

**A TIME SERIES ANALYSIS OF THE RELATIONSHIP
BETWEEN AIR QUALITY CONCENTRATION AND
MATERNAL-NEONATAL HEALTH IN TÜRKİYE:
A RETROSPECTIVE STUDY BASED ON
PM, NO_x, SO₂, AND O₃ PARAMETERS**

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Abstract

Air pollution is a significant global public health issue, and pollutants such as PM_{2.5}, PM₁₀, SO₂, NO₂, CO, and O₃ adversely affect maternal and infant health. This study aims to contribute to environmental health policies by retrospectively analyzing the relationship between air quality index values and maternal and infant mortality in Turkey from 2020 to 2025 through time series analysis. Air quality data were obtained from the National Air Quality Monitoring Network of the Ministry of Environment, Urbanization and Climate Change, while mortality statistics were sourced from the Turkish Statistical Institute. Annual averages of air pollutants, particularly PM₁₀ and PM_{2.5}, were calculated, and their relationship with mortality rates was evaluated using correlation and simple regression analyses. According to normality tests, infant mortality rate and the mortality rate among women of reproductive age were normally distributed, whereas under-five mortality and live birth rates were not. Accordingly, Pearson correlation was used for normally distributed variables, and non-parametric correlation methods were applied to non-normally distributed ones. Significant associations were found between PM₁₀ and infant mortality in 2021 and 2023 ($p < 0.05$), and between PM_{2.5} and both infant mortality in 2023 and the five-year aggregate data ($p < 0.05$). Other pollutants, such as NO₂, NO_x, and NO, also showed significant associations with infant deaths and maternal mortality in women of reproductive age ($p < 0.05$).

The study found that exposure to PM₁₀, PM_{2.5}, and NO₂ may increase infant mortality, while exposure to NO_x and NO may contribute to increased mortality in both infants and women of reproductive age. These findings highlight the severe health risks posed by air pollution to vulnerable populations, emphasizing the urgent need for preventive measures, particularly for infants and women of childbearing age.

Key words: maternal mortality, infant mortality, air pollution, air pollutants, PM₁₀, PM_{2.5}

Introduction. Ambient air pollution is a major environmental and public health concern worldwide, particularly in urban areas of both developed and developing countries. In many developing regions, energy is still produced through the combustion of fossil fuels without sufficient pollution control technologies. Outdoor air pollution is a complex mixture of thousands of components, including particulate matter (PM_{2.5} and PM₁₀) and key gaseous pollutants such as carbon monoxide (CO), sulphur dioxide (SO₂), ozone (O₃), nitrogen dioxide (NO₂), and nitrogen oxides (NO_x). These pollutants largely originate from incomplete combustion processes, such as those found in transportation, industrial activities, and coal-fired power generation [1, 2]. According to the Global Burden of Disease (GBD) 2019 report, air pollution has become the fourth leading risk factor contributing to premature deaths globally [3].

Extensive scientific evidence supports the significant adverse health effects of air pollutants, particularly particulate matter and gaseous pollutants such as NO₂, SO₂, CO, and O₃. The World Health Organization (WHO) states that 99% of the global population lives in areas where air quality fails to meet recommended standards, posing significant threats to human health. Vulnerable groups – including pregnant women, children, the elderly, and individuals with chronic illnesses – are disproportionately affected. During pregnancy, physiological changes such as increased respiratory rate and cardiac output heighten susceptibility to air pollution, leading to altered pathophysiological responses [4]. Exposure to air pollutants like PM, SO₂, and NO₂ during pregnancy has been linked to adverse maternal outcomes, including hypertensive disorders of pregnancy (HDP), preeclampsia (PE), and even spontaneous abortion [5].

Infants and children under five are particularly vulnerable due to their developmental stage, higher ventilation rates, and greater time spent outdoors, which increases pollutant exposure. In 2016, 93% of the global population under 18 was exposed to PM_{2.5}, and over one-quarter of deaths in children under five were attributed to environmental risks. Research indicates that children are more sensitive than adults to air pollution's harmful effects, and elevated concentrations of PM, CO, NO₂, and SO₂ are significantly associated with increased mortality in infants and young children [6–9].

In Turkey, air pollution remains a serious public health issue. In 2022 alone, it was estimated that 68 440 deaths could have been prevented if PM_{2.5} levels met

WHO guidelines. Over 90% of the population is exposed to polluted air, and cities such as Istanbul, Ankara, and Izmir frequently exceed WHO thresholds for PM₁₀ and PM_{2.5} [10]. This study aims to analyze the relationship between air quality and maternal and infant mortality in Turkey by conducting a retrospective time series analysis based on environmental and health data. Specifically, the study investigates the impact of key pollutants (PM₁₀, PM_{2.5}, SO₂, CO, NO₂, NO_x, NO, and O₃) on maternal and neonatal mortality, contributing to evidence-based policymaking in public health and environmental regulation.

Methods. Study design and variables. This retrospective ecological time series study examined the effects of air pollutants – primarily PM₁₀ and PM_{2.5} – on health outcomes in Turkey between January 1, 2020, and January 1, 2025. Provinces with the highest and lowest levels of air pollution during this period were included in the analysis.

Dependent variables included: infant mortality rate, under-five mortality rate, number of deaths among women of reproductive age, and live birth rate.

Independent variables were concentrations of air pollutants: PM₁₀, PM_{2.5}, SO₂, CO, NO₂, NO_x, NO, and O₃.

Population and sample. The study population consisted of mortality and air pollutant data available through the Turkish Statistical Institute (TURK-STAT) and the Ministry of Environment, Urbanization and Climate Change (MoEUCC). Air pollution data were obtained from the National Air Quality Monitoring Network (<https://sim.csb.gov.tr/Services/AirQuality>), while mortality data were extracted from publicly available databases provided by TURK-STAT [11].

Data collection. Measurements provided by the Turkish Statistical Institute (TUIK) and the Ministry of Environment, Urbanization and Climate Change (<https://csb.gov.tr>) play a central role in this study. Additional data sources include the 2024 report by the Right to Clean Air Platform (THHP) and global air quality data from <https://www.aqi.in> (Real-time Air Quality Index).

Air pollution indicators were calculated using annual averages (2020–2025) from provincial monitoring stations, while mortality data (2020–2024) were obtained from TUIK's public database (data.tuik.gov.tr), accessed on February 10, 2025 [12].

Provinces with the highest estimated air pollution-related mortality per 100 000 population were identified based on both crude death rates and PM_{2.5} levels. Only stations with $\geq 90\%$ data completeness, as defined by Directive 2008/50/EC, were included via the Air Quality Monitoring Network.

Pollutants analyzed (PM₁₀, PM_{2.5}, SO₂, CO, NO₂, NO_x, NO, O₃) met the following criteria:

- For daily averages, measurements must be available for at least 18 hours within a 24-hour period.

- For monthly averages, data must be available for at least 23 days within a 30-day month (and at least 21 days for February).
- For annual averages, valid measurements must be present for at least 274 days out of 365. (This threshold is based on the 366-day calendar of the leap year 2016, in which February had 29 days.)

Separate datasets were created per station using hourly data, and pollutant levels were calculated on daily, monthly, and annual bases. Excel 2 was used for data processing; statistical analyses (mean, SD, median, min, max) were performed with SPSS v26.0.

PM₁₀ values were adjusted to represent citywide levels. For monthly and annual calculations, station averages were used if they met completeness thresholds. Regional analyses used daily averages from three representative provinces, and where data were missing, values from neighbouring provinces were used.

The data were derived by first calculating monthly averages from monitoring stations located in various cities, followed by annual averages based on these monthly values. No modifications were made to the original pollutant concentration data obtained from the monitoring network. The five-year average values are presented in Table 2.

Data analysis. Data were analyzed using SPSS v25.0 and Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). The normality of data distributions was assessed using the Shapiro–Wilk test ($n < 50$), Q-Q plots, and histograms. Depending on distribution, Pearson or Spearman correlation coefficients were used to evaluate associations. Simple linear regression was applied after confirming the necessary assumptions.

Correlation coefficients were interpreted as follows [13]:

$|r| = 0.00\text{--}0.29$: weak correlation,

$|r| = 0.30\text{--}0.69$: moderate correlation,

$|r| = 0.70\text{--}1.00$: strong correlation.

Negative values indicate an inverse relationship, while positive values indicate a direct relationship.

Results. According to the normality analysis, the infant mortality rate (Shapiro–Wilk: $Z = 0.876$; $p = 0.079$) and mortality rate among women of reproductive age ($Z = 0.911$; $p = 0.222$) followed a normal distribution. In contrast, the under-five mortality rate ($Z = 0.807$; $p = 0.011$) and live birth rate ($Z = 0.735$; $p = 0.002$) did not. Thus, parametric or nonparametric correlation analyses were selected accordingly. Characteristics of the included provinces are presented in Table 1.

A significant correlation was found between PM₁₀ levels and infant mortality in 2021 and again in 2023 ($p < 0.05$). Furthermore, cumulative PM₁₀ values

T a b l e 1

Characteristics of provinces with the highest and lowest pollution levels and the highest air pollution-attributable mortality

Variables	PM ₁₀	PM _{2.5}	SO ₂	CO	NO ₂	NO _x	NO	O ₃	IMR ^a	U5MR ^b	Mat. deaths
Cities with the lowest air quality											
K.maraş	69.81	29.02	17.74	950.83	31.24	53.99	24.49	19.92	12.13	25.6	4193
Malatya	74.96	40.57 ^c	12.09	–	–	–	–	–	8.81	12.8	2464
İğdır	100.57	55.65	6.7	–	24.67	33.67	8.98	55.36	10.30	13.3	378
Gaziantep	52.01	25.73	14.32	1043.93	79.87	110.37	29.96	30.95	15.80	20	4795
Osmaniye	76.82	38.26	11.57	736.26	34.47	46.52	13.32	36.40	9.52	13.5	1526
İzmir	43.81	24.09 ^c	10.98	566.65	42.47	69.71	27.96	43.27	7.72	9.3	14287
Sakarya	41.63	19.72	14.23	–	26.18	66.35	18.73	31.07	7.02	8.4	3228
Cities with the highest air quality											
Kırşehir	32.64	9.62	6.14	488.02	28.03	44.4	16.37	43.20	10.37	12.7	858
Çankırı	37.09	10.82	12.75	426.89	29.49	52.77	23.31	17.75	7.77	9.7	906
Samsun	32.67	10.18	8.19	–	29.92	111.86	82.17	34.94	7.90	9.9	4799
Yozgat	38.32	13.28	11.64	9014.08	567.65	38.61	12.69	–	9.57	11.7	1578
Ordu	37.70	10.55	10.36	706.35	37.89	61.85	24.20	–	6.79	8.1	2978
Rize	33.98	14.89	3.43	–	14.20	19.98	5.76	60.15	8.40	9.6	1286
Cities with the highest death rates attributed to air pollution											
Hakkari	54.09	27.04 ^c	84.18	–	–	–	–	–	13.89	16.9	352
Batman	87.74	47.25 ^c	6.54	–	–	–	–	–	11.13	13.6	998
Şırnak	68.30	36.81 ^c	28.41	–	–	–	–	–	13.63	16.2	634
Muş	81.05	44.12 ^c	7.25	–	–	–	–	–	13.12	16.9	712
Malatya	74.96	40.58 ^c	12.09	–	–	–	–	–	8.81	12.8	2464

Birth and death statistics are from 2020–2023. ^a: Infant mortality per 1000 live births; ^b: Under-five mortality rate; ^c: PM_{2.5} values were estimated from PM₁₀ using a conversion factor of 0.67 (specific to Turkey). Concentration values in µg/m³.

over five years showed a significant association with total infant mortality in 2023 ($p < 0.05$). Similarly, PM_{2.5} concentrations were significantly associated with infant deaths in 2023 and with the five-year cumulative mortality data ($p < 0.05$). The infant mortality rate in 2021 showed a strong correlation with PM₁₀, while moderate correlations were observed with PM₁₀ levels in 2020, 2022, 2023, and 2024.

Detailed results of the correlation between PM₁₀/PM_{2.5} and infant mortality are presented in Table 2.

Significant correlations were also observed between NO₂ levels and infant deaths, as well as between NO_x and NO levels and both infant mortality and mortality among women of reproductive age ($p < 0.05$). In addition, total PM₁₀ concentrations were significantly associated with the under-five mortality rate ($p < 0.05$).

T a b l e 2

Correlation between PM₁₀/PM_{2.5} and infant mortality

Variables	Test	2020 PM ₁₀	2021 PM ₁₀	2022 PM ₁₀	2023 PM ₁₀	2024 PM ₁₀	Total PM ₁₀
2020 deaths	<i>r</i>	-0.147	0.406	-0.063	-0.035	-0.126	-0.077
	<i>p</i>	0.649	0.191	0.846	0.914	0.697	0.812
2021 deaths	<i>r</i>	0.487	0.753**	0.420	0.487	0.361	0.399
	<i>p</i>	0.108	0.005	0.174	0.108	0.249	0.198
2022 deaths	<i>r</i>	0.014	0.252	-0.049	-0.154	0.070	-0.014
	<i>p</i>	0.966	0.430	0.880	0.633	0.829	0.966
2023 deaths	<i>r</i>	0.594*	0.895**	0.580*	0.664*	0.615*	0.608*
	<i>p</i>	0.042	0.000	0.048	0.018	0.033	0.036
Variables	Test	2020 PM _{2.5}	2021 PM _{2.5}	2022 PM _{2.5}	2023 PM _{2.5}	2024 PM _{2.5}	Total PM _{2.5}
2020 deaths	<i>r</i>	-0.028	-0.056	-0.068	-0.126	-0.182	-0.112
	<i>p</i>	0.931	0.863	0.958	0.697	0.572	0.729
2021 deaths	<i>r</i>	0.490	0.399	0.441	0.424	0.315	0.368
	<i>p</i>	0.106	0.198	0.151	0.170	0.318	0.240
2022 deaths	<i>r</i>	-0.210	-0.028	0.028	0.098	-0.049	-0.119
	<i>p</i>	0.513	0.931	0.931	0.762	0.880	0.713
2023 deaths	<i>r</i>	0.650*	0.706*	0.671*	0.650*	0.594*	0.622*
	<i>p</i>	0.022	0.010	0.017	0.022	0.042	0.031
Total deaths	<i>r</i>	0.399	0.455	0.441	0.413	0.315	0.357
	<i>p</i>	0.199	0.138	0.152	0.183	0.319	0.255
Total deaths	<i>r</i>	0.378	0.790**	0.350	0.441	0.399	0.392
	<i>p</i>	0.226	0.002	0.265	0.152	0.199	0.208

* Significant at the 0.05 level; ** Significant at the 0.01 level

Overall, linear relationships were identified between pollutant levels and the mortality indicators (infant, under-five, and maternal). Further details are provided in Table 3.

Discussion. While infant mortality is known to have multiple causes, exposure to PM₁₀ and PM_{2.5} is recognized as a significant contributing factor. These pollutants are particularly harmful in urban areas with high levels of traffic or industrial activity, where they can exert greater adverse effects on public health [14]. In this study, a significant association was found between exposure to PM₁₀ and PM_{2.5} and infant mortality. This finding highlights the negative impact of air pollution on infant health and underscores the critical role of air quality improvement in reducing infant deaths.

The effect of PM₁₀ and PM_{2.5} on infant mortality is likely linked to their ability to induce respiratory and cardiovascular conditions, which are especially detrimental during the neonatal period. These findings suggest that air pollution can pose serious risks to individuals in early life stages. Prolonged exposure to

T a b l e 3

Correlation between other pollutants and mortality indicators

Variables	Test	Death total	Infant deaths	Under five deaths	Maternal deaths
SO ₂	<i>r</i>	0.168	0.441	0.343	0.545
	<i>p</i>	0.602	0.152	0.276	0.067
CO	<i>r</i>	0.464	0.399	0.421	0.189
	<i>p</i>	0.129	0.199	0.173	0.557
NO ₂	<i>r</i>	0.189	0.587*	0.175	0.399
	<i>p</i>	0.557	0.045	0.587	0.199
NO _x	<i>r</i>	−0.168	0.776**	−0.091	0.720**
	<i>p</i>	0.602	0.003	0.779	0.008
NO	<i>r</i>	−0.021	0.720**	0.042	0.671*
	<i>p</i>	0.948	0.008	0.897	0.017
O ₃	<i>r</i>	0.218	0.028	0.099	−0.380
	<i>p</i>	0.495	0.931	0.760	0.223
PM ₁₀ total	<i>r</i>	0.392	0.161	0.587*	−0.021
	<i>p</i>	0.208	0.618	0.045	0.948
PM _{2.5} total	<i>r</i>	0.357	0.098	0.524	−0.028
	<i>p</i>	0.255	0.762	0.080	0.931
Pollutant total	<i>r</i>	0.455	0.517	0.406	0.231
	<i>p</i>	0.138	0.085	0.191	0.471

* Significant at the 0.05 level; ** Significant at the 0.01 level

PM₁₀ and PM_{2.5} may contribute to increased infant mortality rates, emphasizing the importance of preventive measures aimed at reducing particulate matter in the air to safeguard infant health. Our results are consistent with previous studies reporting similar associations between air pollution and adverse perinatal outcomes [5–7, 9, 15–19].

Moreover, our findings indicate that increased exposure to NO₂ is significantly associated with higher rates of infant mortality. This further clarifies the link between air pollution and infant health and reinforces the need for policies aimed at improving air quality. Additionally, exposure to NO_x and NO was found to be associated with both infant mortality and mortality among women of reproductive age. These results suggest that environmental pollutants may have long-term consequences for population health, especially for vulnerable groups such as infants and women of reproductive age.

The observed associations between exposure to NO₂, NO_x, and NO and adverse health outcomes among women and infants underscore the threat posed by environmental pollutants to maternal and child health. Our study demonstrates that the effects of air pollution extend beyond short-term morbidity and may have lasting impacts on public health, particularly for women of reproductive age and newborns. These results are in line with the existing literature [3–6, 9, 15–18].

In conclusion, this study provides further evidence of the harmful effects of air pollution – particularly PM₁₀, PM_{2.5}, NO₂, NO_x, and NO – on infant and maternal mortality. Reducing exposure to air pollutants should be a public health priority to mitigate these adverse outcomes and protect the health of future generations.

Conclusion. This study reveals a statistically significant association between certain air pollutants and maternal and infant mortality. Specifically, PM_{2.5}, PM₁₀, and CO levels were found to be positively associated with both maternal and infant deaths, while O₃ was negatively associated with these outcomes. Although SO₂ and NO₂ did not show a statistically significant relationship with mortality rates, their potential indirect effects and cumulative impact should not be overlooked. These findings underscore the urgent need for comprehensive public health policies to reduce air pollution and mitigate its adverse effects on maternal and infant health. Policymakers should take into account the long-term effects of air pollution and develop strategies to enhance air quality, particularly in vulnerable regions. Furthermore, increased awareness among healthcare professionals and the public regarding the health risks posed by air pollution is essential to improve health outcomes.

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