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Emissions of Air Pollution in Industrial and Rural Region in Poland and Health Impacts

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ABSTRACT
Air pollution is a global problem. In Europe, ambient air quality remains poor in many areas, particularly in urban ones. Air pollutants have a significantly adverse effect on human health and ecosystems. They are the main cause of many serious illnesses and thus contribute to increased mortality. This paper analyzes the air pollutant emissions in the last four years (2018–2021) in the Upper Silesian Region, which has one of the worst air qualities in Poland and in Europe in general, and the emissions in the Lublin Region in eastern Poland, which is considered as a clean region. In each of the above-mentioned regions, the areas with the highest air pollutant emissions were specified i.e. the Upper Silesian Agglomeration and the Lublin Agglomeration. The emission data for the following pollutants: particulate matter (PM_{10}, $PM_{2.5}$), benzo(a)pyrene (BaP), sulfur oxides (SO_x) and nitrogen oxides (NO_x) have been compared. The obtained results were also compared with the estimated average emissions in Poland. It was indicated that in both agglomerations the exposure to air pollutants was on similar levels, which were several times higher than in the remaining parts of the considered regions and the average values for Poland in general. In the Silesian Agglomeration, the exposure to PM_{10} was over 5 times higher than the average national exposure. The exposure to $PM_{2.5}$ was almost 6 times higher, the exposure to BaP was about 5 times higher, while the exposure to SO_x and NO_x was 16 and 10 times higher than the national average, respectively. This is reflected in the increased number of premature deaths and the number of years of life lost due to the exposure to air pollution. Therefore, the actions aimed at limiting air pollutant emissions are urgent in the above-indicated areas.

Keywords: air pollution, emission sources, exposure, health effects, mortality.

INTRODUCTION

Various types of pollutants are present in ambient and indoor air. The most important ones are those considered as most harmful for human health, as well as those that adversely affect the environment. Most serious pollutants, in terms of harm to human health, are particulate matter (PM_{10} and $PM_{2.5}$), nitrogen dioxide (NO_2) and sulfur dioxide (SO_2). In turn, the pollutants that are most detrimental to ecosystems are ozone (O_3), ammonia (NH_3) and nitrogen oxides (NO_x). PM_{10} refers to the aerosol particles with an aerodynamic diameter of ≤ 10 μm, while $PM_{2.5}$ – to the aerosol particles with an aerodynamic diameter of ≤ 2.5 μm.

Exposure to air pollution can lead to a wide range of diseases, affecting mostly the respiratory (Santos et al., 2021), cardiovascular (Hamanaka et al., 2018) and neurological systems (Mallhi et al., 2021). In terms of the respiratory system, such exposure may cause chronic obstructive pulmonary diseases and lung cancers. It also contributes to the increase of asthmatic and allergic disorders (Huang et al., 2015) as well as respiratory infections (Kirwa et al., 2021). Therefore, it may lead not only to increased morbidity, but also increased mortality. According to the World Health Organization (WHO, 2021a) in 2019 the following diseases (indicated as a percentage) contributed to the overall mortality:

- pneumonia (27%);
- ischaemic heart disease (27%);
- chronic obstructive pulmonary disease (20%);
- stroke (18%);
- lung cancer (8%).

The data published by Lelieveld et al. (2019) indicates that 8.8 million worldwide deaths were due to indoor and outdoor air pollution in 2015. Out of that number, 5.5 million deaths were caused by air pollution from anthropogenic sources and 3.6 million deaths resulted from burning fossil fuels. The mean life expectancy decrease was estimated at 2.9 years. According to WHO, in 2016 there were 7 million premature deaths, out of which 3.8 million were attributed to indoor air pollution (WHO, 2021b). The Institute for Health Metrics and Evaluation (IHME) provided a slightly lower number for the year 2019 – 6.7 million deaths, out of which 2.3 were caused by indoor air pollution (IHME, 2020). IHME estimated that in 2019 exposure to air pollution on average reduced life expectancy by 20 months worldwide, while outdoor air pollution reduced life expectancy by 12 months.

Figure 1 presents the data compiled by WHO concerning the deaths resulting from the exposure to indoor and outdoor air pollutants worldwide and for the individual geographic regions with an indication of regions of higher and lower income. It must be noted that certain groups, such as low-income populations, tend to be more exposed to adverse health effects of air pollution. A contributing factor may be energy poverty, which leads to combustion of low-quality solid fuels for heating purposes (Polednik, 2013; InventAir, 2018; WHO, 2021a). Additionally, such populations often live in industrial areas and busy roads, thus being more exposed to air pollution.

This paper compares the air quality in Upper Silesia – one of the most polluted regions in Poland and in Europe and in the Lublin region located in eastern Poland, which is considered as a region with good air quality. For each of those regions agglomeration with the worst air quality has been selected. The paper also presents the data on premature deaths and number of years of life lost due to exposure to $PM_{2.5}$. Estimates of death toll from air pollution for Poland as a whole have also been presented.

MATERIALS AND METHODS

Air pollutant emissions and the related health effects have been analyzed for the Upper Silesian Region (SR) which is a heavily industrialized and densely populated region located in south-eastern Poland and for the rural Lublin Region (LR) in eastern Poland (PL). The former is characterized by the worst air quality in Poland and one of the worst in Europe. The analysis also includes the most urbanized areas in those two regions – namely the large Silesian Agglomeration (SA) and the less populated Lublin Agglomeration (LA) (Fig. 2) and is limited to the period of the last four years (2018 to 2021), where 2020 was the COVID-19 lockdown year and 2021 was a year of COVID-19-related restrictions. The results of air quality measurement in different locations in SR (Rogula-Kozłowska et al., 2019; Sówka et al., 2019) and in SA (Rogula-Kozłowska et al., 2021; WHO, 2022) have been utilized as well as stationary and mobile air quality measurements carried out in LR (Piotrowicz and Połednik, 2019; Filonchyk et al., 2021) and in LA (WIOS, 2018–2021; Polednik

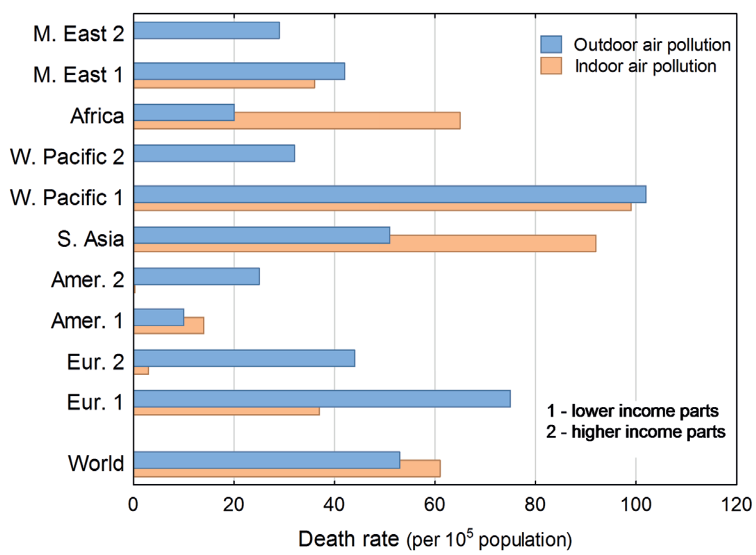

Fig. 1. Deaths attributable to indoor and outdoor air pollution (Compiled from WHO, 2021a and WHO, 2021b)

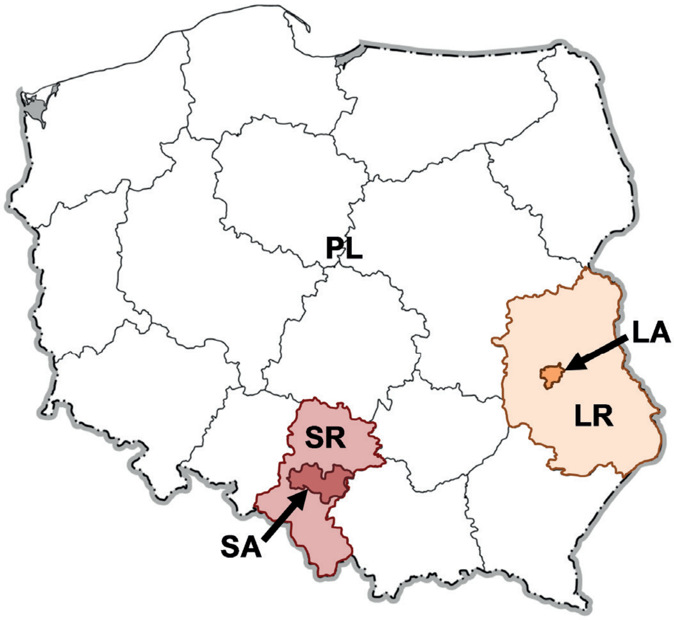

Fig. 2. Map of Poland (PL) with marked Upper Silesian Region (SR), Silesian Agglomeration (SA), Lublin Region (LR) and Lublin Agglomeration (LA)

and Piotrowicz, 2020; Polednik, 2021a). The paper also includes the data on pollutant emissions and their sources (GIOŚ, 2019–2022). While estimating the health effects data on the population number, the demographics and mortality data in the considered regions were also taken into account (GUS, 2019–2022). Descriptive statistics were used to characterize air pollutant emissions, exposure and related health effects reflected in the number of premature deaths and the number of years of life lost.

The paper primarily focuses on the comparison of road traffic emissions and total emissions of the following pollutants: PM_{10}, $PM_{2.5}$, BaP, SO_x and NO_x, which are most suitable and comparable. The methodology described in reports on air quality in Europe (EEA, 2019–2020) was applied while estimating health impacts of air pollution. The relationship between the exposure to ambient pollutant concentrations and health outcomes was utilized. The air pollution-related mortality was estimated based on premature deaths and years of life lost. According to the EEA reports, it was assumed that a premature death (PD) is where a person dies before reaching an expected age which is specified based on the life expectancy for a given country and sex. In turn, years of life lost (YLL) are years of potential life that were lost due to PD and are an estimate of years that would have been lived by people in a population in the absence of PD. The PD attributed to the exposure to $PM_{2.5}$ was considered for the people aged over 30 years, assuming a linear increase in the risk of mortality of 6.2% for a 10 μg/m³ increase in $PM_{2.5}$ for concentrations above 0 μg/m³.

Relative risk (*RR*) – the increase in mortality was estimated by the concentration response function:

$$RR = e^{B(C-C_0)} \tag{1}$$

where: C_o – the background $PM_{2.5}$ concentration ($C_o = 0$),
B – the estimated concentration-response factor ($B = 0.0062$).

The attributable fraction (*AF*) was calculated from the equation:

$$AF = (RR-1)/RR \tag{2}$$

Premature deaths were estimated using:

$$PD = AF \cdot M \cdot Pop \tag{3}$$

where: M – the total number of deaths,
Pop – the size of population.

The number of years of life lost due to premature mortality was calculated from the following:

$$YLL = \sum(PD_i \cdot L_i) \tag{4}$$

where: PD_i – the number of deaths in age class attributable to $PM_{2.5}$,
L_i – the life expectancy at age of death.

The uncertainty range can be expressed using the boundaries of the 95% confidence interval which for $PM_{2.5}$ is 4.0–8.3%.

RESULTS AND DISCUSSION

Emissions of air pollution

The air pollutant emissions are relatively high in Poland and despite numerous initiatives that have been undertaken in recent years, they are still significantly higher than in other European countries. Figure 3 presents the changes of total PM_{10}, $PM_{2.5}$, BaP, SO_x and NO_x emissions in the last four years (2018 – 2021) in the Upper Silesian Region, the Silesian Agglomeration, as well in the Lublin Region and the Lublin Agglomeration and overall in Poland.

The diagrams indicate that in the analyzed period, the emissions of all the considered pollutants have decreased. For example, in the Silesian Agglomeration the greatest reductions have been observed for the SO_x and NO_x emissions, which decreased by almost 10200 and 6700 kg/km^2·year, respectively. The data on total emissions of the individual air pollutants in the considered areas allowed for determining their quotients to the average emission levels in Poland. Figure 4 presents the values of such quotients for the total emissions of PM_{10}, $PM_{2.5}$, BaP, SO_x and NO_x between 2018 and 2021.

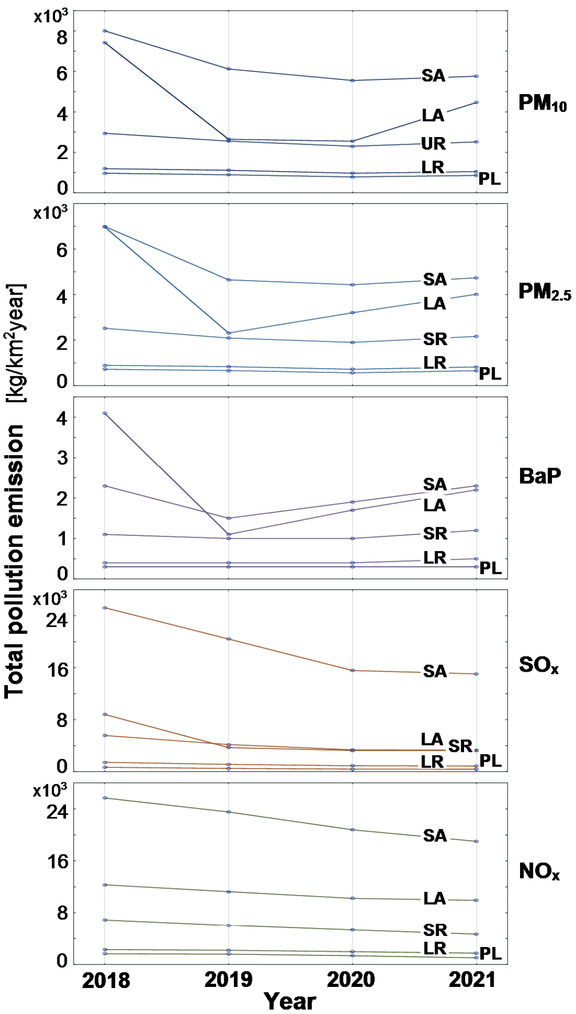

Fig. 3. Emissions of air pollution in the Upper Silesian Region (SR), the Silesian Agglomeration (SA), in the Lublin Region (LR), in the Lublin Agglomeration (LA) and overall in Poland (PL) in 2018 – 2021 (Compiled from GIOŚ, 2019–2022; Polednik and Piotrowicz, 2019; Sówka et al., 2019; WIOS, 2018–2021)

It can be seen that the total emissions of all the above-indicated pollutants in the Upper Silesian Region were almost twice as high as the average emissions in Poland. In turn, the emissions observed in the Lublin Region were lower than the national average. Significantly higher emission quotients ($p < 0.01$) were seen in both agglomerations and, with the exception of BaP emissions in 2018, they were always higher for the Silesian Agglomeration. In the Silesian Agglomeration, the exposure to PM_{10} was over 5 times higher, the exposure to $PM_{2.5}$ was almost 6 times higher and the exposure to BaP was about 5 times higher than the national averages in all the analyzed years. However, the highest exposures, 16 times and 10 times higher than the national average were seen for SO_x and NO_x, respectively. Relatively comparable results were obtained in previous studies in industrial and non-industrial areas in Poland before 2018 (Kobza et al., 2018; Kuźma et al., 2021). It needs to be stated that in the analyzed 4-year period, the exposure values to all the considered pollutants have been reduced. The greatest reduction can be seen in the last two years which, to a significant extent, may be related to limited activities attributed to the COVID-19 pandemic (Polednik, 2021a). The said limitations included, among other things, road transportation that was highly reduced both in Poland, in Europe and generally worldwide during the 2020 lockdowns and in the subsequent year (Polednik, 2021b; Tzvetkova, 2021; Zhang and Hayashi, 2022). Figure 5 presents the pollutant emissions (expressed in kg/(km^2·year) originating from road transportation.

Significantly higher road transportation emissions ($p < 0.02$) were observed in the more densely populated Upper Silesian Region. Both agglomerations were characterized by relatively high emissions; however, higher values were always seen in the Silesian Agglomeration. The most significant differences were observed for

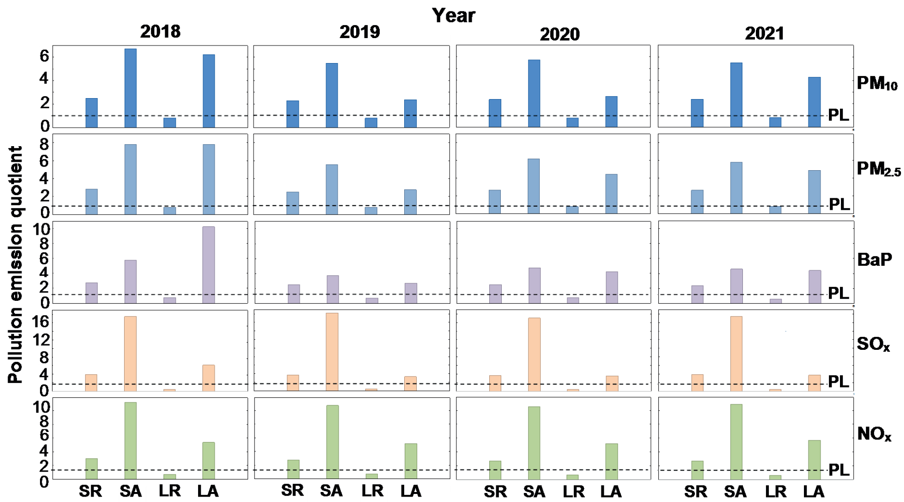

Fig. 4. Pollution emission quotients in the Upper Silesian Region (SR), the Silesian Agglomeration (SA), in the Lublin Region (LR), in the Lublin Agglomeration (LA) to the average emission levels in Poland (PL) (Compiled from GIOŚ, 2019–2022; Filonchyk et al., 2021; Rogula-Kozłowska et al., 2019; WHO, 2022)

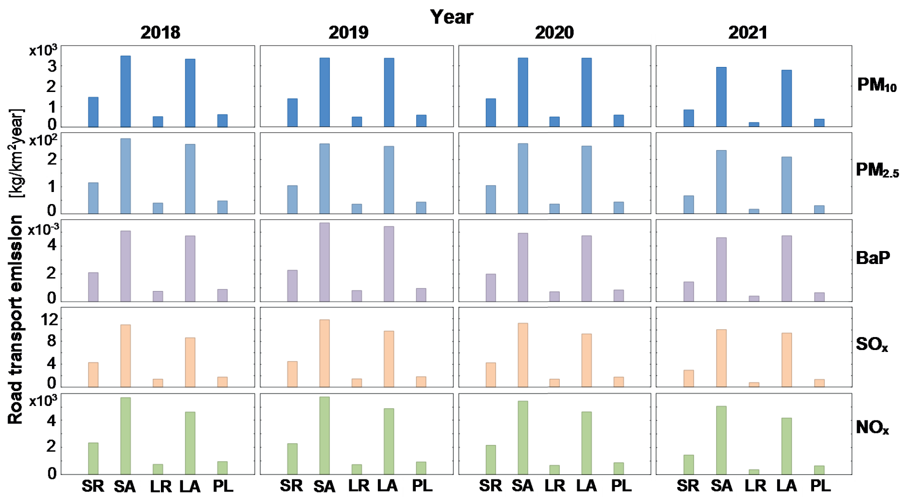

Fig. 5. Pollutant emissions from road transportation in the Upper Silesian Region (SR), the Silesian Agglomeration (SA), in the Lublin Region (LR), in the Lublin Agglomeration (LA) and overall in Poland (PL) in 2018 – 2021 (Compiled from GIOŚ, 2019–2022; Polednik and Piotrowicz, 2020; Polednik, 2021b; Rogula-Kozłowska et al., 2021)

SO_x and NO_x emissions. It can also seen that in the last two years (2020 and 2021) the road transportation emissions were clearly lower.

Health impacts to air pollution

Table 1 presents the data of the European Environment Agency on the population-weighted concentrations of pollutants and the estimated number of premature deaths (PD) attributable to exposure to $PM_{2.5}$, NO_2 and O_3 in Poland for the years 2015–2019.

The premature deaths resulting from the NO_2 exposure were considered for the people over 30 years of age for the concentrations exceeding 20 μg/m^3, assuming a 5.5% linear increase in the mortality risk for a 10 μg/m^3 increase in NO_2. The premature deaths resulting from the O_3 exposure were considered for all age groups, assuming a 0.29% linear increase in the mortality risk for a 10 μg/m^3 increase in the values of O_3 over 35 ppb (EEA, 2020; ETC/ATNI, 2021). Table 1 also presents the population, mortality and life expectancy data. In turn, Table 2 shows the data concerning the number of years of life lost (YLL) and the YLL per 10^5 inhabitants due to the exposure to such pollutants in Poland in the years 2015–2019.

Table 1. Population, mortality (M), life expectancy, population-weighted concentrations of pollutants and premature deaths (PD) attributable to exposure to $PM_{2.5}$, NO_2 and O_3 in Poland for the years 2015–2019 (Compiled from EEA, 2018–2021)

Year	Popul. [×10³]	M [×10³]	Life expect. [years]	$PM_{2.5}$		NO_2		O_3	
				Mean conc. [µg/m³]	PD	Mean conc. [µg/m³]	PD	Mean conc. [µg/m³·days]	PD
2015	38006	394.9	77.6	21.6	44500	15.6	1700	4530	1300
2016	37967	388.0	77.9	20.6	43100	15.2	1500	3699	1100
2017	37973	402.9	77.9	21.4	44800	14.9	1500	3111	920
2018	37977	414.2	77.8	21.7	46300	15.6	1900	5095	1500
2019	37973	409.7	78.0	17.6	39300	14.2	1190	4390	1370

Table 2. Years of life lost (YLL) and the YLL per 10^5 inhabitants due to exposure to $PM_{2.5}$, NO_2 and O_3 in Poland in the years 2015–2019 (Compiled from EEA, 2018–2021)

Year	PM2.5		NO_2		O_3	
	YLL	YLL/10^5 inhabitants	YLL	YLL/10^5 inhabitants	YLL	YLL/10^5 inhabitants
2015	533300	1403	20400	54	16600	44
2016	517700	1364	18500	49	13800	36
2017	596200	1570	20600	54	12800	34
2018	592400	1560	23800	63	20600	54
2019	490300	1291	14900	39	17800	47

Note: data are rounded to the nearest hundred or ten.

The data presented in both tables indicate that in the analyzed period, the highest concentrations of the considered pollutants and thus the highest number of related deaths and YLL, as well as the highest YLL rates per 10^5 inhabitants in Poland were seen in 2018. In that year, 46.3 x10^3 premature deaths were attributed to the $PM_{2.5}$ exposure, 1.9 x10^3 to the NO_2 exposure and 1.5 x10^3 to the O_3 exposure. The YLL rates per 10^5 inhabitants for the above-indicated pollutants amounted to 1560, 63 and 54, respectively. The data from 2018 for 41 European countries indicated that 417 x10^3 premature deaths were attributed to the $PM_{2.5}$ exposure, 55 x10^3 to the NO_2 exposure and 20.6 x10^3 to the O_3 exposure. When considering the uncertainties in health outcomes (expressed as 95% confidence intervals), the premature deaths attributed to $PM_{2.5}$ were in the range 276–543.5 x10^3, those attributed to NO_2 were in the range 32–78 x10^3 and the deaths attributed to O_3 were in the range 10–30.7 x10^3. The assessed YLL/10^5 inhabitants for the 41 countries were 890, 116 and 46 and they were attributed to the $PM_{2.5}$, NO_2 and O_3 exposure, respectively.

As indicated by Khomenko et al. (2021) in Europe diseases and premature deaths are especially numerous among the residents of cities and densely-populated areas. The data on the population, mortality, population-weighted concentration and the estimated PD and YLL attributable to the exposure to $PM_{2.5}$ in the analyzed period from 2018 to 2021 in the SR and LR regions, in the SA and LA agglomerations and in Poland are presented in Table 3.

Mortality in 2020 and 2021 does not include the deaths attributable to COVID-19 (Table 4). The data concerning the population number in the considered regions and in Poland in general was compiled from the statistical yearbooks (GUS, 2019–2022). Missing data for 2020 and 2021 was extrapolated using second-order polynomial trend line. It can be seen that the highest PD values and rates of YLL/10^5 inhabitants in almost all of the analyzed areas and in Poland as a whole were observed in 2018. The lowest, in turn, were in 2020 when the national lockdown was introduced, which significantly contributed to the decrease of air pollutant emissions, including fine particulate matter emissions and thus to the decrease of exposure to such pollutants. In 2020 (and to some extent in 2021) higher M/10^5 inhabitants rates were observed, but they may result from the COVID-19-related restrictions and the lower efficiency of the Polish healthcare system during that time. For the entire 4-year period they highest rates of YLL/10^5 inhabitants were

Table 3. Population, mortality (M), population-weighted $PM_{2.5}$ concentrations (Compiled from GIOŚ, 2019–2022 and GUS, 2019–2022) and premature deaths (PD), years of life lost (YLL) and the YLL per 10^5 inhabitants due to exposure to $PM_{2.5}$ in the period from 2018 to 2021 in the SR and LR regions, in the SA and LA agglomerations and in PL

Year	Popul. [×10^3]	M	$PM_{2.5}$ [μg/m^3]	PD	YLL	YLL/10^5 inhabitants
SR						
2018	4548	52159	30.8	9067	113429	2494
2019	4534	51766	24.3	7240	90572	1998
2020	4518	54323	22.3	7015	87753	1942
2021	4492	58132	23.8	7975	99768	2221
SA						
2018	1856	23009	32.7	4222	52822	2846
2019	1843	23188	26.0	3452	43187	2343
2020	1838	24190	21.7	3045	38094	2072
2021	1823	25886	23.7	3537	44253	2428
LR						
2018	2126	23682	22.4	3071	38416	1807
2019	2118	23015	18.0	2430	30404	1436
2020	2108	24076	16.7	2368	29625	1405
2021	2095	26031	20.4	3093	38690	1847
LA						
2018	340	3535	21.5	441	5519	1624
2019	340	3409	18.0	360	4503	1325
2020	339	3606	17.0	361	4513	1328
2021	338	3897	20.5	465	5819	1719
PL						
2018	38411	414200	21.7	46300	592400	1542
2019	38383	409709	17.6	39300	490300	1277
2020	38268	435913[a]	16.8	39148[*]	489741[*]	1280[*]
2021	38081	428323[a]	19.1	40546[*]	507230[*]	1332[*]

Note: [a] without COVID-19 deaths, [*] extrapolated data.

Table 4. Total death and deaths attributable to COVID-19 in the SR and LR regions, in the SA and LA agglomerations and in PL (Compiled from GUS, 2019–2022)

Location	2020		2021	
	Total	COVID-19	Total	COVID-19
SR	60054	5731	66154	8022
SA	26742	2552	29458	3572
LR	27244	3168	30466	4435
LA	4079	473	4561	664
PL	477355	41442	519517	91194

estimated for SR and SA with an average value of over 2000 YLL/10^5 inhabitants. The presented results confirm the current findings on air pollution and health in Poland (Dąbrowiecki et al., 2021; Kuźma et al., 2021; Nazar and Niedoszytko, 2022). This study is limited by assumption of linear regression deaths vs. exposure to air pollutants in the entire considered range.

Summing up, higher exposure to air pollutants and more serious health effects in the analyzed period were observed in the more industrialized Upper Silesian Region than in the more rural Lublin Region. In turn, relatively high and comparable results were seen in the Silesian and Lublin agglomerations. This shows the need for urgent actions aimed at limiting the emissions of air pollutants in those urban areas. Reasonable, multi-directional activities aimed at lowering the emissions outside of the agglomerations are also of significance.

CONCLUSIONS

The obtained results indicated that in the Silesian Agglomeration and the Lublin Agglomeration the exposure to air pollutants are on comparable levels, which are significantly higher than the exposure levels observed in the remaining parts of the Upper Silesian and Lublin Region as well as than the average exposures in Poland. This is reflected in the data on premature deaths and the number of years lost due to air pollution exposure. Therefore, the actions aimed at limiting air pollutant emissions in these areas are necessary and urgent.

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