Iran J Public Health, Vol. 54, No.11, Nov 2025, pp.2463-2472

Original Article

The Relation of Air Pollution on Morbidity and Mortality of SARS-CoV-2 Infection in Tekirdag, Türkiye

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(Received 20 Jun 2025; accepted 04 Sep 2025)

Abstract

Background: We aimed to investigate the relation between environmental air pollutants such as Particulate Matter 10 (PM_{10}), Particulate Matter 2.5 ($PM_{2.5}$), Sulfur Dioxide (SO_2) on daily cases and deaths associated with SARS-CoV-2 infection.

Methods: The ecological research examined the correlations of the air quality metrics and the data of COVID-19 cases and deaths from March 1, 2020 to March 1, 2021 in the central District of Tekirdağ Province in Türkiye.

Results: During the study period, the average PM_{10} concentration was 32.57±17.86 µg/m^3, $PM_{2.5}$ was 20.68±11.31 µg/m^3, SO_2 was 11.28±13.42 µg/m^3, and NO_2 was 19.07±7.26 µg/m^3. The SARS-CoV-2 case fatality rate in the study area during this period was 3.2%. Correlation analyses between air pollutants and SARS-CoV-2 cases and deaths revealed significant positive associations between SARS-CoV-2 cases (r=0.220 for PM_{10}, P<0.001; r=0.290 for $PM_{2.5}$, P<0.001; r=0.218 for SO_2, P<0.001) and deaths (r=0.203 for PM_{10}, P<0.001; r=0.289 for $PM_{2.5}$, P<0.001; r=0.278 for SO2, P<0.001). Moreover, regression analysis revealed that ambient sulfur dioxide (SO_2) levels significantly predicted both COVID-19 incidence and mortality.

Conclusion: PM_{10}, $PM_{2.5}$, and SO_2, key parameters for assessing air quality, exhibit a positive relationship with the increasing number of daily SARS-CoV-2 cases and daily deaths in the study area.

Keywords: COVID-19; SARS-CoV-2; Air pollution; Mortality

Introduction

The novel coronavirus disease 2019 referred to as COVID-19, which originates from the SARS-CoV-2 (severe acute respiratory syndrome coronavirus 2) virus, emerged in Wuhan province of China in late December 2019 and is known to cause severe respiratory failure (1). As of 02 March 2024, a total of 703,853,191 confirmed cases and 7,003,434 deaths associated with COVID-19 have been reported worldwide (2). Fatal outcomes of COVID-19 depend on conditions that increase cardiovascular risks, such as arterial hypertension, diabetes mellitus, obesity and established coronary artery disease as well as comorbidities, including respiratory conditions such as asthma and chronic obstructive pulmonary disease (COPD) (3). Studies have also associated exposure to ambient air pollution with coronavirus infection and death from this viral infection (4). The potential relationship between air pollution and COVID-19 outbreaks has also been described in recent literature (5-8). Evidence supports a relationship between poor air quality and the likelihood of respiratory viruses to adversely affect the respiratory system and increase disease severity (9).

Globally, average air pollutant concentrations appear to greatly exceed maximum limits in regions with SARS-CoV-2 outbreaks (6). Notably, the worst COVID-19 outbreaks occurred with a high number of cases and deaths in certain geographical regions, such as Italy's Po Valley and China's Hubei province, which have the highest levels of pollution. Studies show a considerable overlap between the geographical distribution of outbreaks and local air pollution levels (6,8). This is linked to the fact that chronic exposure to air pollutants has been associated with pulmonary ACE 2 overexpression, the primary receptor for SARS-CoV-2. Therefore, SARS-CoV 2 infection combined with air pollutants such as particulate matter 2.5 ($PM_{2.5}$) and nitrogen dioxide (NO_2) impairs tissue remodelling, thereby reducing the local inflammatory response and causing an exponential increase in acute pulmonary injury (6). Moreover, air pollutants have been shown to harm respiratory health by inducing oxidative stress, damaging macrophages, and reducing the expression of surfactant proteins (5). Based on comprehensive data, there is substantial evidence of a positive correlation between air pollution, specifically $PM_{2.5}$ concentrations, and COVID-19 cases, hospitalisations and deaths. Epidemiological studies indicate an association between exposure to pollution and increased mortality and morbidity rates (10,11).

The present study aimed to investigate the effects of environmental air pollutants, namely Particulate Matter 10 (PM_{10}), Particulate Matter 2.5 ($PM_{2.5}$), Sulfur Dioxide (SO_2), on daily morbidity and mortality due to SARS-CoV-2 infection.

Methods

Study type

This ecological study has been conducted retrospectively between 01.03.2020 and 01.03.2021 in Süleymanpaşa, the central district of Tekirdağ Province, Türkiye.

Study region

Tekirdağ, located in the Thrace part of the Marmara region on the European side of Türkiye, borders Istanbul and serves an important transit route to Europe. As of 2021, its population is approximately 1,107,491, spread across seven districts, including the central district, within an area of 6,190 km². Tekirdağ has a mixed Mediterranean-continental climate, with humid coastal areas due to the Sea of Marmara. Known for its fertile lands, Tekirdağ is both an agricultural and industrial hub (Fig. 1) (12) contributing about 3% of the Türkiye's gross domestic product (GDP) (13). Intensive industrial activity is concentrated in Çorlu, Ergene, Çerkezköy and Kapaklı, with around 3,200 factories and 1416 small industrial enterprises (14). This concentration, along with emissions from industrial facilities, contributes to poor air quality. Two air quality measurement stations are in the central district, as shown in Fig. 1.

Fig. 1: Geographical location of the study area (= Air quality measurement station)

SARS-CoV-2 healthcare records

The data were obtained from the records of Tekirdağ Province, Healthcare Directorate of Süleymanpaşa District between 01.03.2020 and 01.03.2021. Records show that 9,721 people were assigned the code, U07.3 (confirmed SARS-CoV-2 infection) in study region within the study period and 311 people died due to SARS-CoV-2 infection according to the death reporting system.

Air pollution data

Air quality data were obtained from the Ministry of Environment and Urbanization via its official website (www.havaizleme.org.tr). PM_{10} and SO_2 levels are routinely measured at Tekirdağ Central Air Quality Monitoring Stations. PM_{10} data were converted to $PM_{2.5}$ using the conversion factor (0.66327) recommended by the WHO for Türkiye. For daily SO_2, PM_{10} and $PM_{2.5}$ concentrations, only days with measurements covering at least 75% of the time (≥18 hours) were included.

Statistical analysis

Statistical analyses were conducted using IBM SPSS version 22.0 (IBM Corp., Armonk, NY, USA). Descriptive statistics (frequency, percentage, mean, standard deviation, minimum, and maximum) were used to summarize the data. The study focused on SO_2 and PM_{10} concentrations as the primary air pollutants. The dependent variables were morbidity, and mortality counts from SARS-CoV-2 infection, while the independent variables included daily mean concentrations of PM_{10}, $PM_{2.5}$, NO_2, and SO_2. Correlation analysis and multiple linear regression analysis were conducted. Due to limited continuous, location-specific data, meteorological and demographic variables (e.g. temperature, humidity, and population density) were not included.

Results

SARS-CoV-2 was detected in 9,721 cases, as determined by a precise test and 311 deaths due to SARS-CoV-2 from 01.03.2020 to 01.03.2021 in the study area. During this period, the SARS-CoV-2 fatality rate in Süleymanpaşa was found to be 3.2%. The air pollution parameters, annual mean PM_{10}, $PM_{2.5}$ and SO_2 levels are presented in Table 1.

Table 1: Air pollution parameters pertaining to the study period

Air pollutants (µg/m³) per year	Mean±SD (Min – Max)	The limit determined by the WHO (µg/m³) per year	The value in the Turkish legislation (µg/m³) per year
Particulate Matter$_{10}$ (PM_{10})	32.57±17.86 (9.22 - 154.62)	15	40
Particulate Matter$_{2.5}$ ($PM_{2.5}$)	20.68±11.31 (6.62 - 69.84)	5	n/a
Sulfur Dioxide (SO_2)	11.28±13.42 (1.01-106.48)	20	40

NA: Not applicable

Figure 2 shows the annual average distribution of PM_{10} and $PM_{2.5}$ compared to WHO limits. Türkiye's annual averages (PM_{10}: 32.57 µg/m^3; $PM_{2.5}$: 20,68 µg/m^3) exceed WHO threshold (PM_{10} 15 µg/m^3; $PM_{2.5}$;5 µg/m^3 almost year around.

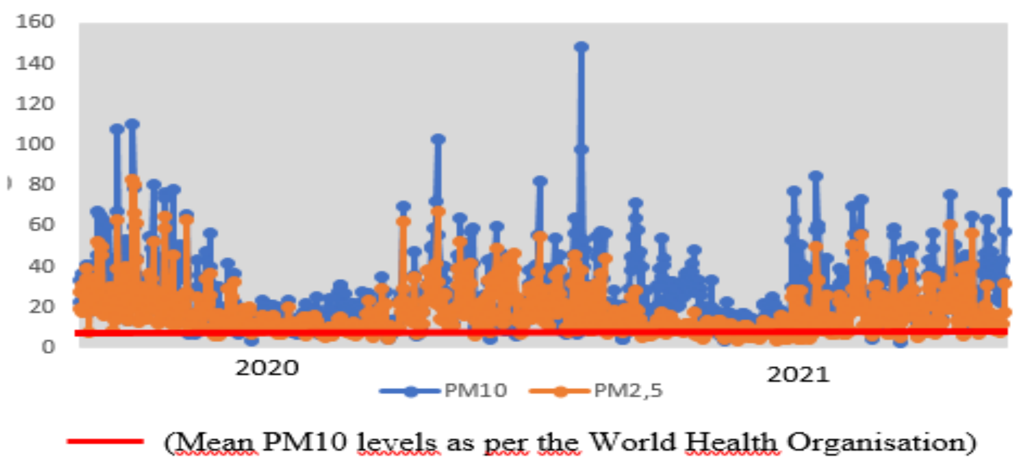

Fig. 2: Time series of daily PM_{10} and $PM_{2.5}$ levels, 2020–2021

Correlation analyses examining the relationship between air pollutants and the number of SARS-CoV-2 cases and associated deaths revealed significant positive correlations with PM_{10} (r=0.220 and r=0.203, respectively), $PM_{2.5}$ (r=0.290, and r=0.289), and SO_2 (r=0.218 and r=0.278, respectively) (P<0.001) (Table 2).

Table 2: Correlation coefficients between the number of COVID-19 patients and deaths and daily air pollutant parameter concentrations

Air pollutants	Number of SARS-CoV-2 confirmed cases	Number of deaths from SARS-CoV-2
PM_{10}	r=0.220	r=0.203
$PM_{2,5}$	r=0.290	r=0.289
SO_2	r=0.218	r=0.278

PM: particulate matter; SO_2 sulfur dioxide, *P<0.01. Spearman's rho, r: correlation coefcient

The relationship between air pollutants and the number of SARS-CoV-2 cases and associated deaths is shown in Fig. 3. Since PM_{10} and $PM_{2.5}$ primarily effects health in the long term, regression analysis was conducted using SO_2 to determine its relationship between COVID-19 cases and deaths (Table 3).

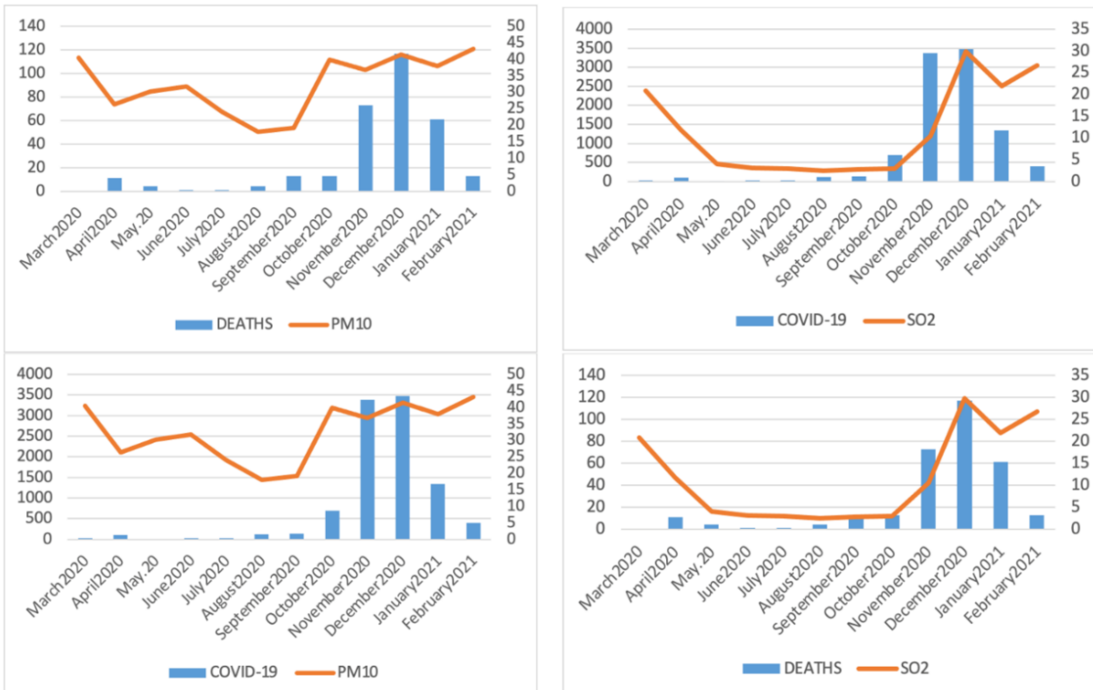

Fig. 3: The relationship between PM_{10} and SO_2 levels with the number of SARS-CoV-2 patients and deaths due to SARS-CoV-2

SO_2 levels were found to be significant predictor of both outcomes, showing a positive association with confirmed COVID-19 cases (B = 0.865, *P* < 0.001, 95% CI: 0.450–1.281) and COVID-19-related deaths (B = 0.035, *P* < 0.001, 95% CI: 0.022–0.048).

Table 3: Predictive effect of air pollution on COVID-19 morbidity and mortality

Model	B	*P*	95.0% CI	
			Lower	Upper
Number of COVID-19 cases				
Constant	18.189		10.908	25.470
SO_2	0.865	0.000	0.450	1.281
Number of COVID-19 deaths				
Constant	0.482	0.000	0.255	0.709
SO_2	0.035	0.000	0.022	0.048

Discussion

Long-term exposure to air pollution is known to reduce pulmonary function and leads to respiratory diseases (15,16). $PM_{2.5}$ related non-communicable diseases (NCDs) remain a major public health concern in low- and middle-income countries, particularly in South and

East Asia (17), while lower respiratory tract infections linked to $PM_{2.5}$ are a leading health burden in low-income countries across Africa and Asia. However, air pollution is not confined to these regions alone; it persists as a global issue. Studies from Greece (18), Italy (4), the United States (19), China (20), Türkiye (21), and Iran (22) consistently demonstrated that long-term $PM_{2.5}$ exposure is significantly associated with morbidity and mortality, including cardiometabolic disorders, COPD, and central nervous system diseases. Evidence also links air pollution to increased emergency visits, hospital admissions healthcare costs (23-25), and premature mortality, suggesting that many deaths could be prevented by maintaining pollutant levels within WHO limits (26).

Although countries differed in their pandemic measures, several restrictions, especially in the initial period, resulted in temporary changes in air quality (27). However, during the period of this study, no improvement was observed in this region; in fact, pollution levels increased (28).

Air pollution is both a cause and an aggravating factor for bronchitis, asthma, and many other respiratory diseases, suggesting a likely link with COVID-19 (6). Although research on this relationship is still limited, the number of studies is growing, and current evidence indicates that air pollution may increase the risk of SARS-CoV-2 infection through various mechanisms (6-8, 29-31). Long-term exposure also contributes to respiratory and cardiovascular diseases, as well as conditions like diabetes and cancer, making individuals more vulnerable to viral infections such as COVID-19 (9).

Several studies have examined the relationship long-term air pollution and COVID-19, with varying results (5). In Italy, long-term $PM_{2.5}$ exposure increased COVID-19 mortality, after adjusting for sociodemographic and meteorological factors (10). Saez et al reported associations between PM_{10} and NO_2 levels and daily COVID-19 cases (31), while Adhikari et al observed a negative correlation between $PM_{2.5}$, and case numbers, a positive correlation with ozone, and no correlation with mortality (28). In China, Zhu et al identified positive association between COVID-19 cases and $PM_{2.5}$, PM_{10}, CO, ozone (32). Similarly, Wu et al (33) and Cole et al (5) reported positive ecological associations between $PM_{2.5}$ and COVID-19 mortality. In London, each 1-mm increase in PM2.5 was associated with 1.1% more cases and 2.3% more deaths (34). In northern Italy, a one-unit rise in $PM_{2.5}$ was linked to a 6-12% increase in mortality (10), while another Italian study found higher hospital and intensive care unit admissions and a two-fold increase in deaths in more polluted regions (6).

The literature highligths a potential link between SARS-CoV-2 infection and air pollution, suggesting that both short- and long-term exposure to high pollutant levels may contribute to increased COVID-19 infection and mortality rates (8, 35). Moreover, the mechanisms by which air pollution affects the outcomes of COVID-19 have been described (5,11,35). Regarding the high mortality rates, atmospheric pollution has been associated with increased susceptibility to infection, and reported to impair pulmonary defense mechanisms, thereby causing more severe forms of the disease (6). Studies suggest that the high levels of air pollution and certain climate characteristics may increase stability of viral aerosols and thereby increase the likelihood of transmission, leading to increased morbidity and mortality (6). Pollution may also increase the transmission risk for respiratory viruses (4,30) and particulate matter has been suggested to carry the SARS-CoV-2 (29), exposure to air pollution could increase the number of cases. Additionally, individuals exposed to long-term air pollution may be at higher risk of hospitalization and death if they contract the virus. In fact, the high number of cases and associated deaths appears to support this hypothesis. In the present study, we observed a high daily and annual mean levels, particularly SO_2, whose acute effects include hospital admissions, inpatient treatment, and exacerbation of chronic respiratory diseases, etc.) (27).

Our study found that the regression linking SO_2 with COVID-19 cases and deaths consistent with the literature (32). However, some studies have emphasized that correlations between $PM_{2.5}$ and COVID-19 outcomes may not causally explain the clustering of COVID-19 cases in major cities where pollution may be higher (5,36). In addition, the quarantine, isolation and lockdowns implemented during the pandemic may have changed the extent to which individuals are affected by outdoor air pollution. Furthermore, contact screening, overall screening and/or diagnostic testing strategies varied from country to country during the pandemic. The differences in study findings may be partially resulting from these differences. Nevertheless, due to the high contagiousness of the COVID-19 disease and the high mortality rate, this topic requires meticulous investigation with studies that rank higher in the evidence hierarchy, apart from ecological research.

A Dutch study reports that $PM_{2.5}$ and, to a lesser extent, NO_2 are associated with COVID-19, whereas this is not the case for SO_2 concentrations. SO_2 levels in the Netherlands have remained below the EU (European Union) limits since 1998, suggesting that in region where SO_2 is not high enough to cause adverse health effects, its contribution to COVID-19 outcomes may be minimal (5). In contrast, our study demonstrated positive correlations between COVID-19 cases, deaths and PM_{10}, $PM_{2.5}$ and SO_2 levels. Regression analyses confirmed that the SO_2 significantly affected COVID-19 mortality and morbidity. Moreover, pollutant levels in our study exceeded WHO limits, reinforcing these findings. Literature further indicates that SO_2 effects progress rapidly, with acute health problems such as rhinitis and conjunctivitis occuring soon after exposure, following by increased mortality, like PM exposure (32,37). SO_2 primarily originates from fossil fuels use of fossil fuels or formed secondarily via meteorological reactions. The causal relationship identified in our multivariate analysis aligned with prior research. Overall, our findings underscore that PM_{10}, $PM_{2.5}$, and SO_2 pollution constitute a significant public health issue in the Süleymanpaşa district.

The literature indicates industrial facilities as the primary sources of SO_2, NO_x, and $PM_{10}/PM_{2.5}$ emissions, while residential heating and road traffic are the main sources to CO emissions (38). Tekirdağ, in Türkiye's Thrace region a hub of intense industrial activity, port operations, and road transportation. In our study, elevated $PM_{2.5}$ concentrations were positively associated with COVID-19 mortality, aligning with finding from highly industrialized Po Valley in Italy (4) and the cities of Tehran and Ahvaz in Iran (39). Additionally, studies conducted in Cairo, Egypt, have demonstrated that areas with poor air quality exhibit higher infection transmission and mortality rates (40). Considering Tekirdağ's industrial density, meteorological characteristics, and emission profile, it shares common environmental health risks with other urban centers across the Mediterranean and Middle East. Our findings underscore the need to assess the interaction between air pollution and infectious diseases within a localized context.

Although the WHO reduced the limit value to 15 μg/m3 for PM_{10} and 5 μg/m3 for $PM_{2.5}$ on an annual basis in 2021, the current value in Türkiye is 40 μg/m3 for both parameters (26). There is an absence of legislation regarding $PM_{2,5}$ in Türkiye and a legal limit value for this pollutant remains undetermined. Moreover, $PM_{2.5}$ is measured only in some of the air quality stations across Türkiye. For instance, the study found that $PM_{2.5}$ data was not available at the air quality measurement stations in the region. This data was therefore obtained by transforming the PM_{10} data. The failure to obtain a significant result in further analyses of the relationship between $PM_{2,5}$, which is the most hazardous pollutant for human health among those evaluated herein, and COVID-19 cases and associated deaths may be due to the use of transformed data. We hereby propose a fundamental recommendation that national standards on air quality should be brought to the limit values of WHO criteria and a legal limit value for $PM_{2.5}$ should be determined.

There are several individual, social and environmental factors influence the transmission of the SARS-CoV-2 virus and the severity of the disease. The elevated levels of air pollutants observed in the Süleymanpaşa district, which exceed the limits recommended by the WHO, may be attributable to the region's geographical and climatic characteristics, as well as to concurrent changes in demographics and urban structure. These structures include intense industrialization, use of fossil fuels, immigration, and the rapid population growth. However, the region is highly accessible to healthcare services and institutions compared to the national average with both the physical infrastructure and human resources of these institutions being comparatively robust.

This study has both strengths and some limitations. Due to its retrospective design and the lack of synchronized, high-resolution meteorological and demographic data, confounders such as temperature, humidity, and population density could not be included. These factors may influence the association between air pollution and health outcomes. To partially address this, we reviewed regional studies (39,40) showing consistent seasonal patterns in pollution and health outcomes, suggesting that the associations—particularly with PM_{10} and SO_2—remain relatively robust.

Another limitation is the indirect estimation of $PM_{2.5}$ using the WHO-recommended PM_{10}-to-$PM_{2.5}$ conversion factor (0.66327), due to the unavailability of direct $PM_{2.5}$ measurements for Tekirdağ. While validated for Türkiye, this ratio may vary by emission source (industrial, vehicular, or residential). Future studies with integrated meteorological and population data are needed to enable more robust adjustments and sensitivity analyses (26,41).

As noted, our analysis explores the association between daily levels of air pollutants and the number of COVID-19 cases and deaths. While correlational studies are valuable for identifying potential patterns and generating hypotheses, they do not establish causality and are limited by the potential confounding factors. Furthermore, we acknowledge that the ecological design of the study carries the risk of ecological fallacy—where associations observed at the population level do not necessarily reflect at the individual-level. The absence of individual-level data, such as age, comorbidities, and socioeconomic status, which are known to influence outcomes, limits our ability to adjust for these variables.

In the study area, only two air quality monitoring stations are available, and their locations may not be fully representative of the entire region. These stations were primarily established in areas with high urban, residential, and traffic density, which could bias in the measurements and limit the generalizability of the findings.

Conclusion

There was a significant relationship between the level of PM_{10}, $PM_{2.5}$, and SO_2 and the number of daily COVID-19 cases and associated deaths. Furthermore, our study has determined that SO_2 level was a parameter affecting the number of COVID-19 cases and associated deaths.

This study highlights the vital importance to combat air pollution and implement policies to reduce pollutants to better manage the COVID-19 pandemic and other possible future outbreaks. Well-designed studies are still needed to elucidate the long-term health effects of air pollution and its association with mortality rates.

Ethics Committee Approval

Since the research is not a study conducted on living things, ethical permission was not obtained since there was no situation that would constitute an ethical violation.

Acknowledgements

No financial support was received for the study.

Conflict of interests

No potential conflict of interest was reported by the authors.

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