



# Transmission of COVID-19 pandemic (Turkey) associated with short-term exposure of air quality and climatological parameters

Aytac Perihan Akan<sup>1</sup>

Received: 6 October 2021 / Accepted: 25 December 2021 / Published online: 31 January 2022  
© The Author(s), under exclusive licence to Springer-Verlag GmbH Germany, part of Springer Nature 2021

## Abstract

The study aims to investigate associations between air pollution, climate parameters, and the diffusion of COVID-19-confirmed cases in Turkey using Spearman's correlation test as an empirical methodology by Statgraphics Centurion XVI (version 16.1) and to determine the risk factors accelerating the spread of SARS-CoV-2 virus. The present study demonstrates the strong impacts of air pollutants and weather conditions on the transmission of COVID-19 morbidity. Particularly, O<sub>3</sub> and PM<sub>10</sub> from air quality parameters exhibited the strongest correlation with the number of daily cases in Kütahya ( $r_s = -0.62$ ;  $p < 0.05$ ) and Sivas ( $r_s = -0.62$ ;  $p < 0.05$ ) provinces, respectively. In meteorological parameters, rainfall showed the highest impact ( $r_s = 0.76$ ;  $p < 0.05$ ) on the number of daily COVID-19 cases in Denizli distinct. Moreover, this study suggested that the diffusion of the novel coronavirus SARS-CoV-2 in regions with high levels of air pollution and low wind speed is dominant. To prevent the negative effects of the future pandemic crisis on public health and economic systems, manifold implications to encourage strategies to reduce air pollution in the polluted region such as being prevalent the usage of renewable energy technologies in particular electricity generation and sustainable policies such as improving the health system should be implemented by decision-makers.

**Keywords** COVID-19 Air quality parameters · Meteorological parameters · SARS-CoV-2 · Coronavirus Disease Air pollution

## Introduction

Since the COVID-19 virus, which has the same symptoms as the severe acute respiratory syndrome (SARS) and the Middle East respiratory syndrome (MERS), such as fever, dry cough, sore throat, shortness of breath and pneumonia, and first appeared in Wuhan, China, in December 2019, has globally spread in a short time, it was announced as a pandemic on 11th March, 2020, by the World Health Organization (WHO) (Bontempi 2020; Schuit et al. 2020; Yao et al. 2020; Zhu et al. 2020). As of June 27, 2021, there have been globally 181,344,224 confirmed cases and 3,934,252 deaths had been reported to WHO, even though a total of 2,660,756,547 vaccine doses have been administered as of

June 27, 2021 (WHO 2021). In Turkey, the first case and death based on the COVID-19 virus were recorded on March 11, 2020, and March 15, 2020. It has rapidly transmitted, reaching a peak in the first four weeks and exceeding about 5 million confirmed cases of COVID-19 by early May 2021 (Ali et al., 2021; WHO 2021).

Coronaviruses are naturally hosted and evolutionarily shaped by bats. Indeed, it has been postulated that most of the coronaviruses in humans are derived from the bat reservoir. In a study conducted by Tang et al. (2020), only 4% variability in genomic nucleotides between SARS-CoV-2 and a bat SARS-related coronavirus was observed (Tang et al. 2020). The principal factors determining the diffusion of infectious diseases, such as the COVID-19, can be listed as: i) air pollution, ii) atmospheric stability/instability measured with wind speed, iii) demographic aspect is given by population density and finally iv) respiratory disorders of people, given by mortality rate for trachea, bronchi and lung cancer. Studies reveal that areas with high levels of air pollution showed higher COVID-19-confirmed cases and deaths. A high wind speed, creating atmospheric instability, seems

---

Communicated by Lotfi Aleya.

✉ Aytac Perihan Akan  
apakan@hacettepe.edu.tr

<sup>1</sup> Department of Environmental Engineering, Hacettepe University, 06800 Ankara, Turkey

to reduce the number of infected individuals because it fosters the dispersion of air pollution that can act as a carrier of the SARS-CoV-2 in the air, whereas a stable atmosphere with low wind speed prevents the dispersion of air pollutants that remain stagnant in the air with the content of bacteria and viruses, such as SARS-CoV-2, generating a higher diffusion of COVID-19 and other infectious diseases. Moreover, high population density is a potential risk factor for transmission dynamics and the spread of COVID-19 at the local and regional levels. Furthermore, people with chronic respiratory diseases, such as chronic obstructive pulmonary disease, are more prone to being infected by viral agents (Coccia 2020a). It is known that the SARS-CoV-2 virus can either directly (droplet and person-to-person) or indirectly (contaminated objects and airborne transmission) infect the respiratory system. Droplets and bioaerosols containing the virus, in case of entering into the human body emitting by coughing/sneezing that can reach an uninfected subject, can cause illness. Any unprotected contact with a contaminated object can potentially increase the virus's transmissibility. Airborne transmission expressing the inhalation of small airborne particles less than ( $5\ \mu\text{m}$ ) in diameter remaining in the air for hours and long distances is another route for COVID-19 transmission (Rahimi et al. 2021 and Domingo et al. 2020).

Various studies have been carried out to determine the reasons contributing to the spread of the COVID-19 virus to prevent the transmission of the outbreak. Previous works proved that air pollution is a severe environmental threat resulting in respiratory diseases such as SARS, MERS and asthma. Accordingly, it was found that viral transmissions were accelerated through the change in air pollutants concentration, and meteorological variables, such as ambient temperature and relative humidity, were also negatively or positively correlated with COVID-19 incidence. Sarkodie and Owusu (2020) reported that high temperature and relative humidity reduce the viability, stability, survival and transmission of COVID-19, whereas low temperature, wind speed, dew/frost point, precipitation and surface pressure prolong the activation and infectivity of the virus. The previous studies exploring precursors of respiratory tract diseases revealed that there were statistically significant associations of both meteorological parameters, especially temperature and air pollutants, including carbon monoxide (CO), nitrogen dioxide ( $\text{NO}_2$ ), sulfur dioxide ( $\text{SO}_2$ ), ozone ( $\text{O}_3$ ), particulate matters ( $\text{PM}_{2.5}$  and  $\text{PM}_{10}$ ) with viral infection disease (Becker and Soukup 1999; Kan et al. 2005; Yuan et al. 2006; Lin et al. 2013; Silva et al., 2014; Beelen et al. 2014; Ghozikali et al. 2016; Iha et al. 2016; Xu et al. 2016; Nenna et al. 2017; Xie et al. 2019; Kowalska et al. 2020). Researchers maintain that the spread of SARS-CoV-2 through air pollution caused by increasing population, irregular urbanization, unplanned industrialization, and preference for private motor

vehicles instead of public transportation can be a critical transmission mechanism. Studies show that in the presence of accumulated airborne pollutants, more microorganisms might be attached to particulate matter, such that environments with heavy air pollution and highly toxic pollutants of  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  may inhibit microbial growth (Coccia 2021a and Caliskan et al. 2020).  $\text{PM}_{2.5}$  emissions mainly originate from traffic, combustion of fossil fuels and biomass for energy production, and industrial facilities, while diesel engines, resuspension of soil particles, industrial activities and residential fossil fuel heating are the main sources of  $\text{PM}_{10}$  pollution. Exposure to high levels of  $\text{PM}_{2.5}$  may adversely impact public health, bringing about some health problems, such as respiratory and cardiovascular diseases, premature death and lung cancer (Goren et al. 2021). Many of the studies performed to investigate the relationship between particulate matter and respiratory illness, including influenza-like illness, respiratory syncytial virus bronchiolitis and cardiovascular disease, demonstrated that particulate matter concentrations have a statistically positive impact both on the occurrence and in the increase of severity of these types of illnesses (Lee et al. 2014; Feng et al. 2016; Carugno et al. 2018; Yarahmadi et al. 2018; Liu et al. 2019). However, in a study conducted by Lanzinger et al. (2016), a positive but statistically insufficient relationship between respiratory diseases and particulate matters consisting of  $\text{PM}_{0.1}$ ,  $\text{PM}_{2.5}$  and  $\text{PM}_{10}$  was observed. Studies show that aerosols containing the coronavirus generated by sneezes and coughs are a major route for spreading the virus (Srivastava 2021). Viruses may be adsorbed through coagulation onto PM and remain airborne for hours or days, thereby increasing inhaled virus concentrations via PM in the lungs. The lungs are the primary target for SARS-CoV-2 infection by droplet-aerosol transmission. Tung et al. (2021) proposed that PM plays a direct role as a “carrier” of SARS-CoV-2 that has a high affinity to the angiotensin-converting enzyme 2 (ACE2) receptor. Indirectly, exposure to PM increases ACE2 expression in the lungs, facilitating SARS-CoV-2 viral adhesion. Thus, the high risk of SARS-CoV-2 in heavily polluted regions can be explained by the upregulation of ACE2 caused by PM (Tung et al. 2021). Bremner et al. (1999) investigated  $\text{PM}_{10}$ ,  $\text{NO}_2$ ,  $\text{O}_3$ ,  $\text{SO}_2$  and CO on cardiovascular deaths. They suggested that  $\text{NO}_2$  and  $\text{O}_3$  are significantly associated with cardiovascular deaths, while  $\text{PM}_{10}$  does not show any association. Gauderman et al. (2000) revealed that while  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$  and  $\text{NO}_2$  had a significant adverse effect on the growth of lung functions of children, ozone did not have any effect. A study conducted by Lin et al. (2013) found a positive association between average temperature and acute upper respiratory diseases. Huang et al. (2016) found a strong association between air pollutants including  $\text{PM}_{10}$ ,  $\text{PM}_{2.5}$ ,  $\text{NO}_2$  and influenza-like illness, investigating 59,860 cases in Nanjing, China, for

one year. Dehghani et al. (2017) investigated the effects of air pollutants including CO, SO<sub>2</sub>, O<sub>3</sub>, NO<sub>2</sub>, PM<sub>10</sub> and PM<sub>2.5</sub> on lung cancer and leukemia in Shiraz, Iran. They found that the mortality rate of leukemia had a significant direct correlation with concentrations of NO<sub>2</sub> and CO in the air ( $P < 0.05$ ). Asl et al. (2018) investigated the effect of air quality parameters including PM<sub>10</sub>, PM<sub>2.5</sub>, NO<sub>2</sub>, SO<sub>2</sub>, CO and O<sub>3</sub> and meteorological parameters containing temperature, humidity and wind speed on public health in Iran. They found that average seasonal temperature and average seasonal concentrations of air pollutants including NO<sub>2</sub>, PM<sub>10</sub> and PM<sub>2.5</sub> showing the tremendous impact revealed a positive linear correlation. In contrast, relative humidity showed a significant negative correlation with them. In a study conducted by Chen et al. (2019), which investigated how the increased concentration of air pollutants including NO<sub>2</sub>, SO<sub>2</sub> and O<sub>3</sub> would influence the mortality rates associated with pulmonary heart disease, a significant and positive correlation was found between the components. Rhee et al. (2019) suggested that exposure to PM<sub>2.5</sub> and O<sub>3</sub> for the long-term increases the risk of acute respiratory distress syndrome (ARDS). Su et al. (2019) suggested that especially PM<sub>2.5</sub>, PM<sub>10</sub>, CO and SO<sub>2</sub> were positively associated with ILI in accordance with results from the study investigating the relationship between air pollutants including PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub>, CO, O<sub>3</sub> and influenza-like illness (ILI) in Jinan, China. In line with these studies, in which parameters with a relationship with respiratory diseases are determined, the current studies investigating the effect of air quality and meteorological parameters on the transmission of COVID-19 outbreak are presented below.

Adhikari and Yin (2020) investigated the association between air pollutants including PM<sub>2.5</sub>, O<sub>3</sub>, daily meteorological variables including wind speed, temperature, relative humidity, absolute humidity, cloud percentages and precipitation levels and COVID-19-confirmed new cases and new deaths in Queens County, New York, during March and April 2020. The findings revealed that daily average temperature, daily maximum eight-hour ozone concentration, average relative humidity and cloud percentages were significantly and positively associated with new confirmed cases related to COVID-19; none of these variables showed significant associations with new deaths. Li et al. (2020) investigated the association between air pollutants including PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub>, CO, meteorological variables including daily temperature, highest temperature, lowest temperature, temperature difference and sunshine duration and COVID-19 incidence in Wuhan and XiaoGan, China, between January 26, 2020, and February 29, 2020. Temperature is the only meteorological parameter correlated well with COVID-19 incidence in both cities but in an inverse correlation ( $p < 0.05$ ). PM<sub>2.5</sub>, NO<sub>2</sub> and temperature are variables that could promote the sustained transmission of COVID-19.

Jiang et al. (2020) investigated the association between air pollutants including PM<sub>2.5</sub>, PM<sub>10</sub>, SO<sub>2</sub>, NO<sub>2</sub>, CO, O<sub>3</sub>, daily meteorological variables including wind speed, temperature, relative humidity and COVID-19 new cases in three cities of China. They found that daily COVID-19 incidence was positively associated with PM<sub>2.5</sub> and humidity in all cities and negatively associated with PM<sub>10</sub> and temperature. Wu et al. (2020) investigated the association between long-term exposure to PM<sub>2.5</sub> and COVID-19 death in the USA. They found a slight increase in long-term exposure to PM<sub>2.5</sub> leading to a significant increase in the COVID-19 death rate. Taniş and Karakaya (2021) investigated the impacts of air pollutants including PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub>, SO<sub>2</sub>, CO and O<sub>3</sub> and weather parameters including temperature, humidity, pressure, dew point, wind speed on the number of SARS-COV-2 cases, hospitalizations, hospital discharges in Istanbul from Turkey between July 15, 2020, and September 30, 2020, considering the Pearson correlation analysis. They observed a statistically significant positive relationship between air quality indexes such as CO, SO<sub>2</sub>, PM<sub>2.5</sub>, PM<sub>10</sub>, NO<sub>2</sub> and the number of daily confirmed SARS-COV-2 cases. At the same time, they noticed a negative association between weather parameters such as temperature and pressure and the number of daily confirmed SARS-COV-2 cases. Tosepu et al. (2020) investigated the association between climate parameters including average temperature, minimum temperature, maximum temperature, rainfall, humidity and COVID-19 pandemic in Jakarta, Indonesia, considering Spearman rank correlation test. They observed that only average temperature was significantly correlated with the COVID-19 pandemic ( $r = 0.392$ ;  $p < 0.01$ ). Zoran et al. (2020a) investigated the association between air pollutants including PM<sub>2.5</sub>, PM<sub>10</sub>, daily meteorological variables including wind speed, temperature, relative humidity, atmospheric pressure and COVID-19-confirmed new cases and lethality rate in Milan metropolitan area, Lombardy region, Italy, between January 1, 2020, and April 30, 2020. They found that air pollution and climate variables significantly impact the increased rates of confirmed COVID-19 cases and deaths. Zoran et al. (2020b) investigated the association between air pollutants including NO<sub>2</sub>, O<sub>3</sub>, daily meteorological variables including wind speed, temperature, relative humidity, atmospheric pressure, precipitation rate and COVID-19-confirmed new cases and lethality rate in Milan metropolitan area, Lombardy region, Italy, between January 1, 2020, and April 30, 2020. Exhibited positive correlations of ambient ozone levels and negative correlations of NO<sub>2</sub> with the increased rates of COVID-19 infections in terms of the total number, daily new positive and total death cases can be attributed to airborne bioaerosols distribution. The results show a positive correlation of daily averaged O<sub>3</sub> with air temperature and inversely correlations with relative humidity and precipitation rates.

Diversities in the number of confirmed cases and mortality rates from the SARS-CoV-2 virus are associated with air pollution and meteorological indicators and can be attributed to the differences in medical and health insurance systems and regional policies in different cities and countries. Moreover, some factors, including age, human behaviors, socioeconomic status, and gross domestic product per capita, also impact morbidity and mortality rates (Yuan et al. 2020; Diao et al 2021; Aykaç and Etiler 2021; Coccia 2021b). In a study conducted by Aykaç and Etiler 2021, socioeconomic status, household size, and elderly population ratio were associated with the COVID-19 mortality rate in Istanbul.

This study aims to reveal the status related to the diffusion of COVID-19 virus in fifteen cities of Turkey, including Adana, Ankara, Bursa, Denizli, Erzurum, İstanbul, İzmir, İzmit, Kayseri, Konya, Kütahya, Sivas, Samsun and Trabzon through the mechanisms of air pollution-to-human transmission and human-to-human transmission of COVID-19-confirmed cases, as a result of the SARS-CoV-2 virus staying in the air for a longer time, with the effect of certain climatic parameters in regions with high air pollution. In light of the existing studies in the literature, the present work can be regarded as the first published exploring the association of gust with the confirmed COVID-19 cases and as one of the rare publications investigating the effect of cloud on the transmission of the COVID-19 epidemic. Hence, this paper will hopefully contribute to filling this gap in the literature. The research questions of this study are as follows:

Can air pollution and climate parameters such as low wind speed and high temperature be associated with the spread of COVID-19-confirmed cases in Turkey?

What are the risk factors that can accelerate the novel coronavirus's diffusion in Turkey, one of the Mediterranean countries?

What strategies can be applied to prevent the spread of the SARS-CoV-2 virus?

## Methods

### Sample and data

The present work examined fifteen provinces with different climatic characteristics and population density to decrease the study's limitations. The general information about these cities is presented in Table 1. Turkey has seven different regions, including Black Sea Region (North), Marmara region (North-West), Aegean Region (West), Mediterranean Region (South), Central Anatolia Region, East Anatolia Region, and Southeastern Anatolia Region (Çoşkun et al. 2021).

Data about the COVID-19-confirmed cases between February 8, 2021, and May 8, 2021, for Adana, Ankara, Bursa, Denizli, Erzurum, İstanbul, İzmir, İzmit, Kayseri, Konya, Kütahya, Sivas, Samsun and Trabzon provinces in Turkey were collected from the COVID-19 information webpage of Ministry of Health of Republic of Turkey (COVID-19 2021). Daily outdoor air quality parameters and some of the meteorological parameters were obtained from the webpage of Air Quality Open Data Platform (AQOD 2021), the Meteorological Department of the Ministry of Agriculture and Forestry of the Republic of Turkey and other meteorological parameters were

**Table 1** The general characteristics of the provinces studied (TUIK 2021)

Provinces	Latitude	Longitude	Population	Climate type	Area (km <sup>2</sup> )
Adana	36.9719 N	35.3324 E	2,258,718	Mediterranean	13,602
Ankara	39.9347 N	32.8496 E	5,663,322	Terrestrial	25,677
Bursa	40.2071 N	29.0708 E	3,101,833	Temperate	10,807
Denizli	37.7735 N	29.0865 E	1,040,915	Mediterranean	11,960
Erzurum	39.9051 N	41.2709 E	758,279	Terrestrial	24,989
Eskişehir	39.77 N	30.5025 E	888,828	Terrestrial	14,084
İstanbul	41.0291 N	28.9766 E	15,462,452	Mediterranean and Black Sea	5,462
İzmir	38.4101 N	21.1297 E	4,394,694	Mediterranean	12,182
İzmit	40.7732 N	29.9507 E	1,997,258	Mediterranean and Black Sea	3,433
Kayseri	38.7239 N	35.4801 E	1,421,455	Terrestrial	17,232
Konya	37.8704 N	32.511 E	2,250,020	Terrestrial	40,768
Kütahya	39.4217 N	29.9879 E	576,688	Aegean and Marmara	11,814
Sivas	39.7515 N	37.0172 E	635,889	Terrestrial	28,777
Samsun	41.2871 N	36.3234 E	1,356,079	Black Sea	9,655
Trabzon	41.0061 N	39.7191 E	811,901	Black Sea	4,648

obtained from the webpage of World Weather Online (WVO 2021). Data used in this study are freely available from these websites.

## Measures of variables

The unit of analysis here is Turkish provincial cities. This study focuses on the following measures:

**COVID-19-confirmed cases:** Number of infected individuals from February 8, 2021, to May 8, 2021, by looking at the positive COVID-19 test results.

**Meteorological parameters:** Average dew point in °C, average relative humidity %, average atmospheric pressure in mbar, the average ambient temperature in °C, average wind speed in km/h, average gust in km/h, average precipitation in mm and average cloud % from February 8, 2021, to May 8, 2021.

**Air quality parameters:** Average CO<sub>2</sub> concentration in µg/m<sup>3</sup>, average NO<sub>2</sub> concentration in µg/m<sup>3</sup>, average O<sub>3</sub> concentration in µg/m<sup>3</sup>, average PM<sub>10</sub> concentration in µg/m<sup>3</sup>, average PM<sub>2.5</sub> concentration in µg/m<sup>3</sup>, average SO<sub>2</sub> concentration in µg/m<sup>3</sup> from February 8, 2021, to May 8, 2021.

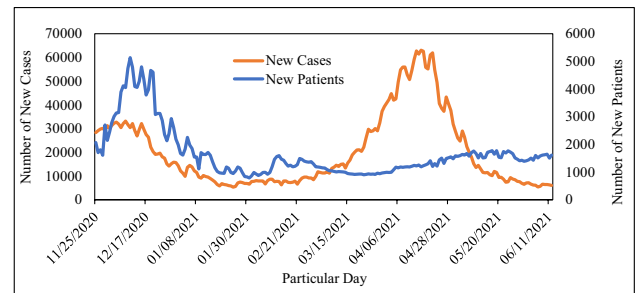
## Models and Data analysis procedure

This study analyzes a database of N = 15 Turkish provincial capitals, considering variables between February and May 2021 to explain the relationships between diffusion of COVID-19, air pollution and climatological indicators.

To statistically evaluate the diffusion of COVID-19 based on the variations of environmental pollutants and meteorological factors and COVID-19-confirmed cases, Spearman's rank correlation test was used as empirical methodology via Statgraphics Centurion XVI (Version 16.1). The value of 0.05 was considered as the significance level. Spearman's rank correlation coefficient ( $r_s$ ) is adopted to determine the correlation between variables. It analyzes how well the association between two variables can be defined using a monotonic function. Given that the data used in this study are not normally distributed, it is appropriate to use correlation coefficients for the analyses. The coefficient can be calculated via Eq. 1 (Şahin 2020):

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

where n represents the number of alterations, and  $d_i$  is the difference between the ranks of two parameters.



**Fig. 1** Variation in the number of new patients and new cases based on SARS-CoV-2 in Turkey. Note: New cases stand for the number of infected individuals in accordance with positive COVID-19 test results, and new patients represent the number of infected individuals having both positive test results and respiratory symptoms (cough and shortness of breath)

## Results and Discussion

The distributions of new confirmed cases and new patients based on COVID-19 between the end of November 2020 and the beginning of June 2021 are presented in Fig. 1. It could be easily said that the first and second peaks for new cases within these periods were observed on December 8, 2020 (33,198 cases) and April 16, 2021 (63,082 cases), respectively. On April 14, 2021, the Turkish government decided to apply lockdown activities to decrease confirmed cases, including between 7 pm and 5 am on weekdays and the whole day on weekends. It could be thought that the downward trend in the number of confirmed cases following 14th April was due to the quarantine precautions applied. The distributions in the number of new cases observed in the provinces when the second and maximum peaks (February 8, 2021–May 8, 2021) are presented in Figure SI-1.

The highest number of confirmed cases recorded in February–March was recorded in Samsun as 458.53 per 100,000 population. In the March–April and April–May periods, the maximum rate in the number of cases per 100,000 population was observed in Istanbul as 804.97 and 359.99, respectively. The increasing and decreasing trends in the number of cases from February to May 2021 for all provinces examined are presented in Table 2.

The main reason for the declining trend in the number of cases in April and May can be attributed to the quarantine-based precautions applied during these periods due to the severe increase of the confirmed cases in especially March, as mentioned before. To examine the effects of air quality parameters and meteorological factors on the spread of the COVID-19 virus, the changes in these parameters in fifteen selected provinces during the peak periods in Turkey (November 25, 2020–January 3, 2021, and February 8–May 8, 2021) are presented in Figure SI-2. The provinces' average

**Table 2** Variations in the number of confirmed cases in provinces over the period from February 8, to May 8, 2021

Provinces	Variations in the number of cases (%)		
	February–March	March–April	April–May
Adana	5.09	172	-83.2
Ankara	93.1	512	-63.5
Bursa	125	433	-73.6
Denizli	27.6	244	-34.9
Erzurum	21.0	710	-48.0
Eskişehir	141	604	-63.4
İstanbul	196	352	-81.8
İzmir	77.0	287	-39.2
İzmit	56.9	278	-82.1
Kayseri	152	178	-61.2
Konya	124	143	-75.3
Kütahya	67.2	230	-45.8
Samsun	168	40.7	-85.2
Sivas	32.6	578	-53.8
Trabzon	-2.50	61.6	-65.2

climate and air quality parameters for the November–January and February–May periods are presented in Tables 3 and 4.

When Figure SI-2 a-c and Table 3 are evaluated together, the most significant change from November 2020 to May 2021 was seen in the dew point with an increase of 37% in Adana, followed by rain with 24% and temperature with 21%, respectively. While temperature, gust and wind speed are the parameters that show the most significant increase at the rates of 52%, 40%, and 26% in Ankara, rain, temperature and dew point are the parameters demonstrating the most significant increase with 80%, 46% and 28% in Bursa. Temperature, gust and wind speed in Denizli showed an increase with the ratio of 56%, 35% and 20%, respectively. Moreover, temperature showed the highest rate of increase with 74% in Erzurum, followed by rain with 59% and wind speed with 42%. In Eskişehir, rain exhibited an increase with a ratio of 58%, followed by the temperature at 38% and wind speed at 35%.

The highest increases in meteorological parameters of Istanbul from November 2020 to May 2021 were observed in the rain with 56%, the wind speed with 17% and the temperature with 14%. In İzmir, the parameters showing a significant increase were dew point with the ratio of 32%, temperature with 25% and wind speed with 21%, while the rain showed a remarkable decrease with the ratio of 61%. In İzmit, the rain exhibited a considerable increase with the ratio of 59%. Furthermore, three meteorological parameters consisting of dew point, temperature and gust showed a similar increase with the ratio of 21%. The parameters demonstrating an increase in their values from November 2020

to May 2021 were the rain with 77%, the dew point with 65% and temperature with 38% in Kayseri. The rain, the wind speed and temperature showed increases with 67%, 43% and 41%, respectively, in Konya. The most significant increases in Kutahya were observed in the gust with 46%, the temperature with 38% and the dew point with 33%. In Samsun, the rain and the cloud were the significant parameters with the ratio of 67% and 18%, respectively. The maximum increase in dew point was observed in Sivas with 77%. Rain and temperature followed this increase with 66% and 50%. In Trabzon, on the other hand, it can be said that the parameters where the maximum increase was observed were only the rain with 57% and the cloud with 18%.

To evaluate the change in air quality parameters from November 2020 to May 2021, Figure SI-2 b-d and Table 4 can be examined together. In this context, O<sub>3</sub> showed an increase with a ratio of 44% in Adana. Moreover, PM<sub>10</sub> and SO<sub>2</sub> increase at the same rate between these periods. In Ankara, O<sub>3</sub>, PM<sub>2.5</sub> and PM<sub>10</sub> are the parameters showing the significant increase at 32%, 23% and 17%, respectively. The air pollutants considerably changing in terms of the increase of their values are O<sub>3</sub> with the ratio of 45% and NO<sub>2</sub> with the ratio of 16% in Bursa province. While there was only an increase in ozone concentration in Erzurum, Eskişehir, Kayseri and Trabzon, other air quality parameters revealed decreasing values in February and May compared to November and January. In Sivas, on the other hand, it was determined that there was a decrease in all parameters except NO<sub>2</sub>. In Samsun, the highest increase was seen in O<sub>3</sub>, with a rate of 79%. While an increase of 72% was observed in CO in Istanbul, a decrease of 71% was observed in PM<sub>10</sub>. While the parameters that increase in İzmir are SO<sub>2</sub> and NO<sub>2</sub> with a ratio of 27% and 18%, in İzmit, they are O<sub>3</sub> and SO<sub>2</sub> with a ratio of 40% and 35%, respectively. In Konya, SO<sub>2</sub> increased a remarkable ratio of 75%, and CO showed an increase with a ratio of 35%.

To determine the relationship between the alterations of the confirmed cases and variations in air quality parameters for all provinces examined from February 8, 2021, to May 8, 2021, Table 2 and Table 5 can be evaluated together. In Adana, while the increase in cases in the February–April period can be attributed to the 23% and 16% increase in O<sub>3</sub> and SO<sub>2</sub> concentrations, the decrease in the number of cases in the April–May period can be attributed to the decreases in O<sub>3</sub>, NO<sub>2</sub> and SO<sub>2</sub> concentrations. In Ankara, it can be said that the 49% increase in the concentration of PM<sub>2.5</sub> can be associated with the increase in the number of cases between February and April, it can also be expressed that the decrease in the cases in May can be due to the 42%, 26% and 21% decreases in the concentrations of PM<sub>2.5</sub>, CO and PM<sub>10</sub>, respectively. In Bursa, the increase in the confirmed cases between February and April may be related to the increase in the O<sub>3</sub> concentration, while the decreases in the May period

**Table 3** Average values of meteorological parameters in provinces over the period from November 25, 2020, to January 3, 2021, and from February 8, 2021, to May 8, 2021

Provinces	November 25, 2020–January 3, 2021							
	Dew point °C	Humidity %	Pressure mbar	Temperature °C	Wind speed km/h	Gust km/h	Rain mm	Cloud %
Adana	7.8±3.5	85±12	1020±3	21±2	5.7±1.9	17±4.8	0.25±0.7	32±28
Ankara	1.9±3.4	91±5	1021±4	11±3	3.7±1.5	9±4.9	0.11±0.3	33±24
Bursa	5.5±2.4	93±7	1021±5	14±3	4.0±2.6	9±3.9	0.13±0.3	38±28
Denizli	4.6±3.6	90±11	1021±4	12±2	5.9±2.1	8±4.4	0.23±0.7	32±24
Erzurum	-4.6±3.9	93±5	941±103	1.2±3.3	2.4±1.6	7±3.1	0.09±0.2	29±29
Eskişehir	2.7±2.8	94±5	1021±4	10±3	4.5±1.4	14±5.5	0.09±0.2	34±23
İstanbul	8.9±1.9	91±7	1021±5	15±3	6.5±1.8	24±9.5	0.09±0.2	45±30
İzmir	9.1±3.8	94±10	1019±5	16±2	6.6±2.1	22±9.8	0.60±1.3	44±29
İzmit	8.6±1.7	98±5	1021±5	15±4	3.6±1.7	9±2.9	0.20±0.6	44±30
Kayseri	-0.1±2.9	91±7	1022±3	10±3	4.0±1.9	9±4.9	0.13±0.4	28±25
Konya	2.1±3.0	91±8	1021±4	10±3	4.2±2.1	11±6.7	0.10±0.3	29±24
Kütahya	2.7±2.7	94±5	1021±4	10±3	4.4±1.4	11±4.6	0.12±0.4	37±25
Samsun	8.2±2.9	88±8	1022±4	16±4	4.7±1.7	16±7.6	0.16±0.5	42±30
Sivas	-1.3±2.7	94±8	1022±3	4±4	5.8±2.3	11±5.1	0.09±0.2	32±30
Trabzon	8.5±2.5	81±12	1022±4	15±3	5.3±2.3	16±5.3	0.31±0.9	42±30
Provinces	February 08, 2021–May 8, 2021							
	Dew point °C	Humidity %	Pressure mbar	Temperature °C	Wind speed km/h	Gust km/h	Rain mm	Cloud %
Adana	13±6	96±9	1017±5	23±6	6±3	14±5	0±0.72	33±27
Ankara	3±5	84±10	1015±20	20±9	5±2	15±8	0±0.38	41±26
Bursa	6±5	94±6	1020±6	15±8	5±2	11±6	1±1.22	50±29
Denizli	4±4	82±12	1019±5	16±8	7±3	12±7	0.8±0.8	35±27
Erzurum	-1±5	86±12	888±98	9±8	5±2	11±5	0±0.7	44±27
Eskişehir	3±5	90±8	1019±6	13±8	6±2	18±8	0±0.69	48±29
İstanbul	7±4	92±7	1020±7	14±7	8±2	23±12	0±0.66	50±29
İzmir	10±9	90±11	1019±6	18±6	8±3	22±11	0±0.74	37±26
İzmit	8±5	100±2	1020±7	15±7	5±1	10±5	1±0.96	56±31
Kayseri	3±5	89±10	1018±6	13±8	6±2	13±5	1±1.29	40±28
Konya	2±5	81±13	1018±5	14±8	8±3	19±10	0±1.21	35±24
Kütahya	3±5	90±8	1019±6	13±8	6±2	18±11	0±0.67	47±28
Samsun	8±4	93±4	1021±6	15±6	6±2	15±8	1±1.00	58±30
Sivas	1±5	91±10	1019±5	8±8	8±3	14±7	0±0.86	44±27
Trabzon	8±4	89±9	1021±6	13±5	6±2	15±7	1±1.08	59±29

may be related to the decreases in PM<sub>2.5</sub> and CO concentrations. In Erzurum, since the only air quality parameter showing an increase between February and April is O<sub>3</sub>, the increase in the number of cases in this period can be based on its concentration. It can be said that the decrease in cases in May has significantly resulted from the decrease of 52% in SO<sub>2</sub> concentration. In Eskişehir, considerable variation in the number of confirmed cases observed between February and April cannot be directly associated with O<sub>3</sub> that became the only parameter showing the increase in concentration even if it is on a small scale (3%). In May, the reduction in the confirmed cases is likely due to the 52% reduction in SO<sub>2</sub> concentration. In İstanbul, increases in NO<sub>2</sub>, SO<sub>2</sub> and CO concentrations between February and April may have caused

an increase in the number of cases in this period, while the low decreases in O<sub>3</sub>, NO<sub>2</sub>, SO<sub>2</sub> and CO concentrations in May may have reduced the number of cases.

In İzmir, it can be easily expressed that the increase in SO<sub>2</sub> concentration severely impacts the increase of confirmed cases between February and April. In May, the decrease in PM<sub>10</sub>, PM<sub>2.5</sub> and SO<sub>2</sub> concentrations can become the reason for the decrease of the cases. In İzmit, the increase in concentrations of SO<sub>2</sub> and CO (11% and 9%) can significantly contribute to the acceleration of confirmed cases from February to April. Moreover, the decreases in PM<sub>10</sub>, PM<sub>2.5</sub> and CO concentrations between April and May can reduce the cases. In Kayseri, the increase in the concentration of O<sub>3</sub> should be associated with the increase in the

**Table 4** Average values of air quality parameters in provinces over the period from November 25, 2020, to January 3, 2021

Provinces	November 25, 2020–January 3, 2021					
	CO $\mu\text{g}/\text{m}^3$	NO <sub>2</sub> $\mu\text{g}/\text{m}^3$	O <sub>3</sub> $\mu\text{g}/\text{m}^3$	PM <sub>10</sub> $\mu\text{g}/\text{m}^3$	PM <sub>2.5</sub> $\mu\text{g}/\text{m}^3$	SO <sub>2</sub> $\mu\text{g}/\text{m}^3$
Adana	20.3±8.5	80±29	22±5	64±12	91±12	28±16
Ankara	38.9±16	62±18	21±7	142±74	226±137	24±17
Bursa	35.5±6.5	49±18	21±9	63±19	134±33	30±12
Erzurum	27.2±15	62±23	33±4	71±29	154±44	35±25
Eskişehir	26.6±84	37±11	57±5	55±24	94±48	13±8
İstanbul	69.2±2.9	85±22	83±23	134±176	91±24	47±4
İzmir	5.2±1.9	7.4±0.5	-	100±109	118±40	18±9
İzmit	31.1±11	47±16	18±6	67±18	102±30	19±11
Kayseri	24.6±8.7	52±16	22±4	104±41	176±45	37±14
Konya	38.9±20	42±12	11±3	158±204	239±241	25±11
Samsun	30.9±5.7	85±24	4±2	75±22	103±35	42±23
Sivas	27.2±6.8	46±8	-	66±15	122±29	16±7
Trabzon	20.2±7.3	64±22	22±6	78±22	111±24	41±85
Provinces	February 8, 2021–May 8, 2021					
	CO $\mu\text{g}/\text{m}^3$	NO <sub>2</sub> $\mu\text{g}/\text{m}^3$	O <sub>3</sub> $\mu\text{g}/\text{m}^3$	PM <sub>10</sub> $\mu\text{g}/\text{m}^3$	PM <sub>2.5</sub> $\mu\text{g}/\text{m}^3$	SO <sub>2</sub> $\mu\text{g}/\text{m}^3$
Adana	11±9	51±26	35±13	56±45	73±18	34±25
Ankara	25±12	48±22	33±8	114±145	151±127	19±20
Bursa	37±6	57±18	46±9	57±17	115±39	33±13
Erzurum	11±6	43±16	45±5	53±18	90±31	14±12
Eskişehir	11±57	32±11	66±12	44±18	64±30	10±7.9
İstanbul	74±7	102±16	49±15	66±23	92±29	46±5
İzmir	4.11±1.03	7.80±1.83	-	64±44	76±30	20±17
İzmit	36±11	51±20	33±7	56±20	89±32	28±18
Kayseri	12±5	42±12	26±8	57±18	109±35	11±11
Konya	29±62	35±9	12±5	85±90	111±33	19±14
Samsun	14±13	62±29	17±11	63±19	96±64	50±42
Sivas	11±6	56±25	-	56±16	81±25	16±7
Trabzon	11±4	47±18	31±7	61±16	89±25	17±13

Data belonging to Denizli and Kütahya provinces are not available. Moreover, data showing ozone concentration in İzmir and Sivas provinces are unavailable.

number of cases between February and April. The decrease in the cases observed in May can stem from reducing the concentration of air quality parameters, including SO<sub>2</sub>, NO<sub>2</sub>, PM<sub>10</sub> and PM<sub>2.5</sub>.

In Konya, the severe increase in the PM<sub>10</sub> concentration between February and April can be considered an indicator for evaluating the parameters increasing confirmed cases. It can be thought that the reductions in CO, O<sub>3</sub>, NO<sub>2</sub> concentrations by 51, 45 and 39 percent caused a decrease in cases in May. In Kütahya, while a remarkable increase was observed in the number of cases between February and April, a general decrease was observed in the concentrations of air quality parameters. In May, it can be said that the 34% and 24% decreases in SO<sub>2</sub> and CO concentrations may be related to the decreases in the number of cases. In Samsun, a significant decrease observed in the confirmed cases between February and April can be associated with reducing the concentrations of PM<sub>2.5</sub> and CO by 39 and 36%,

respectively. A decreasing trend in the cases observed in May can be owing to the reduction of concentrations of NO<sub>2</sub> and CO by 41 and 39%. In Sivas, a severe increase in the confirmed cases mainly observed between March and April can be attributed to the increase in the concentration of SO<sub>2</sub> up to 41%. In May, reductions in the concentrations of the air quality parameters including CO, NO<sub>2</sub>, PM<sub>2.5</sub> and SO<sub>2</sub> could contribute to the decreases in the number of cases. In Trabzon, the decrease in the number of cases in the February–March period and an increase in the March–April period in Trabzon can be attributed to similar changes in the CO concentration in these periods. In May, a 66% decrease was observed in SO<sub>2</sub> concentration compared to the previous month, contributing to the decrease of the cases.

The correlation results between the number of confirmed COVID-19 cases and meteorological parameters including cloud, dew point, gust, humidity, pressure, rainfall, temperature and wind speed based on Spearman's rank correlation



**Table 5** Variations in concentrations of air quality parameters of the provinces from February to May 2021

Provinces	February–April 2021				March–May 2021								
	CO	NO <sub>2</sub>	O <sub>3</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>	CO	NO <sub>2</sub>	O <sub>3</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>	
	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>	Variation µg/m <sup>3</sup>
	Change %	Change %	Change %	Change %	Change %	Change %	Change %	Change %	Change %	Change %	Change %	Change %	Change %
Adana	-3.98	-7.26	6.89	-17.2	-0.90	5.13	-2.05	-15.6	-0.74	1.19	3.29	-3.65	-2.05
Ankara	-8.12	-7.70	-1.32	-93.1	66.6	-19.5	-6.38	-4.30	5.27	-19.2	-84.6	1.82	-6.38
Bursa	-0.10	-2.67	1.39	-10.5	-13.6	-13.2	-3.12	10.02	8.99	-1.12	-13.9	2.30	-3.12
Erzurum	4.03	-8.09	5.22	-8.72	-21.7	-6.96	-3.56	-10.1	-1.51	-4.16	-20.7	-7.87	-3.56
Eskişehir	-1.61	-3.50	2.16	-12.6	-20.5	-6.41	4.08	-4.83	-4.60	6.84	-9.88	-5.06	4.08
İstanbul	1.74	6.22	-8.63	-7.67	-9.42	1.41	-1.56	-2.67	-3.12	1	2.31	-1.34	-1.56
İzmir	-0.50	-0.32	-	5.05	-18.5	6.98	-0.03	1.01	-	-22.8	-21.7	-5.05	-0.03
İzmit	2.91	-6.99	0.63	-6.61	-17.6	2.62	-0.85	6.30	5.91	-3.06	-3.84	9.79	-0.85
Kayseri	-1.30	-9.27	2.87	-13.9	-28.4	-1.75	0.08	-6.96	0.44	-1.92	-14.0	-4.32	0.08
Konya	-53.9	-2.96	1.15	31.5	-32.3	-12	-7.36	-4.33	-6.55	-43	-5.25	0.18	-7.36
Kütahya	-1.55	-2.02	-6.03	-	-35.4	-2.65	-1.51	-2.08	-8	-	-8.14	-8.22	-1.55
Samsun	-7.32	17.8	0.67	2.55	-50.9	14.8	-7.32	-2.08	-39	4.69	5.17	-1.77	-7.32
Sivas	0.91	3.05	-	-8.43	-26.1	5.75	-6.90	-32.0	-41	-17	-6.31	-6.31	-6.90
Trabzon	0.97	-0.73	-3.82	-4.38	-7.71	-6.83	-2.60	-10.8	-21	-5.07	1.09	-13.1	-2.60

**Table 6** Empirical results based on Spearman correlation coefficient for meteorological parameters of selected provinces between February 8, 2021, and May 8, 2021

Cities	Spearman correlation							
	Cloud	Dew point	Gust	Humidity	Pressure	Rainfall	Temperature	Wind speed
Adana	0.29*	0.19	-0.11	0.18	-0.12	-0.10	0.23*	-0.12
Ankara	0.04	0.58*	0.31*	0.04	0.07	0.02	-0.04	0.24*
Bursa	-0.07	0.50*	-0.01	-0.06	-0.15	0.01	0.36*	-0.01
Denizli	-0.21*	0.51*	0.20	-0.06	-0.01	0.76*	0.56*	-0.33
Erzurum	-0.20	0.53*	0.65*	-0.34*	-0.19	0.02	0.72*	0.18
Eskişehir	-0.02	0.43*	0.11	0.15	-0.01	0.01	0.33*	0.21*
İstanbul	-0.05	0.29*	-0.29*	-0.07	-0.12	-0.07	0.32*	-0.11
İzmir	0.67*	0.32*	-0.02	0.13	-0.15	0.24*	0.56*	-0.22*
İzmit	-0.04	0.48*	-0.23*	0.15	-0.17	-0.06	0.15	0.18
Kayseri	0.05	0.53*	0.15	0.12	-0.05	-0.12	-0.15	0.08
Konya	0.07	0.38*	0.11	-0.05	-0.06	0.01	0.28*	0.15
Kütahya	-0.12	0.55	0.08	0.14	-0.15	-0.003	0.45*	0.21*
Samsun	0.33*	0.02	-0.09	0.05	-0.06	0.19	-0.04	0.07
Sivas	-0.07	0.59*	0.36*	-0.06	0.02	-0.08	0.63*	0.17
Trabzon	0.16	0.09	-0.15	0.01	0.01	0.02	0.11	-0.14

\*indicates significance at the 5% level.

tests are presented in Table 6. In Adana, temperature showed a significantly positive correlation with the confirmed cases. According to Spearman's rank correlation, there was a statistically positive significant association between cloud and the number of confirmed cases. Moreover, dew point and humidity showed a positive correlation, while gust, pressure, rainfall and wind speed were negatively correlated with the confirmed cases. In Ankara, dew point ( $r_s=0.58$ ;  $p<0.05$ ), gust ( $r_s=0.31$ ;  $p<0.05$ ) and wind speed ( $r_s=0.24$ ;  $p<0.05$ ) showed statistically significant positive correlations with the confirmed cases. The only parameter showing a negative correlation with the number of cases was temperature. In Bursa, while dew point ( $r_s=0.50$ ;  $p<0.05$ ) and temperature ( $r_s=0.36$ ;  $p<0.05$ ) were positively and significantly correlated with the confirmed cases, the remaining parameters except for rainfall showing a negligibly low correlation were negatively correlated. In Denizli, rainfall ( $r_s=0.76$ ;  $p<0.05$ ), temperature ( $r_s=0.56$ ;  $p<0.05$ ) and dew point ( $r_s=0.51$ ;  $p<0.05$ ) showed statistically significant positive correlations with the number of confirmed cases. Moreover, gust was positively correlated, while cloud, humidity, pressure and wind speed were negatively correlated with the cases. In Erzurum, temperature ( $r_s=0.72$ ;  $p<0.05$ ), gust ( $r_s=0.65$ ;  $p<0.05$ ), dew point ( $r_s=0.53$ ;  $p<0.05$ ) showed statistically significant positive correlations with the number of the confirmed cases, while humidity ( $r_s=-0.34$ ;  $p<0.05$ ) exhibited a statistically significant negative association. Moreover, cloud and pressure were negatively correlated with the cases compared with rainfall and wind speed.

In Eskişehir, gust, humidity, rainfall, dew point, temperature and wind speed were positively correlated with the number of the confirmed cases, but only dew point ( $r_s=0.43$ ;  $p<0.05$ ), temperature ( $r_s=0.33$ ;  $p<0.05$ )

and wind speed ( $r_s=0.21$ ;  $p<0.05$ ) showed statistically significant results. On the other hand, the strength of the relationship between cloud, pressure and rainfall with the number of confirmed cases was very low. The effects of these parameters on the spread of COVID-19 in Eskişehir may not be considered. In İstanbul, while gust ( $r_s=-0.29$ ;  $p<0.05$ ) displayed statistically significant negative correlation, dew point ( $r_s=0.29$ ;  $p<0.05$ ) and temperature ( $r_s=0.32$ ;  $p<0.05$ ) showed statistically significant positive associations with the number of the confirmed cases. Moreover, the remaining parameters showed statistically insignificant and relatively weak associations with the number of cases. In İzmir, most meteorological parameters consisting of cloud ( $r_s=0.67$ ;  $p<0.05$ ), temperature ( $r_s=0.56$ ;  $p<0.05$ ), dew point ( $r_s=0.32$ ;  $p<0.05$ ) and rainfall ( $r_s=0.24$ ;  $p<0.05$ ) revealed a statistically significant positive correlation with the confirmed cases, while the wind speed ( $r_s=-0.22$ ;  $p<0.05$ ) was negatively correlated. In İzmit, dew point ( $r_s=0.48$ ;  $p<0.05$ ) and gust ( $r_s=-0.23$ ;  $p<0.05$ ) showed statistically significant positive and negative correlations, respectively. Besides, temperature and humidity were positively correlated with the confirmed cases, while cloud, pressure and rainfall were negatively correlated. In Kayseri, cloud, dew point, gust, humidity and wind speed are positively correlated with the confirmed cases, while only dew point ( $r_s=0.53$ ;  $p<0.05$ ) displayed a statistically significant correlation. In Konya, dew point ( $r_s=0.38$ ;  $p<0.05$ ) and temperature ( $r_s=0.28$ ;  $p<0.05$ ) showed statistically significant positive correlations. On the other hand, negative correlations of humidity and pressure with the confirmed cases were negligible strength. In Kütahya, temperature ( $r_s=0.45$ ;  $p<0.05$ )

and wind speed ( $r_s = 0.21$ ;  $p < 0.05$ ) exhibited statistically significant positive associations with the number of confirmed cases. Dew point ( $r_s = 0.57$ ;  $p > 0.05$ ) was also positively correlated with the COVID-19 pandemic. In Samsun, the only cloud ( $r_s = 0.33$ ;  $p > 0.05$ ) showed a statistically significant positive association with the COVID-19 pandemic, compared to other parameters, such as gust, pressure and temperature, revealing the negative correlations. In Sivas, temperature ( $r_s = 0.63$ ;  $p > 0.05$ ), dew point ( $r_s = 0.59$ ;  $p > 0.05$ ) and gust ( $r_s = 0.36$ ;  $p > 0.05$ ) revealed statistically significant positive correlations, while cloud, humidity and rainfall displayed negative correlations with the COVID-19 pandemic. In Trabzon, none of the parameters showed statistically significant positive or negative correlations with the cases. The only gust and wind speed were negatively correlated with the confirmed cases.

In the present work, the most significant positive correlation based on the relationship between rainfall and the number of the COVID-19 cases was observed in Denizli ( $r_s = 0.76$ ;  $p < 0.05$ ), while the most significant negative correlation was observed between relative humidity and confirmed cases in Erzurum ( $r_s = -0.34$ ;  $p < 0.05$ ). It is well known that enveloped viruses in droplets and aerosols survive well when the relative humidity levels are below approximately 50% (Cai et al. 2007; Zoran et al. 2020a). Since SARS-CoV is an enveloped virus, it may be more stable in dry air (Cai et al. 2007).

So far, no research has been found on how the gust affects the spread of COVID-19 disease. The most substantial and favorable relationship between gust and disease spread was seen in Erzurum in the current study ( $r_s = 0.65$ ;  $p < 0.05$ ). In this context, the increase in the severity of the gust may increase air pollution, and depending on this situation, the spread of infectious diseases may increase.

The correlation results between the number of confirmed COVID-19 cases and air quality parameters including CO, NO<sub>2</sub>, O<sub>3</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> and SO<sub>2</sub> based on Spearman's rank correlation tests are presented in Table 7.

In Adana, PM<sub>10</sub> ( $r_s = -0.38$ ;  $p < 0.05$ ), CO ( $r_s = -0.31$ ;  $p < 0.05$ ), and NO<sub>2</sub> ( $r_s = -0.28$ ;  $p < 0.05$ ) displayed a statistically significant negative correlation with the confirmed cases, while only O<sub>3</sub> was positively correlated. In Ankara, CO ( $r_s = -0.30$ ;  $p < 0.05$ ), PM<sub>2.5</sub> ( $r_s = -0.33$ ;  $p < 0.05$ ), and SO<sub>2</sub> ( $r_s = -0.43$ ;  $p < 0.05$ ) exhibited statistically significant negative correlations with confirmed cases. On the other hand, the only parameter positively correlated was O<sub>3</sub>. In Bursa, O<sub>3</sub> ( $r_s = 0.42$ ;  $p < 0.05$ ) showed statistically significant positive correlations, and PM<sub>2.5</sub> ( $r_s = -0.21$ ;  $p < 0.05$ ) and SO<sub>2</sub> ( $r_s = -0.22$ ;  $p < 0.05$ ) displayed significant negative correlations. In Erzurum, CO ( $r_s = -0.61$ ;  $p < 0.05$ ), NO<sub>2</sub> ( $r_s = -0.47$ ;  $p < 0.05$ ), PM<sub>10</sub> ( $r_s = -0.51$ ;  $p < 0.05$ ), and SO<sub>2</sub> ( $r_s = -0.54$ ;  $p < 0.05$ ), exhibited statistically significant negative associations with the COVID-19 pandemic, and O<sub>3</sub> ( $r_s = 0.35$ ;  $p < 0.05$ ), showed a significant positive correlation with the confirmed cases. In Eskişehir, CO ( $r_s = -0.29$ ;  $p < 0.05$ ), NO<sub>2</sub> ( $r_s = -0.25$ ;  $p < 0.05$ ), and SO<sub>2</sub> ( $r_s = -0.56$ ;  $p < 0.05$ ) revealed statistically significant negative correlations with the cases of COVID-19 pandemic. In İstanbul, the only parameter showing statistically significant and positively correlation with the number of confirmed cases was CO ( $r_s = 0.25$ ;  $p < 0.05$ ). Furthermore, the remaining parameters showed negative correlations. In İzmir, PM<sub>2.5</sub> ( $r_s = -0.34$ ;  $p < 0.05$ ) and PM<sub>10</sub> ( $r_s = -0.44$ ;  $p < 0.05$ ) displayed statistically significant negative associations with the number of cases, while NO<sub>2</sub> ( $r_s = 0.29$ ;  $p < 0.05$ ) showed a statistically significant positive association. In İzmit, O<sub>3</sub> ( $r_s = 0.30$ ;  $p < 0.05$ ) and

**Table 7** Empirical results based on Spearman correlation coefficient for air quality parameters of selected provinces between February 8, 2021, and May 8, 2021

Cities	Spearman correlation					
	CO	NO <sub>2</sub>	O <sub>3</sub>	PM <sub>10</sub>	PM <sub>2.5</sub>	SO <sub>2</sub>
Adana	-0.31*	-0.28*	0.17	-0.38*	-0.24	-0.09
Ankara	-0.30*	-0.23	0.09	-0.18	-0.33*	-0.43*
Bursa	0.01	0.17	0.42*	-0.12	-0.21*	-0.22*
Erzurum	-0.61*	-0.47*	0.35*	-0.51*	-0.18	-0.54*
Eskişehir	-0.29*	-0.25*	-0.03	-0.17	-0.12	-0.56*
İstanbul	0.25*	-0.14	-0.11	-0.10	-0.11	-0.03
İzmir	-0.19	0.29*	-	-0.44*	-0.34*	-0.19
İzmit	0.18	-0.15	0.30*	-0.16	-0.16	0.24*
Kayseri	-0.19	-0.42*	0.09	-0.38*	-0.32*	-0.29*
Konya	-0.55*	-0.26*	-0.16	-0.39*	-0.18	-0.35*
Kütahya	-0.31*	-0.17	-0.62*	-0.37*	-	-0.27*
Samsun	0.06	0.28*	-0.12	-0.29*	-0.03	-0.07
Sivas	-0.38*	-0.48*	-	-0.62*	-0.19	0.16
Trabzon	0.17	-0.01	0.18	-0.02	-0.06	-0.09

\*indicates significance at the 5% level.

SO<sub>2</sub> ( $r_s = 0.24$ ;  $p < 0.05$ ) showed statistically significant positive correlations with the confirmed cases. Moreover, remaining parameters are negatively correlated with the cases except for CO.

In Kayseri, NO<sub>2</sub> ( $r_s = -0.42$ ;  $p < 0.05$ ), PM<sub>2.5</sub> ( $r_s = -0.32$ ;  $p < 0.05$ ), PM<sub>10</sub> ( $r_s = -0.38$ ;  $p < 0.05$ ) and SO<sub>2</sub> ( $r_s = -0.29$ ;  $p < 0.05$ ) revealed statistically significant negative correlations. In Konya, CO ( $r_s = -0.55$ ;  $p < 0.05$ ), NO<sub>2</sub> ( $r_s = -0.26$ ;  $p < 0.05$ ), PM<sub>10</sub> ( $r_s = -0.39$ ;  $p < 0.05$ ) and SO<sub>2</sub> ( $r_s = -0.35$ ;  $p < 0.05$ ) revealed statistically significant negative correlations. In Kütahya, CO ( $r_s = -0.31$ ;  $p < 0.05$ ), O<sub>3</sub> ( $r_s = -0.62$ ;  $p < 0.05$ ), PM<sub>10</sub> ( $r_s = -0.37$ ;  $p < 0.05$ ) and SO<sub>2</sub> ( $r_s = -0.27$ ;  $p < 0.05$ ) revealed statistically significant negative correlations. In Samsun, NO<sub>2</sub> ( $r_s = 0.28$ ;  $p < 0.05$ ) showed statistically significant positive correlations. However, PM<sub>10</sub> ( $r_s = -0.29$ ;  $p < 0.05$ ) displayed a statistically significant negative correlation. In Sivas, CO ( $r_s = -0.38$ ;  $p < 0.05$ ), NO<sub>2</sub> ( $r_s = -0.48$ ;  $p < 0.05$ ) and PM<sub>10</sub> ( $r_s = -0.62$ ;  $p < 0.05$ ) revealed statistically significant negative correlations with the number of cases considering. In Trabzon, air quality parameters did not demonstrate statistically significant associations. In a study investigating the associations between air pollutants and meteorological parameters during the lockdown period in Turkey performed by Ghasempour et al. (2021), it was found that ambient temperature and atmospheric pressure were highly correlated with air pollutants, including NO<sub>2</sub>, SO<sub>2</sub>, unlike precipitation and wind speed (Ghasempour et al. 2021).

Data of O<sub>3</sub> concentrations in İzmir and Sivas provinces and PM<sub>10</sub> concentrations in Kütahya are unavailable.

The results of correlation analysis in the present work indicated that meteorological and air quality parameters are closely related to the transmission of the COVID-19 outbreak. In this regard, the strongest and statistically the most significant correlation between cloud and COVID-19 incidence was observed in İzmir ( $r_s = 0.67$ ,  $p < 0.05$ ). Similarly, Adhikari and Yin (2020) found a significantly positive association between the transmission of the COVID-19 and cloud percentages. Reduction in the sunshine duration based on increasing cloud percentage triggers the COVID-19 transmission. Solar radiation is the most critical factor, showing a significantly strong correlation with the confirmed cases threats survival of virus, areas with lower solar radiation and higher cloud content, and a high exposure rate to COVID-19 incidence (Rosario et al. 2020; Srivastava 2021). Hence, an increase in the cloud percentage can increase the severity of the spread of COVID-19 morbidity. Few studies investigating the associations between dew point and the diffusion of infectious diseases have been implemented. Şahin (2020) and Tanis and Karakaya (2020) indicated that the dew point was negatively correlated with the COVID-19 incidence.

Relative humidity investigations based on virologic and epidemiologic studies indicated that relative humidity is a climatological variable having a crucial significance on viral

infectivity and transmission (Zoran et al. 2020a). Previous studies (Bashir et al. 2020a; Bolano-Ortiz et al. 2020; Şahin 2020; Zoran et al. 2020a) have indicated a negative effect of humidity on the transmission of COVID-19 incidence. These results are consistent with the findings in the present work. The most significant negative association between relative humidity and COVID-19 morbidity was observed in Erzurum province ( $r_s = -0.34$ ;  $p < 0.05$ ). Correspondingly, dry weather conditions triggering susceptibility to respiratory virus infection will lead to the diffusion of the SARS-CoV-2 virus (Zoran et al. 2020b). Decreased relative humidity levels are associated with decreased severity of pulmonary diseases, while increased levels are associated with higher severity aspects of the respiratory tract (Zoran et al. 2020a).

As with relative humidity, the increase in the air pressure negatively affects the transmission of COVID-19 morbidity. This situation can be attributed to the short suspending time of the SARS-CoV-2 virus in the air owing to high air pressure (Cai et al. 2007). Tanis and Karakaya (2020) indicated that air pressure has an inverse effect on the number of discharges from the hospital due to SARS-CoV-2 ( $r = -0.386$ ). In the present study, findings depicting the maximum impact ( $r = -0.19$  in Erzurum) agree with previous results that air pressure is negatively associated with COVID-19 incidence.

An increase in cloud percentages and precipitations is associated with decreased sunshine duration. Sunlight levels are inversely correlated with influenza transmission (Adhikari and Yin 2020). Bashir et al. (2020a) found a negative correlation between the intensity of the rainfall ( $r = -0.196$ ). On the other hand, Tosepu et al. (2020) indicated that rainfall was not significantly but positively correlated with COVID-19 ( $r_s = 0.139$ ). In the current study, the increase in the level of rainfall increases the number of COVID-19 cases. The strongest positive correlation between rainfall and the transmission of COVID-19 was observed in Denizli province ( $r_s = 0.76$ ;  $p < 0.05$ ). Considering the increase in rainfall intensity, the decrease in the sunlight can be associated with transmitting viral infectious diseases.

In the current study, the average daily temperature was positively associated with COVID-19 incidence. This result is consistent with the findings obtained from previous studies (Adhikari and Yin 2020; Bashir et al. 2020a; Tosepu et al. 2020a; Zoran et al. 2020a; Zoran et al. 2020b). The maximum correlation level was reached in Erzurum province as  $r_s = 0.72$  under significance at the 5% level. These correlation coefficient values are higher than those obtained from other studies conducted by Zoran et al. (2020a), in which the coefficient value is 0.67, and by Tosepu et al. (2020) and Bashir et al. (2020a), where the  $r$  values are equal to 0.392 and 0.379, respectively. Xie and Zhu (2020) aimed to determine whether the temperature significantly impacts the transmission of a novel coronavirus, examining daily confirmed cases and meteorological parameters in 112 cities of

China. They found that COVID-19 may not perish of itself without any public health interventions when the weather becomes warmer. Haque and Rahman (2020) conducted a study aiming to determine the association between average temperature and humidity with the COVID-19 pandemic in Bangladesh. They found a negative correlation between them. They suggested that a reduction in COVID-19 cases can be expected in Bangladesh during the summer and rainy days.

As with previous studies presented by Şahin (2020) and Tanis and Karakaya (2020), the present work showed that wind speed was positively correlated with the number of COVID-19 cases in Ankara and Eskişehir provinces having terrestrial climate, while in the city of Izmir, where the Mediterranean climate is dominant, it was observed an inverse relationship between wind speed and the spread of COVID cases. The strongest positive and negative correlations were observed in Ankara ( $r_s = 0.24$ ;  $p < 0.05$ ) and in Izmir ( $r_s = -0.22$ ;  $p < 0.05$ ), respectively. Coccia (2021c) and Coccia (2020b) suggested that wind speed removes air pollutants contributing to the transmission of viral infectious morbidities (Coccia 2020b; Coccia 2021c; Bolano-Ortiz et al. 2020). As the wind speed increases, air pollution decreases, and thus, the spread of pollution-based viral infectious diseases declines. The current study presented a negative correlation between wind speed and the number of COVID-19 cases ( $r_s = -0.22$ ;  $p < 0.05$ ). If the weather is windy, controlling the virus transmission may be difficult. The transmission of the COVID-19 virus depends not only on the wind's strength and the flow's direction but also on population density, which is the major factor determining the transmission of infectious diseases (Çoşkun et al. 2021; Coccia 2020a). The spread of the virus is expected to be high in areas with dense populations and high wind speeds (Çoşkun et al. 2021). Following the results of this study, considering the correlations between wind speed and the number of cases in Ankara and İzmir provinces, although İzmir has both higher population density and stronger wind speed, the spread of cases is lower than Ankara. This outcome can be explained by the higher air pollution and lower wind speed values observed in Ankara. Coccia (2021a) investigated how geo-environmental factors affect the rate of virus spread. It was suggested that cities with atmospheric stability based on little wind and frequently high levels of air pollution showed much more COVID-19 morbidity and mortality rates (Coccia 2021a, 2020c). It can be attributed to the fact that the novel coronavirus SARS-CoV-2 can remain stagnant and viable in aerosol for hours under atmospheric stability due to low wind speed and high levels of air pollution. To prevent the acceleration of virus transmission, in cities with air pollution, especially in Mediterranean countries such as Turkey, Italy and Spain, if low wind speeds prevail, the virus spread based on geo-environmental factors can be prevented

by paying attention not to exceed the threshold values determined for ozone and particulate matters (Coccia 2021d). Another important point to be emphasized here is that air pollution is closely related to meteorological parameters. In the study carried out by Shen et al. (2021), it was stated that the abnormal changes in the meteorology of the Asian monsoon regions make it difficult to reduce air pollution there.

Çapraz et al. (2016) investigated the associations between the daily variations of air pollutants and mortality in the population of Istanbul, Turkey. In Istanbul, they found significant associations between air pollution and daily mortality from cardiovascular disease, respiratory diseases, and total non-accidental causes. The current work has investigated the correlations between air pollutants and confirmed cases for fifteen provinces of Turkey. In the present study, CO considerably negatively impacted the number of daily cases. Erzurum ( $r_s = -0.61$ ;  $p < 0.05$ ) observed the most significant negative correlation. These results are consistent with those of previous studies implemented by Bashir et al. 2020a; Zhu et al. 2020; Li et al. 2020.

The current study has shown the highest negative correlation between NO<sub>2</sub> and COVID-19 cases in Sivas ( $r_s = -0.48$ ;  $p < 0.05$ ). Decreased concentrations of NO<sub>2</sub> are associated with a higher possibility of transmission of COVID-19 incidence. Several studies also confirmed a negative correlation between the average ground levels of NO<sub>2</sub> and COVID-19 cases (Bashir et al. 2020b; Zoran et al. 2020b). In İzmir and Samsun, NO<sub>2</sub> was positively associated with the number of COVID-19 cases. Some previous studies showed a positive correlation between NO<sub>2</sub> and COVID-19 morbidity (Zhu et al. 2020; Jiang et al. 2020). Many studies have demonstrated that exposure to long-term air pollution based on increasing NO<sub>2</sub> concentration stemming from anthropogenic activities, such as the combustion of fossil fuels to produce electricity, leads to respiratory diseases, including chronic obstructive pulmonary disease (Li et al. 2020; Ogen 2020).

Moreover, O<sub>3</sub> was negatively associated with the number of the COVID-19 cases, and the strongest correlation was observed in Kütahya ( $r_p = -0.62$ ;  $p < 0.05$ ). In Bursa, Erzurum and İzmit, the results are consistent with previous studies presenting a positive correlation between O<sub>3</sub> and COVID-19 incidence (Zoran et al. 2020b; Zhu et al. 2020). The maximum positive effect of O<sub>3</sub> on the transmission of COVID-19 morbidity was observed in Bursa province ( $r_s = 0.42$ ;  $p < 0.05$ ). Moreover, a reduction in the NO<sub>2</sub> concentration increases O<sub>3</sub> concentration at the ground level, in which secondary aerosols adversely impacting human respiratory health are generated (Zoran et al. 2020b). In other words, a lower concentration of NO<sub>2</sub> results in constraints on the NO + O<sub>3</sub> reaction, and the O<sub>3</sub> cannot be effectively further depleted (Xu et al. 2020). In the light of this information, it can be determined that Erzurum province depicted such a type of variation between air quality variables,

including NO<sub>2</sub> and O<sub>3</sub>, from February to April when Table 5 and Table 7 are evaluated together.

The previous studies (Travaglio et al., 2021; Wu et al. 2020; Jiang et al. 2020; Zhu et al. 2020; Yao et al. 2020; Li et al. 2020) suggested a positive association between COVID-19 cases and fine particulate matters (PM<sub>2.5</sub>) that can be inhaled and result in serious respiratory diseases, such as tuberculosis and influenza (Wu et al. 2020; Zhang et al. 2021). Travaglio et al. (2021) investigated the effect of PM<sub>2.5</sub> on the transmission of COVID-19 cases in England and suggested that an increase of 1 m<sup>3</sup> in the long-term average of PM<sub>2.5</sub> was associated with a 12% increase in COVID-19 cases. Wu et al. (2020) analyzed the association of long-term average exposure to PM<sub>2.5</sub> with the COVID-19 death rate in the USA and suggested that an increase of only 1 µg/m<sup>3</sup> in PM<sub>2.5</sub> was associated with an increase 8% increase in the COVID-19 death rate. On the other hand, there was an inverse relationship between PM<sub>2.5</sub> concentration and the confirmed cases in the present study. The strongest correlations between PM<sub>2.5</sub> and COVID-19 incidence were observed in İzmir province ( $r_s = -0.34$ ;  $p < 0.05$ ). As for coarse particulate matters (PM<sub>10</sub>), the previous studies showed that they positively impacted the diffusion of the COVID-19 cases (Zhang et al. 2021; Zhu et al. 2020; Li et al. 2020). Since small airborne pollutants are more likely to permeate the alveolar region, PM<sub>2.5</sub> is expected to demonstrate a robust correlation (Jiang et al. 2020). In the current work, PM<sub>10</sub> that negatively correlated with confirmed cases has shown the strongest correlation ( $r_s = -0.62$ ;  $p < 0.05$ ) in the Sivas district.

The current study has demonstrated significant negative associations between SO<sub>2</sub> and the number of COVID-19 cases. Previous studies also showed a similar effect in the transmission of COVID morbidity based on SO<sub>2</sub> concentration (Bashir et al. 2020b; Zhu et al. 2020). The highest negative effect was observed in Erzurum ( $r_s = -0.54$ ;  $p < 0.05$ ). During the pandemic period, SO<sub>2</sub> concentrations have increased because people prefer to use their own private vehicles instead of public transportation and because the majority of these vehicles are diesel-fueled (Orak and Ozdemir 2021 and Rahimi et al. 2021).

The current study showed the most significant positive associations of cloud, dew point, gust, rainfall, temperature and wind speed, while humidity and pressure were negatively associated with the number of daily confirmed cases. Contrary to the studies in the literature, the positive relationship between temperature and the number of COVID-19 cases can be attributed to the limited period of the study covering the months of February–May. Further studies are needed to explain how temperature affects the spread of COVID-19 definitively. As for air quality parameters, while some of the cities showed a positive relationship between the spread of COVID-19 and air pollutants, some showed reverse correlations. Aral and Bakır (2022) conducted a study in which they proved that the distribution of

COVID-19 cases in Turkey is based on spatial changes and spatiotemporal aggregation; that is, they suggested that the spread of COVID-19 cases is heterogeneous among Turkish cities. The unsteady distribution can be attributed to the socioeconomic and sociocultural status of the people living in these cities. The demographic and geographical differences of the cities can be considered as factors that can be effective in this heterogeneity (Aral and Bakır 2022). Another study performed by Islam et al. (2021), who investigated the relationship between meteorological parameters and COVID-19-confirmed cases from 206 countries/regions, suggested that there was no association between cases and parameters including 7-day lagged temperature, relative humidity, UV index, but there were observed a positive association with 14-day-lagged temperature and a negative association with 14-day-lagged wind speed. Following the result of this study, in determining the factors that accelerate the spread of COVID-19, factors such as public health interventions, socioeconomic implications, ethical ramifications, environmental insights should be evaluated, including not only climate-related parameters (Islam et al. 2021).

When air pollution is accompanied by low wind speeds, which indicates the atmosphere's stability, which is one of the geo-environmental factors, it is expected that the distribution of COVID-19 cases will accelerate in an area with these characteristics. It is a well-known fact that the rate of fatality will be observed lower in the cities with lower air pollution. In this regard, the transmission of COVID-19 based on air pollution in this region can be prevented by various measures that will reduce air pollution, such as encouraging renewable energy sources, especially in electrical energy production, the implementation of incentives such as the necessary tax reduction for the use of vehicles with hybrid technology instead of the use of diesel-fueled vehicles, and tightening of inspections (Caliskan et al., 2020; Coccia 2021e).

Coccia (2022) developed two basic indexes (Index r and Index p) to prevent pandemic threats faced by countries that may cause negative effects on human health and economic systems and cope with such negative effects. In particular, the Index r (as resilience) detects the countries having the best performance in the reduction of the negative impact of mortality related to the COVID-19 pandemic and the Index p (as preparedness and prevention) assesses best-performer countries to support COVID-19 vaccinations to constrain future pandemic threats and support the recovery of socioeconomic systems. Through the indexes presented in this study, it is thought that designing short- and long-term strategies will shed light on countries' preparations for crisis management to prevent future infectious epidemics and will guide policymakers and decision-makers about the measures to be taken (Coccia 2022).

To cope with the global pandemic caused by human-to-human transmission, droplet transmission and airborne

transmission, manifold precautions including the practice of social distancing, staying home, avoiding handshake, using the face mask, handwashing with soap and running water and applying 70% alcohol-based sanitizer should be applied among the people (Sarkodie and Owusu 2020). In this regard, the impact of duration of full lockdown on COVID-19-infected people, mortality rate and economic growth of six European countries was investigated by Coccia (2021f). The study suggested that if the quarantine period is shortened to about 15 days, it has been observed that the number of people caught in COVID-19 and the death rates decreases compared to those who were exposed to longer lockdown applications. It has been determined that longer quarantine periods negatively affect the national economies due to a slowdown in production.

## Conclusion

This study investigates the effects of meteorological parameters (cloud, dew point, gust, humidity, pressure, rainfall, temperature and wind speed) and air quality variables (CO, NO<sub>2</sub>, O<sub>3</sub>, PM<sub>2.5</sub>, PM<sub>10</sub> and SO<sub>2</sub>) on the diffusion of COVID-19 in fifteen cities of Turkey between the period from February to May 2021 showing a peak in the cases and having some quarantine limitations. This paper analyzes the possible associations among air pollution, weather conditions and the viral transmission of COVID-19 morbidity using Spearman's rank correlation test. Results based on climatological variables suggest that an increase in the severity of these parameters, including cloud, dew point, gust, rainfall, temperature and wind speed, may promote the diffusivity of the SARS-CoV-2 virus contrary to humidity and pressure. Since this study, for the first time, analyzes the effect of the gust on the spread of COVID-19 cases, it may serve as a reference to explain the links between meteorological factors and the COVID-19 transmission routes comprehensively. The present study demonstrates the strong impacts of air pollutants and weather conditions on the transmission of COVID-19 morbidity. Moreover, it can be thought that the parameters do not play a role in the spread of COVID-19 alone; the population density and the climate zone of the cities are also important together with the effects of the parameters. The results of the study are consistent with those of other investigations implemented for other countries in which meteorological and air quality parameters exhibited a statistically significant association with the transmission of COVID-19 incidence.

Countries need to develop national planning strategies and implement crisis management promptly and take some critical decisions to eliminate or minimize the effects of the COVID-19 pandemic on health and the economy

(Coccia 2021g-h). At this point, the implementation of certain restrictions for regions where the risk of spreading the COVID-19 epidemic is high since air pollution is high and the atmosphere is stable owing to low wind speeds can be considered among the strategies to be implemented by governments to reduce the effects of the COVID-19 epidemic. In addition to the fact that changes in meteorological parameters accompanying air pollution trigger the spread of COVID-19, future studies should focus on social and behavioral contexts, including age, gender, poverty, education, access to care and community health infrastructure and preexisting health conditions to understand the drivers of the pandemic. The inaccessibility of data related to sociodemographic factors, such as gender and age, which are effective on the acute health effects of gaseous pollutants, constitutes the limitations of the study.

The global pandemic will affect all populations, but some are more vulnerable than others. Children living in developing countries are most vulnerable to the resulting health risks. The health effects are also expected to be more severe for older people and people with infirmities or preexisting medical conditions. People living in areas with weak health infrastructure, mostly in developing countries, are more susceptible to the outcomes of this novel coronavirus. Finally, people living in areas with air pollution are more prone to contracting the COVID-19 disease. In light of this information, manifold administrative or legislative strategies including preventive policies, such as improvement of medical conditions, usage of personal protective equipment like face masks and reduction in air pollution in cities with promoting renewable energy systems and preference of electrical vehicles instead of diesel-fueled vehicles, should be entered into force by policymakers and decision-makers to prevent adverse impacts of the future pandemic crisis on public health and countries' economies and also to cope with new pandemic threats.

**Supplementary Information** The online version contains supplementary material available at <https://doi.org/10.1007/s11356-021-18403-4>.

**Author's contributions** APA performed statistical analyses and interpreted the statistical results and was the sole contributor to writing the manuscript.

**Funding** This study has no specific grant from any funding agency in the official or commercial.

**Availability of data and materials** The datasets used and analyzed during the current study are available from the corresponding author on reasonable request.

## Declarations

**Ethics approval and consent to participate** Not applicable.

**Consent for publication** Not applicable.

**Competing interests** The author has declared no competing interests.

## References

- Adhikari A, Yin J (2020) Short-term effects of ambient ozone, PM<sub>2.5</sub> and meteorological factors on COVID-19 confirmed cases and deaths in Queens New York. *Int. J Environ. Res. Public Health* 17:4047. <https://doi.org/10.3390/ijerph17114047>
- AQOD (2021) Air Quality Open Data. <https://aqicn.org/data-platform/covid19/>. Accessed March 2021
- Ali H, Yilmaz G, Fareed Z, Shahzad F, Ahmad M (2021) Impact of novel coronavirus (COVID-19) on daily routines and air environment: evidence from Turkey. *Air Qual Atmos Health* 14:381–387. <https://doi.org/10.1007/s11869-020-00943-2>
- Aral N, Bakır H (2022) Spatiotemporal Analysis of Covid-19 in Turkey. *Sustain Cities Soc* 76:103421. <https://doi.org/10.1016/j.scs.2021.103421>
- Asl FB, Leili M, Vaziri Y, Arian SS, Cristaldi A, Conti GO, Ferrante M (2018) Health impacts quantification of ambient air pollutants using AirQ model approach in Hamadan. *Iran Environ Res* 161:114–121. <https://doi.org/10.1016/j.envres.2017.10.050>
- Aykaç N, Etiler N (2021) COVID-19 mortality in Istanbul in association with air pollution and socioeconomic status: an ecological study. *Environ Sci Pollut Res.* <https://doi.org/10.1007/s11356-021-16624-1>
- Bashir MF, Ma B, Bilal Komal B, Bashir MA, Tan D, Bashir M (2020) Correlation between climate indicators and COVID-19 pandemic in New York, USA. *Sci Total Environ* 728:138835. <https://doi.org/10.1016/j.scitotenv.2020.138835>
- Bashir MF, Bilal MABJ, Komal B, Bashir MA, Farooq TH, Iqbal N, Bashir M (2020) Correlation between environmental pollution indicators and COVID-19 pandemic: A brief study in California context. *Environ Res* 187:109652. <https://doi.org/10.1016/j.envres.2020.109652>
- Becker S, Soukup JM (1999) Exposure to urban air particulates alters the macrophage-mediated inflammatory response to respiratory viral infection. *J Toxicol Environ Health Part A* 57:445–457. <https://doi.org/10.1080/009841099157539>
- Beelen R, Raaschou-Nielsen O, Stafoggia M, Andersen ZJ, Weinmayr G, Hoffmann B, Wolf K, Samoli E, Fischer P, Nieuwenhuijsen M, Vineis P, Xun WW, Katsouyanni K, Dimakopoulou K, Oudin A, Forsberg B, Modig L, Havulinna AS, Lanki T, Turunen A, Oftedal B, Nystad W, Nafstad P, De Faire U, Pedersen NL, Östenson CG, Fratiglioni L, Penell J, Korek M, Pershagen G, Eriksen KT, Overvad K, Ellermann T, Eeftens M, Peeters PH, Meliefste K, Wang M, Bueno-De-Mesquita B, Sugiri D, Krämer U, Heinrich J, De Hoogh K, Key T, Peters A, Hampel R, Concin H, Nagel G, Ineichen A, Schaffner E, Probst-Hensch N, Künzli N, Schindler C, Schikowski T, Adam M, Phuleria H, Vilier A, Clavel-Chapelon F, Declercq C, Griponi S, Krogh V, Tsai MY, Ricceri F, Sacerdote C, Galassi C, Migliore E, Ranzi A, Cesaroni G, Badaloni C, Forastiere F, Tamayo I, Amiano P, Dorronsoro M, Katsoulis M, Trichopoulos A, Brunekreef B, Hoek G (2014) Effects of long-term exposure to air pollution on natural-cause mortality: an analysis of 22 European cohorts within the multicentre ESCAPE project. *Lancet* 383:785–795. [https://doi.org/10.1016/S0140-6736\(13\)20200-0](https://doi.org/10.1016/S0140-6736(13)20200-0)
- Bolaño-Ortiz TR, Camargo-Cacedo Y, Puliafito SE, Ruggeri MF, Bolaño-Díaz S, Pascual-Flores R, Saturno J, Ibarra-Espinosa S, Mayol-Bracero OL, Torres-Delgado E, Cereceda-Balic F (2020) Spread of SARS-CoV-2 through Latin America and the Caribbean region: A look from its economic conditions, climate and the air pollution indicators. *Environ Res* 191:109938. <https://doi.org/10.1016/j.envres.2020.109938>
- Bontempi E (2020) First data analysis about possible COVID-19 virus airborne diffusion due to air particulate matter (PM): The case of Lombardy (Italy). *Environ Res* 186:109639. <https://doi.org/10.1016/j.envres.2020.109639>
- Bremner SA, Anderson HR, Atkinson RW, McMichael AJ, Strachan DP, Bland JM, Bower JS (1999) Short term associations between outdoor air pollution and mortality in London 1992–4. *Occup Environ Med* 56:237–244. <https://doi.org/10.1136/oem.56.4.237>
- Cai QC, Lu J, Xu QF, Guo Q, Xu DZ, Sun QW, Yang H, Zhao GM, Jiang QW (2007) Influence of meteorological factors and air pollution on the outbreak of severe acute respiratory syndrome. *Public Health* 121:258–265. <https://doi.org/10.1016/j.puhe.2006.09.023>
- Caliskan B, Özengin N, Cindoruk SS (2020) Air quality level, emission sources and control strategies in Bursa/Turkey. *Atmos Pollut Res* 11:2182–2189. <https://doi.org/10.1016/j.apr.2020.05.016>
- Çapraz Ö, Efe B, Deniz A (2016) Study on the association between air pollution and mortality in Istanbul, 2007–2012. *Atmos Pollut Res* 7:147–154. <https://doi.org/10.1016/j.apr.2015.08.006>
- Carugno M, Dentali F, Mathieu G, Fontanella A, Mariani J, Bordini L, Milani GP, Consonni D, Bonzini M, Bollati V, Pesatori AC (2018) PM10 exposure is associated with increased hospitalizations for respiratory syncytial virus bronchiolitis among infants in Lombardy. *Italy Environ Res* 166:452–457. <https://doi.org/10.1016/j.envres.2018.06.016>
- Chen J, Zheng J, Shi C, Liu R, Lu R, Mao S, Zhang L (2019) Associations between short-term exposure to gaseous pollutants and pulmonary heart disease-related mortality among elderly people in Chengdu. *China Environ Health* 18(64):1–10. <https://doi.org/10.1186/s12940-019-0500-8>
- Coccia M (2020a) An index to quantify environmental risk of exposure to future epidemics of the COVID-19 and similar viral agents: Theory and practice. *Environ Res* 191:110155. <https://doi.org/10.1016/j.envres.2020.110155>
- Coccia M (2020b) Factors determining the diffusion of COVID-19 and suggested strategy to prevent future accelerated viral infectivity similar to COVID. *Sci Total Environ* 729:138474. <https://doi.org/10.1016/j.scitotenv.2020.138474>
- Coccia M (2020c) How (Un)sustainable Environments Are Related to the Diffusion of COVID-19: The Relation between Coronavirus Disease 2019, Air Pollution, Wind Resource and Energy Sustainability 12:9709. <https://doi.org/10.3390/su12229709>
- Coccia M (2021a) The effects of atmospheric stability with low wind speed and of air pollution on the accelerated transmission dynamics of COVID-19. *Int J Environ Sci* 78(1):1–27. <https://doi.org/10.1080/00207233.2020.1802937>
- Coccia M (2021b) High health expenditures and low exposure of population to air pollution as critical factors that can reduce fatality rate in covid-19 pandemic crisis. *Environ Res* 199:111339. <https://doi.org/10.1016/j.envres.2021.111339>
- Coccia M (2021c) How do low wind speeds and high levels of air pollution support the spread of COVID-19? *Atmos Pollut Res* 12:437–445. <https://doi.org/10.1016/j.apr.2020.10.002>
- Coccia M (2021d) Effects of the spread of COVID-19 on public health of polluted cities: results of the first wave for explaining the déjà vu in the second wave of COVID-19 pandemic and epidemics of future vital agents. *Environ Sci Pollut Res* 28:19147–19154. <https://doi.org/10.1007/s11356-020-11662-7>
- Coccia M (2021e) Pandemic Prevention: Lessons from COVID-19. *Encyclopedia* 1:433–444. <https://doi.org/10.3390/encyclopedia1020036>



- Coccia M (2021f) The relation between length of lockdown, numbers of infected people and deaths of Covid-19, and economic growth of countries: Lessons learned to cope with future pandemics similar to Covid-19 and to constrain the deterioration of economic system. *Sci Total Environ* 775:145801. <https://doi.org/10.1016/j.scitotenv.2021.145801>
- Coccia M (2021g) The impact of first and second wave of the COVID-19 pandemic in society: comparative analysis to support control measures to cope with negative effects of future infectious diseases. *Environ Res* 197:111099. <https://doi.org/10.1016/j.envres.2021.111099>
- Coccia M (2021h) Comparative Critical Decisions in Management. In: Farazmand A. (eds), *Global Encyclopedia of Public Administration, Public Policy, and Governance*. Springer Nature, Cham. [https://doi.org/10.1007/978-3-319-31816-5\\_3969-1](https://doi.org/10.1007/978-3-319-31816-5_3969-1)
- Coccia M (2022) Preparedness of countries to face COVID-19 pandemic crisis: Strategic positioning and factors supporting effective strategies of prevention of pandemic threats. *Environ Res* 203:111678. <https://doi.org/10.1016/j.envres.2021.111678>
- Çoşkun H, Yıldırım N, Gündüz S (2021) The spread of COVID-19 virus through population density and wind in Turkey cities. *Sci Total Environ* 751:141663. <https://doi.org/10.1016/j.scitotenv.2020.141663>
- COVID-19 (2021) Information about COVID-19 cases from the Republic of Turkey Ministry of Health. [https://covid19.saglik.gov.tr/?\\_Dil=2\\_](https://covid19.saglik.gov.tr/?_Dil=2_) Accessed March 2021
- Diao Y, Kodera S, Anzai D, Gomez-Tames J, Rashed EA, Hirata A (2021) Influence of population density, temperature, and absolute humidity on spread and decay durations of COVID-19: A comparative study of scenarios in China, England, Germany, and Japan. *One Health* 12:100203. <https://doi.org/10.1016/j.onehlt.2020.100203>
- Dehghani M, Keshtgar L, Javaheri MR, Derakhshan Z, Conti GO, Zuccarello P, Ferrante M (2017) The effects of air pollutants on the mortality rate of lung cancer and leukemia. *Mol Med Rep* 15:3390–3397. <https://doi.org/10.3892/mmr.2017.6387>
- Domingo JL, Marquès M, Rovira J (2020) Influence of airborne transmission of SARS-CoV-2 on COVID-19 pandemic. *A Review Environ Res* 188:109861. <https://doi.org/10.1016/j.envres.2020.109861>
- Feng C, Li J, Sun W, Zhang Y, Wang Q (2016) Impact of ambient fine particulate matter (PM<sub>2.5</sub>) exposure on the risk of influenza-like-illness: a time-series analysis in Beijing, China. *Environ Health* 11(15):17. <https://doi.org/10.1186/s12940-016-0115-2>
- Gauderman WJ, McConnell R, Gilliland F, London S, Thomas D, Avol E, Vora H, Berhane K, Rappaport EB, Lurmann F, Margolis HG, Peters J (2000) Association between air pollution and lung function growth in southern California children. *Am J Respir Crit Care Med* 162:1383–1390. <https://doi.org/10.1164/ajrccm.162.4.9909096>
- Ghasempour F, Sekertekin A, Kutoglu SH (2021) Google Earth Engine based spatio-temporal analysis of air pollutants before and during the first wave COVID-19 outbreak over Turkey via remote sensing. *J Clean Prod* 319:128599. <https://doi.org/10.1016/j.jclepro.2021.128599>
- Ghozikali MG, Heibati B, Naddafi K, Kloog I, Conti GO, Polosa R, Ferrante M (2016) Evaluation of chronic obstructive pulmonary disease (COPD) attributed to atmospheric O<sub>3</sub>, NO<sub>2</sub>, and SO<sub>2</sub> using Air Q Model (2011–2012 year). *Environ Res* 144:99–105. <https://doi.org/10.1016/j.envres.2015.10.030>
- Goren AY, Genisoglu M, Okten HE, Sofuoglu SC (2021) Effect of COVID-19 pandemic on ambient air quality and excess risk of particulate matter in Turkey. *Environmental Challenges* 5:100239. <https://doi.org/10.1016/j.envc.2021.100239>
- Haque SE, Rahman M (2020) Association between temperature, humidity, and COVID-19 outbreaks in Bangladesh. *Environ Sci Policy* 114:253–255. <https://doi.org/10.1016/j.envsci.2020.08.012>
- Huang L, Zhou L, Chen J, Chen K, Liu Y, Chen X, Tang F (2016) Acute effects of air pollution on influenza-like illness in Nanjing, China: A population-based study. *Chemosphere* 147:180–187. <https://doi.org/10.1016/j.chemosphere.2015.12.082>
- Iha Y, Kinjo T, Parrott G, Higa F, Mori H, Fujita J (2016) Comparative epidemiology of influenza A and B viral infection in a subtropical region: a 7-year surveillance in Okinawa. *Japan BMC Infect Dis* 16(650):1–8. <https://doi.org/10.1186/s12879-016-1978-0>
- Islam N, Bukhari Q, Jameel Y, Shabnam S, Erzurumluoglu AM, Siddique MA, Massaro JM, D'Agostino RB (2021) COVID-19 and climatic factors: A global analysis. *Environ Res* 193:110335. <https://doi.org/10.1016/j.envres.2020.110335>
- Jiang Y, Wu XJ, Guan YJ (2020) Effect of ambient air pollutants and meteorological variables on COVID-19 incidence. *Infect Control Hosp Epidemiol* 41:1011–1015. <https://doi.org/10.1017/ice.2020.222>
- Kan HD, Chen BH, Fu CW, Yu SZ, Mu LN (2005) Relationship between ambient air pollution and daily mortality of SARS in Beijing. *Biomed Environ Sci* 18:1–4
- Kowalska M, Skrzypek M, Kowalski M, Cyrus J (2020) Effect of NO<sub>x</sub> and NO<sub>2</sub> concentration increase in ambient air to daily bronchitis and asthma exacerbation, silesian voivodeship in Poland. *Int J Environ Res Public Health* 17(754):1–9. <https://doi.org/10.3390/ijerph17030754>
- Lanzinger S, Schneider A, Breitner S, Stafoggia M, Erzen I, Dostal M, Pastorkova A, Bastian S, Cyrus J, Zscheppang A, Kolodnitska T, Peters A (2016) Associations between ultrafine and fine particles and mortality in five central European cities—results from the UFIREG study. *Environ Int* 88:44–52. <https://doi.org/10.1016/j.envint.2015.12.006>
- Lee GI, Saravia J, You D, Shrestha B, Jaligama S, Hebert VY, Dugas TR, Cormier SA (2014) Exposure to combustion generated environmentally persistent free radicals enhances severity of influenza virus infection. *Part. Fibre Toxicol.* 11, 57, 1–10. <http://www.particleandfibretoxicology.com/content/11/1/57>
- Li H, Xu X-L, Dai D-W, Huang Z-Y, Ma Z, Guan Y-J (2020) Air pollution and temperature are associated with increased COVID-19 incidence: A time series study. *Int J Infect Dis* 97:278–282. <https://doi.org/10.1016/j.ijid.2020.05.076>
- Lin YK, Chang CK, Chang SC, Chen PS, Lin C, Wang YC (2013) Temperature, nitrogen dioxide, circulating respiratory viruses and acute upper respiratory infections among children in Taipei, Taiwan: a population-based study. *Environ Res* 120:109–118. <https://doi.org/10.1016/j.envres.2012.09.002>
- Liu C, Chen R, Sera F, Vicedo-Cabrera AM, Guo Y, Tong S, Coelho MSZS, Saldiva PHN, Lavigne E, Matus P, Valdes Ortega N, Osorio Garcia S, Pascal M, Stafoggia M, Scortichini M, Hashizume M, Honda Y, Hurtado-Díaz M, Cruz B, Nunes B, Teixeira JP, Kim H, Tobias A, Íñiguez C, Forsberg B, Åström C, Ragetti MS, Guo Y-L, Chen B-Y, Bell ML, Wright CY, Scovronick N, Garland RM, Milojevic A, Kyselý J, Urban A, Orru H, Indermitte E, Jaakkola JJK, Rytty NRI, Katsouyanni K, Analitis A, Zanobetti A, Schwartz J, Chen J, Wu T, Cohen A, Gasparrini A, Kan H (2019) Ambient particulate air pollution and daily mortality in 652 cities. *N Engl J Med* 381(8):705–715. <https://doi.org/10.1056/NEJMoa1817364>
- Nenna R, Evangelisti M, Frassanito A, Scagnolari C, Pierangeli A, Antonelli G, Nicolai A, Arima S, Moretti C, Papoff P, Villa MP, Midulla F (2017) Respiratory syncytial virus bronchiolitis, weather conditions and air pollution in an Italian urban area: an observational study. *Environ Res* 158:188–193. <https://doi.org/10.1016/j.envres.2017.06.014>
- Ogen Y (2020) Assessing nitrogen dioxide (NO<sub>2</sub>) levels as a contributing factor to coronavirus (COVID-19) fatality. *Sci Total Environ* 726:138605. <https://doi.org/10.1016/j.scitotenv.2020.138605>
- Orak NH, Ozdemir O (2021) The impacts of COVID-19 lockdown on PM<sub>10</sub> and SO<sub>2</sub> concentrations and association with human

- mobility across Turkey. *Environ Res* 197:111018. <https://doi.org/10.1016/j.envres.2021.111018>
- Rahimi NR, Fouladi-Fard R, Aali R, Shahryari A, Rezaali M, Ghalfoury Y, Ghalhari MR, Asadi-Ghalhari M, Farzinnia B, Gea OC, Fiore M (2021) Bidirectional association between COVID-19 and the environment: A systematic review. *Environ Res* 194:110692. <https://doi.org/10.1016/j.envres.2020.110692>
- Rhee J, Dominici F, Zanobetti A, Schwartz J, Wang Y, Di Q, Balmes J, Christiani DC (2019) Impact of long-term exposures to ambient PM<sub>2.5</sub> and ozone on ARDS risk for older adults in the United States. *Chest* 156(1):71–79. <https://doi.org/10.1016/j.chest.2019.03.017>
- Rosario DKA, Mutz YS, Bernardes PC, Conte-Junior CA (2020) Relationship between COVID-19 and weather: Case study in a tropical country. *Int J Hyg Environ Health* 229:113587. <https://doi.org/10.1016/j.ijheh.2020.113587>
- Şahin M (2020) Impact of weather on COVID-19 pandemic in Turkey. *Sci Total Environ* 728:138810. <https://doi.org/10.1016/j.scitotenv.2020.138810>
- Sarkodie SA, Owusu PA (2020) Impact of meteorological factors on COVID-19 pandemic: Evidence from top 20 countries with confirmed cases. *Environ Res* 191:110101. <https://doi.org/10.1016/j.envres.2020.110101>
- Schuit M, Ratnesar-Shumate S, Yolitz J, Williams G, Weaver W, Green B, Miller D, Krause M, Beck K, Wood S, Holland B, Bohannon J, Freeburger D, Hooper I, Biryukov J, Altamura LA, Wahl V, Hevey M, Dabisch P (2020) Airborne SARS-CoV-2 is rapidly inactivated by simulated sunlight. *J Infect Dis* 222:564–571. <https://doi.org/10.1093/infdis/jiaa334>
- Shen L, Zhao T, Wang H, Liu J, Bai Y, Kong S, Zheng H, Zhu Y, Shu Z (2021) Importance of meteorology in air pollution events during the city lockdown for COVID-19 in Hubei Province. *Central China Sci Total Environ* 754:142227. <https://doi.org/10.1016/j.scitotenv.2020.142227>
- Silva DR, Viana VP, Müller AM, Livi FP, PdeTR D (2014) Respiratory viral infections and effects of meteorological parameters and air pollution in adults with respiratory symptoms admitted to the emergency room. *Influenza Other Respi Viruses* 8(1):42–52. <https://doi.org/10.1111/irv.12158>
- Srivastava A (2021) COVID-19 and air pollution and meteorology—an intricate relationship: A review. *Chemosphere* 263:128297. <https://doi.org/10.1016/j.chemosphere.2020.128297>
- Su W, Wu X, Geng X, Zhao X, Liu Q, Liu T (2019) The short-term effects of air pollutants on influenza-like illness in Jinan. *China BMC Public Health* 19:1319. <https://doi.org/10.1186/s12889-019-7607-2>
- Tang X, Wu C, Li X, Song Y, Yao X, Wu X, Duan Y, Zhang H, Wang Y, Qian Z, Cui J, Lu J (2020) On the origin and continuing evolution of SARS-CoV-2. *Natl Sci Rev* 7:1012–1023. <https://doi.org/10.1093/nsr/nwaa036>
- Taniş C, Karakaya K (2021) Investigating the impacts of air quality and weather indicators on the spread of SARS-CoV-2 in Istanbul, Turkey. *Therm. Sci.* <https://doi.org/10.2298/TSCI201126071T>
- Tosepu R, Gunawan J, Effendy DS, Ahmad LOAL, Lestari H, Bahar H, Asfian P (2020) Correlation between weather and covid-19 pandemic in Jakarta. *Indonesia Sci Total Environ* 725:138436. <https://doi.org/10.1016/J.SCITOTENV.2020.138436>
- Travaglio M, Yu Y, Popovic R, Selley L, Leal NS, Martins LM (2021) Links between air pollution and COVID-19 in England. *Environ Pollut* 268:115859. <https://doi.org/10.1016/j.envpol.2020.115859>
- TUIK (2021) The population of provinces in 2021. <https://cip.tuik.gov.tr/#>. Accessed March 2021
- Tung NT, Cheng PC, Chi KH, Hsiao TC, Jones T, BèrùBè K, Ho KF, Chuang HC (2021) Particulate matter and SARS-CoV-2: A possible model of COVID-19 transmission. *Sci Total Environ* 750:141532. <https://doi.org/10.1016/j.scitotenv.2020.141532>
- WHO (2021) World Health Organization. <https://covid19.who.int>. Accessed June 2021
- Wu X, Nethery RC, Sabath BM, Braun D, Dominici, F (2020) Exposure to Air Pollution and COVID-19 Mortality in the United States. *medRxiv*. <https://doi.org/10.1101/2020.04.05.20054502>
- WWO (2021) World Weather Online. <https://www.worldweatheronline.com>. Accessed March 2021
- Xie J, Teng J, Fan Y, Xie R, Shen A (2019) The short-term effects of air pollutants on hospitalizations for respiratory disease in Hefei. *China Int J Biometeorol* 63:315–326. <https://doi.org/10.1007/s00484-018-01665-y>
- Xie J, Zhu Y (2020) Association between ambient temperature and COVID-19 infection in 122 cities from China. *Sci Total Environ* 724:138201. <https://doi.org/10.1016/j.scitotenv.2020.138201>
- Xu K, Cui K, Young LH, Hsieh YK, Wang YF, Zhang J, Wan S (2020) Impact of the COVID-19 Event on Air Quality in Central China. *Aerosol Air Qual Res* 20:915–929. <https://doi.org/10.4209/aaqr.2020.04.0150>
- Xu Q, Li X, Wang S, Wang C, Huang F, Gao Q, Wu L, Tao L, Guo J, Wang W (2016) Fine particulate air pollution and hospital emergency room visits for respiratory disease in urban areas in Beijing, China, in 2013. *PLoS ONE* 11(4):e0153099. <https://doi.org/10.1371/journal.pone.0153099>
- Yao Y, Pan J, Wang W, Liu Z, Kan H, Qui Y, Meng X, Wang W (2020) Association of particulate matter pollution and case fatality rate of COVID-19 in 49 Chinese cities. *Sci Total Environ* 741:140396. <https://doi.org/10.1016/j.scitotenv.2020.140396>
- Yarahmadi M, Hadei M, Nazari SSH, Conti GO, Alipour MR, Ferrante M, Shahsavani A (2018) Mortality assessment attributed to long-term exposure to fine particles in ambient air of the megacity of Tehran. *Iran Environ Sci Pollut Res* 25:14254–14262. <https://doi.org/10.1007/s11356-018-1680-4>
- Yuan J, Li M, Lv G, Lu K (2020) Monitoring transmissibility and mortality of COVID-19 in Europe. *Int J Infect Dis* 95:311–315. <https://doi.org/10.1016/j.ijid.2020.03.050>
- Yuan J, Yun H, Lan W, Wang W, Sullivan SG, Jia S, Bittles AH (2006) A climatologic investigation of the SARS-CoV outbreak in Beijing. *China Am J Infect Contr* 34(4):234–236. <https://doi.org/10.1016/j.ajic.2005.12.006>
- Zhang X, Tang M, Guo F, Wei F, Yu Z, Gao K, Jin M, Wang J, Chen K (2021) Associations between air pollution and COVID-19 epidemic during quarantine period in China. *Environ Pollut* 268:115897. <https://doi.org/10.1016/j.envpol.2020.115897>
- Zhu Y, Xie J, Huang F, Cao L (2020) Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China. *Sci Total Environ* 727:138704. <https://doi.org/10.1016/j.scitotenv.2020.138704>
- Zoran MA, Savastru RS, Savastru DM, Tautan MN (2020a) Assessing the relationship between surface levels of PM<sub>2.5</sub> and PM<sub>10</sub> particulate matter impact on COVID-19 in Milan, Italy. *Sci Total Environ* 738:139825. <https://doi.org/10.1016/j.scitotenv.2020.139825>
- Zoran MA, Savastru RS, Savastru DM, Tautan MN (2020b) Assessing the relationship between ground levels of ozone (O<sub>3</sub>) and nitrogen dioxide (NO<sub>2</sub>) with coronavirus (COVID-19) in Milan. *Italy Sci Total Environ* 740:140005. <https://doi.org/10.1016/j.scitotenv.2020.140005>

**Publisher's note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.