

Original Article

Air Pollution, COVID-19–Related Air-Quality Changes, and Premature Mortality in Türkiye (2019–2023)

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Abstract

OBJECTIVE: Long-term exposure to fine particulate matter (PM_{2.5}) contributes to about 8 million premature deaths worldwide annually. In Türkiye, few studies have examined long-term health impacts, particularly during and after the coronavirus disease-2019 (COVID-19) pandemic. This study aimed to estimate premature mortality and the respiratory disease burden attributable to PM_{2.5} from 1 January 2019 to 31 December 2023.

MATERIAL AND METHODS: Premature deaths attributable to PM_{2.5} were estimated using the World Health Organization's (WHO) AirQ+ software. Inputs included annual provincial PM_{2.5} concentrations (measured directly or at stations without PM_{2.5} measurements, converted from PM₁₀ using the WHO-recommended factor of 0.67 for Türkiye), mortality data for individuals aged ≥25 years, and demographic data from Turkish Statistical Institute. The Estimates focused on chronic obstructive pulmonary disease (COPD) and lung cancer. Population attributable fractions were calculated. Temporal comparisons were made across pre-pandemic (2019), pandemic (2020–2021), and post-pandemic (2022–2023) periods to capture potential effects of COVID-19–related reductions in industrial production and traffic. Differences were assessed using one-way ANOVA.

RESULTS: An annual average of 85,344 premature deaths (95% confidence interval: 79,129–91,559) was attributable to PM_{2.5}. COPD and lung cancer accounted for a significant share of PM_{2.5}-related deaths, with about one in seven linked to COPD. Although temporary improvements in air quality occurred during the COVID-19 pandemic, no statistically significant difference was observed in COPD-attributable mortality across the three study periods ($P = 0.687$).

CONCLUSION: Air pollution remains a major public health challenge in Türkiye. Sustained, region-specific strategies are needed to reduce the burden of PM_{2.5}-related mortality. Inadequate monitoring coverage continues to limit precision in exposure and risk assessment.

KEYWORDS: PM_{2.5}, COVID-19, lung cancer, premature mortality, Türkiye, air pollution

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INTRODUCTION

Air pollution, defined as the contamination of the atmosphere by physical, chemical, or biological agents, can occur naturally or from anthropogenic sources, such as the burning of fossil fuels.¹ According to the World Health Organization's (WHO) Global Air Quality Guidelines, the principal ambient air pollutants of concern are fine particulate matter (PM_{2.5}), coarse particulate matter (PM₁₀), ozone (O₃), nitrogen dioxide (NO₂), sulfur dioxide (SO₂), and carbon monoxide (CO).²

Each year, outdoor and household air pollution contribute to 6.7 million premature deaths worldwide by causing a range of health problems.³ Its effects often overlooked by healthcare professionals and individuals, include both acute issues such as asthma attacks and infections,^{4,5} and chronic conditions like ischemic stroke,^{6,7} ischemic heart diseases,⁸ chronic obstructive pulmonary disease (COPD),⁹ and lung cancer, driven by chronic inflammatory processes.¹⁰ Moreover, climate change, fueled by air pollution, alters the geographical distribution of infectious diseases and intensifies natural disasters. Tackling this global threat demands public awareness and a multidisciplinary approach involving scientific experts and national and international organizations that propose sustainable solutions.¹¹

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Long-term exposure to air pollution substantially increases mortality risk. A meta-analysis conducted in 2020 reported that each 10 $\mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ concentration was associated with a 1.08-fold increase in mortality [95% confidence interval (CI): 1.06–1.09].¹² The AirQ+ software, developed by the WHO, incorporates cohort-based risk estimates to quantify the health impacts of air pollution.¹³ Although national-level assessments of long-term (annual) $\text{PM}_{2.5}$ exposure in Türkiye have been published,¹⁴ these analyses were restricted to single-year estimates.

The coronavirus disease-2019 (COVID-19) pandemic created exceptional conditions: nationwide restrictions reduced industrial production and traffic, resulting in temporary improvements in air quality in many countries, while widespread mask use may also have influenced individual-level exposure patterns.^{15,16} To address these gaps, the present study aimed to compare the pre-pandemic (2019), pandemic (2020–2021), and post-pandemic (2022–2023) periods to capture these exceptional circumstances and estimate the burden of premature mortality attributable to long-term exposure to ambient $\text{PM}_{2.5}$ in Türkiye. Specifically, this study seeks to answer the following questions:

1. What is the estimated burden of premature mortality attributable to long-term exposure to ambient $\text{PM}_{2.5}$ (per AirQ+) in Türkiye?
2. How are premature deaths due to long-term exposure to ambient $\text{PM}_{2.5}$ (per AirQ+) distributed across regions and provinces in Türkiye?
3. What are the temporal trends in the estimated proportion of premature mortality from COPD attributable to long-term exposure to ambient $\text{PM}_{2.5}$ (per AirQ+) before and after the COVID-19 pandemic?

Main Points

- Long-term exposure to particulate matter ($\text{PM}_{2.5}$) air pollution is a major contributor to premature deaths and chronic respiratory diseases globally.
- World Health Organization's AirQ+ software is widely used to estimate health impacts of air pollution using exposure and incidence data.
- Most studies in Türkiye have focused on short-term effects; national long-term analyses remain limited.
- This study presents the first multi-year (2019–2023) national estimate of premature mortality 40 from $\text{PM}_{2.5}$ -related air pollution in Türkiye using AirQ+.
- It reveals notable regional disparities in chronic obstructive pulmonary disease (COPD) and lung cancer mortality, with the greatest burden in Southeastern provinces.
- Although air quality briefly improved during coronavirus disease-2019, no significant reduction in $\text{PM}_{2.5}$ -related COPD deaths was observed, highlighting the need for ongoing interventions.

MATERIAL AND METHODS

Design

This ecological study covered the 2019–2023 five-year period at the national scale. To capture potential effects of COVID-19 restrictions, three temporal strata were defined: pre-pandemic (01-Jan-2019–31-Dec-2019), pandemic (01-Jan-2020–31-Dec-2021), and post-pandemic (01-Jan-2022–31-Dec-2023).

Data Collection Tools

Air quality data were based on PM (PM_{10} and $\text{PM}_{2.5}$), which were used as pollutant parameters. These data were obtained retrospectively from the official website of the Ministry of Environment, Urbanization and Climate Change.¹⁷ For PM_{10} and $\text{PM}_{2.5}$ data to be included, a minimum annual measurement availability of at least 60% was considered acceptable.¹⁸ Since $\text{PM}_{2.5}$ measurements were not available at some national ground-based air quality monitoring stations, PM_{10} data were converted to $\text{PM}_{2.5}$. Household air pollution was not included in this assessment.

Country-specific conversion factors were calculated as the mean ratio of PM_{10} to $\text{PM}_{2.5}$ concentrations among stations reporting both pollutants in the same year. If country-specific conversion factors were not available, regional conversion factors obtained by averaging the available country-specific factors were used. As the conversion factor $\text{PM}_{2.5}/\text{PM}_{10}$ may vary according to location, the converted PM_{10} (or $\text{PM}_{2.5}$) values for individual settlements may deviate from the actual values (generally between 0.4 and 0.8) and should be considered approximate only.¹⁹ The conversion factor of 0.67 recommended by the WHO for converting PM_{10} to $\text{PM}_{2.5}$ in Türkiye was applied.

Population data for Türkiye, from 2019 to 2023, were obtained from the Turkish Statistical Institute (TURKSTAT) database.²⁰ In AirQ+ calculations, the population at risk was defined as the total population excluding individuals younger than 25 years of age.

The data on COPD mortality rates were taken from the COPDTURKEY-1 study, which provides community-based data for 2020.²¹ For the lung cancer mortality rate, data from the Globocan (GCO) statistics for Türkiye²² were used in the calculations. The mortality rate for COPD was 420 per 100,000 population, while that for lung cancer was 35.1 per 100,000 population (GCO).

Ethical Considerations

Ethical approval and institutional permissions were not obtained because the data were collected from online open-access databases for this research. Informed consent was not obtained because disease-specific mortality data were used in the study.

AirQ+ Methodology

The AirQ+ program, developed by the WHO European Region, estimates the health impacts of air pollution by evaluating both

short-term (e.g., hospital admissions, workday losses) and long-term effects (e.g., all-cause and cause-specific mortality) of pollutants such as $PM_{2.5}$, PM_{10} , NO_2 , O_3 , and black carbon. All calculations, which use an integrated risk function rather than relative risks, are based on meta-analyses of studies published since 2013. Required inputs include the cause-specific mortality rate and the exposed adult population. In this study, $PM_{2.5}$ -related premature mortality rates were calculated specifically using the burden of disease (BoD) module for long-term mortality. Due to limited $PM_{2.5}$ data, PM_{10} measurements from 2019–2023 were converted using WHO-recommended factors, and disease burden was estimated following the AirQ+ methodology. For this study, long-term (annual) exposure to ambient $PM_{2.5}$ was used to estimate attributable premature mortality. Inputs included annual provincial $PM_{2.5}$ concentrations, baseline cause-specific mortality rates, and the exposed population (aged 25 and above). Outputs were calculated at the provincial level.

Estimation of Premature Mortality (Non-accidental Deaths) Attributable to $PM_{2.5}$

Mortality estimates were calculated using the BoD module of the WHO AirQ+ software. For input data, cause-specific mortality rates were derived from official TURKSTAT datasets stratified by province and selected causes of death. In this process, the total number of deaths was adjusted by excluding deaths due to accidents and injuries to obtain non-accidental deaths [non-communicable deaths + acute lower respiratory infection (ALRI)]. One required input for the premature mortality calculation is the mortality rate for non-communicable diseases and ALRIs. For each province and year, the total number of deaths was adjusted by excluding external causes (ICD-10 codes V01–Y98). Using the adjusted death counts and the at-risk population obtained from AirQ+, the mortality rate per 100,000 population was calculated. The cut-off value for annual mean $PM_{2.5}$ concentration was set at $2.4 \mu\text{g}/\text{m}^3$, consistent with the Global Exposure Mortality Model.²³ This approach enabled estimation

of premature mortality attributable to long-term exposure to ambient $PM_{2.5}$ at the provincial level in Türkiye for individuals aged 25 years and older.

Province-specific population attributable fractions (PAFs) were calculated using the AirQ+ BoD module based on annual mean $PM_{2.5}$ concentrations and cause-specific mortality rates. All calculations were performed for individuals aged 25 years and above.

Statistical Analysis

All analyses were conducted using IBM SPSS Statistics for Windows, Version 22.0 (IBM Corp., Armonk, NY, USA). Continuous variables were summarized as mean $\pm$ standard deviation. For Türkiye, the estimated proportion of COPD mortality attributable to long-term exposure to $PM_{2.5}$ was derived from the provincial average proportions. These estimated proportions were then compared across the pre-pandemic (2019), pandemic (2020–2021), and post-pandemic (2022–2023) periods using one-way ANOVA. Assumptions of normality and homogeneity were tested with Shapiro–Wilk and Levene tests. Results were reported with 95% CIs, and $P < 0.05$ was considered statistically significant.

RESULTS

Descriptive data on PM_{10} levels in Türkiye from 2019 to 2023 are summarized in Table 1. Over the past five years, the provinces with the highest PM_{10} pollution levels were Muş ($96.70 \mu\text{g}/\text{m}^3$), Batman ($82.83 \mu\text{g}/\text{m}^3$), Iğdır ($79.29 \mu\text{g}/\text{m}^3$), Şırnak ($74.64 \mu\text{g}/\text{m}^3$), and Malatya ($72.72 \mu\text{g}/\text{m}^3$). Among these, Muş showed a decreasing trend in pollution, Malatya exhibited an increasing trend, while the other provinces displayed a fluctuating pattern. The four provinces with the cleanest air quality during this period, based on the lowest 5-year PM_{10} averages, were Bitlis ($22 \mu\text{g}/\text{m}^3$), Artvin ($24 \mu\text{g}/\text{m}^3$), Bilecik ($27 \mu\text{g}/\text{m}^3$), and Rize ($28 \mu\text{g}/\text{m}^3$).

Table 1. Data on the air pollution levels (particulate matter₁₀) by provinces (2019–2023) in Türkiye

NUTS-1	NUTS-2	NUTS-3	2019	2020	2021	2022	2023
İstanbul region (TR1)	İstanbul subregion	İstanbul	40.21	26.15	37.43	36.55	37.54
		Tekirdağ	31.06	29.22	44.05	33.35	36.37
West Marmara region (TR2)	Tekirdağ subregion	Edirne	33.04	30.76	63.00	41.40	45.04
		Kırklareli	38.63	23.07	30.21	22.92	26.37
	Balıkesir subregion	Balıkesir	39.38	23.07	52.89	43.43	46.45
		Çanakkale	26.71	21.53	36.38	27.94	35.74
	İzmir subregion	İzmir	35.55	38.26	35.15	44.37	40.33
		Aydın	50.35	55.54	37.97	53.35	50.36
Aegean region (TR3)	Aydın subregion	Denizli	54.78	59.78	76.49	57.04	42.89
		Muğla	54.74	52.68	43.02	54.32	45.12
	Manisa subregion	Manisa	63.41	53.78	33.21	51.74	56.30
		Afyonkarahisar	24.09	38.55	36.56	39.06	33.85
		Kütahya	30.21	35.38	52.41	30.04	N/A
		Uşak	N/A	N/A	N/A	41.74	33.00

Table 1. Continued

NUTS-1	NUTS-2	NUTS-3	2019	2020	2021	2022	2023
East Marmara region (TR4)	Bursa subregion	Bursa	43.66	39.90	51.38	51.97	55.95
		Eskişehir	32.92	23.07	36.20	29.37	N/A
		Bilecik	26.92	23.07	39.31	24.55	23.27
	Kocaeli subregion	Kocaeli	39.80	26.15	40.54	37.92	39.40
		Sakarya	40.72	39.90	38.32	39.29	40.47
		Düzce	68.18	64.61	43.91	49.97	45.48
		Bolu	37.81	35.38	41.93	33.97	36.80
West Anatolia region (TR5)	Ankara subregion	Yalova	25.15	24.61	35.37	21.28	39.56
		Ankara	44.04	30.76	35.94	31.09	38.61
		Konya	46.23	49.22	55.66	39.97	49.47
	Konya subregion	Karaman	30.37	36.57	30.31	33.12	33.86
		Antalya	39.28	27.69	39.10	29.28	31.01
	Antalya subregion	Isparta	44.75	39.90	36.38	27.72	27.73
		Burdur	37.35	40.98	38.91	35.94	39.15
Mediterranean region (TR6)	Adana subregion	Adana	42.04	30.99	47.34	39.94	43.56
		Mersin	58.89	41.31	61.80	49.98	53.25
		Hatay	12.94	41.37	38.56	40.40	58.68
	Hatay subregion	Kahramanmaraş	75.50	N/A	66.77	49.35	66.33
		Osmaniye	58.29	N/A	75.14	61.07	78.60
	Kırıkkale subregion	Kırıkkale	50.14	40.24	46.08	22.92	N/A
		Aksaray	21.98	44.64	43.77	33.09	37.01
Central Anatolia region (TR7)		Niğde	49.80	30.76	45.30	51.67	51.35
		Nevşehir	24.66	41.45	42.03	52.87	45.66
	Kırşehir	24.91	15.38	42.01	16.35	N/A	
	Kayseri	58.01	38.46	54.85	46.03	48.44	
	Kayseri subregion	Sivas	51.20	38.46	43.74	33.64	42.91
		Yozgat	20.12	37.79	47.13	20.98	N/A
	Zonguldak subregion	Zonguldak	44.38	56.17	53.22	37.92	56.79
Karabük		30.44	36.92	51.60	32.54	N/A	
Bartın		39.80	52.77	48.26	35.97	31.56	
Kastamonu		44.20	33.84	27.38	45.20	N/A	
West Black Sea region (TR8)	Kastamonu subregion	Çankırı	31.97	29.22	38.47	14.03	31.15
		Sinop	50.06	50.30	40.08	36.57	23.33
	Samsun subregion	Samsun	46.88	26.15	41.21	32.17	39.85
		Tokat	51.94	57.85	43.70	40.81	42.22
		Çorum	64.71	55.38	52.60	43.01	43.67
		Amasya	52.47	49.22	39.52	33.09	37.65
	East Black Sea region (TR9)	Trabzon subregion	Trabzon	41.20	36.92	36.83	30.91
Ordu			52.98	47.88	46.36	41.86	41.18
Giresun			42.71	25.50	39.29	30.98	26.18
Rize			26.92	36.78	31.93	24.61	19.91
Artvin			20.58	28.38	28.21	31.97	15.62
Gümüşhane		44.11	45.04	36.71	49.84	49.32	

Table 1. Continued

NUTS-1	NUTS-2	NUTS-3	2019	2020	2021	2022	2023
Northeast Anatolia region (TRA)	Erzurum subregion	Erzurum	46.64	32.30	43.93	40.88	N/A
		Erzincan	55.24	69.71	52.35	52.71	N/A
	Ağrı subregion	Bayburt	33.11	30.71	54.12	49.67	25.68
		Ağrı	82.60	73.53	85.97	62.18	44.95
		Kars	54.98	42.30	52.02	44.61	34.86
		Iğdır	85.98	69.29	98.18	63.69	N/A
	Malatya subregion	Ardahan	39.63	30.06	55.55	54.61	40.95
		Malatya	63.18	66.92	70.43	77.32	85.76
Elazığ		58.32	49.55	41.96	41.80	35.67	
Bingöl		38.84	38.31	40.06	58.43	48.74	
Central East Anatolia region	Van subregion	Tunceli	41.57	43.80	46.19	45.71	37.11
		Van	40.95	39.70	42.32	45.58	38.42
		Muş	136.38	105.65	88.51	79.66	73.29
		Bitlis	21.11	17.69	22.79	28.97	19.68
	Gaziantep subregion	Hakkari	14.61	15.31	14.34	113.55	72.19
		Gaziantep	48.43	N/A	53.37	60.09	59.25
		Adıyaman	53.17	52.81	52.32	26.23	24.91
		Kilis	52.00	73.15	65.89	20.21	59.90
Southeast Anatolia region	Şanlıurfa subregion	Şanlıurfa	43.94	45.28	56.83	63.40	59.74
		Diyarbakır	39.49	39.30	43.67	44.11	40.39
	Mardin subregion	Mardin	40.61	26.91	53.53	54.17	54.25
		Batman	43.95	98.26	108.57	91.37	71.98
		Şırnak	81.44	70.74	75.77	79.67	65.55
		Siirt	42.84	42.86	45.39	51.87	43.24

N/A: non-applicable, NUTS: nomenclature of territorial units for statistics

Total non-accidental deaths at the provincial level are presented in Table 2. In 2023, The highest annual number of deaths occurred in İstanbul (67,985), followed by İzmir (29,715) and Ankara (28,572). The lowest numbers were observed in Bayburt (468), Ardahan (676), and Hakkari (651).

Provincial-level premature deaths attributable to long-term PM_{2.5} exposure are summarized in Table 3. From 2019 to 2023, the annual national mean number of premature deaths was 85,344 (95% CI: 79,129–91,559). At the provincial scale, attributable mortality rates ranged from 100 to 300 per 100,000 population. The highest rates were observed in Sinop (295.81), Çorum (289.56), and Kastamonu (284.28), while the lowest rates were observed in Bitlis (100.29) and Çanakkale (100.58), with Rize (177.57) having the next lowest rate (Table 3).

Between 2019 and 2023, the PAF values attributable to PM_{2.5} for COPD and lung cancer mortality in Türkiye showed significant regional differences. For COPD, the highest PAF values were observed in Muş (34.4%), Batman (30.9%), and Şırnak (29.4%), while the lowest values were recorded in Bitlis (9.5%), Artvin (10.1%), and Kırşehir (11.7%) (Figure 1). Similarly, for lung cancer, the highest PAF values were found in Muş (29.1%), Iğdır (26.8%), and Şırnak (26.5%), whereas the lowest values were

observed in Bitlis (10.3%), Artvin (10.9%), and Bilecik (12.1%). These findings highlight the significant public health impact of air pollution. Particularly in the Eastern and Southeastern Anatolia regions (Figure 1).

Figure 2 shows PAF percentages for deaths from COPD and lung cancer attributable to PM_{2.5} across Türkiye from 2019 to 2023. The highest PAF values for COPD in 2023 were observed in Balıkesir (20.42%) and Aydın (21.86%). For lung cancer, Balıkesir (20.18%) and Aydın (21.30%) also stand out with high PAF values. Meanwhile, cities such as Kırklareli and Çanakkale exhibit lower percentages, suggesting differing levels of pollution exposure or the presence of other risk factors. The persistence of high PAF values in certain regions over multiple years underscores the ongoing health challenges posed by air pollution.

Table 4 presents detailed on COPD-specific and lung-cancer-specific burdens associated with long-term PM_{2.5} exposure in 2019 and 2023. For COPD in 2023, the highest PAFs were observed in Balıkesir (20.42%), Aydın (21.86%), Denizli (19.05%), and Manisa (23.92%). For lung cancer, the corresponding highest PAFs were in Balıkesir (20.18%), Aydın (21.30%), and İzmir (18.21%). The lowest COPD PAFs were

Table 2. Total number of deaths excluding accident injuries at the provincial level in Türkiye (2019–2023)

NUTS-1	NUTS-2	NUTS-3	2019	2020	2021	2022	2023	
İstanbul region (TR1)	İstanbul subregion	İstanbul	61112	74209	82511	71884	67985	
		Tekirdağ	5413	6138	7297	6934	1290	
		Edirne	3427	3682	4486	4134	3864	
West Marmara region (TR2)	Tekirdağ subregion	Kırklareli	2847	3175	3783	3671	3332	
		Balıkesir	10528	10881	13392	12095	11519	
		Çanakkale	4352	2053	2101	1857	1647	
	İzmir subregion	İzmir	26540	28,678	32,972	31,441	29,715	
		Aydın	7922	8739	9952	9353	8633	
		Denizli	6393	7597	7832	7186	6975	
Aegean region (TR3)	Aydın subregion	Muğla	5530	5999	7234	7097	6680	
		Manisa	9455	11343	11750	11253	10503	
		Afyonkarahisar	4929	6003	6083	5486	4993	
	Manisa subregion	Kütahya	4508	5087	5790	5002	4635	
		Uşak	2635	3120	2939	2851	2728	
		Bursa	16024	18789	21330	19032	18232	
	Bursa subregion	Eskişehir	5562	6218	7313	6696	6192	
		Bilecik	1540	1776	1961	1731	1609	
		Kocaeli	8363	9548	11868	10234	9402	
East Marmara region (TR4)	Kocaeli subregion	Sakarya	6031	6767	8030	6837	6447	
		Düzce	2285	2544	3011	2638	2513	
		Bolu	2166	2506	2742	2509	2366	
	Yalova	Yalova	1521	1759	2229	2097	1903	
		Ankara subregion	Ankara	25315	31998	32117	29746	28572
			Konya	11309	14683	15682	12609	12506
West Anatolia region (TR5)	Konya subregion	Karaman	1431	1691	1864	1601	1594	
		Antalya	10677	11691	14783	13351	12820	
		Isparta	3029	3453	3517	3332	3064	
	Antalya subregion	Burdur	2002	2316	2447	2344	2145	
		Adana	10872	12977	14294	12759	12299	
		Mersin	8916	10097	12129	10908	10736	
Mediterranean region (TR6)	Adana subregion	Hatay	7305	9351	9810	8462	8250	
		Kahramanmaraş	4938	6151	6410	5467	5431	
		Osmaniye	2403	2891	3589	2982	2850	
	Hatay subregion	Kırıkkale	1836	2231	2440	2145	2026	
		Aksaray	1993	2333	2656	2311	2169	
		Kırıkkale subregion	Niğde	2025	2237	2509	2318	2101
	Kırıkkale subregion	Nevşehir	1915	2258	2519	2117	2100	
		Kırşehir	1580	1814	1962	1737	1632	
		Kayseri	6650	8335	9466	7751	7517	
Central Anatolia region (TR7)	Kayseri subregion	Sivas	4155	5011	5431	4728	4313	
		Yozgat	3000	3493	3765	3227	3192	

Table 2. Continued

NUTS-1	NUTS-2	NUTS-3	2019	2020	2021	2022	2023
West Black Sea region (TR8)	Zonguldak subregion	Zonguldak	4134	4461	5394	4796	4633
		Karabük	1684	1901	2227	2050	1887
		Bartın	1516	1580	1911	1808	1750
	Kastamonu subregion	Kastamonu	3632	3963	4649	4092	3936
		Çankırı	1662	2053	2101	1857	1647
		Sinop	1976	2395	2682	2487	2219
		Samsun	8236	9457	11736	10054	9271
	Samsun subregion	Tokat	4206	4914	5879	4899	4647
		Çorum	4076	4774	4837	4566	4256
		Amasya	2497	2889	3393	3020	2728
East Black Sea region (TR9)	Trabzon subregion	Trabzon	4864	5711	6881	6129	5212
		Ordu	5181	5773	7502	6695	5897
		Giresun	3587	4027	4945	4398	3917
		Rize	2353	2577	3054	2738	2503
		Artvin	1375	1574	1644	1608	1557
	Erzurum subregion	Gümüşhane	861	1059	1188	1105	943
		Erzurum	3985	4629	4926	4107	3842
		Erzincan	1479	1626	1872	1684	1500
		Bayburt	455	595	645	497	468
		Ağrı	1704	2098	2308	1664	1682
Northeast Anatolia region (TRA)	Ağrı subregion	Kars	1411	1498	1501	1351	1261
		Iğdır	718	796	758	706	676
		Ardahan	712	793	758	706	676
	Malatya subregion	Malatya	4003	5357	5649	4519	4445
		Elazığ	3142	3934	3196	3592	3254
		Bingöl	1052	1286	1346	1106	1070
		Tunceli	524	719	671	640	539
	Van subregion	Van	3097	4085	4080	3091	3182
		Muş	1305	1517	1642	1365	1291
		Bitlis	1080	1440	1412	1244	1175
Central East Anatolia region	Gaziantep subregion	Hakkari	724	929	789	657	651
		Gaziantep	7519	10036	10192	8576	8943
		Adıyaman	2620	3148	3279	2738	2816
	Şanlıurfa subregion	Kilis	817	895	991	823	754
		Şanlıurfa	6093	7088	7770	6275	6653
		Diyarbakır	4993	6982	7295	5646	5688
	Mardin subregion	Mardin	2641	3470	3426	2868	2736
		Batman	1630	2296	2316	1760	1763
		Şırnak	1219	1591	1462	1184	1222
		Siirt	1023	1293	1306	1035	981

N/A: non-applicable, NUTS: nomenclature of territorial units for statistics

Table 3. Provincial-level annual premature deaths excluding accident injuries attributable to average particulate matter_{2.5} levels in Türkiye (2019–2023)

NUTS-1	NUTS-2	NUTS-3	Estimated number of attributable cases			Estimated number of attributable cases per 100,000 population at risk		
			Mean	Min	Max	Mean	Min	Max
İstanbul region (TR1)	İstanbul subregion	İstanbul	13076	10079,00	15926,00	130,44	100,54	158,88
		Tekirdağ	976	752,00	1190,00	135,36	104,30	164,93
	Tekirdağ subregion	Edirne	801	619,00	972,00	274,13	211,96	332,88
West Marmara region (TR2)	Balıkesir subregion	Kırklareli	379	291,00	463,00	144,88	111,29	177,07
		Balıkesir	2332	1802,00	2834,00	263,08	203,27	319,68
	İzmir subregion	Çanakkale	392	301,00	479,00	100,58	77,31	122,84
		İzmir	5112	3946,00	6218,00	168,04	129,71	204,40
	Aydın subregion	Aydın	1998	1549,00	2419,00	258,64	200,56	313,19
		Denizli	1779	1384,00	2147,00	255,64	198,92	308,51
		Muğla	1466	1137,00	1775,00	205,17	159,12	248,39
Aegean region (TR3)	Manisa subregion	Manisa	2498	1938,00	3022,00	258,46	200,60	312,70
		Afyonkarahisar	984	758,00	1200,00	210,67	162,30	256,74
		Kütahya	956	737,00	1163,00	242,31	187,00	294,81
	Bursa subregion	Uşak	-	-	-	-	-	-
		Bursa	4135	3205,00	5009,00	202,25	156,77	245,00
		Eskişehir	1060	815,00	1294,00	173,97	133,77	212,40
		Bilecik	268	206,00	327,00	175,32	134,62	214,36
East Marmara region (TR4)	Kocaeli subregion	Kocaeli	1843	1422,00	2244,00	145,01	111,84	176,54
		Sakarya	1335	1031,00	1623,00	197,73	152,69	240,40
		Düzce	617	479,00	745,00	240,02	186,49	290,08
	Ankara subregion	Bolu	461	356,00	562,00	217,07	167,43	264,20
		Yalova	307	236,00	375,00	164,88	126,71	201,42
	Antalya subregion	Ankara	5448	4200,00	6635,00	146,55	112,99	178,46
		Konya	2939	2278,00	3561,00	205,80	159,49	249,34
West Anatolia region (TR5)	Konya subregion	Karaman	285	219,00	347,00	177,57	136,70	216,55
		Antalya	2221	1710,00	2707,00	130,74	100,67	159,41
		Isparta	596	460,00	726,00	205,12	158,09	249,88
	Adana subregion	Burdur	431	333,00	525,00	235,40	181,68	286,36
		Adana	2512	1941,00	3053,00	184,25	142,34	223,91
		Mersin	2467	1915,00	1983,00	208,16	161,65	251,71
		Hatay	1654	1276,00	2012,00	176,58	136,28	214,81
Mediterranean region (TR6)	Hatay subregion	Kahramanmaraş	1482	1156,00	1785,00	226,51	176,62	272,80
		Osmaniye	794	620,00	955,00	246,12	192,17	296,03
		Kırıkkale	501	389,00	605,00	178,79	138,86	216,17
	Kırıkkale subregion	Aksaray	423	326,00	515,00	166,78	128,58	203,10
		Niğde	478	370,00	579,00	216,91	167,94	263,06
		Nevşehir	437	338,00	531,00	222,41	171,87	270,22
		Kırşehir	257	197,00	314,00	162,82	124,88	199,30
Central Anatolia region (TR7)	Kayseri subregion	Kayseri	1771	1373,00	2145,00	203,47	157,75	246,42
		Sivas	957	740,00	1162,00	236,20	182,58	286,90
		Yozgat	579	446,00	706,00	214,32	164,99	261,38

Table 3. Continued

NUTS-1	NUTS-2	NUTS-3	Estimated number of attribut- able cases			Estimated number of attributable cases per 100.000 population at risk			
			Mean	Min	Max	Mean	Min	Max	
West Black Sea region (TR8)	Zonguldak subregion	Zonguldak	1051	815,00	1273,00	255,50	198,14	309,37	
		Karabük	380	293,00	462,00	230,47	177,96	280,24	
		Bartın	345	267,00	419,00	246,78	190,73	299,79	
	Kastamonu subregion	Kastamonu	762	587,00	927,00	284,28	219,28	346,01	
		Çankırı	300	230,00	366,00	224,97	172,87	274,86	
		Sinop	462	357,00	562,00	295,81	228,46	359,59	
	Samsun subregion	Samsun	1833	1414,00	2231,00	204,23	157,54	248,58	
		Tokat	1069	828,00	1296,00	270,05	209,21	327,29	
		Çorum	1037	805,00	1255,00	289,56	224,75	350,30	
	East Black Sea region (TR9)	Trabzon subregion	Amasya	591	457,00	718,00	258,20	199,61	313,57
			Trabzon	1046	806,00	1274,00	193,47	149,11	235,69
			Ordu	1330	1030,00	1613,00	254,94	197,40	309,14
Trabzon subregion		Giresun	727	560,00	887,00	228,66	176,04	278,85	
		Rize	417	320,00	509,00	177,57	136,38	217,04	
		Artvin	227	174,00	278,00	188,98	144,93	231,35	
Erzurum subregion		Gümüşhane	218	169,00	264,00	228,35	176,74	277,02	
		Erzurum	849	656,00	1032,00	199,56	154,15	242,56	
		Erzincan	392	305,00	474,00	258,53	200,96	312,30	
Northeast Anatolia region (TRA)		Ağrı subregion	Bayburt	102	79,00	124,00	203,12	156,78	247,07
			Ağrı	522	408,00	627,00	218,61	170,86	262,70
			Kars	300	232,00	363,00	192,39	148,95	233,32
	Malatya subregion	Iğdır	214	168,00	257,00	200,81	157,38	240,66	
		Ardahan	152	118,00	185,00	251,85	194,85	305,63	
		Malatya	1355	1060,00	1627,00	275,56	215,59	330,80	
	Van subregion	Elazığ	728	563,00	882,00	197,36	152,78	239,38	
		Bingöl	247	191,00	300,00	155,11	120,04	188,18	
		Tunceli	127	98,00	154,00	206,63	159,79	250,90	
	Central East Anatolia region	Van subregion	Van	704	544,00	855,00	131,18	101,38	159,38
			Muş	473	373,00	564,00	251,69	198,49	299,84
			Bitlis	172	131,00	211,00	100,29	76,79	122,96
Gaziantep subregion		Hakkari	148	114,00	179,00	107,07	82,69	130,15	
		Gaziantep							
		Adıyaman	590	456,00	717,00	171,93	132,89	208,84	
Şanlıurfa subregion		Kilis	222	173,00	268,00	284,25	221,59	342,42	
		Şanlıurfa	1597	1241,00	1931,00	176,12	136,81	212,91	
		Diyarbakır	1228	949,00	1492,00	138,60	107,11	168,39	
Southeast Anatolia Region		Mardin subregion	Mardin	647	501,00	785,00	156,44	121,13	189,71
			Batman	595	468,00	712,00	200,25	157,22	239,57
			Şırnak	383	300,00	460,00	164,72	128,95	197,60
		Siirt	239	185,00	290,00	157,21	121,69	190,69	

N/A: non-applicable, NUTS: nomenclature of territorial units for statistics, min: minimum, max: maximum

found in Bitlis (10.29%), Rize (17.57%), and Bilecik (10.16%), while the lowest lung cancer PAFs were found in Bitlis (10.30%), Artvin (10.90%), and Bilecik (12.10%).

The percentage of COPD mortality attributable to long-term exposure to $PM_{2.5}$ in Türkiye showed minimal variation across the pre-, during-, and post-COVID-19 periods, with means of 18.89% (95% CI: 17.49–20.29), 19.34% (95% CI: 18.14–20.54), and 18.58% (95% CI: 17.45–19.70), respectively. These differences were not statistically significant ($P = 0.687$; Table 5).

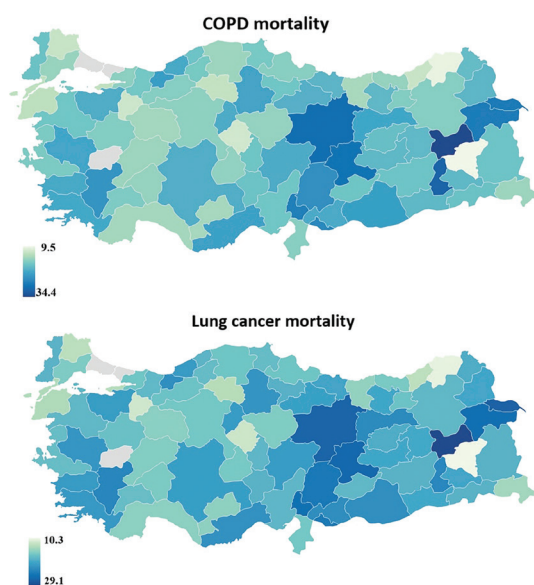


Figure 1. Chronic obstructive pulmonary disease (COPD) and lung cancer mortality attributable to $PM_{2.5}$ in Türkiye (2019–2023)

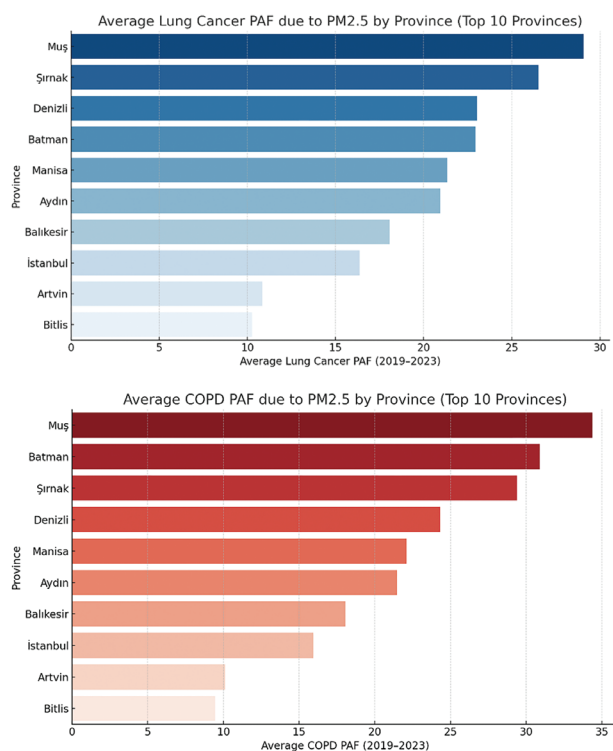


Figure 2. Population of attributable fraction (PAF) of chronic obstructive pulmonary disease (COPD) and lung cancer deaths due to $PM_{2.5}$ in Türkiye (2019–2023)

DISCUSSION

This study aimed to examine long-term trends in premature mortality attributable to air pollution exposure in Türkiye and the burden of respiratory diseases associated with it. Between 2019 and 2023, the provinces with the highest PM_{10} levels were Muş, Batman, Iğdır, Şırnak, and Malatya. The Black Report by the Clean Air Platform (2020–2022) also identified these provinces as among the most polluted areas in the country²⁴. High pollution levels in Batman may be linked to industrial activities, such as the Petkim Petroleum Refinery, while in Iğdır, geographical conditions and heating-related emissions may be prominent contributors. In Muş, southwestern winds have been identified as a significant factor. Although PM_{10} concentrations in Muş declined from $136 \mu\text{g}/\text{m}^3$ in 2019 to $73 \mu\text{g}/\text{m}^3$ in 2023, they still exceed the acceptable limits.²⁴ Although Hakkari and Bitlis are listed among the cities with the best air quality, the insufficient number of national ground-based air quality monitoring stations in these cities may not fully reflect the actual situation.²⁵

The AirQ+ program, which plays a crucial role in assessing the health effects of air pollution, was widely used in studies conducted between 2002 and 2022. A meta-analysis on this subject found that the majority of these studies were conducted in Iran, followed by India. Additionally, one of the main challenges in this field is the quality and validity of air quality data. The lack of justification for essential data in AirQ+ studies, such as demographic data, relative risks, and incidence rates, has also been noted as a significant issue.²⁶ In this study, the demographic and mortality data used for premature mortality calculations were obtained from official statistics covering the relevant years, cities, and regions. The mortality rate data for respiratory diseases were obtained from the latest statistical reports published by GCO and national sources.^{21,22} These factors eliminate some of the methodological limitations commonly associated with AirQ+ studies. The findings of this research indicate that, between 2019 and 2023, the total annual number of premature deaths attributed to $PM_{2.5}$ pollution in Türkiye was 85,344. The total number of deaths reported in Türkiye for 2022 was approximately 500,000.²⁷ A global study investigating trends in premature deaths attributed to air pollution found that these deaths increased from approximately 6.87 million in 2000 to approximately 8.89 million in 2015.²⁸ This figure corresponds to approximately 12% of the 68 million deaths reported worldwide.²⁹ Our study findings are consistent with the literature; premature mortality rates due to air pollution vary by city and average between 100 and 200 per 100,000 people. A Global Burden of Disease study analyzing premature deaths due to air pollution between 1990 and 2019 reported a similar global average of.³⁰ These findings not only underscore the reliability and relevance of using official and locally validated data sources in AirQ+ modeling but also reinforce the critical need for country-specific analyses when assessing the health burden of air pollution. The consistency of Türkiye's estimates with global trends highlights the universal impact of $PM_{2.5}$ exposure, while the city-level variability in mortality rates further emphasizes the importance of regionally tailored mitigation strategies. Future research should aim to integrate more granular exposure data and expand temporal coverage to better capture both short- and long-term health effects, thereby

Table 4. Data on the burden of certain respiratory system diseases attributed to long-term (2019–2023) air pollution (PM_{2.5}) in Türkiye

NUTS-3	COPD-2019				Lung cancer-2019				COPD-2023				Lung cancer-2023			
	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Percent (%)	Number of cases	Mortality rate*
İstanbul	17.97 (12.59-23.24)	74349 (52064-96126)	754.90 (528.63-976.01)	18.17 (12.37-23.75)	628 (428-821)	6.38 (4.34-8.34)	16.86 (11.67-21.93)	72270 (50007-93987)	17.22 (11.59-22.71)	617 (415-814)	708.07 (489.95-920.85)	17.22 (11.59-22.71)	617 (415-814)	17.22 (11.59-22.71)	617 (415-814)	6.04 (4.07-7.97)
Tekirdağ	13.99 (9.38-18.61)	4010 (2689-5336)	587.40 (393.93-781.54)	14.65 (9.55-19.78)	35 (23-47)	5.14 (3.35-6.94)	16.36 (11.26-21.34)	5301 (3649-6913)	16.78 (11.22-22.23)	45 (30-60)	687.09 (473.05-896.14)	16.78 (11.22-22.23)	45 (30-60)	16.78 (11.22-22.23)	45 (30-60)	5.89 (3.94-7.80)
Edirne	14.89 (10.10-19.65)	1801 (1222-2376)	625.55 (424.24-825.10)	15.48 (10.19-20.75)	16 (10-21)	5.43 (3.58-7.28)	19.89 (14.21-25.44)	2507 (1791-3207)	19.75 (13.69-25.42)	21 (14-27)	835.27 (596.74-1068.33)	19.75 (13.69-25.42)	21 (14-27)	19.75 (13.69-25.42)	21 (14-27)	6.93 (4.81-8.92)
Kırklareli	17.32 (12.04-22.47)	1850 (1286-2400)	727.39 (505.75-943.69)	17.61 (11.93-23.14)	16 (11-21)	6.18 (4.19-8.12)	11.73 (7.62-15.99)	1342 (872-1830)	12.53 (7.88-17.3)	12 (8-17)	492.73 (320.19-671.67)	12.53 (7.88-17.3)	12 (8-17)	12.53 (7.88-17.3)	12 (8-17)	4.40 (2.77-6.07)
Balıkesir	17.82 (12.45-23.05)	6464 (4519-8364)	748.27 (523.10-968.23)	18.04 (12.27-23.60)	55 (37-72)	6.33 (4.31-8.28)	20.42 (14.67-26.04)	7863 (5648-1002)	20.18 (14.09-25.87)	65 (45-83)	857.65 (616.03-1093.80)	20.18 (14.09-25.87)	65 (45-83)	20.18 (14.09-25.87)	65 (45-83)	7.08 (4.95-9.08)
Çanakkale	11.9 (7.78-16.2)	1890 (1231-2573)	499.77 (325.60-680.26)	12.69 (8.00-17.49)	17 (11-23)	4.45 (2.81-6.14)	16.09 (11.05-21.02)	2741 (1882-3581)	16.54 (11.02-21.96)	24 (16-31)	675.63 (463.96-882.74)	16.54 (11.02-21.96)	24 (16-31)	16.54 (11.02-21.96)	24 (16-31)	5.81 (3.87-7.71)
İzmir	16.01 (10.98-20.92)	20007 (13729-26154)	672.26 (461.28-878.80)	16.47 (10.96-21.88)	53 (36-71)	1.80 (1.19-2.39)	18.02 (12.62-23.29)	23605 (16538-30513)	18.21 (12.4-23.79)	199 (136-260)	756.74 (530.17-978.18)	18.21 (12.4-23.79)	199 (136-260)	18.21 (12.4-23.79)	199 (136-260)	6.39 (4.35-8.35)
Aydın	21.86 (15.88-27.60)	6871 (4993-8676)	918.03 (667.17-1159.21)	21.30 (15.13-27.08)	56 (40-71)	7.48 (5.31-9.50)	21.86 (15.88-27.6)	7362 (5350-9296)	21.3 (15.13-27.08)	60 (43-76)	918.03 (667.17-1159.21)	21.3 (15.13-27.08)	60 (43-76)	21.3 (15.13-27.08)	60 (43-76)	7.48 (5.31-9.50)
Denizli	23.41 (17.18-29.26)	6697 (4916-8373)	983.07 (721.55-1228.95)	22.47 (16.21-28.39)	17 (12-21)	2.45 (1.77-3.10)	19.05 (13.49-24.48)	5728 (4057-7362)	19.07 (13.1-24.71)	48 (33-62)	800.07 (566.68-1028.29)	19.07 (13.1-24.71)	48 (33-62)	19.07 (13.1-24.71)	48 (33-62)	6.69 (4.60-8.67)
Muğla	23.39 (17.17-29.24)	6696 (4914-8371)	982.41 (721.01-1228.22)	22.46 (16.12-28.38)	54 (39-68)	7.88 (5.68-9.96)	19.92 (14.23-25.47)	6331 (4524-8096)	19.77 (13.71-25.45)	53 (36-68)	836.51 (597.81-1069.76)	19.77 (13.71-25.45)	53 (36-68)	19.77 (13.71-25.45)	53 (36-68)	6.94 (4.81-8.93)
Manisa	26.20 (19.66-32.25)	10427 (7824-12835)	1100.42 (825.65-1354.52)	24.46 (18.01-30.49)	81 (60-101)	8.58 (6.32-10.70)	23.92 (17.62-29.82)	9969 (7342-12429)	22.85 (16.53-28.84)	80 (58-100)	1004.64 (739.94-1252.50)	22.85 (16.53-28.84)	80 (58-100)	22.85 (16.53-28.84)	80 (58-100)	8.02 (5.80-10.12)
Afyonkarahisar	10.58 (6.75-14.59)	2012 (1284-2775)	444.45 (283.43-612.76)	11.41 (7.06-15.94)	18 (11-25)	4.01 (2.48-5.60)	15.25 (10.39-20.07)	3100 (2111-4078)	15.8 (10.44-21.13)	27 (18-36)	640.64 (436.27-842.79)	15.8 (10.44-21.13)	27 (18-36)	15.8 (10.44-21.13)	27 (18-36)	5.55 (3.66-7.42)

Table 4. Continued

NUTS-3	COPD-2019				Lung cancer-2019				COPD-2023				Lung cancer-2023			
	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Percent (%)	Number of cases	Mortality rate*	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Percent (%)	Number of cases	Mortality rate*	Mortality rate*
Kütahya	13.59 (9.07-18.17)	2229 (1487-2981)	570.80 (380.83-763.24)	14.29 (9.26-19.35)		20 (13-27)	5.01 (3.25-6.79)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Uşak	N/A	N/A	N/A	N/A		N/A	N/A		14.87 (10.08-19.62)	1602 (1086-2113)	624.67 (423.54-824.08)	15.46 (10.18-20.73)	14 (9-19)	5.43 (3.57-7.28)		
Bursa	19.35 (13.75-24.83)	16065 (11414-20609)	812.75 (577.47-1042.68)	19.31 (13.31-24.97)		134 (92-173)	6.78 (4.67-8.76)		23.8 (17.51-29.69)	21279 (15658-26547)	999.66 (735.59-1247.14)	22.76 (16.45-28.73)	170 (123-215)	7.99 (5.78-10.09)		
Eskişehir	14.84 (10.06-19.58)	3714 (2517-4900)	623.21 (422.38-822.36)	15.43 (10.16-20.69)		32 (21-43)	5.42 (3.56-7.26)		N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Bilecik	12.01 (7.83-16.33)	731 (477-994)	504.24 (329.04-685.71)	8.98 (4.53-14.69)		7 (4-9)	4.49 (2.84-6.18)		10.16 (6.43-14.08)	652 (413-904)	426.63 (270.11-591.28)	11.00 (6.77-15.42)	6 (4-8)	3.86 (2.37-5.41)		
Kocaeli	17.8 (12.44-23.04)	9061 (6333-11725)	747.74 (522.66-967.60)	18.03 (12.26-23.59)		77 (52-100)	6.33 (4.30-8.28)		17.64 (12.31-22.84)	9931 (6929-12862)	740.81 (516.89-959.46)	17.88 (12.15-23.44)	45 (30-59)	6.28 (4.26-8.23)		
Sakarya	18.18 (12.76-23.48)	4940 (3467-6380)	763.58 (535.90-986.22)	18.34 (12.51-23.93)		42 (28-54)	6.44 (4.39-8.40)		18.08 (12.68-23.36)	5407 (3791-6987)	759.37 (532.38-981.28)	18.26 (12.44-23.84)	46 (31-60)	6.41 (4.37-8.37)		
Düzce	27.63 (20.97-33.88)	2880 (2185-3531)	1160.53 (880.56-1422.99)	25.41 (18.83-31.58)		22 (16-28)	8.92 (6.61-11.08)		20.05 (14.35-25.63)	2253 (1612-2880)	842.20 (602.70-1076.31)	19.88 (13.82-25.56)	19 (13-24)	6.98 (4.85-8.97)		
Bolu	16.98 (11.76-22.06)	1480 (1025-1923)	712.99 (493.96-926.68)	17.32 (11.68-22.82)		13 (9-17)	6.08 (4.10-8.01)		16.54 (11.41-21.55)	1527 (1053-1989)	694.87 (479.24-905.24)	16.94 (11.36-22.41)	13 (9-17)	5.95 (3.99-7.87)		
Yalova	11.12 (7.16-15.25)	830 (534-1137)	467.11 (300.65-640.43)	11.94 (7.45-16.6)		7 (5-10)	4.19 (2.61-5.83)		17.70 (12.36-22.92)	1510 (1055-1956)	743.48 (519.11-962.60)	17.94 (12.19-23.5)	13 (9-17)	6.30 (4.28-8.25)		
Ankara	19.5 (13.88-25)	29666 (21111-38025)	819.04 (582.84-1049.81)	19.44 (13.41-25.09)		247 (171-319)	6.82 (4.71-8.81)		17.31 (12.04-22.46)	27893 (19392-36189)	727.12 (505.52-943.38)	17.61 (11.93-23.14)	237 (161-312)	6.18 (4.19-8.12)		

Table 4. Continued

NUTS-3	COPD-2019					Lung cancer-2019					COPD-2023					Lung cancer-2023				
	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*		
Konya	20.34 (14.6-25.95)	11.308 (8115-14430)	854.24 (613.08-1090.10)	20.11 (14.04-25.8)	93 (65-120)	7.06 (4.93-9.06)	21.54 (15.62-27.25)	12900 (9357-16320)	904.74 (656.22-1144.53)	21.06 (14.89-26.81)	105 (75-734)	7.39 (5.23-9.41)								
Karaman	13.66 (9.12-18.25)	890 (594-1189)	573.84 (383.22-766.55)	14.35 (9.31-19.43)	8 (5-11)	5.04 (3.27-6.82)	15.26 (10.39-20.07)	1071 (109-211)	640.93 (436.50-843.12)	15.81 (10.44-21.13)	9 (6-12)	5.55 (3.66-7.42)								
Antalya	17.59 (12.26-22.78)	11981 (8355-15521)	738.67 (515.11-956.95)	17.84 (12.11-23.39)	102 (69-133)	6.26 (4.25-8.21)	13.96 (9.36-18.58)	10494 (7036-13966)	586.51 (393.22-780.53)	14.63 (9.54-19.76)	92 (60-124)	5.14 (3.35-6.93)								
Isparta	19.77 (14.11-25.3)	2363 (1686-3024)	830.31 (592.48-1062.60)	19.66 (13.6-25.32)	20 (14-25)	6.90 (4.77-8.89)	12.4 (8.14-16.8)	1559 (1023-2113)	520.73 (341.74-705.77)	13.17 (8.37-18.03)	14 (9-19)	4.62 (2.94-6.33)								
Burdur	16.84 (11.65-21.9)	1278 (884-1663)	707.25 (489.28-919.88)	17.2 (11.58-22.69)	11 (7-14)	6.04 (4.06-7.96)	17.54 (12.22-22.72)	1384 (965-1794)	736.52 (513.33-954.43)	17.8 (12.08-23.34)	12 (8-15)	6.25 (4.24-8.19)								
Adana	18.71 (13.2-24.09)	10543 (7441-13578)	785.70 (554.51-1011.91)	18.78 (12.86-24.4)	88 (61-115)	6.59 (4.52-8.57)	19.31 (13.71-24.78)	11026 (7831-14149)	810.98 (575.96-1040.67)	19.28 (13.28-24.93)	92 (63-119)	6.77 (4.66-8.75)								
Mersin	24.77 (18.38-30.68)	11873 (8812-14704)	1040.38 (772.16-1288.49)	23.46 (17.04-29.51)	94 (68-118)	8.23 (5.98-10.36)	22.88 (16.74-28.69)	11931 (8732-14960)	960.88 (703.24-1204.80)	22.08 (15.86-27.95)	96 (69-122)	7.75 (5.57-9.81)								
Hatay	4.31 (2.24-6.71)	1662 (863-2589)	180.89 (94.00-281.85)	4.9 (2.37-7.56)	16 (8-24)	1.72 (0.83-2.65)	24.7 (18.32-30.61)	9458 (7015-11720)	1037.44 (769.49-1285.53)	23.41 (17-29.46)	75 (54-94)	8.22 (5.97-10.34)								
Kahramanmaraş	29.69 (22.79-36.21)	7973 (6120-9726)	1246.88 (957.08-1520.97)	26.71 (19.92-32.93)	60 (45-74)	9.37 (6.99-11.56)	27.08 (20.45-33.27)	7437 (5615-9135)	1137.44 (858.84-1397.24)	25.05 (18.53-31.16)	57 (43-72)	8.79 (6.50-10.94)								
Osmaniye	24.57 (18.2-30.48)	3212 (2380-3985)	1031.97 (764.50-1280.08)	23.32 (16.92-29.36)	25 (18-32)	8.18 (5.94-10.31)	30.52 (23.55-37.2)	4284 (3306-5222)	1281.67 (988.92-1562.24)	27.2 (20.36-33.46)	32 (24-39)	9.55 (7.15-11.74)								
Kırıkkale	-	-	-	-	-	-	-	-	-	-	-	-								
Aksaray	9.48 (5.93-13.25)	963 (602-1347)	398.06 (248.87-556.56)	10.32 (6.28-14.57)	9 (5-12)	3.62 (2.20-5.12)	16.64 (11.48-21.66)	1868 (1289-2432)	698.74 (482.35-909.78)	17.02 (11.43-22.5)	16 (11-21)	5.98 (4.01-7.90)								

Table 4. Continued																
NUTS-3	COPD-2019				Lung cancer-2019				COPD-2023				Lung cancer-2023			
	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	
Niğde	21.66 (15.72-27.38)	1946 (1413-2461)	909.65 (660.26)	21.15 (14.98-26.91)	16 (11-20)	7.42 (5.26-9.44)	21.58 (15.4-27.39)	2103 (1501-2669)	906.25 (646.67-1150.33)	21.58 (15.4-27.39)	18 (13-22)	7.57 (5.40-9.61)				
Nevşehir	10.86 (6.96-14.93)	869 (557-1194)	456.29 (292.42-627.21)	11.69 (7.26-16.29)	8 (5-11)	4.10 (2.55-5.72)	20.12 (14.41-25.71)	1736 (1243-2218)	845.15 (605.25-1079.72)	19.94 (13.87-25.62)	14 (10-18)	7.00 (4.87-8.99)				
Kırşehir	11 (7.06-15.1)	714 (459-980)	461.87 (296.66-634.03)	11.82 (7.36-16.45)	6 (4-9)	4.15 (2.58-5.77)	N/A	N/A	N/A	N/A	N/A	N/A				
Kayseri	24.48 (18.12-30.39)	8680 (6425-10776)	1028.16 (761.03-1276.35)	23.25 (16.87-29.29)	69 (50-87)	8.16 (5.92-10.28)	21.16 (15.31-26.85)	8015 (5797-10166)	888.91 (642.91-1127.51)	20.77 (14.62-26.49)	66 (46-84)	7.29 (5.13-9.30)				
Sivas	22.16 (16.14-27.93)	3688 (2686-4648)	930.72 (677.80-1172.97)	21.54 (15.36-27.34)	30 (21-38)	7.56 (5.39-9.60)	19.06 (13.5-24.49)	338 (239-435)	800.32 (566.89-1028.58)	19.07 (13.1-24.71)	3 (2-4)	6.69 (4.60-8.67)				
Yozgat	8.47 (5.19-12.02)	945 (579-1340)	355.91 (217.93-504.70)	9.3 (5.53-13.29)	9 (5-12)	3.27 (1.94-4.67)	N/A	N/A	N/A	N/A	N/A	N/A				
Zonguldak	19.63 (13.99-25.14)	3364 (2397-4309)	824.57 (587.56-1056.06)	19.54 (13.5-25.21)	28 (19-36)	6.86 (4.74-8.85)	24.08 (17.76-29.99)	633 (467-789)	151.70 (111.87-188.95)	22.96 (16.63-28.97)	34 (24-42)	8.06 (5.84-10.17)				
Karabük	13.69 (9.15-18.28)	925 (618-1236)	575.05 (384.17-767.87)	14.38 (9.34-19.46)	8 (5-11)	5.05 (3.28-6.83)	N/A	N/A	N/A	N/A	N/A	N/A				
Bartın	17.8 (12.44-23.04)	1020 (713-1320)	747.74 (522.66-967.60)	18.03 (12.26-23.59)	9 (6-11)	6.33 (4.30-8.28)	14.21 (9.56-18.86)	867 (583-1150)	596.96 (401.51-792.28)	14.86 (9.72-20.02)	8 (5-10)	5.22 (3.41-7.03)				
Kastamonu	19.56 (13.93-25.06)	2158 (1537-2766)	821.56 (584.99-1052.65)	19.49 (13.45-25.15)	18 (12-23)	6.84 (4.72-8.83)	N/A	N/A	N/A	N/A	N/A	N/A				
Çankırı	14.4 (9.71-19.08)	795 (536-1053)	604.99 (407.89-801.30)	15.03 (9.86-20.23)	7 (5-9)	5.28 (3.46-7.10)	14.03 (9.41-18.66)	833 (559-1107)	589.20 (395.35-783.56)	14.69 (9.59-19.83)	7 (5-10)	5.16 (3.36-6.96)				
Sinop	21.75 (15.8-27.48)	1394 (1012-1761)	913.61 (663.53-1154.33)	21.22 (15.05-26.99)	11 (8-14)	7.45 (5.28-9.47)	10.18 (6.45-14.11)	706 (447-978)	427.64 (270.87-592.50)	11.02 (6.78-15.45)	6 (4-9)	3.87 (2.38-5.42)				

Table 4. Continued

NUTS-3	COPD-2019				Lung cancer-2019				COPD-2023				Lung cancer-2023			
	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Mortality rate*	Number of cases	Percent (%)	Mortality rate*	Percent (%)	Mortality rate*	Number of cases	Percent (%)	Mortality rate*	Number of cases	Mortality rate*	
Samsun	20.58 (14.81-26.22)	7556 (5436-9625)	864.44 (621.93-1101.18)	20.31 (14.21-26.01)	7.13 (4.99-9.13)	62 (44-80)	17.82 (12.46-23.06)	748.54 (523.32-968.54)	18.04 (12.27-23.61)	59 (40-77)	6.33 (4.31-8.29)					
Tokat	22.42 (16.36-28.21)	3725 (2718-4686)	941.69 (687.14-1184.63)	21.73 (15.55-27.57)	7.63 (5.46-9.68)	30 (22-38)	18.78 (13.26-24.18)	788.79 (557.13-1015.43)	18.84 (12.92-24.47)	27 (19-35)	6.61 (4.53-8.59)					
Çorum	26.59 (20.0-32.7)	3951 (2971-4859)	1116.83 (839.94-1373.51)	24.72 (18.26-30.77)	8.68 (6.41-10.80)	31 (23-38)	19.36 (13.75-24.83)	813.00 (577.68-1042.96)	19.32 (13.31-24.97)	25 (17-32)	6.78 (4.67-8.76)					
Amasya	22.61 (16.52-28.41)	2161 (1579-2715)	949.64 (693.86-1193.04)	21.88 (15.68-27.73)	7.68 (5.50-9.73)	17 (13-22)	16.90 (11.70-21.98)	709.99 (491.51-923.12)	17.25 (11.63-22.75)	14 (10-19)	6.06 (4.08-7.99)					
Trabzon	18.37 (12.92-23.71)	4073 (2864-5255)	771.69 (542.71-995.75)	18.51 (12.64-24.11)	6.50 (4.44-8.46)	34 (23-45)	13.63 (9.1-18.21)	572.32 (382.03-764.90)	14.32 (9.29-19.39)	28 (18-38)	5.03 (3.26-6.80)					
Ordu	22.79 (16.67-28.59)	4859 (3554-6097)	957.07 (700.05-1200.81)	22.01 (15.8-27.88)	7.73 (5.55-9.78)	39 (28-50)	18.37 (12.92-23.7)	771.43 (542.49-995.44)	18.50 (12.64-24.1)	35 (24-46)	6.49 (4.43-8.46)					
Giresun	18.98 (13.43-24.4)	2471 (1749-3177)	797.00 (564.08-1024.79)	19.01 (13.05-24.64)	6.67 (4.58-8.65)	21 (14-27)	11.64 (7.55-15.88)	488.88 (317.23-666.96)	12.44 (7.82-17.2)	15 (9-20)	4.37 (2.74-6.04)					
Rize	12.01 (7.83-16.33)	1156 (754-1572)	504.24 (329.04-685.71)	12.79 (8.08-17.6)	4.49 (2.84-6.18)	10 (7-14)	8.36 (5.10-11.87)	350.96 (214.31-498.53)	9.18 (5.44-13.14)	8 (5-11)	3.22 (1.91-4.61)					
Artvin	8.73 (5.37-12.33)	436 (268-616)	366.46 (225.64-517.74)	9.56 (5.72-13.62)	3.36 (2.01-4.78)	4 (2-6)	5.92 (3.36-8.79)	248.51 (141.27-368.98)	6.64 (3.6-9.84)	3 (2-4)	2.33 (1.26-3.45)					
Gümüşhane	19.52 (13.9-25.02)	841 (599-1078)	820.05 (583.70-1050.95)	19.46 (13.43-25.11)	6.83 (4.71-8.82)	7 (5-9)	21.49 (15.58-27.19)	902.39 (654.29-1141.94)	21.02 (14.85-26.76)	7 (5-9)	7.38 (5.21-9.39)					
Erzurum	20.5 (14.73-26.12)	3588 (2579-4573)	860.80 (618.77-1097.23)	20.24 (14.14-25.93)	7.10 (4.96-9.10)	30 (21-38)	N/A	N/A	N/A	N/A	N/A					

Table 4. Continued

NUTS-3	COPD-2019			Lung cancer-2019			COPD-2023			Lung cancer-2023		
	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Number of cases	Mortality rate*
Erzincan	23.51 (17.27-29.38)	1456 (1069-1819)	987.46 (725.15-1233.85)	22.55 (16.27-28.48)	12 (8-15)	7.91 (5.71-10.00)	N/A	N/A	N/A	N/A	N/A	N/A
Bayburt	14.92 (10.12-19.68)	306 (208-403)	626.71 (425.17-826.47)	15.5 (10.21-20.78)	3 (2-4)	5.44 (3.58-7.29)	11.39 (7.36-15.57)	253 (164-346)	478.19 (309.08-653.94)	12.20 (7.63-16.91)	2 (1-3)	4.28 (2.68-5.93)
Ağrı	31.54 (24.53-38.37)	3103 (2413-3775)	1324.88 (1030.28-1611.49)	27.8 (20.8-34.04)	23 (17-28)	9.76 (7.30-11.95)	19.85 (14.18-25.4)	2045 (1460-2615)	833.79 (595.46-1066.61)	19.72 (13.67-25.39)	35 (25-46)	6.92 (4.80-8.91)
Kars	23.47 (17.24-29.34)	1508 (1108-1885)	985.93 (723.89-1232.14)	22.52 (16.25-28.45)	12 (9-15)	7.91 (5.70-9.99)	15.7 (10.74-20.58)	1048 (717-1374)	659.52 (451.19-864.21)	16.2 (10.75-21.58)	9 (6-12)	5.69 (3.77-7.57)
Iğdır	32.38 (25.34-39.31)	1387 (1085-1684)	1360.14 (1064.46-1651.18)	28.27 (21.12-34.56)	10 (8-12)	9.92 (7.41-12.13)	N/A	N/A	N/A	N/A	N/A	N/A
Ardahan	17.73 (12.39-22.96)	450 (314-583)	744.81 (520.22-964.16)	17.97 (12.21-23.53)	4 (3-5)	6.31 (4.29-8.26)	18.27 (12.84-23.59)	468 (329-604)	767.51 (539.20-990.84)	18.42 (12.57-24.02)	4 (3-5)	6.47 (4.41-8.43)
Malatya	26.13 (19.6-32.17)	5341 (4005-6575)	1097.43 (823.06-1351.06)	24.41 (17.97-30.44)	42 (31-52)	8.57 (6.31-10.68)	32.33 (25.29-39.25)	6450 (5046-7831)	1357.77 (1062.15-1648.53)	28.24 (21.1-34.52)	47 (35-58)	9.91 (7.41-12.12)
Elazığ	24.54 (18.17-30.44)	3713 (2750-4607)	1030.49 (763.15-1278.63)	23.29 (16.9-29.33)	29 (21-37)	8.18 (5.93-10.30)	16.06 (11.03-20.99)	2595 (1782-3391)	674.50 (463.07-881.43)	16.52 (11-21.94)	22 (15-30)	5.80 (3.86-7.70)
Bingöl	17.41 (12.12-22.57)	1123 (781-1456)	731.16 (508.87-948.12)	17.69 (11.99-23.23)	10 (6-13)	6.21 (4.21-8.15)	21.27 (15.4-26.96)	1507 (1091-1910)	893.42 (646.73-1132.32)	20.85 (14.69-26.58)	12 (9-16)	7.32 (5.16-9.33)
Tunceli	18.52 (13.05-23.88)	466 (328-601)	777.95 (547.97-1003.07)	18.63 (12.74-24.24)	4 (3-5)	6.54 (4.47-8.51)	16.68 (11.52-21.71)	422 (291-549)	700.39 (483.69-911.74)	17.06 (11.46-22.53)	4 (2-5)	5.99 (4.02-7.91)
Van	18.27 (12.84-23.59)	3960 (2782-5112)	767.51 (539.20-990.84)	18.42 (12.57-24.02)	33 (23-43)	6.47 (4.41-8.43)	17.23 (11.97-22.36)	4063 (2822-5274)	723.61 (502.62-939.24)	17.54 (11.87-23.06)	35 (23-45)	6.15 (4.17-8.09)
Muş	42.35 (35.12-49.63)	3255 (2699-3815)	1778.75 (1475.08-2084.42)	32.67 (24.68-40.02)	21 (16-26)	11.47 (8.66-14.05)	29.09 (22.26-35.52)	2369 (1813-2894)	1221.57 (934.86-1491.73)	26.34 (19.61-32.55)	18 (13-22)	9.24 (6.88-11.43)

Table 4. Continued

NUTS-3	COPD-2019				Lung cancer-2019				COPD-2023				Lung cancer-2023			
	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Percent (%)	Number of cases	Mortality rate*	Percent (%)	Percent (%)	Number of cases	Mortality rate*	Percent (%)
Bitlis	9.01 (5.58-12.68)	619 (383-871)	378.35 (234.35-532.41)	9.85 (5.93-13.98)	6	(3-8)	3.46 (2.08-4.91)	8.23 (5.01-11.71)	628	(383-894)	345.61 (210.44-491.83)	9.05 (5.34-12.97)	6	(3-8)	3.18 (1.88-4.55)	9.05 (5.34-12.97)
Hakkari	5.32 (2.95-8.02)	294 (163-444)	223.59 (123.72-336.87)	6 (3.15-9.01)	3	(1-4)	2.11 (1.10-3.16)	28.78 (21.99-35.16)	11897	(8839-14721)	1045.18 (776.54-1293.35)	26.14 (19.45-32.35)	26	(20-33)	9.18 (6.83-11.35)	26.14 (19.45-32.35)
Gaziantep	21.16 (15.3-26.84)	9280 (6712-11772)	888.68 (642.71-1127.26)	20.76 (14.61-26.49)	76	(54-97)	7.29 (5.13-9.30)	24.89 (18.49-30.79)	1784	(1,326-2,208)	156.78 (116.48-194.0)	23.54 (17.11-29.59)	94	(68-118)	8.26 (6.01-10.38)	23.54 (17.11-29.59)
Adıyaman	22.85 (16.72-28.66)	3228 (2362-4048)	959.76 (702.30-1203.63)	22.06 (15.84-27.93)	26	(19-33)	7.74 (5.56-9.80)	11 (7.06-15.1)	1585	(1018-2175)	461.87 (296.66-634.03)	11.82 (7.36-16.45)	14	(9-20)	4.15 (2.58-5.77)	11.82 (7.36-16.45)
Kilis	22.44 (16.38-28.23)	707 (516-889)	942.61 (687.92-1185.60)	21.75 (15.56-27.59)	6	(4-7)	7.63 (5.46-9.68)	25.1 (18.68-31.01)	889	(662-1099)	1054.13 (784.71-1302.39)	23.69 (17.24-29.74)	7	(5-9)	8.32 (6.05-10.44)	23.69 (17.24-29.74)
Şanlıurfa	19.46 (13.84-24.95)	7048 (5014-9037)	817.28 (581.34-1047.82)	19.4 (13.38-25.06)	59	(41-76)	6.81 (4.70-8.80)	25.04 (18.63-30.95)	10167	(7565-12567)	1051.85 (782.62-1300.08)	23.65 (17.21-29.7)	80	(58-101)	8.30 (6.04-10.42)	23.65 (17.21-29.7)
Diyarbakır	17.68 (12.34-22.89)	6287 (4389-8141)	742.41 (518.22-961.35)	17.92 (12.17-23.47)	53	(36-70)	6.29 (4.27-8.24)	18.04 (12.64-23.32)	7075	(4958-9145)	757.79 (531.06-979.42)	18.23 (12.42-23.81)	60	(41-78)	6.40 (4.36-8.36)	18.23 (12.42-23.81)
Mardin	18.14 (12.72-23.43)	2987 (2095-3858)	761.74 (534.36-984.06)	18.31 (12.48-23.89)	25	(17-33)	6.43 (4.38-8.39)	23.22 (17.03-29.06)	4324	(3171-5410)	975.35 (715.22-1220.35)	22.34 (16.09-28.24)	35	(25-44)	7.84 (5.65-9.91)	22.34 (16.09-28.24)
Batman	19.47 (13.85-24.95)	2281 (1622-2924)	817.54 (581.55-1048.10)	19.41 (13.39-25.06)	19	(13-25)	6.81 (4.70-8.80)	28.72 (21.94-35.09)	3881	(2964-4742)	1206.26 (921.51-1473.91)	26.11 (19.42-32.31)	59	(44-73)	9.16 (6.82-11.34)	26.11 (19.42-32.31)
Şırnak	31.21 (24.21-37.99)	2823 (2190-3436)	1310.94 (1016.88-1595.96)	27.61 (20.67-33.86)	21	(16-26)	9.69 (7.26-11.88)	26.85 (20.24-33)	2910	(2193-3579)	1127.76 (849.93-1386.12)	24.90 (18.41-30.98)	23	(17-28)	8.74 (6.46-10.87)	24.90 (18.41-30.98)
Siirt	19.03 (13.48-24.46)	1151 (566.03-1027.41)	799.30 (566.03-1027.41)	19.05 (13.09-24.69)	10	(7-12)	6.69 (4.59-8.67)	19.19 (13.61-24.64)	1350	(957-1733)	805.92 (571.65-1034.94)	19.18 (13.2-24.83)	11	(8-15)	6.73 (4.63-8.71)	19.18 (13.2-24.83)

*attributed per 100,000 people, COPD: chronic obstructive pulmonary disease, N/A: non-applicable, NUTS: nomenclature of territorial units for statistics

Table 5. Changes in the estimated proportion of chronic obstructive pulmonary disease mortality attributed to long-term (2019–2023) air pollution (PM_{2.5}) in Türkiye across COVID-19 periods

Era	n	Mean	Standard deviation	Standard error	95% CI* for mean		
					Lower bound	Upper bound	P
Pre	80	18.89	6.28	0.70	17.49	20.29	0.687
Covid	80	19.34	5.38	0.60	18.14	20.54	
Post-covid	80	18.58	5.09	0.56	17.45	19.70	
Total	240	18.93	5.59	0.36	18.22	19.64	

CI: confidence interval, COVID-19: coronavirus disease-2019

informing more effective public health interventions and policy planning.

COPD and lung cancer are well-known health conditions that are caused by air pollution. This study examines the burden of COPD and lung cancer attributable to air pollution. During the study period, the long-term percentages of COPD and lung cancer attributable to air pollution were particularly high in the southeastern regions of Türkiye, where air pollution levels were also notably elevated. In this study, approximately 70,000 annual deaths were attributed to air pollution, of which approximately 10,000 were linked to COPD. One in every seven air pollution-related deaths was attributable to COPD. According to the WHO, 14% of air pollution-related deaths are associated with COPD, which aligns with our study findings.³ These findings are consistent with a 2024 study that reported a statistically significant association between ambient air pollution levels and hospital admissions for respiratory diseases.³¹ Taken together, these results reinforce the evidence that air pollution poses a substantial public health threat, not only in terms of increased morbidity but also in terms of premature mortality, as observed in our analysis across the pre, during-, and post-COVID-19 periods in Türkiye. Although studies have reported improvements in air quality due to nationwide measures taken during the COVID-19 pandemic, this study did not observe a significant change in the proportion of deaths attributable to air pollution during the COVID-19 pandemic. This finding aligns with literature suggesting that changes in air pollution levels, or improvements in air quality, do not necessarily lead to a significant change in the trend of attributable premature deaths.²⁸ The absence of a significant COVID-period difference may reflect the lag between exposure and mortality, demographic shifts, limited statistical power, and possible exposure misclassification resulting from conversion of PM₁₀ to PM_{2.5}.

These results provide further evidence that respiratory diseases such as COPD serve as critical indicators of the long-term health impacts of air pollution. The alignment with WHO estimates and recent empirical studies reinforces the validity of our findings and underscores the persistent nature of air pollution-related health risks, even during periods of temporary environmental improvements. This highlights the importance of sustained, structural interventions rather than relying solely on short-term reductions in pollutant levels.

Study Limitations

The study has some limitations. To ensure data adequacy, a minimum threshold of 60% valid annual measurements was used. However, the Black Report recommends at least 75% for reliability. Due to limited monitoring stations in certain provinces, regional disparities emerged. To address data gaps, the threshold was lowered, allowing broader geographic inclusion and more comprehensive pollutant distribution analysis. This adjustment improved study validity and highlighted infrastructure limitations, offering insights for future research. Additionally, the fixed PM₁₀-PM_{2.5} conversion factor (0.67) recommended by the WHO for Türkiye may introduce bias in high-dust regions; this was noted among the study's limitations. Moreover, the inability to use temporal trend analyses, such as Joinpoint, is another limitation, primarily because the five-year evaluation period is too short to detect meaningful changes in trends.

CONCLUSION

This study presents a comprehensive, national-level, multi-year assessment of premature mortality attributable to PM_{2.5} exposure in Türkiye. According to our findings, an average of 85,344 premature deaths per year—approximately 17.0% of all deaths in the country—are attributed to air pollution. The highest provincial premature-death rates were recorded in Sinop (295.8 per 100,000) and Çorum (289.6 per 100,000), while the lowest were observed in Bitlis (100.3 per 100,000) and Çanakkale (100.6 per 100,000). Although temporary improvements in air quality were observed during the COVID-19 pandemic, no statistically significant change was detected in COPD deaths attributable to PM_{2.5}. However, the limited number of PM_{2.5} measurements and insufficient distribution of national ground-based air-quality monitoring stations in certain regions of Türkiye may preclude full characterization of the health risks associated with long-term exposure to ambient PM_{2.5} (per AirQ+). The findings suggest that the Western Black Sea and Aegean regions should be prioritized for targeted interventions. Populations with high baseline mortality and populations in areas with dense urban or industrial activity represent key risk groups. Policy measures should focus on tightening national PM_{2.5} standards, ensuring continuous PM_{2.5} monitoring across all provinces, and expanding clean-heating and industrial emission control

programs, particularly in high-burden areas. These region-specific interventions would contribute more effectively to reducing long-term air pollution-related health impacts in Türkiye.

Ethics

Ethics Committee Approval: Ethical approval was not obtained because the data were collected from online open-access databases for this research.

Informed Consent: Because anonymous online datasets were used, informed consent was not required.

Footnotes

Authorship Contributions

Concept: D.H.Y., Data Collection or Processing: D.H.Y., A.C.Y., Analysis or Interpretation: D.H.Y., A.C.Y., Literature Search: D.H.Y., Writing: D.H.Y., A.C.Y.

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