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Effect of ambient air pollution and meteorological factors on the potential transmission of COVID-19 in Turkey

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ABSTRACT

There is a need to improve the understanding of air quality parameters and meteorological conditions on the transmission of SARS-CoV-2 in different regions of the world. In this preliminary study, we explore the relationship between short-term air quality (nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and particulate matter ($PM_{2.5}$, PM_{10})) exposure, temperature, humidity, and wind speed on SARS-CoV-2 transmission in 41 cities of Turkey with reported weekly cases from February 8 to April 2, 2021. Both linear and non-linear relationships were explored. The nonlinear association between weekly confirmed cases and short-term exposure to predictor factors was investigated using a generalized additive model (GAM).

The preliminary results indicate that there was a significant association between humidity and weekly confirmed COVID-19 cases. The cooler temperatures had a positive correlation with the occurrence of new confirmed cases. The low $PM_{2.5}$ concentrations had a negative correlation with the number of new cases, while reducing SO_2 concentrations may help decrease the number of new cases. This is the first study investigating the relationship between measured air pollutants, meteorological factors, and the number of weekly confirmed COVID-19 cases across Turkey. There are several limitations of the presented study, however, the preliminary results show that there is a need to understand the impacts of regional air quality parameters and meteorological factors on the transmission of the virus.

1. Introduction

The Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2) related pandemic COVID-19 showed different transmission speeds and severity all around the world. Therefore, several studies documented the impact of air quality and meteorological factors on the reported new COVID-19 case numbers with various methods (Copat et al., 2020; Domingo and Rovira, 2020; Ismail et al., 2022; Marques and Domingo, 2021, 2022; Zoran et al., 2022). As of December 23, 2021, more than 9 million people and approximately 78,000 deaths had been reported in Turkey (COVID-19 Saglik, 2021). Vaccination rates drastically increasing all around the world, however, the long-term results of the vaccination program are not well known so there is a need to understand the transmission mechanism and explore the impacts of air quality and meteorological factors on the transmission of the pandemic to help public health efforts in the region. The main reason for exploring this potential association is that the SARS-CoV-2 virus is contacting with droplets in the air and cause transmission (WHO, 2020).

There are two potential ways of the air quality impact; first, there are health problems, including a range of respiratory diseases, associated with acute and chronic exposure to air pollutants (An and Yu, 2018). According to the World Health Organization, air pollution causes more than 7 million premature deaths every year (WHO, 2021). Poor ambient air quality has long-term cumulative effects on human health. A comprehensive study in Spain demonstrated that long-term exposure to PM_{10} increases the risk of COVID-19 severity (Marques et al., 2022). Therefore, there is a potential linkage between the transmission of the virus and air quality parameters, which can be an important indicator of the health status of the individuals. The second way of the impact is the short-term physical impact of air quality concentrations on the transmission of the pandemic as dust particles suspended in the air can facilitate a surface area for viruses (Coccia, 2020). It is challenging to differentiate these two potential impacts of air quality parameters; therefore, this study investigates the physical impact of air quality concentrations and meteorological factors.

Numerous studies have investigated the association between air quality parameters, air temperature, humidity, UV radiation, wind speed, and reported COVID-19 cases. Early studies analyzed small data

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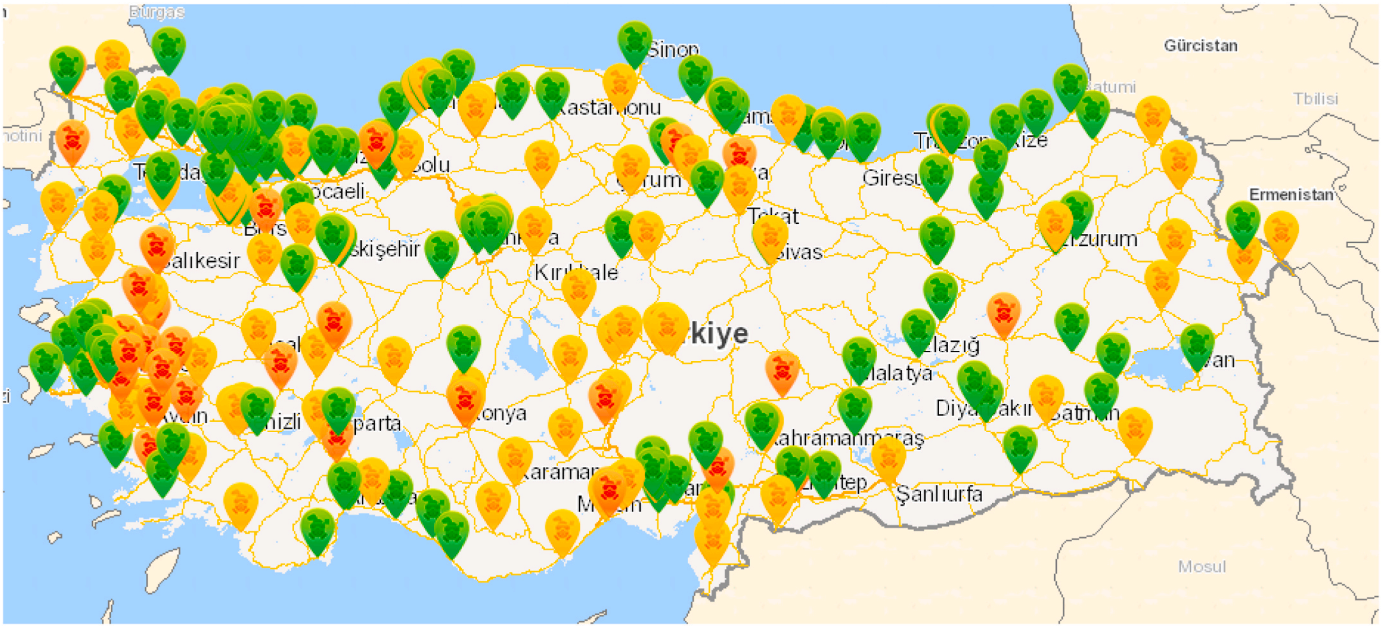

Fig. 1. The air quality monitoring stations in Turkey for January 28, 2022 16:00 (UHKIA, 2022).

sets between April and May of 2020. The spread of the pandemic has been fast in countries with high air pollution, such as China, the USA, Spain, India, and Italy. In the US, findings show that CO, NO_2, SO_2, PM_{10}, and $PM_{2.5}$ have a strong correlation with the COVID-19 cases in California, US (Bashir et al., 2020; Bilal et al., 2021). Another study in the region showed a positive correlation between O_3 and daily confirmed cases, however, a negative relationship with $PM_{2.5}$ and PM_{10} (Gujral and Sinha, 2021). A similar study was conducted in Italy to analyze the primary cause of the transmission of the virus. In Italy, researchers found that there are higher mortality levels in Northern Italy because of higher air pollution, which is a result of industrialization and heavy traffic (Conticini et al., 2020). A significantly high correlation between air quality parameters (PM_{10}, $PM_{2.5}$, CO, and O_3) and the confirmed cases was detected during the lockdown period (Kolluru et al., 2021). Numerous studies claimed that PMs have an important impact on the transmission of the virus (Setti et al., 2020). Another group proposed that CO concentration accelerates the transmission of coronavirus (Lin et al., 2020). An earlier study in Pakistan showed a linkage between $PM_{2.5}$ levels and COVID-19 spread (Ali et al., 2021). In Brazil, researchers found that an increase in $PM_{2.5}$ and O_3 concentrations increase the risk of new cases (Ibarra-Espinosa et al., 2022). Another positive correlation between air quality, ozone, nitrogen and the pandemic spread was reported in Canada (Sarwar et al., 2021). Han et al. (2022) showed that monthly infection rate of new confirmed cases is positively correlated with air pollutants in China.

Similarly, meteorological factors can have a critical role in the transmission mechanism of the virus-infected droplets. This means seasons and geographical characteristics can affect the severity of the pandemic (Stufano et al., 2021). A study conducted in Thailand shared that temperature, relative humidity, and wind speed have a strong relationship with daily COVID-19 confirmed cases in the Bangkok Metropolitan Region (Sangkham et al., 2021). Another study in Japan showed that meteorological variables have an indirect role in the transmission of SARS-CoV-2 (Azuma et al., 2020). In India, researchers found a significant correlation between temperature and COVID-19 cases (Kolluru et al., 2021). A study conducted for cases in China shows that the doubling time causes a positive correlation with temperature; however, this relationship is negative with humidity (Oliveiros et al., 2020). An early study in Saudi Arabia found a positive correlation between daily COVID-19 cases and meteorological factors (relative humidity and temperature) (Ismail et al., 2022). A comprehensive global study including several countries showed new confirmed cases are negatively correlated with meteorological factors and positively correlated with air pollutants (Han et al., 2022).

This study is an extension of a previous study where air quality change and human mobility were investigated during the COVID-19 lockdown period (Orak and Ozdemir, 2021). Turkey started sharing the weekly COVID-19 case numbers in February 2021. Therefore, this study explores the linear and non-linear relationship between confirmed weekly case numbers, short-term exposure to air quality (NO_2, SO_2, O_3, $PM_{2.5}$, PM_{10}), and meteorological parameters (temperature, humidity, wind speed, and wind angle) in Turkey.

2. Methods

The Ministry of Environment and Urbanization has an online air quality monitoring network that covers 81 cities (UHKIA, 2022). We obtained daily average NO_2, SO_2, $PM_{2.5}$, PM_{10}, and O_3 concentrations for February 14 through April 2, 2021. Fig. 1 shows the locations of the air quality monitoring stations in each city. However, several air quality parameters were missing in smaller cities therefore 41 cities were selected for the study.

The weekly confirmed COVID-19 case data for each city in Turkey was directly obtained from the weekly reports of the Ministry of Health, Turkey. The number of COVID-19 cases was available for 9 weeks: Feb 8–14, Feb 15–21, Feb 20–26, Feb 27-March 5, March 6–12, March 13–19, March 20–26, and March 27-April 2 (COVID-19 Saglik, 2021). Meteorological data such as temperature, humidity, and wind were provided by the Meteorological Data Information Sales and Presentation website of the General Directorate of Meteorology (MEVBIS, 2021).

First, trendline and correlation analyses were completed to understand the linear relationship. Second, a generalized additive model (GAM) was used to analyze the nonlinear relationship between COVID-19 weekly confirmed cases and short-term exposure to predictor variables.

$$\mathrm{Logy}_{tit} = \alpha + s(T_{t,i}) + s(PM_{2.5t,i}) + s(NO_{2t,i}) + s(SO_{2t,i}) + s(\mathrm{WindSpeed}_{t,i}) + s(\mathrm{Humidity}_{t,i}) \quad (1)$$

where i is for the city, t is for the date. s(x) shows the basis spline to smooth the data, and the splines were constrained to have four degrees

Table 1
Statistical summary of case numbers, air quality parameters, and meteorological parameters.

	Mean	STD	Min	Median	Max
The weekly confirmed cases	2088	6867	21	580	91,453
The total cases (thousand)	141	116	10.4	100	679
Ambient air quality parameters					
SO_2 (μg/m^3)	17.2	17.9	1.6	12.2	164
NO_2 (μg/m^3)	31.1	17.0	5.1	27.3	108
O_3 (μg/m^3)	41.3	21.0	3.2	43.9	106
PM_{10} (μg/m^3)	45.2	20.8	6.9	41.7	148
$PM_{2.5}$ (μg/m^3)	21.7	11.5	0.8	19.4	84
Meteorological parameters					
Temperature (^{0}C)	5.8	4.2	−11.8	6.3	15
Humidity (%)	68.1	10.4	36.5	69.2	95
Wind angle	188	69	14	190	341
Wind speed (m/s)	1.8	0.9	0.5	1.6	7.7

of freedom. The mgcv package of R was used for computation (Wood, 2011).

3. Results

Table 1 shows the statistical moments for the weekly confirmed cases, the total cases, and the concentration of the pollutants (μg/m^3), SO_2, NO_2, O_3, PM_{10}, and $PM_{2.5}$ for the study time period. The table also summarizes the meteorological parameters of temperature (^{0}C), humidity (%), wind angle, and wind speed (m/s).

Fig. 2 outlines the weekly confirmed cases per 100,000 residents obtained by the Ministry of Health (COVID-19 Saglik, 2021) for 41 cities between February 8 to April 2, 2021 (a) and between February to October (b). As shown in the figure, the selected study period was during the second global wave of COVID-19.

Fig. 3 compares the time series of the total cases, weekly new cases,

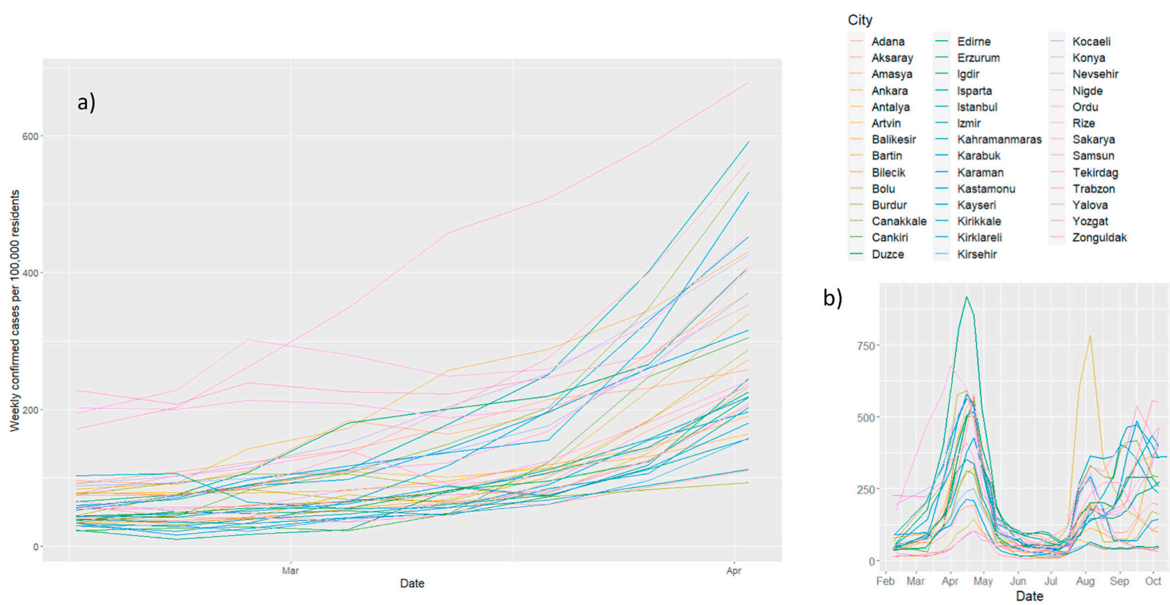

Fig. 2. Weekly confirmed cases (per 100,000 residents) for 41 cities of Turkey between February and April (a) and for February to October (b).

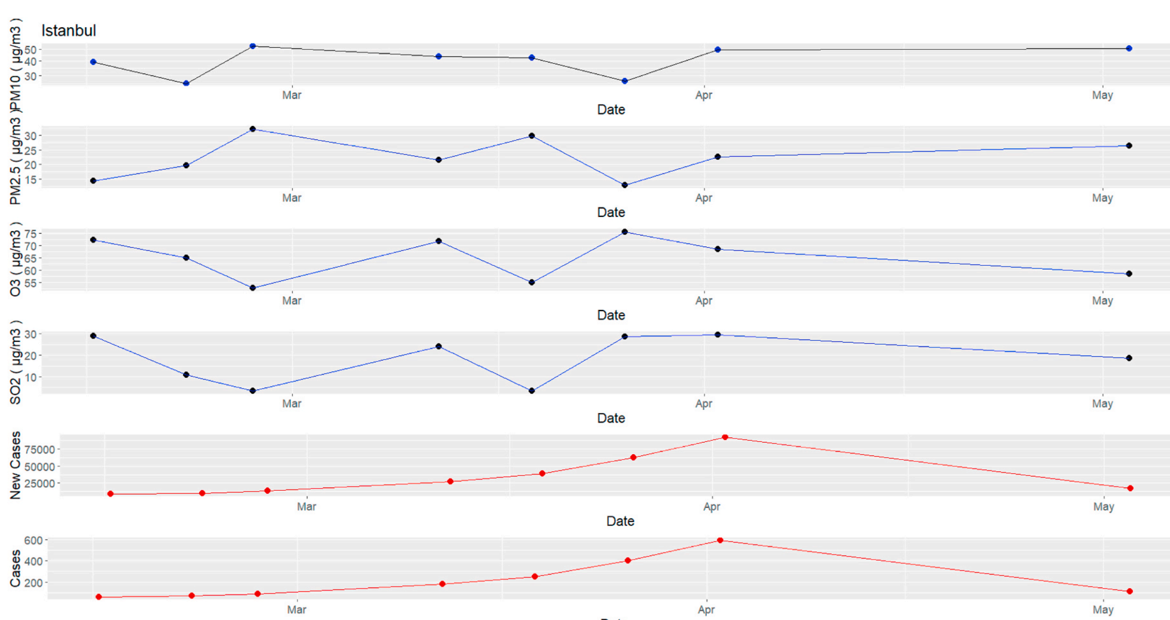

Fig. 3. Time series of the total cases, new cases (per 100,000 residents), SO_2 (μg/m^3), O_3 (μg/m^3), $PM_{2.5}$ (μg/m^3), and PM_{10} (μg/m^3) in Istanbul.

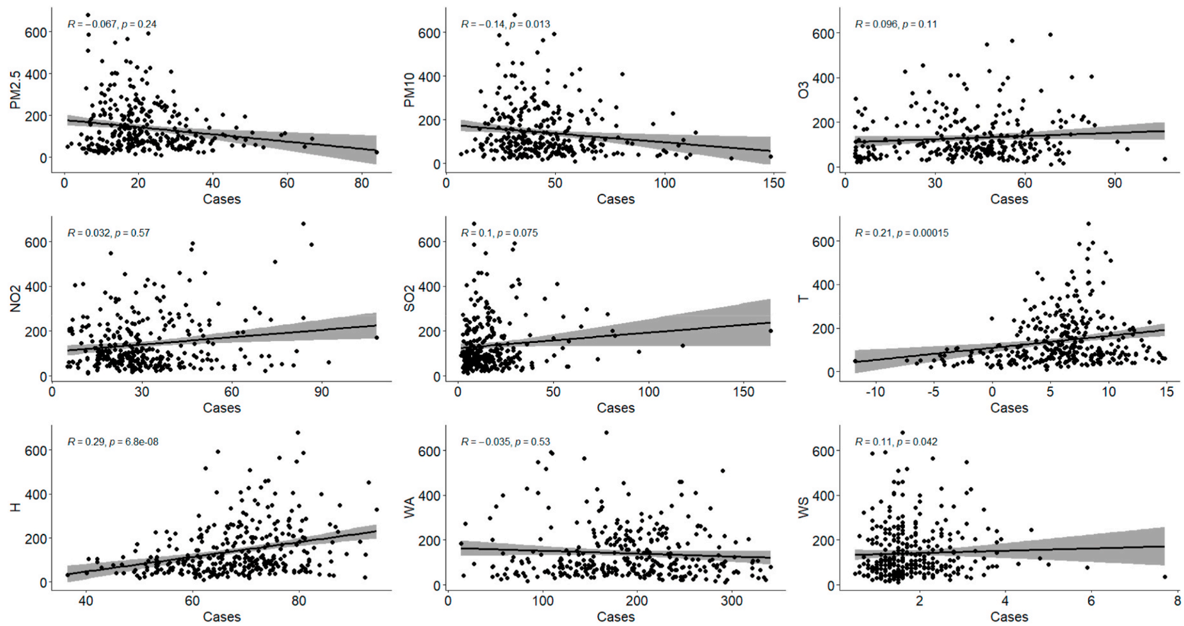

Fig. 4. Exposure-response curves for the effects of, air quality parameters, temperature, wind speed, wind angle, and humidity on COVID-19 confirmed new cases. (Abbreviations: WA: Winds Angle, WS: Wind Speed, H: Humidity, T: Temperature, $PM_{2.5}$: particulate matter with a diameter of 2.5 μm or less, PM_{10}: particulate matter with a diameter of 10 μm or less, O_3: ozone, SO_2: sulfur dioxide, NO_2: nitrogen dioxide).

SO_2 (μg/m^3), O_3 (μg/m^3), $PM_{2.5}$ (μg/m^3), and PM_{10} (μg/m^3) concentrations in Istanbul as an example. We observe parallel trends between PM_{10} and $PM_{2.5}$; O_3 and SO_2 concentrations over time. There is no linear relationship between air quality parameters and the number of COVID-19 cases. These preliminary analyses followed by exploring the correlation between variables and the number of confirmed cases.

Fig. 4 shows the Spearman correlation between the air pollutants and meteorological factors ranging from −0.14 to 0.29. The highest correlation is between weekly confirmed *new cases* and *humidity* ($\rho = 0.29$, $p < 0.0001$), followed by *temperature* ($\rho = 0.21$, $p < 0.001$).

These results raise a question about the potential impact of a city's character on the transmission analysis. Therefore, we analyzed the distribution of PM_{10} and $PM_{2.5}$ concentrations for all cities as an example (Fig. 5). The highly populated cities like Istanbul, Ankara, and Izmir have small distribution compared to other cities. This variance can affect the correlation between air quality parameters and confirmed new case numbers. There was a need to explore the non-linear relationship between the variables, therefore we conducted a general additive model. The GAM results show the partial effect of each variable on the confirmed new case numbers (Fig. 6). The gray area shows the 95% confidence interval. Fig. 6 shows the estimated smoothing spline function. The temperature had a positive linear correlation with the confirmed new cases when it ranged from −5 °C to 10 °C. On the other hand, the increasing temperature at higher temperatures (10 ^{0}C-15 °C) decreased the confirmed numbers. There was a significant negative correlation between $PM_{2.5}$ concentrations and the new COVID-19 cases. There was no significant association between NO_2 concentrations and the new cases.

In general, the increasing concentration of SO_2 increased the occurrence of cases with higher confidence in higher concentrations. Reducing SO_2 concentration may help in limiting the spread of COVID-19 infection. On the other hand, there was a negative correlation between wind speed and the new cases. Higher wind speeds disperse virus particles and lessen the likelihood of infection. In the contrast, the humidity was positively correlated with the propagation of the new cases. There are biological reasons why raising humidity reduces virus transmission by changing particle size; nonetheless, increasing humidity may also affect mask effectiveness. These results show that further data is required to understand the transmission mechanism of the virus and the impacts of air quality parameters.

4. Discussion

The present paper explores the relationship between air quality parameters, meteorological parameters, and weekly COVID-19 confirmed cases in Turkey. There are a few significant differences in our findings compared to literature studies in other regions of the world. Zhang et al. (2020) found temperature and coronavirus transmission have a nonlinear dose-response relationship and they also discovered a link between air pollution indicators and new confirmed cases across China. They found that in southern cities, ambient temperature and air pollution have a negative interaction impact on COVID-19 transmission, implying that rising temperatures reduce the enabling effects of air pollution, resulting in a drop in new confirmed cases. According to nationwide research in the topmost affected states of the USA, the humidity had a little negative influence at low quantiles but a marginal positive impact at high quantiles (South region); similarly, the humidity had a slight negative impact at high quantiles (Northwestern region) (Bilal et al., 2021). Similar to our results, their findings show that $PM_{2.5}$ displays a negative correlation in the middle quantiles of the confirmed cases. A comprehensive study, conducted for 118 countries, showed that there is no link between $PM_{2.5}$, PM_{10} and transmissibility of the virus (Salom et al., 2021). On the other hand, a study for five megacities in India found a significant correlation between $PM_{2.5}$, PM_{10}, O_3 concentrations, and meteorological parameters with the confirmed cases (Kolluru et al., 2021). In addition, Milicevic et al. (2021) found that $PM_{2.5}$ pollution as a key predictor of SARS-CoV-2 transmissibility in the US, utilizing 74 baseline parameters and five distinct analysis methodologies. However, the authors also address that the results do not give information about causality. The temperature had a substantial correlation with the COVID-19 cases during the lockdown and unlock period, among the meteorological factors studied. An early study conducted in South Korea applied GAM to investigate the relationship between air pollutants, meteorology, and confirmed cases (Hoang and Tran, 2021). According to their findings, when the temperature was below 8 °C, each 1 °C rise in temperature was associated with a 9% increase in COVID-19 confirmed cases. Temperature, NO_2, and SO_2 concentrations had strong temporal correlations with daily confirmed cases in South Korea.

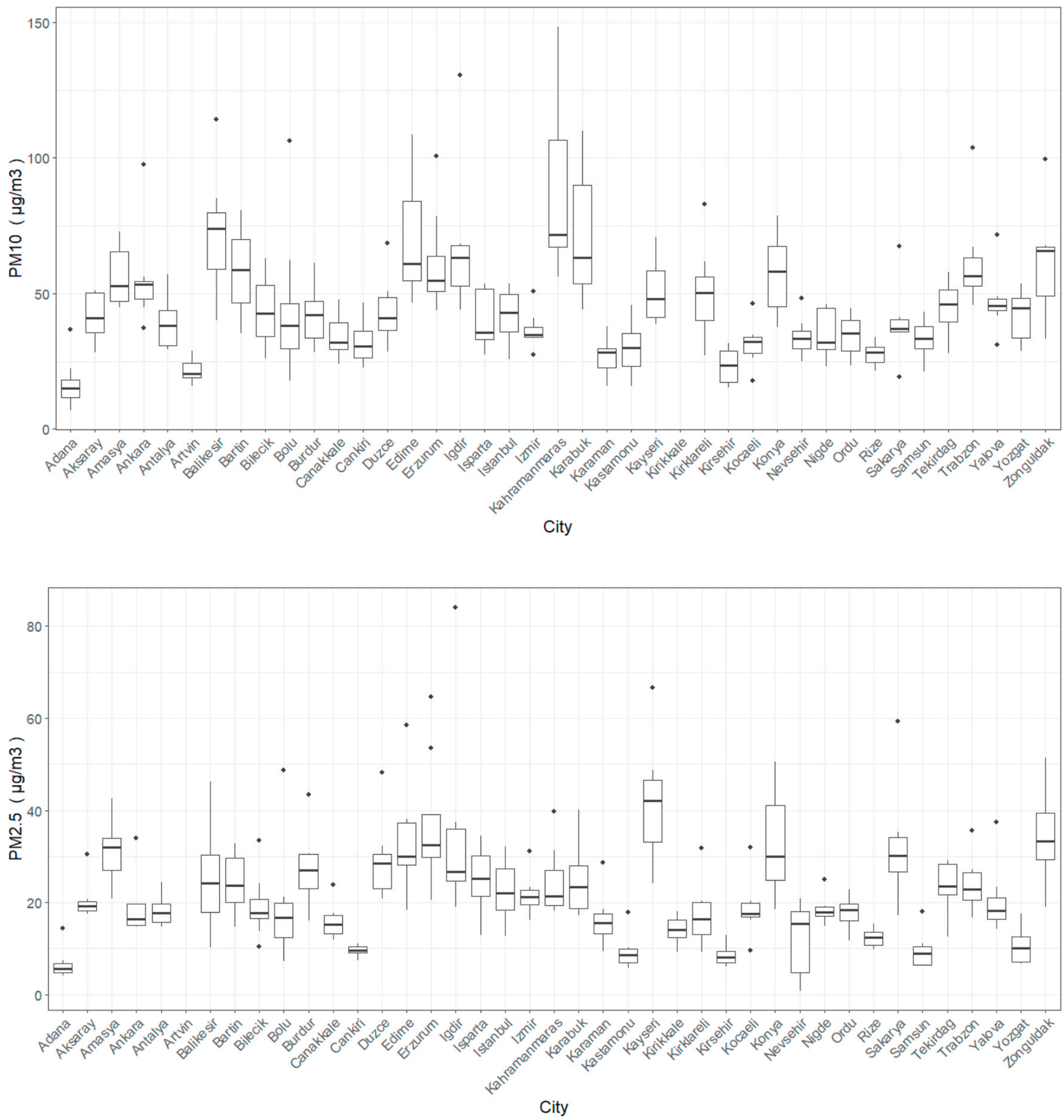

Fig. 5. PM_{10} ($\mu g/m^3$) and $PM_{2.5}$ ($\mu g/m^3$) concentration distribution over the study period for 41 cities in Turkey.

Researchers in Spain found that there was a significant negative correlation between air temperature with daily new confirmed incidences (Zoran et al., 2022). Overall, there is a major challenge to compare different studies due to different methodologies and data characteristics. The inconsistent results were explained by a critical analysis of early studies, which revealed that the majority of the studies looked at linear relationships, and those methodologies have significant limitations that can lead to incorrect interpretation of the data (Shakil et al., 2020). Moreover, most of the studies examining the nonlinear relationship have used the GAM model. There is an increasing need to develop a comprehensive model to analyze available short-term and long-term data for different countries by integration of atmospheric characteristics of the region. Developing a potential model can aid future pandemics in taking precautions and making successful lockdown decisions to prevent disease spread.

5. Limitations

There are several limitations to this study. Although air quality datasets were obtained from measurement stations with high accuracy, since not every air quality parameter was available for every city, 41 of 81 cities had to be selected for the study. Air quality and meteorological data were obtained in real-time; however, the number of confirmed cases was shared weekly. For this reason, analysis on a daily scale could not be performed in the study. If we consider the incubation period of the dominant variant in the first half of 2021, the 7-day data is valid. However, having daily health data for the validation of results would strengthen the study. Finally, since the health data was available as of February 2021, 9-week data could be analyzed. There are limited representing data sets of different meteorological conditions and changing air quality in parallel with it. However, since each city has very different climates due to the geography of Turkey, the diversity in the data minimizes this uncertainty of the study.

6. Conclusion

This study investigated the impact of air quality parameters and meteorological factors on weekly confirmed SARS-CoV-2 cases in 41 cities of Turkey. In theory, there are two potential impacts of air quality parameters on the new cases; first, the virus can interact with the surface

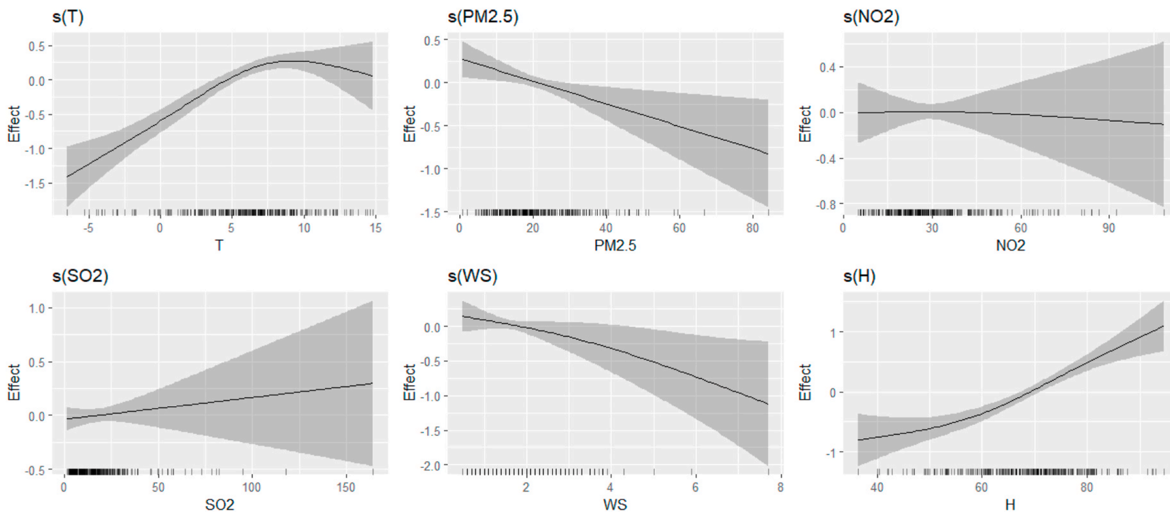

Fig. 6. The marginal effect (%) of each GAM smooth term of air pollutants and meteorological factors on new COVID-19 cases.

of the particles under different meteorological conditions, and the second way is the overall effect on cases exposed to chronic exposure. The most important outcome of this study is showing the importance of spatial data and time resolution for available data sets. Future work can include spatial mobility analysis for a better understanding of the short-term air quality dynamics in different cities. In addition, the long-term impacts of selected factors can provide further insight into the topic. The preliminary results show that there is a need for high-resolution temporal data for more advanced predictive models.

Credit author statement

Nur H. Orak: Conceptualization, Formal analysis, Writing

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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