

## Effect of Air Pollution Parameters on Cardiovascular Mortality in Türkiye; PM<sub>10</sub>, SO<sub>2</sub> and cardiovascular deaths

Gürkan IMRE<sup>1\*</sup> 

<sup>1</sup>Bilecik Seyh Edebali University, Faculty of Medicine, Department Of Cardiology, Bilecik, Türkiye

\*Corresponding author: [gurkan.imre@bilecik.edu.tr](mailto:gurkan.imre@bilecik.edu.tr)

### Abstract

The aim of this ecological study is to evaluate the effects of changes in particulate matter 10 (PM<sub>10</sub>) and sulfur dioxide (SO<sub>2</sub>) levels on mortality rates due to cardiovascular diseases (CVD) across 81 provinces in Türkiye between 2022 and 2023. Cardiovascular disease (CVD) mortality rates were obtained from the Turkish Statistical Institute (TUIK), while PM<sub>10</sub> and SO<sub>2</sub> data were collected from the Ministry of Environment, Urbanization, and Climate Change. Data were analyzed with SPSS 25.0; distribution normality was evaluated with skewness, kurtosis, and q-q plot; and the relationship between variables was examined with the Spearman correlation test. Multiple linear regression analysis was applied to determine the effective variables. In the findings, a weak but significant positive relationship was found between PM<sub>10</sub> and CVD mortality ( $r=0.250$ ,  $p=0.024$ ). In the regression analysis, PM<sub>10</sub> was found to have a significant and independent effect on cardiovascular mortality rate ( $\beta=0.367$ ,  $p<0.001$ ). No significant relationship was found with the SO<sub>2</sub> variable. As a result, it was shown that the increase in PM<sub>10</sub> levels in Turkey between 2022 and 2023 is positively associated with the increase in mortality rates due to circulatory system diseases. In conclusion, the increase in PM<sub>10</sub> levels in Türkiye between 2022 and 2023 was shown to be positively associated with higher mortality rates due to circulatory system diseases. This finding once again underscores the importance of air pollution control strategies for protecting public health.

### Keywords

Air pollution,  
PM<sub>10</sub>,  
SO<sub>2</sub>,  
Cardiovascular  
mortality

## Türkiye'de Hava Kirliliği Parametrelerinin Kardiyovasküler Mortalite Üzerine Etkisi; PM<sub>10</sub>, SO<sub>2</sub> ve kardiyovasküler ölümler

Gürkan IMRE<sup>1\*</sup> 

<sup>1</sup> Bilecik Seyh Edebali Üniversitesi, Tıp Fakültesi, Kardiyoloji Bölümü, Bilecik, Türkiye

\*Sorumlu yazar: [gurkan.imre@bilecik.edu.tr](mailto:gurkan.imre@bilecik.edu.tr)

### Özet

Bu ekolojik çalışmada amaç, Türkiye'de 81 ilin 2022 ve 2023 yılları arasında partikül molekülü 10 (PM<sub>10</sub>) ve sülfür dioksit (SO<sub>2</sub>) düzeylerindeki değişimin kardiyovasküler hastalıklara (KVH) bağlı ölüm hızları üzerindeki etkisini değerlendirmektir. KVH'ye bağlı ölüm hızları Türkiye İstatistik Kurumu'ndan (TÜİK), PM<sub>10</sub> ve SO<sub>2</sub> değerleri Çevre, Şehircilik ve İklim Değişikliği Bakanlığı verilerinden elde edildi. Veriler SPSS 25.0 ile analiz edildi; dağılım normallliği skewness, kurtosis ve q-q plot ile değerlendirildi; değişkenler arası ilişki Spearman korelasyon testi ile incelendi. Etkili değişkenleri belirlemek amacıyla çoklu doğrusal regresyon analizi uygulandı. Bulgularda PM<sub>10</sub> ile KVH mortalite arasında zayıf fakat anlamlı bir pozitif ilişki saptandı ( $r=0.250$ ,  $p=0.024$ ). Regresyon analizinde PM<sub>10</sub>'nın kardiyovasküler mortalite hızı üzerinde anlamlı ve bağımsız etkisi olduğu görüldü ( $\beta=0.367$ ,  $p<0.001$ ). SO<sub>2</sub> değişkeni ile anlamlı bir ilişki bulunmadı. Sonuç olarak, Türkiye'de 2022-2023 yılları arasında PM<sub>10</sub> seviyelerindeki artışın, dolaşım sistemi hastalıklarına bağlı daha yüksek mortalite oranlarıyla pozitif ilişkili olduğu gösterilmiştir. Bu bulgu, halk sağlığını korumak için hava kirliliği kontrol stratejilerinin önemini bir kez daha vurgulamaktadır.

### Anahtar kelimeler

Hava kirliliği,  
PM<sub>10</sub>,  
SO<sub>2</sub>,  
Kardiyovasküler  
mortalite

## 1. INTRODUCTION

Cardiovascular diseases (CVD) refer to all problems of the heart and vascular system, including ischemic heart disease, stroke, hypertension-related diseases, heart failure, and peripheral arterial disease. According to World Health Organization (WHO) projections for 2023, this category of diseases kills roughly 17.9 million people globally each year, making it the leading cause of death. Approximately 85% of these deaths are caused by severe cardiovascular events such as myocardial infarction and stroke [1]. In this environment, public health programs rely heavily on identifying and avoiding the causes of CVD. On the other hand, the World Health Organization (WHO) recognizes air pollution as the greatest environmental health threat on a worldwide scale [2]. Pollutants, particularly particulate matter (PM<sub>10</sub>) and sulfur dioxide (SO<sub>2</sub>), can negatively impact respiratory and circulatory systems [3,4]. PMs are classed according to their size: PM<sub>10</sub>, PM<sub>2.5</sub>, and PM<sub>1</sub>. PM<sub>10</sub> particles are primarily made up of secondary particles [5]. SO<sub>2</sub> is produced by the burning of sulfur-containing fuels, including coal and oil, as well as oil refining. It is regarded as one of the most significant air pollutants. This gas has been recognized as one of the primary air pollutants in significant air pollution episodes of the twentieth century [6]. These chemicals activate systemic inflammatory processes by inflaming the airway epithelium, which may hasten the development of atherosclerosis [7,8]. Many studies in recent years have found that short- and long-term exposure to air pollution increases the risk of heart attack, stroke, and sudden cardiac death [9].

Given regional disparities in Turkey, it is believed that air pollution parameters change by province, and this scenario may be linked to public health effects. This study looked at how changes in PM<sub>10</sub> and SO<sub>2</sub> levels in 2022 and 2023 affected mortality rates from circulatory system disorders. The project intends to objectively demonstrate the influence of changes in air quality on cardiovascular mortality in Turkey over a two-year period.

## 2. MATERIAL AND METHOD

### 2.1. Research Design and Dataset

This study is a retrospective, ecological type analysis. The following data were analyzed for 81 provinces of Turkey for the years 2022 and 2023:

- Cardiovascular disease related mortality rates (TUIK data) [10].
- PM<sub>10</sub> (µg/m<sup>3</sup>) and SO<sub>2</sub> (µg/m<sup>3</sup>) annual average values (Ministry of Environment, Urbanization and Climate Change data) [11].

The differences between 2023 and 2022 for each province were calculated as follows:

- CVD mortality rate: 2023 CVD mortality rate – 2022 CVD mortality rate
- PM<sub>10</sub>: 2023 PM<sub>10</sub> – 2022 PM<sub>10</sub>
- SO<sub>2</sub>: 2023 SO<sub>2</sub> – 2022 SO<sub>2</sub>

### 2.2 Statistical Analysis

The data were analyzed using the SPSS 25.0 statistical package tool. The distribution properties of continuous variables were found by looking at the q-q plot, skewness, and kurtosis.

The Spearman correlation test was used to investigate the relationship between two continuous variables. The correlation coefficients were interpreted as follows

- Weak connection (r = 0.01-0.49)
- Medium relationship (r = 0.50-0.69)
- Strong relationship (r = 0.70-1.00).

The multiple linear regression study used CVD mortality as the dependent variable, with PM<sub>10</sub> and SO<sub>2</sub> as independent variables. For the validation of the regression model:

- Durbin-Watson test for autocorrelation.
- Tolerance and VIF values for multicollinearity.

Statistical significance was accepted at p < 0.05.

### 2.3 Visualization and Graph Analysis

Python was used to perform graphical analysis on the data. In addition to Spearman correlation, the LOWESS (Locally Weighted Scatterplot Smoothing) method was utilized to visually represent data trends. The graphs were created using Seaborn and Matplotlib packages.

## 3. RESULTS

When data from 2022 and 2023 were analyzed across Turkey, an overall increase in CVD death rates was seen in 2023. This increase was clearly prominent in some provinces. The 5 provinces with the highest difference in death rates due to circulatory system diseases were seen to be Hatay, Adiyaman, Malatya, Kayseri, and Gaziantep, respectively (Table 1).

**Table 1.** Differences in mortality rates due to cardiovascular diseases between 2022-2023

City Center	CVD mortality rate	City Center	CVD mortality rate	City Center	CVD mortality rate
Hatay	22.58	Ankara	-7.16	Trabzon	-19.33
Adıyaman	22.13	Kilis	-7.18	Niğde	-19.52
Malatya	17.02	Hakkari	-7.38	Manisa	-20.96
Kayseri	16.32	Diyarbakır	-7.78	Tekirdağ	-21.36
Gaziantep	15.01	Muş	-8.2	Kırkkale	-22.69
Kahramanmaraş	14.92	Karaman	-8.85	Balıkesir	-22.72
Zonguldak	12.6	Bursa	-8.92	Denizli	-25.7
Iğdır	11.75	Tokat	-9.26	Gümüşhane	-26.3
Adana	9.18	Karabük	-9.63	Erzurum	-26.33
Şanlıurfa	7.53	Aksaray	-10.29	Artvin	-26.89
Kastamonu	7.37	Çorum	-10.65	Giresun	-27.41
Isparta	5.48	Rize	-10.84	Sivas	-30.83
Nevşehir	4.66	Muğla	-11.43	Bilecik	-31.59
Ağrı	3.8	Erzincan	-11.83	Uşak	-31.76
Samsun	2.85	Kütahya	-11.99	Bolu	-31.87
İstanbul	1.09	Edirne	-12.02	Burdur	-32.53
Mersin	0.68	Düzce	-12.25	Kırklareli	-33.15
Van	-0.44	Eskişehir	-13.31	Kırşehir	-33.26
Şırnak	-0.94	Elazığ	-13.42	Sakarya	-35.11
Antalya	-1.25	Yozgat	-14.86	Yalova	-37.81
Konya	-1.98	Mardin	-15.08	Bartın	-40.07
Amasya	-3.67	Ardahan	-16.15	Afyon	-45.23
Bitlis	-4.53	İzmir	-16.71	Ordu	-46.68
Batman	-4.58	Siirt	-17.41	Çankırı	-54.77
Kocaeli	-5.47	Kars	-17.61	Sinop	-57.87
Bingöl	-5.78	Bayburt	-18.33	Aydın	-59.93
Osmaniye	-6.48	Çanakkale	-18.66	Tunceli	-72.34

Hatay, Kahramanmaraş, Osmaniye, Karaman, and Malatya saw the biggest increase in PM<sub>10</sub> levels, whereas Aydın, Hakkari, Muğla, Kütahya, and Bayburt had the highest decreases. Table 2 shows that the provinces with the biggest increase in SO<sub>2</sub> were Şırnak, İzmir, Hatay, Yalova, and Isparta, while the five provinces with the highest decrease in SO<sub>2</sub> were Şanlıurfa, Hakkari, Aydın, Kahramanmaraş, and Denizli. A slight and significant correlation ( $r=0.250$ ,  $p=0.024$ ) was found between CVD mortality rate and PM<sub>10</sub> (Table 3, Figure 1).

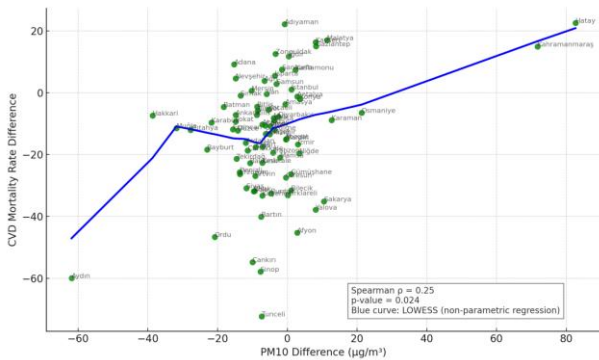
**Table 2.** Differences between PM<sub>10</sub> and SO<sub>2</sub> between 2022-2023

City Center	PM <sub>10</sub>	SO <sub>2</sub>	City Center	PM <sub>10</sub>	SO <sub>2</sub>	City Center	PM <sub>10</sub>	SO <sub>2</sub>	
Hatay	82.61	9.27	Diyarbakır	-	2.51	0.94	Artvin	-9.23	-3.9
Kahramanmaraş	71.71	-17.6	Samsun	-	3.09	-1.2	Uşak	-9.34	-10.17
Osmaniye	21.32	3.92	Zonguldak	-	3.42	0.84	Bolu	-9.65	-1.25
Karaman	12.66	0.9	Isparta	-	3.59	4.77	Çankırı	-10.01	-3.13
Malatya	11.4	-2.73	Edirne	-	3.69	1.73	Mersin	-10.28	-1.26
Sakarya	10.52	-5.15	Bursa	-	3.71	2.63	Balıkesir	-10.66	-5.22
Gaziantep	8.2	-5.43	Muş	-	3.89	3.09	Çanakkale	-11.36	-1.05
Kayseri	8.14	-5.49	Trabzon	-	4.1	1.63	Sivas	-11.74	-3.21
Yalova	8.13	5.06	Burdur	-	4.75	0.84	Ardahan	-11.87	-1.27
Konya	3.61	0.59	Rize	-	4.78	0.73	Şırnak	-13.42	20.61
Niğde	3.43	1.33	Elazığ	-	5.1	1.59	Erzurum	-13.6	2.28
İzmir	3.04	18.4	Kocaeli	-	5.44	1.91	Denizli	-13.67	-16.72
Afyon	2.87	-0.33	Van	-	5.91	0.33	Düzce	-14.23	-2.09
Antalya	2.86	-0.23	Eskişehir	-	6.18	-10	Tekirdağ	-14.57	-2.55
Kastamonu	2.36	0.53	Çorum	-	6.26	4.15	Nevşehir	-14.8	-5.87
İstanbul	1.16	-0.04	Ağrı	-	6.54	2.65	Tokat	-14.81	0.18
Bilecik	1.08	-2.85	Siirt	-	7.07	1.26	Ankara	-14.83	-0.32
Gümüşhane	1.06	-0.51	Aksaray	-	7.15	0.34	Adana	-15.22	0.74
Iğdır	0.43	0.61	Kırkkale	-	7.17	4.39	Erzincan	-15.61	0.29
Kırklareli	0.09	-2.68	Kırşehir	-	7.19	1.15	Batman	-18.27	-0.49
Yozgat	-	-2.2	Tunceli	-	7.34	2.11	Ordu	-20.81	-0.68
Mardin	-0.4	1.34	Bartın	-	7.48	-0.5	Karabük	-21.79	-2.66
Giresun	-	0.43	Sinop	-	7.73	6.63	Bayburt	-23.02	0.6
Amasya	-	0.56	Bingöl	-	8.45	4.29	Kütahya	-27.72	-9.52
Adıyaman	-	0.74	Bitlis	-	8.67	2.13	Muğla	-31.78	0.58
Sanlıurfa	-	1.53	Kilis	-	8.77	1.68	Hakkari	-38.66	25.77
Manisa	-	2.09	Kars	-	9.07	2.59	Aydın	-61.86	-18.97

**Table 3.** Correlation Analysis Of PM<sub>10</sub> And SO<sub>2</sub> With Mortality From Cardiovascular Disease.

		PM <sub>10</sub>	SO <sub>2</sub>
CVD mortality rate	r	0.250	0.178
	p	0.024*	0.112*
	n	81	81

\*Spearman Korelasyon testi, CVD; cardiovascular disease, PM<sub>10</sub>;particulate matter 10 , SO<sub>2</sub>;sulfur dioxide



**Figure 1.** Relationship Between PM<sub>10</sub> Difference and CVD Mortality Rate Difference (Spearman + LOWESS)

The regression model developed with PM<sub>10</sub> and SO<sub>2</sub>, air pollution measures assumed to predict the difference in mortality rates due to circulatory system disorders in 2022 and 2023, revealed no autocorrelation (Durbin-Watson=1.806). The constructed model explained 11.5% of the variation in mortality rates owing to circulatory system disorders, and it was statistically significant (F=6.204(7); Adj. R<sup>2</sup>=0.115; p=0.003). Table 4 shows a positive and substantial independent effect of PM<sub>10</sub> on the model (t=3.426, p<0.001).

**Table 4.** Regression Analysis Of Mortality Rate Due To Cardiovascular Diseases With PM<sub>10</sub> And SO<sub>2</sub>

	B	Std. Error	Beta	t	p*	95.0% CI for B		Collinearity Statistics	
						Lower Bound	Upper Bound	Tolerance	VIF
(Constant)	-11.81	2.12		-5.573	0.000	-16.03	-7.595		
PM <sub>10</sub> difference	0.399	0.116	0.367	3.426	<0.001	0.167	0.631	0.964	1.037
SO <sub>2</sub> difference	0.046	0.287	0.017	0.159	0.874	-0.526	0.617	0.964	1.037

\* Regression Analysis, PM<sub>10</sub>;particulate matter 10 , SO<sub>2</sub>;sulfur dioxide

#### 4. DISCUSSION AND CONCLUSION

This study looked at how increases in PM<sub>10</sub> and SO<sub>2</sub> air pollution affected mortality rates from circulatory system disorders in Turkey in 2022 and 2023. The data revealed a statistically significant association between an increase

in PM<sub>10</sub> concentration and cardiovascular disease death rates. However, the shift in SO<sub>2</sub> did not significantly impact this association. Many investigations have shown that PM<sub>10</sub> particles have a detrimental effect on the cardiovascular system [12,13]. Increased PM<sub>10</sub> levels have been linked to an increase in CVD fatalities in high-pollution cities [14,15,16]. Similar tendencies have been seen in a few studies conducted especially for Turkey [17], but our work makes a unique contribution by offering a comparative analysis at the province level that covers all of Turkey.

The considerable increase in CVD mortality rate as the PM<sub>10</sub> difference increases can be attributed to the fact that PM<sub>10</sub> particles enter the body via the respiratory tract, pass through the alveoli, and enter the systemic circulation, where they cause systemic inflammatory processes [18,19]. Systemic inflammation can destabilize atherosclerotic plaques and cause thrombotic events, resulting in catastrophic cardiovascular consequences [20]. Our investigation discovered no significant association between SO<sub>2</sub> differential and CVD mortality rate. The majority of the literature on this topic has demonstrated a positive association [21,22,23]. Our study found no correlation between SO<sub>2</sub> difference and CVD, which can be attributed to numerous factors. The change in SO<sub>2</sub> levels was minimal and may not have been statistically significant. SO<sub>2</sub> may primarily affect respiratory ailments (e.g., COPD, bronchitis), with indirect effects on circulatory system diseases. Insufficient measurement instruments in some regions may result in lower quality data for SO<sub>2</sub>. These findings should be supplemented with advanced models that account for additional variables. Limitations: This study did not include other major air pollutants such as PM<sub>2.5</sub>, O<sub>3</sub>, and NO<sub>2</sub>. Socioeconomic variables such as access to health care, income, and education level were not included in the model. These limitations suggest that caution should be used when interpreting the study. The results indicate a statistical association rather than direct causality. More advanced causal studies should be performed using time series, panel data, and spatial regression models. Cohort studies using individual health data can provide a more detailed picture of cause-effect linkages. More comprehensive models that account for the effects of socioeconomic factors, health infrastructure, education level, and age distribution should be created. Furthermore, long-term predictions should take into account the relationship between climate change and air pollution.

This study evaluated the effects of air quality changes—specifically PM<sub>10</sub> and SO<sub>2</sub> levels—on mortality due to circulatory system diseases in Türkiye between 2022 and 2023. The results showed that increases in PM<sub>10</sub> levels were significantly associated with higher cardiovascular mortality, while SO<sub>2</sub> showed no significant relationship. Accordingly, national PM<sub>10</sub> limits should be aligned with WHO standards (15 µg/m<sup>3</sup>), existing legislation should be revised, and stricter emission controls implemented. Promoting electric transport, enhancing industrial emission monitoring, expanding air quality measurement networks, and improving public health risk

communication are also essential. Overall, this study emphasizes that air quality regulation is critical for protecting public health and reducing premature deaths from cardiovascular diseases. Future studies covering longer timeframes and including additional pollutants such as PM<sub>2.5</sub> will yield more comprehensive and reliable results.

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