposures, which make it more difficult to assess the effects of ambient air pollution in men. Smoking prevalence in the province of Silesia in 2005 was 46% among men and 27% among women [18]. Additionally, in Silesia men are four times more likely than women to work in jobs with exposure to non-ferrous metal ores [19]. A previous study investigating the effects of ambient air pollution, including PCBs and length of life in Silesia, found a similar effect in women and not in men [9].

The results of our research indicate the importance of inhalation exposure to PCB compounds. However, while the commercial production of PCBs was banned in the USA and other countries 50 years ago, they continue to be released into the environment through the use and disposal of PCB-containing products.

While some previous large-scale epidemiologic studies have found an effect of PM_{10} exposure on lung cancer [20, 21], we did not see an association with PM_{10} in our study in either the univariate or multivariate models. The effect of PM_{10} on lung cancer may be weaker, so we were not able to detect it in a smaller study. Additionally, there may be a greater level of misclassification for PM_{10} exposure as PM_{10} comes from many dispersed sources, including vehicle traffic.

We focused our analysis on pollution levels starting from 1999. While data exist for the previous decade (1989-1998) for some pollutants, data were not available for all 15 cities included in our analysis. We did examine the data for the earlier period for a subset of 13 cities but did not see any significant association between lung cancer and exposure during 1989-1999 for any of the pollutants for which data was available in this period (PM_{10}, BaP and cadmium). As described above, average annual pollution levels were much higher during this earlier time period. However, during the 1990s, as Poland underwent a major economic transformation, many industrial sites were closed. The effects were most visible in Silesia, where 90% of non-ferrous metal processing plants were located, but currently



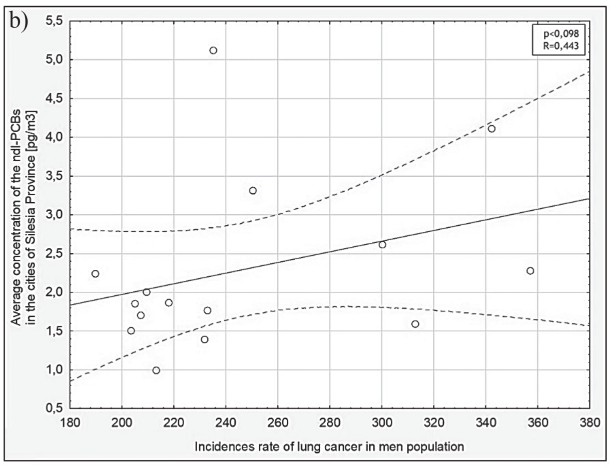


Fig. 3. Relationship between lung cancer incidence in women a) and men b), and average concentration of ndl-PCBs (pg/m^3) in the air of cities of Silesia Province.

Table 2. Multiple regression ranking of PM_{10}, PCDD/F and PCB concentration levels in 15 cities of Silesia Province.

Compounds	R = 0,808	R^2 = 0,653 Men	p<0,114	R = 0,888	R^2 = 0,789 Women	p<0,021
	beta±SE	B±SE	p	beta±SE	B±SE	p
PM_{10}	-0.301±0.598	-4.877±9.697	0.629	-0.025±0.466	-0.318±5.889	0.958
B(a)P in PM_{10}	-0.503±0.488	-4.153±4.032	0.333	-0.731±0.381	-4.700±2.449	0.091
Cd in PM_{10}	0.513±0.434	2.985±2.526	0.271	0.224±0.339	1.016±1.534	0.526
PCDD/F*	0.040±0.245	6.208±38.238	0.875	0.173±0.191	21.045±23.223	0.391
dl-PCBs*	-0.290±0.266	-27.065±24.800	0.307	-0.373±0.207	-27.136±15.061	0.109
ndl-PCB*	0.376±0.341	18.354±16.635	0.302	0.733±0.266	27.853±10.103	0.025

on the basis of indicatory data

only one continues to operate. Nevertheless, variation in pollution levels was greater during the later period 1999-2008 compared with the earlier period 1989-1999. In our analysis, the coefficient of variation in average annual PM_{10} levels across the Silesian cities almost doubled from 15% in 1989 to 27% in 2008. Thus, while pollution levels were higher in the earlier time period, the variation across cities was lower.

One of the unique strengths of this study was the use of data from the National Health Fund of Poland to assess cancer incidence. The fund records comprehensive data on all medical procedures for residents, even when they go to another location for treatment, because all financial claims must be processed through the fund. A previous analysis found that the National Health Fund database is more accurate as a source of cancer incidence data than the National Cancer Registry, as the registry is a passive system that relies on health institutions to record and submit data [17]. Additionally, the province of Silesia provides a unique opportunity to examine the relationship between specific pollutants and lung cancer because of the concentration of industrial facilities and history of environmental monitoring.

According to Cagle [22], lung cancer risk factors include family history/heritable factors, exposure to certain cooking fumes, hormonal factors, preexisting lung disease, dietary factors, human immunodeficiency virus infection, human papilloma virus infection, exposure to ionizing radiation, occupational and environmental exposure (radon, asbestos, arsenic, air pollutants, etc.). Some researchers suggest that inhaled PCBs can increase the risk of cancer. Data specific to the inhalation route are limited [4], but indicate that inhalation exposure to PCBs may be as or even more important than the ingestion route for increasing the risk of cancer [3, 4].

However, while the absolute emission levels may have decreased over time, as with other pollutants the relative differences across cities can be taken to reflect differences in historical exposure patterns.

Conclusions

The results of our study suggest that while overall pollution levels in Silesia have decreased, substantial disparities remain in pollution exposure and in lung cancer incidence. Thus, the benefits in regulation and reduction of industrial activities in the region have not been equally distributed. It is important to note that for Silesia the sources of non-dioxin-like PCBs — the key pollutant associated with lung cancer in our study — tend to be associated with specific domestic or small-scale activities, such as burning plastic waste [23]. Thus exposure to PCBs is more easily controlled compared with exposure to overall PM_{10}, which comes from many sources. It follows that the lung cancer cases described here as associated with PCB exposure are preventable if adequate measures are taken to control particular pollution sources. At the same time, however, PCBs are not part of the current pollution monitoring system in Poland and in other countries. The findings in this study highlight the importance of regular monitoring of PCBs along with other pollutants and of developing strategies to reduce emissions and protect public health.

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Conflict of Interest

The authors declare no conflict of interest.

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