

Original Article: The Association Between Air Quality Parameters and COVID-19 in Turkey



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ABSTRACT

Background: Coronavirus disease 2019 (COVID-19) is an invisible enemy that has made people observe issues such as eating habits, personal hygiene, and environmental factors that may affect their immune systems.

Objectives: Because air pollution can affect the immune system, it is necessary to examine the relationship between air quality parameters and COVID-19.

Methods: his study examines the correlation between air quality and COVID-19 considering 7 air pollutants: PM₁₀, SO₂, CO, NO₂, NO_x, NO, and O₃. The confirmed COVID-19 cases were considered from 9 provinces, accounting for 78% of the total cases in Turkey. The required data were collected from the websites of the country's relevant official institutions. Two statistical tests, the Pearson correlation, and Spearman Rho were conducted to determine any potential linear and monotonic relationships.

Results: Based on both test results, a significant positive correlation was observed between air SO₂ content and the number of COVID-19 cases in Turkey.

Conclusion: The outcomes could help identify provincial actions or measures.

Introduction

Coronavirus disease 2019 (COVID-19) was first detected in China in late December 2019, and it affected virtually the whole world, causing life to move beyond the ordinary. The COVID-19 situation report by the World Health Organization stated 2160207 confirmed cases, 85678 new cases, and 146088 deaths as of

April 18, 2020, globally [1]. This result has led nations to enforce practices such as compulsory social distance, non-compulsory business closure, and compulsory quarantine. Nevertheless, COVID-19 has remained a health crisis, and the risk level is high globally [1].

The examination and determination of the factors affecting COVID-19 are one of the prominent topics of current studies. Some studies have claimed that human-

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to-human transmission through direct contact or droplets has been one of the sources of COVID-19 infection [2-4]. Other studies found that meteorological parameters (e.g. temperature, humidity, and wind speed) are associated with COVID-19 transmission [5-8]. Ma and Zhao analyzed the impact of meteorological factors on COVID-19 mortality and revealed the association [9].

Considering that COVID-19 is an infectious disease, air quality will be a prominent determinant of COVID-19 prevalence. Living in a highly polluted area makes the inhabitants susceptible to infective agents and can cause chronic respiratory conditions; air pollution is a chronic inflammatory stimulus in the long term [10, 11]. Particulate Matter (PM) is an intricate combination of small airborne particles and liquid droplets. PM contributes to haze, affects the climate through direct and indirect impacts, and damages materials such as glass, metals, and stone. PM also causes severe health conditions, including irregular heartbeat, non-fatal heart attack, decreased lung function, aggravated asthma, and premature death [12]. PM_{10} denotes particles with diameters $\leq 10 \mu m$ and is one of the most significant pollution indicators that characterize air quality. PM_{10} particles are small enough to enter the throat and lungs of a person. Nitrogen Dioxide (NO_2) and Sulfur Dioxide (SO_2), separately and together, adversely affect the environment and human health. Ground-level Ozone (O_3) is one of the most substantial atmospheric pollutants, and inhaled ozone can trigger various health problems, including reduced lung functions. Carbon Monoxide (CO) endangers human health while breathing [13]. Air pollutants, including

(PM_{10}), SO_2 , CO, NO_2 , Nitrogen Oxides (NO_x), Nitric Oxide (NO), and O_3 were considered in this study.

There is strong evidence that air pollution is a risk factor for harmful respiratory and vascular health outcomes [14]. Zhu and Xie examined the association between short-term exposure to air pollution factors and COVID-19 in China and found a significant positive association between $PM_{2.5}$, PM_{10} , NO_2 , and O_3 , with COVID-19 [15]. Ogen analyzed the association between COVID-19 fatality and long-term exposure to NO_2 and found it a prominent contributor to fatality caused by the virus [16]. Conticini and Frediani examined the association between atmospheric pollution and COVID-19 lethality in Italy and proposed that air pollution in Northern Italy could be considered as a cofactor [10]. Cui and Zhang found a positive correlation between air pollution and severe acute respiratory syndrome case fatality in China [17].

The present study aims to examine the correlation between COVID-19 pandemic and air quality parameters in Turkey. Unlike previous studies, two statistical tests were conducted, and the linear and monotonic relationships between the air quality parameters and COVID-19 pandemic were analyzed. PM_{10} , SO_2 , CO, NO_2 , NO_x , NO, and O_3 parameters were included in the analysis. Considering Lauer, Grantz and other studies posited that symptoms would develop after 14 days of active monitoring; the average values of the parameters within 14 days of each case were included in the model [18]. Nine provinces with the highest confirmed cases in Turkey were included, totaling 78% of the confirmed cases in

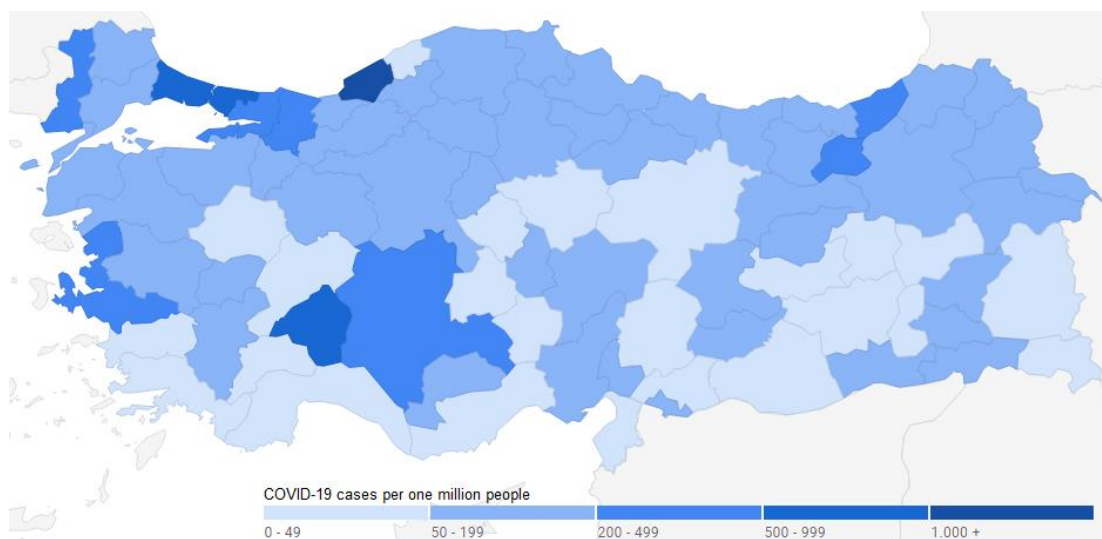


Figure 1. The density of COVID-19 cases by provinces in Turkey (Source: Google)

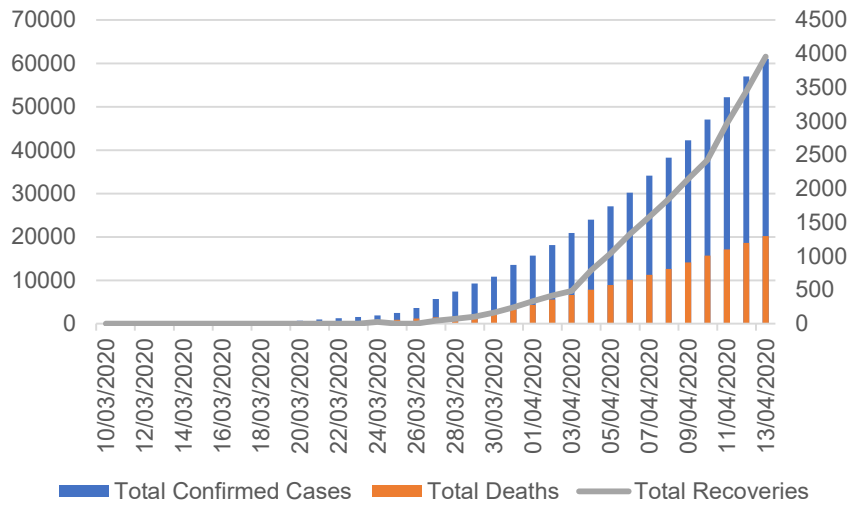


Figure 2. The number of total confirmed cases, deaths, and recoveries in Turkey

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the analysis to discover whether differences exist between countries as well.

Materials and Methods

Study area

As of April 3, 2020, The Ministry of Health of the Republic of Turkey stated that 20921 COVID-19 cases had been identified in Turkey. It should be noted that April 3, 2020, was the latest date in which COVID-19 data was announced on a provincial basis in Turkey. Therefore, the data as of that date were used in this study. Based on the data, 62.5% of these cases were located in Istanbul, the most populous city in Turkey. Eight other provinces

of Izmir, Ankara, Konya, Kocaeli, Sakarya, Bursa, Adana, and Zonguldak were also considered in this study. Therefore, this study analyzed 78% of total confirmed cases. Although Isparta is among the top 10 provinces in terms of approved COVID-19 cases, it was excluded due to incomplete air quality data. Figure 1 demonstrates the general view of the density of COVID-19 cases by provinces in Turkey.

Study data

Data for the confirmed COVID-19 cases were collected from the official website of the Ministry of Health of the Republic of Turkey as country-wide data has been published daily on the website [19]. Figure 2 illustrates

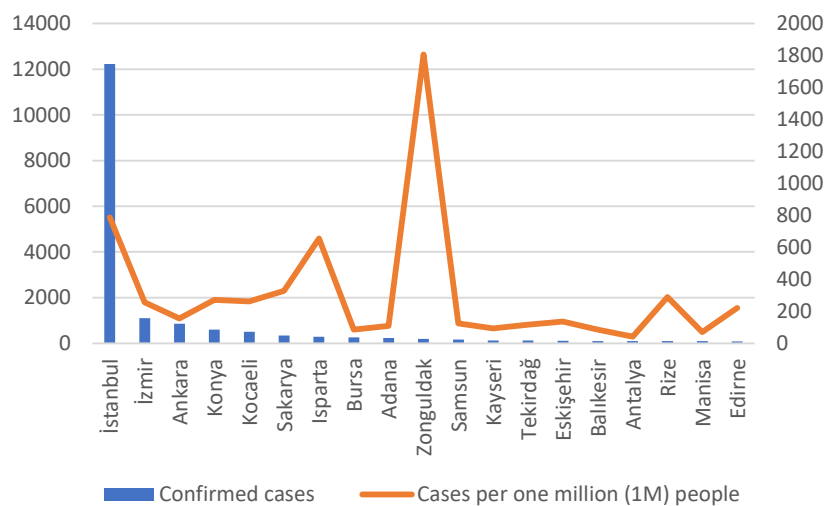


Figure 3. The comparison of locations in terms of confirmed cases and cases per 1 M people

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Table 1. The number of confirmed cases, cases per one million people, and deaths in different locations in Turkey

Location	Confirmed Cases	Cases per 1 M People	Deaths
Istanbul	12.231	788.12	117
Izmir	1.105	255.76	18
Ankara	860	156.25	7
Konya	601	272.49	7
Kocaeli	500	262.28	8
Sakarya	337	327.3	3
Isparta	289	654.72	1
Bursa	259	86.49	2
Adana	241	108.55	3
Zonguldak	197	1.806.01	5
Samsun	167	125.03	1
Kayseri	130	93.55	1
Tekirdağ	121	117.48	0
Eskişehir	118	135.45	1
Balıkesir	106	86.42	5
Antalya	102	42.04	2
Rize	101	289.72	3
Manisa	100	69.95	1
Edirne	91	221.13	2

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COVID-19 data, as of April 13, 2020, in Turkey, including total confirmed cases, total deaths, and recoveries. The first case detected in Turkey was on March 10, 2020, and data collection began on that date.

Table 1 presents the number of confirmed cases, cases per 1 Million (1M) people, and deaths in different locations in Turkey. The highest confirmed COVID-19 cases were in Istanbul, followed by Izmir, Ankara, Konya, Kocaeli, Sakarya, Isparta, Bursa, Adana, and Zonguldak. Approximately 53% of total deaths from COVID-19 were in Istanbul as of April 3, 2020. The population of Istanbul exceeded 15.5 million as of December 2019, according to the Turkish Statistical Institute [20]. Zonguldak has the highest cases per 1 million people, with 1806.01. The comparison of provinces based on confirmed cases and cases per 1 million people is shown in Figure 3.

Air quality parameters were collected from the official website of the Republic of Turkey Ministry of Environment and Urbanization [21]; PM_{10} ($\mu\text{g}/\text{m}^3$), SO_2 ($\mu\text{g}/\text{m}^3$), CO ($\mu\text{g}/\text{m}^3$), NO_2 ($\mu\text{g}/\text{m}^3$), NO_x ($\mu\text{g}/\text{m}^3$), NO ($\mu\text{g}/\text{m}^3$), and O_3 ($\mu\text{g}/\text{m}^3$) parameters were considered in the analysis in the present study. Because the incubation period of COVID-19 is around 14 days, the data of each

parameter for each location were examined from March 21, 2020, to April 3, 2020. The average values of each parameter for that period were included in the analysis. Generally, the provinces examined have multiple stations providing air quality data; however, some of them either do not provide any data or provide incomplete data. Considering this, when choosing a station for each location, the completeness of the required data was the priority. In Isparta, there is one station that does not provide NO_2 , NO_x , or NO data for the period considered. Therefore, Isparta was excluded from analysis, as indicated earlier.

Figure 4 (A-G) compare the air quality parameters of each province. Figure 4a displays the average PM_{10} values for each city (PM_{10} referring to atmospheric particles with diameters $\leq 10 \mu\text{m}$), which is one of the most crucial pollution indicators used to characterize air quality and the greatest threat to human health. The Figure reveals that Ankara had the highest average PM_{10} value ($59.92 \mu\text{g}/\text{m}^3$), whereas Adana had the lowest ($28.06 \mu\text{g}/\text{m}^3$). Figure 4 (B & C) illustrate the comparative average SO_2 and NO_2 values of the provinces, respectively. NO_2 and SO_2 together significantly affect human health and the environment because atmo-

spheric SO₂ and NO₂ mix easily with rainwater and can create acid rains that are very detrimental [22].

Inhaling NO₂ and SO₂ in high concentrations can cause some respiratory problems, including coughing, asthma, and wheezing [23]. The highest SO₂ value (14.65 µg/m³) was observed in İstanbul, whereas the lowest value was in Zonguldak (2.57 µg/m³). The highest NO₂ (56.63 µg/m³) was measured in Bursa and the lowest (9.64 µg/m³) in Izmir. In most ambient cases, NO is emitted and converts to nitrogen dioxide in the atmosphere [24]. NO_x is a general term for nitrogen oxides, which are related to air pollution. Figure 4 (D & E) show the average NO and NO_x values for locations, respectively. The highest NO value (36.62 µg/m³) was seen in Bursa, whereas the lowest (3.91 µg/m³) was detected in Izmir and the highest NO_x value (112.89 µg/m³) was measured in Bursa, and the lowest (13.55 µg/m³) in Izmir. CO is a lethal gas in the atmosphere generated from the imperfect combustion of carbon-containing fuels like natural gas, gasoline, coal, oil, and wood. Inhalation of high CO concentrations can limit O₂ passage within hemoglobin that can be harmful to health [25].

Figure 4F compares the CO values observed in each location. The highest average CO value (2458.57 µg/m³) was seen in Bursa, whereas Adana had the lowest value (44.56 µg/m³). O₃, which is produced mainly from vehicle emissions, is one of the most significant atmospheric pollutants. Inhaled ozone can trigger various health problems such as coughing, chest pain, airway inflammation, and reduced lung functions. Figure 4G illustrates the comparative values of the average O₃ in the provinces. The highest value (68.60 µg/m³) was measured in İstanbul, whereas the lowest (7.25 µg/m³) was in Ankara.

Statistical analysis

The analyses were conducted through the Pearson and Spearman Rho correlation tests. The Pearson correlation is a statistical measure of the strength of the linear relationship between 2 variables, where r designates the linear correlation between 2 variables of a and b (Formula 1). The measure r is described as, where -1 is a complete negative linear correlation, 0 is a non-linear correlation, and +1 is a complete positive linear correlation [26].

$$1. r = \frac{\sum_{i=1}^n (a_i - \bar{a})(b_i - \bar{b})}{\sqrt{\sum_{i=1}^n (a_i - \bar{a})^2 \sum_{i=1}^n (b_i - \bar{b})^2}}$$

Also, n denotes the number of observations, a₁, a₂, ..., a_n and b₁, b₂, ..., b_n denote the individual data value of a and b variables, respectively.

The Spearman Rho is a non-parametric test. As a statistical measure, the Spearman correlation coefficient reflects the strength of a monotonic relationship between 2 variables. The higher the value of the coefficient, the higher was the correlation between the 2 variables. Unlike the Pearson correlation, normality is not required, which makes it a non-parametric statistic. The Spearman correlation coefficient (r_s) is determined through the following function (Formula 2):

$$2. r_s = 1 - 6 \frac{\sum d_i^2}{n(n^2 - 1)}$$

where d_i designates the difference between orders of 2 variables, and n is the number of observations.

Results

Table 2 presents the descriptive statistics of the confirmed COVID-19 cases and air quality parameters. The timespan was from March 21, 2020, to April 3, 2020. In that period, average concentrations were as follows: PM₁₀: 45.69 µg/m³; SO₂: 7.67 µg/m³; CO: 1041.94 µg/m³; NO₂: 27.57 µg/m³; NO_x: 44.9 µg/m³; NO: 13.37 µg/m³; and O₃: 34.41 µg/m³.

Table 3 provides the Pearson correlation coefficients. The results indicate a significant correlation between CO and NO. Besides, there are significant correlations between NO, NO_x, and NO₂, as expected. The focus point in the study was the association of the air quality parameters and COVID-19. It can be inferred that the correlation between SO₂ and COVID-19 is significant at the 0.05 level. This positive correlation means that an increase in SO₂ is an indication of an increase in COVID-19 cases. The correlation between O₃ and COVID-19 cases is also positive and high. However, there are no significant correlations between NO₂, NO, NO_x, and COVID-19; this implies the correlation is negative.

Table 4 presents the Spearman Rho values. The results showed some significant correlations between air quality parameters, namely SO₂ and NO; NO₂ and NO_x; and NO and NO_x. Considering the correlation of COVID-19 cases, the correlation between PM₁₀ and SO₂ with COVID-19 is high and positive. However, based on the Pearson coefficients results, the correlations of NO₂,

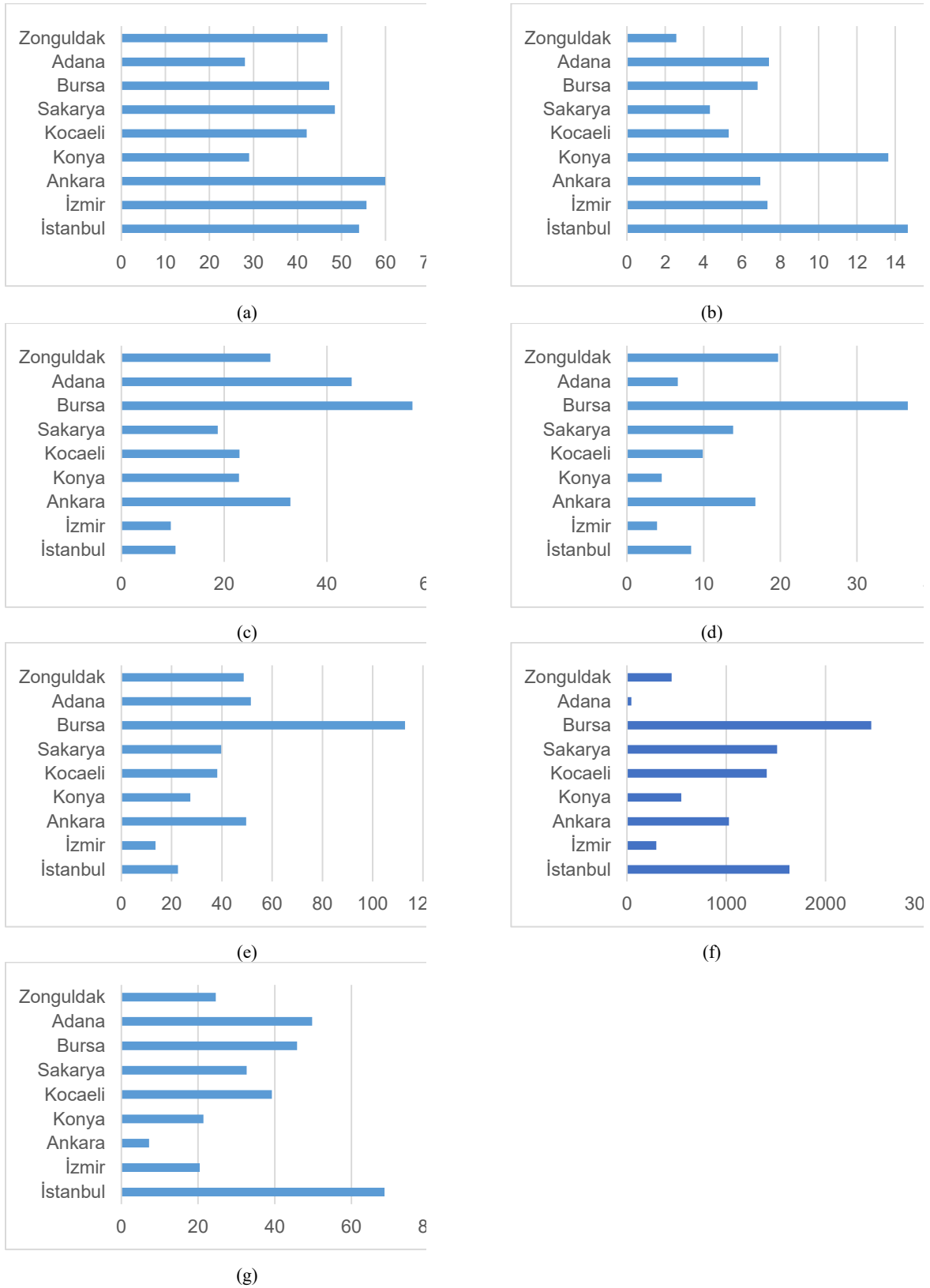


Figure 4. The comparison of average PM10 ($\mu\text{g}/\text{m}^3$)

A: SO_2 ($\mu\text{g}/\text{m}^3$); B: NO_2 ($\mu\text{g}/\text{m}^3$); C: NO ($\mu\text{g}/\text{m}^3$); D: NO_x ($\mu\text{g}/\text{m}^3$); E: CO ($\mu\text{g}/\text{m}^3$); F: O_3 ($\mu\text{g}/\text{m}^3$); and G: Values of the provinces

Table 2. Descriptive statistics of confirmed cases and air quality parameters

Parameters	Mean	Min	Max
PM ₁₀	45.69	28.06	59.92
SO ₂	7.67	2.57	14.65
CO	1041.94	44.56	2458.57
NO ₂	27.57	9.64	56.63
NO _x	44.90	13.55	112.89
NO	13.37	3.91	36.62
O ₃	34.41	7.25	68.60
COVID-19 cases	1814.56	197	12231

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Table 3. The Pearson Correlation coefficients

Parameters	PM ₁₀	SO ₂	CO	NO ₂	NO _x	NO	O ₃	COVID-19 Cases
PM ₁₀	1.000	-0.164	0.355	-0.317	-0.055	0.257	-0.189	0.317
SO ₂	-0.164	1.000	0.044	-0.285	-0.326	-0.397	0.363	0.672
CO	0.355	0.044	1.000	0.237	0.567	0.676	0.391	0.266
NO ₂	-0.317	-0.285	0.237	1.000	0.911	0.706	0.070	-0.454
NO _x	-0.055	-0.326	0.567	0.911	1.000	0.919	0.138	-0.334
NO	0.257	-0.397	0.676	0.706	0.919	1.000	0.044	-0.217
O ₃	-0.189	0.363	0.391	0.070	0.138	0.044	1.000	0.649
COVID-19 cases	0.317	0.672	0.266	-0.454	-0.334	-0.217	0.649	1.000

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Table 4. The Spearman Rho values

Parameters	PM ₁₀	SO ₂	CO	NO ₂	NO _x	NO	O ₃	COVID-19 Cases
PM ₁₀	1.000	-0.017	0.300	-0.367	-0.250	0.150	-0.400	0.617
SO ₂	-0.017	1.000	-0.100	-0.250	-0.367	-0.667	0.217	0.617
CO	0.300	-0.100	1.000	0.033	0.100	0.533	0.367	0.200
NO ₂	-0.367	-0.250	0.033	1.000	0.950	0.617	0.167	-0.667
NO _x	-0.250	-0.367	0.100	0.950	1.000	0.700	0.183	-0.717
NO	0.150	-0.667	0.533	0.617	0.700	1.000	0.083	-0.500
O ₃	-0.400	0.217	0.367	0.167	0.183	0.083	1.000	-0.200
COVID-19 cases	0.617	0.617	0.200	-0.667	-0.717	-0.500	-0.200	1.000

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NO, NO_x, and COVID-19 cases are negative, and these require further analysis. Unlike the Pearson results, the correlation between O₃ and COVID-19 cases is weak and negative.

Discussion

A recent study conducted by Zhu and Xie evaluated the results of this analysis [15]. They detected strong correlations between air quality parameters such as between PM₁₀ and CO as well as between PM₁₀ and SO₂ [15]. These differences may be due to the use of different study data and the incubation periods. The results of that study revealed that COVID-19 is associated with short-term

exposure to high concentrations of CO, PM₁₀, O₃, and NO₂. Their results stated that the risk of COVID-19 infection is negatively associated with short-term exposure to a high concentration of SO₂. A significant positive association was observed between SO₂ and the number of COVID-19 cases. Comparing our study results to theirs indicates that the increase in SO₂ leads to an increased risk of COVID-19 infection. The correlation between PM₁₀ and O₃ with the risk of COVID-19 infection was also detected in this study. However, no association between CO and COVID-19 cases was found in this study.

Guo and Chang examined the association of air pollution and the incidence of lung cancer, taking into account

socioeconomic indicators in China. They found a positive correlation in this regard [27]. Yao and Wu analyzed the impact of air pollutants and claimed that short-term exposure to ambient air pollutants was associated with health burdens and economic loss in China [28]. PM₁₀, CO, O₃, NO₂, and SO₂ were deemed to be the causative factors of death. Finally, the use of both Spearman and Pearson correlation tests may be criticized. Considering the data, the use of the Spearman Rho test might be more relevant for this study. However, Rahman, Luo [22] also applied both Spearman Rho and Pearson correlation tests to analyze the impact of the pollutants (PM_{2.5}, PM₁₀, O₃, CO, NO₂, and SO₂) and weather parameters (temperature, relative humidity, precipitation, and wind speed) on airborne pollen concentrations. Therefore, the use of both methods allowed a comparative and detailed analysis.

Therefore, there is a significant association between SO₂ and the number of COVID-19 cases upon consideration of the results of both Spearman and Pearson correlation coefficients. SO₂ primarily affects respiratory functions and is a direct poisoner of people, so the results were expected. Based on the Spearman Rho values, PM₁₀ is correlated with the number of COVID-19 cases; however, the Pearson coefficient does not validate it. Since PM₁₀ can spread to the lungs, causing inflammation or heart and lung diseases that can adversely affect people, the correlation was expected to be higher. The impact of CO on the number of COVID-19 cases is negligible according to the results of both Pearson and Spearman correlation tests. Due to the previously mentioned adverse impacts of O₃ on health, the effect was expected to be high. Although the Pearson results indicated a correlation, the Spearman results did not detect any positive correlation. The effects of NO₂, NO_x, and NO on the number of COVID-19 cases might have been different; tests revealed that these have no association or have negative associations.

The limitations of this study included a limited amount of data. As city-based COVID-19 data in Turkey are made available in the future, more accurate analysis can be conducted. Second, the air-related parameters may show their effects in the long term; therefore, analysis of the short term may be criticized. The air quality-related parameters for different locations have similar proportionate values for different periods. Thus, the difference between locations in terms of values does not change significantly with time. Third, the values of the air quality parameters change based on the district of a province. Multiple stations exist in most of the provinces, and they measure different values, so it might be more reasonable to evaluate each city using district-based data. Regrettably, it is not possible to obtain such specific COVID-19 data in Turkey yet.

Conclusions

In this study, the impact of air quality parameters, PM₁₀, SO₂, CO, NO₂, NO_x, NO, and O₃, on COVID-19 cases in Turkey were evaluated through statistical analysis. Based on the results of the two tests, a significant positive correlation exists between SO₂ and the number of COVID-19 cases in Turkey. The Pearson correlation coefficients indicated the high impact of O₃ on the number of COVID-19 cases. The Spearman Rho values revealed a correlation between PM₁₀ and the number of cases. The impact of NO, NO₂, and NO_x on COVID-19 cases was negative, and these variables require further evaluation.

As detailed and updated COVID-19 data for each location are made available, further analysis can be conducted. It may be useful to use air quality data of the smallest possible districts for each city. Including different countries in the analysis could also help to generalize the results. If the number of citizens brought from abroad and quarantined in different locations was evaluated as a component of the study, this could enhance the accuracy of the analysis.

Ethical Considerations

Compliance with ethical guidelines

All ethical principles were considered in this article.

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Conflict of interest

The author declared no conflict of interest.

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