PREMATURE DEATHS FROM FINE PARTICLES $PM_{2.5}$ AIR POLLUTION IN REGIONAL CAPITALS OF SLOVAKIA DURING 2016–2020 PERIOD

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SUMMARY

Objectives: The purpose of this quantitative study is to assess the impact of fine particles air pollution in major cities of Slovakia. The study aims to estimate number of premature deaths from long-term exposure to fine particles $PM_{2.5}$ in eight regional capitals of Slovakia in the period 2016–2020. Consequently, the study aims to conduct a comparative analysis using secondary derived indicators.

Methods: For calculations of estimated premature deaths from long-term exposure to fine particles $PM_{2.5}$ air pollution we used standardized methodology developed by the World Health Organization and the European Environment Agency.

Results: The annual average of estimated premature deaths from $PM_{2.5}$ air pollution in the studied period was in Bratislava 353, Košice 219, Prešov 84, Žilina 90, Banská Bystrica 76, Nitra 73, Trnava 59, and Trenčín 52. In relative terms per 1,000 inhabitants Bratislava had annual average 1.14 of estimated premature deaths, Košice 1.32, Prešov 1.38, Žilina 1.61, Banská Bystrica 1.35, Nitra 1.35, Trnava 1.27, and Trenčín 1.31. Bratislava as the largest city in Slovakia recorded the smallest relative number of estimated premature deaths. The worst results were recorded by the city of Žilina.

Conclusions: The estimated number of premature deaths from long-term exposure to particulate matter air pollution in the regional capitals decreased in the given period. The most of the regional capitals with the exception of Bratislava and Žilina, showed similar levels of estimated premature deaths. However, the current geopolitical situation and rising energy prices threaten return to solid fuel burning which is the largest source of particulate matter air pollution in Slovakia and thus reversing positive trends.

Key words: air pollution, fine particulate matter, premature deaths

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INTRODUCTION

Air pollution remains a major threat to human health, globally. The World Health Organization (WHO) considers air pollution as one of the greatest environmental risks to health, estimating ambient (outdoor) air pollution to have caused 4.2 million premature deaths worldwide in 2019. This mortality is due to exposure to fine particulate matter, which causes cardiovascular and respiratory disease, and cancers. The combined effects of ambient air pollution and household air pollution are associated with 6.7 million premature deaths annually (1).

In 2020 in the EU27 the number of estimated premature deaths from exposure to particulate matter decreased from previous years to 238,000, exposure to nitrogen dioxide above the respective guideline level led to 49,000 estimated premature deaths and 24,000 estimated premature deaths occurred due to acute exposure to ozone (2). Premature deaths from air pollution are always estimated for each pollutant individually, however, there are known cross effects thus the estimates for $PM_{2.5}$, NO_2, O_3 cannot be added together as it would result in partial double counting (3).

However, new studies suggest that premature deaths from polluted air in Europe can be higher than previous estimates. Lelieveld et al. (4) estimated the annual excess mortality rate from ambient air pollution in Europe (EU28) to be as many as 790,000. Across Europe air pollution still has a significant impact on health of the population, particularly in urban areas. Europe's most serious pollutants, in terms of harm to human health, are particulate matter (PM), nitrogen dioxide (NO_2), and ground/level tropospheric ozone (O_3) (5).

Air quality in Slovakia ranks poorly among European countries. Within the OECD area Hungary, Poland and Slovakia are burdened with the highest mortality rates from ambient PM pollutions (6). There is an improvement of air quality in Slovakia during the recent two decades. However, the Slovak Environment Agency concludes that despite the decrease in pollutant emissions in the long term, the country is still failing to meet the human health protection limit values of certain pollutants (7).

Pollutant atmospheric particulate matter or fine particulate matter of diameter less than 2.5 µm (micro-meter) $PM_{2.5}$ are solid or liquid particles. The air pollution monitoring also monitors larger particles of diameter less than 10 µm (PM_{10}). The source of these particles can be of natural origin such as wildfires or volcanic eruptions, and of anthropogenic origin such as fuel combustion process for heating, for power generating, in motor vehicles, friction processes, industrial production, etc. In Slovakia, the most significant source of PM emissions is solid fuel burning for household heating followed by road traffic. Locally, certain industrial plants are also major contributors to PM pollution (8).

Health impacts of long-term exposure to air pollution are of various severity. They range from lung function decrements, inflammation, cardiac effects, respiratory symptoms; medication use, asthma attacks; doctor visits, school absences, lost workdays; emergency medical visits, hospital admissions, heart attacks; death (9). Fine particles have ability to penetrate deep into the lungs, blood streams and brain. The smaller the particles the deeper penetration is possible. Health effects also reflect chemical composition of particles (10). According to the Air Quality Life Index study particulate matter air pollution shortens human life on average by 1.8 years (11). That is more than smoking (1.6 years) or alcohol and drugs (11 months). Greenstone and Qing Fan also conclude that sustained exposure to an additional 10 μg/m^3 of $PM_{2.5}$ reduces life expectancy by 0.98 years (11).

MATERIALS AND METHODS

In our study we looked into estimated premature deaths caused by ambient air pollution with pollutant $PM_{2.5}$ in the regional capital cities of Slovakia. Premature deaths (PD) are deaths that occur before a person reaches an expected age. The expected age is typically the age of standard life expectancy for a country and gender. Premature deaths are considered preventable if their cause is eliminated.

Slovakia is divided into eight higher administrative units/regions (Table 1). The regional capitals are the largest cities in the country and all of them are major centres of economic activities and employment. They are also important transportation hubs.

Methodology for health effects calculations of air pollution was standardized by the WHO. The European Environment Agency (EEA) has also adopted the WHO methodology in its annual Air Quality in Europe reports. General formula for air pollution impact calculations considers the following factors: pollution impact = pollution concentration level × impacted population (impact type) × concentration-response function.

Long-term Air Pollution Impact Calculation Algorithm

$$RR_c = exp\ [\beta(C - C_0)]$$

RRc – relative risk at c pollutant concentration; β – concentration-response factor; estimated effect on health based on cohort studies. The coefficient is usually the same for the whole population. C, C_0 – pollutant concentration, C is measured pollutant concentration, C_0 is counterfactual concentration or cut-off value of concentration level to be deducted (baseline concentration, natural concentration, or lowest measured concentration, or concentration level considered not harmful to human health, etc.).

$$AF = [RR_c - 1] / RR_c$$

AF – attributable fraction or number of incidence cases attributable to health risk factor/air pollution.

$$E = AF\ .\ MR\ .\ Pop$$

E – burden of disease* – estimated number of air pollution effects, e.g., illness cases, hospital admissions, premature deaths, etc.; MR – mortality rate/incidence rate; Pop – population exposed to health risk factor.

The WHO Regional Office for Europe created a software tool AirQ+ which encapsulates methodology for quantifying several types of air pollution impacts. The AirQ+ 2.1.1. version calculates both long-term and short-term exposure to ambient and also household air pollution for most prominent pollutants PM, NO_2, O_3 and Bc (black carbon). The calculated effects include mortality, morbidity, hospital admissions, workdays lost, restricted activity days, etc. We chose AirQ+ 2.1.1. software for calculating estimates of premature deaths from $PM_{2.5}$ air pollution in the regional capitals due to its legitimacy and credibility of the authority of WHO as the software tool maker.

All air-pollution related data used in our study were extracted from the Annual Reports on the Air Quality in Slovakia produced by the Slovak Hydrometeorological Institute (SHI). Data on $PM_{2.5}$ pollution in the regional capitals start appearing in these reports as of 2010. Consistent data for capital city of Bratislava start only from 2016. As of 2021 SHI operated network of 53 air

Table 1. *Administrative regions of Slovakia and their capital cities*

Regional unit	Regional capital	Abbreviation	City area km^2
Bratislava self-governing region	Bratislava	BA	367.66
Trnava self-governing region	Trnava	TT	71.54
Nitra self-governing region	Nitra	NR	100.48
Trenčín self-governing region	Trenčín	TN	82.00
Žilina self-governing region	Žilina	ZA	80.03
Banská Bystrica self-governing region	Banská Bystrica	BB	103.38
Prešov self-governing region	Prešov	PO	70.43
Košice self-governing region	Košice	KE	242.77

*Burden of disease is a concept developed by Harvard University, World Bank and WHO describing loss of health and loss of life as a result of disease, injury or health risk factor.

quality monitoring stations out of which 47 measure fine particles pollutant $PM_{2.5}$. All monitoring stations are categorized by area/settlement type: urban (U), suburban (S), rural (R); and station/pollution type: background (B), industrial (I), traffic (T).

All the regional capitals (except for Žilina) have one $PM_{2.5}$ monitoring station located in wider city centre area by a major road with significant local traffic measuring street canyon concentrations (U, T category). The only monitoring station in the city of Žilina is of U, B category although located close to a major road. In case of cities of Trnava, Trenčín, Žilina, and Prešov the city centre monitoring stations are also the only stations in the city. Cities of Banská Bystrica, Nitra and Košice have also a second $PM_{2.5}$ monitoring station located in residential areas of U, B category to monitor urban background levels of $PM_{2.5}$ air pollution. The 2016–2020 five-year $PM_{2.5}$ background concentration level average in Banská Bystrica was lower by 29.17% to the street canyon average (U, T); in Košice the background to traffic five-year concentration average was lower by 17.71%. On the contrary, in the city of Nitra the average $PM_{2.5}$ background pollution level in the residential area located monitoring station (U, B) was higher by 11.9% than the city centre located station (U, T). In the period 2016–2020 the capital city of Bratislava had four $PM_{2.5}$ monitoring stations in total: one station of U, T category, two stations of U, B category and one station of S, B category. The monitoring station of U, T category, however, had not produced reliable data until 2020. Only one U, B monitoring station and one S, B station had produced reliable data.

Yearly averages of $PM_{2.5}$ in the regional capitals were not the highest among the Slovak cities and municipalities with monitoring stations. There are cities with significantly less population which consistently record higher $PM_{2.5}$ concentrations. In 2021 the yearly average of $PM_{2.5}$ concentration amongst the regional capitals has been the highest in Žilina (U, B) and Banská Bystrica (U, T) at level of 19 µg/m^3. There were four monitoring stations in Slovakia with even higher concentration levels: the city of Krompachy (U, T) with 20 µg/m^3; the city of Martin (U, T) with 21 µg/m^3; the municipality of Veľká Ida (S, I) with 21 µg/m^3; and the city of Jelšava (U, B) with 24 µg/m^3. The city of Jelšava and the surrounding area are for many years among the most PM air-polluted municipalities in Slovakia. On the opposite end the lowest level of $PM_{2.5}$ pollution was recorded in the municipality of Stará Lesná (R, B) with 8 µg/m^3 annual average in 2021. According to legislation of the Slovak Republic, the human health protection yearly average of $PM_{2.5}$ concentration was limited to 25 µg/m^3 until the end of 2020. In 2021 the limit was lowered to 20 µg/m^3.

The structure of available $PM_{2.5}$ pollution data of the regional capitals is uneven in terms of number of monitoring stations per city; (un)availability of background concentration levels data; and data quality in terms of varying number of valid measurements per year. In order to conduct a comparative analysis among the regional capitals we needed to make some decisions regarding analysis input data selection.

Since all the regional capitals apart from Žilina have monitoring station of U, T category, we used data from these stations. In case of Žilina we had to use data from the only available monitoring station, which is of U, B category. Most of the population in the regional capitals is exposed to street canyon air pollution due to necessity of communal travel. According to SHI reports concentration levels of $PM_{2.5}$ and other pollutants as well were higher in the past two decades than averages in the studied period 2016–2020. Thus, opting for street canyon pollution levels would generate more realistic premature death estimates and also enable more precise comparative analysis. In 2017 the yearly average of $PM_{2.5}$ from all background monitoring stations (U, B and S, B) in Slovakia was 19.5 µg/m^3 and yearly average of all traffic stations (U, T) was lower at 18.8 µg/m^3 (12). SHI estimated mean $PM_{2.5}$ exposure for the whole territory of Slovakia in 2017 to 16.3 µg/m^3 (lower limit based on modelled data) and 18.9 µg/m^3 (upper limit – average of measured concentrations from all stations with minimum 75% validity). The SHI study (12) explicitly states that data modelling underestimates concentrations to measured concentrations. SHI also calculated yearly average of $PM_{2.5}$ concentrations in built up areas to be by 6.4 µg/m^3 higher to measured concentrations in open landscape, concentrations near local heating points to be by 7.3 µg/m^3 higher to open landscape, concentrations near traffic routes* to be higher by 4.8 µg/m^3 to open landscape (12). The regional capitals are the most built-up areas in Slovakia where the primary source of $PM_{2.5}$ pollution is household heating. Due to these stated facts, we opted for U, T category station data to be representative for our analysis.

Table 2. *Regional capitals annual $PM_{2.5}$ concentration averages from monitoring station of urban, traffic category in 2016–2021 (µg/m^3)*

Regional capital	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
Bratislava	15*	15*	17*	13*	15	15
Košice	N/A	23	20	18	16	18
Prešov	N/A	24	20	18	16	18
Žilina	N/A	**26***	22*	18*	17*	19*
Banská Bystrica	N/A	23	20	18	16	19
Nitra	17*	18*	19*	15	13	16
Trnava	N/A	17	20	16	16	16
Trenčín	18	13	20	18	15	15

*Data from monitoring station of urban, background category. Bold numbers indicate concentrations above legal annual limit. N/A – not available.
Source: Slovak Hydrometeorological Institute

*Traffic routes typically record higher concentrations of NO_X and PM_{10} pollutants. Not necessarily of $PM_{2.5}$ pollutant.

Only data in the range of 90–100% of valid measurements were used. It is due to the fact that some data in lower validity ranges showed volatility in form of dramatic changes from one year to the next. Modelled data for the studied period and locations were not available. We consider results based on measured pollution levels to be on the higher end.

Period and location which did not meet the above two criteria were excluded from our analysis.

All yearly $PM_{2.5}$ pollution averages considered in our analysis can be found in Table 2. This table also includes concentrations for 2021 in order to illustrate further pollution trends.

We set pollution counterfactual concentration cut-off value for our calculations at zero $C_0 = 0$ µg/m^3 which follows methodological recommendations of the WHO Regional Office for Europe and EEA. According to the WHO several cohort studies reported effects on mortality at $PM_{2.5}$ concentrations well below an annual average of 10 µg/m^3 (3). EEA in its methodology guidelines also follows zero counterfactual concentration recommendation by the WHO in cases of estimating premature deaths from $PM_{2.5}$ pollution all natural causes in 30+ years age group (13).

All demographic data were extracted from the public database of the Statistical Office of the Slovak Republic. Due to COVID-19 pandemic our analysis is restricted to the period 2016–2020. The mortality data for 2021 are severely affected by the pandemic and would skew results.

As the total population of an area estimates of premature deaths are calculated for, we used the total year-end population of each regional capital for each year in the period 2016–2020 (Table 3).

Population at risk is a portion of the total population that a particular impact assessment focuses on. Long-term exposure to health risk factor (two or three decades according to cohort studies) determines that the population at risk in our study is restricted to age category 30 years and above.

Relative risk in epidemiology measures the probability that a member of group exposed to health risk factor (breathing air polluted with $PM_{2.5}$ particles) will develop disease (or die as a result of the disease), relative to the probability that a member of group unexposed to health risk factor will develop the same disease. The value of relative risk for a particular disease is determined by cohort studies. In our calculations of premature death estimates as a result of long-term exposure to air polluted with $PM_{2.5}$ particles we used relative risk recommended by the WHO and EEA of $\beta = 1.062$ for a 10 µg/m^3 increase of $PM_{2.5}$ concentration (13). The value means that the increase of $PM_{2.5}$ concentrations by 10 µg/m^3 increases overall mortality in the exposed population by 6.2%. The 95% confidence interval for this relative risk is 1.040–1.083.

Mortality rate needed for our calculations had to reflect population at risk which is the population of 30+ years of age and only natural non-violent (therefore excluding road accidents, homicides, suicides, etc.) causes of death (codes A00-R99 of the International Statistical Classification of Diseases and Related Health Problems). The standard total mortality rate provided in reports of the Statistical Office of the Slovak Republic did not meet these requirements. The WHO methodology suggests using if available a five-year average mortality rate in order to avoid calculations on possible one year anomaly.

The Statistical Office restricts publicly available data on deaths by cause to administrative level of counties/districts. Thus, exact mortality rates of all regional capitals, all natural causes of death in population 30+ years of age, could not be calculated. However, the two largest cities of Bratislava and Košice are themselves administratively divided into several counties. Death cause and age group adjusted mortality rates of these two largest cities were calculated by adding up the rates of their respective counties. The remaining six regional capitals are themselves also county capitals. Each of these counties extend beyond the county capital city limits and include other areas and municipalities. Death cause and age group adjusted mortality rates of these six regional capitals were therefore calculated on county population data. Using county level mortality rates instead of unavailable city level mortality rates was the nearest possible approximation. Table 4 shows all calculated mortality rates for each regional capital and for the whole period from 2016–2020. For the final calculations of premature deaths estimates we used five-year average mortality rates for each regional capital as per WHO/EEA recommendations.

RESULTS

Results of our calculations of premature death estimates from $PM_{2.5}$ air pollution in eight regional capitals of Slovakia in the period 2016–2022 are shown in Table 5. In absolute terms the results reflect the population size of each city meaning the highest number of estimated PD, on average 353 annually, appeared in the largest city Bratislava and the lowest number of estimated PD, on average 55 annually, appeared in the smallest regional capital Trenčín. All other regional capitals ranked in number of estimated PD accordingly to their population size rank with exception of

Table 3. *Total population of the regional capitals in 2016–2020*

Regional capital	2016	2017	2018	2019	2020
Bratislava	425,923	429,564	432,864	437,726	440,948
Košice	239,141	239,095	238,757	238,593	238,138
Prešov	89,618	89,138	88,680	88,464	87,886
Žilina	81,041	80,978	80,810	80,727	80,386
Banská Bystrica	78,635	78,484	78,327	78,084	77,719
Nitra	77,374	77,048	76,655	76,533	76,028
Trnava	65,536	65,382	65,207	65,033	64,735
Trenčín	55,593	55,537	55,333	55,383	55,416

Source: Statistical Office of the Slovak Republic

Table 4. Mortality rate in age group 30+ (all natural causes of death) per 10,000 inhabitants in the regional capitals and counties of the regional capitals in 2016–2020

Regional capital	2016	2017	2018	2019	2020	5-year average
Bratislava (city)	13.10	13.37	13.63	12.77	13.46	13.26
Košice (city)	11.47	11.59	11.76	12.15	13.63	12.12
Prešov (county)	11.65	12.21	12.31	11.85	14.19	12.44
Žilina (county)	14.40	14.02	13.40	12.70	14.35	13.77
Banská Bystrica (county)	11.85	11.98	12.43	12.66	13.02	12.39
Nitra (county)	13.77	13.38	14.36	13.74	16.45	14.34
Trnava (county)	12.61	12.89	13.58	12.21	13.40	12.94
Trenčín (county)	12.92	13.21	14.31	13.36	14.52	13.66

Source: Own processing based on data of the Statistical Office of the Slovak Republic

Žilina. The city of Žilina had in each year of the 2016–2020 period more estimated premature deaths than the city of Prešov which on average had population larger by almost 10%.

Table 6 shows the lower and upper limits of estimated premature deaths in 95% confidence interval that the real number of premature deaths lies within. This table shows that on average in the period 2016–2020 all regional capitals in Slovakia combined recorded somewhere between 665 and 1,305 estimated premature deaths from long-term exposure to $PM_{2.5}$ air pollution annually.

Positive downwards trend was clear in yearly estimated totals for all regional capitals. In 2017 the estimated total number of premature deaths from $PM_{2.5}$ air pollution in all eight regional capitals was 1,090 estimated PD. The following year it was 1,110, in 2019 930, and in 2020 920 estimated premature deaths. In the national context, the total deaths in Slovakia in 2017 were 53,914 which made the share of estimated PD from all regional capitals on total deaths in the country at 2.01%. In 2018 the share was 2.02% of 54,293 of total deaths in the country. In 2019 the share

Table 5. Estimated premature deaths form $PM_{2.5}$ air pollution in the regional capitals in 2016–2020

Regional capital	2016	2017	2018	2019	2020	Average all data	Average 2017–2020
Bratislava	346*	350*	398*	312*	361	353	355
Košice	N/A	257	227	206	185	219	219
Prešov	N/A	101	86	78	70	84	84
Žilina	N/A	111*	96*	79*	75*	90	90
Banská Bystrica	N/A	90	79	72	64	76	76
Nitra	75*	80*	84*	67	59	73	72
Trnava	N/A	58	67	54	55	59	59
Trenčín	55	41	61	56	47	52	51
Total	–	1,086	1,098	925	916	1,006	1,006

*Results based on data from monitoring station of urban, background category. N/A – not available.

Table 6. Range of estimated premature deaths form $PM_{2.5}$ air pollution in the regional capitals in 2016–2020

Regional capital	2016 95% CI	2017 95% CI	2018 95% CI	2019 95% CI	2020 95% CI	Average 95% CI
Bratislava	229–452*	232–457*	264–519*	206–408*	239–472	234–461
Košice	N/A	171–333	151–295	137–269	123–242	145–283
Prešov	N/A	68–131	57–112	52–102	46–91	52–102
Žilina	N/A	74–144*	64–124*	53–103*	50–98*	61–119
Banská Bystrica	N/A	60–116	53–103	48–94	43–84	50–99
Nitra	50–98*	53–104*	56–109*	45–88	39–77	48–95
Trnava	N/A	38–75	45–88	36–71	36–71	39–77
Trenčín	37–72	27–53	41–80	37–73	31–62	35–68
Total		723–1,413	730–1,429	613–1,208	607–1,197	665–1,305

*Results based on data from monitoring station of urban, background category. N/A – not available.

was 1.74% of 53,234 deaths, and in 2020 the estimated PD share was 1.55% of 59,089 deaths (14).

Secondary indicators/coefficients derived from the results enabled further comparative analysis. Table 7 shows number of estimated premature deaths per thousand inhabitants in each regional capital. The city of Žilina had the highest estimated PD/1,000 inhabitants ratio (2017–2020 average) of all regional capitals with 1.61 estimated premature deaths per thousand inhabitants. Žilina was followed by Prešov 1.38, Banská Bystrica 1.35, Nitra 1.33, Košice 1.32, Trenčín 1.29, Trnava 1.27, and Bratislava with the lowest ratio of 1.14 estimated PD/1,000 inhabitants. In case of Žilina and partially in cases of Bratislava and Nitra the calculations used background concentration levels data.

All regional capitals average of 2017 indicated that there were 1.47 estimated premature deaths from $PM_{2.5}$ air pollution per thousand inhabitants. The same rate occurred in 2018, then decreased to 1.25 in 2019, and to 1.16 in 2020.

The trends of decreasing share of PD per 1,000 inhabitants in all regional capitals are visualized in Figure 1. Žilina, Prešov, Banská Bystrica, Trnava, Košice and Nitra all had positive downward trends. However, in case of Bratislava and Trenčín the positive trends were imperceptible. Overall trend for all regional capitals annual averages was positive.

Table 8 shows estimated premature deaths as portion of total deaths in the regional capitals (the number of deaths in six regional capitals, except Bratislava and Košice, was derived from the total number of deaths in their respective county).

The results show that the highest estimated PD share on total deaths recorded the city of Prešov at 14% and city of Žilina at 13.98% in 2017. The lowest estimated PD share on total deaths was recorded by Nitra at 6.43% in 2020, and Bratislava at 7.39% in 2019. The 2017–2020 period averages show that Žilina with 11.60% followed by Prešov with 11.12% were the regional capitals with the highest share of estimated PD on total deaths, followed by Banská Bystrica with 10.30%, and Košice with 10.14%. The average share smaller than ten percent occurred in the cities of Trnava with 9.41%, Nitra and Trenčín both with 9.05% share. The best average was recorded by Bratislava with 8.15%. Yearly averages for all regional capitals in the period 2017–2020 show decreasing share of estimated PD from $PM_{2.5}$ air pollution on the total number of deaths in these cities dropping from 11.08% in 2017 to 8.08% in 2020. The average estimated PD share on all deaths in the period for all the regional capitals was 9.85%.

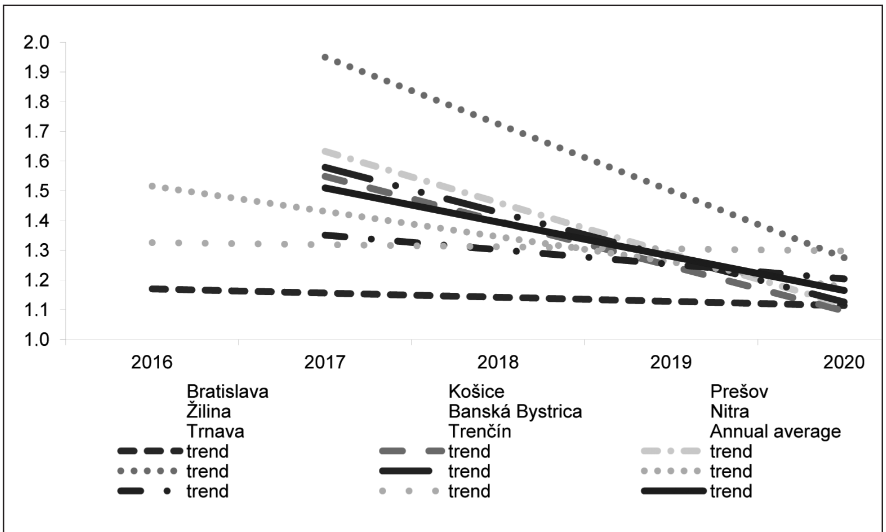

Fig. 1. *Trends of estimated premature deaths from $PM_{2.5}$ air pollution per 1,000 inhabitants of the regional capitals in 2016–2020.*

Table 7. *Estimated premature deaths from $PM_{2.5}$ air pollution per 1,000 inhabitants of the regional capitals in 2016–2020*

Regional capital	2016	2017	2018	2019	2020	Average all data	Average 2017–2020
Bratislava	1.14*	1.14*	1.29*	1.00*	1.14	1.14	1.14
Košice	N/A	1.57	1.37	1.24	1.11	1.32	1.32
Prešov	N/A	1.67	1.41	1.28	1.14	1.38	1.38
Žilina	N/A	1.99*	1.71*	1.41*	1.34*	1.61	1.61
Banská Bystrica	N/A	1.60	1.40	1.27	1.14	1.35	1.35
Nitra	1.39*	1.47*	1.55*	1.24	1.08	1.35	1.33
Trnava	N/A	1.26	1.47	1.19	1.19	1.27	1.27
Trenčín	1.40	1.03	1.55	1.40	1.18	1.31	1.29
Annual average	–	1.47	1.47	1.25	1.16	1.34	1.34

*Results based on data from monitoring station of urban, background category. N/A – not available.

Table 8. *Estimated premature deaths from $PM_{2.5}$ air pollution as a share on total deaths in the regional capitals in 2016–2020*

Regional capital	2016 (%)	2017 (%)	2018 (%)	2019 (%)	2020 (%)	Average all data (%)	Average 2017–2020 (%)
Bratislava	8.28*	8.07*	9.04*	7.39*	8.09	8.17	8.15
Košice	N/A	12.53	10.81	9.57	7.65	10.14	10.14
Prešov	N/A	14.00	11.36	10.82	8.29	11.12	11.12
Žilina	N/A	13.92*	12.49*	10.85*	9.16*	11.60	11.60
Banská Bystrica	N/A	12.68	10.68	9.48	8.37	10.30	10.30
Nitra	9.72*	10.63*	10.51*	8.64	6.43	9.19	9.05
Trnava	N/A	9.31	10.27	9.38	8.68	9.41	9.41
Trenčín	10.53	7.51	10.46	10.24	7.99	9.35	9.05
Annual average	–	11.08	10.70	9.54	8.08	9.91	9.85

*Results based on data from monitoring station of urban, background category. N/A – not available.

DISCUSSION

Contemporary industrial societies pollute the natural environment with their economic activities in many ways. Pollution has complex detrimental effects on humans, all living creatures, infrastructure, and the natural environment as a whole. People getting ill and dying prematurely from exposure to pollution negatively impacts the whole society. Air pollution hurts economic activities, health services, quality of life, human relationships, and society as such. Globally almost a quarter of all premature deaths are attributable to environmental factors (15). Pollution is undoubtedly an issue for the political economy to deal with.

In this study we estimated premature deaths from long-term exposure to $PM_{2.5}$ air pollution in all regional capitals of Slovakia in the period 2016–2020. Our findings confirm continuation of positive trends in decreasing air pollution and its impacts on the regional level. All eight regional capitals experienced improvement in air quality to a various degree in the given period. Despite the positive trends of the past decade Slovakia still ranks poorly in Europe in terms of particulate matter air pollution. In 2018, out of 41 European countries, Slovakia ranked 31st with its annual average concentration at 18.2 $\mu g/m^3$ $PM_{2.5}$, followed by Czechia, Hungary and Greece (18.3 $\mu g/m^3$ $PM_{2.5}$), Montenegro (20.5), Albania (21.6), Poland (21.7), Serbia (26.3), Bosnia and Herzegovina (26.4), Kosovo (28.2), and North Macedonia (30.7 $\mu g/m^3$ $PM_{2.5}$) (16).

Our results show that number of estimated premature deaths from long-term exposure to $PM_{2.5}$ air pollution in absolute terms follows the population size of each regional capital with exception of Žilina which had more estimated PD than the larger city of Prešov. The average number of estimated PD in the period 2016–2020 in the capital city of Bratislava was 353 estimated PD, followed by Košice with 219 estimated PD, Žilina 90 estimated PD, Prešov 84, Banská Bystrica 76, Nitra 73, Trnava 59, and Trenčín with 52 estimated PD. All regional capitals combined recorded somewhere between 665 and 1,305 estimated PD on average each year in the studied period.

Comparing the regional capitals in relative terms by number of estimated PD per 1,000 inhabitants revealed that Bratislava despite being the largest city experienced the lowest number of estimated PD at 1.14 deaths per thousand inhabitants. The second best was the city of Trnava with 1.27 estimated PD/1,000 inhabitants followed by Trenčín (1.31), Košice (1.32), Banská Bystrica (1.35), Nitra (1.35), Prešov (1.38), and Žilina (1.61). Bratislava and Žilina stand out each at opposite ends. The annual average of all eight regional capitals was 1.34 estimated PD/1,000 inhabitants in the period 2016–2020.

We were unable to identify other studies estimating premature deaths from $PM_{2.5}$ in the regional capitals of Slovakia for the period 2016–2020. A study by Khomenko et al. (17) estimated premature deaths from $PM_{2.5}$ and NO_2 in 2015 for almost one thousand European cities which included eight regional capitals of Slovakia. The study estimated premature deaths for adults aged 20+ all natural causes of death, relative risk used was 1.07 (95% CI: 1.04–1.09), counterfactual cut-off values for two scenario calculations were 10 $\mu g/m^3$ and 3.7 $\mu g/m^3$ (the lowest concentration recorded in the studied cities), $PM_{2.5}$ concentrations used were modelled on AirBase data. The findings of the study estimated premature deaths in 2015 (at 3.7 cut-off) to be for Bratislava 331 PD, Košice 196, Prešov 63, Žilina 65, Banská Bystrica 49, Nitra 61, Trnava 50, and Trenčín 47 PD. Compared to these results our 2016 estimates for Bratislava were +4.53%, Trenčín +17.2%, Nitra +22.95% and our 2017 estimates for Trnava were +16%, Košice +31.12%, Prešov +60.32%, Žilina +70.77%, Banská Bystrica +83.67%. Our 2016 estimates were higher on average by 14.83%, and our 2017 estimates were higher on average by 52.38%. Khomenko et al. conducted a sensitivity analysis using measured pollution data (urban and suburban background measurement stations with ≥75% data validity within the city and greater city boundaries) which produced results +11% higher number of preventable deaths than results based on modelled data for the year 2015. Khomenko et al. also conducted a sensitivity analysis using EEA recommended values (as used in our study) and concluded that the estimates using EEA guidelines were on average 27% higher.

It is necessary to point out the fact that some of the regional capitals are located more or less in open terrain (Bratislava, Trnava) and some are surrounded by mountains (Banská Bystrica, Žilina). Thus, each city has different dispersion conditions which play a significant factor in air pollution levels. Bratislava is among the windiest cities in Central Europe (8). Bratislava is also the most southern city of all regional capitals with the shortest winter period. Winter due to heating season is the most polluted time of the year. On the contrary the regional capital Žilina is the most northern city of all regional capitals and is surrounded by mountains. Local weather patterns are significant factors effecting pollution concentration levels.

It is important for regional governments to be aware of the magnitude of air pollution problem and its consequences in their regional capitals in order to prioritize the correct policies aimed at mitigating particulate matter pollution. There are examples from several European cities where local governments achieved a reduction in PM air pollution despite the fact that regional governments have limited tools at their disposal as opposed to national governments. The national government of Slovakia in terms of environmental policy follows environmental policy of the EU. In this regard the Green Deal grand strategy of the EU is relevant. As a part of this strategy the EU introduced "Zero pollution action plan for water, air and soil" in 2021. Among the targets set to be achieved by 2030 is the reduction by more than 55% the health impacts (premature deaths) of air pollution as compared to 2005 (18). This study does not provide answer whether Slovakia is on the path towards reaching this goal. It remains an open question whether available quality air pollution data reach back all the way to 2005 thus making proper assessment of the premature deaths from long-term exposure to air pollution in Slovakia possible.

Our study has some limitations. The pollution data from the regional capitals were in some cases mixed in terms of monitoring station categories. We opted for pollution data from traffic corridor monitoring stations, however, in some cases we had to use data from urban background monitoring stations instead as the traffic/ street canyon data were not available. The second limitation is that the demographic data, namely the mortality rate in required parameters for six regional capitals were not available and had to be substituted with county level mortality rates. Both of these limitations we considered minor with insignificant impact on the study results and conclusions.

CONCLUSION

The political economy of the EU prioritizes economic growth which is explicitly stated in the Green Deal. The Green Deal describes itself as a new growth strategy. Economic growth means more economic activity. More activity requires more energy, more resources. Consumption of energy and resources partially translates into pollution depending on technology. Thus, decoupling economic growth from environmental pollution has its limitations and achieving zero pollution may be an unrealistic target or even more so it may be considered as in direct conflict with politically desired economic growth.

Moreover, it is necessary to asses pollution in the global context due to ability of large transnational corporations to move their production to other countries with more favourable conditions including lesser environmental protection. Also, there are shifts in pollution types, for example electric vehicles may reduce to some degree local air pollution but on the other hand the need for building new necessary infrastructure generates new pollution. Also the need for additional electric power creates more pollution from power generating, etc. The whole life cycle of an electrical vehicle may reduce certain types of pollution, but it may at the same time increase other types of pollution or introduce new types (car battery related pollution for example). Without significant changes in the way of life of our societies the reduction of overall pollution faces limits imposed by the nature of capitalist production and consumption relations.

Slovak governments for long time prioritized short-term economic growth over environmentally orientated long-term development of national economy and society as such. Public debate regarding pollution and air pollution in particular is rare.

In 2022 the war in Ukraine caused major shift in energy policy of the EU and other European countries. In many countries (Germany, Austria, Italy, etc.) governments announced reopening of coal power plants (19). The shift back to burning more coal and wood in Europe became apparent. This shift is undoubtedly in part a consequence to the EU decision to decrease consumption of natural gas from the Russian Federation. In Slovakia, the return to solid fuel was already in progress in 2021 (6). The price of cleaner energy significantly impacts population choices regarding household heating which is the number one source of particulate matter pollution in Slovakia. The third decade of the 21st century is marked with major geopolitical events and changes which are expected to have severe and long-term implications including possible increase of air pollution.

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